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Development of the Cretaceous Sedimentary Basin of the Sanchû Graben, Kanto Mountains, Japan

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(With 13 Figures and 13 Tables)

Abstract

The Sanchû Graben of the Kanto Mountains is one of the Cretaceous basins of the Chichibu Belt, but is unique in its tectonic position that it is located at the eastern wing of the syntaxis structure against the other basins which form the western wing. The Cretaceous strata in the Sanchû Graben are composed of marine and partly brackish sediments and form synclinal structures. The writer studied petrographically Cretaceous sandstones and conglomerates of the eastern half of the Sanchû Graben. Furthermore, lithofacies, biofacies, paleocurrent system and thickness distribution of the Cretaceous sediments are investigated.

On the basis of above-mentioned analyses, provenance and depositional environment of the Cretaceous sediments, and their change with time are discussed. Concerning paleocurrent system, longitudinal current from SE to NW is dominant (excepting the first (Ishidô) epoch), while lateral currents from NE to SW, and from SW to NE are also recognized. It is pointed out that supply of clastic materials from sedimentary terrain dominated at first (Ishidô epoch) and that those from granitic terrain increased with time. Clastics of granitic rock origin are mainly derived from the Ryôke Belt. Concerning clastics of the other origins, sedimentary component is derived most probably from pre-Cretaceous rocks of the Chichibu Belt, crystalline schist from the Sanbagawa Belt, and acid pyroclastics and granite-porphyry from the Inner side of Southwest Japan. As to depositional environment, that of the northern and the southern subbelts was near to shore, while that of the middle subbelt is probably offshore, deeper water below wave base.

Attention is drawn to subsiding pattern of the Cretaceous basin. Judging from the right-hand *en echelon* arrangement of the depressions, it is suggested that the Cretaceous sedimentary basin of the Sanchû Graben was under the right-lateral strike-slip stress field in Early Cretaceous time. In early Late Cretaceous time, however, the sedimentary basin was no more under the strike-slip stress field. Thus a remarkable change in stress condition is recognized in the Sanchû Graben in Mid-Cretaceous time.

Contents

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I. Introduction

In the Chichibu Belt, the Outer side of Southwest Japan, there are several areas occupied by marine and partly brackish Cretaceous sediments. These Cretaceous areas are generally narrow and elongate with their long axis subparallel to the general trend of the Chichibu Belt, and the strata form synclinal structure. The geological studies of these Cretaceous sediments have furnished many data on the problems of the geologic development of the Japanese Islands (e.g. YABE, 1927; KOBAYASHI, 1941; MATSUMOTO, 1953; YAMASHITA, 1957; TAKEI, 1965; MIYAMOTO, 1980; MATSUMOTO *et al.*, 1982).

The Sanchû Graben of the Kantô Mountains is one of these Cretaceous areas of the Chichibu Belt. Stratigraphic and Paleontologic studies in the Sanchû Graben have been made by many geologists including the writer (e.g. OTSUKA, 1887; HARADA, 1890; YOKOYAMA, 1890, 1895; YABE *et al.*, 1926; FUJIMOTO, 1936, 1939, 1958; OISHI, 1940; KOBAYASHI *et al.*, 1943; IWAI, 1947; EGUCHI, 1951; YABE, 1955; NAKANO, 1960; TAKEI, 1963, 1969; TANAKA, 1965; HAYAMI, 1965–1966; OHTA, 1973, 1982; INOUE, 1974; OBATA *et al.*, 1976; TAKEI *et al.*, 1977; MATSUKAWA, 1977, 1979; TAMURA, 1978; KIMURA and MATSUKAWA, 1979; NISHIDA and TANAKA, 1982).

The petrographic works in the Sanchû Graben had been done on some of the granitic rock pebbles and the detrital minerals (SEKI, 1965; SEKI and MOCHIZUKI, 1965; SEKI and TAKIZAWA, 1965; KANO, 1969, 1970). Recently, studies on the current markings and current system were published (ARAI and NAGANUMA, 1975; SAKA, 1974, 1980; SAKA and KOIZUMI, 1977).

The writer also studied current markings of the Cretaceous strata of the Sanchû Graben (ARAI *et al.*, 1958; TAKEI, 1962; TAKEI *et al.*, 1977). Petrographic work also has been carried out by the writer on sandstones and on pebbles of igneous, metamorphic and acid pyroclastic rocks (TAKEI, 1974, 1975, 1980). In the present paper the writer presents the collective results of his sedimentologic and petrographic research of the Cretaceous sediments in the eastern half of the Sanchû Graben, in order to throw a light on the origin of the Cretaceous sediments and on the Cretaceous basin development.

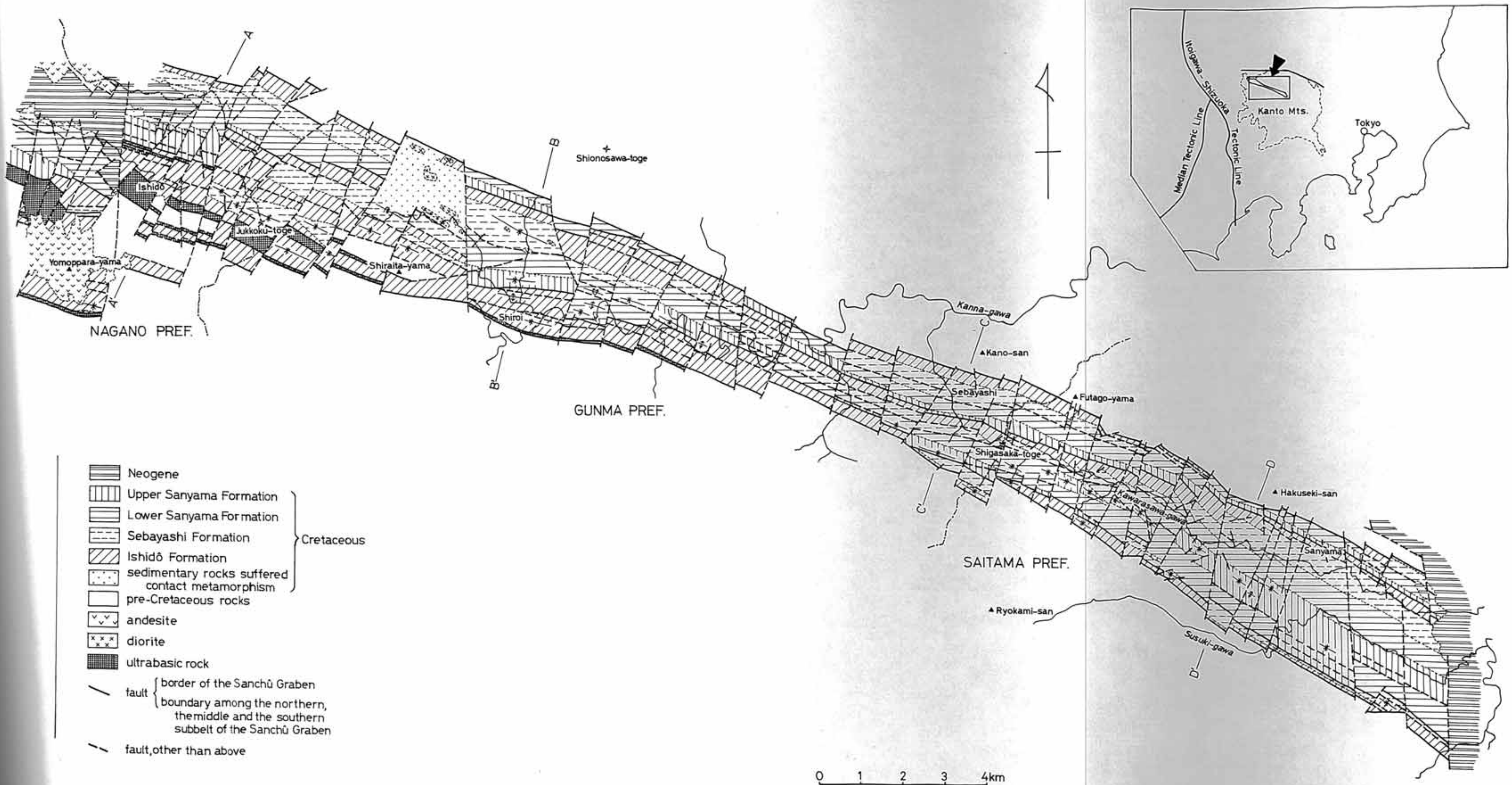

Fig. 1. Geologic map of the Sanchu Graben

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II. Outline of geology

The Sanchû Graben (HARADA, 1980) is a narrow structural basin, 40 km long and 2 to 4 km wide, surrounded by the basement strata of the pre-Cretaceous age (so-called Paleozoic Chichibu system). The following is the outline of geology of the eastern half of the Sanchû Graben after the writer's study (TAKEI, 1963, 1969).

Although the Cretaceous rocks are, strictly speaking, in fault contact with the pre-Cretaceous rocks at the present state, the Ishidô Formation, the lowest of the Cretaceous system of this area is interpreted to overlie the pre-Cretaceous rocks unconformably. The Cretaceous sediments are overlain unconformably in the eastern extremity of this area by Neogene sediments of the Chichibu basin.

The Sanchû Graben is subdivided into three subbelts: the northern, the middle and the southern subbelts (TAKEI, 1963). The lithofacies and structure of the Cretaceous sediments are different among these subbelts, although these sediments are considered to be a product under a single sedimentary basin (Table 1). The Cretaceous system of the area has been divided into three formations in ascending order: Ishidô Formation, Sebayashi Formation and Sanyama Formation. The Sebayashi Formation is unconformably overlain by the Sanyama Formation. In the present paper, the Sanyama Formation is divided into the Lower Sanyama Formation and the Upper Sanyama Formation. Thus four formations are now recognized within the Cretaceous sequence. Each formation shows a fining-upward sequence, and the Lower Sanyama Formation can be further divided into two sub-sequences of upward fining trend. The generalized stratigraphic sequence of the area is shown in Figure 3. A short comment on geologic age will be made below.

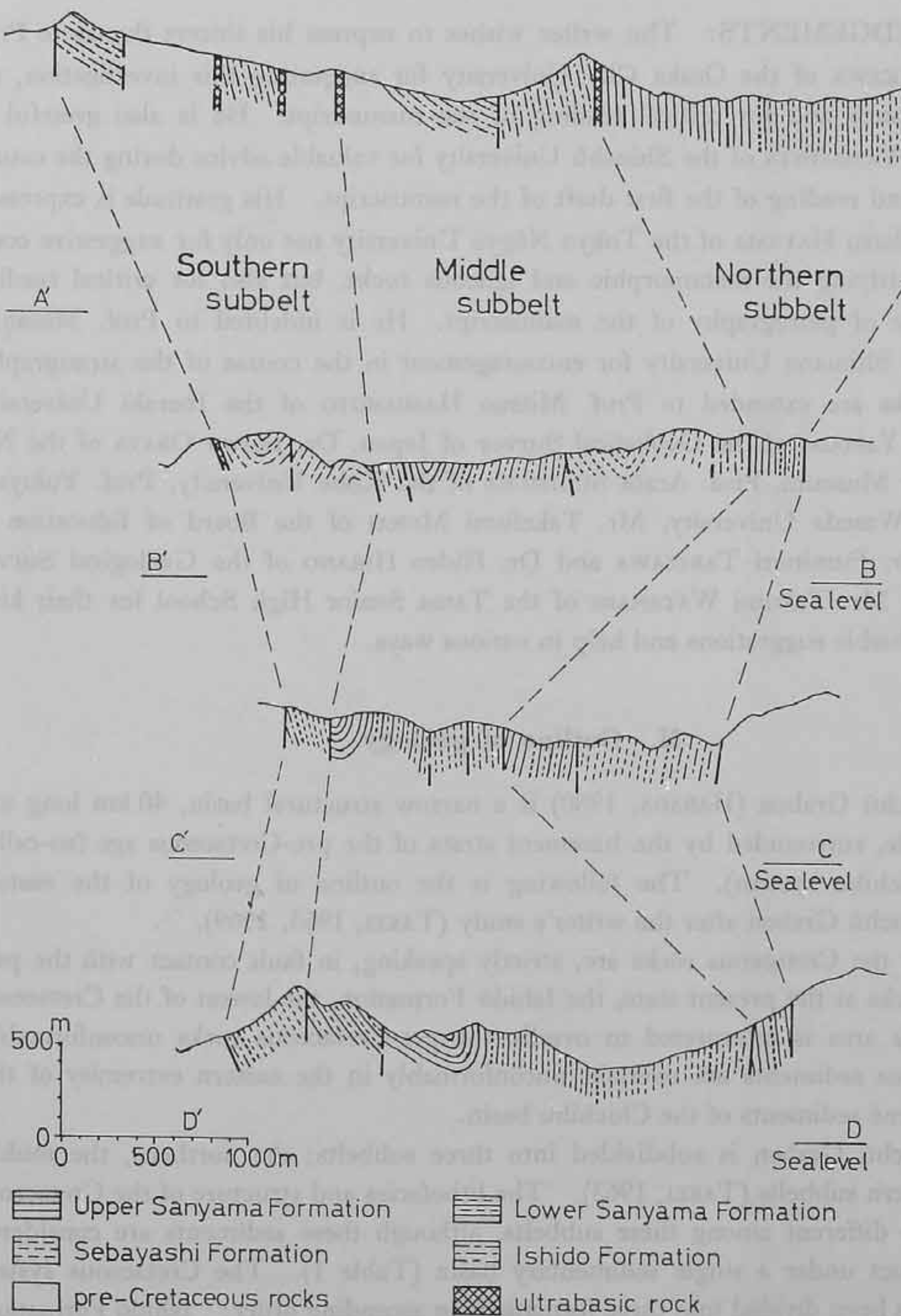

Fig. 2. Geologic sections across the Sanchu Graben

MATSUKAWA (1979) considered that the Ishidô Formation is underlain by the Shiroi Formation, which yields brackish Shiroi faunule, in the western part of the Sanchû Graben (the area not treated in this paper), and that the Shiroi Formation may be Kochian in age. Mudstone with the Shiroi faunule is, however, intercalated in the "sandy shale" of the Ishidô Formation (TAKEI *et al.*, 1977). Therefore, it can be said that the Shiroi Formation is a part of the writer's Ishidô Formation. Recently, detailed geologic

Table 1. Lithologic and biologic characters of the Cretaceous formations

		Ishido Formation			Sebayashi Formation		Lower Sanyama Formation		Upper Sanyama Formation	
		Northern subbelt	Middle subbelt	Southern subbelt	Northern subbelt	Middle subbelt	Northern subbelt	Middle subbelt	Northern subbelt	Middle subbelt
Lithology	dominant	"sandy shale"	mudstone	sandstone, conglomerate	sandstone	sandstone	mudstone	mudstone	mudstone	mudstone
	subordinate	sandstone, conglomerate	sandstone, conglomerate	mudstone, limestone	mudstone, limestone	mudstone	sandstone, conglomerate	sandstone, conglomerate	sandstone, conglomerate	sandstone, conglomerate
Thickness (m)		100 - 300	200 - 450	200 - 450	100 - 400	150 - 650	100 - 300	150 - 700	100 - 200	50 - 650
Graded bedding		absent	occasional	absent	absent or indistinct	common	common	common	common	common
Sandstone		lithic wacke			feldspathic arenite	feldspathic wacke	feldspathic arenite	feldspathic wacke	feldspathic arenite	feldspathic wacke
Pebbles in conglomerate		sandstone, slate, limestone, chert			granitic rocks, andesite, sandstone, slate, chert		granitic rocks, granite-porphyry, andesite, basalt, gneiss, biotite schist, hornfels, acid tuff, "schalstein", sandstone, slate, limestone, chert		granitic rocks, granite-porphyry, andesite, acid tuff, "schalstein", sandstone, slate, limestone, chert	
Animal fossils		marine molluscs, echinoids	*Orbitolina*, corals, marine molluscs crinoids, echinoids	*Orbitolina*, corals, marine and/or brackish molluscs, echinoids	Trigonian molluscs	marine molluscs	marine molluscs, echinoids		marine molluscs, echinoids	

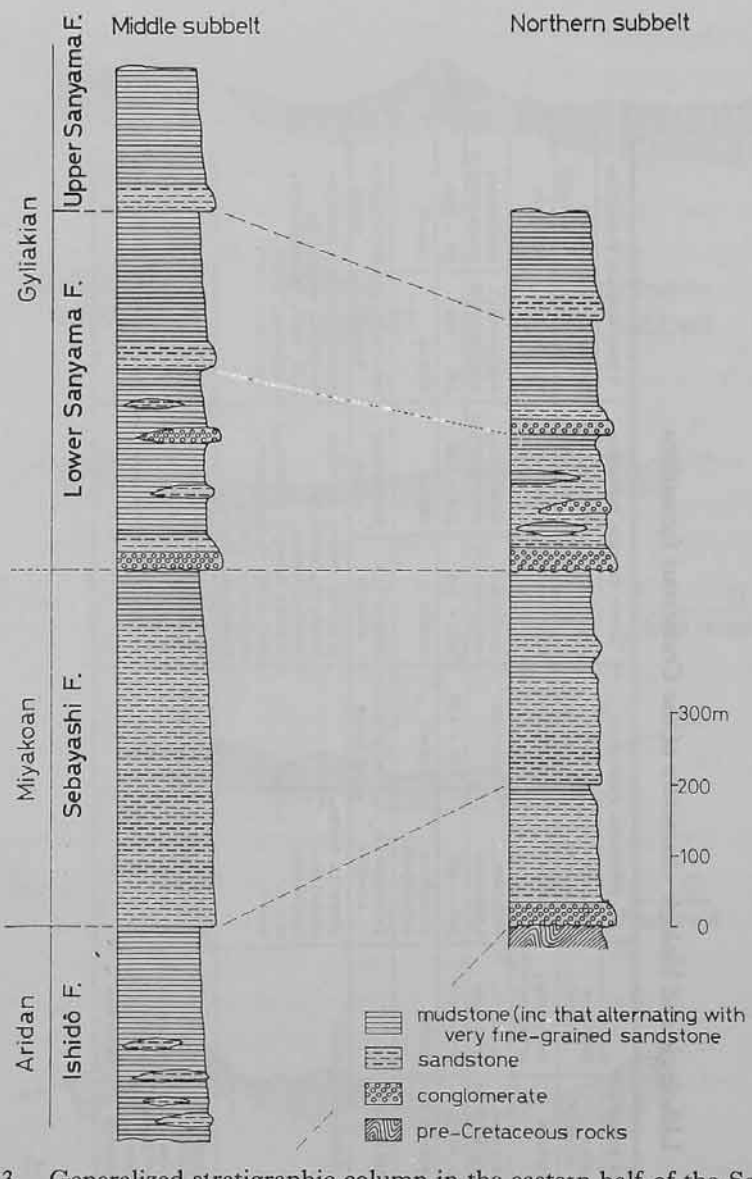

Fig. 3. Generalized stratigraphic column in the eastern half of the Sanchu Graben (compiled from 61 stratigraphic columns given in TAKEI, 1963, 1965)

age of the Ishidô Formation has been discussed, based especially on ammonites. According to MATSUMOTO *et al.* (1982), the Ishidô Formation is Late Hauterivian to early half of Late Barremian in age.

