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Coarse Clastic Rocks of the Shimanto Supergroup in Eastern Shikoku and Kii Peninsula, Southwest Japan

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Abstract

The stratigraphy and correlation of the Cretaceous strata in eastern Shikoku and Kii Peninsula are examined based on the radiolarian biostratigraphy. As the results, the stratigraphic change of the sandstone composition was recognized. The sandstones of the late Early Cretaceous are rich in feldspar, especially of plagioclase, and poor in rock fragments. Most sandstones of the Late Cretaceous are dominant in rock fragments, especially of acidic to intermediate volcanic rocks. Most of the Paleogene sandstones are characterized by very dominant quartz and poor rock fragments. Such stratigraphic change is also supported by the change of conglomerate composition. It reflects the change of the provenance nature.

The increasing trend of rock fragments consisting mainly of volcanic rocks in the Cretaceous sequences indicates that the volcanism of acidic to intermediate nature took place in the provenance to the north of the basin contemporaneously with the sedimentation of the Late Cretaceous Shimanto Supergroup, and provided a large amount of volcanic materials to the basin. This volcanism corresponds to the so-called late Mesozoic Igneous Activity in the Inner Zone of Southwest Japan. Thus, the Late Cretaceous Shimanto Supergroup represents one type of the forearc sedimentation in magmatic arc-trench system.

The difference of clastic composition between the Cretaceous and the Paleogene is explained by the unroofing process of the Cretaceous magmatic terrane.

Lastly, the geotectonic development of the Shimanto Belt and its provenance is discussed mainly based on the sedimentological analyses. The marginal sea setting similar to the present Philippine Sea is considered to be preferable for the Shimanto geosyncline.

I. Introduction

The circum-Pacific regions are characterized by arc-trench systems which have very conspicuous features of topograpy. They also represent a remarkable orogenic belt called the Circum-Pacific mobile belt, which suffered "polycyclic orogenies" from middle Paleozoic to Cenozoic (MATSUMOTO, 1967). According to the plate tectonic theory, these regions were the site of consumption of oceanic plate, called the "active plate margin" (DICKINSON, 1974; DICKINSON and SEELY, 1979; etc.). Within the belt, late Mesozoic to early Cenozoic geosynclinal sediments are widely distributed. Moreover, it has been well known that the igneous activities contemporaneous with the sedimentation took place violently in this orogenic belt. Southwest Japan is one of the best studied areas where late Mesozoic to early Cenozoic geosynclinal sediments are well developed in its outer zone, and coeval igneous rocks in its inner zone.

In the Outer Zone of Southwest Japan, the geosynclinal strata called the Shimanto Supergroup occupy the outermost zone, the Shimanto Belt (Fig. 1). Because of scarce megafossils, complicated geologic structures and the absence of key beds, the Shimanto Supergroup had remained undivided Mesozonic for a long time. Several pioneer contributions were made by HASHIMOTO (1962), KATTO (1961), HARATA

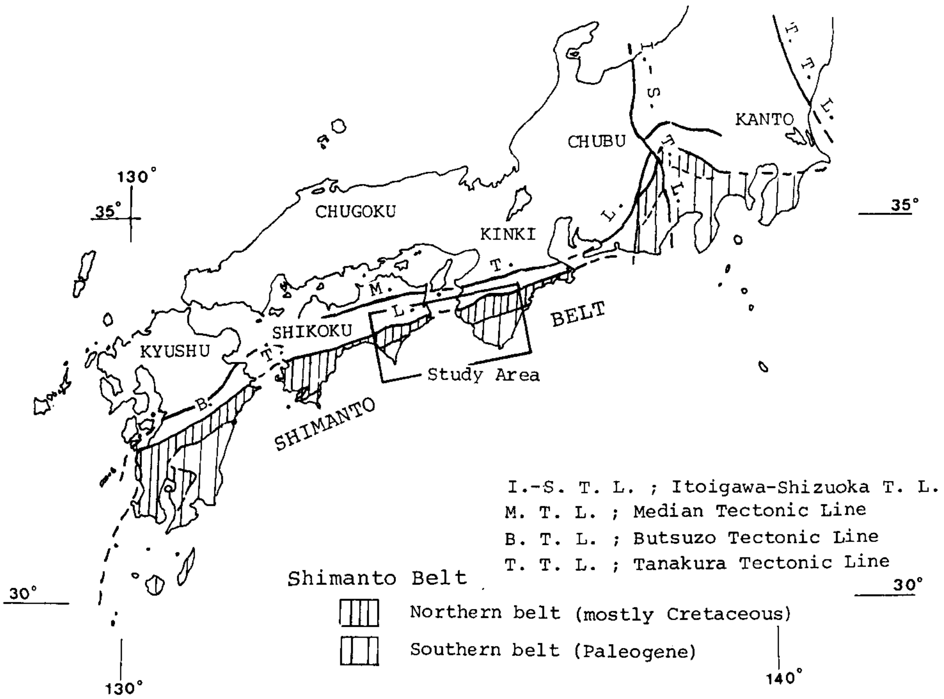

Fig. 1 Index map of the study area.

(1964), etc., and in 1960's the Shimanto basin was regarded as one of the typical orthogeosynclines in Japan (MINATO *et al.,* 1965). Recently, in accordance with the development of the plate tectonic theory, some workers have advocated that the Shimanto geosyncline* must have been a site of the subduction of oceanic plate where the accretion of pelagic sediments and a part of oceanic crust took place (KANMERA and SAKAI, 1975; DICKINSON, 1977; TAIRA *et al.,* 1980). However, from sedimentological studies of the Shimanto Supergroup in the Kii Peninsula, KISHU SHIMANTO RESEARCH GROUP (1968, 1970, 1975) and HARATA *et al.* (1978) insisted that the source area was situated not only to the north of the basin but also toward the south of it, and no plate subduction occurred within the basin.

Under such circumstances, the author has mainly studied the Shimanto Supergroup in eastern Shikoku, and in the Kii Peninsula with his colleagues and the members of KISHU SHIMANTO RESEARCH GROUP (KUMON, 1981; KUMON and INOUCHI, 1976; SUZUKI *et al.,* 1979; TATEISHI *et al.,* 1979; TOKUOKA *et al.,* 1981; etc.). Both regions are situated in the central part of the Shimanto Belt, and the strata exposed in these regions have suffered less metamorphism and tectonic disturbance than those in the other regions. Furthermore, coarse clastic sediments are developed dominantly there, occupying about a half of the total sediments. The main purposes of the present paper are, first, to clarify the properties of the coarse clastic rocks of the Shimanto Supergroup, secondly, to reconstruct its provenance, and finally, to discuss the provenance evolution and its paleogeography.

In the present paper, stratigraphic, structural and paleontologic data of eastern Shikoku mainly depend on KUMON (1981), KUMON and INOUCHI (1976) and KATTO and ARITA (1966), and those of the Kii Peninsula are mainly taken from KISHU SHIMANTO RESEARCH GROUP (1975), HATENASHI RESEARCH GROUP (1980), SUZUKI *et al.* (1979), TATEISHI *et al.* (1979), TOKUOKA *et al.* (1981), and KUMON and KISHU SHIMANTO RESEARCH GROUP (1981) in addition to some unpublished data of the author.

II. Geology of the Shimanto Belt in Eastern Shikoku and Kii Peninsula

The Shimanto Belt, bordering on the Chichibu Belt to the north by the Butsuzo Tectonic Line, extends 2,000 km long from the Kwanto Mountains to the Nansei Islands (Fig. 1). Eastern Shikoku and Kii Peninsula are situated in the central portion of the belt. The strata in this belt are characterized by thick geosynclinal sediments, ranging from late Mesozoic to early Cenozoic in age, and are collectively called the Shimanto Supergroup. They are overlain by the late Early to Middle Miocene

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* In this papaer, the term "geosyncline" means an elongated furrow which situates between a continent and an ocean, or between a continent and a continent, filled with a great deal of sediments.

deposits with an angular unconformity, and are intruded by the Neogene igneous rocks at places. The Shimanto Belt is divided into the northern and southern belts, that are bounded by a remarkable tectonic line. The notrhern belt is composed of Cretaceous strata, while the southern belt is mostly occupied by the Paleogene strata.

1. Geology of Eastern Shikoku

The generalized geologic map of eastern Shikoku is shown in Fig. 2, and the stratigraphy and lithology of the Shimanto Supergroup are summarized in Fig. 3. The Shimanto Belt is divided by the Aki Fault into the northern and southern belts. In the northern belt, muddy rocks and subordinate sandstone are widely distributed, accompanied with conglomerate, greenstones, chert and acidic tuff. In the southern belt, sandstone and flysch-type alternating beds of sandstone and mudstone are dominant, accompanied with mudstone.

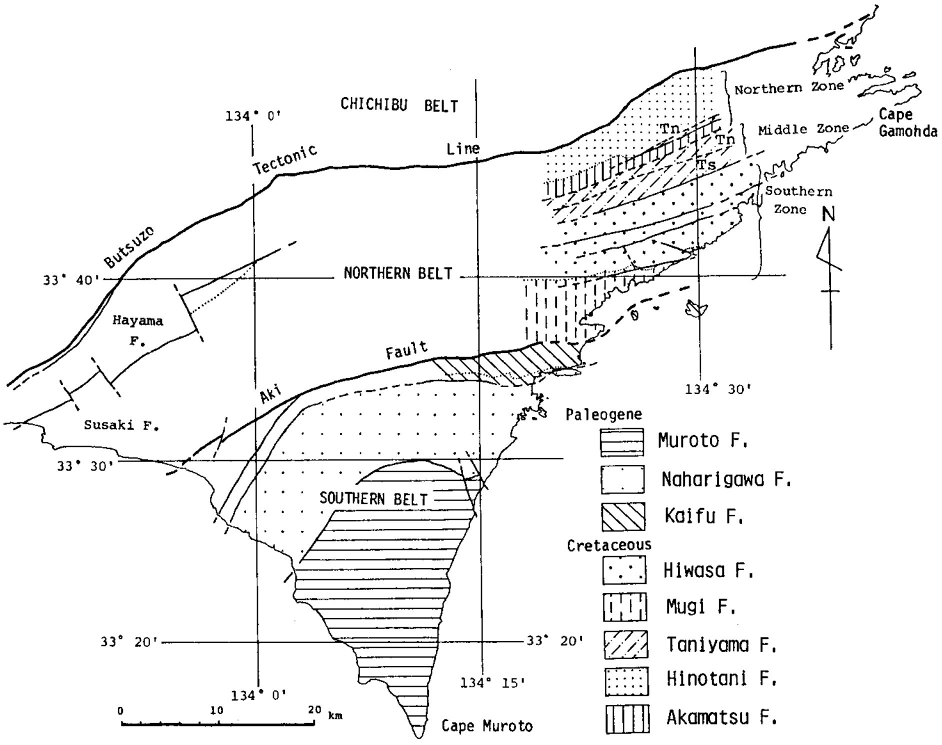
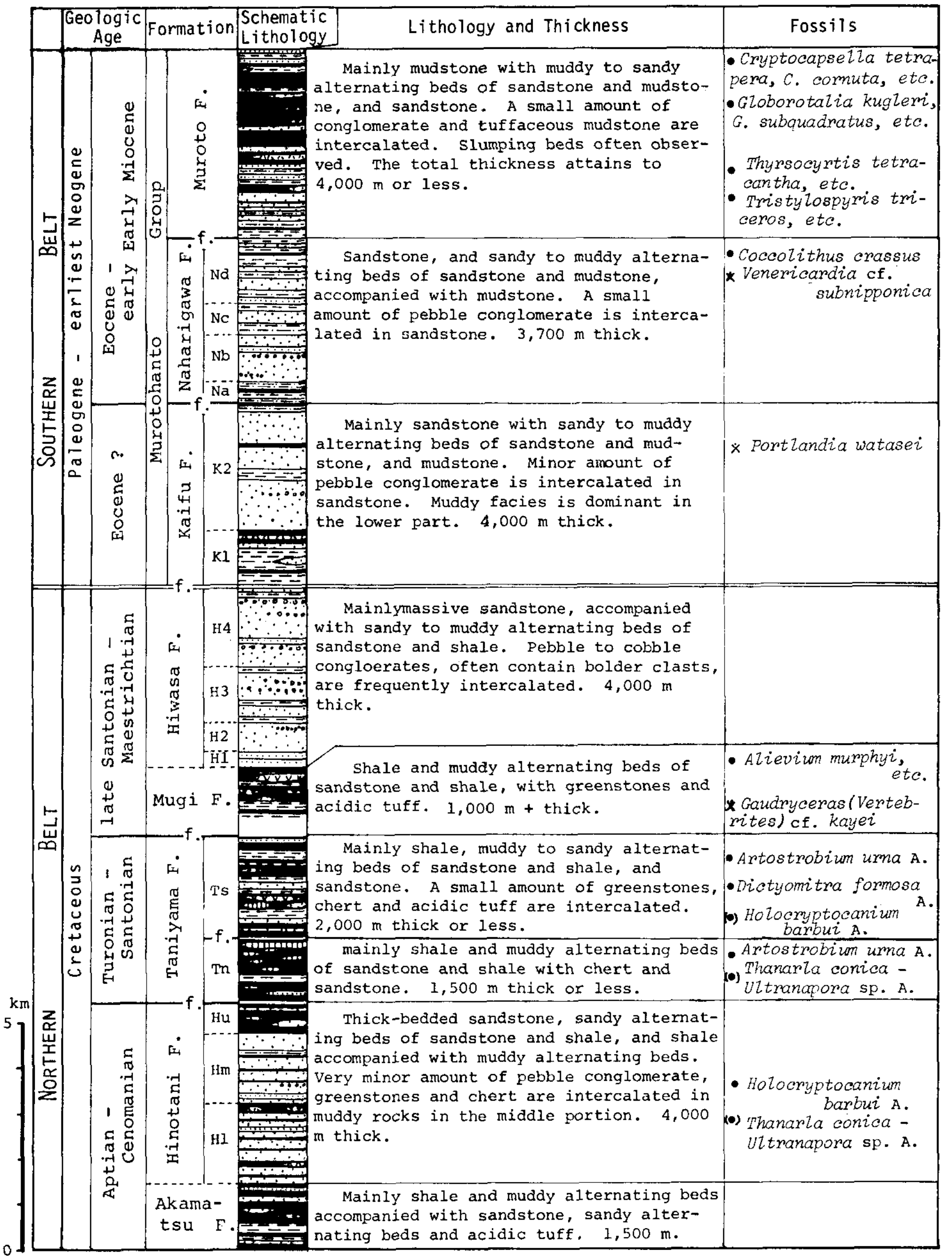


Fig. 2 Generalized geologic map of the Shimanto Belt in eastern Shikoku. Compiled from KUMON (1981), KUMON and INOUCHI (1976) and KATTO (1961), and partly modified as mentioned in the text.



	Geologic Age			Formation			Schematic Lithology	Lithology and Thickness	Fossils
SOUTHERN BELT	Paleogene - earliest Neogene	Eocene - early Early Miocene	Murotohanto Group	Muroto F.				Mainly mudstone with muddy to sandy alternating beds of sandstone and mudstone, and sandstone. A small amount of conglomerate and tuffaceous mudstone are intercalated. Slumping beds often observed. The total thickness attains to 4,000 m or less.	• *Cryptocapsella tetrapera, C. cornuta, etc.* • *Globorotalia kugleri, G. subquadratus, etc.* • *Thyrsocyrtis tetracantha, etc.* • *Tristylospyris triceros, etc.*
				Naharigawa F.	Nd Nc Nb Na			Sandstone, and sandy to muddy alternating beds of sandstone and mudstone, accompanied with mudstone. A small amount of pebble conglomerate is intercalated in sandstone. 3,700 m thick.	• *Coccolithus crassus* x *Venericardia* cf. *subnipponica*
		Eocene ?		Kaifu F.	K2 K1			Mainly sandstone with sandy to muddy alternating beds of sandstone and mudstone, and mudstone. Minor amount of pebble conglomerate is intercalated in sandstone. Muddy facies is dominant in the lower part. 4,000 m thick.	x *Portlandia watasei*
NORTHERN BELT	Cretaceous	late Santonian - Maestrichtian		Hiwasa F.	H4 H3 H2 H1			Mainlymassive sandstone, accompanied with sandy to muddy alternating beds of sandstone and shale. Pebble to cobble congloerates, often contain bolder clasts, are frequently intercalated. 4,000 m thick.	
				Mugi F.				Shale and muddy alternating beds of sandstone and shale, with greenstones and acidic tuff. 1,000 m + thick.	• *Alievium murphyi, etc.* x *Gaudryceras (Vertebrites)* cf. *kayei*
		Turonian - Santonian		Taniyama F.	Ts			Mainly shale, muddy to sandy alternating beds of sandstone and shale, and sandstone. A small amount of greenstones, chert and acidic tuff are intercalated. 2,000 m thick or less.	• *Artostrobium urna* A. • *Dictyomitra formosa* A. (•) *Holocryptocanium barbui* A.
					Tn			mainly shale and muddy alternating beds of sandstone and shale with chert and sandstone. 1,500 m thick or less.	• *Artostrobium urna* A. (•) *Thanarla conica - Ultranapora* sp. A.
		Aptian - Cenomanian		Hinotani F.	Hu Hm Hl			Thick-bedded sandstone, sandy alternating beds of sandstone and shale, and shale accompanied with muddy alternating beds. Very minor amount of pebble conglomerate, greenstones and chert are intercalated in muddy rocks in the middle portion. 4,000 m thick.	• *Holocryptocanium barbui* A. (•) *Thanarla conica - Ultranapora* sp. A.
				Akamatsu F.				Mainly shale and muddy alternating beds accompanied with sandstone, sandy alternating beds and acidic tuff. 1,500 m.	

Fig. 3 Stratigraphy and lithology of the Shimanto Supergroup in eastern Shikoku. Compiled from KUMON (1981), KUMON and INOUCHI (1976) and KATTO and ARITA (1966), and partly modified as mentioned in the text. Fossil data are based mainly on SHINOAKI (1958), SUYARI *et al.* (1967), NAKAGAWA *et al.* (1980), TAIRA *et al.* (1980) and KUMON (1981 and unpub. data). Legend in the column is same as in Fig. 5.

A. Northern Belt

The eastern part of this belt has been mapped in detail by the author (KUMON, 1981), but the stratigraphy and geologic age are partly modified here on the basis of the new data of radiolarian fossils. This belt is subdivided by two strike faults into three zones, namely, northern, middle, and southern zones, each represented mainly by the Akamatsu and Hinotani Formations, Taniyama Formation, and Mugi and Hiwasa Formations, respectively (Fig. 2).

The Akamatsu Formation, about 1,500 meters thick, is dominant in muddy rocks, accompanied with sandstone and alternating beds of sandstone and shale. The Hinotani Formation conformably overlying the Akamatsu Formation is dominant in thick-bedded sandstone, and alternating beds of sandstone and shale, rarely accompanied with pebble conglomerate, greenstones and chert. Its thickness is about 4,000 m. Molluscan fossils* such as *Natica* (*Amauropsis*) *sanchuensis*, *Glauconia neumayri*, *Astarte* cf. *semicostata*, etc., weres once discovered at the northern margin of the Hinotani Formation (Shinoaki, 1958). Recently, radiolarian fossils of *Holocryptocanium barbui* Assemblage** (late Albian to Cenomanian) were found in black and red shales of the formation (Nakagawa *et al.*, 1980; Kumon, unpub. data), and the Hinotani Formation is assigned to Aptian to Cenomanian in age. The Akamatsu Formation underlying the Hinotani Formation is supposed to be Aptian or earlier in age.

