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REPORT No. 235
GEOLOGICAL SURVEY OF JAPAN

GEOLOGICAL SIGNIFICANCE OF ZIRCON-GARNET-TOURMALINE RATIO OF THE PALEOGENE SANDSTONES OF NORTHWESTERN KYUSHU, JAPAN

By
Yoshiaki SATO

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Konosuke SATO, Director

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CONTENTS

Geological Significance of Zircon–Garnet–Tourmaline Ratio of the Paleogene Sandstones of Northwestern Kyushu, Japan*

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Abstract

A heavy mineral study was made on the Paleogene (Eocene to Oligocene) sandstones from major coal fields in the northwestern Kyushu, Japan. Zircon, garnet, and tourmaline are major heavy minerals. Generally, they occupy the greater part of the non-opaque heavy minerals. Zircon-garnet-tourmaline ratio (ZGT ratio) is computed for each sample and the values are plotted in the ternary diagram (ZGT diagram). Following results are obtained from the distribution patterns of the ZGT ratios in the diagram.

a. Generally, each formation has a characteristic distribution pattern in the diagram and can be differentiated one from another.

b. It is hard to distinguish only by the diagram the geologic relation whether it is conformity or unconformity.

c. The sediments of the coal bearing formations of the Amakusa, Isahaya, and Takashima coal fields were deposited on a large basin under the almost same environmental condition.

d. Source rocks can be inferred from the pattern. When the values distribute along the ZT side, the sediments might be derived from granite or acid igneous rocks. When they distribute along the GT side, the sediments might be derived from crystalline schists.

e. Garnet contents fluctuate between less than 20 percent and more than 20 percent in the same formation. The reason is attributed to the minor change of the depositional condition.

f. Three types of the distribution patterns are found in the Ōchi group in the Karatsu coal field. The distinction is due to the difference of source rocks or a depositional condition.

g. The coal bearing formations which distribute along the present coastline of the northwestern Kyushu, have characteristic distribution pattern or high contents of zircon and very low contents of garnet with about 10 percent rutile. Although the sediments might be derived from granite which are supposed to be exposed at west Kyushu at that time, there remain still some questions.

h. The distribution patterns of the Ishikari coal field in Hokkaido are different from those of the Kyushu. There is no regular change of the pattern through the Cretaceous to Paleogene strata in the Ishikari.

i. The ZGT ratio in the sediments seems to be easily affected by the difference of source rocks and the depositional condition such as current intensity, changes of the water course or depth, distance from the land, and so on. Accordingly, the further study of heavy minerals with the study of the paleocurrent direction would provide the valuable information for the reconstruction of the paleogeography of ancient sediments.

* Dissertation submitted to the University of Tokyo for the degree of Doctor of Science.

** Fuel Department

I. Introduction

The important Paleogene coal fields in the northwestern Kyushu, Japan, are the Amakusa, the Isahaya (important only geologically), the Takashima, the Miike, the Sakito-Matsushima, the Karatsu, and the Chikuhō. Although the stratigraphy and paleontology of these coal fields have been studied by many geologists since 1924, it was only recent that heavy mineral studies on the Paleogene formations were published by OHARA (1959, 1960a, 1960b, 1961a 1961b, 1961c, 1962, 1964) and KATO (1957a, 1957b, 1957c, 1957d, 1957e, 1960a 1960b, 1960c). Nevertheless, since 1956, the writer has been also investigating heavy mineral assemblages in sandstones of the areas (except the Chikuhō), as a part of the project: the geologic studies of coal resources in the northwestern Kyushu, conducted by the Geological Survey of Japan. Recently, NAGAHAMA (1964, 1965a, 1965b) has made clear the transport directions and source rocks of the Paleogene and Neogene sediments of the northwestern Kyushu from the viewpoint of the diagonal bedding.

In the sandstones, zircon, garnet, and tourmaline are always found as the major non-opaque heavy minerals. Accordingly, he has tried to characterize the composition of each stratum by Zircon-Garnet-Tourmaline ratio using ternary diagrams. The writer discussed the geological significance of the ZGT ratio in detail for the Paleogene sandstones of the coal fields, together with the Ishikari coal field, Hokkaido. The diagram will be of considerable convenience in correlating each formation and in clarifying source rocks and depositional environments.

The writer wishes to extend special acknowledgment to Professor Toshio KIMURA, Professor Fuyuji TAKAI, and Professor Noriyuki NASU of the University of Tokyo for their valuable guidance and encouragement in the course of his investigation. He is deeply indebted to Doctor Takao SAKAMOTO and the late Doctor Takeshi ICHIMURA, formerly professors of the University of Tokyo, for introducing him to this branch of study and for their helpful advices. Thanks are also due to Doctors Konosuke SATO, Shingoro IJIMA, Hiroshi KAMISHIMA, Yasuaki TAKAI, and Mr. Eiji INOUE of the Geological Survey of Japan and Doctor Jonosuke OHARA of Kyushu University for the fruitful discussions of problems, valuable suggestions, and kind encouragement. Many mining companies and company staffs were most helpful in permitting use of their drill-core samples and in providing many assistance.

II. General Geology

The stratigraphical and paleontological studies of the whole coal fields in the northwestern Kyushu were first made by NAGAO (1926 to 1928). Then, MATSUSHITA (1949, 1956) had revised the correlation of those coal fields and published paleographic maps of the Paleogene stage. Another regional or paleontological studies have been done by ASANO (1962), KAMADA (1956, 1957), KIHARA (1956, 1960), MIZUNO (1956, 1964), YAMASAKI (1953, 1967), and others.

The stratigraphy and the rock facies of Paleogene sediments in the coal fields are briefly compiled from the above and some other literatures and shown in tables 1 to 7.

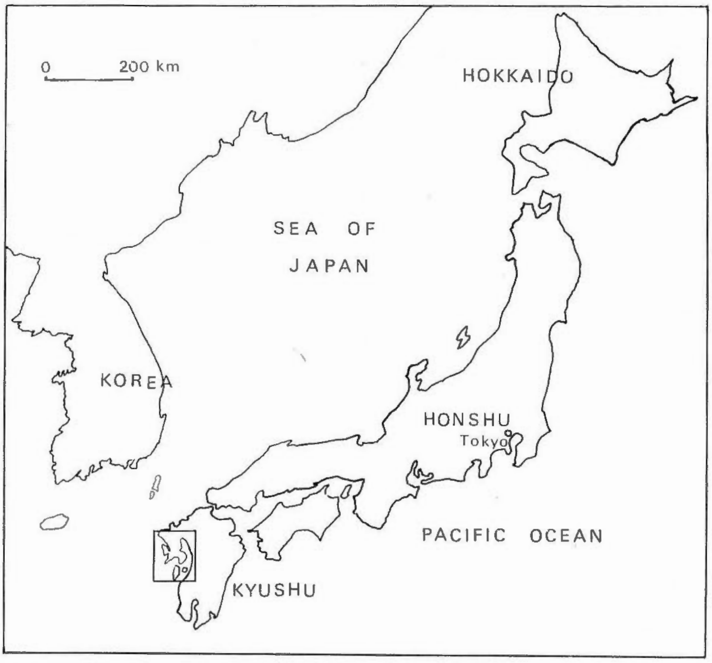

Fig. 1 Index map of the studied area.

Table 1 Description of stratigraphic units in the Amakusa coal field (TAKAI and BOJO, 1963).

Stratigraphic Unit		Thickness (m)	Description
Group	Formation		
Sakasegawa	Sakasegawa	500+	Mainly greyish black platy shale, with a sandstone bed in the middle.
	Itchoda	10～30	Dark green medium- to fine-grained sandstone, bearing abundant marine molluscan fossils and green minerals.
Shimoshima	Toishi*	350～650	Massive white medium-to fine-grained sandstone.
	Shikiyama	450～1,000	Greyish black shale (bearing many foraminifera tests), alternating with thin sandstones.
	Fukuregi	50～140	Greyish white conglomerate at the lower part but coarse sandstone at the upper. Bearing Turritella
Akasaki	Akasaki	20～50	Basal conglomerate, purple to bluish green sandstone and shale. Developing at Kamishima.
Cretaceous sedimentary rocks (Including the Fukami formation, formerly belonged to the Akasaki group.)			

* Important coal bearing formation.

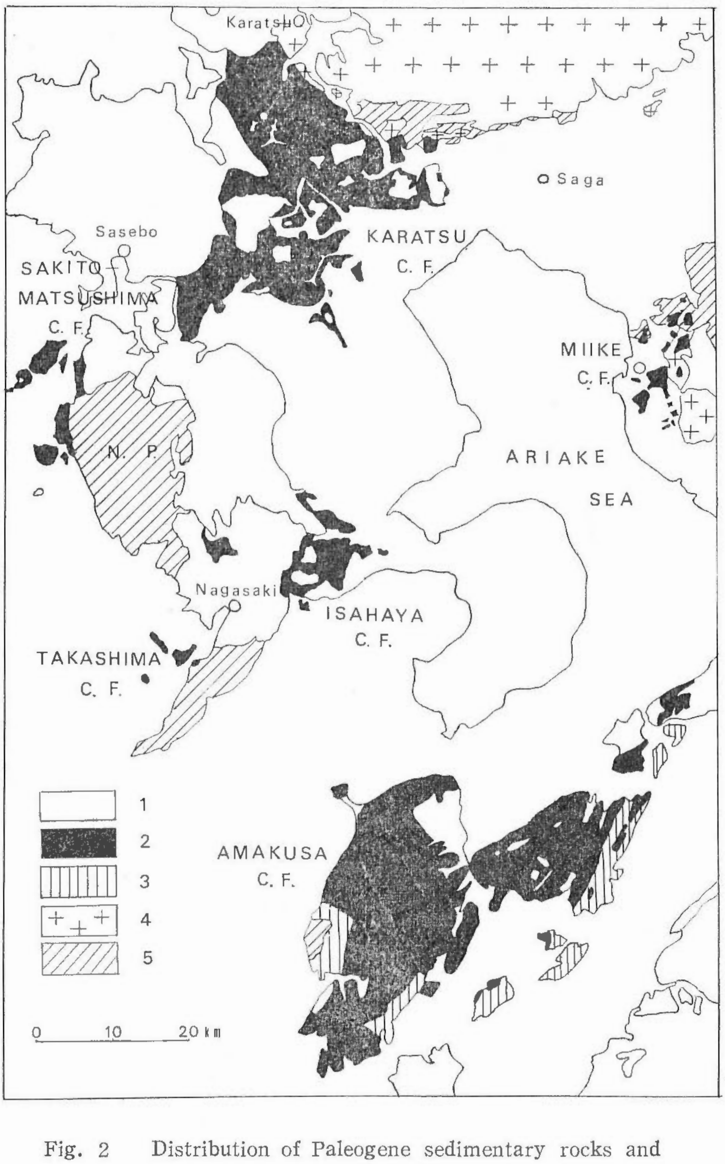

Fig. 2 Distribution of Paleogene sedimentary rocks and pre-Tertiary rocks in the northwestern Kyushu.

(After 1/500,000 geologic maps of Fukuoka, 1952, and Kagoshima, 1954.)

1—Neogene and Quaternary; 2—Paleogene; 3—Cretaceous; 4—Granite; 5—Crystalline schist.

Table 2　Description of stratigraphic units in the Isahaya coal field.

Stratigraphic Unit		Thickness (m)	Description
Group	Formation		
Yagami	Koga	100～	
	Kirimiya	130	Pale bluish grey, fine- to medium-grained sandstone.
	Saburaishi	30	Dark grey massive siltstone. Abundant foraminifera and molluscan fossils. Green minerals at the base.
Isahaya	Keya	400～470	White to greyish white, medium-grained sandstone with a few thin coal beds.
	Enoura	250+	Greyish black to dark grey shale.

Table 3　Description of stratigraphic units in the Takashima coal field (Geological Survey of Japan, 1960).

Stratigraphic Unit		Thickness (m)	Description
Group	Formation		
Iōjima	Iōjima	400+	Conglomerate, glauconite bearing sandstone, bluish grey micaceous sandstone, coaly shale, blue muddy sandstone, and grey shale.
	Okinoshima	150	Dark green to green sandstone, muddy sandstone, and shale.
Takashima	Hashima*	190～300	White sandstone, greyish black shale with coal beds.
	Futagojima	300	Conglomeratic sandstone in the lower part, bluish grey sandstone with shale in the middle, and alternation of sandstone and shale in the upper.
Akasaki	Kōyagi (Akasaki)	400	Conglomerate, conglomeratic sandstone, coarse sandstone, and purple shale.

* Important coal bearing formation.

Table 4　Description of stratigraphic units in the Miike coal field (Geological Survey of Japan, 1960).

Stratigraphic Unit		Thickness (m)	Description
Group	Formation		
Manda	Yotsuyama	200	Greenish grey fine- to medium-grained sandstone and dark grey shale in the lower part and sandstone, sandy shale, and greyish black shale in the upper.
	Kattachi	150～200	Greenish grey sandstone in the lower and bluish green coarse-grained sandstone with glauconite in the middle and upper.
Ōmuta	Nanaura	100±	White medium- to coarse-grained sandstone.
	Tōka*	100	White medium-grained sandstone in the lower part and alternation of sandstone and shale in the upper.
	Komenoyama	20～40	Black shale and white sandstone in the lower and grey fine-grained sandstone in the upper.
Akasaki	Ginsui	50～80	Conglomerate and sandstone, intercalates purple shale.
Crystalline Schists (North)		Granites (South)	

* Important coal bearing formation.

Table 5 Description of stratigraphic units in the Sakito-Matsushima coal field (NAGAHAMA and MATSUI, 1958).

Stratigraphic Unit		Thickness (m)	Description
Group	Formation		
Nishisonogi	Higire	90+	Omitted
	Shioda	50±	
	Yuridake	110±	
	Tokuman	55~110	
	Mase upper	140~300	Mainly sandstone with molluscan fossils and sand pipes.
	Mase lower		Dark grey medium-grained and micaceous sandstone at Oshima. Sandy mudstone or mudstone at Sakito.
Matsushima	Sakito*	35~120	White sandstone. Shale is rich at the middle.
	Ichigojima	5~130	Conglomerate, greyish black mudstone with foraminifera and molluscan fossils, and alternation of sandstone and mudstone.
Terashima	Terashima	400±	Sandstone, conglomerate, and mudstone.
Akasaki	Akasaki	120±	Purple to blue sandstone, shale, and conglomerate.
Crystalline schists, partly granites.			

* Important coal bearing formation.

Table 6 Description of stratigraphic units in the Karatsu coal field (Saga-ken, 1954).

