MEMOIRS OF THE FACULTY OF SCIENCE, KYOTO UNIVERSITY, SERIES OF GEOL. & MINERAL.,
Vol. XLVI, No. 1, pp. 1–60, pls. 1–5, 1979

Three Dimensional Analysis of a Large Sandy-Flysch Body, Mio-Pliocene Kiyosumi Formation, Boso Peninsula, Japan

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(Received January 13, 1979)

Contents

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Abstract

Three dimensional analysis of flysch sequence is very important as it makes substantially possible to compare the depositional process of it with that of the current submarine fan model and to clarify the phased development of submarine fan sedimentation. Such study has been almost lacking until now.

The Kiyosumi Formation is composed of a large lenticular sandy-flysch body, measuring 850 m in maximum thickness and more than 20 km in E–W direction along the folding axis and more than 6 km in N–S direction. The Kiyosumi Formation is divided into five units by means of six main tuff marker-beds. Each unit is composed mainly of both channel deposits and depositional tongue. Channel deposits are characterized by an upward thinning cycle beginning with thick pebbly sandstones and ending with thin siltstone-dominated alternations and by accompanying a large trough-like erosive morphology at the base attaining up to some 50 m in maximum depth and more than 5 km in maximum width. The depositional tongue is characterized by extensive and thick sandstone-dominated alternations downcurrent of the channel deposits and shows negligible basal erosion. Further downcurrent, the depositional tongues are replaced by siltstone-dominated alternations or massive siltstones.

The Kiyosumi Formation has been deposited by the lateral supply from north into the E–W trending restricted slope basin by the same process as that of the recent submarine fans. Channel deposits in each unit seem to have been deposited on the upper-fan segment. Depositional tongue in each unit must have formed a suprafan (NORMARK, 1970) on the middle fan segment. Siltstone-dominated alternations or massive siltstones must have been deposited on the lower-fan segment or basin floor. However each depositional tongue in the Kiyosumi Formation, covering a wide area more than 20 km, occupys a much more extensive segment on a fan than suprafans on recent submarine fans. Individual thick sandstone beds also continue persistently as wide as the tongue. The channel deposits and the depositional tongue in the lowermost unit show a peculiar distribution as fan sedimentation. They seem to be the deposits at "a preparatory stage" of fan sedimentation or at "a pre-fan-sedimentation stage" during which preexisting reliefs on the basin floor are smoothed and an equilibrium profile of the slope-fan-basin is attained.

The phased retreat of the terminus of channel deposits from the lowermost unit to the uppermost unit caused the first order upward thinning cycle detected throughout the Kiyosumi Formation. Shift of the channel to the different site was caused by beginning of each second order upward thinning cycle commonly observed in the channel deposits or by the rejuvenation of turbidity currents. The causes of these multiple upward thinning cycles, characterizing the vertical variation of the flysch sequence in the Kiyosumi Formation, are also discussed.

I. Introduction

A. Preliminary Remarks to the Present Study

1. Start of modern flysch sedimentology

Modern flysch sedimentology started when the turbidity current theory was applied to geology on land. First paradigmatic works were performed by KUENEN's two papers with two micropaleontologists (KUENEN and MIGLIORINI, 1950; NATLAND and KUENEN, 1951). Hereupon has come into the world an entirely new-styled scientific province which is based on land geology, marine geology and hydraulics. Turbidity current theory has not only coined the term "turbidite", but also produced the revolutionary effects on a realm of clastic sedimentation. According to WALKER (1973), the turbidity current hypothesis constitutes a revolution perhaps equal in magnitude and importance to the continental drift revolution.

Until now, a large number of papers have been published on turbidite and flysch (KUENEN and HUBERT, 1964; DZULYNSKI and WALTON, 1965; WALKER, 1973; *etc.*).

Modern flysch sedimentology landed in Japan in 1960's. Thereafter, many results of flysch sedimentology have been obtained in succession in various areas in Japan (SHIKI, 1961; HARATA, 1965; TANAKA, 1965; SUYARI, 1966; SUYARI *et al.*, 1968; HIRAYAMA and SUZUKI, 1965, 1968; SASAKI and USHIJIMA, 1966; HARATA *et al.*, 1967; KISHU SHIMANTO RESEARCH GROUP, 1968, 1970; TSUDA and NAGATA, 1969; TERAOKA, 1970; TANAKA, 1970). In 1970's, much more papers on flysch sedimentology have been continuously produced by many researchers.

2. Unique investigation in the Boso Peninsula

Studies on turbidites and flysch in the Boso Peninsula occupy an unique portion in flysch sedimentology not only in Japan but also in the world.

Neogene flysch deposits are developed thick and widely in the Boso Peninsula, and they intercalate numerous extensive and characteristic tuff-beds. Since 1950's, these tuff-beds have been used as very useful marker-beds in order to correlate formations separated from each other, to analyze the lateral change of thickness and lithofacies of succession between two specific tuff-beds and to estimate the quantity of eroded succession below an unconformity (MITSUNASHI, 1954; MITSUNASHI and YAZAKI, 1958; MITSUNASHI *et al.*, 1961; BOSO PENINSULA RESEARCH COLLABORATING GROUP, 1965; NAKAJIMA, 1973, 1978; RESEARCH GROUP FOR NEOGENE TECTONICS OF THE KANTO DISTRICT, 1977).

On the other hand, HIRAYAMA and SUZUKI (1965, 1968) succeeded in tracing individual beds of a monoclinic sequence over 30 km along the strike with the aid of many thin tuff marker-beds. They clarified the geometry and sedimentary structures of individual constituent beds of the sequence. Subsequently, various studies on turbidites based on bed-by-bed correlation have been made in the Boso Peninsula (HIRAYAMA *et al.,* 1969; YAMAMOTO, 1971; TOKUHASHI and IWAWAKI, 1975; TOKUHASHI, 1976a, b).

WALKER (1973) pointed out that the first thing of the main three aspects which still need "mopping up" of the "turbidite mess" is to know about the extent of individual turbidite beds and the way in which bundles of beds are related to basin geography, because little is known about them. Such important studies have been done in the Boso Peninsula that fill a large gap in the knowledge of flysch sedimentology in the world. The introduction of these works to the world has been long overdue (HIRAYAMA and NAKAJIMA, 1977).

B. Necessity of the Three Dimensional Analysis of Flysch Sequence

1. Submarine fan model and facies association

Since "fluxo-turbidites" (DZULYNSKI *et al.,* 1959) and "Bouma sequence" (BOUMA, 1962) were recognized, many active discussions on a domain of turbidite facies and the interrelationship of the various kinds of facies have been made among the flysch sedimentologists (RADOMSKI, 1961; STANLEY and BOUMA, 1964; DZULYNSKI and WALTON, 1965; WALKER, 1966, 1967; STAUFFER, 1967; CORBERT, 1971; W. SCHLAGER and M. SCHLAGER, 1973; MUTTI, 1975). These discussions were combined with a submarine fan model and resulted in proposal of an overall facies association of the turbidites (WALKER and MUTTI, 1973; RICCI-LUCCHI, 1975). As a result, the domain of the turbidite facies was remarkably expanded. The work on recent submarine fans played a great role to interpret the turbidite facies on land (MENARD, 1955; GORSLINE and EMERY, 1959; HAND and EMERY, 1964; GORSLINE and NELSON, 1969; SHEPARD *et al.,* 1969; NORMARK and PIPER, 1969; NORMARK, 1970; NELSON *et al.,* 1970; HANER, 1971; NORMARK and PIPER, 1972; NELSON and KULM, 1973, SAKURAI *et al.,* 1974; NORMARK, 1974; *etc.*).

2. Some problems on current submarine fan models

An overall depositional process of flysch is not clarified in terms of the current submarine fan model. The present submarine fan model has at least two basic shortcomings as follows.

In the first place, minutely investigated submarine fans until now are restricted to those at stable continental margins. But little or nothing is known about turbidites in the trenches, in the interarc and marginal basins (WALKER and MUTTI, 1973). Therefore, other depositional environments must be also considered in addition to such submarine fan models.

In the second place, the present submarine fan model is based mostly on the surface morphology and very thin core samples (WALKER and MUTTI, 1973; MUTTI, 1974). Consequently a little is known about the detail internal structures of the fan and nothing is known or discussed about an early stage of fan deposition.

On the other hand, in case of studying flysch deposits on land, it is more easy to recognize and analyze the vertical facies sequence but it is very difficult to analyze the areal or lateral facies change (NORMARK and PIPER, 1969; MUTTI, 1974; RICCI-LUCCHI, 1975). Therefore, it is inevitable to depend on the current submarine fan model, when flysch sedimentologists estimate the interrelationship among the various types of facies and their extents and depositional sites.

But it is still unknown whether the depositional process of the early stage of submarine fan sedimentation is the same as that of the current submarine fan model. There is no guarantee that the extent of each facies in ancient flysch deposits is the same as that of the submarine fan model which is estimated based only on the recent submarine fans. Thus, there is still a large gap to be filled between the submarine fan model and the overall depositional process of the real flysch sedimentation.

3. Purpose and method of this study

If three dimensional analysis of a flysch body containing various types of facies is possible and their depositional relation is clarified independently based on the field evidence, flysch sedimentologists need not interpret the genesis entirely depending on the current submarine fan model, but can reexamine it with their results from a geologic new viewpoint. Moreover they may recognize more substantial problems on submarine fan sedimentation. But such studies have not been performed yet except for few preliminary papers (PIPER *et al.*, 1978). The main reason is that the flysch body is composed of thick and somewhat monotonous sequences and generally and very unfortunately lacks useful marker-beds. If many extensive marker-beds indicating the time surface such as tuff-beds are intercalated in the flysch sequence, three dimensional analysis is really possible. Such is the case in the Boso study area.

In this paper, the author first presents a detailed three dimensional analysis of a large sandy flysch body named the Kiyosumi Formation in the Boso Peninsula. The Kiyosumi Formation is composed mainly of sandstone-dominated alternations attaining 850 m in maximum thickness. Several sedimentary cycles indicating upward thinning can be recognized in its sequence. This formation is gently folded and distributed for about 25 km along the folding axis and about 6 km across it. Numerous tuff-beds are intercalated in the Kiyosumi Formation and many of them are tracable throughout the peninsula for 40 km along E–W direction and 6 km across it.

TOKUHASHI (1976a, b) correlated the individual sandstone beds in sandstone-dominated alternation of about 50 m in maximum thickness just below the Hk tuff named by MITSUNASHI and YAZAKI (1958) for about 40 km in E–W direction and about 5 km in N–S direction. He demonstrated the geometry of them with a panel-diagram method and analyzed the depositional process of them. Then he first proposed that these sandstones were supplied not from the south but from the north, and the depositional environment might have been a submarine fan.

In the present paper the author aims to clarify the depositional process of the overall Kiyosumi Formation. The formation is divided into five units mainly based on the upward thinning cycles in it. These units are tracable throughout the surveyed area by means of six selected tuff marker-beds lying near the boundary of the cycles. Exact geometry and detailed facies distribution of each unit are firstly demonstrated with other sedimentological data. The depositional patterns of the three representative units are analyzed and then the depositional process of the overall Kiyosumi Formation is inferred. At last the difference from the current submarine fan model, an early stage of fan sedimentation and other related problems are discussed.

II. Geologic Outline

A. Geologic Setting of the Neogene Sediments in the Boso Peninsula

It is well known that the characteristic geologic belts in the southwest Japan, such as the Ryoke, the Sambagawa, the Chichibu and the Shimanto belts from north to south, stretch to the Kanto region (KOIKE, 1957; ISHII, 1962; ICHIKAWA *et al.*, 1970; YOSHIDA, 1975; Fig. 1). They constitute the basement rocks of mostly the Quarternary sediments under the Kanto Plain located between the northern and southern Kanto regions. Neogene sediments in the southern Kanto region including the Boso Peninsula are developed mainly on the Shimanto belt. The zonal structures along the Sagami and Suruga Troughs are also observed in the Neogene sediments developed concordantly with the northern and western older geologic belts mentioned above (OMORI, 1960; MATSUDA, 1962; KIMURA, 1977).

KIMURA (1977) stretched the zonal Neogene depositional trend in the southern Kanto region to the slope region between the shelf and the Nankai Trough off the Pacific coast of the southwest Japan. On the slope are developed many basins containing Neogene and Quaternary sediments. The Kumano Trough, Muroto Trough, Tosa Terrace and Hyuga Terrace which are located in the inner part of the upper slope are basins of the first order in magnitude but less than 100 km in their maximum length (Fig. 1). These isolated basins are generally restricted with the outer ridges, spurs and so on (MOGI and SATO, 1975; OKUDA, 1977). The author calls these basins on the slope between shelf and trough (or trench) "slope basins" here collectively.