The Taniyama Formation***, about 2,000 meters thick, is composed mainly of muddy rocks accompanied with sandstone, chert, acidic tuff and greenstones. The half (Tn) of it is abundant in chert, and in contrast, the southern half (Ts) is rich in northern sandstone and coarse acidic tuff. The precise relation of the two parts remains uncertain. The Taniyama Formation is inferred to be Turonian to Santonian age, judging from the occurrences of *Dictyomitra formosa* Assemblage (Turonian) and *Artostrobium urna* Assemblage (Coniacian to Santonian) in tuffaceous and black shales (NAKAGAWA *et al.*, 1980; KUMON, 1981 and unpub. data). Tithonian to Cenomanian assemblages from chert and red shale older than the above two assemblages suggest that the chert and red shale are exotic in origin as pointed by NAKASEKO (1979). The geologic age of the Taniyama Formation is extended here to Santonian, being younger than the age inferred by KUMON (1981).

The Mugi Formation, more than 1,000 meters thick, is composed mainly of muddy rocks with greenstones and acidic tuff. The Hiwasa Formation which overlies

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* Recently, MATSUMOTO *et al.* (1982) pointed that this fauna resembles the Hauterivian brackish water fauna of the Shiroi Formation in Kwanto Mountains.

** The zonation and name of the radiolarian assemblages follow those proposed by MATSUYAMA *et al.* (1982) in the Kii Peninsula.

*** Some parts of the Akamatsu Formation defined by KUMON (1981) is included into the Taniyama Formation in this paper, because of the new occurrence of radiolarian fossils of Turonian to Santonian age (NAKAGAWA *et al.*, 1980; KUMON, unpub. data). The Taniyama Formation is considered to be in fault contact with the Akamatsu Formation.

conformably the Mugi Formation, is composed mostly of sandstone and conglomerate. This formation is considered to be submarine fan deposits. The Mugi Formation is assigned to late Santonian to Campanian in age on the basis of ammonite *Gaudryceras* (*Vertebrites*) sp. cf. *kayei* and the occurrence of Coniacian to Campanian radiolarian fossils from red shale (SUYARI *et al.*, 1967; KUMON, 1981). The Hiwasa Formation conformably overlying the Mugi Formation is estimated to be Campanian to Maestrichtian, judging from its large thickness.

The geologic age of each zone becomes younger southward. Homoclinal structure is dominant in each zone, although frequently faulted and rarely folded.

The cumulative thickness of the strata in the northern belt attains to 14,000 meters, but the main depositional site may have migrated southward step by step.

B. Southern Belt

The upper half of the Shimanto Supergroup is widely distributed in the Muroto Peninsula and was named the Murotohanto Group (KATTO, 1961). The southern belt in the eastern part of the peninsula is subdivided by two strike faults into three zones, each represented by the Kaifu, Naharigawa and Muroto* Formations from north to south (Fig. 3).

The Kaifu Formation, about 4,000 meters thick, is composed mostly of sandstone with sandy to muddy alternating beds of sandstone and mudstone. Pebble conglomerates are rarely intercalated in sandstones. The Naharigawa Formation, about 3,500 meters thick, is made up largely of sandstone and flysch-type alternating beds of sandstone and mudstone, with intercalations of conglomerate and mudstone. The Muroto Formation, about 4,000 meters thick, is formed of mudstone with muddy to sandy alternating beds of sandstone and mudstone. Conglomerate, tuffaceous shale and basaltic rocks are rarely intercalated in the formation.

The cumulative thickness of these strata in the southern belt attains to 12,000 meters, but the sedimentary basin was shifted step by step, as in the northern belt.

Many molluscan fossils were reported by KATTO (1961), MATSUMOTO and TERASHIMA (1976), KUMON and INOUCHI (1976), KATTO and TASHIRO (1979), etc., and foraminiferal and radiolarian fossils, and nannofossils have recently been discovered (SAITO, 1980; OKADA and OKAMURA, 1980; TAIRA *et al.*, 1980; ISHIKAWA, 1982; etc.). These fossils clearly indicate that the strata in the southern belt range from Eocene to early Miocene in age. The precise geologic age of each formation remains uncertain.

3. Geology of the Kii Peninsula

The generalized geologic map in the Kii Peninsula is illustrated in Fig. 4, and the

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* This formation was subdivided into two groups and several formations by TAIRA *et al.* (1980), some problems, however, remain in stratigraphy. As no sample from the strata has been treated here, the author follows the name of Muroto Formation to include the whole strata as used formerly.

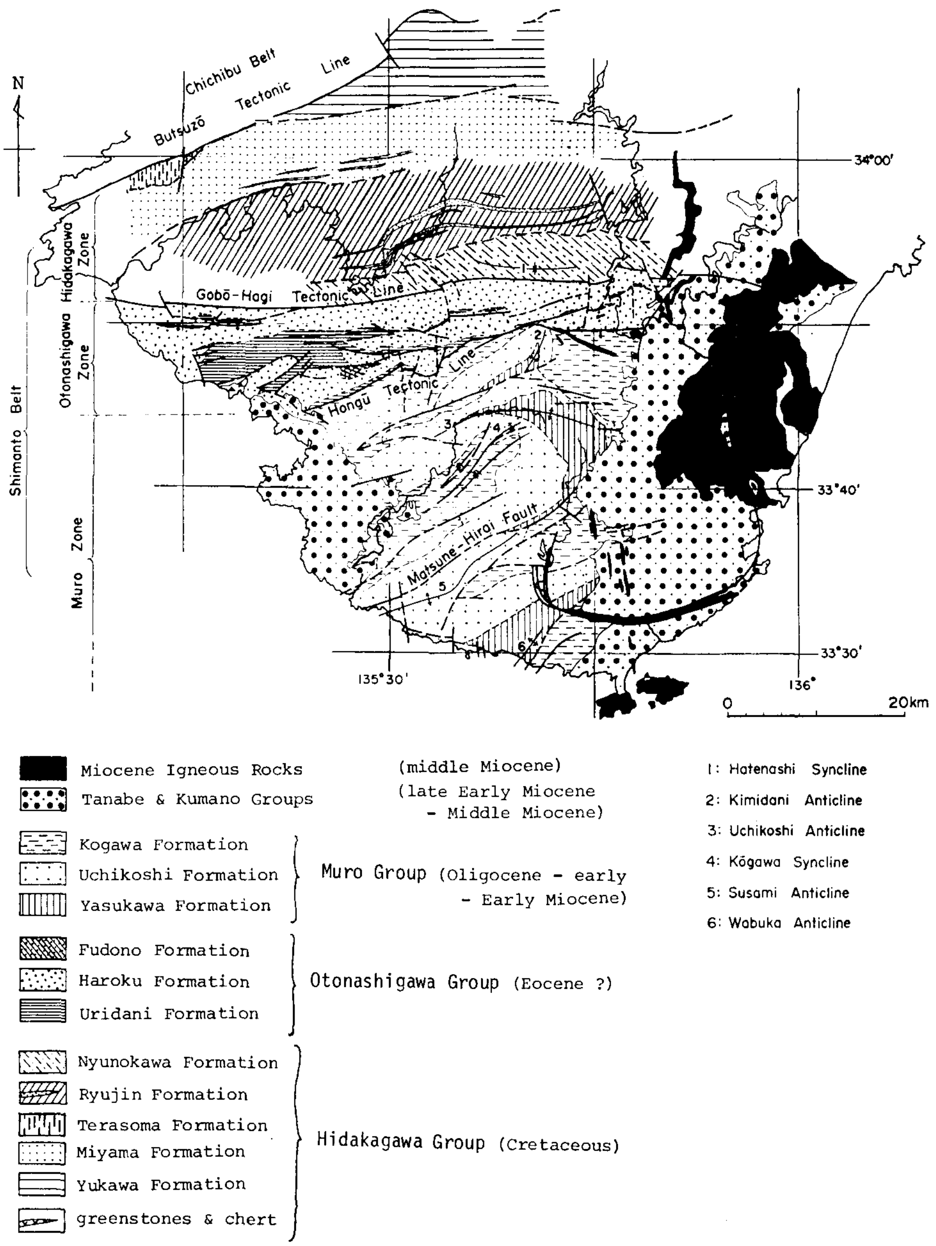
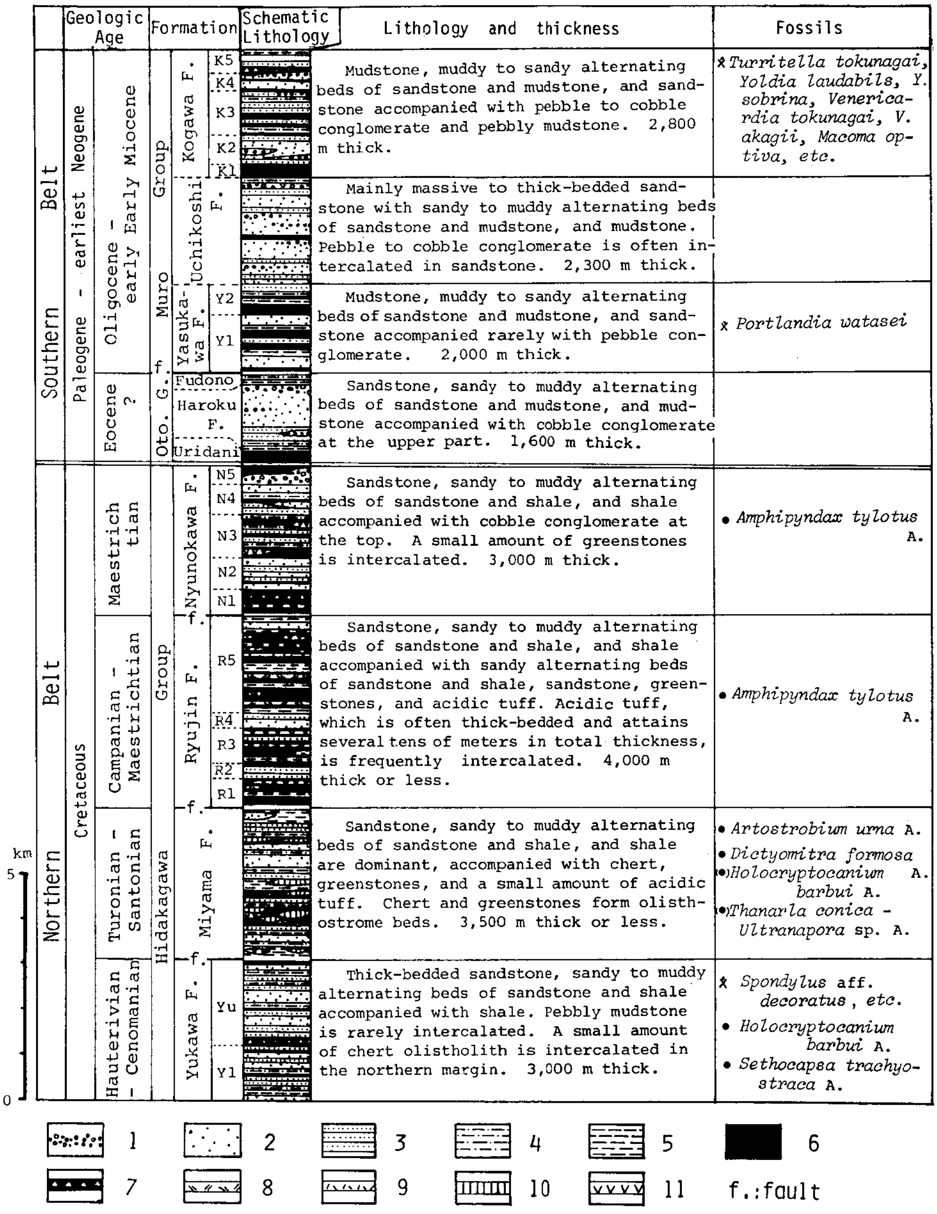


Fig. 4 Generalized geologic map of the Shimanto Belt in the Kii Peninsula. After TOKUOKA *et al.* (1981), partly modified as mentioned in the text.



Belt	Geologic Age		Formation			Lithology and thickness	Fossils
Southern Belt	Paleogene - earliest Neogene	Oligocene - early Early Miocene	Muro Group	Kogawa F.	K5 K4 K3 K2 K1	Mudstone, muddy to sandy alternating beds of sandstone and mudstone, and sandstone accompanied with pebble to cobble conglomerate and pebbly mudstone. 2,800 m thick.	✕ *Turritella tokunagai*, *Yoldia laudabils*, *Y. sobrina*, *Venericardia tokunagai*, *V. akagii*, *Macoma optiva*, *etc.*
				Uchikoshi F.		Mainly massive to thick-bedded sandstone with sandy to muddy alternating beds of sandstone and mudstone, and mudstone. Pebble to cobble conglomerate is often intercalated in sandstone. 2,300 m thick.	
				Yasukawa F.	Y2 Y1	Mudstone, muddy to sandy alternating beds of sandstone and mudstone, and sandstone accompanied rarely with pebble conglomerate. 2,000 m thick.	✕ *Portlandia watasei*
			f.				
		Eocene ?	Oto. G.	Fudono Haroku F. Uridani		Sandstone, sandy to muddy alternating beds of sandstone and mudstone, and mudstone accompanied with cobble conglomerate at the upper part. 1,600 m thick.	
Northern Belt	Cretaceous	Maestrichtian	Hidakagawa Group	Nyunokawa F.	N5 N4 N3 N2 N1	Sandstone, sandy to muddy alternating beds of sandstone and shale, and shale accompanied with cobble conglomerate at the top. A small amount of greenstones is intercalated. 3,000 m thick.	• *Amphipyndax tylotus* A.
				f.			
		Campanian - Maestrichtian		Ryujin F.	R5 R4 R3 R2 R1	Sandstone, sandy to muddy alternating beds of sandstone and shale, and shale accompanied with sandy alternating beds of sandstone and shale, sandstone, greenstones, and acidic tuff. Acidic tuff, which is often thick-bedded and attains several tens of meters in total thickness, is frequently intercalated. 4,000 m thick or less.	• *Amphipyndax tylotus* A.
				f.			
		Turonian - Santonian		Miyama F.		Sandstone, sandy to muddy alternating beds of sandstone and shale, and shale are dominant, accompanied with chert, greenstones, and a small amount of acidic tuff. Chert and greenstones form olisthostrome beds. 3,500 m thick or less.	• *Artostrobium urna* A. • *Dictyomitra formosa* (•) *Holocryptocanium barbui* A. (•) *Thanarla conica* - *Ultranapora* sp. A.
				f.			
		Hauterivian - Cenomanian		Yukawa F.	Yu Yl	Thick-bedded sandstone, sandy to muddy alternating beds of sandstone and shale accompanied with shale. Pebbly mudstone is rarely intercalated. A small amount of chert olistholith is intercalated in the northern margin. 3,000 m thick.	✕ *Spondylus* aff. *decoratus*, *etc.* • *Holocryptocanium barbui* A. • *Sethocapsa trachyostraca* A.

Fig. 5 Stratigraphy and lithology of the Shimanto Supergroup in the central part of the Kii Peninsula. Complied from K.S.R.G. (1975), Suzuki *et al.* (1979), Tateishi *et al.* (1979), Tokuoka *et al.* (1981), Kumon and K.S.R.G. (1981) and unpublished data of K.S.R.G.

1: conglomerate, 2: sandstone, 3: sandy alternations, 4: normal alternations, 5: muddy alternations, 6: shale(mudstone), 7: pebbly shale(mudstone), 8: acidic tuff, 9: tuffaceous shale(mudstone), 10: chert, 11: greenstones, 12: megafossil, 13: microfossil, 14: derived microfossil.

stratigraphy and lithology are summarized in Fig. 5. As shown in Fig. 4, the Shimanto Belt is divided by the Gobo-Hagi Tectonic Line into the notrhern and southern belts. The strata in the northern belt are called the Hidakagawa Group and those in the southern belt are named the Otonashigawa and Muro Groups.

A. Hidakagawa Group

The Hidakagawa Group in the central part of the peninsula was previously divided into the Nyunokawa, Ryujin, and Miyama Formations in ascending order, and the Yukawa Formation. Among them, the last one had been considered to be correlated to the Nyunokawa Formation (K.S.R.G.*, 1975). This stratigraphy, however, was revised on the basis of radiolarian biostratigraphy (KUMON and K.S.R.G., 1981), that is, the Yukawa, Miyama, Ryujin and Nyunokawa Formations in ascending order (Fig. 5), as will be mentioned later. These four formations are bounded with each other by reverse strike-faults (Fig. 4).

Yukawa Formation, about 3,000 meters thick, is composed mainly of sandstone, flysch-like alternating beds of sandstone and shale, and shale, rarely intercalating exotic blocks of chert presumably derived from the Chichibu Belt on the north. No greenstones are found within this formation. The bivalve fossils in sandstone, such as *Spondylus* aff. *decoratus, Plicatula* aff. *hanaii, Amphidonte* cf. *subhaliotoidea,* etc., indicate Aptian to Albian age and *Inoceramus* cf. *concentricus* from shale suggests Cenomanian age (NAKAZAWA *et al.*, 1979). Recently, radiolarian fossils of *Sethocapsa trachyostraca* Assemblage of FOREMAN (1975) is discovered in black shale at a few localities of the lower part of this formation (KAMON and TAKETOMI, 1982), and *Holocryptocanium barbui* Assemblage was found in red and black shales of the upper part of the formation (YOKOI, 1980MS; KAMON, oral comm.). Therefore, geologic age of the Yukawa Formation ranges from Hauterivian to Cenomanian, mainly from Aptian to Cenomanian.

As clarified by NAKAZAWA *et al.* (1983), the Miyama Formation is formed of two different lithologic units, that is, the "flysch unit" consisting of massive sandstone, sandy to muddy alternating beds of sandstone and shale, and shale, and the so-called "pre-flysch unit" made of greenstones, chert, and shale. The thickness of the Miyama Formation is about 3,500 meters or less. Most of the chert and greenstones are olistoliths and the "pre-flysch unit" is considered to be an olistostrome bed. The Miyama Formation is inferred to range from Turonian to Santonian in age, judging from the occurrence of *Dictyomitra formosa* and *Artostrobium urna* Assemblages in black and tuffaceous shales, although the older radiolarian assemblages were found in chert and red shale of exotic origin.

The Ryujin Formation, about 4,000 meters thick, consists largely of muddy rocks

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* KISHU SHIMANTO RESEARCH GROUP.

often intercalating flysch-like alternating beds of sandstone and shale, greenstones, and acidic tuff. There occurs no chert. Acidic tuff, often attaining several tens of meters in thickness, are frequently intercalated in the formation, especially in R_3 and R_5 Members. Sandstone becomes abundant in the uppermost part of the formation. This uppermost part had been previously included into the Miyama Formation (K.S.R.G., 1975), but a reverse fault was found on the northern border, and the radiolarian assemblage younger than that of the Miyama Formation was newly discovered. The Ryujin Formation is assigned to Campanian to Maestrichtian in age on the basis of the occurrence of *Amphipyndax tylotus* Assemblage (Campanian to Maestrichtian) in black and red shales at several horizons.

The Nyunokawa Formation, about 3,000 meters thick, is composed of sandstone, alternating beds of sandstone and shale, shale, and conglomerate. Cobble conglomerate often containing boulder clasts is well developed in the upper part, and is called the Nyunokawa Conglomerate (Tokuoka *et al.*, 1981). Greenstones are rarely intercalated in the lower portion. This formation shows a thickening- and coarsening-upward sequence as a whole, and seems to have formed a submarine fan (Kimura, 1978MS). Radiolarian fossils of *Amphipyndax tylotus* Assemblages was also found in black shale of this formation. This faunal association in the assemblage, however, indicates a slightly younger age than that of the Ryujin Formation, because it lacks the species of relatively older age in the assemblage. The Nyunokawa Formation is probably Maestrichtian in age.