Stratigraphic Unit		Thickness (m)	Description
Group	Formation		
Kishima	Hatatsu shale	250~300	Omitted
	Hatatsu sandstone	100~180	
	Yukiaino sandstone	150~250	
	Sari sandstone	70~80	
	Kishima	100~220	Muddy sandstone, sandy shale, shale with marine molluscan fossils.
Ōchi	Yoshinotani*	400~1,000	White medium- to fine-grained sandstone.
	Kyuragi		Conglomerate and sandstone with marine molluscan fossils in the lower part and green to dark green, massive, coarse- to medium-grained sandstone with coal seams at the upper.
Granites and metamorphic rocks.			

* Important coal bearing formation.

Table 7 Correlation of the Paleogene formations among coal fields in the northwestern Kyushu (MIZUNO, 1964).

Series	Stage	Amakusa G.	Amakusa Formation	Isahaya G.	Isahaya Formation	Takashima G.	Takashima Formation	Miike G.	Miike Formation	Sakito-Matsushima G.	Sakito-Matsushima Formation	Karatsu G.	Karatsu Formation
Oligocene	Nishisonogian									Nishisonogi	Katashima Higire Shioda Yuridake Tokuman	Kishima	Hatatsu sh. Hatatsu ss. Yukiaino ss. Sari ss.
Oligocene	Mazean					Iōjima	Upper Iōjima: Daimyō-ji			Nishisonogi	Mase	Kishima	Kishima
Oligocene	Funazuan				?	Iōjima	Upper Iōjima: Funazu			Matsu-shima	Sakito Ichigojima	Ōchi	Yoshinotani Kyuragi
Eocene	Okinoshiman	Sakasegawa	Sakasegawa Itchoda	Yagami	Koga Kirimiya Saburaishi	Iōjima	Lower Iōjima Okinoshima	Manda	Yotsuyama Kattachi				
Eocene	Takashiman	Shimoshima	Toishi Shikiyama Fukuregi	Isahaya	Keya. Enoura	Takashima	Hashima Futagojima	Ōmuta	Nanaura Tōka Komenoyama	Tera-shima	Terashima		
Eocene	Takashiman	Akasaki	Akasaki			Akasaki	Kōyagi	Akasaki	Ginsui	Akasaki	Akasaki		

III. Samples and Method of Study

Most samples were collected from outcrops. Four drill-cores were also used. They are mostly Paleogene sandstones and some are crystalline schists, granites, and Cretaceous rocks.

The method of the heavy mineral analysis is briefly described below. The sample is crushed with a stamp mill and screened through the sieve with opening size of about 0.25 mm (2ϕ). The fine material less than 0.06 mm is removed by decanting. The sample of sand fraction (0.25 mm to 0.06 mm in size) is heated with 1 N. hydrochloric acid for about fifteen minutes to clean the grains and to dissolve the calcareous material. The sample is then washed in water several times, dried, and weighed. Heavy minerals are separated from the light using acetylene tetrabromide (specific gravity ≒ 2.9). After the separation, heavy minerals were weighed and magnetite is removed by the horseshoe magnet. The heavy mineral grains are mounted on a glass slide with synthetic resin "Rigolac No. 2004"*. A total of 200 to 300 grains of non-opaque heavy minerals excluding authigenic anatase were examined. They are counted under a petrographic microscope.

Since zircon, garnet, and tourmaline have such characteristic features, as crystal forms or optical properties under the microscope, it is easy to distinguish them. Nevertheless, to make sure the result, three samples from the Nishisonogi Peninsula, Sakito-Matsushima coal field were examined by the X-ray diffractometer. Sample 105 contains 98 percent garnet, 1.5 percent tourmaline, and 0.5 percent zircon as non-opaque heavy minerals; sample 81, 99 percent tourmaline and one percent zircon; sample 103, 72 percent zircon, 14 percent tourmaline, 10.5 percent rutile, and 2.5 percent garnet. The patterns are shown in figure 3. They clearly reflect the composition and the relative abundances of each heavy mineral.

IV. Zircon-Garnet-Tourmaline Ratio

Heavy mineral assemblage of each coal field were already reported by SATO (1961, 1963, 1964) and OHARA (1959, 1960a, 1960b, 1961a, 1961b, 1961c, 1962, 1964). Their data show that zircon, garnet, and tourmaline are generally abundant throughout the whole areas but sometimes rutile and epidote appear to be significant in their quantities. A total percentage of zircon, garnet, and tourmaline makes more than 80 percent of non-opaque heavy minerals in a sample. Thus, the writer concluded that they are the most important constituent of the Paleogene sediments in Kyushu (Fig. 4).

The ratio among those minerals varies from place to place or from a formation (or formations) to formation. To grasp the compositional changes at a glance, the writer re-calculates the zircon-garnet-tourmaline ratio from the above data and plots the value in the ternary diagram. He calls the diagram "ZGT Diagram" by which characteristic compositions of zircon + garnet + tourmaline in each formation or each area can be easily seen. In the following discussion, the value of the ratios among zircon, garnet, and tourmaline is represented as "the value" for simplicity.

Description of the Results

In the ZGT diagram, the characteristic distribution patterns of the values of each formation (or group) are described below, although some of them were already reported (SATO, ibid.).

* Rigolac No. 2004: It can be obtained from Riken Polyester Resin LTD., Ota-ku, Tokyo. Rigolac, though its refractive index is rather low (1.54), has low viscosity and solidifies rapidly with addition of a catalyser and a hardner at room temperature with few bubbles. This is a very good medium for the mounting purpose.

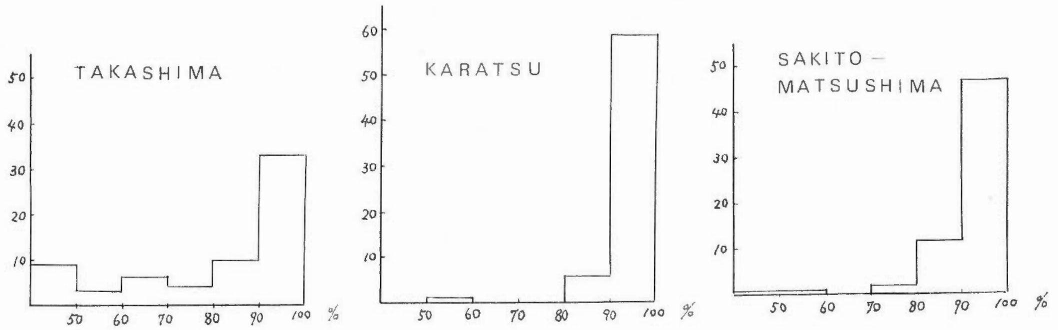

Fig. 4 Frequency distribution of the zircon-garnet-tourmaline percentage among the non-opaque heavy minerals in some coal fields.

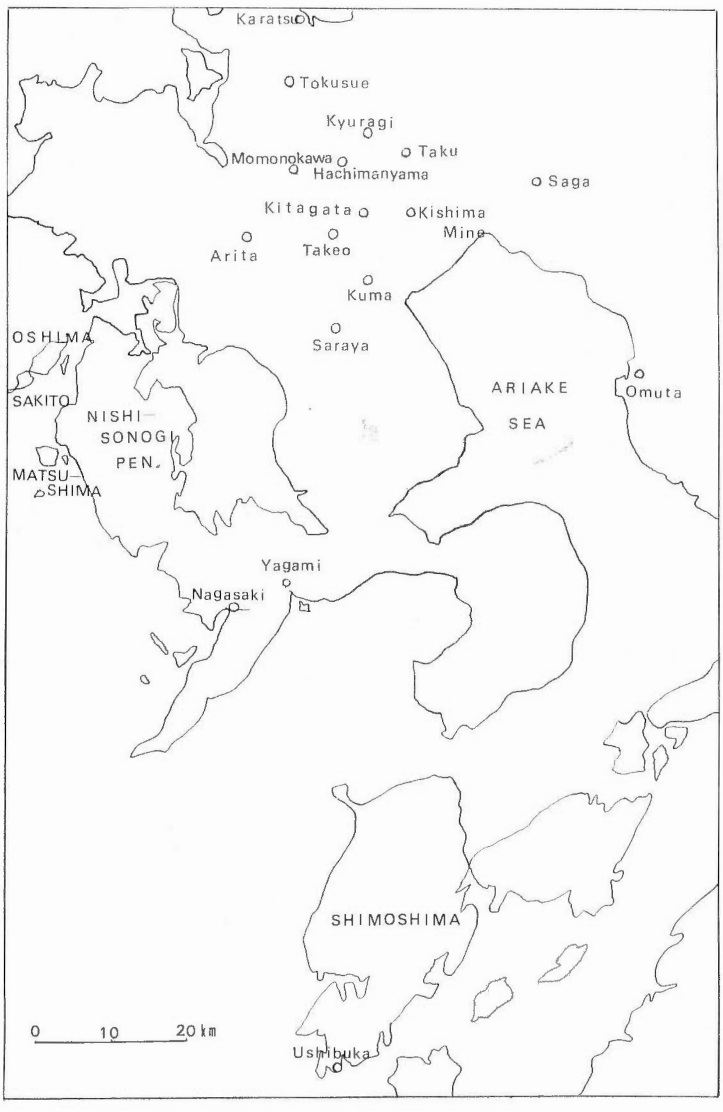

Fig. 5 Location map of the coal fields.

IV. 1 Amakusa Coal Field

Cretaceous formations: They are characterized by fairly high contents of garnet and low zircon (some samples contain abundant epidote). The values occupy broad area in the diagram (Cr. in Fig. 6).

Paleogene

Shimoshima group

Zircon is the most abundant minerals. All the values are concentrated in a quite limited area (Si in Fig. 6). No compositional difference is seen among the three formations within this group.

Sakasegawa group

The samples except those of the Itchōda formation contain somewhat higher contents of garnet than those of the Shimoshima group. The values cover Sk area (Fig. 6). The Itchōda formation which is the lowest formation of the group and composed of thin green sandstones, has about the same heavy mineral composition as those of the underlying Shimoshima group.

IV. 2 Isahaya Coal Field (Fig. 7)

Isahaya group

Only the Keya formation (coal bearing) are treated here, since the other formation of the group, the Enoura, is not sandstone. The Keya formation is characterized by high contents of zircon and low conten s of garnet. All the values are distributed along the ZT side (Is area in Fig. 7) as observed for the Shimoshima group in Amakusa.

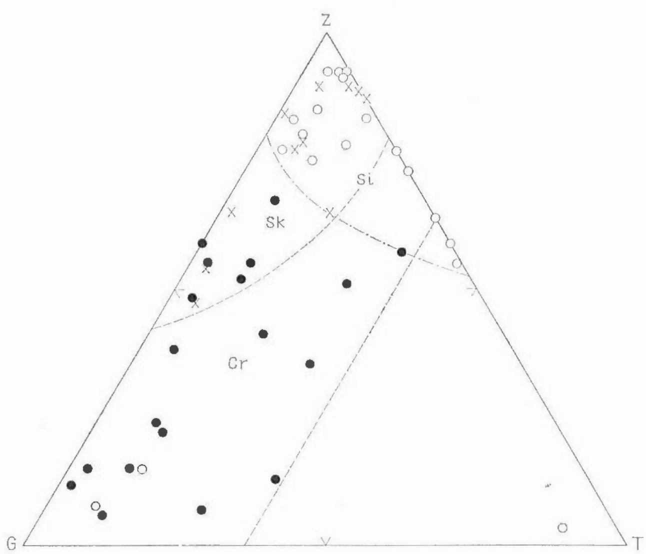

Fig. 6 ZGT diagram of the Cretaceous (●), Shimoshima (○), and Sakasegawa (×) groups of the Amakusa coal field.

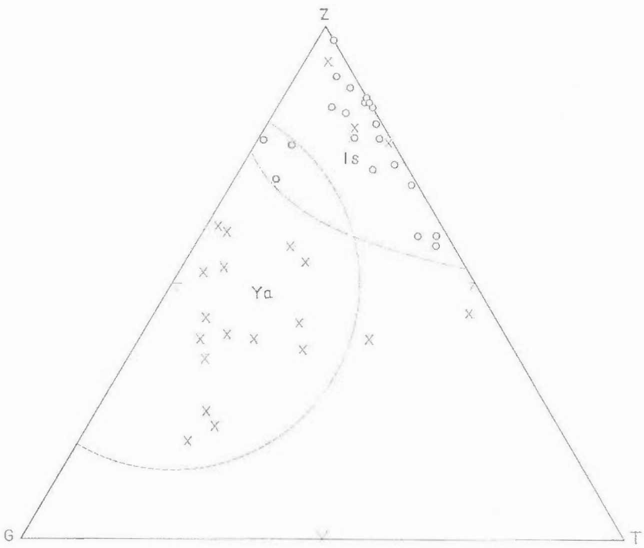

Fig. 7　ZGT diagram of the Isahaya (○) and Yagami (×) groups of the Isahaya coal field.

Yagami group

The garnet contents increases in contrast to the Isahaya group. The values are scattered over the wide area in the diagram (Ya area in Fig. 7).

IV. 3 Takashima Coal Field* (Figs. 8, 9)

Akasaki group

Kōyagi formation: The formation contains many epidote and the total percentage of the three heavy minerals is less than 40 percent. In spite of these difficulties, the values were computed. The result shows that the relative abundances of zircon to garnet in the formation are characterized by two distinct areas in the diagram. The Kou has much more garnet than the Kom. They coincide with the upper and middle members of the formation.

Takashima group

Futagojima formation: The tourmaline contents are somewhat higher than those of the Kōyagi formation, while the garnet contents decreases with ascending from the lower member (Ful area) to the upper member (Fuu area) (Fig. 8).

Hashima formation (coal bearing): The high zircon and low garnet contents are characteristic in this formation. The values are shown in the Ha area in the diagram.

* Ohara's data (1960b) were used to obtain the values of the ZGT ratio in this coal field.

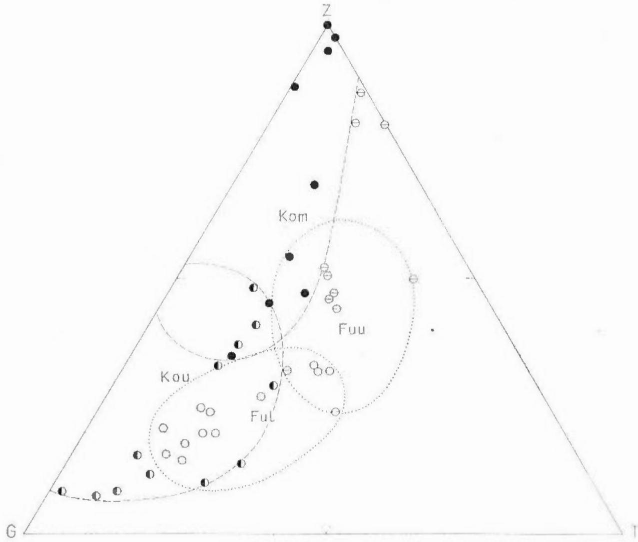

Fig. 8 ZGT diagram of the Akasaki and Takashima groups of the Takashima coal field.
⊖, upper member of the Futagojima formation; ○, lower member of the Futagojima formation; ◐, upper member of the Kōyagi formation; ●, middle member of the Kōyagi formation.