A part of the Lower Sanyama Formation is said to be Late Aptian, based on planktonic foraminifera (MATSUMOTO *et al.*, 1982). There is a possibility, however, that the mudstone yielding the Late Aptian planktonic foraminifera does not belong to the writer's Lower Sanyama Formation, but to the writer's Sebayashi Formation (considered from the oral communication by OBATA concerning the locality of that mudstone). In the western part of the Sanchû Graben (the area not treated in this paper), *Collignoniceras* (?) is found from the Lower Sanyama Formation (TAKEI *et al.*, 1977).

The Upper Sanyama Formation offers *Desmoceras* (s.l.) sp., *Marshallites* sp. (TAKEI, 1963) and *Inoceramus* cfr. *hobetsensis* (TAKEI, 1964). Recently, *Anagaudryceras* cfr. *sacya* is reported from the Upper Sanyama Formation (MATSUMOTO *et al.*, 1982). Therefore, the Lower Sanyama and the Upper Sanyama Formations may be mainly Gyliakian in age. However, it is a future problem whether the lower part of the Lower Sanyama Formation ranges down to the Miyakoan or not.

III. Lithofacies and biofacies

1. Ishidô Formation

There are distinct differences in lithofacies of the Ishidô Formation among the northern, the middle and the southern subbelts of the Sanchû Graben.

In the northern subbelt, the Ishidô Formation is mainly composed of so-called sandy shale, which comprises massive dark gray muddy very fine-grained sandstone with sporadic occurrence of parallel laminae, with burrows and presumed bioturbation structures at times and with calcareous nodules; medium-grained sandstone and mudstone are intercalated. The basal part of the Ishido Formation is occupied by conglomerate with occasional occurrence of stratification. The pebbles of the conglomerate, subangular to subrounded, 2 to 10 cm in diameter, are composed of chert, sandstone, slate and limestone. The matrix of the conglomerate is sandstone which often becomes muddy especially in the lowermost part of the conglomerate. Fossils are more abundant and less fragmental in the northern subbelt than in the other subbelts. Important fossils from the very fine-grained sandstone, the main constituent of this formation, collected by the writer are as follows: *Pterotrigonia, Gervillaria, Lopha, Amphidonta, Astarte, Anisomyon, Phylloceras, Shasticrioceras, Crioceratites, Barremites, Washitaster.* Localities of fossils mentioned above is given in the writer's previous papers (TAKEI, 1963, 1969), but some of the generic names in the previous papers are revised in this paper.

The Ishidô Formation of the middle subbelt consists of black mudstone with subordinate amount of sandstone and conglomerate. Parallel laminae are found sometimes in the mudstone. The sandstone and conglomerate occur mostly in the lower part of this formation and are several centimeters to more than a meter in thickness, often thinning out within a short distance. The sandstone and conglomerate are generally calcareous and contain abundant fossil fragments, such as *Orbitolina, Nipponitrigonia*, ostreids, pectinids, gastropods, hexacorals and calcareous algae. The pebbles in the conglomerate are generally less than a centimeter in diameter, sometimes attaining more than 3 cm, and are composed of chert, limestone, sandstone and slate.

In the southern subbelt, the Ishidô Formation consists of conglomerate, dark gray sandstone and black mudstone. Although they often grade each other laterally as well as vertically within a short distance, conglomerate generally becomes abundant in the lower part of this formation. The conglomerate consists of subangular to subrounded pebbles of chert, sandstone, slate and limestone; among them the chert pebble is generally predominant. The sandstone varies in grain size. Fine-grained massive muddy sandstone resembles "sandy shale" of the northern subbelt. In the sandstone, molluscan shell fragments are sometimes found, and furthermore, belemnoids, crinoid stem and echinoids are rarely found. The black mudstone sometimes yields brackish molluscan fossils such as *Costocyrena* and *Tetoria*. In the westernmost part of this area, at Otchi-zawa, and farther west (TAKEI *et al.*, 1977), there exists muddy limestone in the fine-grained sandstone. In and around this muddy limestone, *Orbitolina,* bryozoa, corals, pelecypods and gastropods are found.

2. Sebayashi Formation

The Sebayashi Formation is largely represented by the thick-bedded sandstone, in contrast to the underlying Ishidô Formation, which the latter is represented by massive very fine-grained sandstone or mudstone. The difference in lithofacies between the northern and the middle subbelt is distinct. The Sebayashi Formation of the southern subbelt is indistinct in lithology owing to limited distribution and inferior outcrop.

In the northern subbelt, the Sebayashi Formation consists mainly of medium-grained light gray sandstone with subordinate amount of mudstone. The sandstone is well bedded and intercalates thin layers of muddy sandstone or mudstone at intervals of 30 to 100 cm. Cross-lamination of low angle planar type is often found. The sandstone is sometimes conglomeratic, but the size of pebbles rarely exceeds 1 cm. Although rounded chert is the most common pebbles of the conglomerates, other sedimentary rocks and igneous rocks, such as granite and andesite, are not rare. Brackish molluscan fossils, such as *Ostrea* (s.l.), *Costocyrena* and *Tetoria*, are contained in the Sebayashi Formation, and the latter two are sometimes crowded together in the mudstone. Plant fragments are commonly found in the mudstone, and well preserved plant leaves are sometimes contained. *Onychiopsis* and *Zamites* were reported by YOKOYAMA (1895), OISHI (1940) and KIMURA and MATSUKAWA (1979). A number of ripple marks, including linguoidal ripples, are found in the sandstone at some place (ARAI *et al.*, 1958; TAKEI, 1962).

The Sebayashi Formation of the middle subbelt is characterized by dark gray, medium- to coarse-grained sandstone which shows generally graded bedding. The thickness of a sandstone bed is usually tens of centimeters, but not rarely exceeds 2 m. The thicker a bed is, the coarser grained its basal part generally. Although internal sedimentary structure of the sandstone is obscure in general, Bouma sequence and/or dish structure are sometimes found. On the lower surface of the sandstone bed, sole marks are often observed. Fragments of molluscan shells and of plants are sometimes contained in the sandstone and mudstone. Although molluscan fossils are generally scarce in the middle subbelt and merely "*Propeamussium*" and belemnoid were found in the interbedded mudstone, trace fossils (trails) are commonly found in the mudstone.

3. Lower Sanyama Formation

The Lower Sanyama Formation consists of conglomerate, sandstone and mudstone.

In comparison with the underlying Sebayashi Formation, conglomerate and mudstone become abundant and sandstone becomes coarser grained in the Lower Sanyama Formation. Conglomerate and sandstone are abundant in the lower part of this formation. Proportion of conglomerate and sandstone in the Lower Sanyama Formation is greater in the northern than in the middle subbelt. Except for this and for matrix content of sandstone (Chap. IV-3), there is no marked lithologic difference between the northern and the middle subbelts.

The so-called black shale, predominant constituent of the Lower Sanyama Formation, consists of frequently interbedded black mudstone and dark gray, very fine-grained sandstone. The mudstone shows sometimes horizontal parallel-lamination. The sandstone exhibits cross-lamination and convolute lamination. Bluish gray, medium- to very coarse-grained sandstone is often intercalated in the "black shale" and generally shows graded bedding. Lateral changes in their grain size, at times into conglomerate, are seen sometimes within a short distance. Lateral variation of the thickness is sometimes also distinct. Solemarks are often found in the sandstone of the middle subbelt. The conglomerate is generally abundant in the northern subbelt and the pebble size is larger in the northern than in the middle subbelt. Pebbles in the conglomerate consist of various kinds of sedimentary rocks and igneous rocks, among which granitic rock is conspicuous. Pebbles of sedimentary rocks probably derived from the Ishidô Formation are not rare. Matrix of the conglomerate, generally sandstone, is often muddy. Molluscan fossils, scarcely found by the writer in the Lower Sanyama Formation, are *Ostrea* (s.l.) from the conglomerate and *Aphrodina* from the mudstone of the northern subbelt, and *Nucula* (?) from the conglomerate and *Cerithium* (?) from the mudstone of the middle subbelt. Plant fragments are ubiquitously found in the mudstone and tend to increase northward in abundance and size.

4. Upper Sanyama Formation

The Upper Sanyama Formation is represented by black mudstone in both the northern and the middle subbelts. Compared with the underlying Lower Sanyama Formation, conglomerate becomes less abundant and mudstone becomes massive in the Upper Sanyama Formation. Horizontal parallel-lamination is sporadically found in the mudstone. The basal part of the Upper Sanyama Formation consists of bluish gray sandstone, 20 to 40 m thick. The sandstone is medium- to very coarse-grained, sometimes conglomeratic and at times changes laterally into conglomerate. The sandstone generally exhibits graded bedding and has often solemarks especially in the middle subbelt. Sandy material is scarcely contained in the mudstone for the most part. In the northern subbelt, however, mudstone becomes sometimes interbedded with very fine-grained sandstone. In the middle subbelt, on the other hand, calcareous nodules are often found in the mudstone, and they tend to become abundant and larger towards the south.

From the mudstone of the Upper Sanyama Formation, *Solemya, Nucula, Parva-*

mussium and *Desmoceras* were found in the northern subbelt, and *Inoceramus* in the middle subbelt, although occurrence of molluscan fossils is rather rare. Plant fragments are not rare in the Upper Sanyama Formation, but tend to become less common and smaller in size southward, as in the case of the underlying Lower Sanyama Formation.

IV. Petrography

1. Sampling and procedures

Sandstone and pebble of conglomerate are examined petrographically. The locality of the examined sandstone specimens are given in Figs. 4–7. The constituents of sandstone is examined for some 290 thin sections by the Glagolev-Cheyes method of point counting (GALEHOUSE, 1971). 500 points were counted on each slide. The results are presented in Tables 2–11.

The pebbles of conglomerate were studied on about 150 thin sections. All of them are from the Upper and the Lower Sanyama Formations. The pebbles in the Ishidô and the Sebayashi Formations, except sedimentary rock pebbles, are generally less than 1 cm in diameter. Therefore, the pebbles from these formations were not studied microscopically.

2. Constituents of sandstone

Quartz (single crystal) Single crystal of quartz is commonly found in the examined sandstones but is generally less abundant than feldspar. Quartz grain has hitherto been classified into several types in the studies of the various authors (GILBERT, 1954; WEAVER, 1955; FUJII, 1962; cfr. PETTIJOHN, 1957; SHOJI, 1971). In the present study the writer discriminates the following three types of single crystal quartz: (1) free from inclusion, (2) containing bubbles and vacuoles, (3) containing inclusions of other minerals. Among these type, the second is most dominant. Inclusions in the third type are biotite, zircon and apatite in many cases. Most of the quartz grains more or less show wavy extinction.

Quartz grains are generally angular to subangular in outline. Subrounded quartz grains are sometimes found, but well-rounded ones are very rare.

Feldspars (single crystal) Feldspar is most abundant among the detrital grains in many sandstone samples. In the feldspar grains, there are recognized orthoclase, plagioclase, microcline and myrmeckite, but plagioclase (albite to oligoclase) is most abundant. Plagioclase shows commonly the albite-lamellar twin. Zoned plagioclase is sometimes found.

Many of the feldspar grains, especially plagioclase, are clouded by the alteration products, mainly sericite and kaolinite. Replacement of feldspar by calcite is sometimes found and is perhaps a result of diagenesis. Feldspar grains are generally subangular in outline.

Rock fragments Sand grains composed of more than two crystals either of same or different mineral species are defined as rock fragment (GRIFFITHS, 1967). Rock fragments in sandstone can be classified as follows:

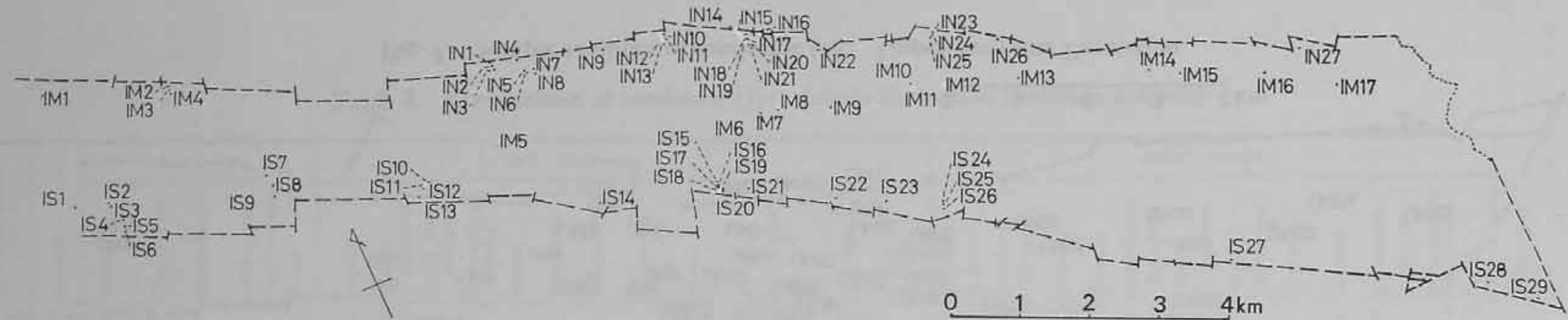

Fig. 4. Sample localities of sandstone (1): Ishido Formation

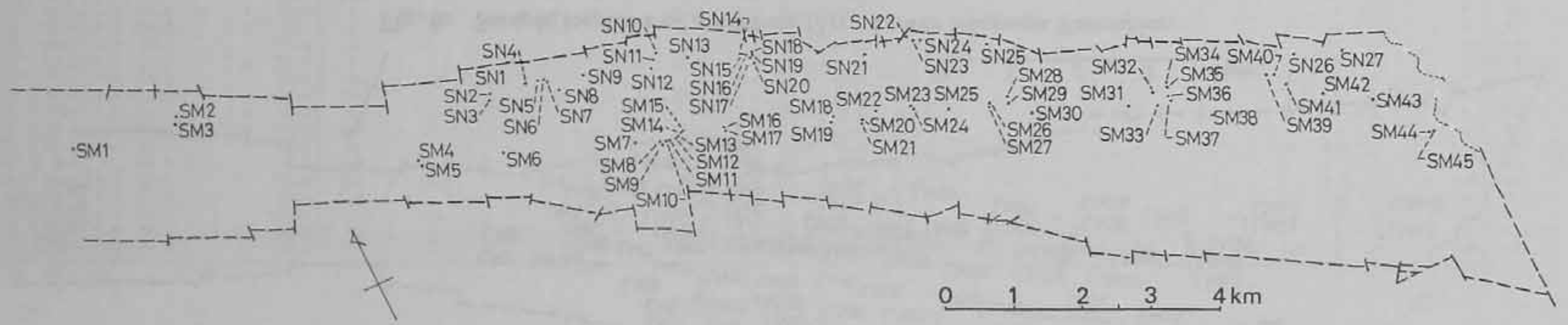

Fig. 5. Sample localities of sandstone (2): Sebayashi Formation

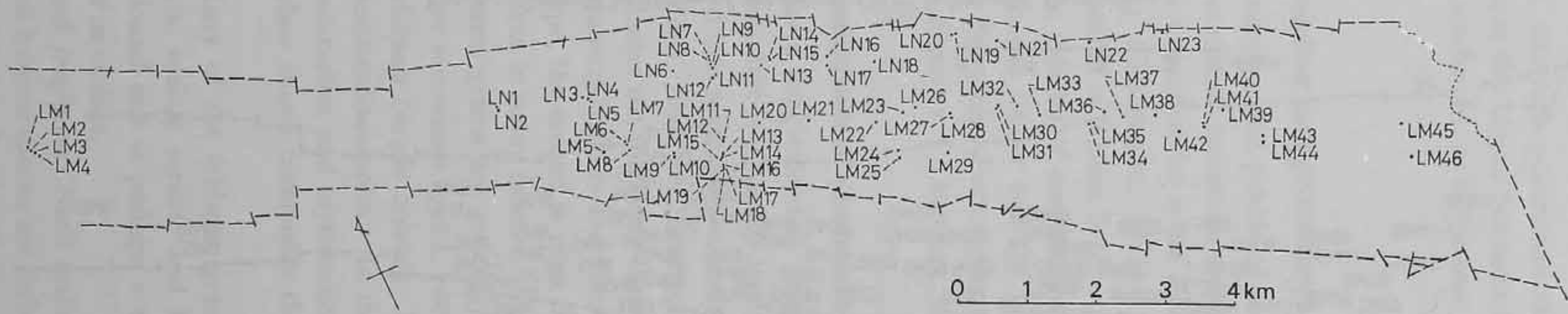

Fig. 6. Sample localities of sandstone (3): Lower Sanyama Formation

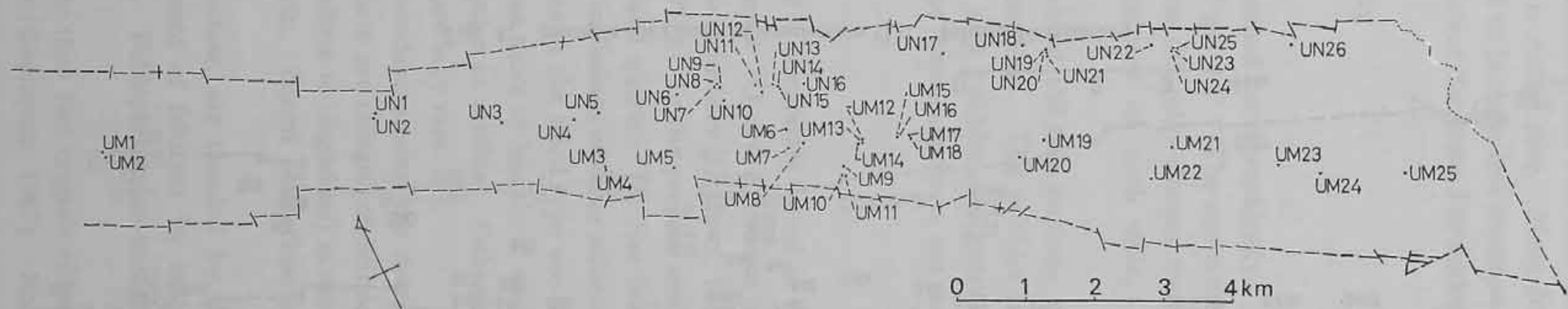

Fig. 7. Sample localities of sandstone (4): Upper Sanyama Formation

Table 2. Composition of sandstone (1): Ishido Formation (northern subbelt)