The Terasoma Formation, about 800 meters thick, is distributed in a small area of the northwestern part of the peninsula, being situated in the northern margin of the Shimanto Belt (Fig. 3). This formation is mainly composed of alternating beds of sandstone and shale, and shale. The Terasoma Formation yeilds abundant megafossils exceptionally in the Shimanto Belt such as *Yubariceras* aff. *kanei, Mytiloides* cf. *sublabiatus* or *M.* cf. *mytiloidiformis, Inoceramus* cf. *amakusensis, I.* (*Platyceramus*) *cycloides vanuxemiformis, I.* (*P.*) *rhomboides rhomboides,* etc. (Morozumi, 1970; Matsumoto and Yoshimatsu, 1982). *Artostrobium urna* Assemblage was also recovered from many places in the Upper Member of the formation (Nakaseko *et al.*, 1979; Matsuyama *et al.*, 1982). Consequently, the Terasoma Formation is safely assigned to range from middle Turonian to early Santonian in age, and is correlated with the Miyama Formation. The Terasoma Formation is inferred to be formed in shallower environment than the Miyama Formation (K.S.R.G., in press).

The strata in the northern belt generally trend east-west, and dip northward at high angles. Several reverse faults dipping to the north are present, and the repetition of the strata is often recognized. Several large-scale folds are observable in both the Nyunokawa and Terasoma Formations, and middle- to small-scale folds are commonly observable throughout the belt.

The cumulative thickness of the whole strata in the northern belt attains to

13,000 meters, but the depocenter migrated southward step by step as in the case of eastern Shikoku.

B. Otonashigawa Group

In the southern belt, the Otonashigawa Group is distributed in its northern subbelt, occupying comparatively narrow zone. It is about 1,600 meters thick, and is divided into the Uridani, Haroku and Fudono Formations in ascending order (HATENASHI RESEARCH GROUP, 1980).

The Uridani Formation is composed mostly of mudstone, and calcareous nodules are contained sporadically. The Lower Member of the Haroku Formation consists of muddy to normal flysch-type alternating beds of sandstone and mudstone, and the Upper Member is composed of sandy alternation and thick-bedded sandstone with conglomerate intercalation. The Fudono Formation, about 200 meters thick, is formed of muddy to normal flysch-type alternating beds of sandstone and mudstone.

The group dips steeply or moderately to the north. Several major faults making repetition of the strata, and minor folds are frequently observed in it.

Its geologic age is supposed to be Eocene by its structural situation, although no reliable fossil evidence has been obtained yet.

C. Muro Group

The Muro Group is divided into the Yasukawa, Uchikoshi and Kogawa Formations in ascending order in the type area (SUZUKI *et al.*, 1979).

Yasukawa Formation, about 2,000 meters thick, consists of mudstone, sandstone, and muddy flysch-type alternating beds of sandstone and mudstone. The Uchikoshi Formation is composed largely of sandy alternating beds of sandstone and mudstone, and thick-bedded sandstone accompanied with conglomerate. The thickness is about 2,300 meters. The Kogawa Formation, about 2,800 meters thick, is variable in lithofacies, being formed of alternating beds of sandstone and mudstone, sandstone, mudstone and frequent intercalations of conglomeratic mudstone and angular-fragment-bearing mudstone.

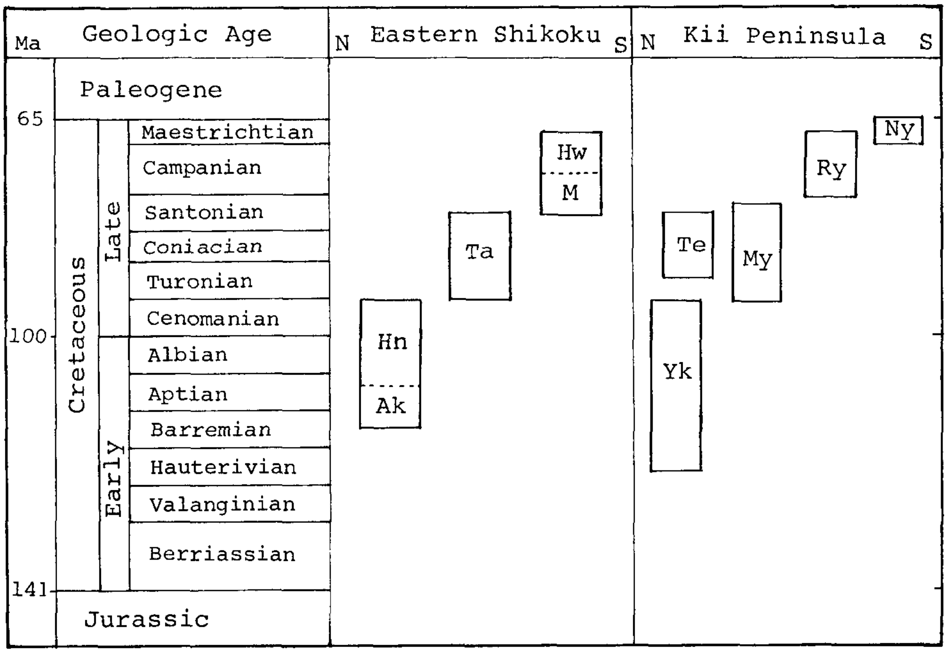
The Muro Group is folded and faulted, but not so strongly sheared compared with the Hidakagawa Group. The total thickness attains to 7,000 meters.

The Muro Group yields relatively abundant molluscan fossils, such as *Turritella tokunagai, Yoldia laudabils, Y. sorbina, Portlandia watasei, P. yotsukurensis, Venericardia tokunagai, V. akagii, Macoma optiva, Cultellus izumoensis,* etc., (K.S.R.G., 1970; MIZUNO, 1973; KATTO and MASUDA, 1978). The Kumano Group, which overlies unconformably the Muro Goup, is assigned to late Early to Middle Miocene in age, on the basis of foraminiferal fossils such as *Lepidocyclina* (*Nephrolepidina*) *japonica, Miogypsina* sp., *Orbulina universa,* etc. (NISHIMURA and MIYAKE, 1973; IKEBE *et al.*, 1975). Consequently, the Muro Group is considered to be Oligocene to early Early Miocene in age.

3. Correlation between Eastern Shikoku and Kii Peninsula

The correlation of the Cretaceous strata in eastern Shikoku and Kii Peninsula is shown in Fig. 6.

The Akamatsu and Hinotani Formations in eastern Shikoku are correlative to the Yukawa Formation in the Kii Peninsula. The both are mainly Aptian to Cenomanian in age. The Hinotani Formation is similar to the Yukawa Formation also in lithology. The Taniyama Formation in eastern Shikoku is correlated with the Miyama Formation in the Kii Peninsula. The both are Turonian to Santonian in age, and are characterized by frequent intercalations of exotic blocks of chert and greenstones. The Terasoma Formation representing the shallower facies is safely equated with the above two formations by molluscan and radiolarian fossils. The Mugi and Hiwasa Forma-



Eastern Shikoku

Ak: Akamatsu F., Hn: Hinotani F., Ta: Taniyama F.,

M: Mugi F., Hw: Hiwasa F.

Kii Peninsula

Yk: Yukawa F., Te: Terasoma F., My: Miyama F.,

Ry: Ryujin F., Ny: Nyunokawa F.

Fig. 6 Correlation of the Cretaceous Shimanto Supergroup between eastern Shikoku and Kii Peninsula.

tions in eastern Shikoku are roughly compared to the Ryujin Formation in the Kii Peninsula, although the Mugi Formation may go back slightly older than the Ryujin Formation. The both are mainly Campanian to Maestrichtian. The Nyunokawa Formation in the Kii Peninsula is inferred to be Maestrichtian in age, and its correlative formation is not found in eastern Shikoku.

The strata of the southern belt in eastern Shikoku and Kii Peninsula range from Eocene to early Early Miocene. Nevertheless, molluscan fossils of early Tertiary are not so useful for detailed biostratigraphy, and microfossils useful for age determination are rare in the Paleogene* Shimanto Supergroup. Therefore, the precise correlation between the Paleogene formations in eastern Shikoku and those in the Kii Peninsula remains unsolved. The Kaifu Formation is possibly correlated to the Otonashigawa Group, and the Naharagawa and Muroto Formations are roughly correlative to the Muro Group, however.

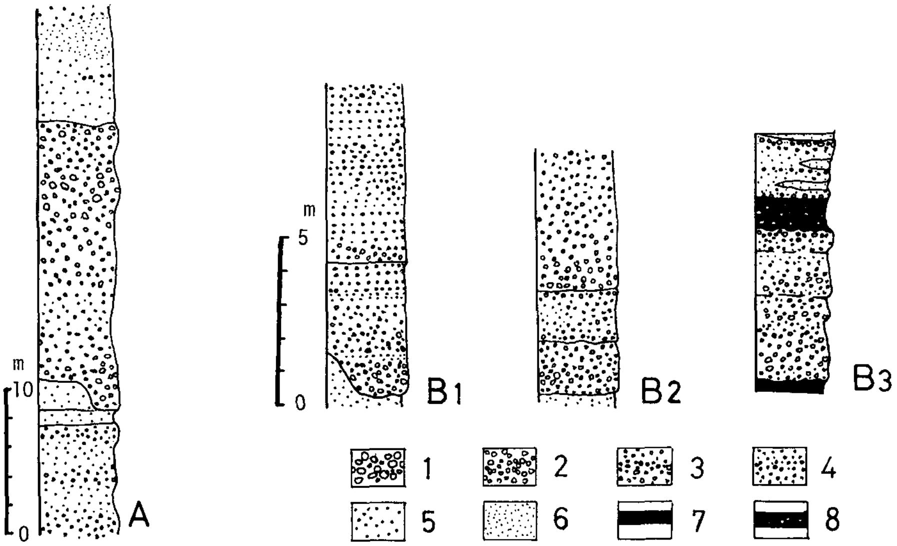


Fig. 7 Columnar sections of typical conglomerate sequence in the Shimanto Supergroup.
A: Hiwasa F. (after KUMON, 1981), B1-3: Muro G. (after TATEISHI, 1978). 1-4: conglomerate (1. boulder, 2. cobble, 3. pebble, 4. granule), 5-6: sandstone (5. coarse-grained, 6. medium-grained), 7: mudstone, 8: pebbly mudstone.

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* The strata in the southern belt range from Eocene to early Early Miocene in age, the main part, however, is inferred to belong to Paleogene age. For convenience sake, the early Early Miocene strata of the Shimanto Supergroup are included into the "Paleogene" in this papaer.

III. Coarse Clastic Rocks of the Shimanto Supergoup in Eastern Shikoku and Kii Peninsula

1. General Occurrence of Clastic Rocks

The main lithology of the Shimanto Supergroup in eastern Shikoku and Kii Peninsula are briefly shown in Figs. 3 and 5, respectively. At first, the typical features of the clastic rocks in these regions will be shortly mentioned.

Conglomerates are several to several tens of meters thick, and usually intercalated in sandstone. They are also frequently found as lens or thin layer within thick-bedded sandstone, sometimes changing gradually to sandstone without any sharp boundary. Clasts in conglomerates are mostly pebble, sometimes cobble, and rarely boulder in size, and are subrounded to rounded in shape (Plate 5–3 and 5). These are usually contained in coarse sandy matrix. Typical occurrences of conglomerate are shown in Fig. 7. Sedimentary features such as grading, stratification, and clast fabric are frequently observed in them, suggesting that they have been transported and deposited partly by turbidity current, and partly by grain flow as discussed by Tateishi (1978)

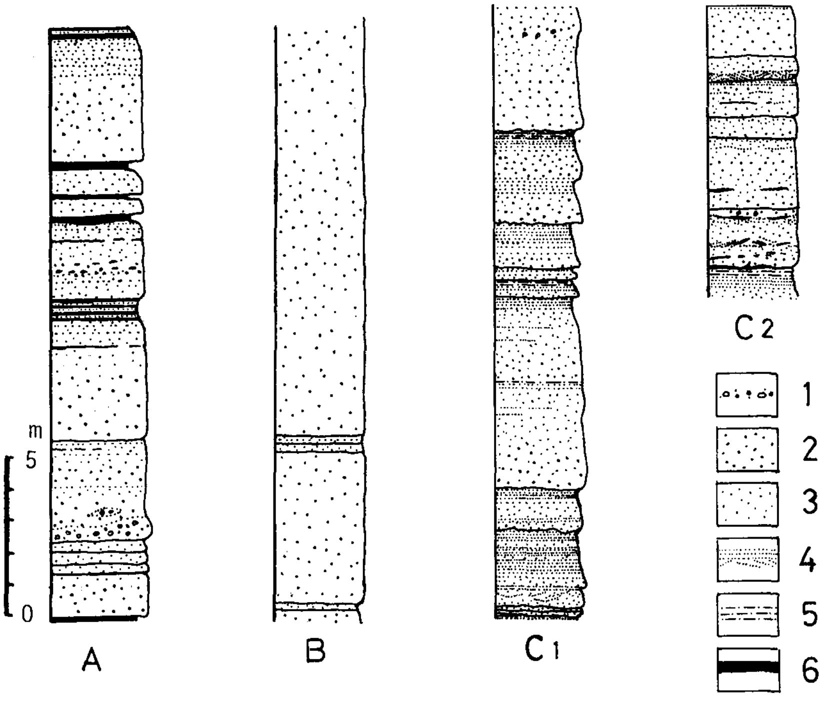

Fig. 8 Columnar sections of typical sandstone sequence in the Shimanto Supergroup. A: Hinotani F., B: Hiwasa F., C1-2: Muro G. (after Tateishi, 1978). 1: pebble conglomerate, 2-5: sandstone (2. coarse-grained, 3. medium-grained, 4. fine-grained, 5. very fine-grained), 6: shale(mudstone).

on the conglomerates of the Muro Group.

Thick-bedded sandstones are in beds 0.5 to 2 meters thick with thin shale intercalations (Plate 5–1, 4 and 6). They are mainly medium- to coarse-grained. Typical Bouma sequence of Ta-c is frequently observable, indicating that they have been transported and deposited as proximal turbidites. Sandstone beds sometimes attain several to several tens of meters in thickness (Plate 5–2). In this case, no stratified intercalation can be recognized. Some of them may have been formed as grain-flow deposits. Typical occurrences of the thick-bedded sandstones are shown in Fig. 8.

Alternating beds of sandstone and shale(mudstone) are composed of rhythmical alternation of sandy part (3 to 50 cm thick) and muddy part (1 to 30 cm thick). Graded bedding, parallel lamination, current ripple mark in addition to sole markings are frequently observed, all of which indicate obviously that they have been formed by turbidity currents.

Shales(mudstones) are several to several tens of meters in thickness. Mostly, they have varied fissility, and intercalations of thin sandstone layer or sandy lamina are often observed in them. They are considered to have been deposited as distal turbidites and/or hemipelagic sediments, and true pelagic sediments are very small in amount, if present.

2. Properties of Conglomerate

The composition of conglomerate is one of the useful keys to consider the provenance of sediments. In the Shimanto Supergroup in eastern Shikoku and Kii Peninsula, conglomerate beds are commonly intercalated at various horizons, and were examined fairly well by several authors, such as KUMON and INOUCHI (1976), and KUMON (1981) in eastern Shikoku, TOKUOKA (1966, 1967, 1970), K.S.R.G. (1970), HATENASHI RESEARCH GROUP (1973, 1977), SUZUKI *et al.* (1979), TATEISHI *et al.* (1979), and TOKUOKA *et al.* (1981) in the Kii Peninsula. The following summary is mainly founded on the above-mentioned papers in addition to the author's investigation (Fig. 9 and Tab. 1).

A. Eastern Shikoku

In the Cretaceous Shimanto Supergroup, conglomerates are poorly developed in the Hinotani and Taniyama Formations, but common in the Hiwasa Formation. The conglomerate composition was examined at four localities in the Hinotani Formation,

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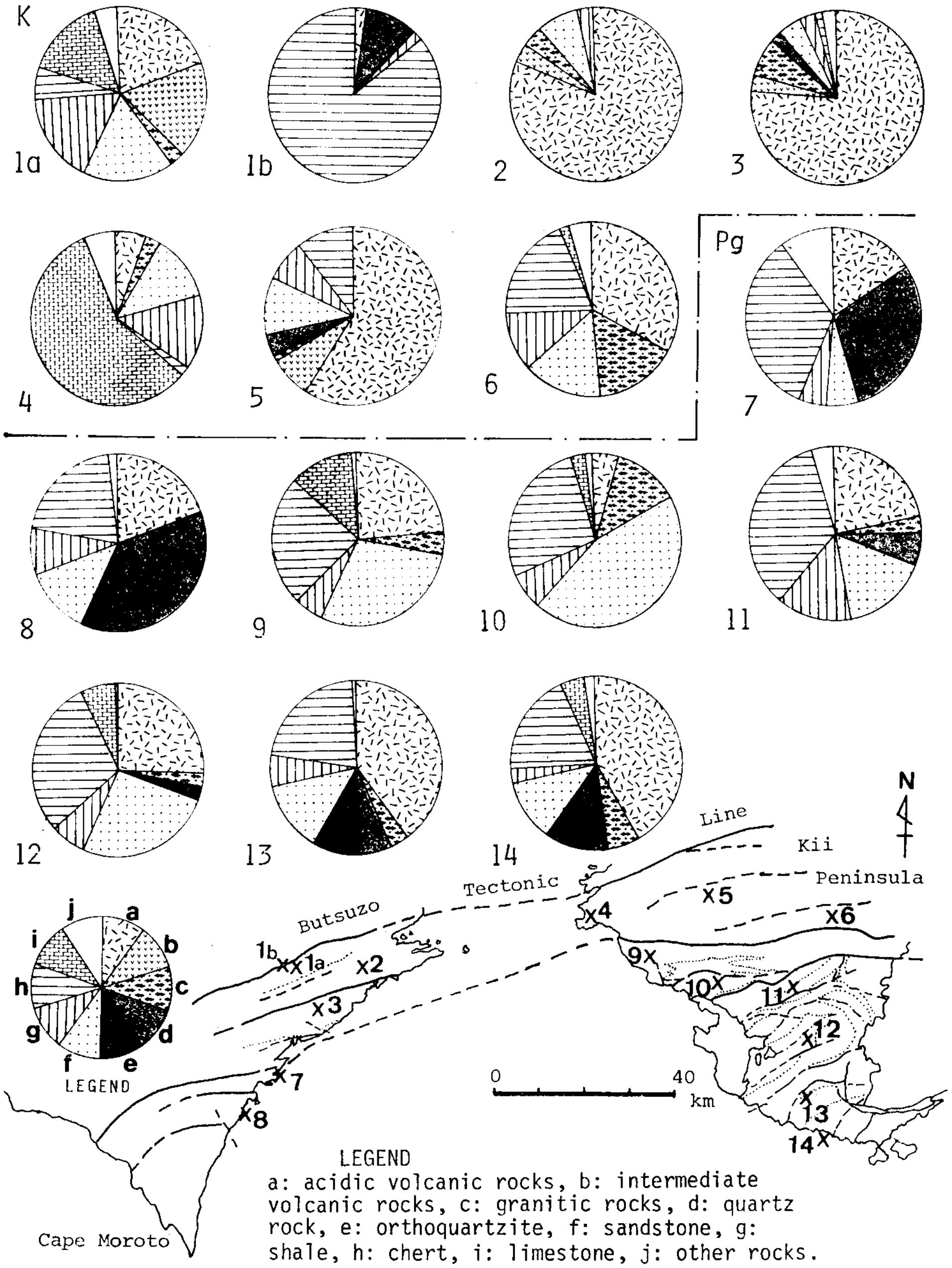
Fig. 9 Mean compositions of the congolmerates of the Shimanto Supergroup in eastern Shikoku and Kii Peninsula.
1: Hinotani F. (1a. Hm Member, 1b. Hu Mem.), 2: Taniyama F., 3: Hiwasa F., 4: Miyama F. in Gobo district, 5: Ryujin F., 6: Nyunokawa F., 7: Kaifu F., 8: Naharigawa F., 9-10: Haroku F. (9. Lower Mem., 10. Upper Mem.), 11-14: Muro Group (11. area north of the Uchikoshi Anticline, 12. area between Uchikoski Anticline and Matsune-Hirai Fault, 13. area south of Matsune-Hirai F., 14. southern coastal area). (In diagrams of Nos. 7 and 8, acidic volcanic rocks includes acidic plutonic and hypabyssal rocks.)