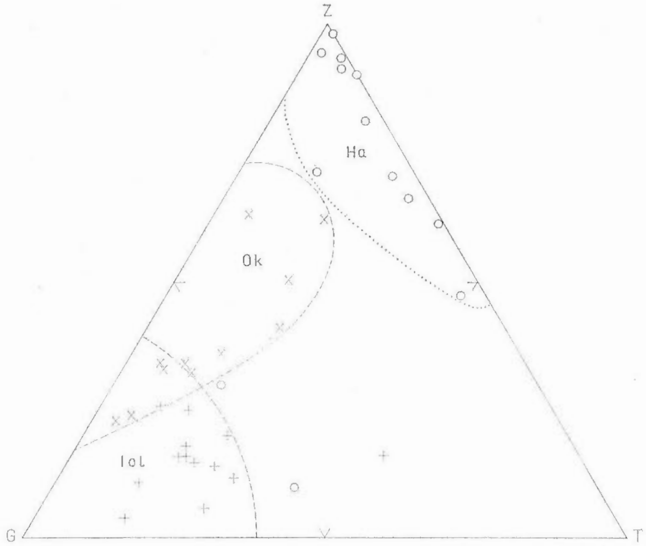

Fig. 9 ZGT diagram of the Takashima (Hashima formation) and the Iōjima groups of the Takashima coal field.
+, lower member of the Iōjima formation; ×, Okinoshima formation; ○, Hashima formation.

Iōjima group

The garnet contents increase again in the Okinoshima formation (Ok area). Moreover, the lower member of the Iōjima formation (Iol area) has abundant garnet (Fig. 9). The distribution areas of the Ok and the Iol are almost corresponding with the Kom and the Kou areas of the Kōyagi formation, respectively.

IV. 4 Miike Coal Field (Figs. 10, 11)

The data are based upon mainly from OHARA's (1961b) and partly from SATO's (1963).

Akasaki group

Ginsui formation: The values are distributed into two quite different areas, GiA and GiM. The former pattern lies along the ZT side and the latter along the GT side. The sandstone, from which the samples of the GiA area are collected, overlies the granites in the south, while the sediments, which include samples of the GiM area, cover the crystalline schists and gneisses in the north.

Ōmuta and Manda groups: The tourmaline and garnet contents decrease gradually toward upper formations, that is, distribution areas of the values are becoming narrower and narrower (KT→Na→Ka→Yo area) and finally it occupies near the Z pole as shown in figures 10 and 11.

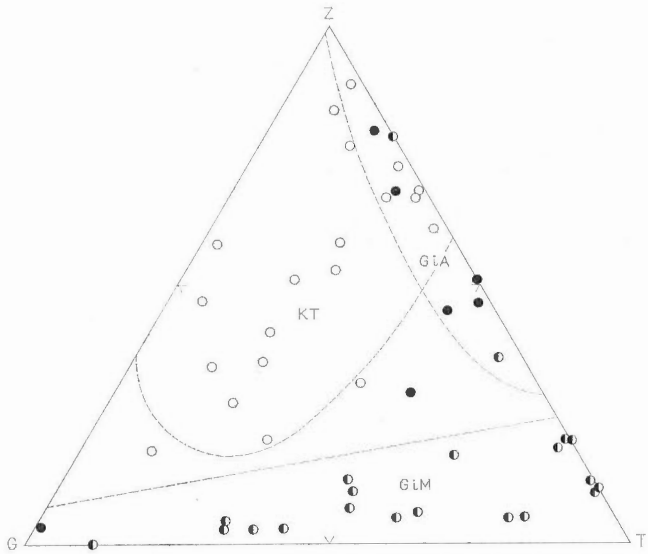

Fig. 10 ZGT diagram of the Akasaki and Ōmuta groups in the Miike coal field.
○, Tōka and Komenoyama formations; ◐, Ginsui formation in the north; ●, Ginsui formation in the south.

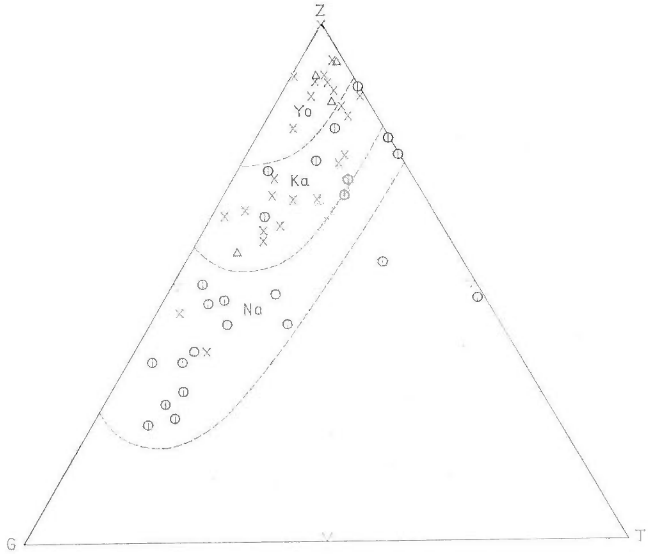

Fig. 11 ZGT diagram of the Ōmuta (Nanaura formation) and Manda groups of the Miike coal field.
△, Yotsuyama formation ; ×, Kattachi formation ; ⓘ, Nanaura formation.

IV. 5 Sakito-Matsushima Coal Field

The data at Sakito-Ōshima district are taken from OHARA's (1961c). The distribution areas of the values of each formation in figures 12 and 13 are somewhat schematic, because of their complexity of the boundary lines.

Akasaki and Terashima groups

They are rich in zircon and tourmaline and the values are distributed along the ZT side (AT area).

Matsushima group

The composition is characterized by small contents of garnet and nearly constant contents of tourmaline (40 to 50 percent). The values overlap about a half of the AT area. At Matsushima, however, the Ichigojima formation which is the lower formation of the Matsushima group, contains abundant garnet so that the values in the diagram are distributed near the G pole.

Nishisonogi group

Three different distribution patterns of the value MaI, MaII, and MaIII are observed in the Mase formation which is the lowest formation of the group. The difference is definitely due to the sampling locations. The MaI area is characterized by high contents of tourmaline and less contents of garnet, whereas the MaIII by high contents of garnet. The samples which belong to the MaI are from Ōshima and the MaIII from the Nishisonogi Peninsula. The composition of the MaII lies between those of the MaI and MaIII and the samples represent Sakito district, southwest of Ōshima.

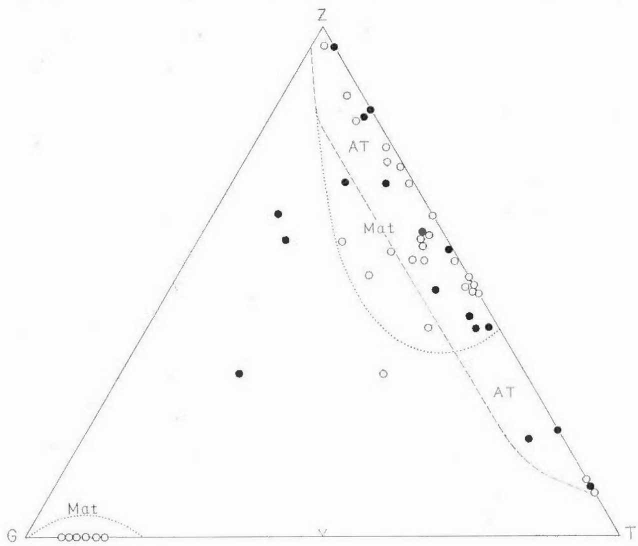

Fig. 12 ZGT diagram of the Akasaki, Terashima, and Matsushima groups of the Sakito-Matsushima coal field.
○, Matsushima group ; ●, Akasaki and Terashima groups.

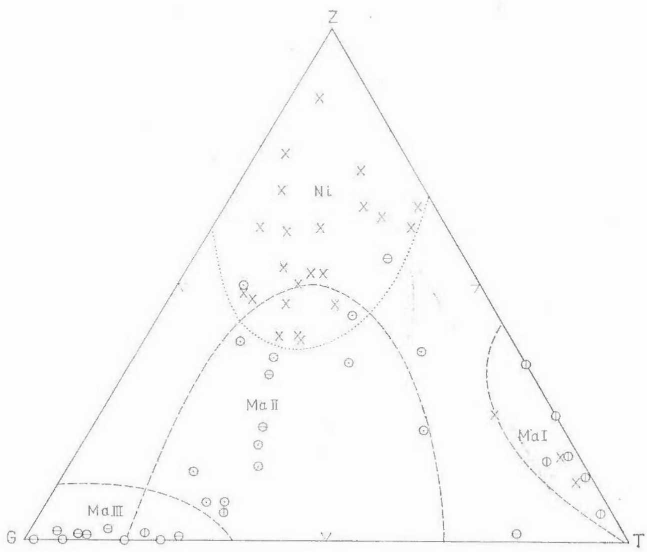

Fig. 13 ZGT diagram of the Nishisonogi group of the Sakito-Matsushima coal field.
⊕, Mase formation at Ōshima ; ⊙, Mase formation at Sakito ; ⊖, Mase formation at the Nishisonogi Peninsula ; ×, Tokuman formation.

Those regional differences in composition, however, disappear in the overlying Tokuman formation of which the samples from those different localities show fairly high contents of zircon. The values occupy the Ni area. The similar tendency of the composition can be observed in even overlying formations.

IV. 6 Karatsu Coal Field (Figs. 14 to 23)

The distribution patterns of the values varies from place to place even within one formation in this coal field. Therefore, it is hard to describe the composition of each formation in a simple manner. However, all the data show that the patterns can be classified into two in the diagram, type I and type II. The type I is the area between the 20 percent garnet line and the ZT side. The type II occupies the area of less than 30 percent tourmaline line (Fig. 33). Usually the zircon contents is more than 20 percent. Around the Z pole both types overlap each other.

Ōchi group

The Kyuragi and Yoshinotani formations can not be distinguished by the distribution pattern of the values. The type I pattern is found at following localities; Kita-Taku, Tokusue, and Kuma. The type I pattern is also found at Takeo where the Kyuragi formation is absent.

The type II pattern is found at Kyuragi where samples are taken from the Kyuragi formation only, the Kishima coal mine, western Taku, Hachimanyama, Momonokawa (a mixed type of the I and II), and Arita (no sample of the Kyuragi formation was taken, because of the depth beyond the drill-cores).

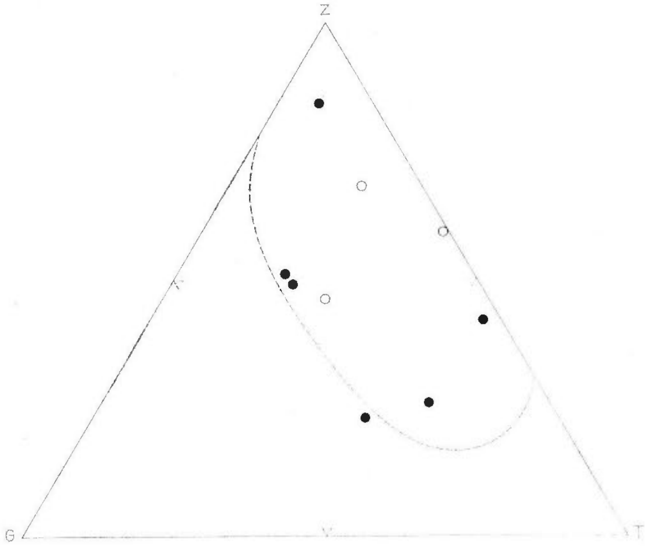

Fig. 14 ZGT diagram of the Ōchi group at Kita-Taku.
○, Yoshinotani formation; ●, Kyuragi formation.

Kishima group

Only the Kishima formation is discussed below. The type I pattern is observed at Tokusue, while the type II at Hachiman-yama, Momonokawa, Takeo, and Arita.

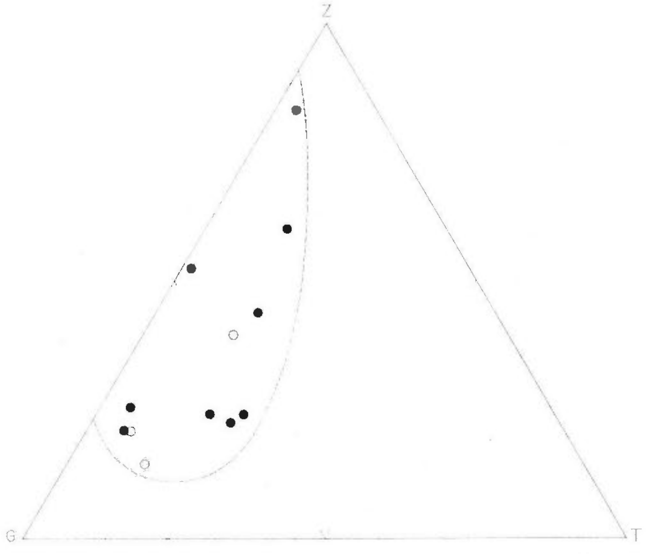

Fig. 15 ZGT diagram of the Ōchi group at western Taku.
○, Yoshinotani formation; ●, Kyuragi formation.

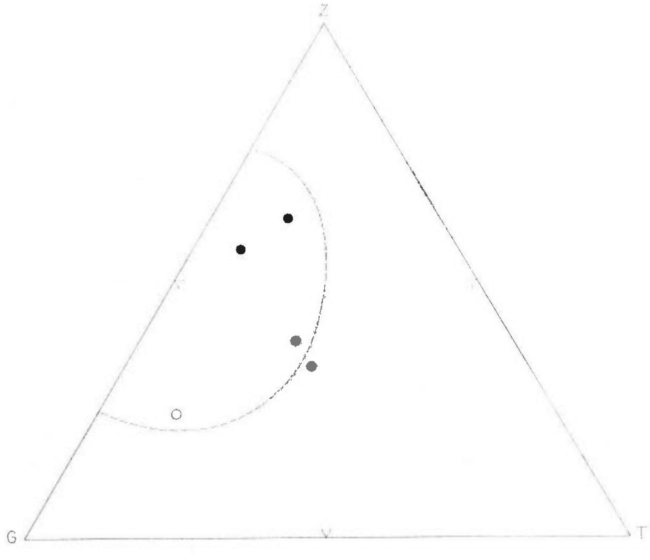

Fig. 16 ZGT diagram of the Ōchi group at Kyuragi.
○, Yoshinotani formation; ●, Kyuragi formation.