Specimen number	Quartz	Feldspar					Rock fragments											Clay matrix	Calcite	Heavy minerals																		Grain size
		Orthoclase	Plagioclase	Microcline	Myrmekite	Total	Granite	Quartz-porphyry	Basic volcanic rock	Crystalline schist	Gneiss	Sandstone	Mudstone	Limestone	Chert	Others	Total			Zircon	Garnet	Titanite	Allanite	Epidote	Zoisite	Pumpellyite	Tourmaline	Augite	Hornblende	Apatite	Glauconite	Chlorite	Biotite	Muscovite	Prehnite	Iron opaques	Total	
IN 1	7.0	+	5.0		+	5.8	+		+				-		28.6	46.4	75.8	11.4		+													+	+			+	c.
IN 2	16.6	2.0	8.0		+	10.0	+		+			+	-	+	15.4	17.0	33.8	28.2	11.4	+				+									+	+			+	m.
IN 3	21.0	1.4	14.0			15.4	+							-	8.0	18.6	26.8	29.8	6.6					+									+	+			-	f.
IN 4a	19.8	+	3.4			3.8	1.4		+				+		19.0	34.2	55.0	20.6						+									+	+			+	c.
IN 4b	15.4	+	3.4		+	3.8	+		+				+		22.6	30.4	62.2	18.6																+			-	c.
IN 4c	12.4	1.0	7.0			8.0	+		+				3.2		26.8	28.[illegible]	59.4	19.4												+			+	+			+	c.
IN 5	17.0	1.6	10.4			12.0	+								2.8	3.4	6.4	50.8	12.6	+													1.0	+			1.2	v.f.
IN 6	28.0	4.0	23.2	+		27.2	1.0	+							1.2	12.4	14.8	26.0	1.4					+									2.4	+			2.6	f.
IN 7	27.6	3.8	41.4	+	+	45.6	+									6.4	7.2	17.8				-	+	+	+							+	1.2	+			1.8	f.
IN 8	36.8	4.0	33.4		+	38.0	2.0		+						3.6	4.8	10.6	13.8	+			+							+				+	+			+	m.
IN 9	1.6	+	1.2			1.6							2.4	4.8	14.2	14.6	36.0	11.0	49.8															+			+	c.
IN 10	16.0	2.6	8.8		+	11.6	+		+						22.4	18.0	40.6	20.2	11.0			+											+	+			+	m.
IN 11	23.2	+	12.2		+	13.0	+								15.6	12.0	25.0	32.6	2.6	+				+	+								+	+			+	v.f.
IN 12	19.6	3.0	14.2			17.2									16.4	8.4	24.0	32.3	4.6					-									+	+			1.0	v.f.
IN 13	27.8	2.6	52.6	+	+	55.4	+		+						+	2.0	2.2	12.4		+		+	+	+	+								2.2	+			2.2	f.
IN 14a	21.1	1.1	31.9		+	33.7	2.2					+	+		8.3	3.2	13.7	31.2															+	+			+	m.
IN 14b	14.8	1.0	17.6	+	+	18.6	+		+			+	-		18.6	7.2	27.0	39.6			+												+	+			+	m.
IN 15	18.8	2.8	15.8		+	19.4	+								6.8	14.8	22.1	39.0		+				+									+	+			+	f.
IN 16	16.8	1.4	15.2			16.6	+								3.6	9.6	9.8	41.0	15.2	+				+					-				+	+			+	v.f.
IN 17	16.4	1.0	12.6		+	13.8	+								11.6	9.4	21.0	37.2	11.6	+				-									+	+			+	v.f.
IN 18	15.2	2.6	14.4			17.0	+		+						[illegible]	7.4	10.8	41.6	15.2					+	+	-	+					-	+	+			+	v.f.
IN 19	21.4	1.8	11.0			12.8	+							-	23.8	13.4	37.6	24.0	3.8			+											+	+		+	+	f.
IN 20	28.0	2.0	16.2		+	18.4	+								+	19.8	20.4	26.4	6.2					+	+							+	+	+			+	v.f.
IN 21	24.6	1.8	24.4	+	+	26.2	1.0						+		11.4	8.2	20.6	25.4	2.6					+	+								+	+			+	f.
IN 22	21.4	2.0	19.2		+	21.2	+								13.8	8.8	23.0	33.0	+			+		+								+	1.0	+			1.4	v.f.
IN 23	4.0	+	5.2			5.8	2.0		1.0				1.2		25.8	20.2	50.2	9.2	30.8																			c.
IN 24a	16.2	4.6	18.4			23.0	6.6	+	1.8			3.8	2.6	+	8.0	16.8	40.2	17.6	1.2														1.4			+	1.8	c.
IN 24b	11.6	2.4	15.8	+		18.2	1.4						+		10.6	10.8	22.8	29.6	17.4			+											+	+			+	m.
IN 25	18.8	2.0	11.2			13.2	+		+						[illegible].0	11.8	21.0	41.6	15.4					+						+			+	+			+	m.
IN 26	22.8	1.6	25.0			26.6	+								11.6	4.8	17.0	33.0						+									+	+			+	v.f.
IN 27	22.6	4.0	16.8			20.8	+								14.0	11.8	26.4	17.8	10.4	+		+	+	-					+		+	1.2	+	+		+	2.0	v.f.

+: < 1%

Table 3. Composition of sandstone (2): Ishido Formation (middle subbelt)

Specimen number	Quartz	Feldspar: Orthoclase	Plagioclase	Microcline	Myrmeckite	Total	Rock fragments: Granite	Quartz-porphyry	Basic volcanic rock	Crystalline schist	Gneiss	Sandstone	Mudstone	Limestone	Chert	Others	Total	Clay matrix	Calcite	Heavy minerals: Zircon	Garnet	Titanite	Allanite	Epidote	Zoisite	Pumpellyite	Tourmaline	Augite	Hornblende	Apatite	Glauconite	Chlorite	Biotite	Muscovite	Prehnite	Iron opaques	Total	Grain size
IM 1	7.0		4.2			4.2	1.0		1.8					3.2	38.6	14.6	59.2	18.0	11.6													+					+	m.
IM 2	10.0	+	7.5			8.3	+	+	+					+	13.3	14.5	29.1	3.8	48.7													+					+	m.
IM 3	12.0	+	4.8			5.6	+		1.2						38.4	18.4	58.4	12.0	12.0													+		+			+	c.
IM 4	14.0	1.8	12.2			14.0	1.8		+						27.6	14.8	44.4	15.4	12.2															+			+	m.
IM 5	15.4	1.2	5.4			6.6	+		+					+	25.8	16.2	44.0	12.0	21.4														+	+			+	m.
IM 6	8.0	1.2	8.8			10.0	+		+				+		18.8	14.6	34.6	5.0	42.4			+								+			+	+			+	m.
IM 7	11.0	1.8	12.0			13.8	+		1.4			+	+		11.6	11.0	24.6	4.0	46.2														+				+	m.
IM 8	8.8	+	3.8			4.4	+		+				+		29.6	13.0	44.4	14.6	27.8																			m.
IM 9	3.8	+	2.6			3.2	2.0		1.2				1.0		15.2	9.4	28.8	1.8	62.2																	+	+	c.
IM 10	10.0	2.2	10.4		+	12.6	+		+						23.4	17.4	41.6	15.8	19.8		+			+					+				+	+			+	m.
IM 11	18.4	1.4	27.2		+	28.8	2.4		+	+				+	12.4	12.2	23.0	10.0	14.6	+		+								+			+	+			+	m.
IM 12	7.4	+	3.8			4.4	+	+	1.4				+	2.8	32.8	17.8	56.6	12.0	19.6														+	+			+	c.
IM 13	4.6	+	4.8			5.4	+		3.0				+	+	26.6	17.8	48.6	8.8	32.2														+				+	v.c.
IM 14	14.0	1.2	6.4			7.6	2.2		1.2				+		29.8	24.6	58.2	12.2	8.0					+									+				+	m.
IM 15	12.8	+	5.8			6.2	+						+		32.8	16.6	49.6	25.2	6.0														+				+	m.
IM 16	16.4	+	4.8		+	5.4	+		+				+		35.0	22.6	58.8	15.2	4.0		+											+	+				+	m.
IM 17	22.8	1.0	34.0		+	35.0	1.4			+			+		2.0	9.6	14.0	20.0	7.8														+			+	+	m.

Table 4. Composition of sandstone (3): Ishido Formation (southern subbelt)

Specimen number	Quartz	Feldspar: Orthoclase	Plagioclase	Microcline	Myrmeckite	Total	Rock fragments: Granite	Quartz-porphyry	Basic volcanic rock	Crystalline schist	Gneiss	Sandstone	Mudstone	Limestone	Chert	Others	Total	Clay matrix	Calcite	Heavy minerals: Zircon	Garnet	Titanite	Allanite	Epidote	Zoisite	Pumpellyite	Tourmaline	Augite	Hornblende	Apatite	Glauconite	Chlorite	Biotite	Muscovite	Prehnite	Iron opaques	Total	Grain size
IS 1	26.8	3.0	18.0			21.0	+								10.4	8.6	19.2	23.4	9.6	+				+									+	+			+	v.f.
IS 2	31.0	2.2	12.0			14.2	+								9.4	12.4	22.0	29.6	2.8						+								+	+			+	f.
IS 3	22.8	2.0	6.2			8.2	3.0		+				+		33.8	15.0	52.0	15.4	1.0	+	+	+		+									+	+			+	m.
IS 4	25.2	3.2	14.6			17.8	1.8		+				+		19.4	12.0	33.2	23.8		+											+		+	+			+	f.
IS 5	20.4	2.8	17.2	+	+	20.2	+								13.0	9.2	22.4	36.6		+		+		+									+	+			+	f.
IS 6	18.8	2.8	11.0	+	+	14.2	+		+						37.2	9.2	48.4	16.4	+		+			+	+							1.0	+	+			1.8	m.
IS 7	15.0	1.8	9.6			11.4	+							+	17.2	4.6	23.2	40.0	9.6													+	+	+		+	+	v.f.
IS 8	20.8	4.4	20.8			25.2	+								10.4	7.8	18.4	34.6	+			+	+	+								+	+	+		+	+	f.
IS 9	17.4	4.4	16.4	+	+	21.0									15.6	10.0	25.6	32.2	3.6				+	+	+							+	+				+	v.f.
IS 10	23.8	3.4	10.0	+		13.4	6.2	+	2.0				+		16.4	29.4	54.0	7.6	+					+										+			+	c.
IS 11	33.6	3.4	10.6	+	+	14.0	1.4								21.4	16.0	38.8	12.6		+				+									+	+			1.0	m.
IS 12	21.6	2.4	15.0			17.4	+								13.4	7.8	21.8	12.2	26.4			+											+	+			+	f.
IS 13	10.0	+	5.4			6.0	+	+	+	+					40.6	24.6	66.6	16.8															+	+			+	c.
IS 14	21.6	1.4	10.6		+	17.2	1.2								17.2	15.4	33.8	28.0	4.4					+													+	m.
IS 15	36.0	3.8	15.6			19.4	1.0								23.6	7.0	31.6	13.0						+									+	+			+	m.
IS 16	22.4	2.2	10.0			12.2	1.8								29.6	13.8	45.2	17.2	3.0	+													+	+			+	f.
IS 17	26.0	3.4	13.4			16.8	1.0								26.6	9.6	37.2	20.0						+							+		+	+			+	f.
IS 18	17.8	2.4	15.6			18.0	+		+						25.6	13.0	39.2	20.8	3.8	+				+							+		+	+			+	m.
IS 19	22.6	4.0	18.2			22.2	1.2						+		22.8	11.4	35.4	18.8	+					+									+	+			+	f.
IS 20	16.6	+	6.8			7.6	+								16.2	19.8	36.2	36.4															3.2				3.2	f.
IS 21	26.0	2.2	20.2			22.4	1.2								10.0	6.6	17.8	22.8	10.8			+											+	+			+	v.f.
IS 22	22.0	3.4	18.0	+		21.4	+								22.2	6.2	29.2	26.2	1.0					+									+	+			+	v.f.
IS 23	30.6	4.2	15.2	+		19.6									18.0	7.2	25.2	24.2															+				+	v.f.
IS 24	21.8	2.4	15.8			18.2	+		+						18.0	14.0	33.0	27.0						+									+	+			+	f.
IS 25	22.2	3.6	18.6	+	+	22.2	+								20.8	8.2	29.6	23.6	1.8														+	+			+	f.
IS 26	4.8	+	9.8			10.2	1.2	+	9.4				1.2		11.6	15.6	39.2	45.8																				m.
IS 27	28.6	6.8	12.8	+	+	19.6	3.4	+		+			+		12.2	20.2	36.4	12.6	2.8			+											+	+			+	c.
IS 28	21.0	2.4	8.6			11.0	+						+		41.2	9.4	52.4	15.2															+					m.
IS 29	24.2	1.6	13.4			15.0									7.2	4.8	12.0	45.6	+					+								+	1.4	+			2.4	v.f.

Table 5. Composition of sandstone (4): Sebayashi Formation (northern subbelt)

Specimen number	Quartz	Feldspar: Orthoclase	Plagioclase	Microcline	Myrmekite	Total	Rock fragments: Granite	Quartz-porphyry	Basic volcanic rock	Crystalline schist	Gneiss	Sandstone	Mudstone	Limestone	Chert	Others	Total	Clay matrix	Calcite
SH 1	30.4	2.2	44.6	+	+	46.8	3.0		+						+	8.6	12.6	9.6	
SH 2	34.0	2.6	38.4			41.0	+								2.0	3.8	5.6	16.4	1.8
SH 3	30.4	4.2	41.4		+	45.6	2.8		+						-	7.2	10.4	12.6	
SH 4	13.2	+	12.4			12.8	3.6	+	1.0	+			2.0		17.6	18.2	43.2	26.4	3.0
SH 5	17.1	1.8	15.3			17.1	1.3	+	1.6				1.1		12.8	19.8	36.6	29.1	
SH 6	37.0	1.8	35.4		+	37.4	+								-	3.6	4.2	16.0	5.0
SH 7	28.4	1.6	56.8		+	58.8	1.4								1.4	+	3.6	8.4	+
SH 8	33.4	3.8	32.4	+	+	36.4	4.2		+	+					5.4	9.6	20.0	8.2	+
SH 9	22.4	1.4	11.4		+	12.8	+								+	2.8	3.0	+	60.4
SH 10	24.8	1.8	30.0	+	+	32.0		+		+					1.4	5.6	7.2	26.0	8.8
SH 11	27.2	1.4	44.4	+	+	46.2	2.4	+	1.0						+	11.0	14.6	11.2	+
SH 12	37.0	2.2	41.2	+	+	43.6	+		+	+					+	2.2	2.6	16.2	+
SH 13	32.2	2.2	25.2		+	27.4	+	+	+						+	12.8	13.0	10.8	16.2
SH 14	27.2	1.4	32.4	+	+	33.6	+		+					+	+	2.4	3.4	28.0	6.4
SH 15a	32.8	2.4	45.8		+	48.4	1.2								-	3.6	5.0	12.8	+
SH 15b	22.4	2.0	45.6			47.6									+	1.0	1.8	26.2	+
SH 15c	37.4	2.4	39.8	+	+	42.4	+								+	5.2	6.6	12.4	
SH 16	34.6	4.4	38.2	+	+	42.6	1.4		+						+	3.4	6.0	15.4	
SH 17	16.6	+	28.8	+	+	29.8	+		+					+	+	4.0	5.0	45.4	1.8
SH 18	17.4	1.6	21.4			23.0	2.2		+	+					2.0	19.4	24.2	34.6	-
SH 19	19.8	4.6	23.2	+		27.8	4.6	+	2.4	+			+		+	14.4	22.0	29.0	
SH 20	32.8	4.4	33.0	+	+	38.2	+								+	3.8	4.0	23.0	+
SH 21	41.0	7.2	21.8	+	+	29.6	2.4			+					7.4	12.2	22.0	7.0	
SH 22	42.2	2.2	35.2	+	+	37.8	1.2								+	8.8	10.2	7.4	1.8
SH 23	37.2	2.2	31.8	+	+	34.0	+									4.8	5.2	3.8	19.4
SH 24	38.0	1.8	39.8	+	+	40.6	+									1.4	2.2	4.2	14.6
SH 25	45.4	2.4	38.0			40.4	+								1.6	2.8	4.8	9.0	+
SH 26	28.4	7.8	28.8	+	+	36.8	4.4		+						6.2	12.2	23.6	10.2	
SH 27	42.0	3.6	35.0	+	+	38.6				+					+	2.2	2.4	12.3	1.8

Specimen number	Heavy minerals: Zircon	Garnet	Titanite	Allanite	Epidote	Zoisite	Pumpellyite	Tourmaline	Augite	Hornblende	Apatite	Glauconite	Chlorite	Biotite	Muscovite	Prehnite	Iron opaques	Total	Grain size
SH 1	+		+		+	+								+	+			+	m.
SH 2	+			+	+									1.0	+			1.2	f.
SH 3					+	+								+	+			1.0	m.
SH 4		+												1.4				1.4	c.
SH 5					+									+	+		+	+	m.
SH 6	-		+	+								+	+	+	+			+	m.
SH 7	+		-	+	+									+	+			+	f.
SH 8			+	+	-	+								+	+			2.0	f.
SH 9	+	+	+		+	+						+	+	+	+			1.2	m.
SH 10	+				+			+						1.2	+			1.2	m.
SH 11					+	+								+	+			+	m.
SH 12	+		+	+	+	+				+				+	+			+	m.
SH 13			+	+	+					+				+	+			+	m.
SH 14		+			+	+								1.2	+			1.2	f.
SH 15a	+		+	+	+	+								+	+			1.0	f.
SH 15b					+	+								1.4	+			2.0	f.
SH 15c	+		+		+	+						+		+	+			1.2	f.
SH 16	+		+	+	+									1.4	+			1.4	f.
SH 17			+		+	+						+	+	+	+			1.4	m.
SH 18			+		+	+					+		+	+	+		+	+	c.
SH 19			+		+	+							+	+	+			1.4	c.
SH 20	+		+		+	+							+	1.8	+			2.0	f.
SH 21				+							+			+	+			+	f.
SH 22	+	+	+		+	+								+	+			+	m.
SH 23			+		+						+			+	+			+	f.
SH 24		+	+	+	+	+								+	+			+	m.
SH 25	+		+	+	+	+								+	+			+	m.
SH 26			+		+	+				+				+	+		+	1.0	m.
SH 27														2.4	+			2.4	f.