LEGEND
a: acidic volcanic rocks, b: intermediate volcanic rocks, c: granitic rocks, d: quartz rock, e: orthoquartzite, f: sandstone, g: shale, h: chert, i: limestone, j: other rocks.

Table. 1 Mean composition of conglomerate from the Shimanto Supergroup in eastern Shikoku and Kii Peninsula. H. R. G. maens HATENASHI RESEARCH GROUP. In the data of * symbol, acidic volcanic rocks include granitic rocks. Numbers same as in Fig. 9.

formation	number of studied local.	acidic vol. rocks	intermediate vol. rock	granitic rocks	quartz rock	sandstone	shale	chert	orthoquartzite	limestone	others	reference
1a Middle Hinotani F.	3	20	18	3	0	17	17	6	0	15	4	Kumon(1981)
1b Upper Hinotani F.	1	2	0	0	10	0	2	86	0	0	0	*ibid.*
2 Taniyama F.	1	81	4	4	0	8	3	0	0	0	0	*ibid.*
3 Hiwasa F.	14	75	4	7	2	5	3	1	+	0	2	*ibid.*
4 Miyama F.	2	6	0	3	0	13	13	2	0	58	6	Tokuoka (1967)
5 Ryujin F.	1	59	8	1	5	10	8	10	0	0	0	K. S. R. G. (unpub. data)
6 Nyunokawa F.	5	32	0	15	0	15	11	20	0	2	4	Tokuoka *et al.* (1981)
7 Kaifu F.	1	16*	0	—	29	6	5	34	0	0	10	Kumon and Inouchi(1976)
8 Naharigawa F.	7	20*	0	—	33	13	8	21	5	0	2	*ibid.*
9 Lower Haroku F.	9	21	0	3	6	17	14	34	0	0	4	H.R.G. (1973)
10 Upper Haroku F.	11	5	0	11	0	45	7	27	0	3	2	Tokuoka (1967) H.R.G. (1977)
11 Muro G.	6	24	0	4	0	30	6	24	0	12	1	Suzuki *et al.* (1979)
12 Muro G.	26	25	0	2	1	26	7	30	2	7	+	*ibid.*
13 Muro G.	18	39	0	3	7	13	6	22	8	0	1	*ibid.*, Tateishi *et al.* (1979)
14 Muro G.	14	41	0	6	0	12	3	19	13	5	2	Tateishi *et al.* (1979)

at one in the Taniyama Formation, and at fourteen in the Hiwasa Formation (KUMON, 1981). In the Paleogene Murotohanto Group, conglomerates are rare in the Kaifu Formation and common in the Naharigawa Formation. The examination was performed at one locality in the former, and eight localities in the latter (KUMON and INOUCHI, 1976). The results are shown in Fig. 9 (1, 2, 3, 7 and 8) and Table 1.

1) Hinotani Formation

The clasts are mostly granule to fine pebble in size. The identification of rock type was performed under the microscope. In the conglomerates of the Middle Member of the Hinotani Formation, sedimentary rocks, such as sandstone, shale, chert and muddy limestone occupy more than a half of the total composition, and acidic and intermediate volcanic rocks* occupy about one-fifth of the total (Fig. 9, la; Plate 6–1 and 2). A conglomerate bed at the northern margin of the formation is characterized by abundant chert clasts (Fig. 9, lb). Similar conglomerates were found only at the northern margin of the formation, and the compositional properties are very different from those of the major part of the Hinotani Formation. Therefore, the chert-rich conglomerate might reflect a small localized provenance.

2) Taniyama Formation

Only one conglomerate bed is intercalated in the northern half of the formation. The clasts are mainly coarse pebble, scattered in muddy matrix. Acidic volcanic clasts are very dominant (Fig. 9, 2).

3) Hiwasa Formation

The clasts are mostly pebble to cobble in size, sometimes attaining to boulder-size (Plate 5-3). Acidic volcanic clasts are very predominant, and they are mostly of rhyolite tuff and lava (Fig. 9, 3; Plate 6–3 to 5). Clasts of welded rhyolite tuff are frequently found in them (Plate 6–3). They are lithologically similar to the late Mesozoic volcanic rocks distributed extensively in the Inner Zone of Southwest Japan (KUMON, 1981). Clasts of granitic rocks, sandstone, and shale are commonly contained, but in a small amount. Orthoquartzite clasts, although very rare, were discovered in a few conglomerates (Plate 6–7).

4) Kaifu and Naharigawa Formations

The clasts are mainly pebble in size. The sedimentary rocks, such as chert, shale, and sandstone, occupy a half of the total composition (Fig. 9, 7 and 8). The acidic igneous rocks comprising volcanic rocks and granitic rocks are one-fifth of the total. Quartz rock probably derived from quartz vein is relatively abundant. Orthoquartzite clasts were obtained from six conglomerate beds of the Naharigawa Formation, although their amount is less than several per cent.

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* In this paper, the term "volcanic rocks" is used to include pyroclastic rocks.

B. Kii Peninsula

In the Cretaceous Hidakagawa Group, conglomerates are poorly developed. A few conglomerate beds are found in the Miyama Formation at the western coast of the peninsula, and in the uppermost Ryujin Formation. Thick-bedded conglomerates are well developed in the upper part of the Nyunokawa Formation (Nyunokawa Conglomerate). In the Paleogene strata, conglomerates are limited at a few horizons in the Haroku Formation of the Otonashigawa Group, but are well developed at various horizons in the Muro Group. The composition are collectively shown in Fig. 9 (4 to 6, 9 to 14) and Table 1.

1) Miyama Formation

According to TOKUOKA (1967), it is chatacteristic that limestone clasts are very dominant in the conglomerats and acidic volcanic rocks, shale, sandstone, etc. are small in amount (Fig. 9, 4). Most limestones are dark gray in color and micritic in texture. Judging from the irregular shapes and poor sorting of the clasts, most limestone clasts and a part of the other sedimentary clasts are inferred to be of intra-basinal origin.

2) Ryujin Formation

The clasts are mostly pebble, rarely cobble to boulder in size, scattered in sandy mudstone. Acidic volcanic rocks, mostly of rhyolite tuff and lava, are very dominant (Fig. 9, 5). Clasts of welded rhyolite tuff are often observed in them. Sedimentary rocks, such as shale and sandstone of intra-basinal origin, are also contained, and some of them are difficult to be distinguished from the true conglomerate clasts (K.S.R.G. unpub. data).

3) Nyunokawa Formation

According to TOKUOKA (1967) and TOKUOKA *et al.* (1981), sedimentary rock clasts of sandstone, shale, and chert occupy about a half of the total composition (Fig. 9, 6). Acidic volcanic clasts, mainly rhyolite tuff and lava, are one-third in amount. The rhyolite tuff is often welded (Plate 6–8). Granitic rock clasts, mostly granophyric in texture, are relatively abundant, occupying about 15 per cent of the total.

4) Otonashigawa Group

According to TOKUOKA (1966) and HATENASHI RESEARCH GROUP (1973, 1977), sedimentary clasts comprising sandstone, chert, shale and limestone are predominant, and clasts of acidic volcanic rocks and granitic rocks occupy a quarter of the total composition (Fig. 9, 9 and 10). The conglomerates at the top of the Haroku Formation (Kizekkyo Conglomerate) contain boulder clasts of sandstone, chert, limestone, granite, gneiss and rarely gabbro. K-Ar whole rock age of a boulder clast of hornblende gabbro is 51 m. y. (KUMON *et al.*, in preparation).

4) Muro Group

The properties of the conglomerates had been precisely examined in each formation. According to K.S.R.G. (1970), SUZUKI *et al.* (1979) and TATEISHI *et al.* (1979), the composition is not so different among the formations. It is characterized by the abundance of both sedimentary rocks and acidic volcanic rocks accompanied with a little amount of granitic rocks (Fig. 9, 11 to 14). Chert and sandstone predominate in the sedimentary rock clasts. Chert is gray to greenish gray and black in color, and red chert is very rare. It is noticeable fact that orthoquartzite clasts presumably of Precambrian age are commonly contained (TOKUOKA, 1970; TOKUOKA and BESSHO, 1980). Furthermore, they are found only in the southern part of the peninsula, that is, to the south of the Uchikoshi Anticline (see Fig. 3), and their amount increases southward (TOKUOKA and OKAMI, 1979). K-Ar age of orthoquartzite clast, 309 m. y., is considered to be of secondary thermal event, and that of biotite-gneiss clast is 70 m. y. (SHIBATA and NOZAWA, 1973).

3. Properties of Sandstone

Sandstone is the most predominant element of clastic rocks in the Shimanto Belt and gives many informations on the provenance. The analysis of sandstone composition in eastern Shikoku has been made by the present author (KUMON and INOUCHI, 1976; KUMON, 1981), and in the Kii Peninsula by several workers including the present author (K.S.R.G., 1977; SUZUKI *et al.*, 1979; TATEISHI *et al.*, 1979; TOKUOKA *et al.*, 1981). In these studies, specimens for examination were taken mostly from massive or bedded sandstones, thicker than 50 cm and medium- to coarse-grained. The modal composition was obtained by counting more than 500 points in one thin-section for each specimen under the microscope (Glagolev-Chayes procedure, grid spacing 0.5 × 1.0 mm). The constituents are divided into monocrystalline quartz, polycrystalline quartz, plagioclase, potash feldspar, rock fragments, matrix (including calcite and silicate cement, and grains smaller than 0.03 mm), and others which consist of heavy minerals, shale patch, etc.

The numbers of analyzed samples are as follows.

	Eastern Shikoku	Kii Peninsula
Lower half of Shimanto Supergroup (Cretaceous):	191	116
Upper half of Shimanto Supergroup (Paleogene):	29	265

The results are shown in Figs. 10 to 12, and Tables 2 and 3.

The sand grains are mostly angular to subrounded, and are moderately to well sorted. Main framework grains are monocrystalline quartz, polycrystalline quartz, plagioclase, potash feldspar and rock fragments of various kinds. Monocrystalline quartz is a grain of single quartz crystal which sometimes shows undulatory extinction. Polycrystalline quartz is an aggregated grain of several quartz crystals in mosaic texture. About one-third of plagioclase show albite twinning, and most of plagioclase are partially replaced by sericite. Potash feldspar comprises orthoclase and microcline. Rock fragments are constituted by rhyolite, andesite, granite, chert, shale (slate), schist, etc., among which the first one is most common. Heavy minerals consist of zircon, tourmaline, sphene, epidote, biotite, muscovite, rutile, etc., and the total amount is less than one per cent in all cases. Matrix is formed of clay minerals, cryptocrystalline silicate minerals and calcite. Detrital grains smaller than 0.03 mm were also included in matrix, because of the difficulty of mineral identification.

The mineral composition of sandstones in the Shimanto Supergroup in eastern Shikoku and Kii Peninsula is highly variable vertically.

A. Eastern Shikoku

The mineral composition of sandstone is plotted on Q-F-R and Q-P-K diagrams (Fig. 10). The mean mineral composition of each formation or member is shown in Table 2. As to the rock fragments in sandstone, a special examination was made on several selected specimens which are supposed to have a nearly average mineral composition of each formation (Fig. 11). This will be discussed later in detail.

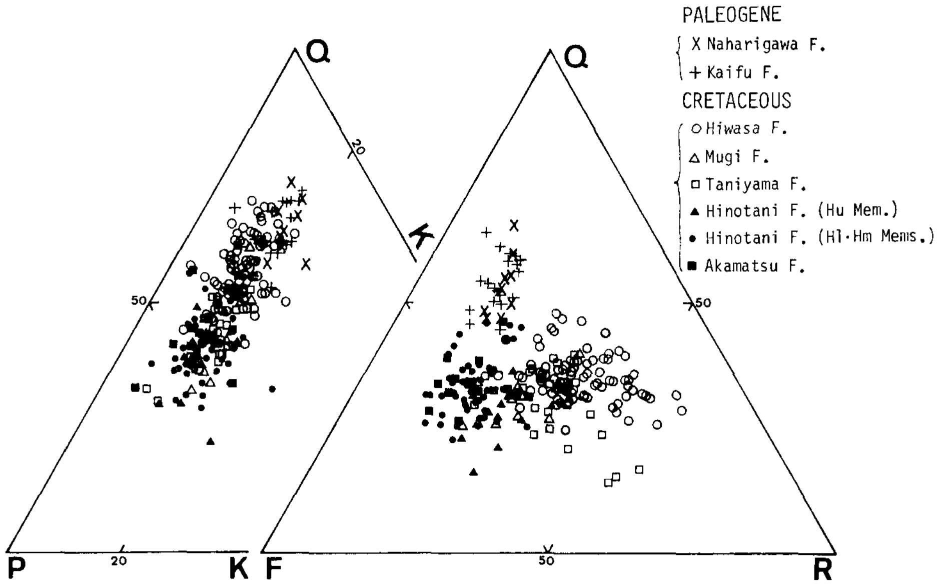

Fig. 10 Q-F-R and Q-P-K plots of the sandstone compositions from the Shimanto Supergroup in eastern Shikoku.
Q: quartz, F: feldspar, R: rock fragments (total), P: plagioclase, K: potash feldspar.

Table. 2 Mean mineral composition of sandstone from the Shimanto Supergroup in eastern Shikoku. ( ): standard deviation, *n*: number of examined specimens.

formation		n	quartz			feldspar			rock fragments	others	matrix	mean grain size φ
			I	II	total	plagio.	K-fel.	total				
Naharigawa F.		10	35. 4(3. 1)	5. 5(1. 8)	43. 6(6. 1)	13. 8(3. 0)	11. 3(1. 9)	25. 0(3. 0)	12. 5(1. 8)	4. 8(2. 6)	14. 1(2. 4)	2. 33(0. 23)
Kaifu F.		19	33. 0(2. 5)	7. 2(1. 8)	43. 3(5. 0)	14. 9(3. 3)	10. 1(2. 2)	25. 0(3. 8)	11. 8(2. 1)	4. 4(2. 1)	15. 5(2. 1)	2. 33(0. 15)
Hiwasa F.	H4	26	22. 7(3. 1)	3. 9(1. 3)	26. 6(3. 3)	13. 9(4. 0)	6. 0(1. 8)	19. 9(5. 1)	30. 9(6. 9)	3. 0(2. 4)	19. 6(4. 9)	2. 05(0. 30)
	H3	32	22. 8(3. 5)	3. 5(1. 4)	26. 9(4. 3)	14. 5(3. 1)	5. 8(1. 9)	20. 3(3. 9)	30. 7(5. 7)	3. 0(1. 4)	19. 2(4. 8)	2. 17(0. 29)
	H2	25	23. 2(4. 2)	4. 1(1. 3)	27. 5(4. 2)	17. 7(4. 8)	6. 7(2. 0)	24. 4(5. 8)	24. 9(6. 0)	4. 8(3. 9)	18. 4(5. 0)	2. 20(0. 35)
	total	83	22. 8(3. 6)	3. 8(1. 3)	27. 0(3. 9)	15. 3(4. 2)	6. 1(1. 9)	21. 4(5. 3)	29. 0(6. 7)	3. 5(2. 8)	19. 1(4. 9)	2. 14(0. 32)
Mugi F.		11	18. 9(3. 0)	3. 6(1. 2)	22. 5(3. 8)	21. 6(4. 5)	8. 3(1. 5)	29. 9(5. 3)	21. 5(4. 5)	4. 1(2. 5)	21. 8(3. 6)	2. 44(0. 40)
Taniyama F.	Ts	13	17. 6(5. 6)	3. 3(1. 6)	20. 9(6. 5)	18. 1(2. 7)	6. 1(1. 7)	24. 2(3. 4)	29. 6(7. 0)	4. 1(1. 2)	21. 3(5. 4)	2. 30(0. 35)
	Tn	12	19. 6(3. 9)	3. 5(1. 5)	23. 1(5. 0)	19. 4(4. 3)	6. 8(2. 3)	26. 1(6. 3)	26. 1(6. 0)	6. 2(2. 8)	18. 6(5. 3)	2. 28(0. 19)
	total	25	18. 6(4. 9)	3. 4(1. 5)	21. 9(5. 8)	18. 7(3. 5)	6. 5(2. 0)	25. 1(5. 0)	27. 9(6. 6)	5. 1(2. 4)	20. 0(5. 4)	2. 29(0. 28)
Hinotani F.	Hu	11	18. 2(4. 4)	1. 8(0. 6)	20. 0(4. 7)	25. 6(3. 6)	7. 6(2. 1)	33. 2(4. 3)	20. 2(3. 0)	4. 3(1. 6)	22. 2(4. 3)	2. 55(0. 32)
	Hm	25	21. 3(4. 2)	2. 2(0. 9)	23. 5(4. 7)	26. 7(2. 6)	9. 3(2. 0)	36. 0(3. 3)	15. 9(2. 5)	4. 4(1. 9)	20. 2(5. 6)	2. 45(0. 19)
	Hl	23	23. 5(4. 3)	2. 8(2. 1)	26. 3(5. 5)	26. 8(3. 9)	8. 3(2. 8)	35. 1(4. 8)	13. 2(3. 1)	5. 0(2. 6)	20. 4(6. 2)	2. 36(0. 28)
	total	59	21. 6(4. 6)	2. 4(1. 5)	24. 0(5. 4)	26. 5(3. 3)	8. 6(2. 4)	35. 1(4. 2)	15. 7(3. 8)	4. 6(2. 2)	20. 6(5. 6)	2. 43(0. 26)
Akamatsu F.		13	22. 3(5. 1)	2. 4(1. 2)	24. 7(5. 9)	26. 6(5. 3)	7. 0(2. 8)	33. 6(6. 2)	13. 7(2. 8)	4. 0(1. 8)	24. 0(9. 6)	2. 47(0. 24)

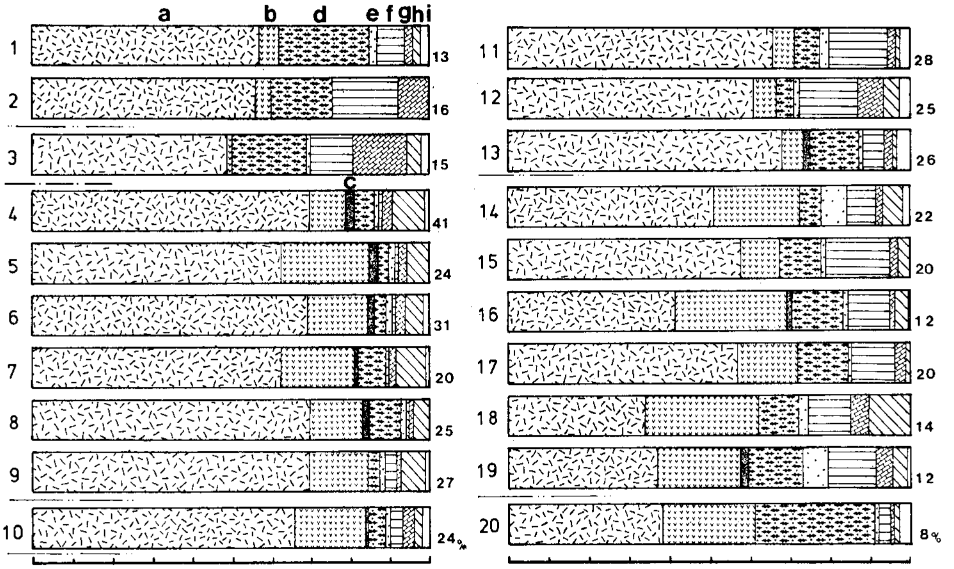

Fig. 11 Composition of rock fragments in the representative sandstone specimens from the Shimanto Supergroup in eastern Shikoku.
1-2: Naharigawa F., 3: Kaifu F., 4-9: Hiwasa F., 10: Mugi F., 11-13: Taniyama F., 14-19 Hinotani F., 20: Akamatsu F. a: acidic volcanic rocks, b: intermediate volcanic rocks, c: basaltic rocks, d: granitic rocks, e: sandstone, f: shale, g: chert, h: hornfels-like rocks, i: schistose rocks. Number at the right end of each diagram is the total amount of rock fragments in per cent.