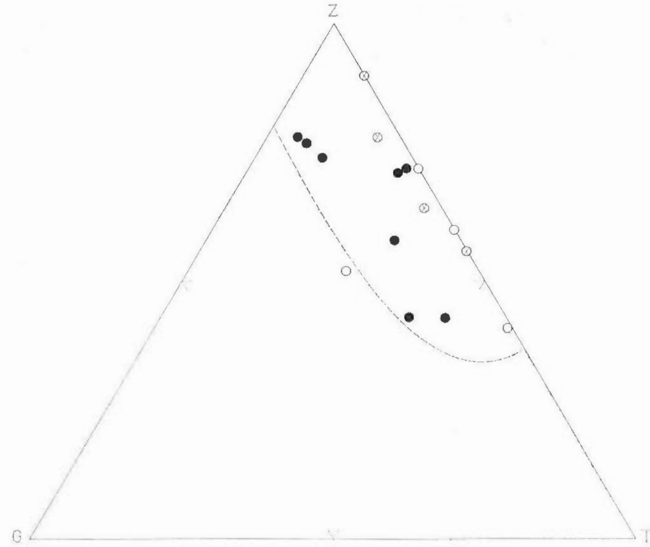

Fig. 17 ZGT diagram of the Ōchi and Kishima groups at Tokusue. ⊗, Kishima formation; ○, Yoshinotani formation; ●, Kyuragi formation.

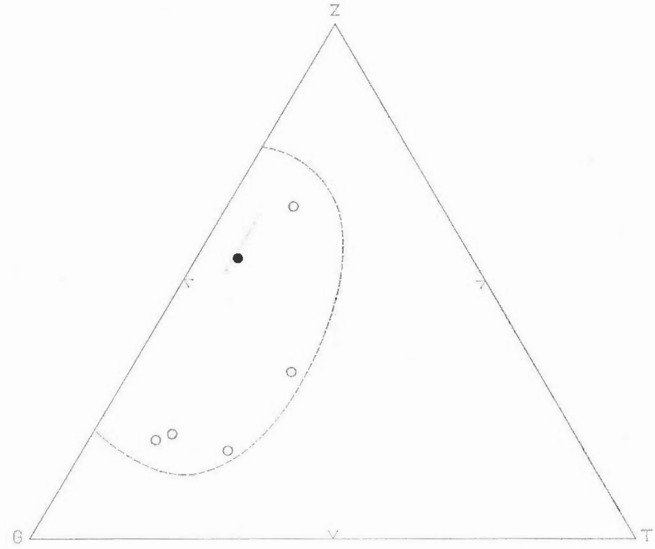

Fig. 18 ZGT diagram of the Ōchi group at the Kishima coal mine. ○, Yoshinotani formation; ●, Kyuragi formation.

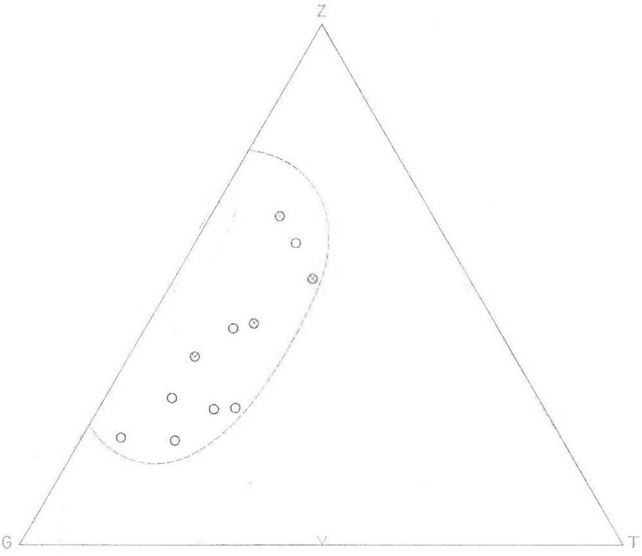

Fig. 19 ZGT diagram of the Ōchi and Kishima groups at Hachiman-yama.
⊗, Kishima formation ; ○, Yoshinotani formation.

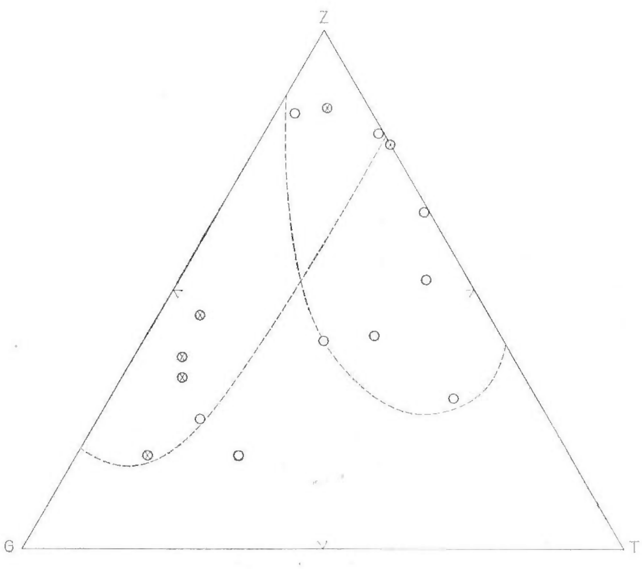

Fig. 20 ZGT diagram of the Ōchi and Kishima groups at Momonokawa.
⊗, Kishima formation ; ○, Yoshinotani formation.

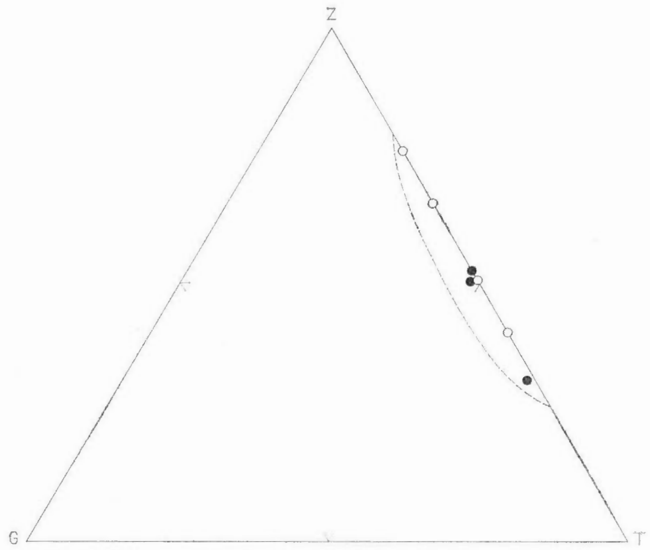

Fig. 21 ZGT diagram of the Ōchi group at Kuma.
○, Yoshinotani formation ; ●, Kyuragi formation.

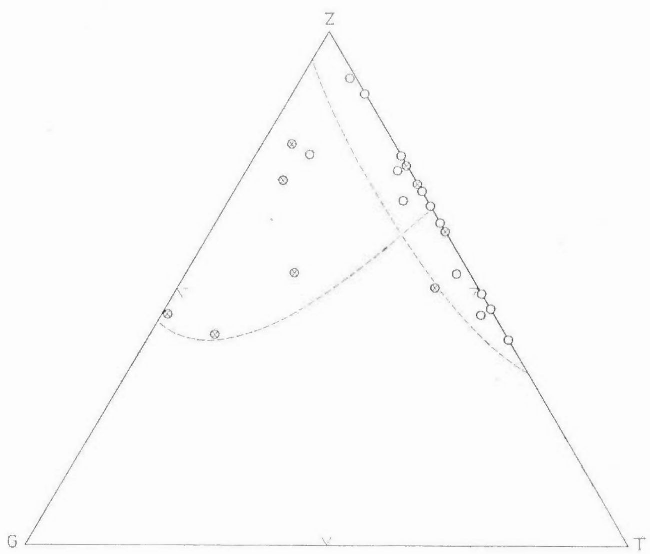

Fig. 22 ZGT diagram of the Ōchi and Kishima groups at Takeo.
⊗, Kishima formation ; ○, Yoshinotani formation.

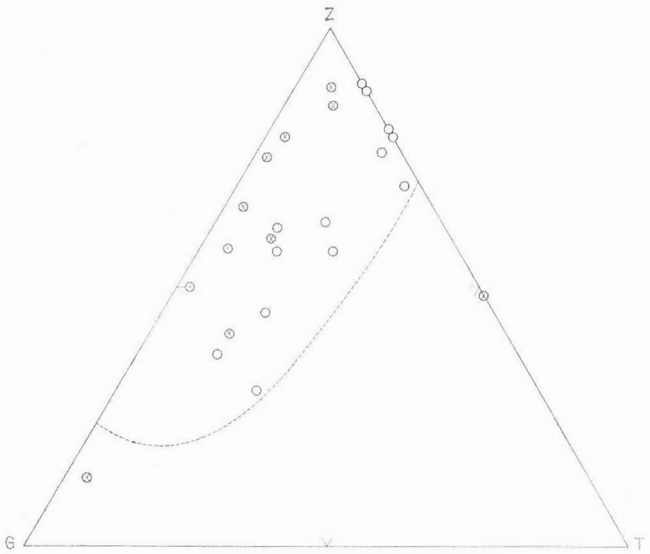

Fig. 23 ZGT diagram of the Ōchi and Kishima groups at Arita. ⊗, Kishima formation ; ○, Yoshinotani formation.

V. Stratigraphic Boundaries and the ZGT Ratio

Unconformity

There are several definite unconformities in the area (Tables 1 to 6). Among them, distinct compositional changes are observed between the Cretaceous formation (Cr area) and the Shimoshima group (Si area) in the Amakusa coal field (Fig. 6) and between the Terashima formation (AT area) and the Ichigojima formation (Mat area) in the Sakito-Matsushima coal field (Fig. 12).

The composition between the Sakito formation (Mat area) and the Mase formation (Ma area) is quite different and, furthermore, the latter composition varies from place to place (Fig. 13). The relation between the Sakito and the Mase formation has been controversial. Ohara (1961c) attributes the difference of the composition of the Mase formation to the changing depositional environment at the beginning of a large transgression, and the relation between the two formations is conformity. Nagahama (1965b) shows the two quite different transport directions and source rocks between the two formations on the basis of the study of paleocurrent. He stressed the existence of an unconformity. The writer inclined to consider that the striking contrast of the composition means a large unconformity between the two formations. It is more reasonable to consider that the movement of the background during the long period brought about the change of the distribution of source rocks and differentiation of the sedimentary basin. Those factors might influence the heavy mineral composition.

Conformity

As mentioned in chapter IV, the patterns or the values of the ZGT ratio of each stratum occupy a certain area in the ZGT diagram. Marked compositional change are seen between the groups in the Amakusa and Isahaya coal fields (Figs. 6, 7) and between the groups or formations in the Miike and Sakito-Matsushima (Figs. 12, 13). Similar changes are also observed between the formations or members in the Takashima (Figs. 8, 9). However, there appears no clue to determine the relation between the two strata because the changing patterns of the values are similar in both conformable relation and unconformable relation.

Generally speaking, though every formation (or group or member) has a certain characteristic distribution pattern of the values, it is hard to distinguish whether the boundary means a conformity or an unconformity only from the heavy mineral data.

Correlation

The Toishi, Keya, Hashima, and Tōka formations, which are important Eocene coal bearing formations, have been correlated with each other by the geologic data. The distribution pattern of the value in the ZGT diagram is almost the same (i. e., high zircon contents and low garnet contents) among the former three formations and the changing patterns toward overlying formations show a common feature that is the increasing contents of garnet. The pattern of Tōka formation differs considerably.

Judging from those facts, the Amakusa, Isahaya, and Takashima coal fields were formed in one large sedimentary basin under the almost same environmental condition through the period while the Miike coal field were formed in another basin. It is impossible to correlate between the former three formations and the Tōka formation by the heavy mineral composition.

The values of the ZGT ratio differ distinctly from place to place even in a same formation in the Sakito-Matsushima and Karatsu coal fields, so that the pattern goes for very little for the correlative use in those coal fields.

As above examples show, the ZGT ratio is sometimes very useful for the correlation but sometimes not. However, the further study of characteristic heavy mineral species, crystal form, and so on with the values of the ZGT ratio will help the zoning or correlation of the Tertiary sediments.

VI. Source Rocks and the ZGT Ratio

Zircon is common in acid igneous rocks especially granites and diorites. Tourmaline distributes widely in schists and gneisses and common in some pegmatites, and garnet is usually found in schists and gneisses (Pettijohn, 1957; Winchell, 1951). This statement is supported by the following data.

The values of the ZGT ratio of some pre-Tertiary rocks, including granites, crystalline schists, and some gneisses from several localities show that granites are rich in zircon and situate near the Z pole along the ZT side, whereas the crystalline schists contain much garnet and situate near the G pole along the GT side in the diagram (Fig. 24). In both cases, no sample that contain much tourmaline are found, though some tourmaline are described as an accessory mineral in the schists (NAGAHAMA and MATSUI, 1958).

Then, let us consider the values of the ZGT ratio of sandstone which might be derived with certainty from granites and crystalline schists. In the Miike coal field, the underlying rocks of the Ginsui formation are granites in the south and metamorphic rocks (schists and gneisses) in the north. The heavy mineral compositions of the sandstone lying on granites are characterized by high zircon contents and low garnet contents. They can be expressed by the A1 area along the ZT side (Fig. 24). Nevertheless, overlying metamorphic rocks, the sandstone contain abundant garnet or tourmaline. Thus, the distribution area of the values is shown by the M1 along the GT side (Fig. 24). The Kyuragi formation that distributes near Tokusue in the Karatsu coal field has commonly monazite. The formation is in contact with granodiorite by a fault. The sediments have been considered to be

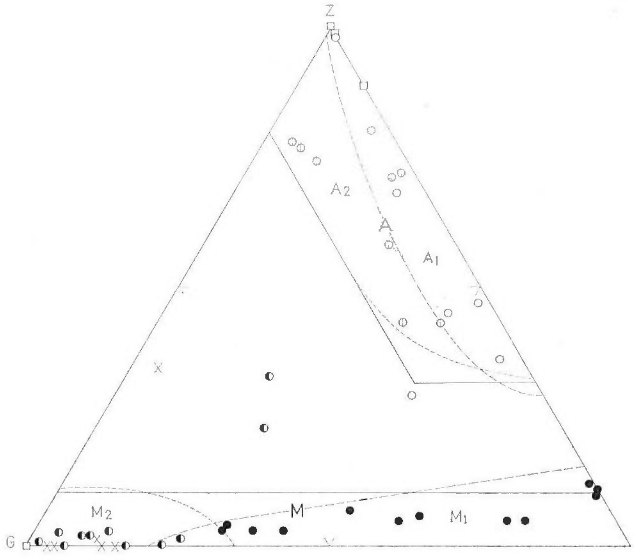

Fig. 24 ZGT diagram of granite, crystalline schist, gneiss, and sediments of the above origin.
□, Granite ; ×, crystalline schist and gneiss ; ○, sediments of granite origin (Ginsui formation) ; ◐, sediments of granite origin (Kyuragi formation at Tokusue) ; ●, sediments of schist origin (Ginsui formation) ; ◑, sediments of schist origin (Mase formation).

derived from granitic rocks. The composition of the formation is shown by the A2 area between the ZT side and the 20 percent garnet line (Fig. 24). The lower part of the Mase formation at the Nishisonogi Peninsula contains abundant angular pebbles and cobbles of crystalline schists which distribute widely at present in the peninsula. The abundant garnet in the sandstone has the same character as in the schists (SATO, 1964). It is certain that the sandstone of the Mase formation are derived from the schist terrain. In the diagram the composition of the sandstone is represented by the M 2 area near the G pole (Fig. 24).