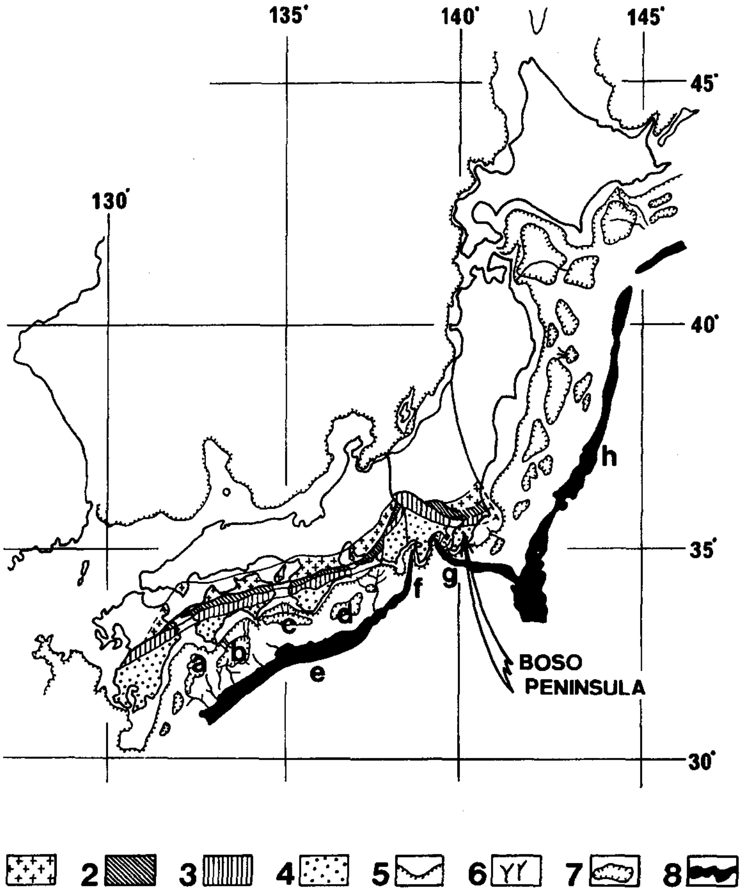

Fig. 1. Geologic and geographic setting of the Boso Peninsula (modified from MOGI and SATO, 1975).

1. Ryoke belt, 2. Sambagawa belt, 3. Chichibu belt, 4. Shimanto belt, 5. Margin of the continental shelf, 6. Submarine canyon, 7. Slope basin, 8. Trench (Trough),
a. Hyuga Terrace, b. Tosa Terrace, c. Muroto Trough,
d. Kumano Trough, e. Nankai Trough, f. Suruga Trough,
g. Sagami Trough, h. Japan Trench.

B. Geology of the Middle Part of the Boso Peninsula

1. Preliminary remarks

A thick sequence of the Oligocene to Pleistocene marine sediments are successively developed throughout the Boso Peninsula, and have been regarded as one of the most important and representative type successions of the Late Cenozoic Era in

Japan (ASANO, 1970). Since 1880's, a lot of geologists have studied this area and numerous papers have been published. Geologic outline of the middle part of the peninsula is briefly explained here according to the papers published after the World War II.

After the World War II, stratigraphic works by many geologists have resulted in many different stratigraphic divisions (IKEBE, 1948; OTUKA and KOIKE, 1949; KOIKE, 1949, 1951, 1957; IDA *et al.*, 1956; KAWAI, 1957, 1961; MITSUNASHI and YAZAKI, 1958; MITSUNASHI, 1968; NAKAJIMA, 1973, 1978). In this paper the author

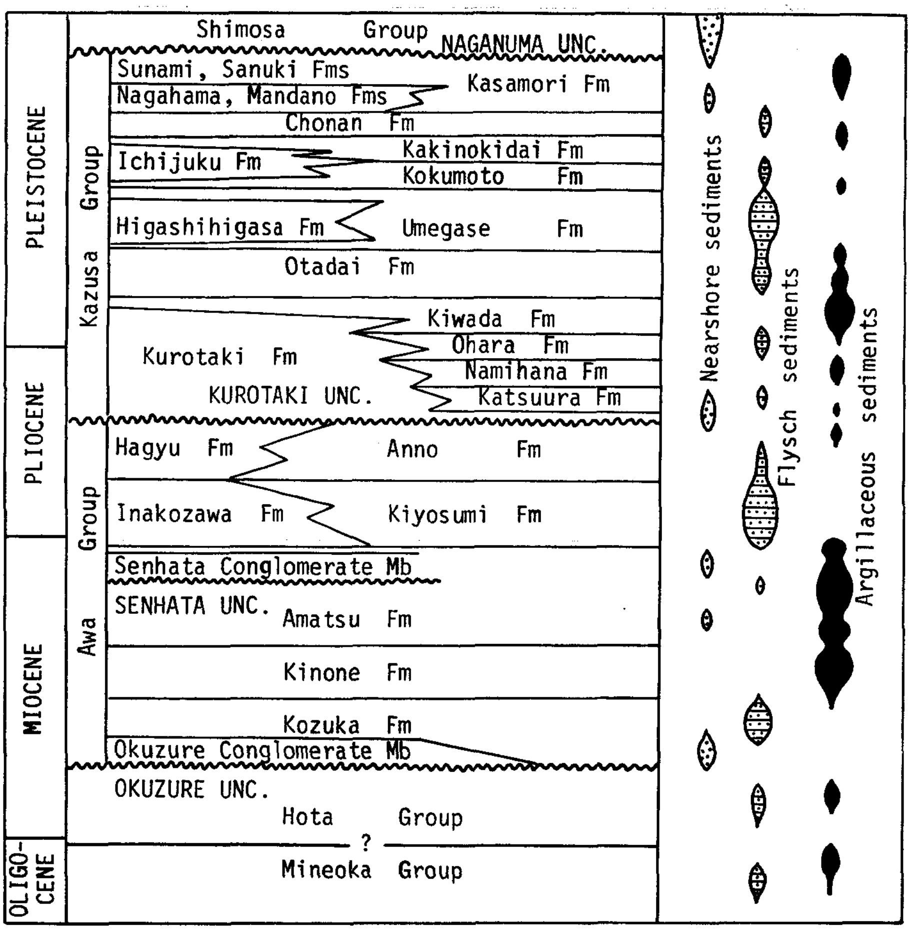

Fig. 2. Stratigraphic division of sequence in the middle and northern parts of the Boso Peninsula (NAKAJIMA, 1978; partly modified).

Width of the vertical lenticular forms in the right column means the relative degree of development of each facies in the eastern half of the peninsula.

follows the latest division by NAKAJIMA (1978) (Fig. 2). For a description of each formation except for the Kiyosumi Formation, the reader is referred to such papers as KOIKE (1949, 1957), KIKUCHI (1964) and NAKAJIMA (1972MS). Only a few aspects are briefly explained here.

2. Stratigraphy

In this area are developed the Oligocene Mineoka Group, Oligo-Miocene Hota Group, Mio-Pliocene Awa Group and Plio-Pleistocene Kazusa Group (Fig. 3). The uppermost Pleistocene Shimosa Group is distributed in the northern part of the peninsula. Only the Mineoka Group occurs as an E–W trending block with tectonic contacts. The younger groups are distributed in the more northern side of the Mineoka Group than the older ones. The Shimosa Group and most of the Kazusa Group are monoclinic. Other groups underlying them are more or less folded. Trend of these folds is about E–W. The degree of folding becomes more complicated in the lower groups (KOIKE, 1957).

The Mineoka Group is composed largely of interbedded sandstones and mudstones. Chert, limestone, siliceous shale and green tuff occur only in this group in the Boso Peninsula.

The Hota Group includes massive tuffaceous sandstones, massive shaly mudstones and sandstone-dominated alternations. Detailed stratigraphy of the Mineoka Group and Hota Group is not still clarified.

The Awa and Kazusa Group are composed of neritic coarse-grained sediments, argillaceous sediments and various flysch-type alternations and respectively divided into many formations as shown in Fig. 2.

Two main groups of sediments are recognized in the neritic coarse-grained sediments. One is characterized by the existence of basal conglomerates overlain by well stratified coarse sediments, such as the Okuzure Conglomerate and Senhata Conglomerate in the Awa Group and the basal part of the Kurotaki Formation in the Kazusa Group. The other group is characterized by a large massive or well cross-bedded sandstone body which interfingers with flysch-type alternations and/or massive siltstones. The Higashihigasa and Ichijuku Formations are the examples.

Thick argillaceous sediments develop below, above and between flysch-type alternations. Most of them are hemipelagic and composed of coarse- to fine-grained siltstones. The Kiyosumi Formation is a main constituent of the upper Awa Group.

3. Igneous activity

Only around the Mineoka Mountains are exposed the igneous associations such as serpentinized peridotite, basalt, picrite basalt, gabbro, gabbroic pegmatite and diorite which intrude the Mineoka Group and the surrounding Hota Group (SAMEJIMA, 1950; KAWAI, 1957; KANEHIRA, 1976). These rocks are included in the

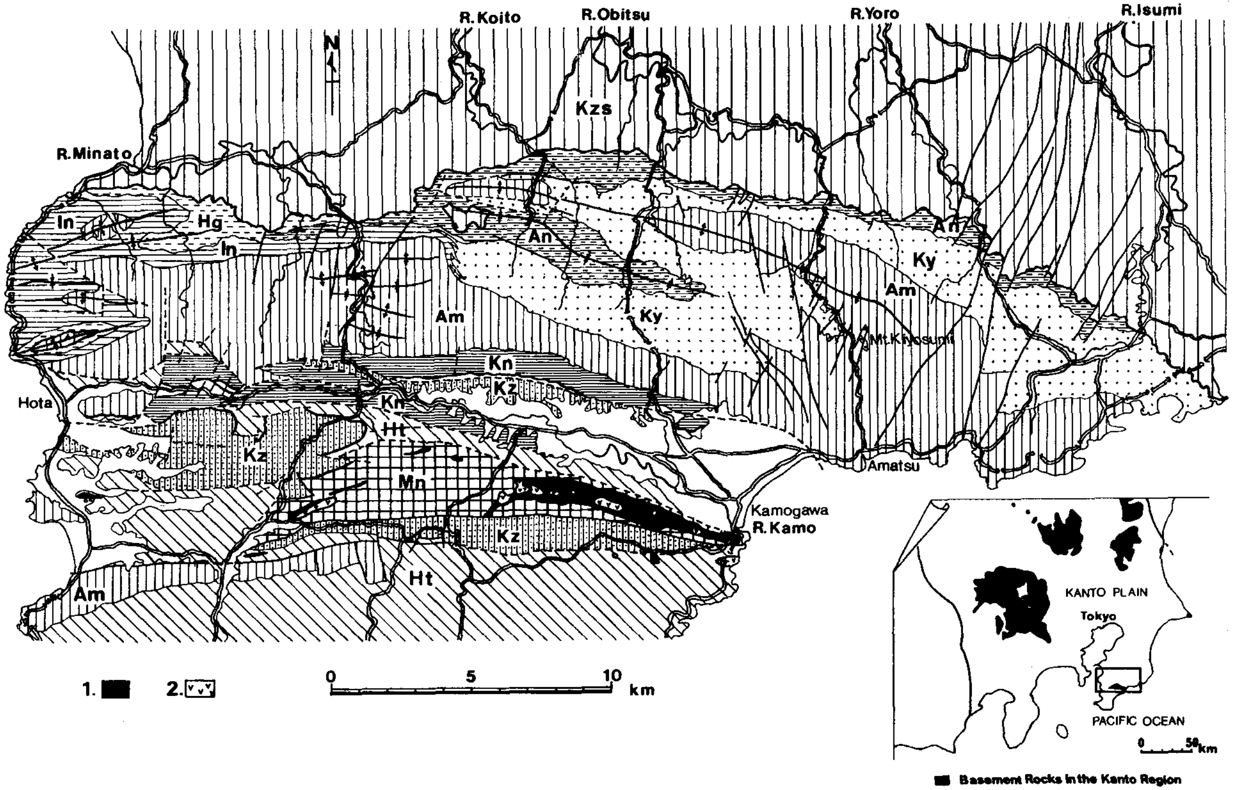

Fig. 3. Geologic map in the middle part of the Boso Peninsula (Geol. Surv. Japan, 1978; partly modified).

Mn: Mineoka Group, Ht: Hota Group, Kz: Kozuka Formation, Kn: Kinone Formation, Am: Amatsu Formation, Ky: Kiyosumi Formation, In: Inakozawa Formation, Hg: Hagyu Formation, An: Anno Formation, Kzs: Kazusa Group, 1. Ultra-basic rock, 2. Basaltic rock.

Okuzure and Senhata Conglomerates in the Awa Group as gravels (KOIKE, 1949; TAKAHASHI, 1954). Therefore, the period of intrusion or eruption of these igneous rocks is estimated to be after the deposition of the Hota Group and before the deposition of the Awa Group (OTUKA and KOIKE, 1949; KOIKE, 1952, 1957; KAWAI, 1957; KANEHIRA, 1976).

Following these igneous activities, the Boso Peninsula was divided into three different tectonic regions characterized by different movements, namely, a geanticlinal elevation of the Mineoka zone, a rapid submergence on its southern side and a gentle, basin-forming down-warping on its northern side (KOIKE, 1952, 1957). KANEHIRA (1976) supposed that a submarine volcanic chain more than 20 km long in E–W direction was formed along the Mineoka zone when basaltic magma erupted.

A number of acidic to basic tuff-beds are intercalated in the Awa and Kazusa Groups. Thus the active volcanic explosions are supposed to have taken place in the surrounding areas during their deposition.

C. Kiyosumi Formation

1. General remarks

Sandstone-dominated alternations distributed around Mt. Kiyosumi and on the northern side of it was first named the Kiyosumi Formation by WAKIMIZU (1901) (see Plate 3, Figures 1, 2, 3 and 5). The Kiyosumi Sandstone is synonymous with the Kiyosumi Formation (KOIKE, 1949).

Distribution of the Kiyosumi Formation is controlled by a pair of anticline and syncline with axes in NWW–SEE trend (Fig. 3). The Kiyosumi Formation stretches for about 25 km in E–W direction and about 6 km in N–S direction from the east coast toward the central part of the peninsula. That is, this formation is distributed in the drainage area of the Isumi, Yoro, Obitsu and Koito Rivers from east to west. The Inakozawa Formation or the Inakozawa Mudstone, which is distributed in the drainage area of the Minato River in the western part of the peninsula, interfingers with the Kiyosumi Formation between the Koito and Minato Rivers.