CRETACEOUS SANDSTONES

Most of the Cretaceous sandstones have matrix of more than 15 per cent, and belong to lithic or feldspathic graywacke of PETTIJOHN's classification (PETTIJOHN, 1975). Differences in mineral composition among the formations can be clearly recognized as described in the followings (Fig. 10).

1) Akamatsu and Hinotani Formations

Both plagioclase and potash feldspar, especially plagioclase, are dominant, and rock fragments are poor (Plate 7–1 and 2). Intermediate volcanic rocks and granitic rocks are relatively rich in the rock fragments (Fig. 11, 14 to 19), although acidic volcanic rocks are most abundant. Sedimentary rock fragments such as shale and chert are also commonly contained. In the upper part of the Hinotani Formation (Hu Member), the amount of rock fragments incresase slightly.

2) Taniyama Formation

Rock fragments are dominant, and feldspar is relatively poor (Plate 7–3). Some specimens are poor in quartz. In rock fragments, acidic volcanic rocks are predominant, and sedimentary rocks such as shale and chert, and schistose rocks are commonly contained (Fig 11, 11 to 13).

3) Mugi Formation

Feldspar and rock fragments are abundant (Plate 7–4). Sandstones of this formation seem to have an intermediate mineral composition between those of the Hinotani Formation and the Hiwasa Formation described below.

4) Hiwasa Formation

Rock fragments are dominant and feldspar is common (Plate 7–5 and 6). Acidic volcanic rocks is predominant in the rock fragments, and intermediate volcanic rocks are also commonly observable (Fig. 11, 4 to 9). Sandstones of the lower part (H_2 Member) are relatively poor in rock fragments.

PALEOGENE SANDSTONES

Compared with the Cretaceous sandstones, the Paleogene sandstones are very dominant in quartz and little in rock fragments and matrix, and belong mostly to arkose, partly to arkosic wacke (Fig. 10; Plate 7–7 and 8). No significant difference in mineral composition can be recognized between the Kaifu and Naharigawa Formations. The ratio of potash feldspar to plagioclase is a little larger in the Paleogene than in the Cretaceous, and microcline grains are more frequently observable in the former. In the rock fragments, acidic volcanic rocks is most dominant (Fig. 11, 1 to 3), and granitic rocks, shale and chert are fairly common.

B. Kii Peninsula

The mineral composition of sandstones are shown in Fig. 12. The mean mineral composition of each formation or member is shown in Table 3.

CRETACEOUS SANDSTONES

Most of the Cretaceous sandstones have matrix of more than 15 per cent, and belong to lithic or feldspathic graywacke. Differences in mineral composition of sandstone among the formations can be recognized (Fig 12).

1) Yukawa Formation

Feldspar, especially plagioclase, is dominant, and rock fragments are common (Plate 8–1). In rock fragments, acidic and intermediate volcanic rocks, shale and chert are commonly observable.

2) Miyama and Terasoma Formations

The Miyama and Terasoma Formations are correlative in age with each other, and are also similar in sandstone composition. The both sandstones are dominant in rock fragments, and are relatively poor in feldspar. In rock fragments, acidic volcanic rocks are dominant, and intermediate volcanic rocks are subordinate.

3) Ryujin Formation

In the lower part of the formation (R_1 to R_4 Members), rock fragments are

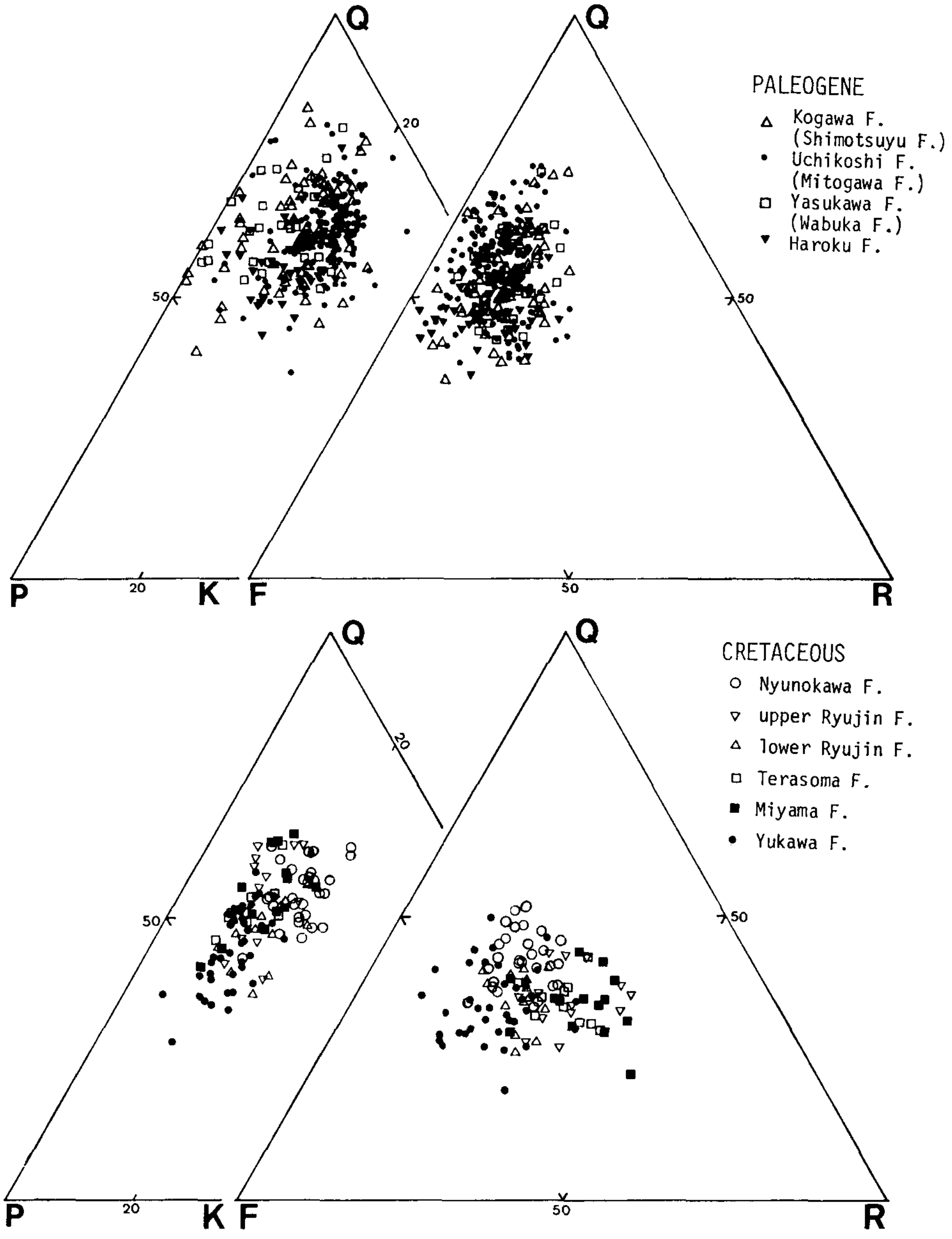

Fig. 12 Q-F-R and Q-P-K plots of the sandstone compositions of the Shimanto Supergroup in the Kii Peninsula. Symbols of Q, F, R, P and K are same as in Fig. 10.

Table. 3 Mean mineral composition of sandstone from the Shimanto Supergroup in the Kii Peninsula. ( ): standard deviation, n: number of examined specimens.

formation		n	quartz			feldspar			rock fragments	others	matrix
			I	II	total	plagio.	K-fel.	total			
Kogawa F.		61	37.8(6.5)	7.9(4.3)	45.7(7.9)	18.9(7.2)	9.9(5.0)	28.7(7.0)	10.8(3.9)	3.4(2.1)	11.4(5.6)
Uchikoshi F.		122	38.7(6.4)	8.1(4.8)	46.8(7.1)	17.1(5.9)	13.0(3.8)	30.2(5.9)	10.3(4.1)	3.3(2.2)	9.4(4.6)
Yasukawa F.		31	37.5(6.7)	6.4(2.5)	43.8(7.8)	18.2(5.4)	8.5(5.0)	26.8(5.6)	10.6(3.5)	3.3(1.8)	15.6(6.3)
Haroku F.		51	36.8(5.8)	5.2(2.9)	42.0(4.7)	21.2(6.9)	11.7(3.8)	32.9(6.6)	12.2(4.7)	3.8(2.5)	9.0(3.7)
Nyunokawa Formation	N5	7	29.9(3.7)	4.0(1.8)	33.8(5.0)	16.1(3.4)	10.7(2.3)	26.7(3.1)	18.2(3.6)	6.7(5.3)	14.5(6.4)
	N4	11	28.2(2.9)	5.6(2.9)	33.8(3.9)	16.2(4.7)	12.8(2.6)	29.0(5.1)	18.2(3.8)	5.0(2.3)	14.0(5.5)
	N2·N3	12	31.1(4.5)	3.3(1.9)	34.4(4.0)	17.2(3.1)	11.4(2.4)	28.6(4.2)	16.2(3.6)	3.1(1.2)	17.7(4.4)
	total	30	29.7(3.9)	4.3(2.5)	34.1(4.1)	16.5(3.7)	11.7(2.5)	28.3(4.3)	17.4(3.7)	4.6(3.2)	15.6(5.4)
Ryujin Formation	R5	12	22.7(3.9)	4.3(1.4)	26.9(4.2)	17.3(4.9)	6.5(2.0)	23.7(5.9)	25.5(5.2)	3.5(2.3)	20.5(5.1)
	R4	9	21.7(2.2)	3.4(1.1)	25.1(2.9)	19.7(2.9)	8.8(2.3)	28.4(3.5)	19.1(3.0)	3.6(1.6)	23.8(4.0)
	R2·R3	5	23.7(5.7)	4.0(3.1)	27.7(5.2)	21.6(4.3)	8.9(2.0)	30.5(2.4)	20.5(2.6)	3.3(1.9)	18.0(4.3)
	total	26	22.5(3.8)	3.9(1.7)	26.5(4.0)	18.9(4.4)	7.7(2.3)	26.7(5.3)	22.3(5.0)	3.5(1.9)	21.2(4.9)
Terasoma F.		10	23.0(2.4)	3.1(2.0)	26.1(3.8)	18.3(3.1)	5.9(1.1)	24.2(2.9)	24.8(4.5)	4.1(2.2)	20.8(6.9)
Miyama F.		15	21.1(4.4)	5.1(2.3)	26.2(5.5)	16.2(3.7)	6.5(1.9)	22.8(4.1)	27.4(4.9)	3.1(1.3)	20.5(4.7)
Yukawa F.	upper	27	22.5(4.2)	3.1(1.5)	25.6(5.1)	23.6(4.8)	8.1(1.8)	31.7(5.1)	17.5(3.8)	3.7(1.4)	21.6(5.1)
	lower	8	25.0(5.9)	3.5(1.4)	28.5(6.7)	25.3(4.5)	6.6(1.4)	31.9(4.3)	14.7(5.7)	4.1(1.9)	20.9(2.8)
	total	35	23.1(4.7)	3.2(1.5)	26.2(5.5)	24.0(4.7)	7.8(1.8)	31.8(4.9)	16.8(4.4)	3.8(1.4)	21.4(4.7)

relatively poor, and feldspar are abundant (Plate 8–4). In the upper part (R_5 Member), rock fragments increase, while feldspar decreases (Plate 8–5). Acidic volcanic rocks are dominant in the rock fragments.

4) Nyunokawa Formation

The sandstones of this formation are characterized by dominant quartz and relatively poor rock fragments (Plate 8–6). It is worthy to note that quartz and potash feldspar are most abundant in this formation among the Cretaceous formations in the Kii Peninsula.

PALEOGENE SANDSTONES

The Paleogene sandstones are much dominant in quartz and abundant in feldspar, and are poor in rock fragments and matrix (Plate 8–7 and 8). They mostly belong to arkose and partly to arkosic wacke. Consequently, the Paleogene sandstones are clearly distinguished from the Cretaceous ones in mineral composition, especially in the larger amount of quartz and the smaller amount of rock fragments.

No significant difference is observed in mineral composition throughout the Paleogene. In the Muro Group, some of the examined specimens almost lack potash feldspar. The absence of potash feldspar seems to be due to hydrothermal alteration probably related to the Kumano Acidic Igneous Rocks of Middle Miocene age, because these specimens are distributed in the altered zones. The areal variation of mineral composition is found in the Uchikoshi Formation, that is, there is a tendency that quartz is increasing southward, corresponding to the decrease of rock fragments in the same direction (TATEISHI *et al.*, 1979). The mineral composition of the sandstones in the Kogawa Formation is more variable than that in the other formations of the Muro Group, as indicated by scattered distribution on the triangular diagrams (Fig. 12).

4. Dispersal Pattern of Clastic Sediments

Sedimentary structures such as flute mark, prod mark, groove mark, cross-lamination, etc., offer the informations on the transportation pass and provenance of the clastic sediments. Such directional sedimentary structures are frequently observed in the Paleogene Shimanto Supergroup, while they are rarely found in the Cretaceous strata. The diagramatic sketch of the paleocurrent direction deduced from such sedimentary structures are shown in Fig. 13.

Although the paleocurrents of late Early Cretaceous to earliest Late Cretaceous are mainly longitudinal from west to east, lateral paleocurrents from north to south or from northwest to southeast are clearly recognized. The paleocurrents of early Late Cretaceous (Turonian to Santonian) are rarely confirmed in the Kii Peninsula. The paleocurrents of the Miyama Formation are longitudinal from west to east and lateral from north to south. Those of the Terasoma Formation which occupies the north-

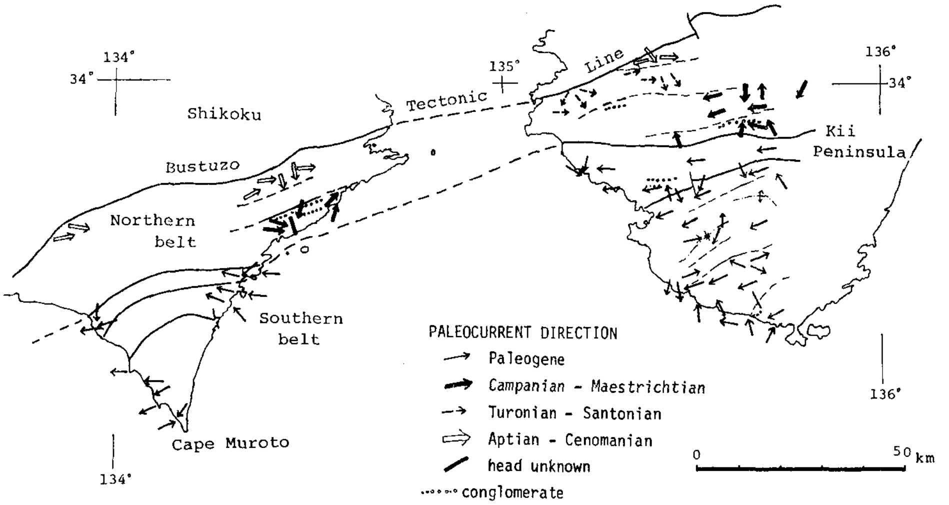

Fig. 13 Diagramatic sketch of the paleocurrents of the Shimanto Supergroup in eastern Shikoku and Kii Peninsula. Complied from KUMON (unpub. data), MIYAMOTO (1980), KUMON and INOUCHI (1976), KATTO and ARITA (1966) and TAIRA *et al.* (1980) in eastern Shikoku, and TANAKA (1974), NAKAZAWA *et al.* (1979), TOKUOKA *et al.* (1981), and K.S.R.G. (1975, and unpub. data) and TATEISHI (1978).

western marginal part of the Hidakagawa belt, are mostly lateral from north to south. The paleocurrents of late Late Cretaceous (Campanian to Maestrichtian) are fairly variable, namely those of the Hiwasa Formation are mainly longitudinal from west to east, while those of the Ryujin Formation are also longitudinal but from the opposite direction. A few lateral current directions from north to south and south to north are also found in the Hiwasa and Ryujin Formations. In the Nyunokawa Formation, lateral paleocurrents from south to north are superior to the longitudinal ones from east to west.

It is obvious that the clastic sediments of the Cretaceous had been transported mainly by the longitudinal currents and lateral currents from north to south, with the exception of the Nyunokawa Formation. Furthermore, the clastic sediments of the Cretaceous are similar in composition with those of the correlative strata in the Chichibu Terrain on the north which were certainly derived from the northern source land (MIYAMOTO, 1980). These facts indicate that the major source land situated to the north of the basin in the Cretaceous age excluding the latest Cretaceous Nyunokawa Formation. The clastic sediments of the Nyunokawa Formation were probably derived from the southern source land, judging from the northerly lateral paleocurrents. The different sandstone composition of the Nyunokawa Formation from that of the other Cretaceous formations may reflect such paleogeographic difference. In western Shikoku, a southern source land in latest Cretaceous age was also supposed by TANAKA (1977), on the basis of the fact that southward increase of the coarse clastic sediments, the northerly lateral currents, and the compositional pecularity of the sediments derived from the south.

Many paleocurrent directions were measured in the Paleogene strata. Although the directions are fairly variable, the longitudinal paleocurrents from east to west or northeast to southwest are much more common than the other directions. Lateral paleocurrents from north to south and from south to north are also clearly observable. In the southern coast of the Kii Peninsula, submarine channel deposits derived from the south were recognized by TATEISHI (1978).

These facts indicate the existance of the source land to the both sides of the basin in the Paleogene (K.S.R.G., 1968, 1975; TATEISHI, 1978). The lateral currents from south, however, is limited in distribution to the southernmost part of the Kii Peninsula, and the northern land is referred to a major source of the Paleogene sediments. The clastic sediments certainly derived from the south are not so different from those derived from the north, excepting the presence of orthoquartzite clasts in the former (SUZUKI *et al.*, 1979; TATEISHI *et al.*, 1979).

IV. Characteristics of the Coarse Clastic Rocks and Their Stratigraphic Change

Founded on the description on the coarse clastic sediments of the Shimanto Supergroup given in the preceding chapter, the author will give some consideration on the composition of conglomerate and sandstone mainly from the stratigraphic viewpoint.

1. Stratigraphic Change of Sandstone Composition

A. Stratigraphic Change in Eastern Shikoku and Kii Peninsula.

In discussing the crustal movements which occurred in the hinterland, mineral composition of sandstone is more useful than conglomerate composition, because the successive occurrence can be examined throughout the geologic column of the Shimanto Supergroup.

The mineral compositions of the sandstones from the Shimanto Supergroup in eastern Shikoku and Kii Peninsula are fairly variable among the formations or members (Figs. 10, 12 and 14). The stratigraphic correlation between eastern Shikoku and the Kii Peninsula had been discussed in Section II-3 (Fig. 6). It is evident that the sandstones of the correlative strata between the both areas have similar mineral composition, as mentioned in the followings (Fig. 14). The stratigraphic change of sandstone composition is shown in Figs. 15 and 16.