Then, two separate areas are recognized by the difference of source rocks in the diagram. The one is the area of over 30 percent zircon and less than 20 percent garnet, and the other the area encircled by the 10 percent zircon line and the GT side. If we call the former composition the type A, and the latter the type M, respectively, we can conclude that the type A represents the sediments which may be derived from granitic rocks and the type M the crystalline schists.

Some examples are given below.

(a) The composition of the samples from the Fukuregi formation of the Shimoshima group is mostly the type A. Nevertheless, the values of some samples which were collected from near Ushibuka city in the southern part of the Amakusa coal field belong to the type M (Fig. 25). It could be concluded that in most part of the Fukuregi formation materials are of granitic rocks origin but in the particular area the sediments are derived from crystalline schists though the transport direction has not been known yet. This is a new datum about the source of the Fukuregi formation.

(b) In the Takashima coal field, pebbles of crystalline schists and other rocks are found in the Kōyagi formation (Akasaki group), the lower part of the Futagojima formation (Takashima group), and the lower Iōjima formation (Iōjima group) (Geological Survey of Japan, 1960). The composition of the three major heavy minerals in those formations is rich in garnet and situates the M area near the G pole (Figs. 8, 9). It is concluded that the source materials of the sediments are mainly crystalline schists.

NAGAHAMA (1965b) stated that the transport direction of the materials of these formations was mainly from the east to the west and the source area was crystalline schist in the Nishisonogi-Nomo upheaval zone (Fig. 27). The fact corresponds closely with the writer's conclusion.

(c) The Akasaki and Terashima formations in the Sakito-Matsushima coal field contain pebbles of granite and other rocks but no crystalline schist (NAGAHAMA and MATSUI, 1958). Although amount of tourmaline is high, the values generally distribute along the ZT side. Thus, this pattern coincide with the type A. Therefore, the most sediments were derived from granitic

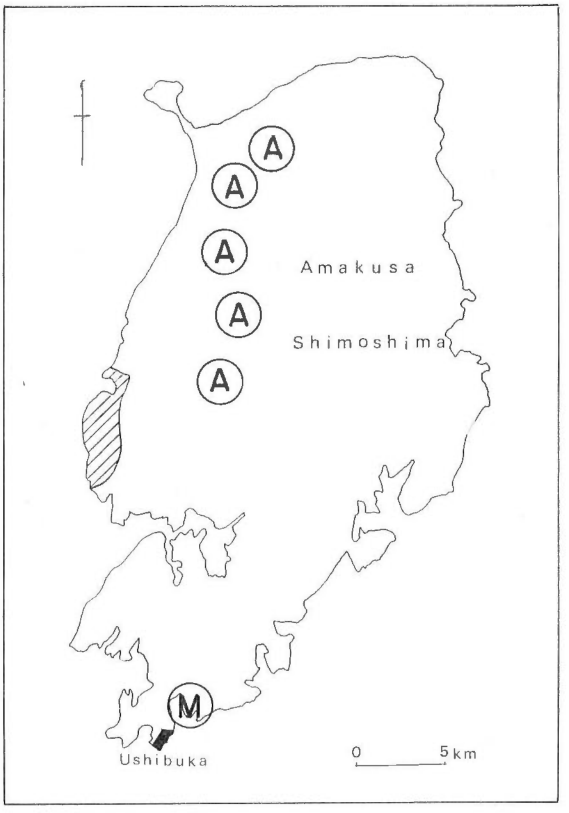

Fig. 25 Distribution of the type A and M sediments of the Fukuregi formation, Amakusa coal field.
Hatched area, crystalline schists.

rocks and not from schist.

Two prevailing directions of the diagonal bedding were distinguished and the source rocks were granites in the Terashima small upheaval area between Ōshima and Matsushima and the Ainoshima-Odatejima upheaval zone in the west (NAGAHAMA, 1965) (Fig. 27).

(d) The composition of the Sakito formation, Matsushima group, belongs to the type A. The paleogeographic map in the Matsushima stage shows various paleocurrent directions (NAGAHAMA, 1965b). The source rocks of the type A sediments can be explained from the map that one is granite of the Ainoshima-Odatejima upheaval zone and the other is that of the Terashima small upheaval area (Fig. 28).

(e) The composition of the Mase formation belongs to the type M (i. e., the sediments is schist origin). The materials were derived from crystalline schists in the Nishisonogi Peninsula by the westward current (NAGAHAMA, 1965b) (Fig. 29).

Fig. 26 Location map of the Sakito-Matsushima and Takashima coal fields.

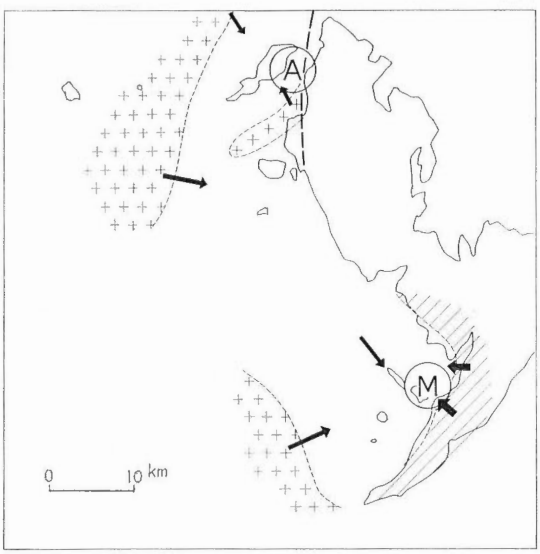

Fig. 27 Relation between the composition of the Akasaki group (including the Terashima group in the Sakito-Matsushima coal field) and the paleocurrent directions. (Paleogeographic map after NAGAHAMA, 1965b).

Cross, granites; hatched area, crystalline schists.

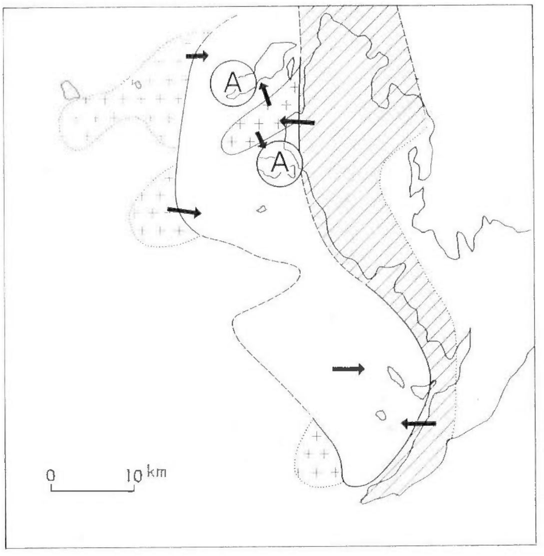

Fig. 28 Relation between the composition of the Sakito formation and the paleocurrent directions. (Paleogeographic map after NAGAHAMA, 1965b).
Cross, granites; hatched area, crystalline schists.

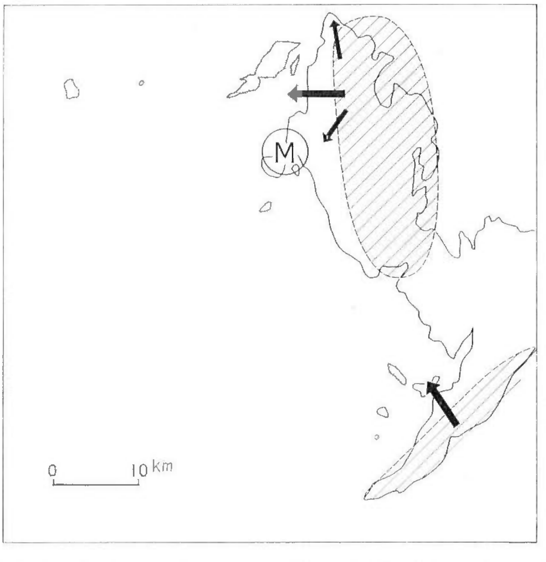

Fig. 29 Relation between the composition of the Mase formation and the paleocurrent directions. (Paleogeographic map after NAGAHAMA, 1965b).
Hatched area, crystalline schists.

VII. Depositional Conditions and the ZGT Ratio

Zircon, garnet, and tourmaline are the most stable minerals. They are commonly found from older to younger deposits (PETTIJOHN, 1957). They have marked differences in specific gravity (zircon≒4.7, garnet≒3.4～4.3, tourmaline≒2.9～3.3), so that the relative abundance of those minerals must reflect not only the kind of the source rocks but also environmental conditions.

Zircon is rich in cross-bedded part of the Mase formation where the mineral increases up to 55 percent, while the garnet contents is 13 percent and the tourmaline 32 percent. Nevertheless, the rest of the formation contains high percentage of garnet (70 to 90 percent) and a certain amount of tourmaline. It seems probable that the zircon and garnet concentration is easily affected by flowing currents under certain conditions but toumaline is not.

There are the cases that the amount of garnet varies from zero to 50 percent, while the tourmaline contents is uniform in a same formation (i. e., the composition is the type II). In these cases, there exists a gap around the 20 percent line of the garnet, which means that only few samples contain the said amount of garnet in the diagram. This line also corresponds to the boundary line of the type I. Good examples of these can be seen at the Miike and Arita.

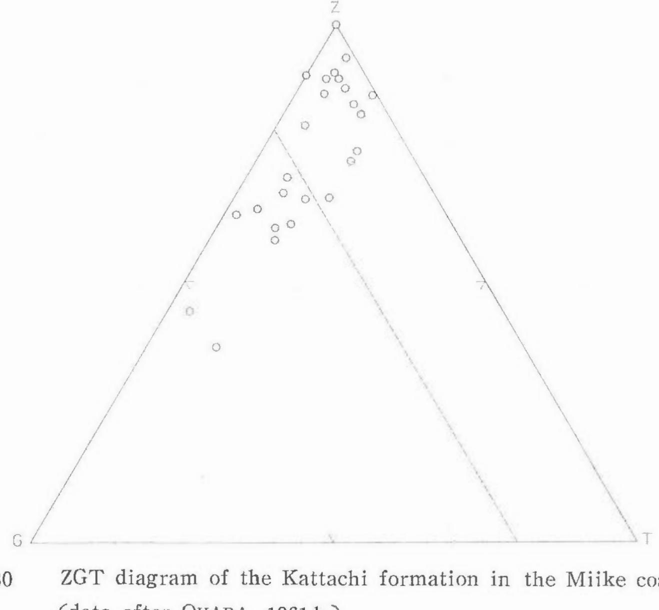

Fig. 30 ZGT diagram of the Kattachi formation in the Miike coal field (data after OHARA, 1961 b).

The Kattachi formation of the Miike coal field, of which thickness is about 200 m, is deposited under marine to brackish water conditions. It shows three sedimentary cycles (KIKUCHI, 1963). The oscillation feature of the garnet contents between less than 20 percent and more than 20 percent are shown in figures 30 and 31. The oscillation occurs with intervals of 10 to 30 meters in thickness.

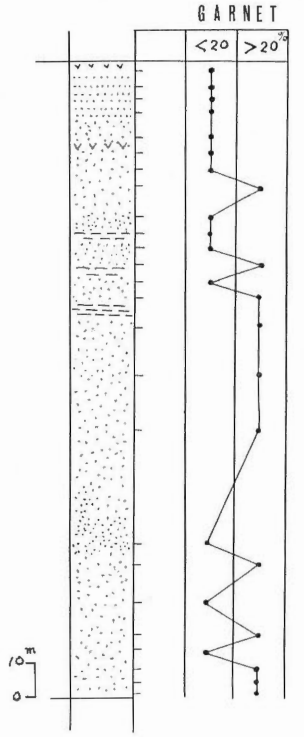

Fig. 31 Vertical change of garnet contents (between less than 20% and more than 20%) in the stratigraphic column of the Kattachi formation (the column and sampling points are after OHARA, 1961b).

The similar relations are observed in the Yoshinotani formation at Arita, Karatsu coal field (Figs, 23, 32). The formation, over 320 meters in thickness, consists mostly of pale grey fine sandstones except for the intermediate part, 120 meters in thickness, where dark grey fine-grained sandstones alternate with medium-grained sandstones or shales. The oscillations of the garnet are with intervals of several tens to a hundred meters in thickness. Generally speaking, garnet is poor in quantity (that is, zircon is abundant) at the lower and upper parts, while garnet is abundant at the middle. Towards the uppermost part, the garnet content again increases.

The sediments in those formation are rather uniform and the variation of the garnet contents in the column seems to reflect not the difference of source rocks but, to some extent, the changes of such depositional conditions as water depth or distance from the land, water course or current velocity, etc.

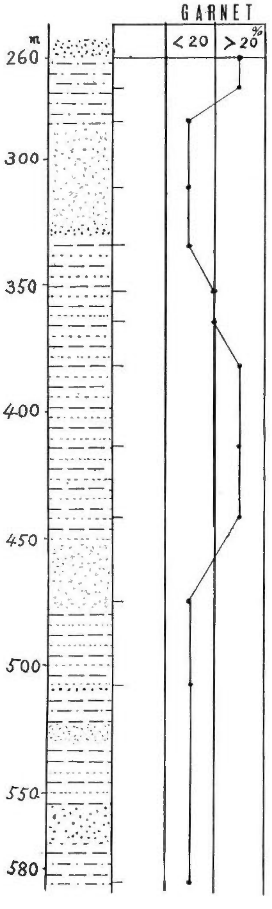

Fig. 32 Vertical change of garnet contents (between less than 20% and more than 20%) in the stratigraphic column of the Yoshinotani formation at Arita.

Tourmaline contents is usually less than 30 percent. In an extreme case, however, nearly 100 percent tourmaline are found in the Ginsui, Akasaki, and part of the Mase formations. The pre-Tertiary rocks which are rich in tourmaline as a constituent mineral, are not known yet in the studied area. Then, the high concentration of tourmaline in the sediments would indicate a peculiar condition of deposition.

Classification of the ZGT Distribution Pattern

Glancing at the ZGT diagrams, it will be seen that there exists a definite distribution pattern of the values. It is rather rare that zircon content is less than 20 percent. If the sample shows that composition, the source rock is suggested as crystalline schists. The garnet content varies from zero to 100 percent. It is found, however, that there are few samples which contain about 20 percent garnet. Therefore, there is a gap around that composition in the diagram. Furthermore, whenever the values are scattered parallel to the ZT side, the garnet contents is definitely less than 20 percent. The tourmaline contents is rare to exceed 60 percent. The most samples contain the mineral less than 30 percent.