The Kiyosumi Formation consists mostly of thick-bedded sandstones attaining about 850 m in maximum thickness. The formation conformably overlies the Amatsu Formation or the Amatsu Mudstone attaining about 1,000 m. The facies transition from the former to the latter is very abrupt and the boundary between them is very sharp (Plate 3, Figure 5). Many rounded small pebbles are included near the base of the Kiyosumi Formation (WAKIMIZU, 1901; SAWADA, 1939; KOIKE and NISHIKAWA, 1955; IIJIMA and IKEYA, 1976) (Plate 2, Figures 1–5). Scouring of the underlying mudstone is observed at the base of the Kiyosumi Formation (SAWADA, 1939; IIJIMA and IKEYA, 1976). KOIKE and NISHIKAWA (1955) recognized a large upward thinning cycle throughout the Kiyosumi Formation.

The Kiyosumi Formation is conformably overlain by the Anno Formation or the Anno Alternation attaining 400 m to 500 m in thickness. The lower and middle parts of the Anno Formation is composed largely of alternated sandstones and siltstones. Siltstone-dominated alternations predominate over sandstone-dominated alternations (TOKUHASHI and IWAWAKI, 1975). This seems to indicate that the tendency of upward thinning of the Kiyosumi Formation continues to the overlying Anno Formation.

The alternated sandstones and mudstones of the middle and lower parts of the Anno Formation pass upward into the massive siltstones and then sandy siltstones of the upper part of it. Therefore, the flysch-type alternations of sandstones and siltstones in the Kiyosumi and Anno Formations together constitute a positive turbidite suite (RICCI-LUCCHI, 1975).

KOMATSU (1958) and IIJIMA and IKEYA (1976) considered the Mineoka uplift zone on the southern side as the provenance of the Kiyosumi Formation. But, as already mentioned, TOKUHASHI (1976a, b) first indicated the supply of them from the northern area and the probability of a submarine fan as a depositional environment of the Kiyosumi Formation.

2. Chronologic data

Recent geologic dating of the Late Cenozoic sequence in the Boso Peninsula is discussed based on the planktonic foraminifera and the paleomagnetic evidence.

According to ODA (1975), such chronologically important planktonic foraminifera as *Globigerina nepenthes, Pulleniatina primalis, Globorotalia margaritae, Sphaeroidinellopsis* spp. occur in the Kiyosumi Formation. Based on the range chart of these foraminifera and the paleomagnetic column by NIITSUMA *et al.* (1972), the boundary between the Gilbert Reversed Epoch and the Epoch 5 is estimated in the lower part of the Kiyosumi Formation. The Mio-Pliocene boundary is positioned near the base of the Gilbert Epoch (BERGGREN, 1973). Therefore, most of the Kiyosumi Formation seems to have been deposited in the period from N. 18 to N. 20 of BLOW's zone. According to ODA (1975), the term of deposition of the Kiyosumi Formation is about one million years. Consequently, maximum depositional rate of the Kiyosumi Formation is estimated at about 85 cm per 1,000 years.

NIITSUMA (1976) pointed out based on the paleomagnetic stratigraphy that the depositional rate become remarkably large since the start of deposition of the Kiyosumi Formation.

3. Depositional depth

Since NATLAND and KUENEN (1951), benthonic foraminifera in the hemipelagic sediments have been noticed to be valuable to estimate the depositional depth. However, a few data on the benthonic foraminifera in the Kiyosumi Formation are available now. Aoki (1968) suggested that the fauna of benthonic foraminifera in the Kiyosumi Formation has closest affinity with the *Gyroidina-Melonis* fauna in the Kazusa Group, the most constituents of which are representative of the middle to lower bathyal biofacies. According to Hatta (unpublished data), benthonic foraminiferal assemblages in a siltstone bed just below the Hk tuff at two localities indicate upper bathyal environment. These data seem to indicate the middle to upper bathyal environment for the Kiyosumi Formation.

4. Type of basin

The basin of the Kiyosumi Formation is considered to have been a slope basin, because the geologic setting around the basin is similar to that of slope basins off the southwest Japan. The Mineoka uplift zone seems to have been an outer ridge which dammed up the sediments from north. In the southern area of the uplift zone, the lower part of the Chikura Formation partly including flysch sediments were being deposited in a more outer slope basin during the deposition of the Kiyosumi Formation (Naruse *et al.*, 1951; Maiya, 1972).

In the N–S cross-section through the Boso Peninsula, Neogene sediments are interpreted to be thickest where they are now exposed (Kikuchi, 1964; Naruse, 1968). Therefore, the basin of the Kiyosumi Formation was probably located at the innermost or at least inner position on the slope. Based on such position and size, the basin of the Kiyosumi Formation seems to have been a slope basin of the first order in magnitude comparable to the Muroto Trough and so on formed on the upper slope off the coast of the southwest Japan now (Fig. 1).

The type of these basins is more or less different in the surrounding geologic setting from those of borderland basins off California, oceanic basins at the continental margins and marginal sea basins such as Japan Sea and so on.

III. Basic Sedimentological Data

A. Main Tuff Marker-Beds Used to Divide the Formation into Units

At least more than two hundred tuffs are intercalated in the Kiyosumi Formation. Most of them are thinner than 50 cm. Many tuff marker-beds can be identified by means of the individual and characteristic tuff-beds or the combination of several associating tuff-beds. These tuff marker-beds are traceable over the wide area because of the remarkable consistency of their thickness and other features. Among them six main marker-beds are selected to divide the Kiyosumi Formation into five units. These are here named Kr, Tk, Km, Hk, Nm and Sa for short respectively in ascending order (Plate 1, Figures 1–6). Their localities and columnar sections along the type route are shown in Fig. 4 and Fig. 5, respectively. A geologic

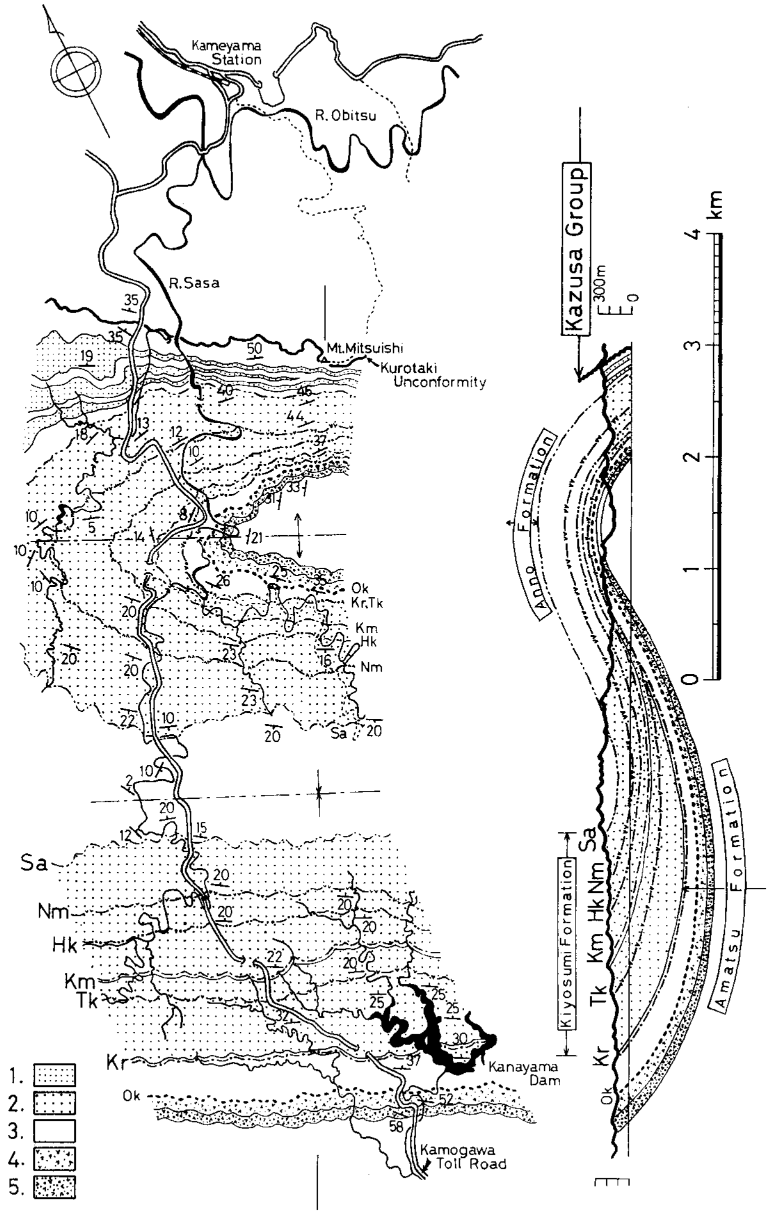

Fig. 4. Localities of the main six tuff marker-beds along the type route (Kamogawa Tall Road and Sasa River).

1. Sandstone-dominated alternations (in Anno Formation),
2. Sandstone-dominated alternations (in Kiyosumi Formation),
3. Siltstone-dominated alternations and massive siltstones,
4. Sandy siltstones, 5. Silty sandstones.

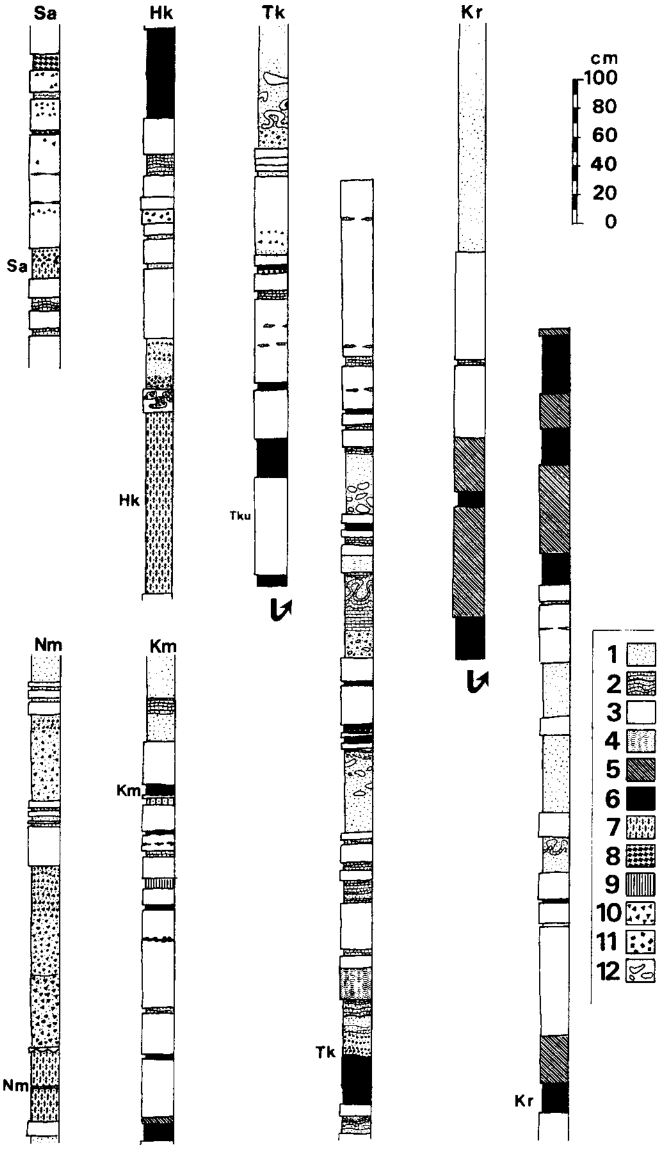

Fig. 5. Columnar sections near the six tuff marker-beds along the type route.

1. Massive sandstone, 2. Laminated sandstone, 3. Siltstone, 4. Turbiditic siltstone, 5. Scoria-colored tuffaceous siltstone, 6. Scoria tuff, 7. "Gomashio" tuff (white glassy and felsic minerals with randomly scattering mafic minerals), 8. "Haigoma" tuff (dark grey scoriaceous tuff), 9. Very fine white tuff, 10. Pumice grains, 11. Scoria grains, 12. Siltstone clasts.

map of the upper Awa Group in the central part of the Boso Peninsula is shown in Fig. 6.

The lowermost marker-bed Kr is positioned just below the boundary between the Kiyosumi and Amatsu Formations (see Figures 9A, B). The uppermost main tuff marker-bed Sa is positioned within a few meters just above the boundary of the Anno and Kiyosumi Formations. Other main marker-beds, that is, Tk, Km, Hk and Nm are respectively included in the thin siltstone-dominated alternations (less than 20 m) in the Kiyosumi Formation. According to RICCI-LUCCHI (1975), each unit may correspond to a thick turbidite megasequence or a turbidite subsuite. Where thick pebbly sandstones are developed near the base of the unit, each unit shows a typical upward thinning cycle.

Sedimentological data on the Kiyosumi Formation are shown by dividing them into these five units.

B. Facies Distribution

In the Kiyosumi Formation occur not only the sandstone-dominated alternations of main facies but also other associated facies. Various facies, which are observed in the Kiyosumi Formation and its western equivalent, the Inakozawa Formation, are indicated with symbols so as to easily understand the facies distribution of each unit. Classification and symbolization of the facies are presented in Table 1. This classification approximately corresponds to the descriptive characteristics of facies. WALKER and MUTTI (1973) tried to classify the various kinds of facies observed in flysch deposits. Their classification is very comprehensive as they give consideration to the various facies reported by many flysch sedimentologists in the world. In this table, the author uses a little modified classification and symbols mainly to express the sandstone-dominated alternations more quantitatively, but the correspondence to the WALKER and MUTTI's division is also indicated in this table.

Facies distribution of five units are shown in Fig. 7 by means of symbols in Table 1. Facies "b" group, that is, sandstone-dominated alternations are obviously dominant. Facies "a", that is, pebbly sandstone is observed in places surrounded by facies "b" group. The distribution area of facies "c", that is, normal alternations is very narrow. Therefore it is concluded that the transition from facies "b" (sandstone-dominated alternations) to facies "d" (siltstone-dominated alternations) occurs very rapidly or abruptly in the Kiyosumi Formation. On the other hand, facies "d" and "e" are observed in the surrounding areas of the facies "b" and "c". Argillaceous sediments in these facies are composed mostly of medium- to coarse-grained silt. But in the particular sites, they are composed of sandy siltstone ("el") or silty sandstone ("e0").