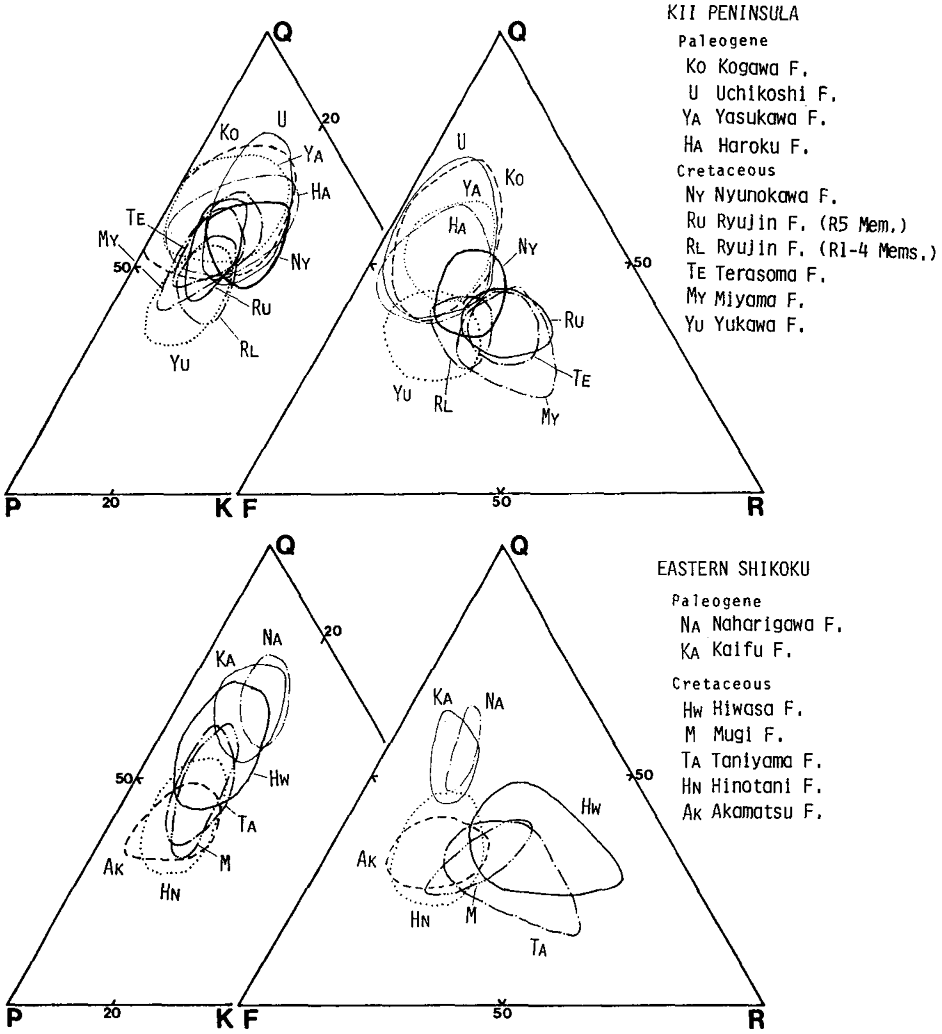

Fig. 14 Comparison of the sandstone compositions between the formations of the Shimanto Supergroup in eastern Shikoku and Kii Peninsula.

CRETACEOUS

The sandstones of the Hauterivian to Cenomanian strata, that is, the Akamatsu and Hinotani Formations in eastern Shikoku, and the Yukawa Formation in the Kii Peninsula, are characterized by the abundance of feldspar, especially of plagioclase, and a relatively small amount of rock fragments. Additionally, andesitic volcanic rocks are relatively abundant in volcanic rock fragments. The sandstones of the upper part of the Hinotani Fromation are relatively rich in rock fragments.

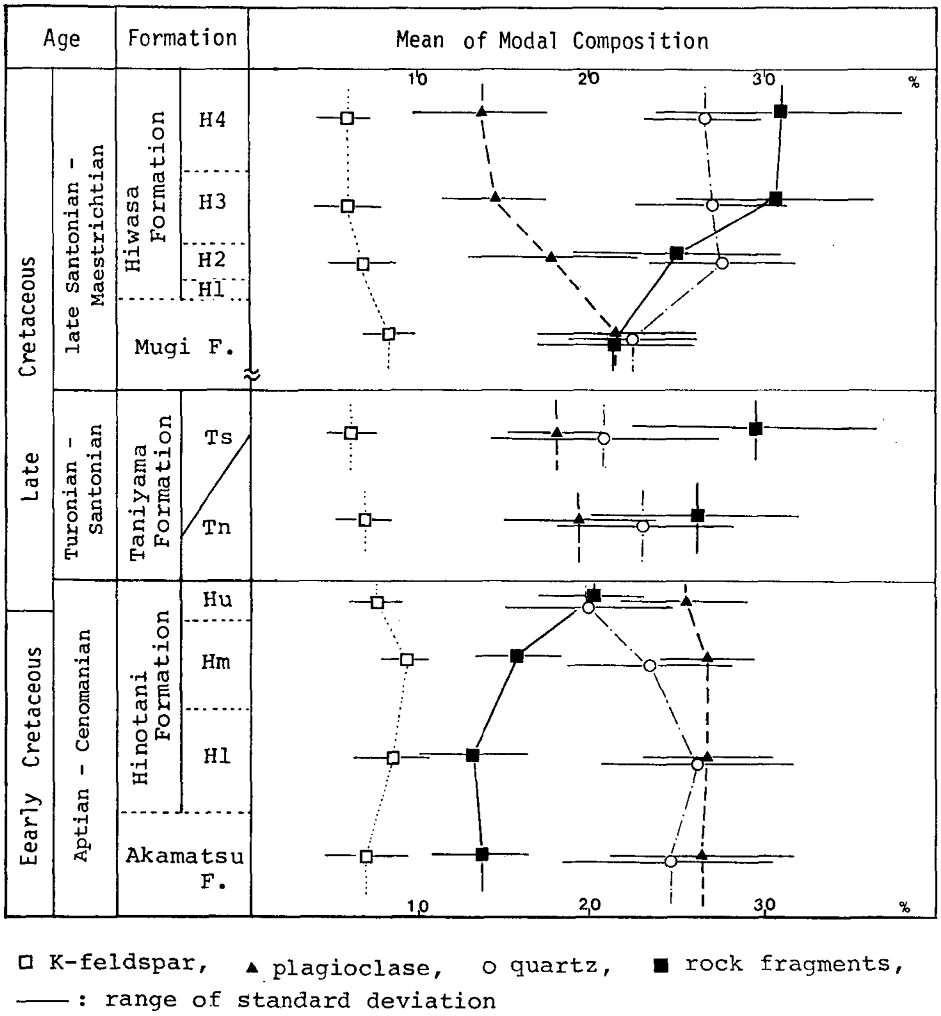

Fig. 15 Stratigraphic change of sandstone composition in the Cretaceous sequences of the Shimanto Supergroup in eastern Shikoku.

The sandstones of the Turonian to Santonian strata, that is, the Taniyama, Miyama and Terasoma Formations are dominant in rock fragments and poor in feldspar. Acidic volcanic rocks are predominant in volcanic rock fragments.

The sandstones of the late Santonian to Campanian strata, that is, the Mugi and lower Ryujin Formations are slightly rich in plagioclase, and not so abundant in rock fragments as those below and above.

The sandstones of the Campanian to Maestrichtian strata, that is, the Hiwasa and upper Ryujin Formations, are characterized by the dominance of rock fragments,

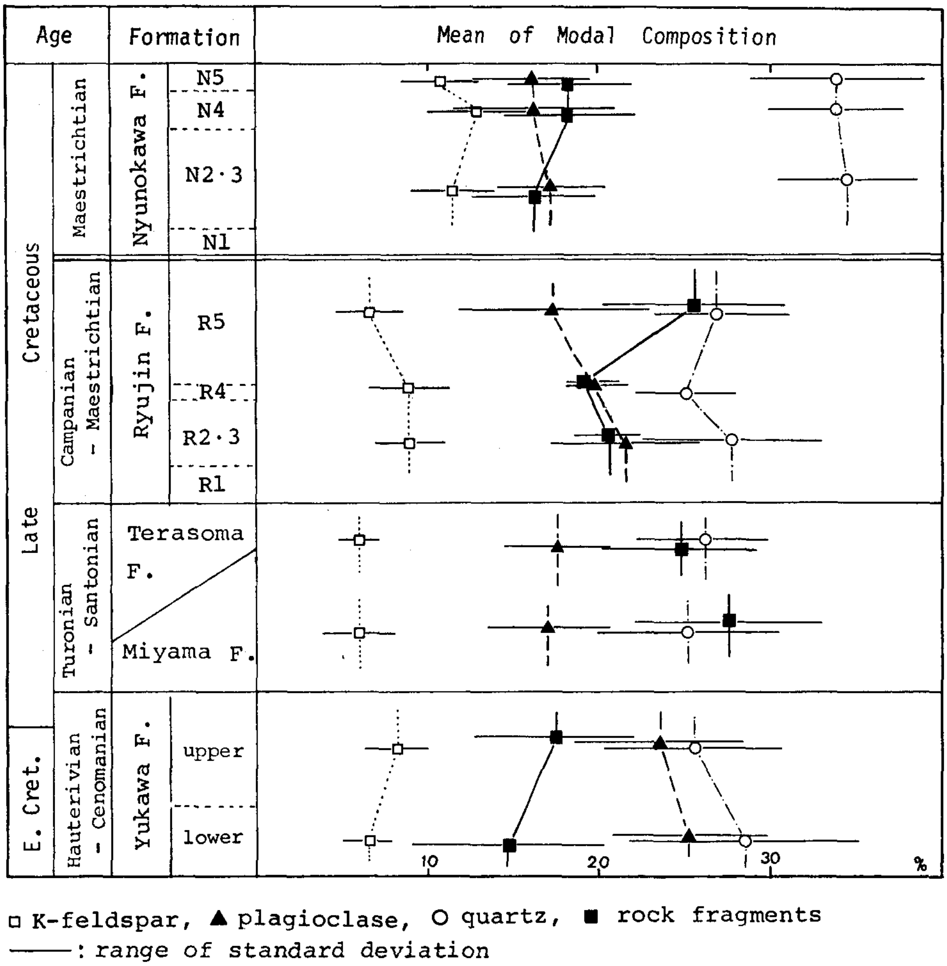

Fig. 16 Stratigraphic change of sandstone composition in the Cretaceous sequences of the Shimanto Supergroup in the Kii Peninsula.

especially of acidic volcanic rock fragments, and a relatively small amount of plagioclase. The sandstones of the lower part of the Hiwasa Formation (H_2 Member) have a small amount of rock fragments compared with the those of the major Hiwasa Formation (H_3 and H_4 Members), and have a transitional properties from the Mugi to the major Hiwasa Formations.

The sandstones of the Nyunokawa Formation, probably of Maestrichtian age, are characterized by the dominance of quartz and a relatively small amount of rock fragments. The amount of potash feldspar and quartz in this formation is largest among the Cretaceous formations. There are no strata in eastern Shikoku, of which sandstones have the petrographic properties similar to those of the Nyunokawa Formation. The sedimentologic study suggests the northerly supply of its clastic sediments. Therefore, it is probable that the characteristics of sandstone composition are caused by the difference of the source land, namely, the southern source land.

In general, mineral composition of sandstone relates to the textural properties such as grain size, grain shape, sorting, and transportation process. In the case of the present study, however, there are no significant differences in grain size, grain shape and sorting of sandstone among the above-mentioned formations. Furthermore, most of the sandstones are considered to have been transported and deposited by the sediment gravity flows such as turbidity currents and/or grain flows as mentioned previously. Therefore, the characteristics of sandstone compostion in the formations are considered to have resulted from the change of the nature of provenance.

The conglomerates of the middle Hinotani Formation are composed mainly of sandstone, shale, muddy limestone, acidic volcanic rocks and intermediate volcanic rocks, each in almost equivalent amount. Those of the Taniyama, Hiwasa and upper Ryujin Formations are predominant in acidic volcanic rocks associated with a small amount of intermediate volcanic rocks and sedimentary rocks. The conglomerates of the Nyunokawa Formation are composed mostly of acidic volcanic rocks, granitic rocks, sandstone, shale and chert, and are characterized by abundant granitic rocks. The compositional properties of the conglomerates are concordant with the sandstone composition in each formation. This fact also indicates that the change of the sandstone composition had resulted from the change of the provenance nature.

PALEOGENE

The sandstones of the Paleogene are very different from the Cretaceous sandstones in mineral composition. They are very dominant in quartz, and poor in rock fragments in both eastern Shikoku and Kii Peninsula. The Paleogene sandstones are rather uniform in mineral composition, and any remarkable stratigraphic change can not be observed throughout the Paleogene. The conglomerates of the Paleogene are abundant in sedimentary rocks such as chert, sandstone and shale, which occupy one-half to two-thirds of the total. Granitic rocks are commonly contained, although small in amount. These conglomerate properties seem also to be concordant with the sandstone composition of the Paleogene, which is characetrized by significant increase of granitic rocks and sedimentary rocks in the rock fragments.

B. Comparison with the Sandstones in the Other Regions

The difference of sandstone composition between the Cretaceous and Paleogene is clearly distinguished in the Akaishi Mountains, western Shikoku and Kyushu (TOKUOKA and KUMON, 1979; TERAOKA, 1979; OKADA, 1977), with some exceptions. Most Paleogene sandstones are dominant in quartz, and poor in rock fragments compared with the Cretaceous sandstones throughout the Shimanto Belt, as insisted by

TERAOKA (1979).

The stratigraphic change of sandstone composition could not be observed among the Paleogene formations. On the other hand, the modal composition of the Cretaceous sandstones in the above-mentioned areas are considerably variable among the formations. Unfortunately, the geologic ages of the sandstones examined are not so reliable in most cases, because of the lack of fossil evidence.

There is a tendency that the sandstone in the northern zone of the Cretaceous belt are rich in feldspar and poor in rock fragments, those in the middle and southern zones are rich in rock fragments. For example, the sandstones in northern zone of the Cretaceous Morotsuka belt in Kyushu are feldspathic, especially of plagioclase, and those in the southern zone are rich in rock fragments, especially of acidic to intermediate volcanic rocks (TERAOKA, 1977; IMAI *et al.*, 1979; OKADA, 1977). The sandstones of the Aptian to Albian Hayama Formation in the northern part of the Cretaceous belt in central Shikoku are dominant in feldspar and poor in rock fragments (MIYAMOTO, 1976). The sandstones in the southern margin of the Cretaceous belt in the Akaishi Mountains are dominant in rock fragments, mainly of acidic volcanic rocks (TOKUOKA and KUMON, 1979). If the strata in the Cretaceous belt become young southward zone by zone throughout the Shimanto Belt like as in eastern Shikoku and Kii Peninsula, the difference of the sandstone composition among the Cretaceous formations are roughly concordant with the stratigraphic change of sandstone composition elucidated in eastern Shikoku and Kii Peninsula.

3. Implication of the Successive Change of Sandstone Composition during the Cretaceous Time

As stated previously (Section IV-1), the stratigraphic change of the mineral composition of the Cretaceous sandstones in the Shimanto Supergroup, is well recognized in eastern Shikoku and Kii Peninsula. It is of particular interest that the content of rock fragments consisting mainly of acidic and intermediate volcanic rocks, increases from late Early Cretaceous to Late Cretaceous in both areas, with some fluctuation (Figs. 15, 16 and 17). Conglomerates in the Late Cretaceous are also characterized by the dominance of acidic volcanic rocks in which pyroclastic rocks, often welded, are predominant. A large volume of coarse clastic rocks with high content of volcanic materials of the Hiwasa Formation suggests violent volcanism of acidic to intermediate composition which produced much pyroclastic rocks on the land during the Late Cretaceous age (KUMON, 1981). The volcanic activity seems to have begun in Cenomanian or Turonian, judging from the increasing amount of the rock fragments from Cenomanian to Turonian (Fig. 17). A great deal of volcanic products had covered extensively the surface of the source land, and immediately after the volcanic eruptions, they had begun to be eroded and transported to the site of deposition. This presumption is strongly supported by the evidence that acidic

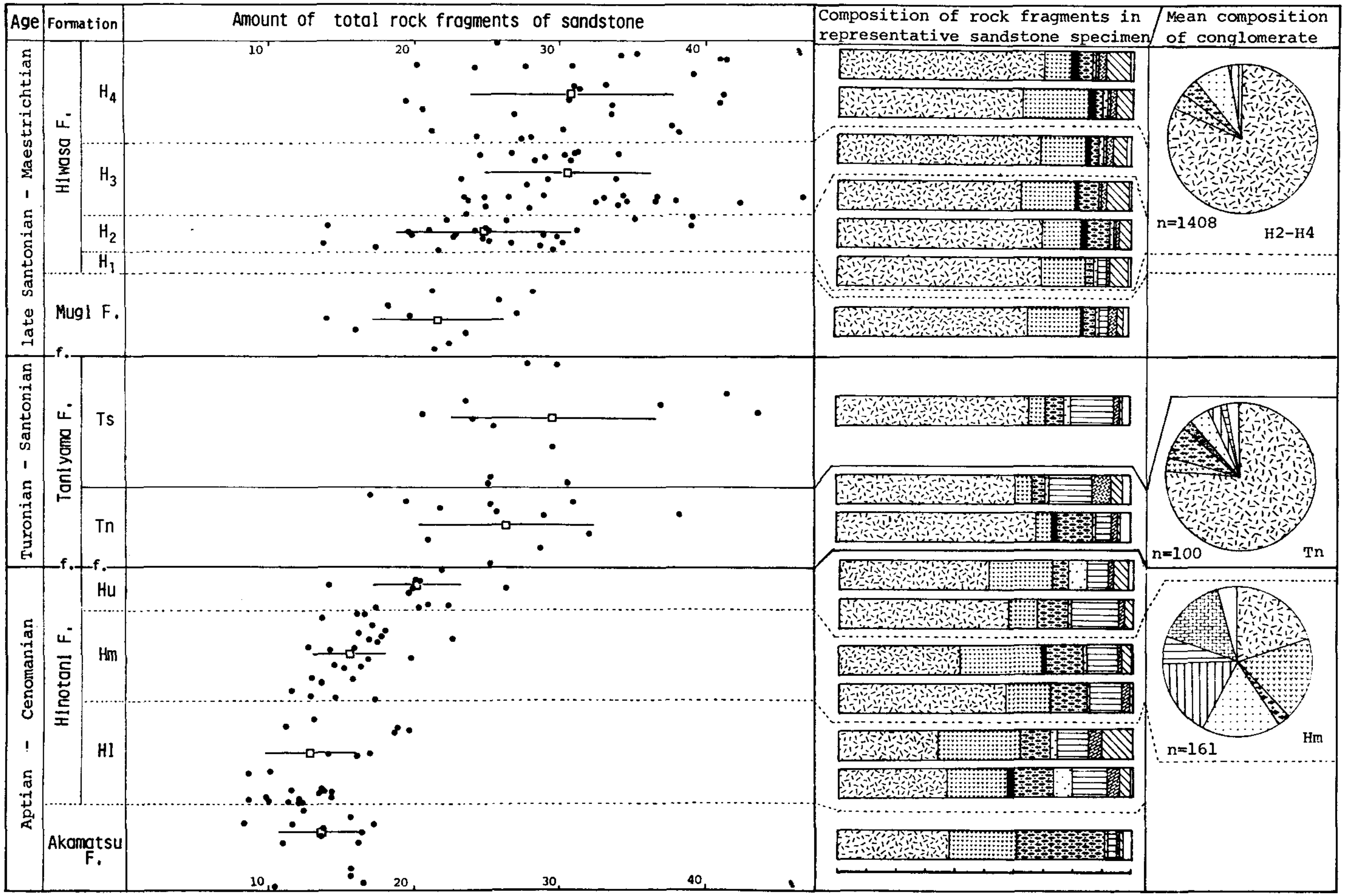

Fig. 17 Increasing trend of rock fragments, mainly of acidic to intermediate volcanic rocks, in the Createceous sequences of the Shimanto Supergroup in eastern Shikoku. Keys of the compositional diagrams are same as in Fig. 9 and Fig. 11, repectively.

tuffs are frequently intercalated in the Late Cretaceous strata in the Shimanto Belt. They are mainly fine-grained, but coarse-grained tuffs or even lapilli tuffs are often discovered in them. Furthermore, some of the acidic tuffs attain to severla tens of meters in thickness. It is probable that these tuffs are transported directly from the volcanism sites in the hinterland near the basin.