Table 6. Composition of sandstone (5): Sebayashi Formation (middle subbelt)

Specimen number	Quartz	Feldspar					Rock fragments											Clay matrix	Calcite	Heavy minerals																		Grain size
		Orthoclase	Plagioclase	Microcline	Myrmeckite	Total	Granite	Quartz-porphyry	Basic volcanic rock	Crystalline schist	Gneiss	Sandstone	Mudstone	Limestone	Chert	Others	Total			Zircon	Garnet	Titanite	Allanite	Epidote	Zoisite	Pumpellyite	Tourmaline	Augite	Hornblende	Apatite	Glauconite	Chlorite	Biotite	Muscovite	Prehnite	Iron opaques	Total	
SM 1	17.2	1.8	29.2			31.0	+								+	2.8	3.8	43.0	4.2	+				+							+		+	+			+	f.
SM 2	20.8	3.2	38.2		+	41.4	2.2	+	+	+			+		+	10.6	13.8	21.6	1.6			+	+	+	+								+	+			+	c.
SM 3	22.4	6.2	35.6	+	+	41.8	8.8	1.0	2.4				+		+	9.0	21.6	12.4	+	+		+	+	+	+				+				+	+			1.2	c.
SM 4	19.6	4.0	46.8	+	+	50.8	1.4	+	+						+	2.8	5.6	18.8	4.4			+	+	+							+		+	+			+	m.
SM 5	23.0	1.8	40.4	+		42.2	2.0	+	+				+		+	4.2	7.2	6.8	20.2					+									+	+			+	m.
SM 6	17.4	3.4	28.2	+	+	31.6	+	+	+						3.6	6.2	11.0	15.0	23.4												+		1.4	+			1.6	f.
SM 7	18.4	4.2	30.2	+	+	34.8	2.0		+						1.6	11.8	16.0	26.8	2.4	+		+		1.0	+					+	+		+	+	+		1.6	f.
SM 8	23.4	2.0	41.6		+	43.8	1.0		+				+	+		5.0	6.6	22.0	3.0	+			+	+	+						+		+	+			1.2	m.
SM 9	21.6	2.8	50.4	+		53.2	1.8		+				+		+	4.6	6.8	16.6	1.6			+		+	+						+		+	+			+	c.
SM 10	19.4	3.2	41.0	+	+	44.2	3.2	+	+				1.0		+	5.6	11.4	17.2	7.4	+		+	+	+						+	+		+	+			+	m.
SM 11	14.6	2.4	38.2		+	40.6	2.0	2.8	+				1.6		+	8.8	16.6	6.4	21.4		+	+		+	+						+		+	+			+	m.
SM 12	24.6	3.0	43.4	+	+	46.4	2.8		+						+	4.4	7.8	18.8	1.2					+	+					+			1.0	+			1.2	m.
SM 13	23.6	3.0	36.4	+	+	39.4	2.2		+				+		+	10.2	14.0	21.6	1.0		+	+		+	+						+		+	+			+	c.
SM 14	15.6	1.2	27.8	+	+	29.0	1.6		+	+			1.2		+	8.6	12.8	5.0	36.4			+		+	+					+	+	+	+	+			1.2	m.
SM 15	20.8	2.0	31.0		+	33.0	1.4		1.0				+		1.4	7.0	11.2	30.4	3.6	+		+		+	+					+	+		+	+			1.0	m.
SM 16	28.6	1.6	58.4	+	+	60.4	1.4		+				+		+	1.0	2.4	8.0	+			+		+	+						+		+	+			+	m.
SM 17	27.0	1.0	46.2		+	47.2	1.4		+						+	2.6	4.8	17.6	1.8			+		+							+		+	+			1.6	m.
SM 18	25.4	4.0	37.4	+		41.4	4.4		+	+			+			3.8	9.2	4.2	18.8			+		+	+								+	+			1.0	c.
SM 19	27.4	5.0	32.4	+		37.6	3.8			+					+	6.6	10.6	15.0	9.0			+		+	+								+	+			+	c.
SM 20	17.0	3.2	33.8			37.0			+						+	+	+	36.4	7.8			+		+	+								+	+			1.0	f.
SM 21a	32.0	2.4	39.4	+	+	41.8	2.0	+	+							3.4	5.4	18.0	1.0			+		+	+						+		+	+			1.0	c.
SM 21b	16.0	2.4	27.4			29.8	1.6	+	+	+				+	+	4.6	8.2	17.4	28.6					+	+								+	+			+	c.
SM 22	21.2	3.2	22.4	+	+	25.6	1.4		+						+	5.0	7.2	4.2	41.0	+		+		+	+			+	+				+	+			+	c.
SM 23	22.4	2.2	32.4		+	34.6	7.2	+	1.6	+					+	13.6	23.6	14.0	3.0														1.6	+			1.6	c.
SM 24	22.0	1.4	27.6	+		29.0	1.2		+						+	5.8	7.4	3.8	37.0			+	+	+	+						+		+	+			+	m.
SM 25	34.4	2.4	39.0	+		41.4	1.8	+	+	+					+	6.0	8.0	15.2				+		+	+								+	+			1.0	c.
SM 26	28.4	2.8	36.2	+	+	39.0	+		+				2.0		+	4.0	6.4	26.2	+				+	+	+								+	+			+	c.
SM 27	23.8	2.2	29.0			31.2	+									+	+	7.8	36.2	+		+	+	+	+					+	+		+	+			+	f.
SM 28	23.0	2.0	42.0		+	44.0										1.8	1.8	27.6	2.0			+		+	+					+	+		1.4	+			1.6	f.
SM 29	15.6	+	41.4			42.2	1.2									1.5	3.0	39.0	+					+	+								+	+			+	m.
SM 30	15.8	2.8	34.0	+	+	36.8	2.0		+				+		+	8.2	12.4	30.6	3.0	+		+	+	+	+					+			1.0	+			1.4	m.
SM 31	18.8	2.4	28.0	+	+	30.4	5.6	1.6	+						+	13.2	20.8	10.6	17.8			+		+	+	+							1.0	+			1.6	m.
SM 32	19.6	3.0	38.4	+	+	41.4	1.0		+	+					+	6.8	8.2	26.8	2.0			+	+	+	+						+		1.8	+			2.0	f.
SM 33	16.6	2.6	38.6	+	+	41.2	1.2	1.0	+						+	10.8	13.4	27.4				+		1.4	+						+		+	+			1.4	m.
SM 34	16.2	1.4	28.4		+	29.8	+	+	+				+		+	12.4	14.4	11.4	26.2					+							+	+	1.4	+			2.0	c.
SM 35	23.8	2.6	30.4	+	+	33.0	4.0		+						+	10.4	15.4	25.6	1.0			+	+	+	+								+	+			1.2	m.
SM 36	19.0	2.4	37.4		+	39.8	3.8		+				+		+	6.2	10.6	29.0	+			+		+	+						+		+	+			1.0	c.
SM 37	16.4	1.4	39.4	+	+	40.8	1.6	+	+						+	10.6	12.8	27.0	2.0		+	+		+	+				+	+	+		+	+			+	c.
SM 38	17.2	2.6	57.2	+	+	59.8	+	+	+	+					+	1.4	2.0	20.4	+	+		+		+	+						+	+	+	+			+	m.
SM 39	14.2	2.6	34.6	+		37.2	3.0	1.6	+						+	12.2	18.2	22.0	7.6			+	+	+	+						+		+	+	+		+	c.
SM 40	13.4	2.4	45.6			48.0	+	+	+						+	[illegible]	[illegible]	27.2	8.8			+		+	+						+		+	+			+	m.
SM 41a	20.2	+	20.8		+	21.6	7.2	1.8	3.6	+			1.2		1.4	20.6	35.8	18.0	2.6		+	+		+	+						+		+	+			1.0	c.
SM 41b	32.4	1.8	33.8	+	+	35.8	1.2	+	+	+					+	[illegible]	7.6	17.0	3.2	+		+		+	+					+			+	+			2.0	m.
SM 42	21.0	5.4	34.2	+	+	40.2	3.2	+	+	+			+		2.6	9.2	16.6	18.2	1.4	+		+		+	+						+		+	+		+	2.6	f.
SM 43	15.0	3.2	20.8	+	+	24.0	2.4	+	1.0				+	+	1.8	10.8	16.0	13.4	28.8	+		+		+	+								+	+			+	m.
SM 44	44.6	3.8	29.0	+	+	32.8	+								+	3.4	4.4	15.6		+				+	+								2.6	+			2.6	m.
SM 45	25.0	4.8	44.6	+	+	49.6	2.0		+					+	+	7.[illegible]	10.4	12.6				+		+	+								+	+			1.2	c.

Table 7. Composition of sandstone (6): Lower Sanyama Formation (northern subbelt)

Specimen number	Quartz	Feldspar: Orthoclase	Plagioclase	Microcline	Myrmekite	Total	Rock fragments: Granite	Quartz-porphyry	Basic volcanic rock	Crystalline schist	Gneiss	Sandstone	Mudstone	Limestone	Chert	Others	Total	Clay matrix	Calcite
LN 1	21.4	5.0	25.8	1.4	+	32.8	7.0	+	6.8	+			+		3.6	10.6	29.2	12.6	2.8
LN 2	24.0	6.4	25.2	+	+	32.0	11.6	+	1.6				+		2.6	14.0	31.0	9.4	2.8
LN 3	28.8	2.0	22.2			24.2									+	+	1.6	13.8	30.4
LN 4a	18.6	3.4	27.8	+		31.2	14.0	+	1.2	2.0	+	1.0	2.0		3.2	9.4	33.0	11.6	4.0
LN 4b	16.4	2.0	16.8	+	+	19.0	7.6	+	2.8			+	+		+	8.2	20.4	2.0	41.2
LN 4c	13.4	1.6	16.4	+	+	18.8	11.0		1.4				+		1.2	15.0	28.8	2.6	34.6
LN 5	16.2	3.2	17.2	+	+	21.6	19.6	5.6	2.2	+			1.0		1.8	22.6	53.0	8.6	+
LN 6	28.0	3.6	35.0	+	+	38.6	4.6	1.4	+	+			+		+	8.6	14.8	15.4	
LN 7	32.6	4.2	31.0			35.2	+								+	6.8	7.8	19.4	4.6
LN 8	44.8	3.4	29.0			32.4	5.6		+						+	6.8	13.2	8.0	
LN 9a	20.8	+	30.8		+	31.3	+	+	+				1.2			10.0	11.8	23.4	12.8
LN 9b	43.6	3.6	31.6	+	+	35.2	1.0			+					1.2	8.0	10.2	10.8	
LN 9c	11.4	3.6	7.4	+	+	11.2	7.6	2.2	+						36.0	27.0	73.2	4.0	
LN 10	44.8	1.2	30.0			31.2	+								+	3.8	4.4	18.6	
LN 11	44.0	3.8	24.6	+	+	28.4	1.2		+						1.0	18.0	20.2	7.2	
LN 12	24.0	1.6	32.0	+	+	33.8	3.4	+	1.4	+			+		+	11.0	17.0	14.4	8.8
LN 13a	22.6	4.0	24.0	1.2	−	29.6	18.4	1.6	1.2				1.2		+	10.4	33.6	12.0	1.6
LN 13b	27.8	4.2	15.0	+		19.2	3.4	+							24.0	13.6	41.2	11.6	
LN 14	35.8	3.8	28.2	+	+	32.0	3.2		+	+					1.8	12.8	18.0	13.4	+
LN 15	39.0	3.4	30.4	+	+	34.0	2.6		+						1.0	9.2	13.6	13.4	+
LN 16	31.6	7.8	31.6	+	+	39.4	6.6		+	+			+		+	11.8	19.4	9.0	
LN 17	30.8	+	38.4		+	39.0	3.2		2.4				1.8		+	5.8	13.6	1.0	13.4
LN 18	20.0	4.8	27.8	+	+	32.6	1.6	+	1.0						+	15.6	19.4	24.4	3.0
LN 19	26.4	3.6	46.8	+	+	50.4	3.6								+	6.6	10.2	12.6	
LN 20	30.8	4.8	33.4	+	+	38.4	9.6	+	+				1.2		+	13.0	24.6	5.0	
LN 21	25.2	4.0	30.0		+	34.0	8.8	+	1.6			+			3.6	14.6	29.6	11.0	
LN 22a	27.8	2.6	21.0	+	+	23.6	4.4			+					4.6	16.0	25.2	22.4	
LN 22b	26.0	5.0	32.0	+		37.0	12.2	1.2	+				+		+	7.8	22.0	13.2	
LN 23	36.4	3.4	27.0	+	+	30.4	+								2.0	10.8	13.6	18.2	

Specimen number	Heavy minerals: Zircon	Garnet	Titanite	Allanite	Epidote	Zoisite	Pumpellyite	Tourmaline	Augite	Hornblende	Apatite	Glauconite	Chlorite	Biotite	Muscovite	Prehnite	Iron opaques	Total	Grain size
LN 1			+		+						+			+	+		+	1.2	m.
LN 2		+					+				+		+	+	+		+	+	m.
LN 3					+									+	+			1.2	v.f.
LN 4a			+		+									+				1.6	m.
LN 4b			+	+	+									+				1.0	m.
LN 4c			+		+	+								+	+			1.8	m.
LN 5														+	+			+	c.
LN 6			+	+	+									3.0				3.2	c.
LN 7	+	+	+		+									+	+			+	f.
LN 8			+		+									+	+			1.6	f.
LN 9a					+	+						+		+	+			+	m.
LN 9b	+	+	+	+	+									+	+			+	m.
LN 9c			+		+					+				+	+			+	m.
LN 10	+				+									1.0	+			1.0	f.
LN 11	+			+	+									+	+			+	m.
LN 12														1.8	+	+		2.0	c.
LN 13a			+								+			+	+			+	m.
LN 13b	+		+		+									+	+			+	f.
LN 14	+		+	+	+									+	+			+	m.
LN 15			+	+	+	+								+	+			+	m.
LN 16			+	+	+	+								+	+			+	c.
LN 17					+						+			2.2	+			2.2	c.
LN 18	+				+	+						+		+	+			+	m.
LN 19			+	+	+							+		+	+			+	m.
LN 20	+	+	+	+	+					+	+			+	+			1.2	m.
LN 21			+											+	+			+	m.
LN 22a	+	+	+		+	+				+				+	+			1.0	m.
LN 22b					+									1.8	+			1.8	v.c.
LN 23			+	+	−									1.2	+			1.4	f.

Table 8. Composition of sandstone (7): Lower Sanyama Formation (middle subbelt)

Specimen number	Quartz	Feldspar					Rock fragments											Clay matrix	Calcite	Heavy minerals																		Grain size
		Orthoclase	Plagioclase	Microcline	Myrmekite	Total	Granite	Quartz-porphyry	Basic volcanic rock	Crystalline schist	Gneiss	Sandstone	Mudstone	Limestone	Chert	Others	Total			Zircon	Garnet	Titanite	Allanite	Epidote	Zoisite	Pumpellyite	Tourmaline	Augite	Hornblende	Apatite	Glauconite	Chlorite	Biotite	Muscovite	Prehnite	Iron opaques	Total	
LM 1	21.6	4.2	44.0	+	+	48.2	2.8	+	3.0	+		+	+		+	7.8	14.0	13.6	2.6			+	+	+									+	+			+	c.
LM 2	19.2	1.0	36.8		+	37.8	+	4.6	+						+	11.4	16.8	21.4	2.8														+	+			+	c.
LM 3	20.0	3.6	46.2	+	+	49.8	2.2	+	+						+	7.6	10.4	13.4	5.8						+								+	+			+	m.
LM 4	14.2	4.4	47.0	+		51.4	+		+							5.2	6.6	18.0	9.2					+		+					+		+	+			+	f.
LM 5	21.4	2.0	33.6		+	35.6									1.0	1.4	2.4	16.6	23.0		+			+	+					+			+	+			1.0	m.
LM 6	20.4	4.0	41.4	+	+	45.4	5.6	+	1.2	+			+		+	7.8	15.0	9.2	8.8			+	+	+	+						+		+	+			1.2	m.
LM 7	23.2	3.4	46.8	+	+	50.2	6.6	+	+				+		+	3.8	11.2	12.2	2.2			+		+	+						+		+	+			1.0	c.
LM 8	26.8	3.0	36.0		+	39.0	1.2	+	+				+		+	4.4	7.0	25.4	+					+									+	+			1.2	m.
LM 9	32.2	2.0	32.2			34.2	2.2	+	+	+			+		+	6.8	9.8	22.8	+												+		+	+			1.0	m.
LM 10	26.6	2.0	35.4	+		37.4	1.8						+		1.4	3.8	7.0	24.6	3.8														+	+			+	m.
LM 11	23.0	+	36.4	+	+	37.0	3.6	+	1.2	+			+		+	12.4	19.4	16.0	4.2	+	+	+		+	+					+			+	+			+	c.
LM 12	20.8	2.4	44.2	+	+	46.6	2.4	1.0	+				+		+	10.4	14.2	13.0	5.4			+	+	+	+								+	+			+	m.
LM 13	15.2	2.0	44.0			46.0	3.8	+					+		+	11.6	16.2	13.2	4.4		+	+		+									+	+			1.0	m.
LM 14	33.2	1.6	23.8			25.4			+							2.0	2.0	35.2	4.2					+									+	+			+	v.f.
LM 15a	12.2	1.8	24.8		+	26.6	+	+	+				+	+	+	3.6	4.4	4.8	51.4					+	+								+	+			+	m.
LM 15b	22.2	2.2	45.2	+	+	47.4	2.0		+				+		1.2	3.8	7.2	21.8	+		+	+		+	+								+	+		+	1.4	m.
LM 15c	29.0	1.6	39.8			41.4									1.2	+	1.6	26.8	+			+		+	+								+	+			1.0	f.
LM 16	29.2	1.4	23.8		+	25.2									1.6	6.4	8.0	36.0	1.6	+			+										+	+			+	f.
LM 17	28.6	1.2	23.0			24.2	+								1.6	7.4	9.6	37.6															+	+			+	f.
LM 18	25.4	1.2	24.4			25.6	+								2.2	3.6	6.0	43.0															+	+			+	f.
LM 19	30.8	1.4	28.4	+		29.8	+								6.0	4.2	10.4	26.2	2.2	+				+									+	+			+	f.
LM 20	24.6	3.4	21.6	+		25.0	28.6	+	2.2						+	10.2	41.6	6.2	2.0		+	+		+	+							+	+	+			+	v.c.
LM 21	25.4	1.4	42.0	+		43.6	3.0	+	1.4			+	+		+	10.2	14.6	12.8	3.2	+										+			+	+			+	c.
LM 22	17.8	1.6	22.2	+	+	23.8	2.6	+	+	+					+	9.0	12.8	5.8	39.2	+		+		+									+	+			+	c.
LM 23	17.6	4.8	26.6	+	+	31.6	3.2	1.2	+				1.0		1.6	11.8	19.2	27.0	3.8	+	+			+	+							+	+	+			+	c.
LM 24	19.4	3.6	34.2			37.8	1.0		+						4.6	7.8	13.4	20.6	8.6					+							+	+	+	+		+	+	f.
LM 25	20.2	4.6	28.2	+	+	32.8	+	+	+						2.8	6.2	9.8	18.0	17.8	+		+	+	+								+	+	+		+	1.4	f.
LM 26	13.6	2.6	39.0			41.6	+		+						+	12.2	12.8	3.2	28.4			+		+	+								+	+			+	c.
LM 27	21.8	2.2	44.8			47.0	+		+						+	5.4	7.0	21.6	2.2			+	+	+	+								+	+			+	m.
LM 28	12.0	2.2	27.2		+	29.4	2.2	1.4	1.2				+	+	+	10.4	16.2		42.0					+	+								+	+			+	m.
LM 29	14.4	2.2	40.8	+		43.0	1.2		+				+	+	+	4.8	6.8	5.2	30.2	+				+									+	+			+	f.
LM 30	22.0	2.4	39.2	+	+	41.6	3.0	1.2	+				+		+	6.4	11.0	21.4	1.4		+	+	+	+	+						+		+	+			2.6	c.
LM 31	28.2	1.4	44.4			45.8	1.0		+						+	3.2	4.4	19.0	+			+		+	+								1.4	+			2.0	f.
LM 32	26.2	3.4	30.2		+	33.6	6.4		+						3.4	7.0	17.2	15.8	5.6			+		+	+					+			+	+			1.6	c.
LM 33	23.0	5.4	29.4	+	+	34.8	6.6	+	+				+		+	12.6	21.0	14.2	6.4			+		+	+						+		+	+			+	c.
LM 34	21.8	3.8	47.8			51.6	2.0	+	+							4.8	7.8	15.0	3.0	+				+	+					+			+	+			+	f.
LM 35	24.4	3.4	36.4		+	39.8	9.8	2.2	1.2							5.2	18.4	17.0	+			+		+									+	+			+	c.
LM 36a	21.4	3.0	32.8	+	+	35.8	6.8	1.6	5.2						+	10.0	23.6	15.8	1.4			+		+	+								+	+		+	2.0	c.
LM 36b	21.2	1.6	36.0	+	+	37.6	9.0		1.4				+	+	+	9.4	20.4	18.2	1.4					+	+						+		+	+			1.2	c.
LM 37	24.0	4.6	29.2	+	+	33.8	10.4	1.0	2.0	+					+	7.0	20.4	21.0		+		+		+	+								+	+	+		+	c.
LM 38	26.8	4.8	37.4	+	+	42.2	9.2	+	+	+					+	9.6	20.2	7.8	+			+		1.0	+								1.6	+			3.0	c.
LM 39	30.4	2.2	28.2		+	30.4	6.8			+						11.4	18.2	9.2	9.4														2.0	+			2.4	m.
LM 40	23.0	2.2	30.6		+	33.0	+	+	+						+	4.2	5.6	14.8	22.8			+	+	+									+	+			+	f.
LM 41	20.4	3.4	32.6		+	36.2	1.0		+						+	21.2	22.6	11.6	9.0	+		+		+							+		+	+			+	f.
LM 42	20.4	2.0	40.8	+	+	42.8	1.6	+	+				+		+	13.6	16.6	16.0	2.8			+		+	+								+	+			1.4	c.
LM 43	15.0	4.0	37.8	+	+	42.4	6.0	1.2	1.8					+	1.8	12.4	23.4	16.2	2.6	+		+		+	+							+	+	+			+	m.
LM 44	13.0	3.6	29.8	+		33.6	3.4	+	1.0	+			+	+	6.6	13.2	25.8	15.6	5.6	+													+	+		+	+	f.
LM 45	16.6	4.2	23.2	+	+	27.6	6.0	3.4	1.0	+		+	+		3.6	12.4	26.8	27.4	+	+	+	+		+	+						+		+	+			1.4	m.
LM 46	23.2	5.8	23.0	+	+	29.2	2.6		+	+		+	+		6.2	11.2	21.8	19.0	6.2	+		+		+		+							+	+		+	+	f.