From these data, four areas are distinguished in the diagram (Fig. 33). The composition of each type is;

type I—over 20% zircon and less than 20% garnet,

type II—over 20% zircon and less than 30% tourmaline,

type III—less than 20% zircon,

type IV—the rest of the above areas.

The type II area can be classified into two by garnet contents,

type IIa—less than 50% garnet,

type IIb—over 20% garnet.

The type I and the type II overlap near the Z pole. The former distribution area, however, extends parallel to the ZT side, while the latter parallel to the ZG side.

In this grouping, (for the most part) the type I coincides with the type A (granitic rocks origin) and the type III with the type M (crystalline schists origin).

The samples which have the type II composition, belong mostly to marine formations. It is noteworthy that if the formations of which composition shows the type II, overlies the type I formations, the type II formations are deposited during a large transgressive period. The examples are given by the Sakasegawa, Yagami, and Iojima formations.

The type IIa and IIb will be discussed in the following chapter.

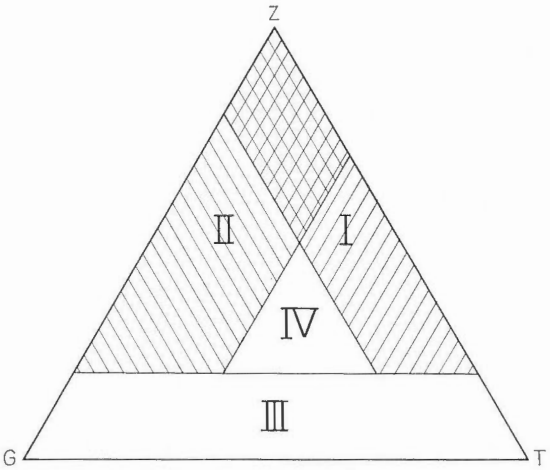

Fig. 33 Classification of the ZGT distribution pattern.

VIII. Sedimentation of the Ōchi Group, the Karatsu Coal Field

As already mentioned (chapters IV and VII) the patterns of the ZGT ratio of the Ōchi group are classified into two, the type I and the type II. The type II can be further subdivided into the type IIa and IIb (chapter VII). Those types have a close relationship with the difference of source rocks and/or sedimentary environments. In the figure 34, those types are plotted at each locality. The following conclusions are drawn from the heavy mineral composition and the distribution patterns of the ZGT ratio:

(a) The Ōchi group consists of the Kyuragi and Yoshinotani formations. Though the composition differs from place to place, it is about the same in the two formations at the same locality. Consequently, it is hard to distinguish them. It is deduced that there were no marked changes of environments and source rocks during the deposition of the both formations. When the samples of the Yoshinotani formation are scarce, the distribution pattern of the formation can be inferred from the pattern of the Kyuragi formation.

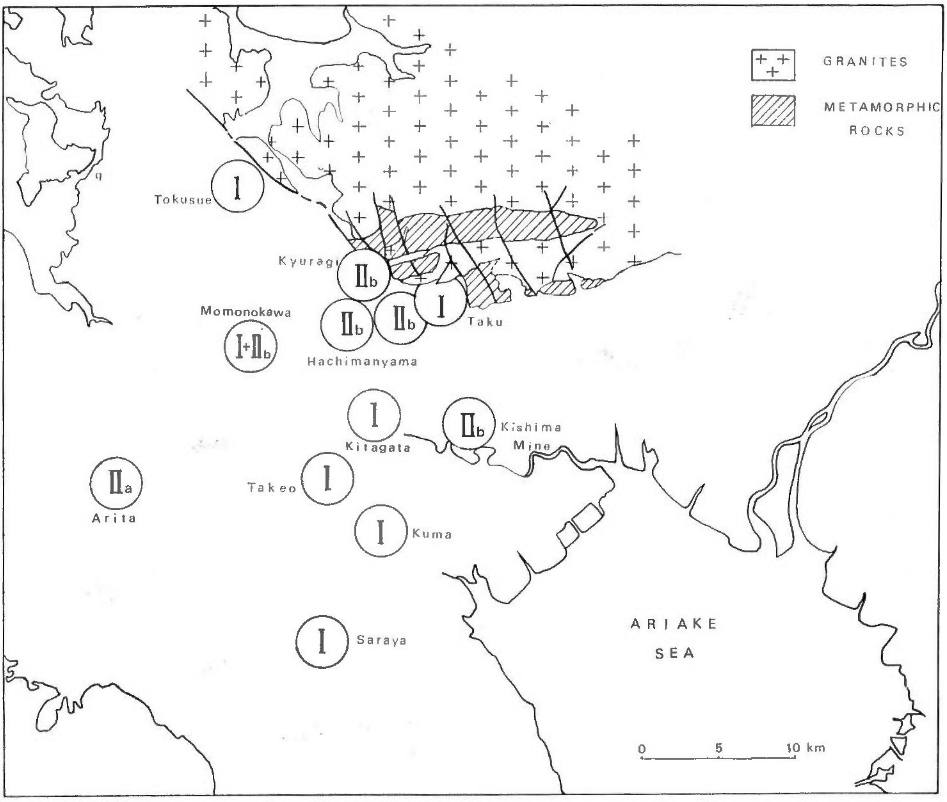

Fig 34 Distribution map of the various types of the ZGT ratio of the Ōchi group, Karatsu coal field.

(b) The type I is found at Tokusue, an uncertain type I at Kita-Taku, and the type IIb at the rest of the localities on the line connecting Tokusue with the Kishima coal mine. The type I is also found in areas covering Kitagata, Takeo, Kuma, and Saraya, at the south of the line. At Momonokawa, between Tokusue and Takeo, the composition shows a mixed pattern of the type I and IIb, though the data are scanty, and at Arita, the type IIa.

(c) The type I coincides with the type A and the type III with the type M. The former suggests a granitic rocks origin and the latter a crystalline schists origin. However, there has been no representative type III sediments found in the field. Some samples, collected from the Kyuragi formation which overlies crystalline schists unconformably at Kyuragi, contain fairly abundant garnet and show the type IIb composition. Though the type IIb has less garnet and tourmaline contents than the type III, it may represent that a part of the source materials of the sediments is at least crystalline schists.

From this point of view, it is inferred that most sediments were derived from granitic rocks near Tokusue and Kita-Taku and from crystalline schists at Kyuragi, Hachiman-yama, and western Taku. The ZGT composition of the sediments at the Kishima coal mine which situates far from the border between Tertiary and pre-Tertiary rocks shows the type IIb. This suggests that the sediments might be derived from crystalline schists which is hidden under the Saga plain in the east.

The type I composition is found at several localities in the south of the coal field; Kitagata, Takeo, Kuma, and Saraya. Those places are far from the granites in the north, and between the granites and those places there exists a different sediment composition (the type IIb). Moreover, granites distribute only a limited area in the southwest where crystalline schists distribute widely. Where we should seek for the granite as a source of the sediments in the south. Kikuchi (1963a) reported the granitic rocks which compose the Minenosu barrier and limit the western margin of the Miike coal field, at the center of Ariake sea. These rocks are apparently the possible source of the type I sediments in the south. A few fragments of crystalline schists are found in the sandstone at Kuma, so that the schists were also the source materials of the sediments in this area.

(d) The composition of the sediments at Momonokawa is the mixed pattern of the type I and IIb. It can be interpreted that the either sediments were derived from both granites and crystalline schists or they are the product under a special environmental condition. No definite conclusion about these could be drawn.

IX. Heavy Minerals of the Sandstones of the Coal Bearing Formations

The sandstones which compose the coal bearing formations in the northwestern Kyushu have a characteristic lithology and heavy mineral assemblages. The sandstones are generally light brown, medium- to fine-grained, and have a good sorting. The heavy minerals are fine in grain size and well-sorted and rounded and have two quite distinct compositional patterns. The one is rich in zircon and poor in garnet, belonging to the type I or rather to the type A. Usually about 10 percent or more rutile are found together (Table 8). Another belongs to the type II and the rutile contents is only a few percent. The type I distributes along the present coastline of the northwestern Kyushu and a part of the Karatsu coal field. The type II is found at the Miike coal field, Kyuragi, the Kishima coal mine, and at Arita.

Hubert (1962) proposed a zircon-tourmaline-rutile maturity index (i. e., zircon+tourmaline+rutile %) to express the sandstone maturity. He said "…. In most arkoses and graywackes, the average ZTR index is low but varies widely among samples. …. The ZTR index is over 90 percent in most orthoquartzite sandstones." The mature sandstone, according to Krumbein and Sloss (1951), represents stable conditions, with a very mild subsidence during accumulation, and with a considerable transport and winnowing action before final accumulation. Coal, however, occurs in association with subgraywacke sand-

Table 8 Compositional pattern and rutile contents in the coal bearing sandstones.

Coal Field	Formation	Type	Rutile Contents %
Amakusa	Toishi	I	7～27
Isahaya	Keya	I	7～13
Takashima	Lower Hashima (upper part)	I	5～18
Sakito-Matsushima	Sakito	I	9～20
Karatsu			
Kitataku	Yoshinotani	I ?	10
Tokusue	〃	I	12
Momonokawa	〃	I + II	6～8
Kitagata	〃	I	5～23
Kuma, Saraya	〃	I	12～17
Takeo	〃	I	15
Miike	Tōka	II	less than 2
Karatsu			
Kishima coal mine	Yoshinotani	II	〃 〃 3
Kyuragi	〃	II	〃 〃 3
Arita	〃	II	〃 〃 4

stone. The sandstone occurs, under conditions of moderate subsidence, in sedimentary basins where the rate of burial is rapid enough to prevent thorough winnowing action by transportational agents (ibid., 1951).

The ZTR index of the coal bearing sandstones of which composition is the type I, is very high; 97 to 99 percent in the Amakusa and Isahaya coal fields, 80 to 100 percent in the Sakito-Matsushima coal field, and more than 90 percent in the Karatsu coal field. They are very "mature" by HUBERT's classification. In the Miike and a part of the Karatsu coal fields where the type II composition is characteristic, the ZTR index is rather low and shows 30 to 80 percent.

The high ZTR index, as well as the good sorting and roundness, indicates that the sediments are a mature sandstone, while coal does not occur in such a condition. The type I composition suggests the possibility that the sediments

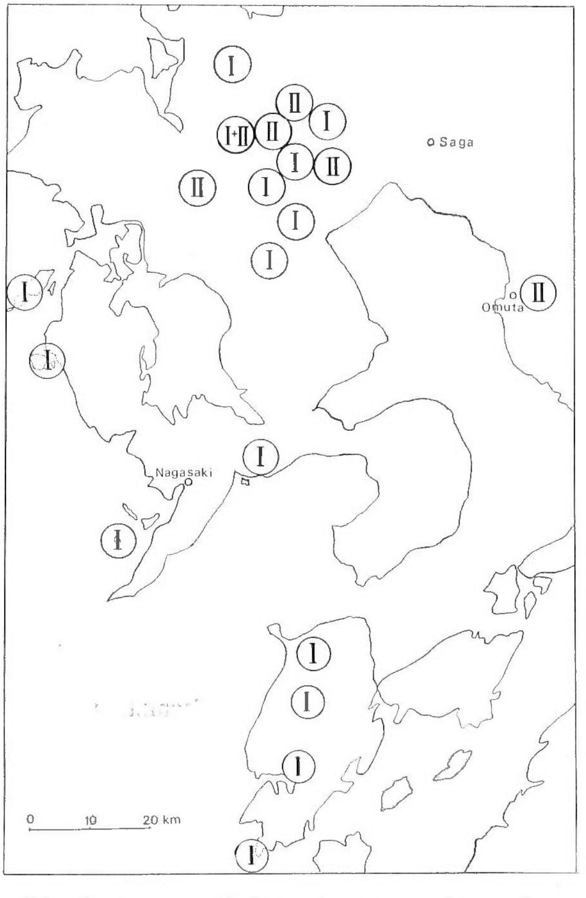

Fig. 35 Distribution map of the various types of the ZGT ratio of the coal bearing formations.

were derived from granitic rocks. Rutile, however, occurs commonly in schists (Winchell, 1951) and it is confirmed in the Nishisonogi Peninsula (Plate 1). There are some contradictions about the depositional condition and the source rocks as shown above. According to Ohara (1962), the origin of the sediments was granites and gneisses in the Korea Peninsula of the Asian continent. The idea explains the most conditions, but the distance from Kyushu to Korea is too far. Thus, the carbonaceous materials might be too diluted to make the coal seam.

During the deposition of the Hashima formation, granite was exposed near Mitsuse in the west of the Takashima coal field (Nagahama, 1965b). There were also granite masses in the Ainoshima-Odatejima upheaval zone and the Terashima small upheaval area through the depositional period of the Akasaki, Terashima, and Matsushima groups (Figs. 27, 28). From these facts, the writer considers that there were more extensive exposures of granites west of Kyushu at that time and the heavy mineral composition reflects the nature of these rocks rather than environmental factor. There still remains question about the source of rutile and the cause of well-sorted and rounded nature of the sediments. The classification of sandstones and environments in foreign countries can not be applied directly to Japanese sediments without questioning.

X. The ZGT Ratio in the Ishikari Coal Field, Hokkaido

The Ishikari group ranging from Eocene to lower Oligocene, distributes widely above the Cretaceous sedimentary groups in the Ishikari coal field, Hokkaido. The group consists of many coal bearing formations which deposited under fresh to brackish water conditions. They intercalates sometimes with shallow marine formations.

The Ishikari group is divided into following nine formations (Geological Survey of Japan, 1960).

Ishikari group	Upper	Ashibetsu coal bearing formation
		Hiragishi formation
		Ikushumbetsu coal bearing formation
		Akabira formation
	Middle	Bibai coal bearing formation
		Wakkanabe formation
	Lower	Yubari coal bearing formation
		Horokabetsu formation
		Noborikawa coal bearing formation

〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜〜

Upper Cretaceous groups

The ZGT diagrams were prepared from the IIJIMA's (1959b) and SATO's (1959) data. Their samples were collected from the Bibai, Naie, and Ashibetsu coal mines. The samples are arranged in order of the Cretaceous group, the lower, middle, and upper Ishikari groups respectively.

From the figures 36 to 39, the following conclusions can be drawn.

(a) The most common heavy mineral distribution pattern is the type IIa or the samples which contain more than 50 percent zircon and less than 30 percent tourmaline. At some localities, such as Bibai and Ashibetsu, garnet is less than 30 percent. This means that the samples have a certain element of the type I. Those two types, however, are not similar to those of Kyushu coal fields. The ZGT pattern of the Ishikari coal field may be one of the intermediate between the types I and IIa.