Generally, volcanism produces a high relief of topography, and destroys extensively the vegetative cover on the land. These factors increase significantly the production of clastic sediments, mainly of volcanic rocks, resulting in rapid and thick accumulation in the depositional site. Such an example in modern times was reported by KUENZI *et al.*, (1979) in southwestern Guatemala. It seems likely that the similar processes had occurred in the hinterland and the depositional site of the Shimanto Supergroup during the Late Cretaceous.

As well known, aicdic to intermediate volcanic and plutonic rocks, mostly of acidic composition, are widely distributed in the Inner Zone of Southwest Japan, especially in the Sangun and Tamba Belts (YAMADA, 1977). YAMADA distinguished three intrusive phases of the plutonic rocks, that is, Phase I (early Late Cretaceous), Phase II (latest Cretaceous to earliest Paleogene), and Phase III (middle Paleogene). He also divided the volcanic activities into five stages, that is, Stage I (late Early Cretaceous), Stage II (earliest Late Cretaceous), Stage III (Late Cretaceous), Stage IV (early Paleogene), and Stage V (late Paleogene). Among the five stages, the volcanic rocks of Stage III are most extensive in distribution, and those of the Stage IV and Stage V are sporadically distributed in small areas. It is noticeable that the stage of extensive volcanism roughly corresponds to the time of a large supply of volcanic materials to the Shimanto basin. As the acidic volcanic clasts in the late Late Cretaceous Shimanto Supergroup are petrographically similar to the volcanic rocks in the Inner Zone (KUMON, 1981), and the paleocurrent analysis indicates the provenance to the north, the sedimentation of the Shimanto basin is considered to have related to the magmatism in the Inner Zone. It is highly probable that the volcanism of the Stages II and III associated with plutonic intrusions of Phases I and II in the Inner Zone, resulted in the supply of much volcanic materials into the Shimanto basin.

An intimate relation between the geosynclinal sedimentaion in the basin and volcanism in the hinterland is found in arc-trench system. DICKINSON and his colleagues (DICKINSON and RICH, 1972; INGERSOLL, 1979; MANSFIELD, 1979) advocated that the clastic sediments of the Great Valley Sequence in California, ranging in age from late Jurassic to Late Cretaceous, were supplied from the Sierra Nevada magmatic arc to the east, and formed a very thick sedimentary sequence. DICKINSON and SEELY (1979) regarded it as a typical forearc sediments in arc-trench system. In the case of the Great Valley Sequence, however, the amount of volcanic rocks fragments decrease upward as a whole (MANSFIELD, 1979), indicating that the main volcanism in the source area had already ended before the major sedimentation took palce. They explained the stratigraphic change of the sandstone composition as the result of the unroofing and dissecting process of the Sierra Neveda magmatic arc. In the case of the Cretaceous Shimanto Supergroup, the sedimentation proceeded with contemporaneous volcanism as clarified in the present study, and the transition from the Cretaceous to the Paleogene may be compared to the Great Valley Sequence, as will be mentioned in the next section.

On the basis of the recent study by NAKAZAWA *et al.* (1983), the Turonian to Santonian Miyama Formation which intercalates chert-greenstones olistostromes among the flysch units was considered to be trench sediments, and the chert and greenstones were inferred to have been derived from submarine volcanic seamounts. Then, the Shimanto basin and its hinterland in the Late Cretaceous period seems to have formed an arc-trench system.

In conclusion, it is evident that the sedimentation of the Late Cretaceous Shimanto Supergroup had progressed contemporaneously with the violent volcanisms in the hinterland, receiving much clastic sediments from the sites of volcanism.

4. Implication of the Major Change of the Sandstone Composition from the Cretaceous to the Paleogene

As mentioned before, the Paleogene sandstones are very dominant in quartz and poor in rock fragments, and are quite different in mineral composition from the Late Cretaceous sandstones. The increase of sedimentary rocks and granitic rocks in conglomerate clasts and also in rock fragments of sandstone suggests the larger exposure of those rocks in the source land during Paleogene than before. Judging from the abundance of quartz, plagioclase and potash feldspar, and the relatively high ratio of granitic rock fragments to the total rock fragments, granitic rocks must have played an important role. A relatively small amount of granitic clasts in the conglomerates may be explained by the fact that granite is easily weathered to sand. It is reasonable to infer that the acidic volcanic rocks once distributed widely in the source area had been much eroded during the latest Cretaceous to early Paleogene time, and that the older sedimentary rocks and granitic rocks beneath the volcanic rocks had become to be exposed in the Paleogene. Namely, the compositional change of clastic rocks in the Shimanto Terrain can be explained by the unroofing process of magmatic arc as supposed by MANSFIELD (1979) in the Great Valley Sequence. Additionally, the sedimentary rocks in the Chichibu and Sambagawa Belts which probably emerged in this time might become an another source of the Paleogene sediment.

TERAOKA (1979) emphasized the paleogeographic change between the latest Cretaceous and early Paleogene age as a cause of the difference of sandstone composition between the Cretaceous and the Paleogene, although he considered that the igneous rocks in the Inner Zone remained as main source during the Paleogene time.

According to him, the Sambagawa and Chichibu Belts, and even the northern part of the Shimanto Belt, had rised to be land at early Paleogene, and this land should have interrupted the immediate supply of sediments from the Inner Zone to the Shimanto Terrain. In addition, the main depositional site of the Shimanto basin migrated southward. He considered that the long distance and long time of the sediment transportation and also the recycled derivation from the older sedimentary rocks produced quartz-rich sediments of the Paleogene age. But, the grains of the Paleogene sandstones are mostly subangular to subrounded and not so mature in texture. Furthermore, they have nearly same grain-size as those of the similar bedded sandstone of the Cretaceous. Moreover, unstable grains such as granitic rocks, shale and polycrystalline quartz are commonly observable. Therefore, it is difficult to explain the high content of quartz only by the maturation of the sediments during the transportation and the recycled derivation process.

OKADA (1977) proposed three petrographic zones, that is, of the Cretaceous, early Paleogene and late Paleogene age, respectively, on the basis of the regular decrease of the feldspar content in sandstone. Most sandstone of the Paleogene, however, contain the same amount of feldspar as those of the Late Cretaceous in this study area, and there found no difference of feldspar content among the Paleogene strata. In Kyushu and western Shikoku, the difference of feldspar content is very small between the late Cretaceous and the Paleogene, and the difference is not observed between the early and late Paleogene, according to TERAOKA's study (1977, 1979). Therefore, it is not suitable to define such petrographic zones based on feldspar amount only. OKADA also insisted that the clastic materials of the Paleogene were mainly derived from the older Cretaceous sediments in the same Shimanto Belt. He explained the characteristics of the Paleogene sandstones by the recycled derivation from the Cretaceous sandstones. His opinion seems to be inappropriate by the same reasons stated above. Furthermore, clasts of red chert which occurs frequently and characteristically in the Cretaceous of the Shimanto Belt are almost absent in the Paleogene conglomerates, in spite of common occurrence of the other-type chert clasts in them. This is also a negative fact for recycling concept.

V. Geological Development of the Shimanto Geosyncline in Eastern Shikoku and Kii Peninsula Deduced from the Coarse Clastic Rocks

The developmental course of the Shimanto geosyncline can be divided into four stages mainly on the basis of the stratigraphic results and the compositional properties of the coarse clastic rocks as discussed in the foregoing chapters, and also taking the geologic setting in consideration as well.

Late Early to earliest Late Cretaceous (Hauterivian to Cenomanian)

Judging from the composition of coarse clastic materials, granitic rocks and sedimentary rocks such as sandstone, shale, chert, etc., were rather widely exposed in the source area, being accompanied with andesitic and rhyolitic volcanic rocks. The clastic sediments of this stage have similar properties of composition with those of the Upper Monobegawa Group in the Chichibu Terrain to the north. The clastic sediments of the Shimanto Supergroup in this stage were transported by the southerly lateral currents and easterly longitudinal currents. The source area situated to the north of the basin should be assigned to the Inner Zone, and a part of the Chichibu and Sambagawa Belts in the Outer Zone. There were extensive andesitic volcanism of late Early Cretaceous in the Inner Zone, especially in its western part, as indicated by pyroclastic rocks of the Shimonoseki Subgroup (YAMADA, 1977). This may be reflected in a relatively large ratio of andesitic materials among the volcanic clasts of the Shimanto Belt, although the rock fragments are not so abundant. As discussed by NAKAZAWA *et al.* (1979), the sedimentary environment was relatively shallow. There are found almost no accretional sediments of oceanic nature. Exotic chert rarely seen in this stage is considered to be derived from the Chichibu Belt on the north.

The former geosynclinal basins in the Mino-Tamba and Chichibu Belts had uplifted in the latest Jurassic or earliest Cretaceous age, and the major sedimentary basin had shifted southward, generating Shimanto basin in the early Cretaceous. This stage may be an initial phase of the subduction of oceanic plate.

Late Cretaceous (Turonian to Maestrichtian)

This stage is characterized by the predominant volcanic materials in the sediments of the Shimanto Belt corresponding to the violent acidic volcanism in the Inner Zone of Southwest Japan. The paleocurrents show the sediments to have been transported to the Shimanto basin from the northern terrain by longitudinal and lateral turbidity currents and/or grain flows. Abundant volcanic materials are also found in the sediments of the coeval Sotoizumi Group in the Chichibu Belt and Izumi Group in the Ryoke Belt. Another feature of this stage is the development of chert-greenstones olistostrome, which is typically represented by the Taniyama Formation in eastern Shikoku and the Miyama Formation in the Kii Peninsula (NAKAZAWA *et al.*, 1983). The both formations are made of the repetition of flysch-like alternating beds of sandstone and shale, and intercalated chert-greenstones olistostromes both of which are presumably trench deposits. It is noticeable that the forearc basin deposits, such as the Terasoma Formation, are also developed in the northern part of the Shimanto basin in this stage. Thus, in this stage, the continental-margin arc-trench system was fully established.

The strata of late Santonian to Campanian age, that is, the Mugi and lower Ryujin Formations, are characterized by the dominance of muddy facies. The contemporaneous strata in the Chichibu Belt are also dominant in muddy facies. Rock fragments in sandstone are relativley small in amount. This period may represent a relatively quiescent crustal movement. In Campanian to Maestrichtian age, longitudinal currents from west are occasionally observed in eastern Shikoku, while those from the opposite direction are recognized in the Kii Peninsula (Section III-4). The compositional properties of clastic rocks of the Campanian to Maestrichtian Izumi Group in the Inner Zone resemble those of the Shimanto Supergroup of this period (NISHIMURA, 1975; TERAOKA, 1976). This period is characterized by the dominance of coarse clastic sediments both in the Shimanto Belt and Izumi belt. The large amount of clastic materials in the Shimanto Belt may have been transported by bypassing the Izumi basin.

Latest Cretaceous (Maestrichtian)

In this stage, there appeared another source land to the south of the basin, judging from the paleocurrent analysis of the Nyunokawa Formation. It is inferred that the southern landmass was composed mainly of acidic volcanic rocks, granitic rocks and sedimentary rocks, and had the crust of continental nature, on the basis of the conglomerate and sandstone composition. Granitic rocks and sedimentary rocks were more widely cropped out there than in the above-mentioned northern land. The size and extension of the southern source land is unknown. The landmass seems to have migrated from the south by the plate movement. This southern land may be a precursor of the Kuroshio Paleoland in the Paleogene time proposed by K.S.R.G. (1968, 1970, 1975) and HARATA *et al.* (1978). The Shimanto basin was put into the continent-microcontinent or continent-island arc situation.

Paleogene (Eocene to early Miocene)

Entering into the Paleogene time, the depositional site was migrated southward, presumably caused by the shifting of subduction zone south of the southern land. Terrigenous materials were transported mainly from the north as stated in SectionIII-4. Acidic volcanic rocks which have widely covered the northern hinterland during the Late Cretaceous time had largely been eroded in the Paleogene time, and the granitic rocks and sedimentary rocks underlying the volcanic rocks cropped out more widely. Thus the compositional change from the Cretaceous to the Paleogene can be explained by the unroofing of the hinterland. On the other hand, a part of the Paleogene sediments were derived from the south (K.S.R.G., 1968, 1970, 1975; TATEISHI, 1978). Granitic rocks and sedimentary rocks were distributed widely also in the southern source land. Supposing that the orthoquartzite clasts are Precambrian in origin, the Precambrian basement might have been exposed in the southern land in the Paleogene time (TOKUOKA and OKAMI, 1979).

The lithology, geologic structures, and sandstone and conglomerate composition of the Shimanto Supergroup were much changed from the Cretaceous to the Paleogene.

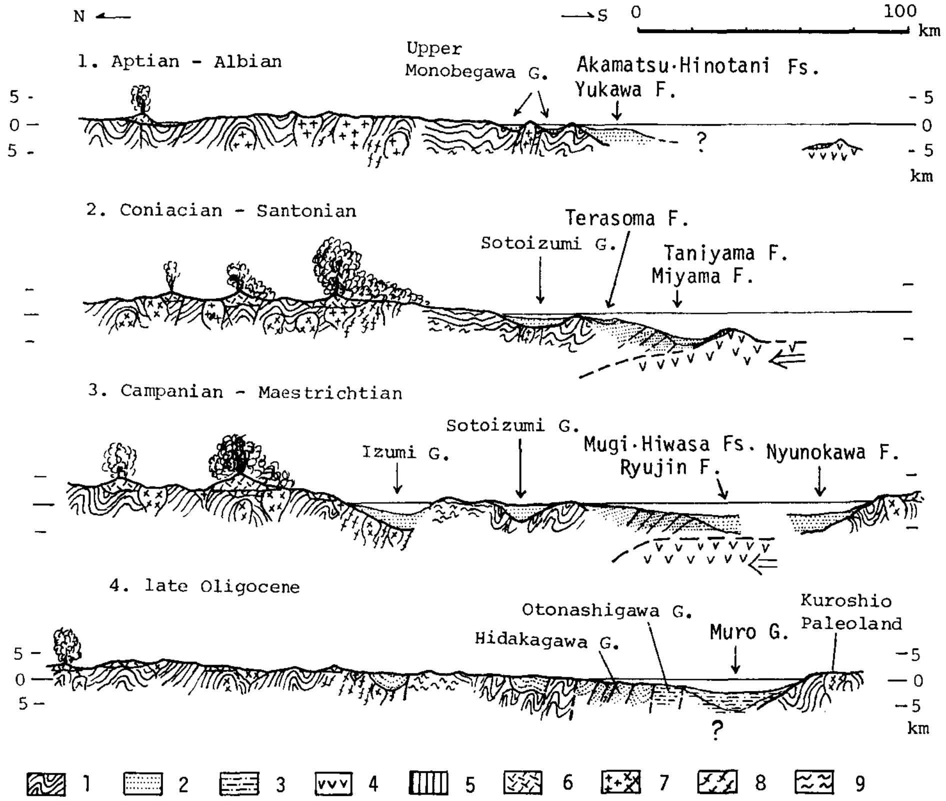

Fig. 18 Schematic cross sections of the Shimanto geosyncline and its hinterland deduced from clastic sediments. The figures are illustrated as a typical one in each stage.
1: Paleozoic to early Mesozoic strata, 2: Cretaceous sediments, 3: Paleogene sediments, 4. greenstones, 5: chert, 6: acidic to intermediate volcanic rocks, 7: granitic rocks, 8: gneiss, 9: schist.

These differences are recognized throughout the Shimanto Belt. These facts suggest that there occurred a tectonic movement during the Cretaceous-Paleogene transition, resulting in a different geotectonic setting of the Paleogene basin from the Cretaceous. It is supposed that the latest Cretaceous southern landmass collided with the northern continent, and the both lands were upheaved leaving the Paleogene remnant basin similar to a forearc basin. The geologic development of the Shimanto Terrain is schematically illustrated in Fig. 18.

There are two different opinions on the geotectonic setting of the Shimanto geosyncline. Kanmera and Sakai (1975), Suzuki and Hada (1979), Taira et al. (1980) and others tried to explain the Shimanto Supergroup as the accretionary complex of the subduction belt. On the other hand, K.S.R.G. (1975), Kimura (1977), Teraoka (1979) and Yanai (1981) considered that the Shimanto Supergroup was formed in an "intercontinental basin" or forearc basin with the sialic basement. As discussed above, the geotectonic setting of the Shimanto belt has changed stage by stage, and was not so simple. It seems to be comparable to a kind of marginal sea setting something like the present Philippine Sea rather than a simple arc-trench system.

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Locality Name

Akaishi	赤石	Akamatsu	赤松	Chichibu	秩父
Fudono	伏菟野	Gamohda	蒲生田	Gobo	御坊
Hagi	萩	Haroku	羽六	Hayama	半山
Hinotani	日野谷	Hiwasa	日和佐	Hidakagawa	日高川
Hongu	本宮	Kaifu	海部	Kii	紀伊
Kimidani	紀美谷	Kogawa	合川	Kumano	熊野
Kwanto	関東	Matsune	松根	Miyama	美山
Morotsuka	諸塚	Muro	牟婁	Muroto	室戸
Murotohanto	室戸半島	Naharigawa	奈半利川	Nansei	南西
Nyunokawa	丹生ノ川	Otonashigawa	音無川	Ryujin	龍神
Shikoku	四国	Shimanto	四万十	Susami	周参見
Taniyama	谷山	Terasoma	寺杣	Tanabe	田辺
Uridani	瓜谷	Uchikoshi	打越	Wabuka	和深
Yasukawa	安川	Yukawa	湯川		

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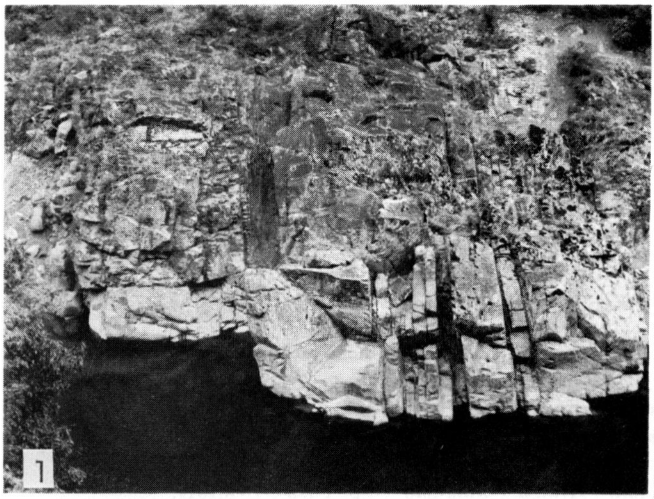
* In Japanese with English abstract.