Table 9. Composition of sandstone (8): Upper Sanyama Formation (northern subbelt)

Specimen number	Quartz	Feldspar: Orthoclase	Plagioclase	Microcline	Myrmekite	Total	Rock fragments: Granite	Quartz-porphyry	Basic volcanic rock	Crystalline schist	Gneiss	Sandstone	Mudstone	Limestone	Chert	Others	Total	Clay matrix	Calcite
UN 1	23.0	6.2	38.6	+	+	44.8	11.8	−	1.4				+		+	12.0	25.6	6.2	
UN 2	14.2	+	18.8			19.4	3.0	+	4.2	+			−		+	35.6	43.6	14.0	8.6
UN 3	23.4	2.2	46.2		+	48.4	11.4		+	+					+	2.6	14.8	9.2	1.0
UN 4	21.8	3.6	37.8		+	41.4	12.2			+					1.4	5.8	19.4	7.0	3.8
UN 5a	27.8	4.2	46.0			50.2	6.0								+	4.6	11.0	5.8	2.0
UN 5b	21.8	1.6	33.6			35.2	8.6			+						8.4	17.0	3.8	15.2
UN 6	24.8	9.8	31.0	+	+	41.2	13.4	+	1.8						+	8.2	24.0	9.2	
UN 7	25.8	2.2	26.4		+	28.6	1.0								−	2.3	4.0	9.2	27.4
UN 8	13.4	5.2	30.2	+	+	35.8	7.2	+	3.8	1.0		1.8	+		1.0	9.6	25.0	12.6	4.0
UN 9	15.0	2.8	33.2	+	+	36.6	2.2	1.0	1.0						3.6	11.0	18.8	27.0	2.0
UN 10	14.0	8.4	27.6			36.0	+						−		+	8.4	9.2	38.4	+
UN 11	19.8	2.4	31.8	+	+	34.2	11.2	+	+	+					−	5.4	19.6	14.6	10.0
UN 12	21.4	1.4	45.4		−	46.8	15.2						+		+	6.2	21.4	9.2	
UN 13	30.6	+	41.4	+	+	42.0	3.2	+	1.0	+			+		+	5.0	10.2	10.4	2.4
UN 14	22.0	5.2	24.2		+	29.4	2.4		+						3.8	9.0	15.2	32.6	+
UN 15	8.4	1.4	61.0			62.4									−	−	+	15.6	8.4
UN 16	27.0	2.8	37.8		−	40.6	2.4								−	2.8	5.8	8.8	16.0
UN 17a	24.4	2.4	27.8	+	1.2	31.6	12.6	1.0	+	−			+		−	13.2	27.4	14.8	+
UN 17b	15.4	1.0	20.8			21.8	32.4		+	+			1.6		+	15.2	50.0	7.0	+
UN 18	16.8	1.4	31.2			32.6	24.2						−		+	10.0	34.4	5.6	4.6
UN 19a	22.8	2.6	32.2		+	34.8	18.0			+			+		+	7.8	27.0	6.6	1.2
UN 19b	28.4	2.2	31.6		+	33.8	1.2			+						4.6	5.8	27.8	
UN 20	22.4	+	22.4		+	23.2	13.4			−				+	+	7.6	21.8	15.4	13.6
UN 21	13.4	1.4	40.2		+	41.8	5.2	+		+			+		+	4.6	11.2	3.6	29.8
UN 22a	26.8	1.0	31.6		+	33.0	6.0	+	+	+			+		+	8.0	14.6	17.4	4.8
UN 22b	25.4	2.2	25.5		+	28.2	16.6	3.6	+	+					+	4.2	24.6	19.2	+
UN 23	22.8	1.6	37.4		−	[illegible]	18.4								+	5.4	24.0	11.0	1.0
UN 24	12.0	1.6	31.0		+	32.6	17.0			−					+	5.6	23.6	19.8	−
UN 25a	17.8	1.2	25.0		−	26.2	32.2		1.0	+		+	+		+	6.8	41.8	9.6	+
UN 25b	16.0	1.6	24.8		+	26.1	27.4			+			7.6			7.6	42.6	8.6	+
UN 26	29.2	3.0	34.4		+	37.4	9.0						−		−	5.6	15.0	7.6	2.6

Specimen number	Heavy minerals: Zircon	Garnet	Titanite	Allanite	Epidote	Zoisite	Pumpellyite	Tourmaline	Augite	Hornblende	Apatite	Glauconite	Chlorite	Biotite	Muscovite	Prehnite	Iron opaques	Total	Grain size
UN 1		−			+						+			+	+			+	c.
UN 2										+				+	+			+	v.c.
UN 3	+		+											3.2	+			3.2	c.
UN 4			+							+	+			6.2	+			6.6	c.
UN 5a	+		+		+						+			2.8	+			3.2	c.
UN 5b	+		+	+	+						−			6.6	+			7.0	c.
UN 6	+		+	+	−	+								+	+			+	c.
UN 7	+					+					+			4.8	+			5.0	m.
UN 8	−				+						+			3.2	+			3.2	m.
UN 9					+									+				+	m.
UN 10			+		−	+					+			2.0				2.0	m.
UN 11			+		−	+								1.0	+			1.8	c.
UN 12	−													1.2	+			1.2	c.
UN 13	−	+									+			4.2	+			4.4	c.
UN 14					−									−	+			+	m.
UN 15			+		−									4.2				4.4	m.
UN 16		−	+							+				1.6	+			1.8	m.
UN 17a					+						+			1.8	+			1.8	c.
UN 17b			+	+	−									3.8	+			5.2	c.
UN 18		+	+		−	+					−			5.8	+			6.0	v.c.
UN 19a	+	+	−	+	−						+		1.6	5.8	+			7.6	c.
UN 19b	−		+		−						+		+	3.6	+			4.2	c.
UN 20	+		+		+						+			3.6	+			3.6	v.c.
UN 21			+								+			+	+			+	c.
UN 22a			+									+		3.2	+			3.4	m.
UN 22b	+		+								−	+		2.2	+	+		2.4	c.
UN 23		+	+		−	+	+			+	+			6.0	+			6.2	c.
UN 24	+		+		1.8									2.4	+			4.4	v.c.
UN 25a	+		+		+						+			3.6	+			4.4	v.c.
UN 25b	+		−		−						−			4.6	+			6.0	v.c.
UN 26	+	+	+	+	+	−					+			7.0	+			8.2	c.

Table 10. Composition of sandstone (9): Upper Sanyama Formation (middle subbelt)

Specimen number	Quartz	Feldspar					Rock fragments											Clay matrix	Calcite	Heavy minerals																		Grain size
		Orthoclase	Plagioclase	Microcline	Myrmekite	Total	Granite	Quartz-porphyry	Basic volcanic rock	Crystalline schist	Gneiss	Sandstone	Mudstone	Limestone	Chert	Others	Total			Zircon	Garnet	Titanite	Allanite	Epidote	Zoisite	Pumpellyite	Tourmaline	Augite	Hornblende	Apatite	Glauconite	Chlorite	Biotite	Muscovite	Prehnite	Iron opaques	Total	
UM 1	22.4	4.4	41.6	+	+	46.0	+		+				+		+	2.4	3.2	26.8	1.6	+									+				+	+			+	f.
UM 2	23.2	2.4	35.0		+	37.4	1.2	+	1.2						+	5.6	8.4	25.0	5.6	+									+				+	+			+	m.
UM 3	26.6	1.4	31.4		+	32.8	+		+						+	2.6	4.0	12.2	24.2	+.													+	+			+	m.
UM 4	27.8	4.0	22.2		+	26.2	+		+						1.8	8.6	11.4	31.6	2.0											+			+	+			1.0	m.
UM 5	32.0	3.2	35.4	+	+	38.6	1.2		+	+			+			5.8	7.4	21.0	1.0					+			+						+	+			+	m.
UM 6	21.4	3.2	32.8			36.0	2.4	1.0	+	+		+			1.4	18.0	23.0	19.0	+		+	+		+	+								+	+			+	c.
UM 7	23.0	3.4	29.8	+	+	33.2	2.4	+	+				+		2.0	7.0	12.0	20.2	11.0					+						+			+	+			+	m.
UM 8	22.6	3.6	33.6		+	37.2	1.0		+						1.2	6.2	8.6	23.4	7.6			+		+									+	+			+	f.
UM 9	21.2	2.6	34.0	+	+	36.0	+								+	4.6	5.4	23.4	13.4	+				+						+			+	+			+	f.
UM 10	27.2	1.8	25.8	+	+	27.6	2.8	+	+				2.8		2.6	11.6	20.8	19.2	1.2			+		+	+							+	3.0	+			4.0	c.
UM 11	27.2	1.8	29.0	+	+	31.0	2.4	+	+				3.2		+	11.4	18.6	22.2	+	+		+		+	+								+	+			+	m.
UM 12	28.4	3.0	31.8		+	34.8	+	+	+				+		1.4	4.0	6.6	27.8	1.6	+										+			+	+			+	m.
UM 13	27.4	3.0	31.4		+	34.4	1.6	+	+						+	5.2	8.4	24.8	4.4			+		+									+	+			+	m.
UM 14	23.6	2.4	30.2	+		32.6	+		1.0	+			+		+	7.2	10.2	30.6	3.0			+		+					+				+	+			+	c.
UM 15	21.4	3.4	27.4			30.8	1.6		+						+	2.8	4.6	29.8	12.6	+				+						+			+	+			+	f.
UM 16	20.8	4.2	31.0	+	+	35.2	+		+						+	9.0	9.8	20.6	12.8				–	+		+		+	+				+	+			+	f.
UM 17	24.2	4.4	27.0		+	31.4	+	+	+						+	9.0	9.8	29.2	5.0	+													+	+			+	m.
UM 18	27.2	1.2	30.8		+	32.0	1.4		+	+			+		+	9.0	11.2	26.6	2.4					+									+	+			+	f.
UM 19	20.4	4.6	40.6	+	+	45.6	8.6		1.2							7.2	17.0	14.4		+		+		+						+			1.6	+			2.6	m.
UM 20	26.0	2.0	30.6		+	32.6	4.2	1.4	1.0	+			2.4		+	10.4	20.2	18.2	2.8					+									+	+			+	c.
UM 21	27.4	2.6	39.6	+	+	42.2	3.0	+	+				1.0		+	5.0	10.0	20.0	+		+									+			+	+			+	m.
UM 22	25.0	2.8	26.0	+		28.8	1.4	+	+					+	+	8.8	12.0	13.0	21.2			+		+									+	+			+	c.
UM 23	30.4	2.6	28.0		+	30.6	3.0								+	6.0	9.0	25.6	4.4	+		+				+			+				+	+			+	f.
UM 24	21.6	4.2	37.2		+	41.4	2.0		+				+		+	4.8	7.6	23.4	5.6			+		+									+	+			+	f.
UM 25a	24.4	1.6	27.2	+	+	29.0	2.4		+						+	7.8	10.4	31.6	3.2	+		+								+			+	+			1.4	f.
UM 25b	17.8	1.8	25.6		+	27.4	+		+						+	6.2	7.2	21.4	24.8			+	+			+					+		1.0	+			1.4	f.

Igneous rock: granite, quartz-porphyry and basic volcanic rock.
Metamorphic rock: crystalline schist and gneiss.
Sedimentary rock: sandstone, mudstone, limestone and chert.
Others: aggregate of quartz crystals, aggregate of feldspar crystals and indeterminable grains.

Description of these rock fragments are given on the followings:

Granite. —It consists of large equidimensional minerals such as quartz, orthoclase, microcline and acid plagioclase. Biotite and muscovite are often accompanied.

Quartz-porphyry. —Rock fragments composed of groundmass and phenocrysts of quartz, orthoclase and acid plagioclase are recognized as quartz-porphyry. The groundmass is sometimes cryptocrystalline. Biotite also occurs both in the groundmass and as phenocryst.

Basic volcanic rock. —This is an aggregate of "lath-shaped" plagioclase crystals (less than 0.2 mm in length), which sometimes show flowage arrangement. Plagioclase is usually acid to intermediate. The spaces between the plagioclase crystals are filled with chlorite, calcite, dark-coloured glassy materials, iron opaques etc.

Crystalline schist. —Two types of crystalline schist fragments can be distinguished. One is quartz schist, which is composed mainly of quartz, often with albite, sericite, chlorite etc. Quartz is elongated with a zigzag outline and arranged with a subparallel orientation showing nearly same extinction position. The other is biotite schist, which consists of quartz, albite, biotite (reddish brown in general), with subordinate amounts of muscovite, apatite and opaque minearls.

Sandstone. —Quartzose sandstone, rich in quartz grain and siliceous matrix, is abundant.

Limestone. —Most of the limestone fragments is micrite.

Chert. —This is mainly composed of microcrystalline quartz and generally contains minute impurities.

In addition to the rock fragments mentioned above, there are other rock fragments such as aggregate of quartz crystals, aggregate of plagioclase crystals and indeterminable rock fragments with a microcrystalline or cryptocrystalline texture. Among them, aggregate of quartz crystals is most abundant in general, and sometimes attains to 30 percent among all the constituents. The aggregate of quartz crystals might be derived from various igneous and metamorphic rocks, and chert.

Matrix and cement Matrix and cementing material of sandstone are mainly clayey materials of dark brown colour under the microscope, but chlorite, sericite and calcite are detectable. Calcite is probably of detrital origin, fossil fragment and of secondary origin as a cementing material.

Calcite-cement is variable in its amount according to the sandstone specimen. Sandstone rich in fossil- and limestone-fragments contains usually much calcite-cement. The secondary outgrowth of quartz on detrital quartz grains is sometimes observed.

Other minerals (heavy minerals) Heavy minerals constitute a minor fraction. Heavy minerals in sandstone are zircon, garnet, titanite, allanite, epidote, zoisite (including clinozoisite), pumpellyite, tourmaline, hornblende, augite, apatite, glauconite, biotite, muscovite and iron opaques. From their occurrence, it can be said that they are detrital origin except glauconite and pyrite, which seem to be diagenetic origin for the most part. Titanite, epidote, biotite and muscovite are found in almost every sandstone specimen.

Biotite is brown to reddish brown, and generally abundant among the heavy minerals. Epidote and clinozoisite often form granular aggregate, sometimes with albite. Some of the clinozoisite aggregate resembles "saussurite".

3. Pattern of sandstone

Many classification schemes and nomenclatures of sandstone have been proposed (cfr. OKADA, 1968a, b; SHOJI, 1971). In the present paper, sandstone of the Sanchû Graben is examined on the basis of the OKADA's scheme (1971). There are two lithologic types of sandstone in the Sanchû Graben, namely, feldspathic sandstone and lithic sandstone. Each of the Cretaceous formations is characterized by predominance of either one of these sandstone types, i.e. the Ishidô Formation is characterized by the lithic, and the Sebayashi, the Lower Sanyama and the Upper Sanyama Formations by the feldspathic (Fig. 8).

Although the Sebayashi, the Lower Sanyama and the Upper Sanyama Formations are characterized by feldspathic sandstone, there are certain differences between the

Table 11. Summary of the composition of the sandstones

			Feldspar					Rock fragments														
		Average (%)																				
		Quartz	Orthoclase	Plagioclase	Microcline	Myrmeckite	Total	Granite	Quartz-porphyry	Basic volcanic rock	Crystalline schist	Gneiss	Sandstone	Mudstone	Limestone	Chert	Others	Total	Clay matrix	Calcite	Heavy minerals
Upper Sanyama F.	Northern subbelt																				
	All samples	21.3	2.7	33.0	•	•	35.3	11.2	•	4.7	•		•	•	•	•	8.0	21.0	13.1	5.2	3.5
	Med. gr.	19.8	3.6	34.0	•	•	37.8	2.7	•	•	•		•	•		1.3	6.5	11.7	20.2	8.0	2.6
	Middle subbelt																				
	All samples	24.7	2.4	26.3	•	•	28.8	1.8	•	3.9	•		•	•	•	•	7.0	10.7	23.2	6.6	•
	Med. gr.	26.1	3.1	32.1	•	•	35.2	2.0	•	•	•			•		•	6.4	10.3	22.6	5.0	•
Lower Sanyama F.	Northern subbelt																				
	All samples	28.0	3.5	27.2	•	•	30.9	6.1	•	1.0	•	•	•	•	•	3.2	11.4	22.6	12.1	5.5	1.0
	Med. gr.	26.0	3.6	26.4	•	•	30.3	6.7	•	1.1	•	•	•	•		3.7	12.9	25.4	11.6	6.0	•
	Middle subbelt																				
	All samples	22.3	2.8	34.6	•	•	37.4	3.5	•	•	•	•	•	•	•	1.1	7.8	13.9	17.7	7.9	•
	Med. gr.	21.2	2.7	36.3	•	•	39.0	2.9	•	•	•		•	•	•	•	7.5	12.3	15.9	10.6	•
Sebayashi F.	Northern subbelt																				
	All samples	30.5	2.7	33.4	•	•	36.2	1.4	•	•	•			•		2.2	7.1	11.2	16.3	4.9	•
	Med. gr.	30.7	2.4	32.8	•	•	35.3	1.3	•	•	•			•		1.7	7.3	10.7	14.9	7.8	•
	Middle subbelt																				
	All samples	21.6	2.7	36.2	•	•	38.9	2.2	•	•	•			•	•	•	6.7	10.5	19.1	9.0	1.0
	Med. gr.	21.5	2.3	38.2	•	•	40.5	1.8	•	•	•			•	•	•	6.0	9.3	18.3	9.5	•
Ishidô F.	Northern subbelt																				
	All samples	18.9	2.0	16.4	•	•	18.5	•	•	•	•		•	•		12.2	14.5	28.0	26.6	7.4	•
	Med. gr.	19.4	2.2	18.1	•	•	20.5	•		•			•	•	•	12.6	10.4	24.2	27.7	7.9	•
	Middle subbelt																				
	All samples	11.6	1.0	9.8		•	10.3	•	•	•	•		•	•		24.3	15.6	43.2	12.1	23.3	•
	Med. gr.	13.0	1.1	11.0		•	12.1	1.0	•	•	•		•	•	•	23.1	15.6	40.8	13.2	20.8	•
	Southern subbelt																				
	All samples	22.5	2.8	13.4	•	•	16.3	1.1	•	•	•			•		20.0	12.1	33.8	24.1	2.9	•
	Med. gr.	22.1	2.3	11.0	•	•	13.4	1.2	•	1.4				•		26.5	12.7	41.9	20.9	1.2	•