(b) Though only a few samples of the Cretaceous were taken into consideration, the composition of the Ishikari group seems to be similar to that of the Cretaceous group.

(c) It is hard to classify the Ishikari group into several zones with the ZGT pattern, except at Naie where the upper group contains much more garnet than the middle and lower groups do.

(d) There is no marked compositional variations along the vertical and/or horizontal directions, contrary to the common observation in Kyushu.

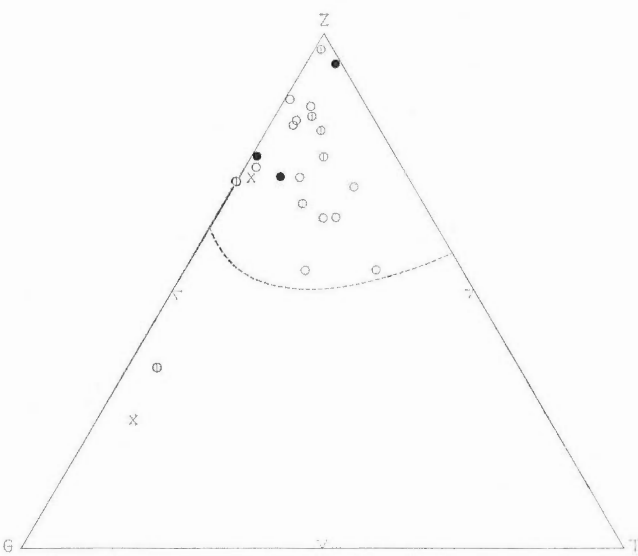

Fig. 36 ZGT diagram of the Cretaceous and Ishikari groups at Bibai, Ishikari coal field, Hokkaido (data after IIJIMA, 1959 b).
×, Upper Ishikari group; ⦶, Middle Ishikari group; ○, Lower Ishikari group; ●, Cretaceous.

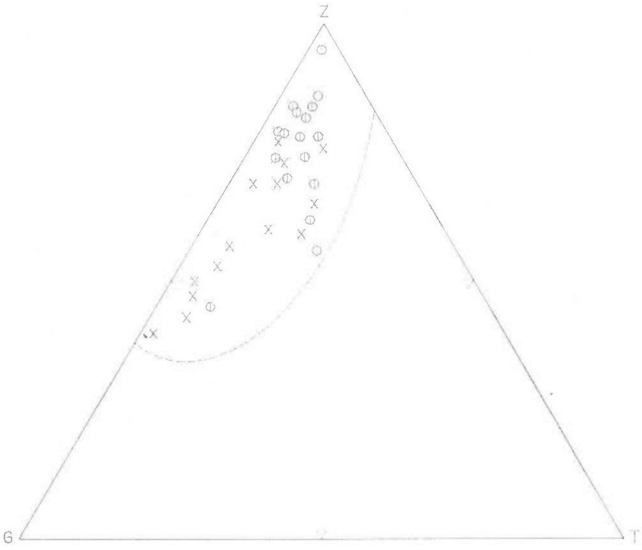

Fig. 37　ZGT diagram of the Ishikari group at Naie, Ishikari coal field (data after IIJIMA, 1959b).
×, Upper Ishikari group ; ⦶, Middle Ishikari group.

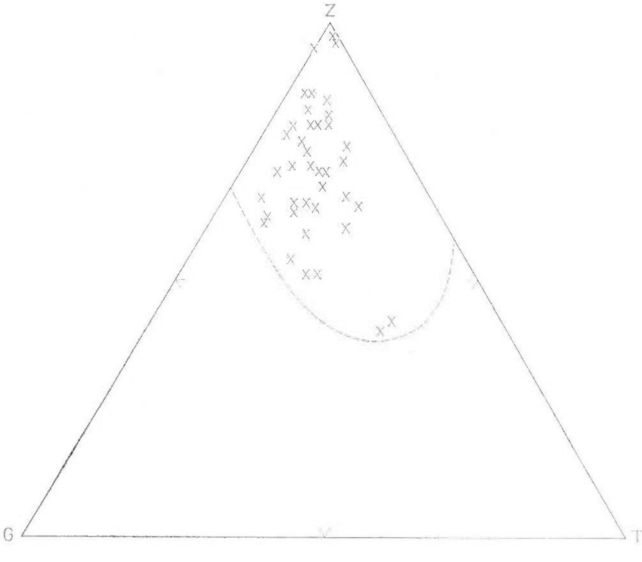

Fig. 38　ZGT diagram of the Ishikari group at Naie, Isikari coal field (drill-core samples were used).
×, Ishikari group (Cretaceous rocks may be included).

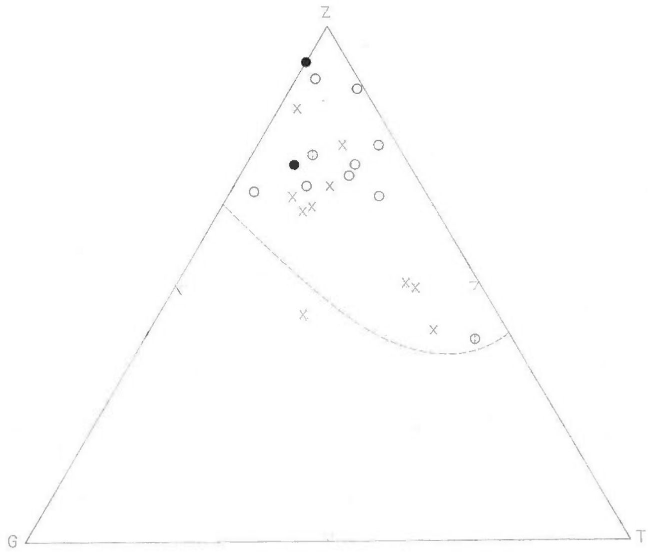

Fig. 39 ZGT diagram of the Cretaceous and Ishikari groups at Ashibetsu, Ishikari coal field (data after IIJIMA, 1959b).
×, Upper Ishikari group; ⊕, Middle Ishikari group; ○, Lower Ishikari group; ●, Cretaceous.

(e) The pattern of the values of the ZGT ratio is the type IIa and rutile content is about 2 to 3 percent (IIJIMA, 1959b) throughout the group. In its composition, the Ishikari group can correspond to the Manda group in the Miike coal field and to the Yoshinotani formation at Arita in the Karatsu coal field. Although there are several coal bearing formations within the group, no type I pattern is observed.

(f) The type IIa pattern is a characteristic of the marine condition, and suggests a gentle movement of the sedimentary basin in Kyushu (chapter VII). In this coal field no compositional variations are observed through brackish to shallow marine sediments and through the Cretaceous to the Paleogene sediments.

XI. Conclusion

By the heavy mineral study of the Paleogene sandstones in the several coal fields of the northwestern Kyushu, the writer reached the following conclusions.

Zircon, garnet, and tourmaline are major constituents among transparent heavy minerals, but epidote and rutile are occasionally abundant. These minerals were identified under the petrographic microscope and confirmed by the X-ray diffractometry. The zircon-garnet-tourmaline ratio (ZGT ratio) were computed and plotted on the ternary diagram (ZGT diagram) for formations of each coal field. In the diagrams, characteristic compositions of each formation can be easily distinguished.

The distribution patterns of the value of the ZGT ratio varies in every group, formation or member depending on the area. Thus, it is possible to correlate two strata within a limited area. When the strata lay at a long distance or compositional difference of mineralogy exists in a stratum, however, it is hard to correlate them. It is also difficult to distinguish whether it is conformity or unconformity, using only the differences of the ZGT patterns. The changing patterns of the ZGT ratio from the lower groups to the upper in the Amakusa, Isahaya, and Takashima coal fields are almost the same. This suggests that those coal bearing formations were formed in a large sedimentary basin, and materials were derived from the same provenance.

The distribution patterns of the granites, crystalline schists, and the sediments which are positively derived from the above rocks, occupy the definite area in the ZGT diagram. Two patterns, type A and type M, are established. In the type A, the materials are granitic rocks origin, and in the type M, the materials are crystalline schists origin. If a sandstone sample has the composition of more than 30 percent zircon and less than 20 percent garnet, the materials might be derived from granitic rocks, and if the zircon contents are less than 10 percent in the ZGT diagram, the source rocks could be metamorphic rocks, especially crystalline schists.

Furthermore, four types can be distinguished from the distribution patterns of the ZGT ratios of the sediments. They are the type I, II, III, and IV. The type I and III mostly overlap with the type A and the type M, respectively. The sandstone of the type II composition is generally a marine deposit. It can be emphasized that when a stratum of the type II overlies a stratum of the type I assemblage, the upper stratum is the deposit at the beginning of a large transgressive period.

When we examine the scattered values of the ZGT ratio of samples of the type II in the diagram, we can find a narrow gap near the 20 percent line of the garnet contents. Those values fluctuate between less than 20 percent and more than 20 percent garnet area with several tens meters to a hundred meters interval vertically in a uniform sandstone formation. This suggests such minor changes of sedimentary environment as a rise or fall of sea level, changing water course or current velocity, etc.

In the Karatsu coal field, the distribution patterns of the values in the Ōchi group vary from place to place. These variations are mainly due to the difference of source rocks, granitic or metamorphic rocks, and partly due to the difference of environments. The sandstones which might have been derived from granites were found in the south of the field far from the present exposed pre-Tertiary rocks. This suggests that around center of Ariake sea there were exposures of a granite mass, which are now covered by Tertiary and Quaternary deposits.

The coal bearing formations along the present coastline of the northwestern Kyushu have peculiar a heavy mineral composition ; that is, high in zircon contents, low garnet, and about 10 percent rutile. In the Miike coal field, some 70 kilometers far from that coastline, the formation has a quite different mineral composition. The formation in the Karatsu coal field has both types. The striking contrast between the two composition may be ascribed mainly to the difference of source rocks. Granite might be widely exposed at the west of Kyushu.

In the Ishikari coal field, there is no distinct variation of the pattern of the ZGT ratio along horizontal and vertical directions throughout the Cretaceous to Paleogene formations. This is a marked contrast to that of Kyushu.

It is believed that zircon, garnet, and tourmaline are very stable minerals. They are often found in the sandstones of high maturity in foreign countries. HUBERT (1962) presented the ZTR index (zircon+tourmaline+rutile %) as a measure of maturity. Those minerals are very common and even abundant in the sandstones of the northwestern Kyushu. Hence, there should be very mature sandstones according to HUBERT. The sandstones, however, contain good coal seams everywhere. Therefore, it is hard to consider that their maturity is high. This suggests that the rule established in the foreign country is not always applicable to our cases. We must think of the particular geologic circumstances in our country.

If we are able to have the knowledge of the hydrodynamic properties of the major heavy minerals in detail with the paleocurrent study, we can draw a clearer picture on the conditions of deposition, sedimentary environments, and the paleogeography.

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北西九州古第三紀砂岩中のジルコン―ざくろ石―電気石比がもつ地質学的意義

佐 藤 良 昭

要 旨

北西九州に分布する主要炭田（筑豊炭田を除く）の古第三紀砂岩について，重鉱物組成の研究を行なった。ジルコン，ざくろ石，電気石は透明重鉱物の大半を占め，時に緑れん石やルチルをかなり含む。これら鉱物は岩石顕微鏡により同定したが，さらに一部試料についてはX線回折計数装置によって，その存在を確かめた。各試料について，ジルコン―ざくろ石―電気石比（ＺＧＴ比）を計算し，その結果を三角図表にプロットした。これをＺＧＴ図と呼ぶ。

この図上におけるＺＧＴ比の分布状態から各累層（または層群・部層）を容易に識別することができる。したがって限定された地域内では，地層の対比も可能である。しかし，対比する地層間の距離が遠い時，あるいはＺＧＴ比が同一地層内でも地域によって異なる場合には困難を生ずる。また，上下に重なる２地層間の関係が整合であるか，不整合であるかの判別についても，ＺＧＴ比の分布状態のみからは，一概に判断を下すことは難しい。

天草・諫早・高島炭田においては，夾炭層の重鉱物組成は，ＺＧＴ図上の非常に限られた，ジルコンに富む範囲を占める。この夾炭層に重なる上位の地層では，組成が変化してざくろ石に富むようになる。このような変化は各炭田で共通している。これら３炭田における夾炭層は，同一堆積盆地で，共通の原岩から物質の供給を受けて堆積したものと考えられる。

花崗岩類ならびに確実にこれらの原岩に由来した堆積物，および結晶片岩類ならびに確実にこれらの原岩に由来した堆積物中の重鉱物のＺＧＴ比は，前者はＺＧＴ図のＺＴ辺に沿いジルコンに富む区域，後者はＧＴ辺沿いの区域という，２つの確然とした範囲に分かれて分布する。この事実から，砂岩試料中の重鉱物のＺＧＴ比が，ジルコン30％以上でざくろ石20％以下の値を示すとき，その砂岩はおもに花崗岩類からもたされたものであり，ジルコンの量が10％以下でとくにざくろ石に富むときには，その砂岩構成物質は主として結晶片岩類からもたらされたものであると判断することが可能である。この性質を用いて，天草炭田の福連木層，高島炭田の香焼層・双子島層・下部伊王島層，崎戸―松島炭田の赤崎層・寺島層・崎戸層・間瀬層につき，その堆積物の起源を推定した。この結果，長浜（1965 b）の結論と一致した。

各試料のＺＧＴ比の値の三角図上における分布から，４つの型が区別される。Ⅰ型は花崗岩類起源の物質の組成と，Ⅲ型は結晶片岩類起源の物質の組成と一致する。Ⅱ型の組成をもつ砂岩は，海成層であることが多い。とくに，Ⅰ型の組成をもつ地層の上位にⅡ型のそれがくる場合，後者は大きな海進期の初期の堆積物を示している。

Ⅱ型の組成をもつ，ほぼ一様な地層中のざくろ石量の変化を垂直的に詳細にみると，ざくろ石の量が20％以下と，それ以上の間で変化が繰返され，20％付近の組成をもつ試料はほとんどない。この付近に間隙が存在する。この変化に対応する地層の厚さは，20～30ｍないしは100ｍ単位となっている。一様な岩相中におけるこのような組成変化の原因としては，堆積環境の小変化，すなわち海水準の上下変動，水流の速度や流路の変化などが考えられる。

唐津炭田において，相知層群の重鉱物組成のＺＧＴ図上における分布は地域によって異なるが２大別される（Ⅰ型とⅡ型）。これには堆積物の供給源の差に基づくものと，堆積環境の相異に起因するものがある。

現在みられる基盤岩類から，遠く離れて分布する炭田南部の相知層群砂岩は，花崗岩類起源の組成をもっている。この原岩は，有明海中央部付近に分布が認められている花崗岩体の可能性がある。