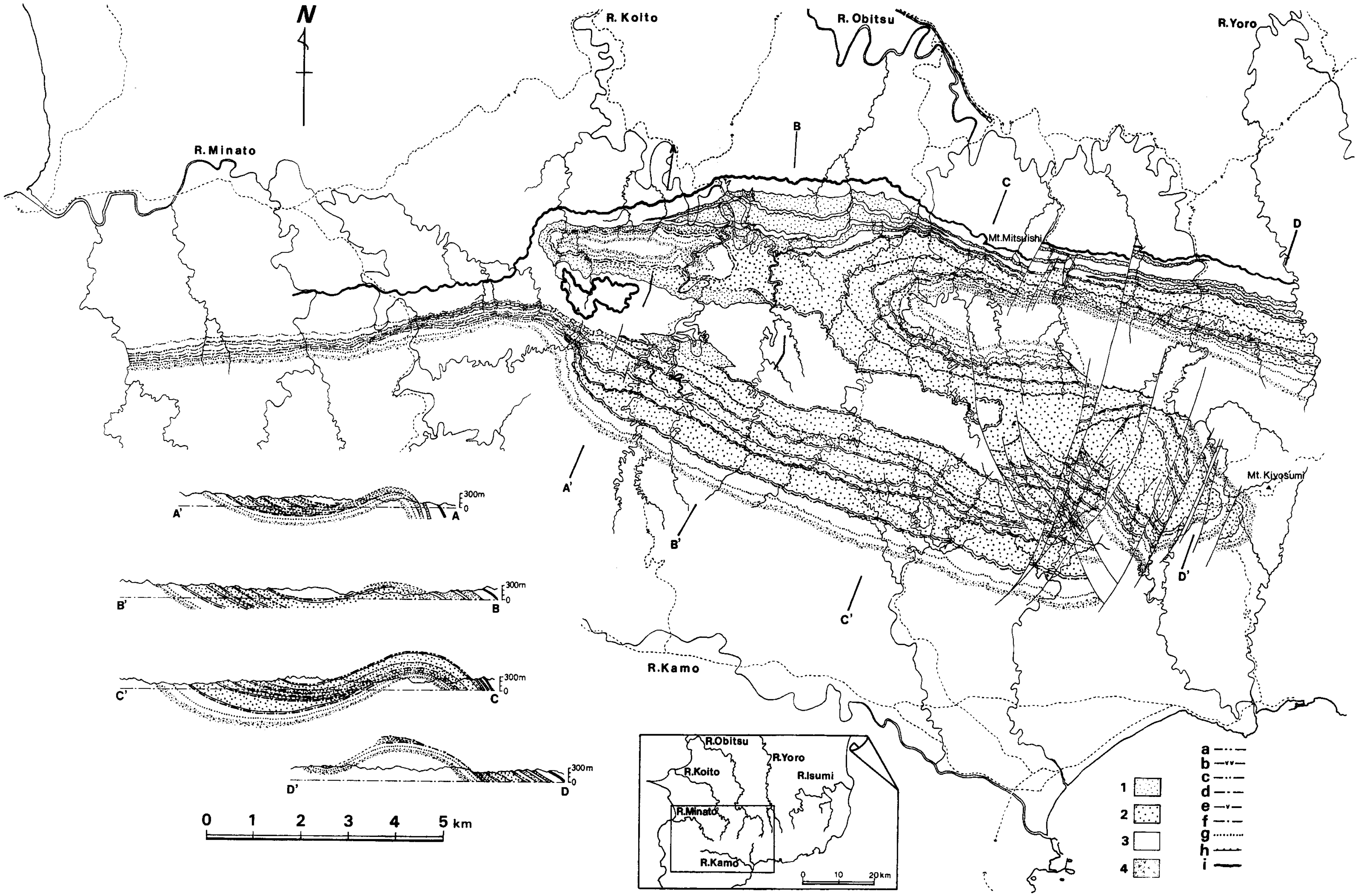

Fig. 6. Geologic map of the upper Awa Group in the central part of the Boso Peninsula.

1. Sandstone-dominated alternations (in Anno Formation), 2. Sandstone-dominated alternations (in Kiyosumi Formation), 3. Siltstone-dominated alternations and massive siltstones, 4. Sandy siltstones and silty sandstones, a: Sa, b: Nm, c: Hk, d: Km, e: Tk, f: Kr, g: Ok, h: Thrust fault, i: Kurotaki Unconformity.

Unpublished data by Hirayama and Nakajima are partly referred.

Table 1. Classification of facies.

Facies		Definition of Facies	Walker & Mutti (1973)
a		Pebbly sandstones Amalgamation of pebble conglomerates and massive sandstones with no interbedded siltstones Frequent occurrence of outsize siltstone-clasts	A3, A4
b		Sandstone-dominated alternationes (Sandy flysch) sandstone siltstone ratio, sd/st>5	B
	b0	Massive or amalgamated sandstones with few interbedded siltstones	
	b1	Modal thickness of sandstone beds, Mo.>2 m	
	b2	0.5<Mo.<2 m	
	b3	Mo.<0.5 m	
c		Nomal alternations (Normal flysch) 1<sd/st<5	C
d		Siltstone-dominated alternations (Silty flysch) sd/st≤1	D
e		Massive siltstones Partly including thin-bedded sandstones	G
d0, e0		Silty sandstone	Main grain size of silty beds
d1, e1		Sandy siltstone	
d2, e2		Coarse-grained siltstone	
d3, e3		Medium-grained siltstone	
d4, e4		Fine-grained siltstone	

In this table the existence of intercalated pyroclastic beds is not considered.

C. Lateral Variation of Thickness

Lateral thickness variation of the five units are shown in Fig. 8. As a whole, geometric characteristics of these units resemble each other. A detailed examination indicates that the lower units are more remarkable in the lateral thickness variation than the upper ones. The lowermost Tk–Kr unit shows the greatest lateral variation in thickness. This unit is composed largely of siltstones about 10 m thick along the north row, that is, on the northern side of the anticline. But it consists of the sandstone-dominated alternations of about 300 m in thickness along the south row, that is, on the southern side of the syncline. Columnar sections near the base of the Kiyosumi Formation on the both sides of the anticline, where the Tk–Kr unit is extremely thin, are shown in Fig. 9A. In Fig. 9B are shown the columnar sections near the base of the formation on the southern side of the syncline, where the Tk–Kr unit is remarkably thick, and in the eastern area of the peninsula.

It is definite from these data that on the southern side of the syncline and in the eastern area of the peninsula, the Tk–Kr unit occupies the lowermost part of the

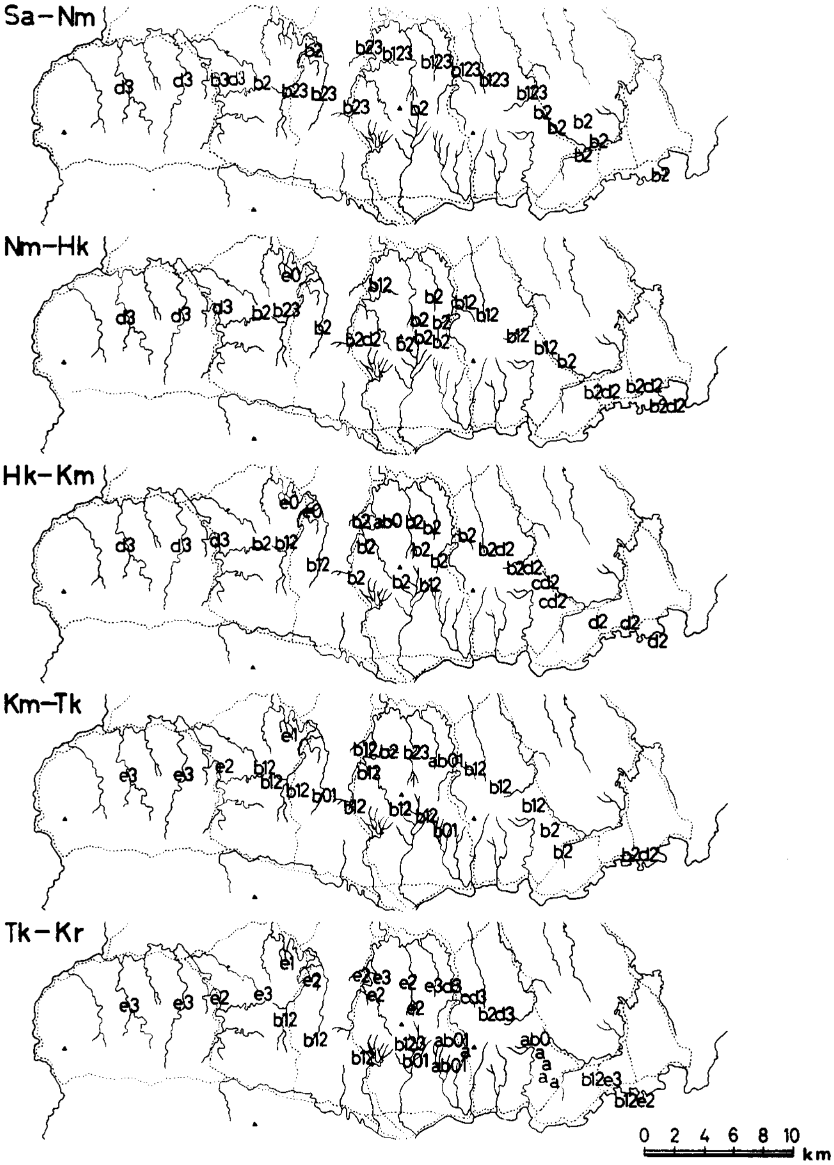

Fig. 7. Areal variation of facies of each unit.
For description of symbols see Table 1.

Kiyosumi Formation, but the overlying Km–Tk unit occupies the lowermost part of it on both sides of the anticline. It is the most important to analyze the depositional process of the lowermost Tk–Kr unit in clarifying the overall depositional

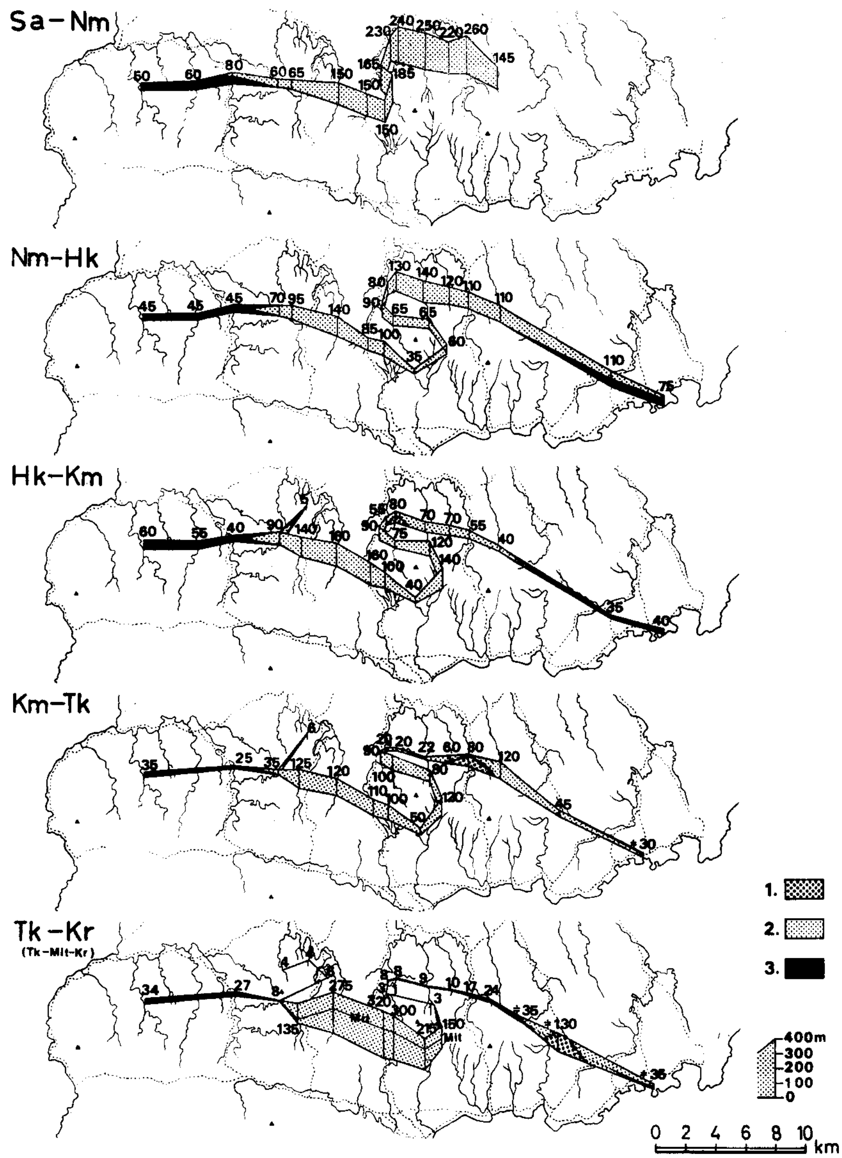

Fig. 8. Areal variation of thickness and main facies of each unit.

1. Pebbly sandstones, 2. Sandstone-dominated alternations, 3. Siltstone-dominated alternations and massive siltstones.

process of the Kiyosumi Formation (TOKUHASHI, 1976a, b).