•: <1% Med. gr: Medium-grained sandstone

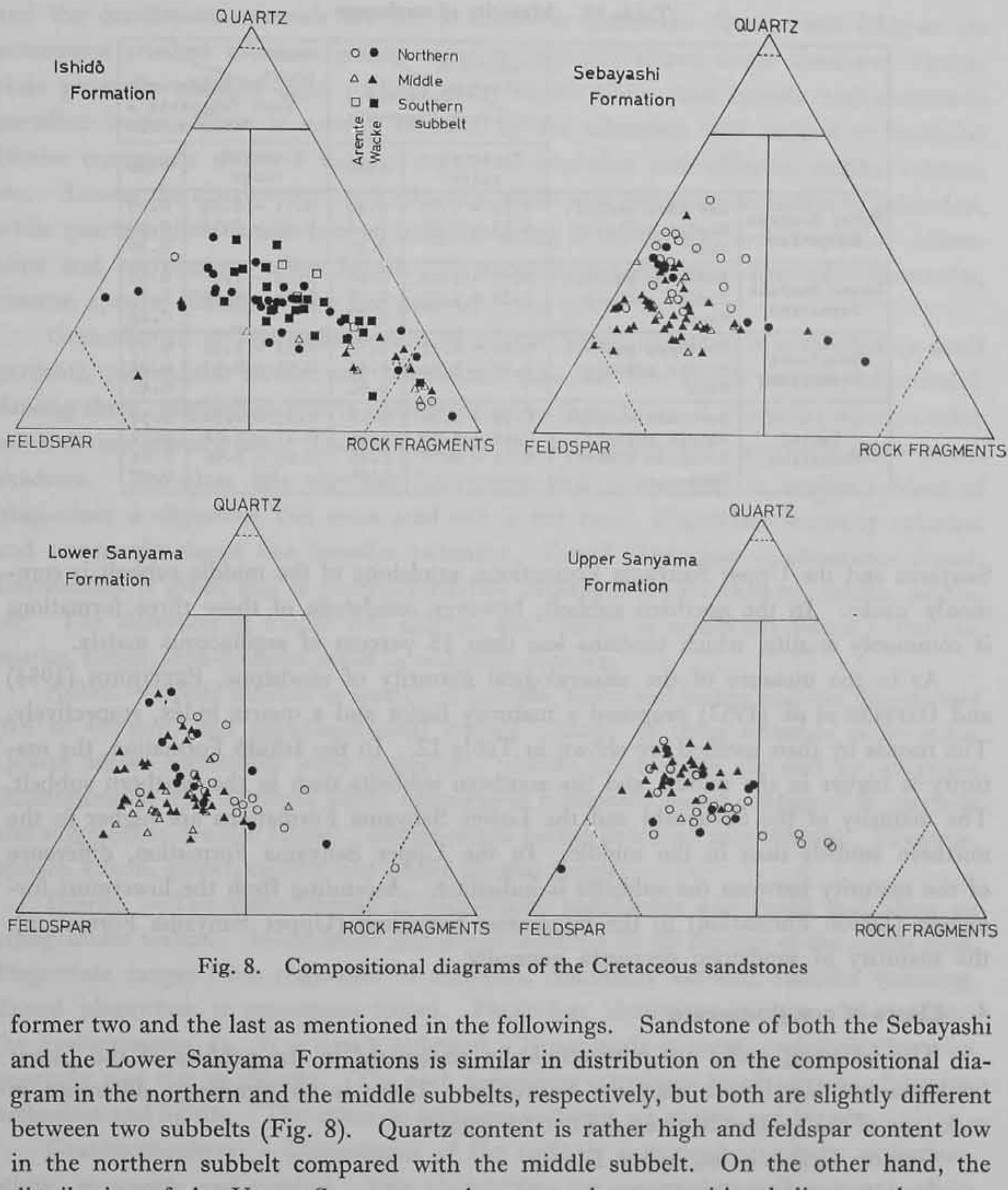

Fig. 8. Compositional diagrams of the Cretaceous sandstones

former two and the last as mentioned in the followings. Sandstone of both the Sebayashi and the Lower Sanyama Formations is similar in distribution on the compositional diagram in the northern and the middle subbelts, respectively, but both are slightly different between two subbelts (Fig. 8). Quartz content is rather high and feldspar content low in the northern subbelt compared with the middle subbelt. On the other hand, the distribution of the Upper Sanyama sandstone on the compositional diagram shows no distinct difference between the northern and the middle subbelt. In addition, sandstone of the Upper Sanyama Formation has a more limited distribution on the compositional diagram than that of the Sebayashi and the Lower Sanyama Formations.

A considerable amount of clay matrix is generally contained in sandstone. Therefore, more than half of the sandstone specimens is classified as wacke, which is impure sandstone containing more than 15 percent of argillaceous matrix. Especially, sandstone of the Ishidô Formation is mostly wacke. Also in the cases of the Sebayashi, the Lower

Table 12. Maturity of sandstone

		(Quartz + Chert) / (Feldspar + Rock fragments)		(Quartz + Chert) / (Feldspar + Rock fragments + Clay matrix)	
		Observed range	Mean	Observed range	Mean
Upper Sanyama Formation	Northern subbelt	0.14 - 0.80	0.40	0.11 - 0.63	0.33
	Middle subbelt	0.33 - 0.83	0.58	0.27 - 0.56	0.38
	Mean		0.49		0.36
Lower Sanyama Formation	Northern subbelt	0.31 - 1.42	0.66	0.22 - 1.08	0.53
	Middle subbelt	0.26 - 1.21	0.50	0.21 - 0.56	0.35
	Mean		0.58		0.44
Sebayashi Formation	Northern subbelt	0.41 - 1.42	0.75	0.22 - 1.40	0.58
	Middle subbelt	0.25 - 1.24	0.47	0.19 - 0.87	0.34
	Mean		0.61		0.46
Ishidô Formation	Northern subbelt	0.44 - 1.70	0.96	0.27 - 0.89	0.52
	Middle subbelt	0.42 - 2.00	1.31	0.37 - 1.34	0.89
	Southern subbelt	0.43 - 2.80	1.48	0.20 - 1.66	0.84
	Mean		1.25		0.75

Sanyama and the Upper Sanyama Formations, sandstone of the middle subbelt is commonly wacke. In the northern subbelt, however, sandstone of these three formations is commonly arenite, which contains less than 15 percent of argillaceous matrix.

As to the measure of the mineralogical maturity of sandstone, PETTIJOHN (1954) and DAPPLES *et al.* (1953) proposed a maturity factor and a quartz index, respectively. The results by their method are shown in Table 12. In the Ishidô Formation, the maturity is higher in the middle and the southern subbelts than in the northern subbelt. The maturity of the Sebayashi and the Lower Sanyama Formations are higher in the northern subbelt than in the middle. In the Upper Sanyama Formation, difference of the maturity between the subbelts is indistinct. Ascending from the lowermost formation (Ishidô Formation) to the uppermost formation (Upper Sanyama Formation), the maturity of sandstone decreases generally.

4. Clasts of conglomerate

The following rocks are microscopically recognized in the pebbles of the Lower Sanyama and the Upper Sanyama Formation. There is no significant difference in rock-type of the pebbles between the two formations.

Granite, Granodiorite, Aplite, Diorite.

Granite-porphyry, Porphyrite.

Andesite, Basalt, Acid tuff, "Schalstein".

Hornfels, Biotite schist, Gneiss.

Sandstone, Slate (and Shale), Limestone, Chert.

On the following lines, the petrographic description will be given for the pebble-rocks other than the sedimentary rocks.

Granite. —The main constituents are quartz (20–30 percent), orthoclase (up to 20 percent), albite, and biotite (about 10 percent). The rocks show equigranular texture and the constituent minerals are 0.5 to 2 mm in diameter. Quartz and feldspar are sometimes crushed to small grains. Quartz generally shows strain shadows. Orthoclase generally remains clear. Albite often shows albite twin lamella and sometimes pericline twin. Albite is usually clouded by the alteration into sericite or kaolinite. Biotite commonly shows a various degree of alteration into chlorite, calcite, epidote, etc. Among the above-mentioned minerals, albite and biotite are euhedral to subhedral, while quartz and orthoclase take an irregular shape in occupying the interspaces. Microcline and perthite are often found. Myrmeckite is sometimes detected. Muscovite, titanite, apatite, allanite, zircon and iron-ore occur too.

Granodiorite. —The rocks consist of quartz (about 10 percent), orthoclase (a small percent), plagioclase, biotite and hornblende (the last two 10–15 percent collectively). Among them, plagioclase attains sometimes more than 3 mm in diameter, whereas other minerals are about 1 mm. Quartz occupies the interspaces and commonly shows strain shadows. Orthoclase fills also the interspaces and is irregular in outline. Most of plagioclase is oligoclase, but more acid one is not rare. Plagioclase is nearly euhedral and commonly shows fine lamellar twinning. Zoned plagioclase is sometimes found. Hornblende is green and is generally heavily decomposed into chlorite, calcite, zoisite, etc. The alteration of biotite into chlorite and epidote is commonly found. Titanite, apatite, zircon, iron-opaques occur as accessory minerals.

Aplite. —Aplite consists of quartz, orthoclase, albite and biotite and has fine-grained (0.1 to 0.9 mm) and equidimensional texture. Shape of these minerals is irregular. Quartz shows sometimes wavy extinction. Albite is generally clouded by alteration (kaolinitization ?). Multiple albite twinning is commonly found. Microcline, perthite and myrmeckite are also found. Biotite shows partial alteration into chlorite. Mscovite, apatite, zircon, garnet, epidote and zoisite are also found.

Diorite. —The rocks consist of plagioclase, hornblende and augite and show an equigranular texture. Hornblende and augite make up 20–30 percent of the whole rock. Plagioclase ranges from oligoclase to andesine, commonly showing lamellar twinning. Zoned plagioclase is sometimes found. Plagioclase shows generally a turbid aspect (by kaolinitization ?). It is nearly euhedral. Hornblende is green, and their alteration generally give rise to chlorite. The rock sometimes contains a small amount of quartz, orthoclase and biotite. The common accessory minerals are apatite and titanite.

Granite-porphyry. —Groundmass of the rocks is composed of quartz, orthoclase, albite, muscovite and epidote. The phenocrysts are quartz (a small percent), albite (more than 20 percent) and biotite (a small percent). The size of the minerals is 0.1 to 0.2 mm for the groundmass, and 0.5 to 2.0 mm for the phenocryst. Quartz phenocryst is ill-shaped in general and is sometimes corroded. Quartz phenocrysts composed of two or three grains are sometimes found. Albite is almost idiomorphic. Albite with albite-lamellation and with a zonal structure is commonly found. Alteration of feldspar is common. Biotite is altered into chlorite to a considerable extent. Microcline, myrmeckite, muscovite, zircon, allanite, titanite and iron-ore also occur.

Porphyrite. —The rocks have phenocrysts of quartz (a small percent), plagioclase (30 percent) and hornblend (30 percent). Phenocryst is about 2 mm in diameter. Quartz has a roughly bipyramidal habit. The plagioclase phenocryst is euhedral and oligoclase. Plagioclase is somewhat altered and clouded (kaolinitization ?). Hornblende is completely altered into chlorite, calcite and epidote, but in many cases retains its original outline. Groundmass of the rocks consists of quartz and albite. The accessory constituents are apatite, zoisite, muscovite, biotite and titanite.

Andesite. —The phenocrysts of the rocks are plagioclase (a small percent) and hornblende (15–20 percent). The plagioclase phenocryst is 0.5 to 2.5 mm in diameter. Plagioclase is andesine, and commonly shows a zonal structure and fine lamellar twinning. The hornblende phenocryst is somewhat larger than plagioclase, and measures 1.0 to 3.0 mm in diameter. Groundmass consists essentially of lath-shaped plagioclase, about 1 mm long, and is accompanied with chlorite, epidote and sometimes quartz. The rocks are commonly accompanied with calcite vein.

Basalt. —The rocks are aphyric and chiefly composed of lath-shaped plagioclase. Plagioclase is oligoclase, strongly altered, and its outer margin is not clear. Epidote, chlorite and iron-ore are also found. Some of these minerals may be the decomposition product of augite.

Acid-tuff. —The rock is generally "porphyritic", and abundant with quartz. Megaclast is composed of quartz, feldspar and lithic fragments. Their size is variable, but the crystal fragments attain 1 mm in diameter, and the lithic ones 8 mm. Quartz grains are often corroded. Feldspar is in many cases albite, but in some cases K-feldspar. The lithic fragments seem to be acid volcanic rock. The constituent minerals of the matrix are often difficult to determine, owing to their very small size, but may be largely quartz, albite, muscovite, chlorite and epidote.

"Schalstein". —The rocks consist mainly of chlorite, epidote, albite and calcite, varying in their size and proportion, but the original texture is not clear. Some rock is composed mainly of fine-grained chlorite, with prehnite and fine net of pumpellyite vein.

Hornfels. —The rocks consist of quartz, albite and mucovite, and have a mosaic texture. The mineral grains are generally 0.03 to 0.2 mm in diameter, but sometimes attain more than 0.5 mm.

Biotite schist. —Only one specimen is found. The main constituents of the rock are quartz, plagioclase, muscovite and biotite. Quartz, plagioclase and biotite grains measure 0.05 to 0.1 mm in diameter, and show preferred orientation. Biotite and muscovite occupy about 30 percent and they are nearly equal in abundance. Biotite shows yellowish brown to reddish brown colour and tend to concentrate in thin bands or in lenses. Muscovite grain sometimes attains to 1 mm or more in diameter, and shows a poikiloblastic texture. Quartz shows generally wavy extinction. Plagioclase is oligoclase. Garnet is sometimes found as aggregate, 0.5 to 1.5 cm in diameter, in which individual garnet grain measures 0.1 to 0.6 mm. Apatite is found as an accessory mineral.

Gneiss. —The rocks consist of quartz and plagioclase, ranging from 0.1 to 0.5 mm, and subordinate amount of biotite (less than 10 percent). These minerals show preferred orientation, resulting in a banded structure. The boundary of these mineral grains usually is not smooth and is often sutured. Wavy extinction is commonly seen in quartz. Plagioclase is oligoclase and generally clouded (kaolinitization ?). Myrmeckite is commonly found. K-feldspar is sometimes found. Biotite is somewhat chloritized. Zircon and iron-ore occur as accessory minerals.

V. Sedimentation

1. Current system

Current marks, such as ripple mark, flute cast, prod cast, groove cast, bounce cast and frondescent mark, have been reported from the sandstone of this region except for the Ishidô Formation, and paleocurrent system has been discussed (ARAI *et al.*, 1958; TAKEI, 1962; ARAI and NAGANUMA, 1975; SAKA and KOIZUMI, 1977). Sole marks are mainly found in the middle subbelt of the Sanchû Graben, but sometimes also in the northern subbelt. The writer reexamined stratigraphic position of the already-reported current marks, and the data, with some additions, are illustrated in Fig. 9.

In the northern subbelt, current data is too little to discuss directional tendency of flow. However, in the Sebayashi and the Lower Sanyama Formations, current from N to S, indicated by current ripples, may be related to the lateral supply.

In the middle subbelt, three flow patterns, from SE to NW, from NE to SW, and from SW to NE, are generally recognized. The pattern from SE to NW is longitudinal flow, and seems to be main flow during Cretaceous time. Flow from NE to SW is sporadically found both in the Lower Sanyama Formation and the Upper Sanyama Formation. This flow is a lateral current and possibly reflects lateral supply of sediment, which is in harmony with general abundance of conglomerate and/or sandstone in the northern subbelt. Flow from SW to NE is another lateral current, found almost exclusively in the Upper Sanyama Formation. In the Upper Sanyama Formation, this flow pattern is mainly found in the eastern part of this region. Toward the east, sandstone increases in abundance in the Upper Sanyama Formation. Then, there is a view that the land existed to the south of the Sanchû Graben in the Sanyama epoch (SAKA and KOIZUMI, 1977). However, the southern provenance in this epoch, as will be mentioned later in this chapter, cannot be affirmed from the petrographic study of clastics.