北西九州の現海岸線に沿って分布する諸炭田の，夾炭層の重鉱物組成は，多量のジルコン，少量のざくろ石を含む他に，10％前後のルチルが常に存在する特徴を有する。この海岸線から約 70 km 離れた三池炭田の夾炭層の組成は，これと全く異なっている。前者の組成は花崗岩類起源の堆積物の特徴であり，九州西方海上に，当時，花崗岩体が広く分布していたことを暗示する。しかし，ルチルの起源については，まだ疑問がある。

北海道石狩炭田に分布する古第三紀砂岩のＺＧＴ比を，九州のそれと比較してみた。石狩炭田においては，白堊系上部・古第三系を通じてＺＧＴ図上における分布範囲はほとんど変化せず，九州の例とは顕著な対照を示している。

前段で述べた北西九州の夾炭層の重鉱物組成は，HUBERT（1962）の指数によると，非常に "mature" な砂岩の特徴を示す。だが "mature" な環境は，炭層の生成には好条件ではないと考えられる。しかるにこの地域においては，HUBERT の指数による "mature" な環境に，主要な夾炭層を生じているのである。すなわち外国の例をそのままわが国の堆積物に適用することの危険性を示すものである。

Geologische Bedeutung der Schwermineral-Verhältnisse Zirkon-Granat-Turmalin in Paläogenen Sandsteinen von Nordwestkyushu Japans

Zusammenfassung

Schwermineral-Untersuchungen über den Paläogenen Sandsteinen (Eozän und Oligozän) aus dem haupt Kohlenfeld in Nordwestkyushu Japans sind dargestellt. Zirkon, Granat und Turmalin sind 3 haupt Schwerminerale und nehmen allgemeine einen großeren Teil der Nicht-Opakminerale. In jeder Probe wird das Zirkon-Granat-Turmalin-Verhältnis (ZGT-Verhältnis) gerechnet und im Triangular-diagramm (ZGT-Diagramm) dagestellt. Die Ergebnisse der Untersuchung über die Verbreitungsmuster des ZGT-Diagramms lassen sich folgenderweise zusammenfassen.

a. Allgemein zeigt eine Schicht einen charakteristischen Muster der Verbreitung im Diagramm und daher läßt sich von anderen Schichten durcheinander unterscheiden.

b. Diese Eigenschaften des Diagramms sind aber nicht genug, um eine geologische Beziehung der zwei Schichten festzustellen, ob die zwei konkordant oder diskordant liegen.

c. Die Sedimente der kohlführenden Schichten der Kohlenfelder Amakusa, Isahaya und Takashima sind in ein desselben großes Becken unter denselben Bedingungen des Milieus abgelagert worden.

d. Die Herkunftsgesteine sind aus der Analyse der Muster der Verbreitung zu schließen. Wenn sich das Verbreitungsraum einer Schicht neben an der ZT-Linie entlang befindet, so mögen die Sedimente aus den granitischen Plutoniten und Vulkaniten geschüttet werden. Wenn es sich an der GT-Linie entlang befindet, so kann man schätzen, daß die Sedimente aus den Kristallinen geschüttet worden sind.

e. Granat-Gehalt schwebt um 20%. Die Veränderungsmenge ändert sich vielleicht von kleinen Änderung von Absatzbedingungen.

f. Drei Mustertypen der Verbreitung sind in der Ochi-Gruppe des Karatsu-Kohlenfeld zu finden. Die Verschiedenheit der drei Typen hängt von der Unterschied in Herkunft und Absatzbedingungen ab.

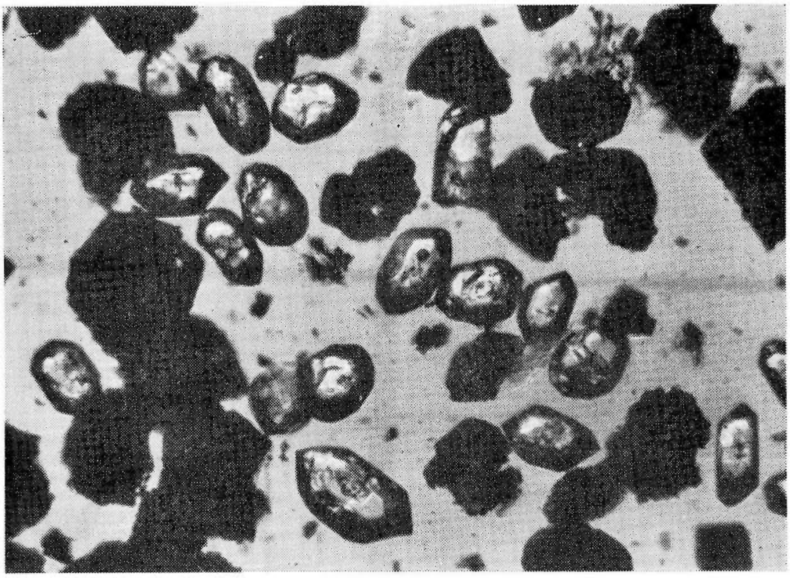
g. Neben gegenwärtiger Nordwestküste von Kyushu besetzen kohlführenden Schichten einen höheren Prozentzahl von Zirkon, niedrigeren von Granat und etwa 10% Rutil. Die Sedimente sind vielleicht von granitischen Gesteinen geschüttet worden, die damals in Westen von Kyushu zu Tage kamen. Über das Liefergebiet ist aber die Frage noch schwebend.

h. Verbreitungsräume der Schwermineral-Bestandteile im Ishikari-Kohlenfeld in Hokkaido unterscheiden sich von den in Kyushu. Es besteht keine regelmäßige Veränderung der Verbreitungsräume in Sandsteinschichten zwischen Kreide und Paläogenen in Ishikari.

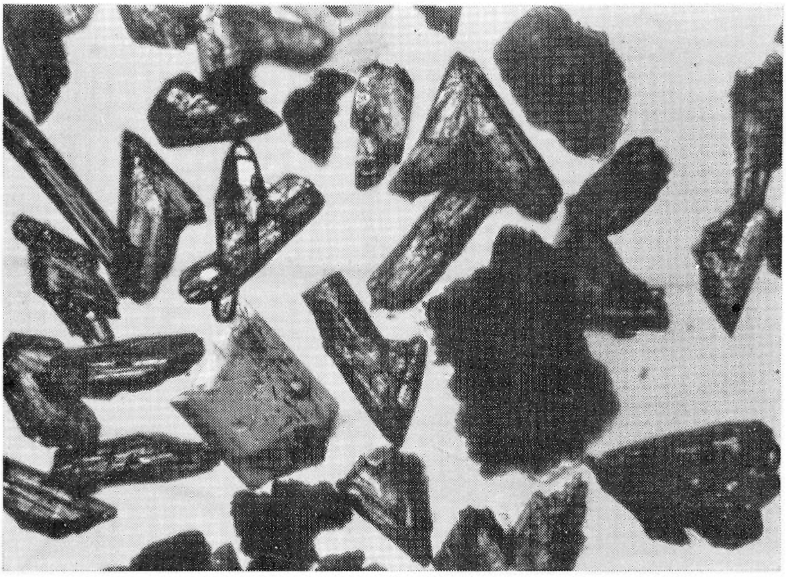
i. Es scheint, im ZGT-Verhältnis sich die Unterschied in Herkunft und Absatzbedingungen, wie z. B. Strömungsintensität, Veränderung in der Tiefe und Laufbahn des Wassers, Abstand von der Küste usw., wiederzuspiegeln. Weitere Schwermineraluntersuchungen zusammen mit Untersuchungen über die Strömungsrichtungen werden daher einen guten Hinweis auf die Paläogeographie der Sedimente.

PLATES
AND
EXPLANATIONS

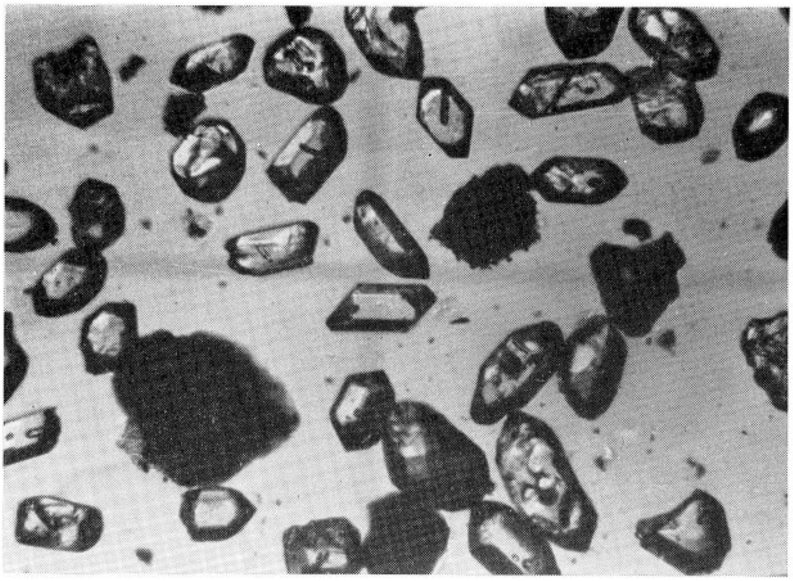
(with 3 Plates)



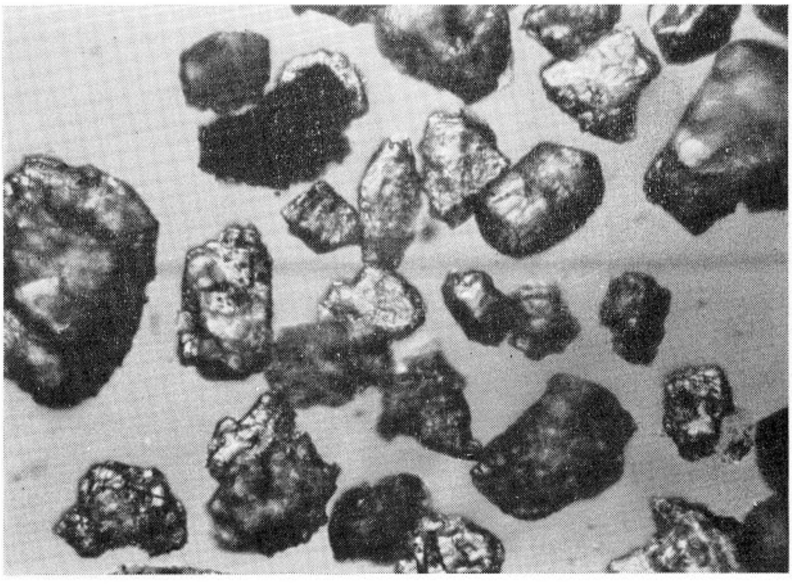
1. Zircon in granite at Oshima. (× 150)



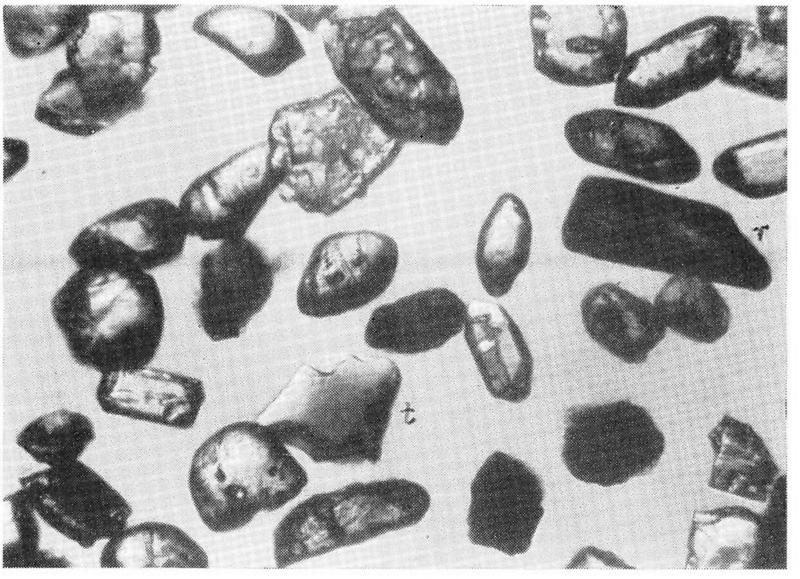
2. Rutile in crystalline schist in the Nishisonogi Peninsula.
Note the geniculated twin. (× 150)



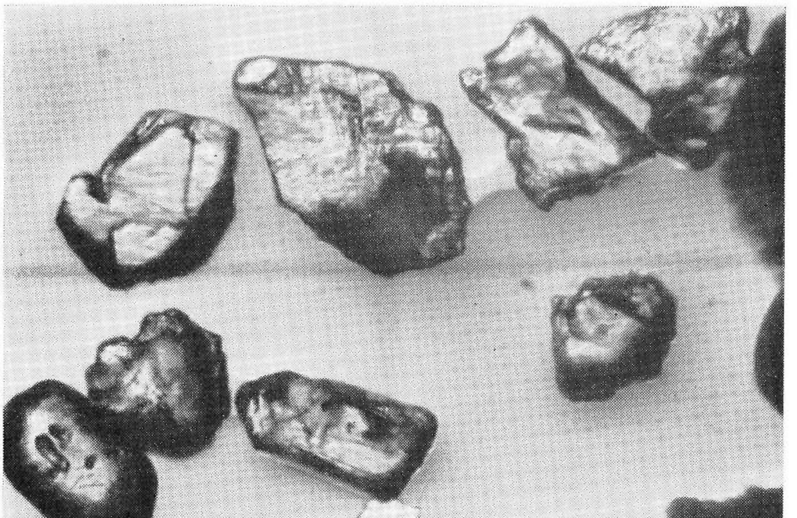
1. Zircon in the Fukuregi formation (type A), Amakusa coal field. (× 160)



2. Garnet in the Mase formation (type M), materials of which are definitely derived from crystalline schist in the Nishisonogi Peninsula. (× 160)



1. Zircon, tourmaline, and rutile in the Yoshinotani formation (type I) at Takeo. (× 160)



2. Garnet and zircon in the Yoshinotani formation (type II) at Kyuragi. (× 160)

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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

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- c. Paleontology
- d. Volcanology and Hot spring
- e. Geophysics
- f. Geochemistry

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- b. Coal
- c. Petroleum and Natural gas
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- f. Physical prospecting, Chemical prospecting & Boring

C. Miscellaneous

D. Annual Report of Progress

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SATO, Y

Geological Significance of Zircon-Garnet-Tourmaline Ratio of the Paleogene Sandstones of Northwestern Kyushu, Japan

Yoshiaki SATO

Report, Geological Survey of Japan, No. 235, p. 49, 1969.
39illus., 8tab., 3pl.

A heavy mineral study was made on the Paleogene (Eocene to Oligocene) sandstones from major coal fields in the northwestern Kyushu. Zircon, garnet, tourmaline are major heavy minerals. Their ratio (ZGT ratio) are plotted in the ternary diagram. Generally, each formation has a characteristic distribution pattern in the diagram. The diagram is of considerable convenience in correlating each formation and in clarifying source rocks and depositional environments.

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