All units are thicker in facies "b" group (sandstone-dominated alternations)

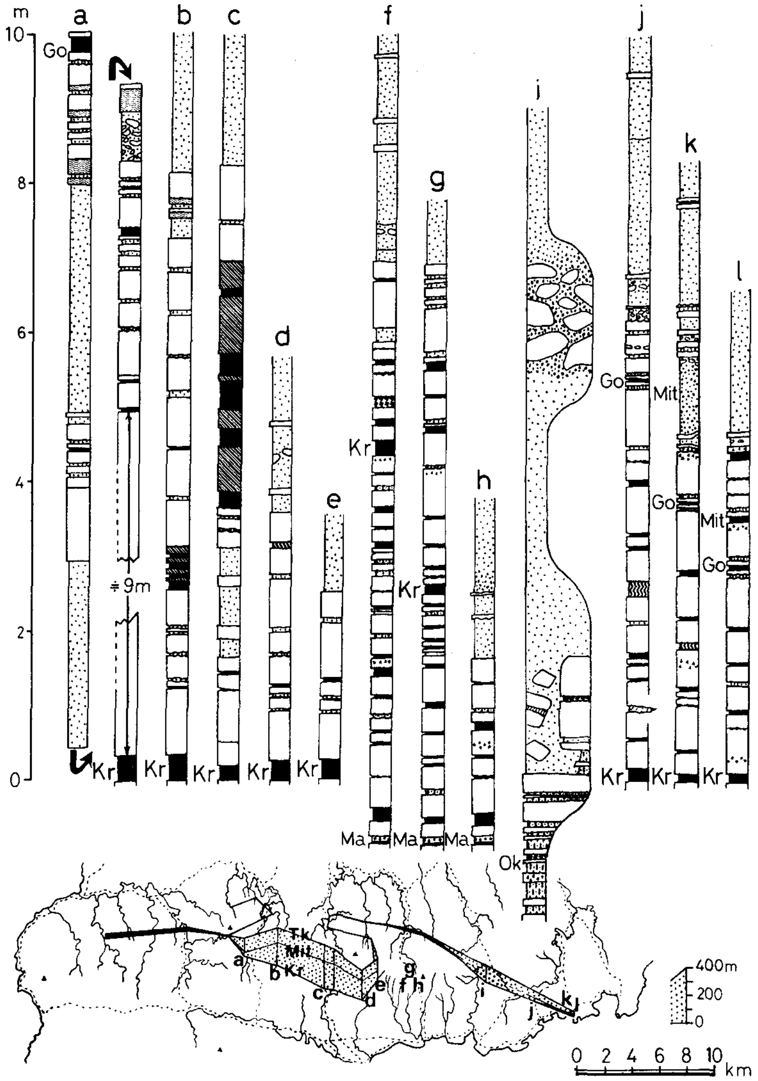

Fig. 9B. Columnar sections near the base of the Kiyosumi Formation (Part II).
These sections are in the area where Tk–Kr unit is composed of sandstone-dominated alternations or pebbly sandstones and is remarkably thick. Locality of each column is shown in the lower figure. For legend see Fig. 9A.

than in facies "a" (pebbly sandstones). Every unit becomes thicker in the order of facies "e", "d", "a" and "b".

Geometry of the Kiyosumi Formation is shown in Fig. 10 which shows the lateral

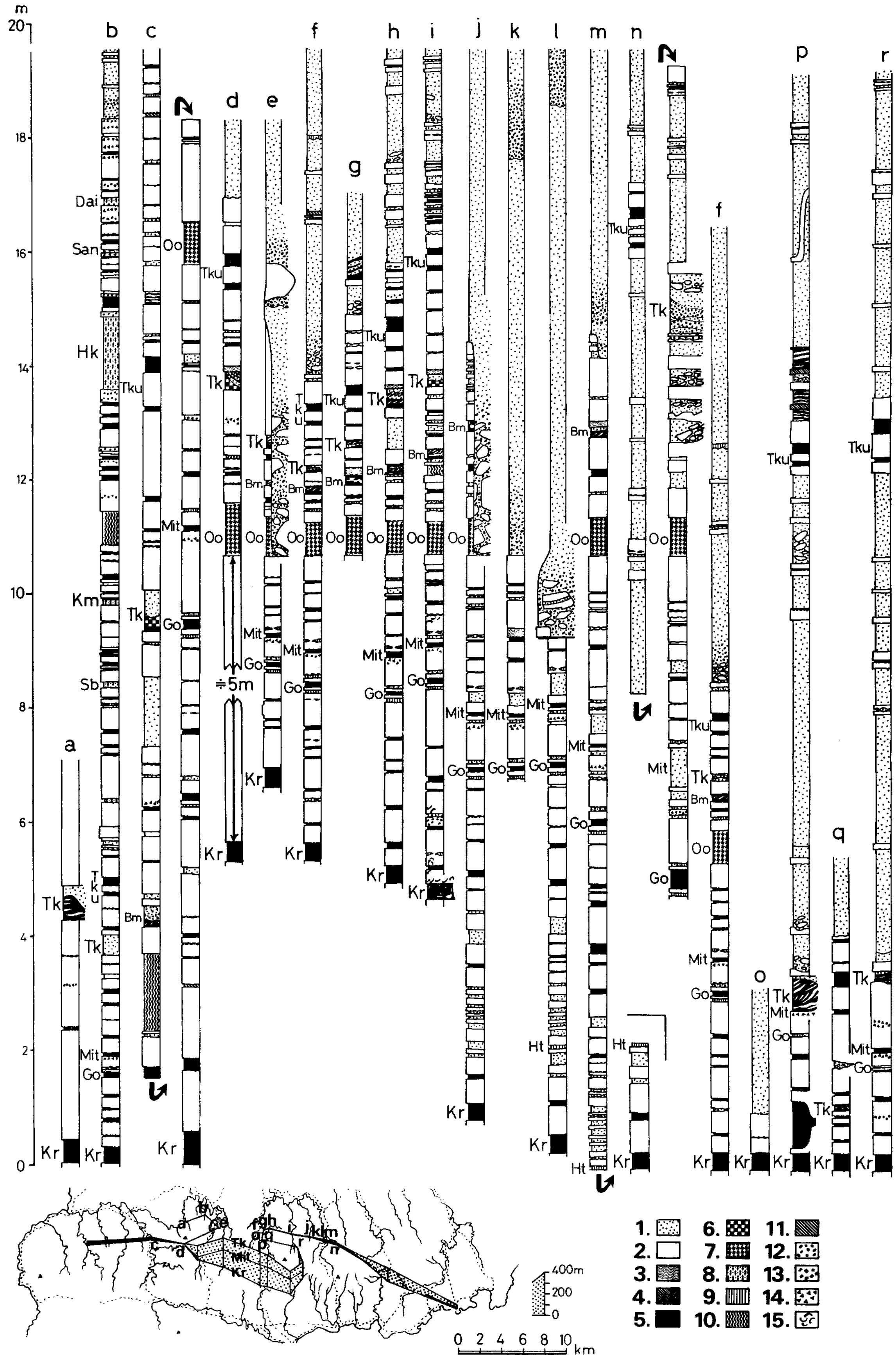

Fig. 9A. Columnar sections near the base of the Kiyosumi Formation (Part I).

These sections are in the area where Tk–Kr unit is composed mainly of siltstone beds and remarkably thin. Locality of each column is shown in the lower figure. 1. Sandstone, 2. Siltstone, 3. Turbiditic siltstone, 4. Scoria-colored tuffaceous siltstone, 5. Scoria tuff, 6. "Pumisco" tuff (random mixture of pumice and scoria grains), 7. "Haigoma" tuff (intermediate between scoria and pumisco tuff), 8. "Gomashio" tuff (white glassy and felsic minerals with randomly scattering mafic minerals), 9. Very fine white tuff, 10. Very fine grey tuff, 11. Very fine pink and pinkish tuff, 12. Gravels of hard basement rocks, 13. Scoria grains, 14. Pumice grains, 15. Shell fragments.

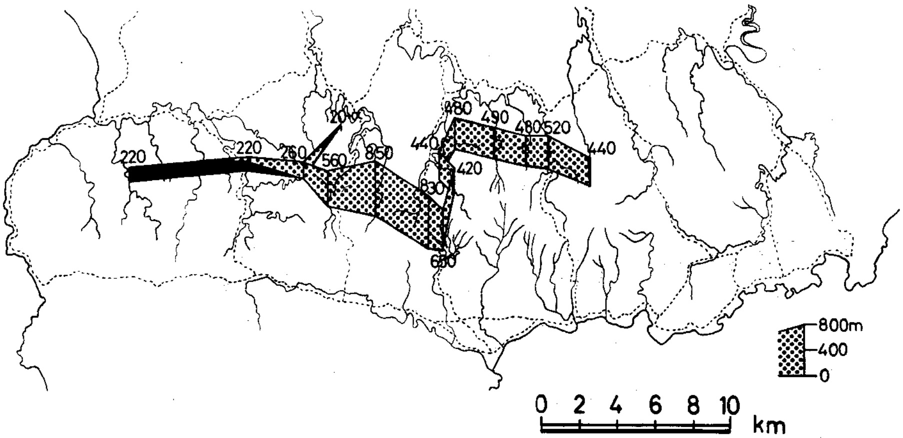

Fig. 10. Areal variation of total thickness of five units between Sa and Kr marker-beds. Dotted part means facies composed mainly of sandstone-dominated alternations and partly of pebbly sandstones. Black part means facies composed of siltstone-dominated alternations and massive siltstones.

variation of the thickness and main facies between Sa and Kr main tuff marker-beds. It is obvious as also shown in Fig. 8 that the thickness of the Kiyosumi Formation decreases both westward and eastward. Therefore, the Kiyosumi Formation consists of such a large lenticular sandy-flysch body attaining 850 m in maximum thickness, more than 20 km long in E–W direction and more than 6 km in N–S direction.

D. Trough-like Basal Erosion

Where facies "a" (pebbly sandstones) is developed, the underlying beds are more or less widely eroded and the trough-like erosive morphology is formed at the base of the units (Fig. 11). Especially at the base of the lowermost Tk–Kr unit is developed the largest trough-like morphology measuring about 50 m deep and more than 5 km wide. Even the Ok tuff (Mitsunashi and Yazaki, 1958) in the uppermost part of the Amatsu Formation, is eroded in the area of the maximum erosion (see locality i in Fig. 9B). Profile of this large trough-like morphology at the base and the Tk–Kr unit filling it is illustrated in Fig. 12.

E. Size and Constitution of Gravels

Distribution of the maximum diameters of the hard gravels included in the turbidite sandstones of the Kiyosumi Formation is shown in Fig. 13. In this figure are shown the maximum diameter and the mean value of the larger ten diameters

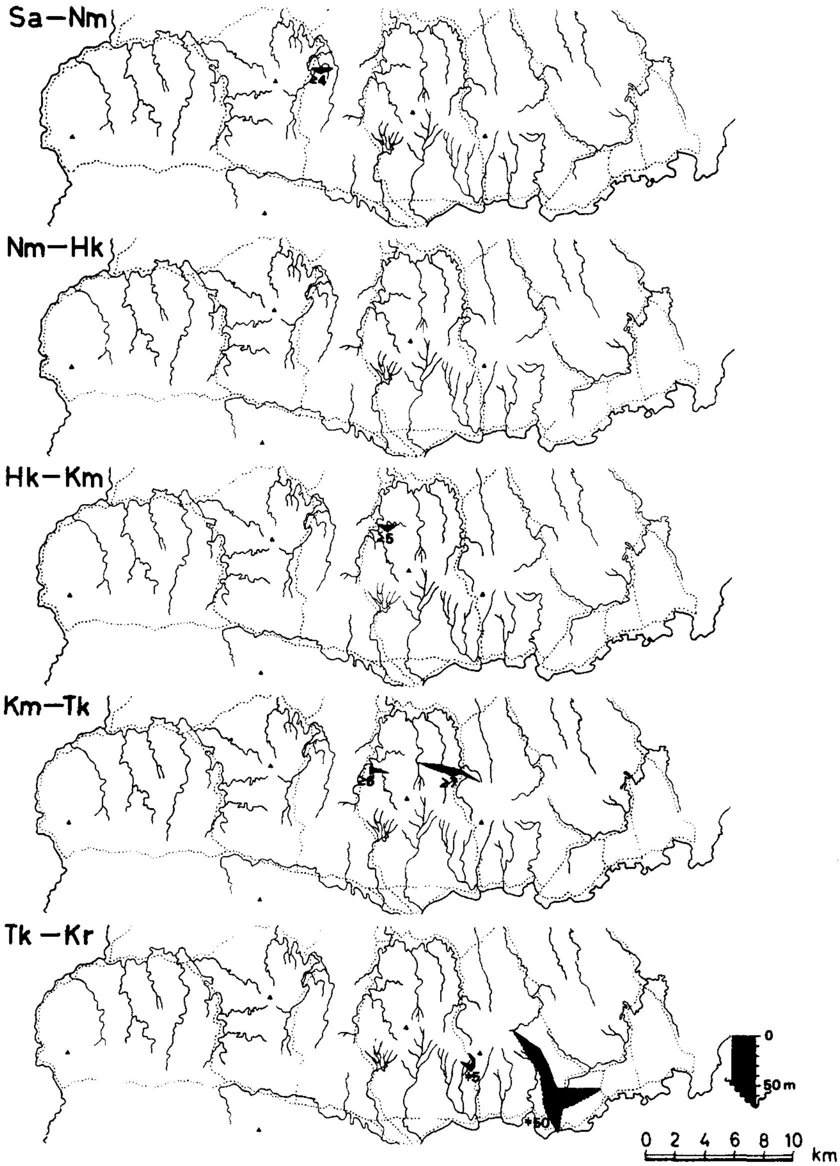

Fig. 11. Trough-like erosive morphology at the base of each unit.
Each number means a estimated value of the maximum thickness of eroded succession.

of the gravels observed at each outcrop. Most gravels observed are less than a few centimeters in diameter. But in the uppermost Sa–Nm unit, larger gravels occur in places.