** In Japanese.

Explanation of Plate 5

1. Thick-bedded sandstone of the Hinotani Formation. Maximum thickness of the sandstone bed is about 4 metres. Ondani, Kaminaka-cho, Tokushima Pref.
2. Cliff of the massive sandstone of the Hiwasa Formation. Senba Cliffs, Hiwasa-cho, Tokushima Pref.
3. Cobble conglomerate of the Hiwasa Formation. Okugawachi, Hiwasa-cho, Tokushima Pref. The scale is 30 cm long.
4. Thick-bedded sandstone of the Naharigawa Formation. The sandstone beds are about 1 to 2 meters thick. Chichizaki, Shishikui-cho, Tokushima Pref.
5. Pebble conglomerate of the Uchikoshi Formation of the Muro Group. Nishi, Susami-cho, Wakayama Pref. The hammer is 28 cm long.
6. Thick-bedded sandstone of the Mitogawa Formation of the Muro Group. Mitogawa, Kozagawa-cho, Wakayama Pref.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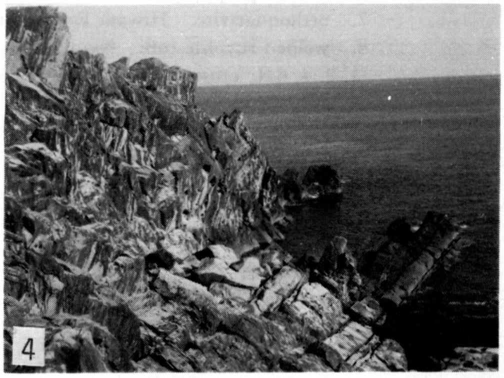
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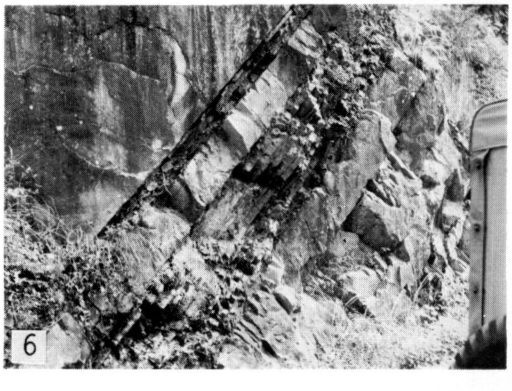
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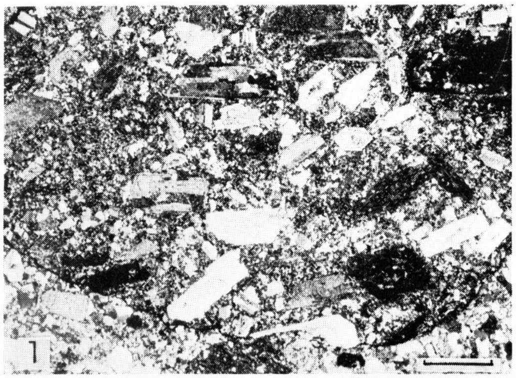
Kumon: Coarse Clastic Rocks of the Shimanto Group

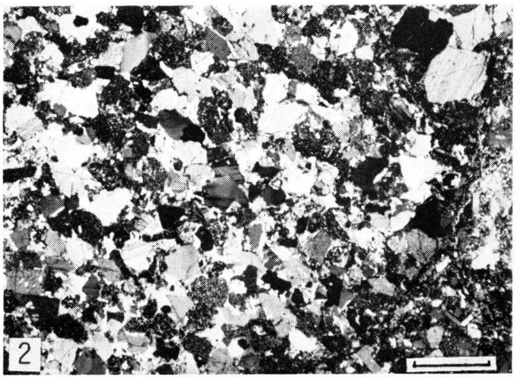
Explanation of Plate 6

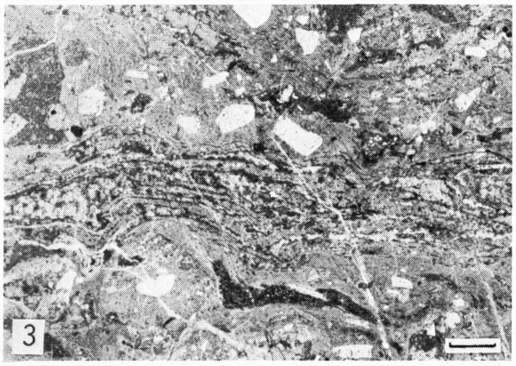
Photomicrographs of the conglomerate clasts from the Cretaceous Shimanto Supergroup. The scale are 1 mm in all figures.

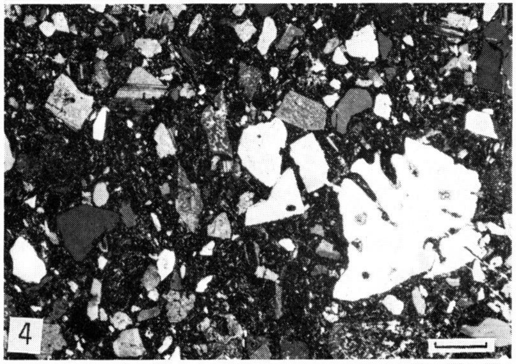
1. andesite clast. Hinotani Formation. (Sp. 7852704-b-5).
2. arkosic sandstone clast. Hinotani Formation. (Sp. 7852704-f-16).
3. welded rhyolite tuff. Hiwasa Formation. (Sp. Yibunohana-70).
4. vitric crystal rhyolite tuff. Hiwasa Formation. (Sp. Fukase-7690101).
5. vitric crystal rhyolite tuff with accretionary lapilli. Hiwasa Formation. (Sp. Honmura-24).
6. granite-porphyry. Hiwasa Formation. (Sp. Otani-7952806).
7. orthoquartzite. Hiwasa Formation. (Sp. Tsubadani-7583002).
8. welded rhyolite tuff. Nyunokawa Formation. (Sp. TOK-072, Loc. H-25).

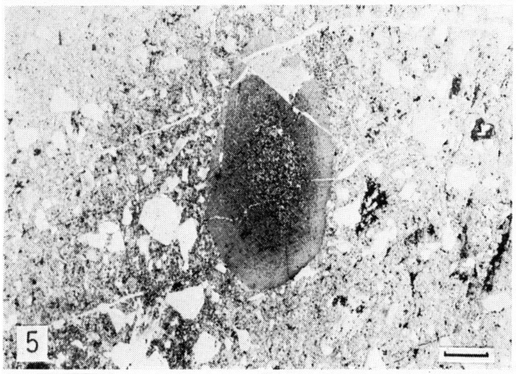
(1, 2, 4, 6-8: crossed nicols; 3, 5: open nicol)

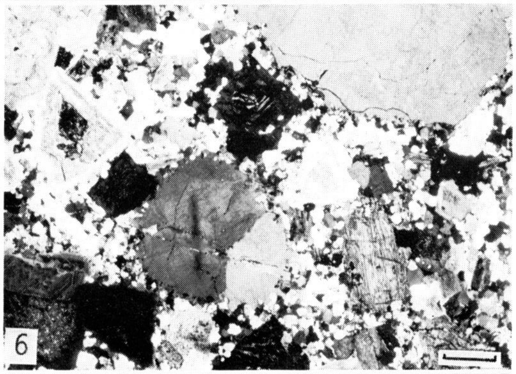


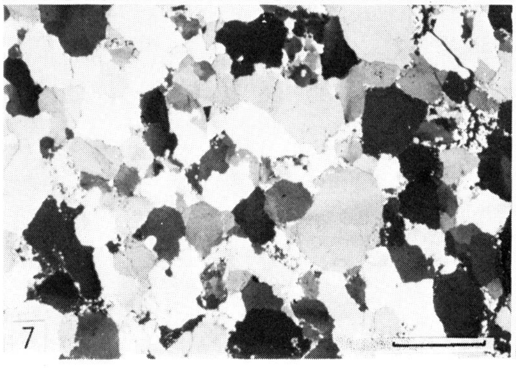


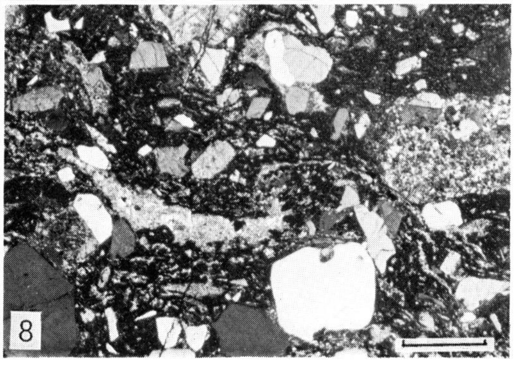












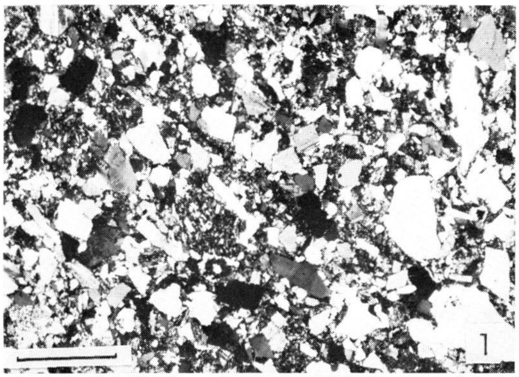
KUMON: Coarse Clastic Rocks of the Shimanto Group

Explanation of Plate 7

Photomicrographs of the sandstones from the Shimanto Supergroup in eastern Shikoku. The scales are 1 mm in all figures.

1. Hl Member of the Hinotani Formation. (Sp. 78X2805).
2. Hm Member of the Hinotani Formation. (Sp. 7732009).
3. Taniyama Formation (northern part). (Sp. 7682301).
4. Mugi Formation. (Sp. 7872502)
5. H_3 Member of the Hiwasa Formation. (Sp. 7571504).
6. H_4 Member of the Hiwasa Formation. (Sp. 7571706)
7. Kaifu Formation. (Sp. 7473121)
8. Naharigawa Formation. (Sp. 7473007).

(1–5, 7–8: crossed nicols; 6: opennicol))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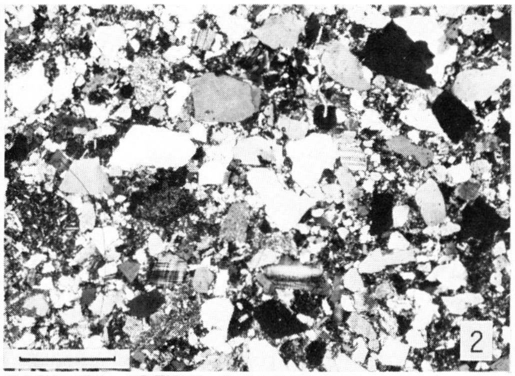
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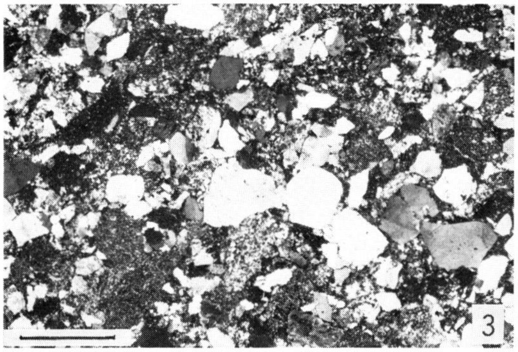
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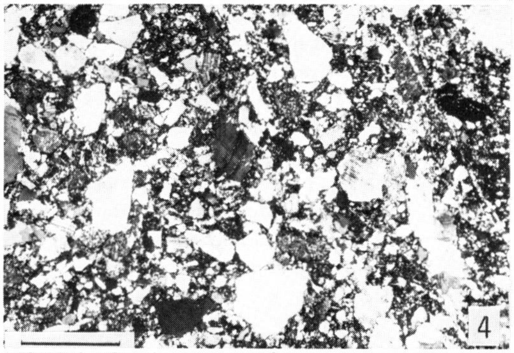
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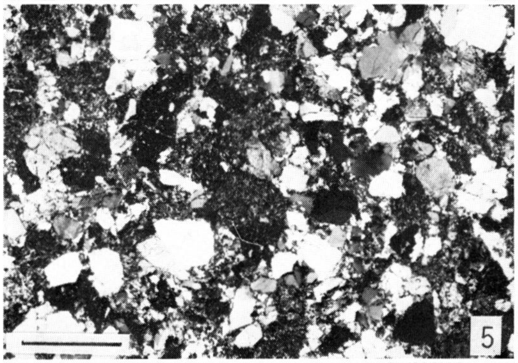
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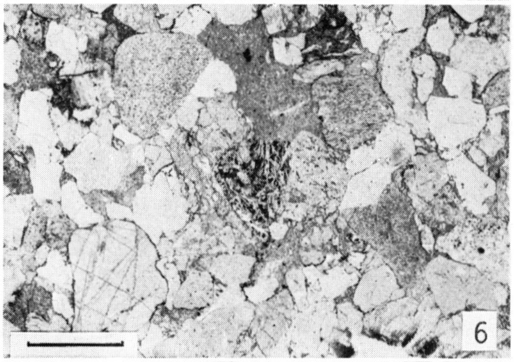
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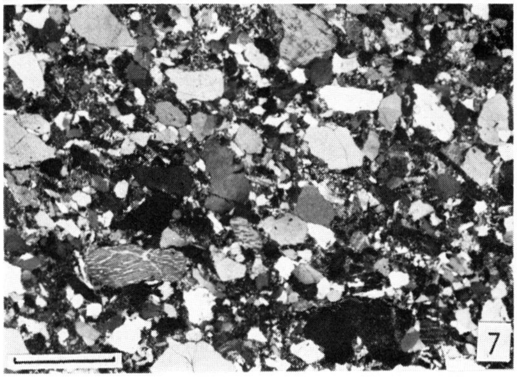
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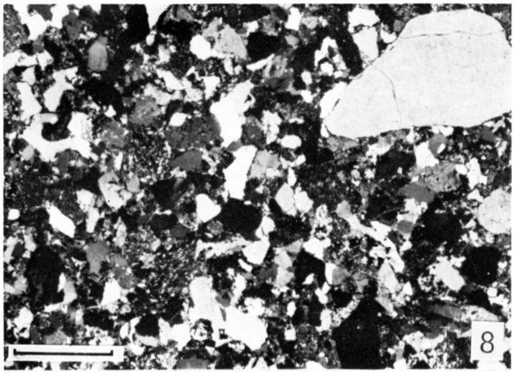
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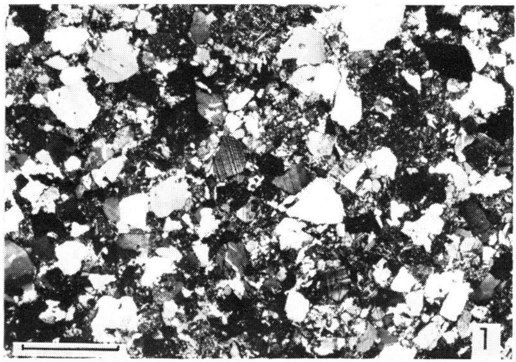
KUMON: Coarse Clastic Rocks of the Shimanto Group

Explanation of Plate 8

Photomicrographs of the sandstones from the Shimanto Supergroup in the Kii Peninsula. The scales are 1 mm in all figures.

1. Yukawa Formation. (Sp. Obako-BIII-2).
2. Miyama Formation. (Sp. Todoroki-FV-3).
3. Terasoma Formation. (Sp. 8032210).
4. R_4 Member of the Ryujin Formation. (Sp. Ryujin-CII-7).
5. R_5 Member of the Ryujin Formation. (Sp. Ryujin-EI-11).
6. N_4 Member of the Nyunokawa Formation. (Sp. Ryujin-CIV-7).
7. Upper Member of the Haroku Formation. (Sp. Takahara-3).
8. Uchikoshi Formation. (Sp. TOK-S-209).

(1–8: crossed nicols)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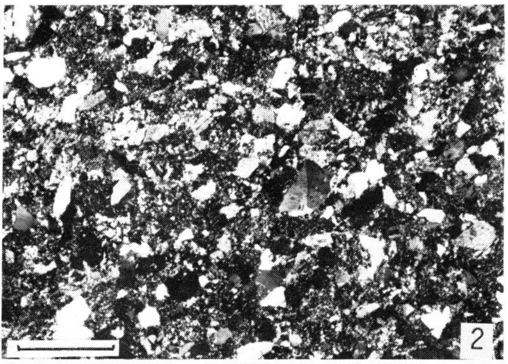
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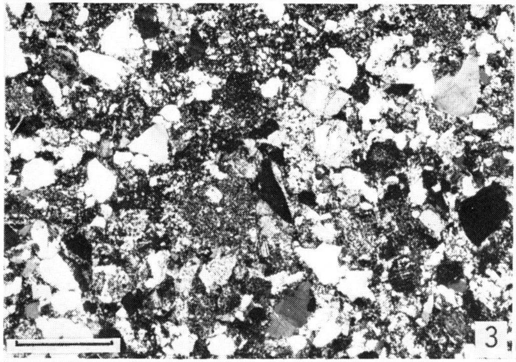
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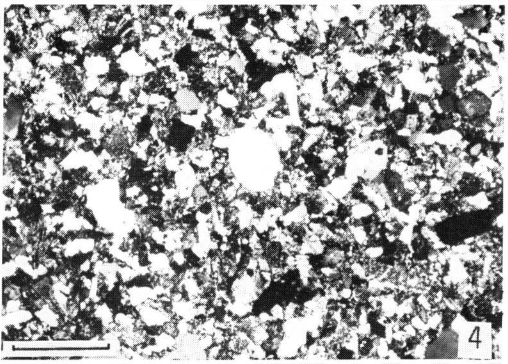
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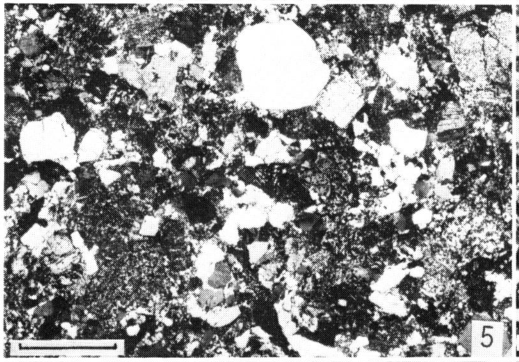
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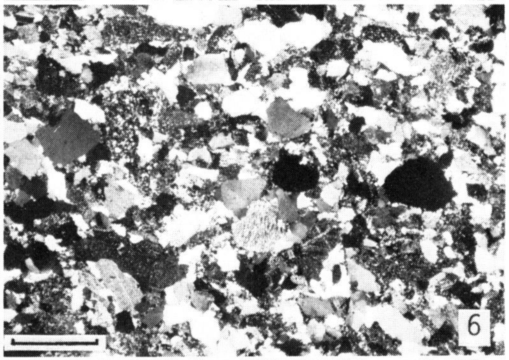
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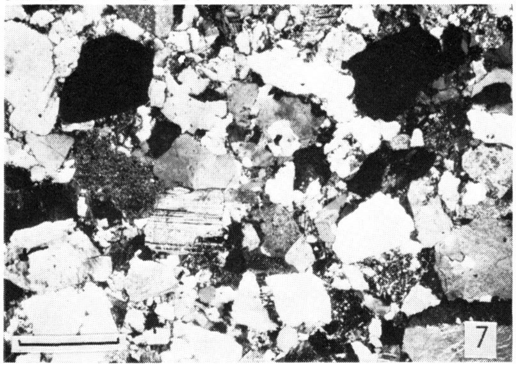
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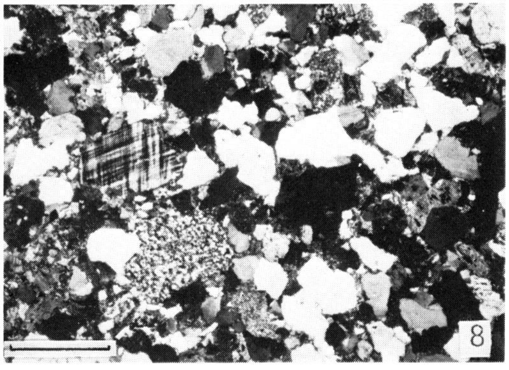
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Kumon: Coarse Clastic Rocks of the Shimanto Group