2. Provenance

Source rocks of the Cretaceous sediments can be inferred from the major constituents and heavy minerals of the sandstone, as well as from pebbles of the conglomerate. Although the various kinds of rocks constituted the provenance, they can be grouped into five classes, i.e. sedimentary rocks, crystalline schist, gneiss, granitic rocks and volcanic rocks. The detrital material constituting the sandstone is similar in all of the

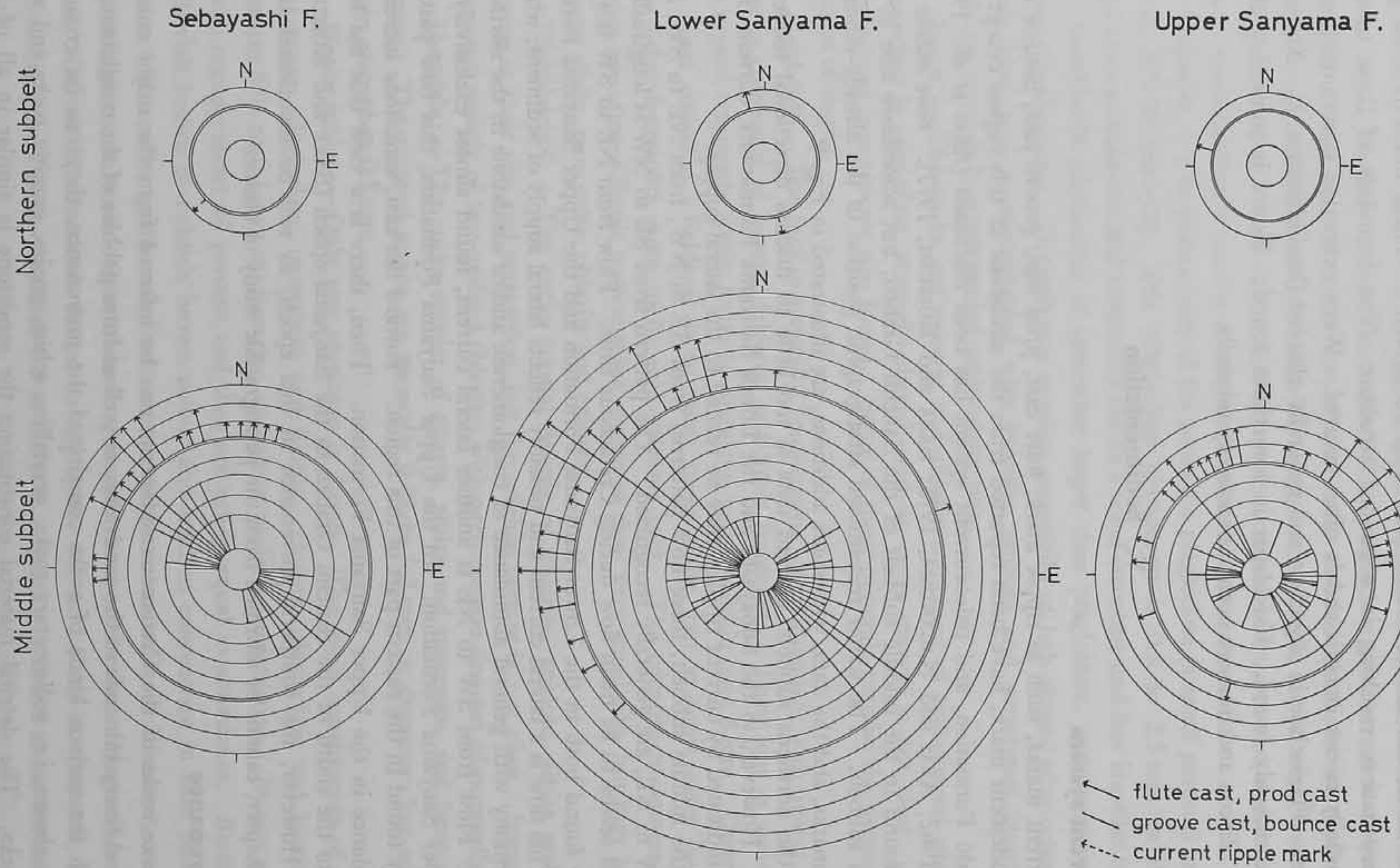

Fig. 9. Paleocurrent system of the Cretaceous formations

Table 13. Correlation between clastic materials of the Cretaceous formations and source regions

Source region	Source rocks	Pebbles	Sand-grains	
			Rock fragments	Heavy minerals
Terrain of late Mesozoic volcanism	acid volcanic rocks and tuffs	granite-porphyry, acid tuff	quartz-porphyry	zircon, biotite, muscovite
Ryoke terrain	granitic rocks	granite, granodiorite, aplite	granite	zircon, garnet, allanite, hornblende, apatite, biotite, muscovite
	biotite schist and gneiss	biotite schist, gneiss	biotite schist, gneiss	garnet, biotite, muscovite
Sanbagawa terrain	crystalline schists (without biotite schist)		quartz schist	epidote, zoisite, pumpellyite, chlorite, prehnite
	intermediate and basic volcanic rocks, and tuffs	andesite, "schalstein"	basic volcanic rocks	augite, hornblende
Chichibu terrain	sedimentary rocks	sandstone, slate, limestone, chert	sandstone, slate, limestone, chert	

Cretaceous sandstones. Rock fragments and heavy minerals in the sandstone are similar in kinds to those of the pebbles in the conglomerates. Table 13 shows the general summary of the constituents of the sandstone, the kinds of the pebbles of the conglomerates and the inferred source rocks.

Although the kinds of rocks constituting the provenance are similar during Cretaceous time, the predominant rock types vary from time to time (Tables 1 and 11). Older sedimentary rock terrain was probably a primary source in the Ishidô epoch. In the next Sebayashi epoch, detritus from the crystalline schist and granitic rock terrains increased in amount. Lastly, in the Lower Sanyama and the Upper Sanyama epochs, detritus was abundantly supplied from the granitic rock terrain.

As the conglomerate and sandstone contain fragments of rocks and minerals which are less durable for chemical and mechanical weathering, these fragments probably had been transported for not a long distance. Considering the paleogeographic features in Cretaceous time, sediments might be largely supplied from the land of the northern side. It is accordingly conceivable that many of the pebbles of granitic rocks, metamorphic rocks and acid pyroclastics were originated from the terrain belonging to the Inner side of Southwest Japan, which seems to have existed on the north of the Kantô Mountains at those times (TAKEI, 1975). A possible relation between the source region and the source rocks is shown in Table 13.

Granite-porphyry and acid pyroclastics can be seen in the pebbels of the conglomerate of both the Lower Sanyama Formation and the Upper Sanyama Formation. Many of these rocks are similar in texture and composition to the latest Mesozoic acid volcanic product in the Inner side of Southwest Japan. A representative of these volcanic products is the Nôhi rhyolites in the Chûbu district, which are mainly composed of rhyolitic or rhyodacitic welded tuff and granite-porphyry (e.g. KAWADA, 1971; YAMADA *et al.*, 1971), and are considered to be Miyakoan to Hetonaian in geologic age (KOIDO, 1975; YAMADA, 1977; SEKI, 1978). In the Shimonita and the Yorii districts, the northern marginal part of the Kantô Mountains, there are other volcanic products of the latest Mesozoic age (ARAI *et al.*, 1966; KOKATSU *et al.*, 1970). Their geologic age is said to be Hetonaian from the structural relation to the surrounding clastic sediments. In these districts of the Kantô Mountains, acid tuff and granite-porphyry of Gyliakian or older age have not yet been known. It is likely, however, that acid tuff and granite-porphyry of the Gyliakian and older age, some of them possibly being associated with the Older Ryôke granitic rocks, might have been opened to erosion in the north of the Kanto Mountains at the Gyliakian epoch. Rocks comparable to the Ryôke granitic rocks are recently reported in the Hiki district for the first time (HIKI HILLS RESEARCH GROUP, 1982). Furthermore, there is another possibility that volcanic products in the supposed paleo-Ryôke terrain (ICHIKAWA, 1970) were present in the north of the Kantô Mountains. In connection with these problems, it must be noted that the fragments of quartz-porphyry are ubiqitously found in the sandstone of all the Cretaceous formations of the Sanchû area. Although some of these rock fragments was perhaps derived from the latest Mesozoic volcanic products to the north of the Kantô Mountains, exact provenance of all these rock fragments remains for future study.

Granitic rocks, biotite schist and gneiss are commonly found in the Ryôke Belt of Southwest Japan (cfr. TANAKA and NOZAWA, 1977). Recently, the eastern extension of the Ryôke Belt was confirmed in the northern margin of the Kantô Mountains (TAKEI, 1982). Biotite schist found as pebbles of the Lower Sanyama Formation is similar in petrographic character to biotite schist of the Ryôke Belt (TAKEI, 1975). Some of the pebbles of the granitic rocks are, according to KANO (1969, 1970), supposed to have been derived from the Ryôke granites, on the basis of their chemical composition. The geologic age of the Ryôke metamorphic rocks and granites has not yet been confirmed. However, the Ryôke metamorphic rocks and the Older ("pre-Nôhi") Ryôke granites are supposed to be early Cretaceous in age (HAYAMA and YAMADA, 1980). It is therefore natural to presume that the pebbles of granitic rocks, biotite schist and gneiss of both the Lower Sanyama Formation and the Upper Sanyama Formation were mainly derived from the Ryôke Belt (TAKEI, 1975). In the sandstone, on the other hand, fragments of granite and biotite schist are ubiquitously found for all the Cretaceous formations. If these rock fragments were also derived from the Ryôke Belt, the Ryôke Belt might have been formed before the deposition of the Ishidô Formation (Aridan). Another possibility is that they were derived from the paleo-Ryôke terrain, which was supposed to have been present between the Ryôke and the Sanbagawa terrains in pre-Cretaceous time (ICHIKAWA, 1970).

The rock fragments and mineral grains which seem to have been derived from the crystalline schist terrain, are those found generally in crystalline schist of prehnite-pumpellyite-meta-greywacke facies, greenschist facies and glaucophane schist facies (SEKI, 1961; BARTH, 1962; MIYASHIRO, 1965; HASHIMOTO, 1966). In the Kantô Mountains, these minerals and rocks of crystalline schist origin are commonly found in the Sanbagawa metamorphic terrain (SEKI, 1958; TORIUMI, 1975). Some of these minerals and rocks are found also in the northern subbelt of the Chichibu terrain. These minerals and rock fragments are supposed to have been derived mainly from the Sanbagawa terrain.

There are many petrographic similarities between the pre-Cretaceous sedimentary rocks of the Chichibu terrain and fragments of sedimentary rocks in the Cretaceous conglomerate and sandstone. Limestone pebbles containing fusulinid foraminifera have been found in the Ishidô Formation (TAKEI, 1963, 1969). It can be said without doubt that the pre-Cretaceous sedimentary rock terrain of the Chichibu Belt supplied a large amount of material to the Cretaceous sedimentary basin.

3. Depositional environment

Cretaceous sediments of this area seem to be deposited in the elongated basin, trending approximately parallel to the Sanchû Graben. From the foregoing descriptions, it can be said generally that sediments of the northern subbelt, as well as of the southern subbelt, are abundant in coarser grained clastics than those of the middle subbelt. As judged from the directional sole marks, mainly found in the middle subbelt, longitudinal current from SE to NW is conspicuous. Lateral current from NE to SW, and from SW to NE, also indicated from the sole marks of the middle subbelt, suggests paleoslope from both the northern side and the southern side to the axial part of the basin. Sediments of the northern and the southern subbelts often yield brackish molluscan fossils and sometimes well-preserved fossil plant leaves, whereas sediments of the middle subbelt contain only marine fossils except for small-sized fragments of plant. From these facts, sediments of the northern and the southern subbelts can be considered generally as deposits near to shore, compared with those of the middle subbelt. Accordingly, it is certain that there was land area to the north of the Cretaceous marine basin of the Sanchû Graben. To the south of this Cretaceous basin another land existed in the Ishidô epoch. In the succeeding Sebayashi and Sanyama epochs, however, an existence of the southern land cannot be positively ascertained from the petrographic study, though it is advocated from the paleocurrent data in the Sanyama epoch (SAKA and KOIZUMI, 1977).

Ishidô Formation As mentioned already, the very fine-grained sandstone, the the main constituent of the Ishidô Formation of the northern subbelt, is muddy and massive with sporadic occurrence of laminae and contains abundant marine molluscan fossils at places. It often offers *Lopha* and *Pterotrigonia*, which seem to have lived in a neritic environment. It seems that primary sedimentary structures were practically destroyed by organic activity. There is no signs of mass gravity flow. From the above, main part of the Ishidô Formation of the northern subbelt seems to be nearshore deposits.

As to the Ishidô Formation of the southern subbelt, lithology and fossils contained have resemblance to the northern subbelt. Then, the depositional environment seems to be similar for both the northern and the southern subbelts.

The Ishidô Formation of the middle subbelt is mainly composed of massive mudstone with occasional occurrence of parallel laminae. "*Propeamussium*" (=*Parvamussium* ?) was obtained from this mudstone. According to TAMURA (1979, 1980), the *Inoceramus-Parvamussium* assemblage in Cretaceous strata of Japan occurs in black shale facies and can be assigned to "deep sea offshore" fauna. Recent species of *Propeamussium*, *Parvamussium* and related genera are said to live generally in several hundreds meters depth of water (HABE, 1977). From the lithological and paleobiological features mentioned above, it can be said that the Ishidô Formation of the middle subbelt is sediments of deeper water than wave base, probably of offshore environment. Calcareous, medium- to coarse-grained sandstone, containing fossil fragments of pelecypods, gastropods, calcareous algae, *Orbitolina*, etc., is sometimes intercalated in the mudstone, mostly in the lower part of the Ishidô Formation. This sandstone is not well sorted, and shows lenticular occurrence. It may be said that this sandstone was brought into the environment below the wave base, by storm wave or mass gravity flow.

Sebayashi Formation In the northern subbelt, the Sebayashi Formation mainly consists of medium-grained sandstone with small amount of clay matrix. Low angle planar cross-lamination often occurs. Ripple marks formed by current from north to south sometimes occur, in which linguoidal ripples were reported (ARAI *et al.*, 1958; TAKEI, 1962). Linguoidal ripple is formed in a very shallow water, several centimeters depth (ARAI *et al.*, 1958) and have been found on the sand banks of estuaries and in tidal efflux channels (cfr. ALLEN, 1968). The mudstone, intercalated in the sandstone, sometimes yields *Tetoria*, occurring often as cluster. Well-preserved plant fragments are found sometimes also in the mudstone. From the above, it is assumed that the sediments of the northern subbelt is of littoral to lagoonal environment.

In the middle subbelt, "*Propeamussium*" (=*Parvamussium* ?), which seem to have lived in a deep water as mentioned above, is found in the mudstone intercalated in the sandstone. The sandstone generally shows graded bedding, sometimes with Bouma sequence. On the upper surface of sandstone, ripple mark, with parallel ridge, is found only in rare cases. Therefore, sediments of the middle subbelt is generally of deep water environments, strongly affected by mass gravity transport from SE to NW.

Lower Sanyama Formation The Lower Sanyama Formation is represented by alternating beds of mudstone and very fine-grained sandstone. In the mudstone commonly occurs horizontal parallel-lamination, and sometimes low angle planar cross-lamination. In the sandstone occur cross-lamination and/or convolute lamination. Coarse-grained sandstone, generally showing graded bedding and frequently with current marks on its lower surface, and conglomerate are often present in the lower part of the Lower Sanyama Formation. Except that the ratio of the coarse-grained sandstone and conglomerate in this formation is higher in the northern than in the southern subbelt, there is no distinct difference in lithology between the two subbelts. Fragments of molluscan shells, such as *Ostrea*, are sometimes found in the conglomerate of the northern subbelt. The mudstone, however, affords no fossils indicative of environment.

Although additional data are needed, there is a possibility that the sediments of the Lower Sanyama Formation is of nearshore to offshore environment. Generally speaking, the Lower Sanyama Formation is the sediments of deeper water than the Sebayashi Formation.

Upper Sanyama Formation The Upper Sanyama Formation generally consists of black mudstone with sporadic occurrence of horizontal parallel-lamination. Basal part of this formation is represented by the coarse-grained sandstone showing generally graded bedding and with well developed current marks on its lower surface. The northern and the middle subbelts are similar in lithofacies. From the mudstone, *Solemya* and *Parvamussium* were collected in the northern subbelt, and *Inoceramus* was collected in the middle subbelt. They seem to correspond to the *Inoceramus-Parvamussium* assemblage, "deep sea offshore" fauna of the Japanese Cretaceous (Tamura, 1979, 1980). Hence, it is likely that the main part of the Upper Sanyama Formation is mostly deposited in a deep water environment. It should also be noticed that the deep water environment prevailed not only in the middle subbelt, but also in the northern subbelt in the Upper Sanyama epoch, differing from all of the other foregoing epochs.

4. Sedimentation and tectonics

The writer already prepared isopach maps of each Cretaceous formation in the eastern half of the Sanchû Graben (Takei, 1964, 1980). The isopach maps used in the present paper (Figs. 10–13) cover not only the eastern half (with revision) but also the western half of the Sanchû Graben.

The Cretaceous strata of the Sanchû Graben show complicated geological structure owing to the folding and faulting of later age, so that there is some difficulty in restoring the original Cretaceous sedimentary basin of the Sanchû Graben. In the previous works, the writer prepared the isopach maps, regardless of the lateral shortening of the strata by folding movement. In the present paper, however, an attempt is made to restore an extent of the depositional basin. It is assumed that the Cretaceous strata generally have been laterally compressed to about half in width of the original depositional area. Horizontal displacement of about 1.5 km, along the fault of NS-trend running near Kagikake, in the western part of the Sanchû Graben is also restored.

In the isopach maps, several strongly subsiding areas can be recognized in this Cretaceous basin. They are designated as depression in the present paper. For the Ishidô epoch, there are four depressions. They are called from the western to the eastern ones, the Barakuchi, the Otomo, the Myôke and the Osamiya depressions. Each of these depressions shows oval outline, with their long axis of 6–8 km, and short axis of 2–4 km. These depressions arrange *en echelon* in right-hand. Amount of subsidence of each depression tends to become larger one after another, from the Myôke depression toward

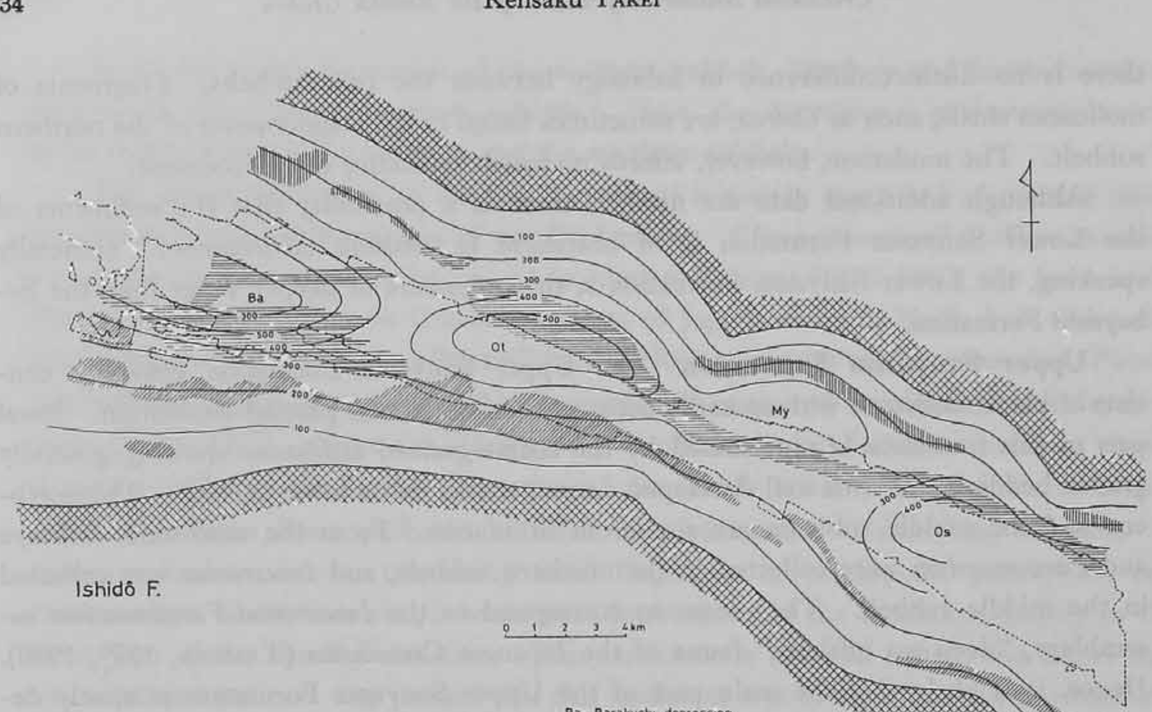

Fig. 10. Isopach map (1): Ishido Formation (Assumed amount of lateral shortning (50%) is reconstructed. Explanation is same in all the isopach maps.)