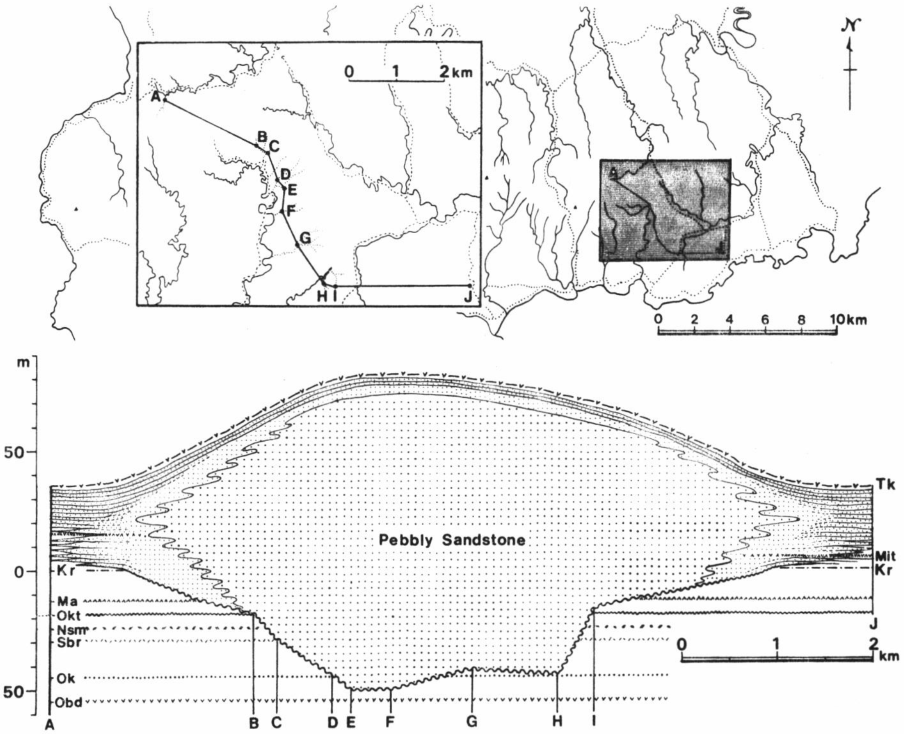

Fig. 12. A profile of the largest trough-like erosive morphology filled with the largest pebbly sandstone body of the lowermost Tk–Kr unit.

Constitution of these gravels is shown in Fig. 14 and Table 2. Chert and sandstone are predominant. Rhyolite, andesite, hornfels and quartz rock are commonly observed. Crystalline schist is also commonly observed except for outcrops at locality a, b and c which belong to the uppermost Sa–Nm unit and include the larger gravels. In addition, shale, granitic rock and meta-quartzite are observed.

These gravels is generally rounded to well rounded. However, only gravels of the crystalline schists show edged and discal forms although some are rounded or well rounded. Data on sphericity, shape and roundness of the gravels (larger than 3.2 cm) at the locality a in Fig. 14 are shown in Fig. 15 according to KRUMBEIN (1941).

F. Paleocurrent

In the case of turbidite sandstones, the orientation and sense of transporting currents can be measured by means of the external and internal sedimentary struc-

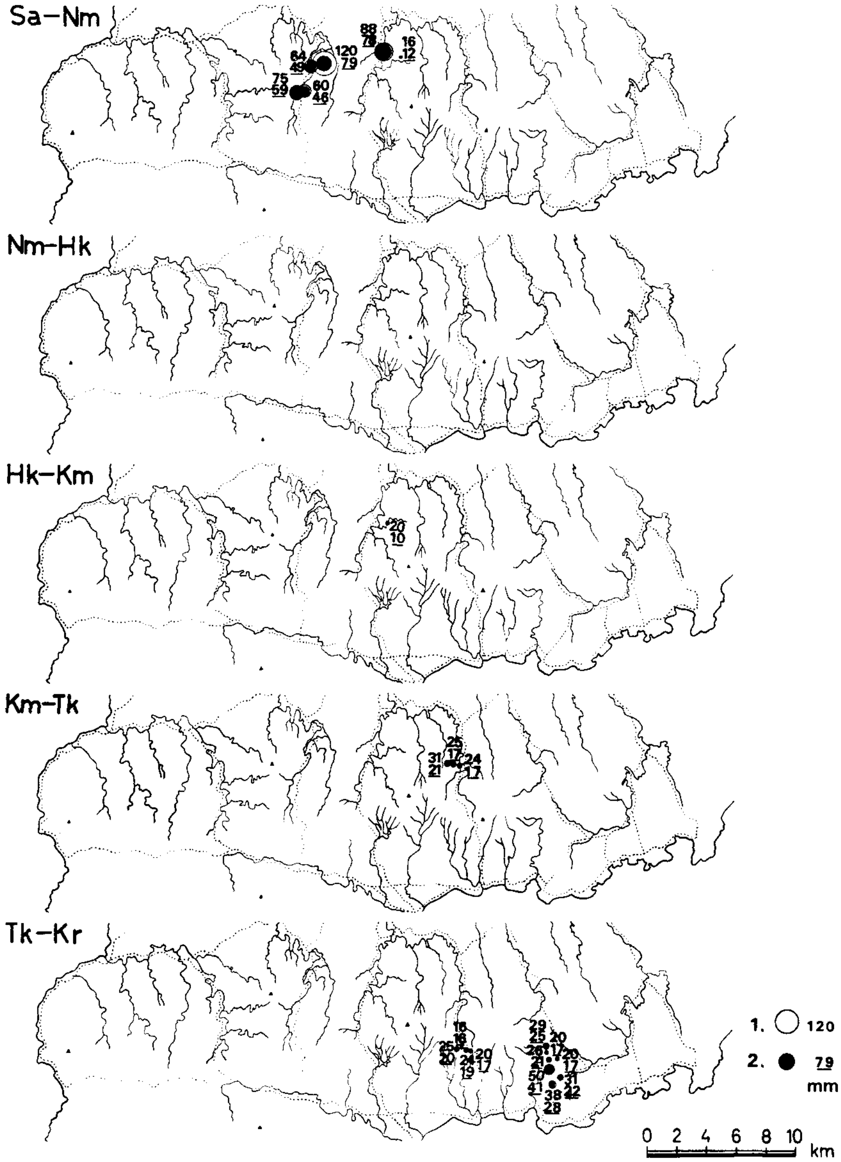

Fig. 13. Size of gravels included in each unit.

1. Diameter of the largest gravel among gravels occuring in each outcrop, 2. Mean value of diameters of the larger ten gravels among them.

tures. Among these data, those which at least indicate definite current orientation are summarized in Fig. 16A. They are obtained from sole markings, preferred

Table 2. Basic data on constitution of gravels in the Kiyosumi Formation

1	2	3	4	5	Ch	Ss	Sh	Rh	GR	An	Hf	QR	MQ	CS
a	Sa–Nm	32–64	135	31	55	24	4	6	0	3	6	2	0	0
a	Sa–Nm	4–8	260	115	47	9	3	7	0	29	2	3	0	0
b	Sa–Nm	32–64	84	41	43	21	0	17	0	13	6	0	0	0
c	Sa–Nm	32–64	82	34	50	15	0	28	0	2	5	0	0	0
c	Sa–Nm	4–8	345	130	60	25	2	7	0	2	2	2	0	0
d	Sa–Nm	4–8	440	354	55	11	1	7	3	6	3	8	2	4
e	HK–Km	2–4	301	301	47	15	3	7	1	7	3	9	2	5
f	Km–TK	4–8	329	260	49	15	2	7	1	2	1	11	3	9
g	Tk–Kr	4–8	79	54	49	18	4	4	1	5	3	5	1	10
h	Tk–Kr	4–8	378	187	52	26	2	4	0	2	2	9	0	3
i	Tk–Kr	4–8	461	209	52	25	3	3	0	2	1	10	0	4

1. Locality (Fig. 14), 2. Unit including gravels, 3. Size (mm), 4. Total number of gravels, 5. Total number of gravels examined under thin section.
Ch; Chert, Ss; Sandstone, Sh; Shale, Rh; Rhyolite, Gr; Granitic rock, An; Andesite, Hf; Hornfels, QR; Quartz Rock (Meta-Chert, Vein Quartz), MQ; Meta-Quartzite, CS; Crystalline Schist.

orientation of wood fragments and strike of walls of channel-like scores filled with small pebbles. Sole markings imprinted on the top of siltstone beds are revealed by carefully removing the overlying semi-consolidated sandstones with a set of tools (Plate 4, Figures 3 and 4). It is confirmed based on both the laboratory work and field observation that the preferred orientation of wood fragments generally included in the upper part of the sandstone beds approximately coincide with the direction of currents and the orientation of sole markings (NAKAJIMA, 1977).

Data which indicate the definite sense but broad orientation of currents are summarized in Fig. 16B. These data are based on the current ripple cross lamination observed in the cross sections of sandstone beds (Plate 4, Figures 1 and 2) and imbrication of outsize siltstone clasts developed mainly in facies "a", that is, pebbly sandstone facies (Plate 5, Figures 1–6). Most of these data indicate the currents from north or northwest, but in the Nm–Hk unit, such current ripple cross laminations which indicate the currents from south are observed only at one locality in the eastern part of the peninsula.

These various sedimentological data on the Kiyosumi Formation are examined and used to clarify the depositional process of it in the next chapter.

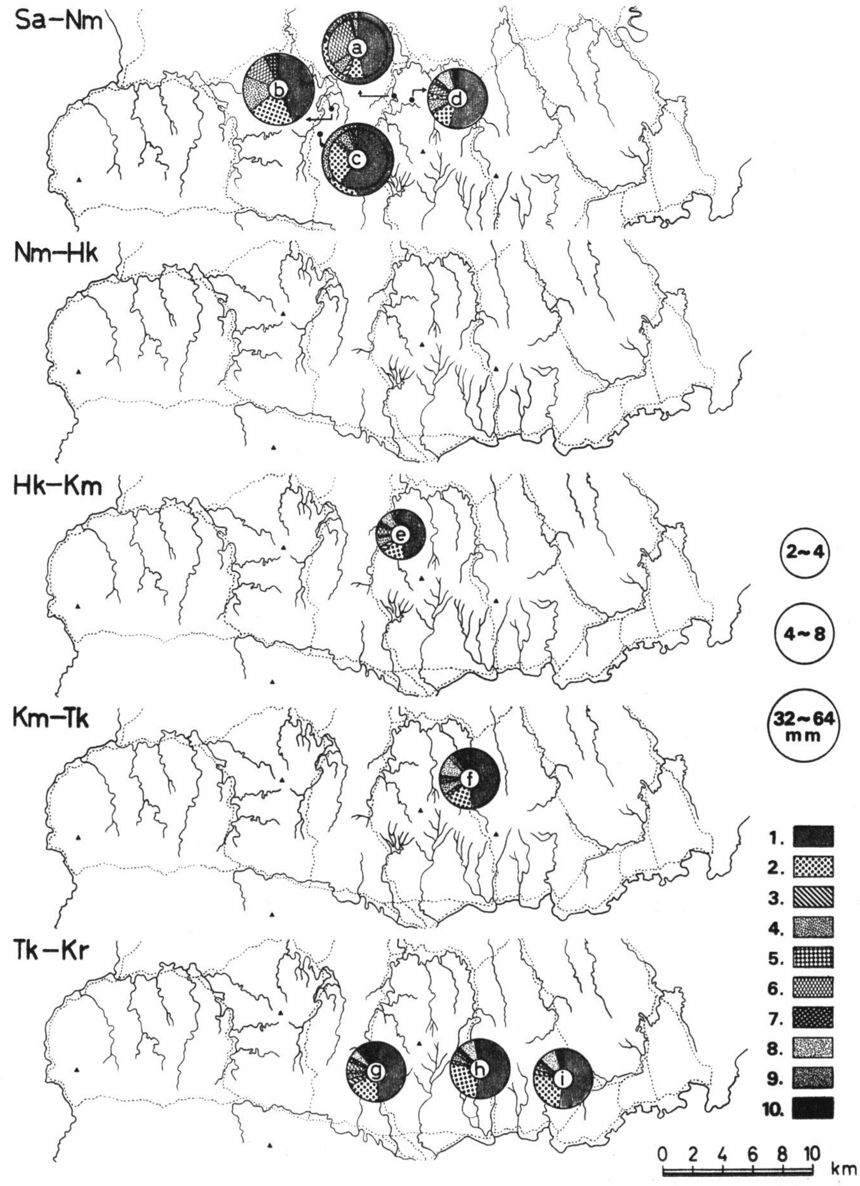

Fig. 14. Constitution of gravels included in each unit.

1. Chert, 2. Sandstone, 3. Shale, 4. Rhyolite, 5. Granitic rock, 6. Andesite, 7. Hornfels, 8. Quartz rock (meta-chert and vein quartz), 9. Meta-quartzite, 10. Crystalline schist.

The constitution is analyzed for gravels of 2–4, 4–8 and 32–64 mm in diameter.

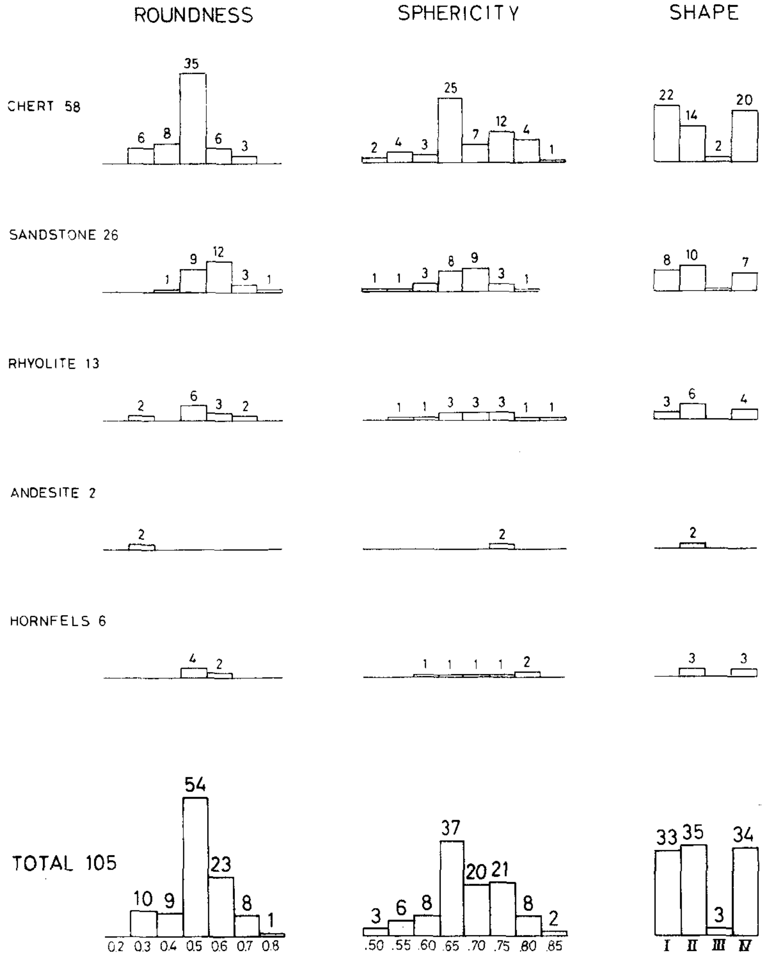

Fig. 15. Roundness, sphericity and shape of gravels (>3.2 cm in maximum diameter) occuring at locality a in Fig. 14.

Each value is measured based on the method by KRUMBEIN (1941). These gravels are rounded to well rounded, and sphericity is relatively high. Disc-shaped gravels (type III) are very rare.

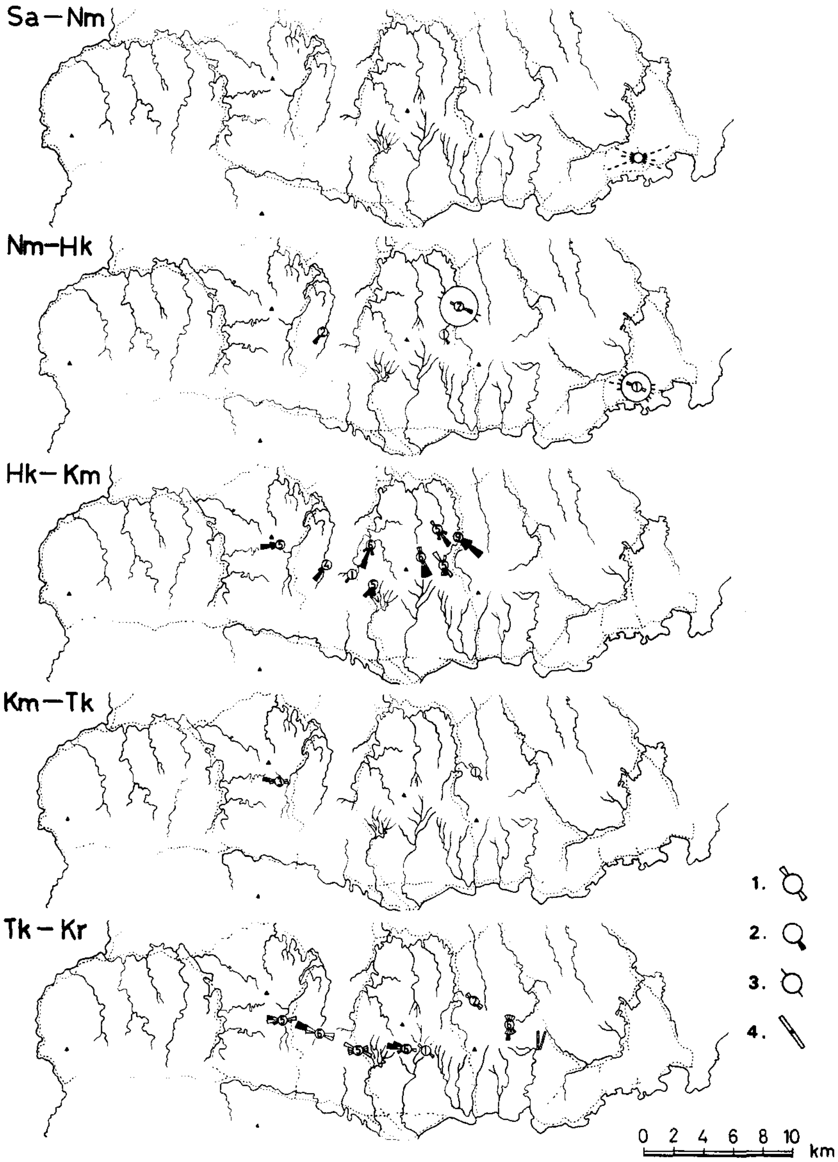

Fig. 16A. Paleocurrent directions measured by some sedimentary structures indicating distinct orientation.

1. Sole marking (Sense is unknown.), 2. Sole marking (Sense is known.), 3. Preferred orientation of wood fragments, 4. Mean orientation of strikes of walls of both sides of a distinct channel-like scour in the pebbly sandstone facies.

The value in each circle is number of sandstone beds whose sole markings were measured.

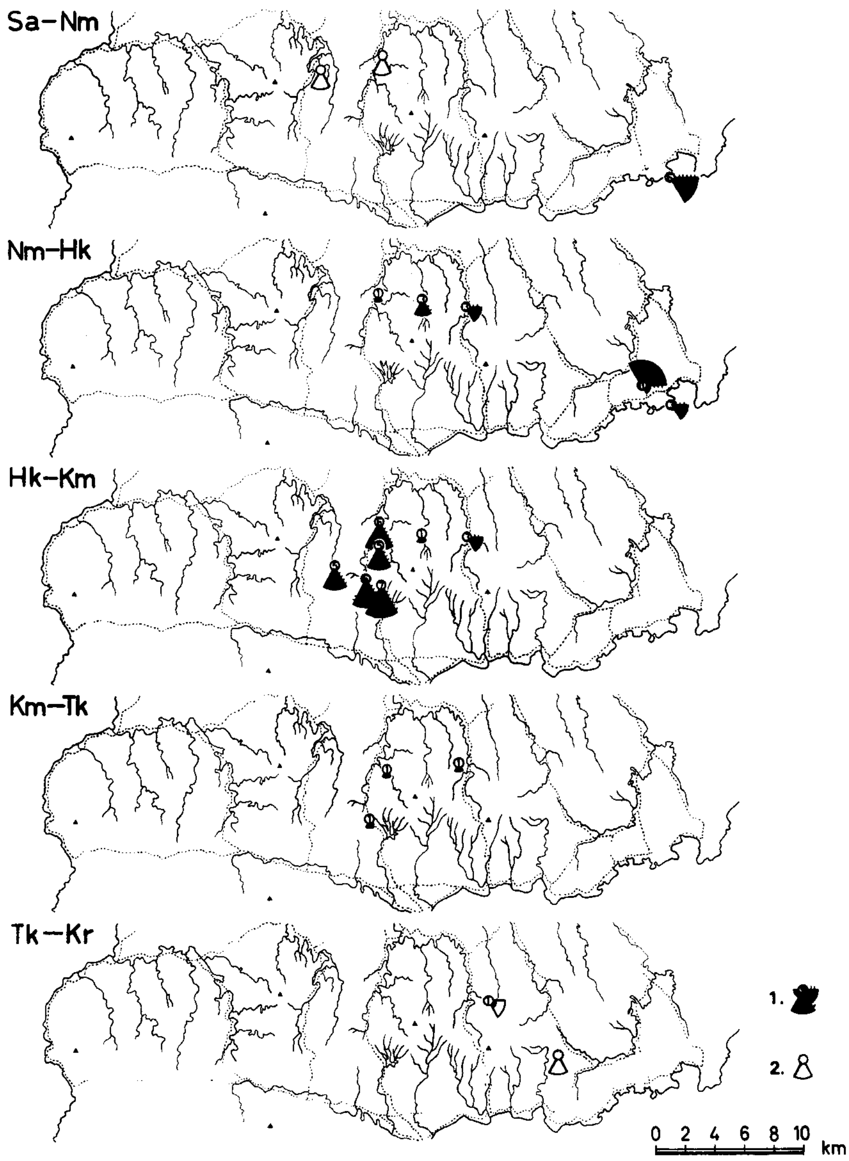

Fig. 16B. Paleocurrent directions measured by some sedimentary structures indicating distinct sense but broad orientation.

1. Current ripple cross lamination. The value in each circle means number of sandstone beds whose cross laminations were measured.
2. Imbrication of large siltstone clasts mainly in the pebbly sandstone facies. One datum per one locality.

IV. Inferred Depositional Process

A. On the Origin of Gravels

Before discussing the depositional process of the Kiyosumi Formation, the origin of gravels is considered here. Gravels offer the very important geologic information on the provenance of the gravels themselves and the enclosing sandstones as well, with the paleocurrents responsible for the turbidite sandstones.

Gravels of igneous rocks exposed around the Mineoka Mountains on the southern side, such as ultra-basic rocks, basalt, gabbro, diorite and so on, are not included in the Kiyosumi Formation (Fig. 14; Table 2). IIJIMA and IKEYA (1976) also noticed the same fact though they inferred the supply from south. In addition, rhyolite, andesite and hornfels, which are commonly included in the gravels of the Kiyosumi Formation, are not exposed around the present Mineoka Mountains.

Some of the rhyolite gravels closely resemble the Cretaceous Okunikko Rhyolites, the Paleogene Katashinagawa Rhyolites and Neogene Kinugawa Rhyolites which are now distributed around the Ashio Massif in the northern Kanto regions (SUDO, 1976). The Cretaceous Rhyolites may have stretched widely in the northern Kanto region in the Late Cretaceous Period (TANAKA and KAWADA, 1971). Also the Neogene Rhyolites may have been distributed more widely than now in the northwestern Kanto region.*1)

Gravels of crystalline schist consist mostly of such low-grade metamorphic rocks as pelitic schist (quartz-albite-muscovite-graphite), basic schist (quartz-albite-chlorite-pumpellyite-actinolite-sphene) and psammitic schist, as well as such high-grade metamorphic rocks as siliceous schist (quartz-muscovite-garnet-biotite). These rocks are different from those metamorphic rocks that were reported from two very small islands near the Kamogawa port located in the Mineoka uplift zone (KANEHIRA *et al.*, 1968; KANEHIRA, 1976). These rocks are characteristic to the Sambagawa metamorphic belt, Mikabu green rocks and Ryoke metamorphic belt.*2) As already mentioned, these belts are well known to be distributed below the Kanto Plain (ISHII, 1962).

These facts mentioned above strongly support the supply from north, that is, from the middle and northern Kanto regions. Moreover, the imbrication of the aggregates of the outsize siltstone clasts which occur together with these hard gravels, also indicates the supply from north at the several outcrops (see Fig. 16B; Plate 5, Figures 1–6).

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*1) Personal suggestion by Dr. N. YAMADA, Geological Survey of Japan.

*2) Personal advice by Prof. K. KANEHIRA, Chiba University.

B. Depositional Patterns of the Representative Units

1. Depositional pattern of the Tk–Kr unit

The sedimentological data on the lowermost Tk–Kr unit of the Kiyosumi Formation are summarized in Fig. 17A to E. Main characteristics of the Tk–Kr unit are as follows.

First, the unit abruptly thickens southward in the central part of the peninsula. Then the thickest pebbly sandstones (facies "a") are developed, filling the largest trough-like morphology by erosion attaining about 50 m in maximum depth and more than 5 km in width in the eastern part of the peninsula (Fig. 12).

Paleocurrent directions measured in the southern area, where sandstone-dominated alternations are thick, indicate the currents from east to west. On the other hand, paleocurrent directions measured in the eastern area indicate the currents from north to south.

Fig. 18 shows the detailed columnar sections between the Mit and Go tuff marker-beds in the middle part of the Tk–Kr unit. Lateral change of thickness and facies between the Mit and Go tuff marker-beds closely resembles that of the overall Tk–Kr unit. It may well be said that the former is a miniature of the latter. Between the Mit and Go tuff marker beds, bed-by-bed correlation of individual sandstone beds is possible. Geometry of each correlated sandstone bed is shown in Fig. 19. This figure shows that several sandstone beds observed along the north row (localities a–k) on the northern side of the anticline, such sandstone beds 1 to 4, continue to the sandstone beds developed along the south row (localities q–u) on the southern side of the syncline. Along the north row, including localities v, w and x near the east coast, these sandstone beds increase their thickness and their capacity to scour the underlying beds both from west and from east to the middle part where pebbly sandstones are thick developed. Along the south row, they increase their thickness much more but decrease their scouring capacity (see sandstone bed 1).

These data strongly indicate that the turbidity currents were funneled southward through the area in the eastern part of the peninsula where a large trough was formed and thick pebbly sandstones were deposited. Then they changed their direction toward west and deposited thick-bedded sandstones of the lowermost Tk–Kr unit on the southern side of the syncline. Therefore, it is most reasonable to conclude that the thick pebbly sandstones filling the trough are channel deposits. This conclusion coincides well with WALKER and MUTTI (1973) in interpretation of their facies A3 and A4.