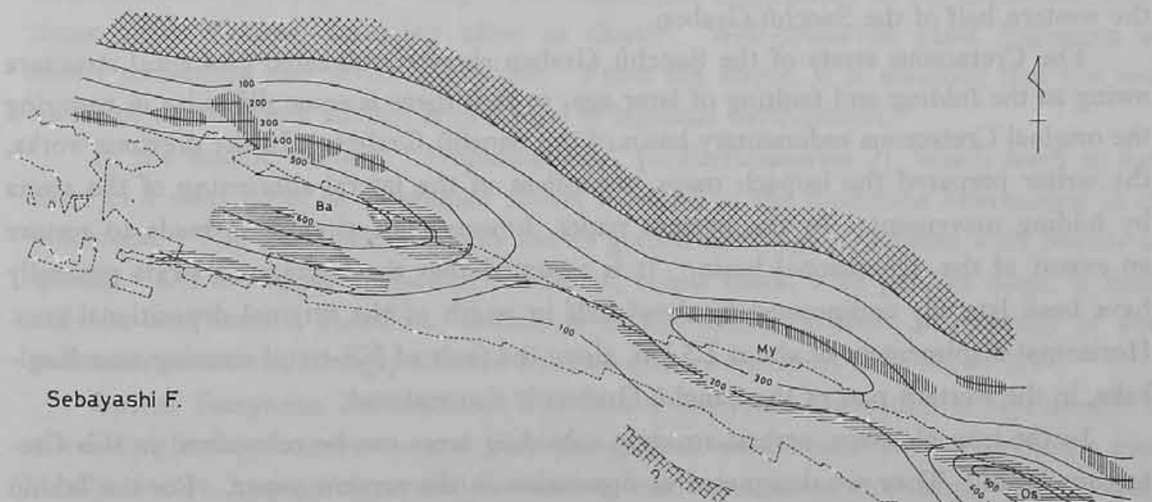

Fig. 11. Isopach map (2): Sebayashi Formation (ibid.)

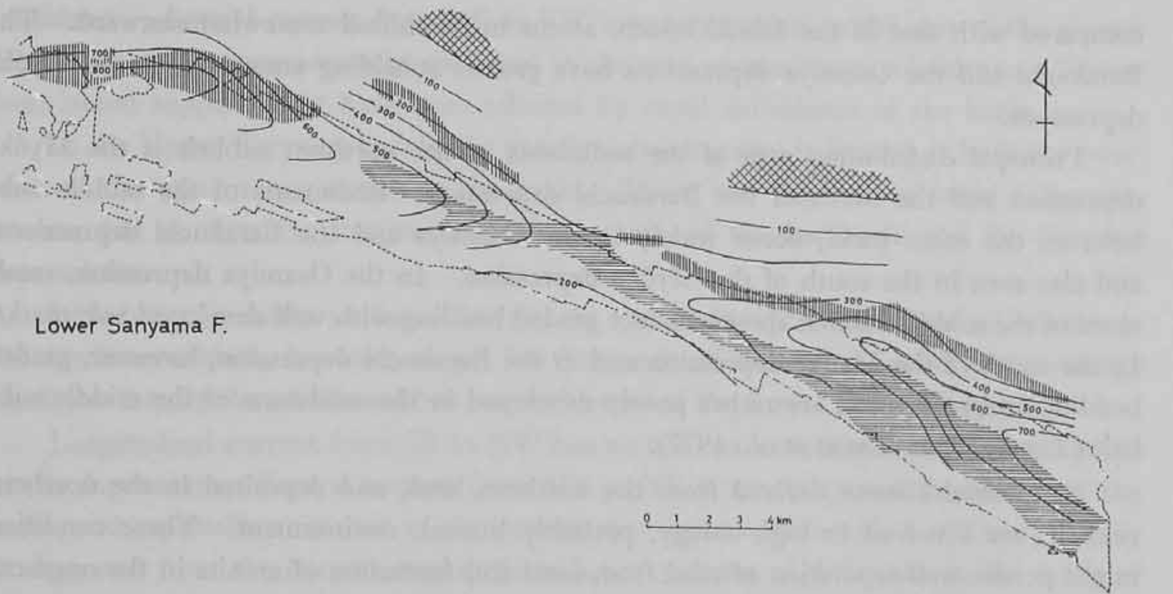

Fig. 12. Isopach map (3): Lower Sanyama Formation (ibid.)

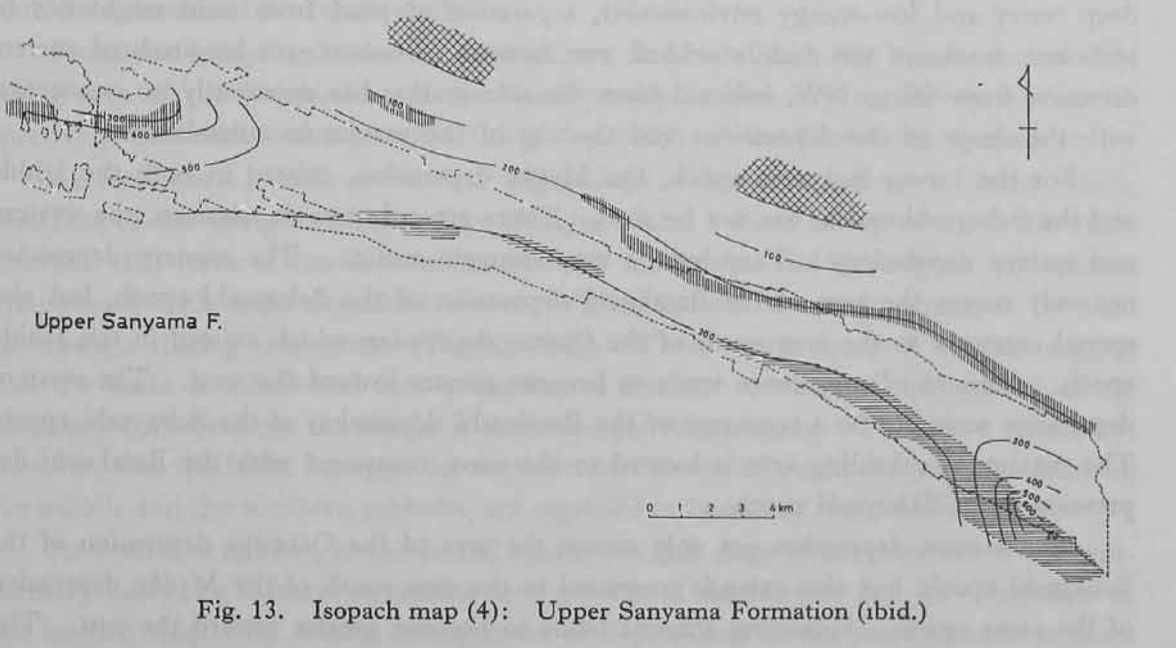

Fig. 13. Isopach map (4): Upper Sanyama Formation (ibid.)

both the western and eastern depressions.

Sediments of the middle subbelt extend along the axial part of the basin, and cover large area of each depression, while sediments of the northern and the southern subbelts mainly occupy respectively northern and southern marginal part of each depression. Accordingly, deep water area of the basin coincides with a zone connecting the central part of each depression. Sandstone of the Ishidô Formation is formed generally in the low-energy environment, being represented by wacke. There is no definite relation between matrix content of sandstone and depositional site within the basin.

In the Sebayashi epoch, three depressions can be recognized. The Otomo depression existed in the Ishidô epoch is no more seen. The center of the Barakuchi depression, compared with that of the Ishidô epoch, seems to be shifted somewhat eastward. The Barakuchi and the Osamiya depressions have greater subsiding amount than the Myôke depression.

Principal distribution area of the sediments of the northern subbelt is the Myôke depression and the north of the Barakuchi depression. Sediments of the middle subbelt, on the other hand, occur widely in the Osamiya and the Barakuchi depressions, and also seen in the south of the Myôke depression. In the Osamiya depression, sandstone of the middle subbelt shows distinct graded bedding with well developed sole marks. In the south of the Myôke depression and in the Barakuchi depression, however, graded bedding and sole marks are rather poorly developed in the sandstone of the middle subbelt (TAKEI, 1964; TAKEI *et al.*, 1977).

Sand-sized clastics derived from the northern land, and deposited in the northern subbelt, are involved in high-energy, probably littoral, environment. These condition might permit well separation of mud from sand and formation of arenite in the northern subbelt. On the contrary, in the Barakuchi and the Osamiya depressions, owing to deep water and low-energy environment, separation of mud from sand might not be sufficient, wacke of the middle subbelt was formed. Predominant longitudinal current direction from SE to NW, inferred from the sole marks, has apparently no connection with the shape of the depressions and the site of the maximum subsidence.

For the Lowei Sanyama epoch, the Myôke depression, existed in both the Ishidô and the Sebayashi epoch, can not be seen. There are only two depressions, the western and eastern depressions. They have a very elongate outline. The western depression not only covers the area of the Barakuchi depression of the Sebayashi epoch, but also spread eastward to the area south of the Otomo depression which existed in the Ishidô epoch. Amount of subsidence tends to become greater toward the west. The western depression seems to be a successor of the Barakuchi depression of the Sebayashi epoch. The maximum subsiding area is located to the west, compared with the Barakuchi depression of the Sebayashi epoch.

The eastern depression not only covers the area of the Osamiya depression of the Sebayashi epoch, but also extends westward to the area south of the Myôke depression of the same epoch. Subsiding amount tends to become greater toward the east. The eastern depression seems to be a successor of the Osamiya depression of the Sebayashi epoch. The subsiding area is extended to the west, compared with the Osamiya depression of the Sebayashi epoch.

Both of the eastern and the western depressions are filled with sediments of the northern and the middle subbelts. Sediments of the northern subbelt occupy in the area nearer to the basin-margin, than that of the middle subbelt. Predominance of arenite in the northern subbelt might be resulted from deposition under higher-energy condition than in the middle subbelt.

Longitudinal current from SE to NW are subparallel to the axes of the western and the eastern depressions, but has no peculiar connection with the site of maximum subsidence. Lateral current from NE to SW is nearly normal to the axis of the eastern depression and is approximately restricted in the area of maximum subsidence. Therefore, lateral supply might have been affected by rapid subsidence of the basin.

In the Upper Sanyama epoch, the greatly subsiding area is located at both the western and the eastern extremities of the basin. These two depressions seem to be successors, and to show the last stage of development, of the Barakuchi and the Osamiya depressions.

Lithofacies is fairly uniform laterally in the basin. Predominance of arenite in the northern subbelt, however, might be the result of deposition under higher-energy condition than in the middle subbelt, as in the case of the Lower Sanyama epoch.

Longitudinal current from SE to NW has no net connection with the site and shape of the depressions. Lateral current from SW to NE is nearly normal to the axis of the basin, and especially abundant in the eastern depression. Although a southerly supply is suggested from the current marks, there is no evidence of difference in the kinds of source rocks from the petrographic study of clastics. Settling of this southern land problem is remained for future study.

From the foregoing historical descriptions, it can be said that the maximum subsiding area of the Barakuchi and the Osamiya depressions is progressively shifted respectively westward and eastward during deposition of the Cretaceous formations.

As seen above, there are several depressions within this basin. In other words, thickness of the Cretaceous formations changes within a short distance. It is also characteristic that some of the depressions, such as the Otomo and the Myôke depressions, disappeared with time described above. These features are well explained by fault movements during deposition (Takei, 1965). These same features further suggest that the basin is subdivided into a number of blocks. Settling of the location of the boundary fault between the blocks is remained for future study. There is a possibility, however, that the faults between the northern and the middle subbelts, and also between the middle and the southern subbelts, are regarded as boundary faults of the blocks.

As described already, in the Ishidô epoch, the first stage of development of the sedimentary basin, right-hand *en echelon* arrangement of depressions can be recognized in the isopach map. *En echelon* arrangement of depressions in the same attitude is more or less maintained in the succeeding Sebayashi epoch. These features may be a reflection of right-lateral strike-slip shear early in the history of the Cretaceous sedimentary basin. From this point of view, it can be interpreted that the longitudinal faults reflect main shear fault, and that the cross-faults reflect pull-apart during the formation of blocks mentioned already.

The above-mentioned *en echelon* arrangement of depressions, however, is no more seen in the Lower Sanyama and the Upper Sanyama epochs. In these epochs, the sedimentary basin is not under the strike-slip shear field. Furthermore, fold axes of the Cretaceous formations do not show right-hand arrangement. It also should be taken into consideration that the Lower Sanyama Formation unconformably covers the

Sebayashi Formation. The above-mentioned facts show change of stress condition during the Cretaceous between the Sebayashi and the Lower Sanyama epochs.

VI. Comparison with other Cretaceous formations of the Chichibu Belt

Cretaceous formations, comparable with those of the Sanchû Graben, are distributed at several districts of the Chichibu Belt. Stratigraphic studies of these Cretaceous sediments have been reported in many papers. Petrographic works of these Cretaceous sediments have been done in the Yatsushiro district of Kyûshû (FUJII, 1956; MIYAMOTO, 1980), in the Monobegawa district (MIYAMOTO and NAKAI, 1974) and in the Katsuragawa district (NAKAI, 1971) of Shikoku, and in the Aridagawa district of Kinki (MIYAMOTO, 1980). Comparing the results of the petrographic works on sandstone of these districts, some similarities in the change of the character of sandstone during Cretaceous time are noticed, though some differences are also recognized. The following remarkable features can be pointed out.

(1) The predominant sandstone in each of the Cretaceous basins is wacke type in general. In the Sanchû Graben, however, considerable amount of arenite type sandstone occurs also. There is a possibility that the arenite type sandstone, once deposited, was completely removed away in the areas other than the Sanchû Graben. Another possibility is that higher-energy condition was more prevalent in the Sanchû Graben than in other Cretaceous basins.

(2) There seems to be a systematic change in sandstone characters during Cretaceous time, from lithic sandstone in the lowest formation to feldspathic sandstone in the upper formations.

(3) The source rocks of these Cretaceous sediments are granitic rocks, metamorphic rocks, older sedimentary rocks and volcanic rocks. In Early Cretaceous time, it is likely that the amount of detrital material from the granitic terrain progressively increased in these regions. In the Gyliakian epoch, on the other hand, decrease of the role of the granitic rocks in the provenance was presumed (MIYAMOTO, 1980). In the Sanchû Graben, however, it seems that the clastics from the granitic rock terrain increased in the Gyliakian. It is suggested from this fact that tectonic behavior of the Ryôke Belt as provenance was different that of the remaining part of Southwest Japan.

VII. Conclusions

During Cretaceous time, narrow sedimentary basins were formed and developed at several areas of the Chichibu Belt, the Outer side of Southwest Japan. Cretaceous strata of the Sanchû Graben were emplaced in one of these basins, and are divided into four formations, namely, Ishidô Formation, Sebayashi Formation, Lower Sanyama Formation and Upper Sanyama Formation in ascending order. These formations are distributed in three subbelts, the northern, the middle and the southern subbelts.

From the sedimentological study, based mainly on the petrography of the clastic sediments, the writer obtains following conclusions.

Sandstones of the Ishidô Formation are characterized by lithic wacke (classification and nomenclature of sandstone are based on OKADA, 1971). Lithic fragments are, for the most part, chert of pre-Cretaceous age. Sandstones of the Sebayashi, the Lower Sanyama and the Upper Sanyama Formations are, on the contrary, represented by feldspathic arenite and wacke. The former is dominant in the northern subbelt, and the latter in the middle. Slower subsidence of the basin and higher-energy conditions in the basin-margin resulted possibly in formation of arenite in the northern subbelt.

Cretaceous basin received clastic materials mainly from three terrains, i.e. that of sedimentary rocks, of crystalline schists, and of granitic (and acid volcanic) rocks. These terrains may be approximately correlated, respectively, with the Chichibu, the Sanbagawa and the Ryôke (and further northern) terrains, of which presence of the Ryôke terrain was recently confirmed in the northern margin of the Kantô Mountains. Clastic materials from the three terrains changed in proportion from time to time during Cretaceous time.

In the Ishidô epoch, sediments were supplied from the northern as well as the southern lands, and the pre-Cretaceous Chichibu complex was the main source rocks. In the Sebayashi, the Lower Sanyama and the Upper Sanyama epochs, sediments were derived from the northern land, and the existence of the southern land is uncertain. Clastics from the granitic terrain progressively increased in amount and size from older to younger formations. This might be connected intimately with the successive upheaval of the granitic terrain, i.e. the Ryôke terrain during Cretaceous time.

From the isopach maps, changes in subsiding pattern of the sedimentary basin can be traced. In the Ishidô epoch, there are four depressions, namely, Barakuchi, Otomo, Myôke and Osamiya depressions from west to east (Fig. 10). They show right-hand *en echelon* arrangement, which is more or less maintained into the succeeding Sebayashi epoch, although the Otomo depression disappeared in this epoch. These features may be a reflection of right-lateral strike-slip shear early in the history of the Cretaceous sedimentary basin. The Sebayashi Formation is unconformably overlain by the Lower Sanyama Formation. In the Lower Sanyama and the Upper Sanyama epochs, *en echelon* arrangement of depressions cannot be seen, and main subsiding areas are located at both the easternmost and the westernmost parts of the Sanchû Graben. In these epochs, the sedimentary basin was no more under the strike-slip shear field. Thus, a remarkable change in stress condition is recognized during the development of the Cretaceous sedimentary basin of the Sanchû Graben between Early and Late Cretaceous times.

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POSTSCRIPT After the completion of the present work, the writer had oppotunities to refer to the following papers.

MATSUKUWA, M. (1983) Stratigraphy and sedimentary environments of the Sanchu Cretaceous, Japan. *Mem. Ehime Univ.*, ser. D, vol. 9, p. 1–50.

OBATA, I., MATSUKUWA, M., TANAKA, K., KANAI, Y. and WATANABE, T. (1984) Cretaceous Cephalopods from the Sanchu area, Japan. *Bull. Natn. Sci. Mus.*, ser. C, vol. 10, p. 9–37.

Here, some comments should be given on the MATSUKUWA's paper, because it contains some divergent views from the writer's.

MATSUKUWA discusses stratigraphic succession and geologic age of the Cretaceous formations, based mainly on ammonites and bivalves, and infers depositional environment. In his work, name of the Cretaceous formations of the Sanchû Graben are approximately equal to those of the writer, except for the Shiroi Formation, which the writer considers as a part of the Ishidô Formation, as mentioned in the present paper. Conserning the geologic map, however, there are significant differences between the writer's and MATSUKAWA's. Besides, MATSUKAWA disregards the writer's subdivision of the Sanchû Graben into three subbelts. In consequence, developmental history as well as paleogeography of the Cretaceous sedimentary basin of the Sanchû Graben is fairly differently interpreted by MATSUKAWA and by the writer. Some important causes originating the above-mentioned differences are discussed below.

The writer's Ishidô Formation of the middle subbelt is regarded by MATSUKAWA in many cases as a part of his Sanyama Formation. His interpretation seems inadequate for the following reasons.

The Ishidô Formation of the middle subbelt and the Upper Sanyama Formation of the writer are significantly different from each other in lithofacies. Furthermore, sandstone intercalated in the Ishidô Formation of the middle subbelt is petrographically different from that of the Upper Sanyama Formation, and bears a resemblance to that of the Ishidô Formation of the northern and the southern subbelts, as discussed in the present paper. Although the writer's Ishidô Formation of the middle subbelt often occurs adjacent to the south of the writer's Upper Sanyama Formation of the northern subbelt, there runs a significant fault between them, which separates the northern subbelt from the middle subbelt.

MATSUKAWA regards the conglomerate and the sandstone beds of the writer's Lower Sanyama and the Upper Sanyama Formations as the top member of his Sebayashi Formation, and ignores the distinct change of lithofacies from the top of the writer's Sebayashi Formation to the basal conglomerate of the writer's Lower Sanyama Formation. Therefore, the Lower Sanyama Formation and the basal part of the Upper Sanyama Formation of the writer are in many cases regarded as the upper member of the Sebayashi Formation by MATSUKAWA. As described in the present paper, however, sandstones of the Lower Sanyama Formation and of the Upper Sanyama Formation of the writer are petrographically different each other. Therefore, it is inappropriate to put both of these sandstones into a single member, i.e. the upper member of the Sebayashi Formation as done by MATSUKAWA.