The depositional pattern of the Tk–Kr unit are shown in Fig. 17F. A topographic high as a tectonic uplift zone (KOIKE, 1952, 1957; ISHII, 1962) or a submarine volcanic chain (KANEHIRA, 1976) has been considered to have existed around the

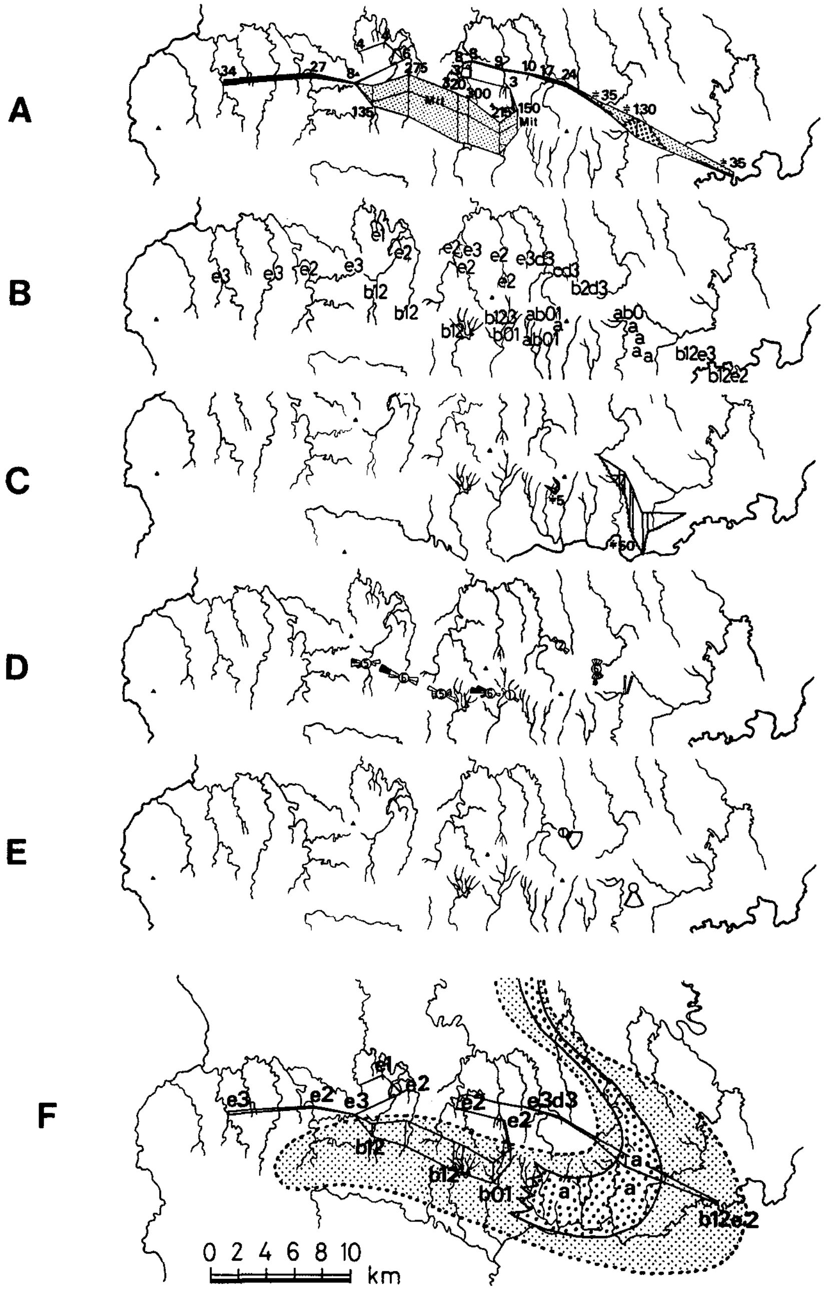


Fig. 17. Summary of some basic sedimentological data on the Tk–Kr unit (A–E) and an inferred depositional pattern of the unit (F).

For explanation see the text.

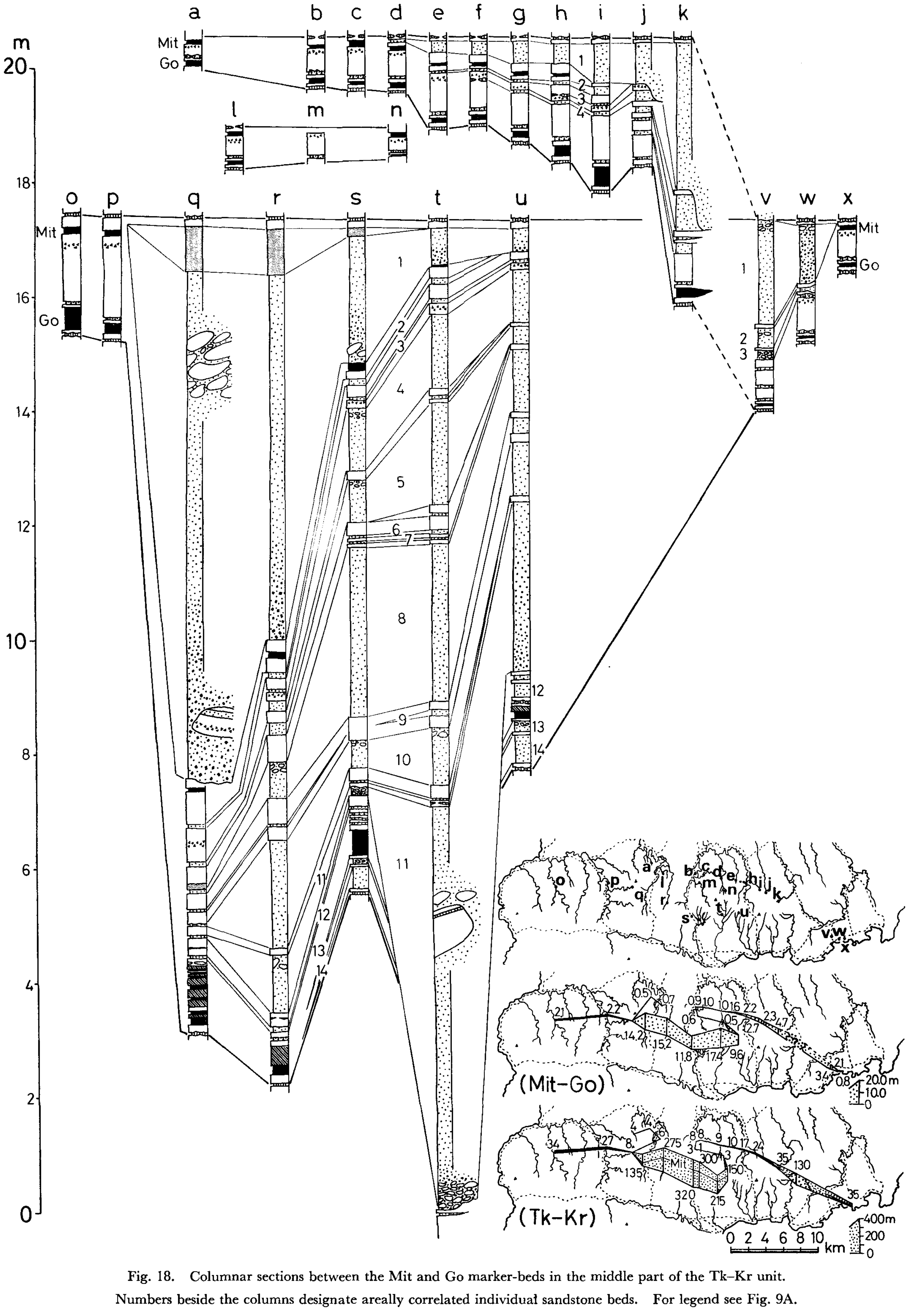


Fig. 18. Columnar sections between the Mit and Go marker-beds in the middle part of the Tk–Kr unit. Numbers beside the columns designate areally correlated individual sandstone beds. For legend see Fig. 9A.

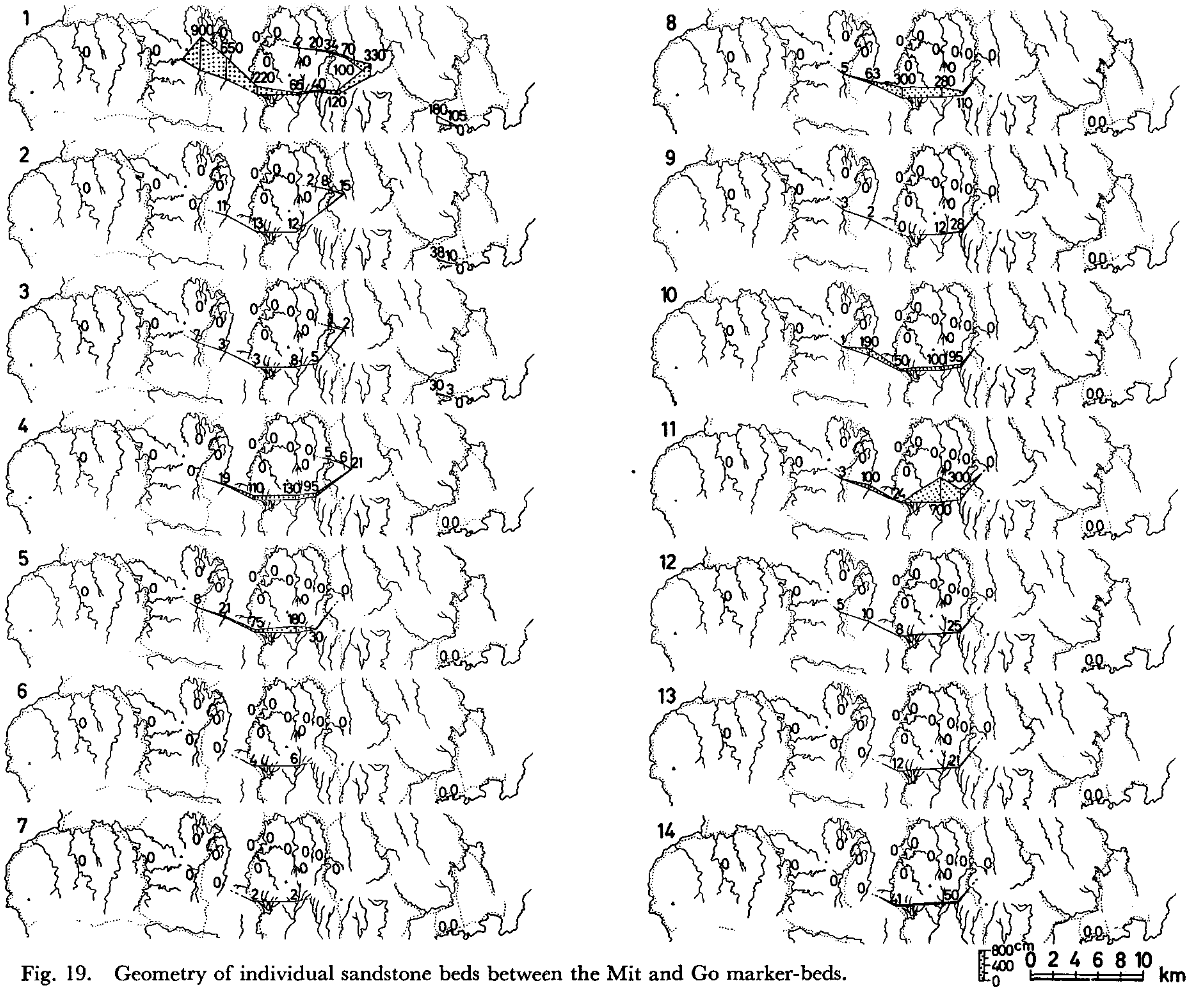


Fig. 19. Geometry of individual sandstone beds between the Mit and Go marker-beds.

Mineoka Mountains. Therefore the distribution of the turbidite sandstones supplied from north seems to have been restricted to the northern side of the Mineoka uplift zone. The width of the topographic high at that time is not considered to have been much larger than that of the present distribution area of the Mineoka Group. Because the Mineoka uplift zone is interpreted to have been lifted along the faults by the tectonic movements. In Fig. 17F, the distribution boundary is drawn along the Kamo River located just on the northern side of the Mineoka Mountains.

2. Depositional pattern of the Hk–Km unit

Sedimentological data on the Hk–Km unit are summarized in Fig. 20A to E. TOKUHASHI (1976a, b) already reported the geometry and depositional process of the individual sandstone beds in the upper half of the unit. It is characteristic that the Hk–Km unit thickens toward south very gradually but not as abruptly as in the case of the lowermost Tk–Kr unit, and that the facies of the sandstone-dominated alternations in the central area of the peninsula changes into siltstone-dominated alternation facies both in the eastern and western areas. Paleocurrent data on this unit indicate such a pattern fanning out toward south in the central area of the peninsula much like the results obtained from the upper half of the unit by TOKUHASHI (*op. cit.*). Pebbly sandstones (facies "a"), though being much thinner and narrower than those in the Tk–Kr unit, is distributed with a small-scale trough-like erosive morphology at the base just near the area where the paleocurrent begins to diverge. Therefore, the area where the pebbly sandstones are observed seems to be the nearest portion to the terminus of the channel. Depositional pattern of the Hk–Km unit is shown in Fig. 20F.

3. Depositional pattern of the Sa–Nm unit

Sedimentoligical data on the Sa–Nm unit are summarized in Fig. 21A to E. It is the characteristics of this unit that the unit thickens toward north, and that the sandstone-dominated alternations (facies "b") continue to the east coast. In addition, two a little different groups of conglomeratic gravels occurs in this unit. One is characterized by containing a lot of larger gravels and including no crystalline schists not only in gravels but also in sand-size grains. It occurs only in this unit (localities a, b, c and so on). The other one consists of smaller gravels and commonly includes gravels of the crystalline schist. It also constitutes the pebbly sandstone facies of other underlying units. It is clear that the former group was also supplied from north, because the imbrication of the outsize siltstone-clasts coexisting with hard gravels indicates their supply from north (Plate 5, Figures 1–4).

Based on these facts, two different channels are presumed on the northern side in the case of the Sa–Nm unit (Fig. 21F). The terminus of the channel which have played the most important role in supplying the turbidite sediments of the underlying

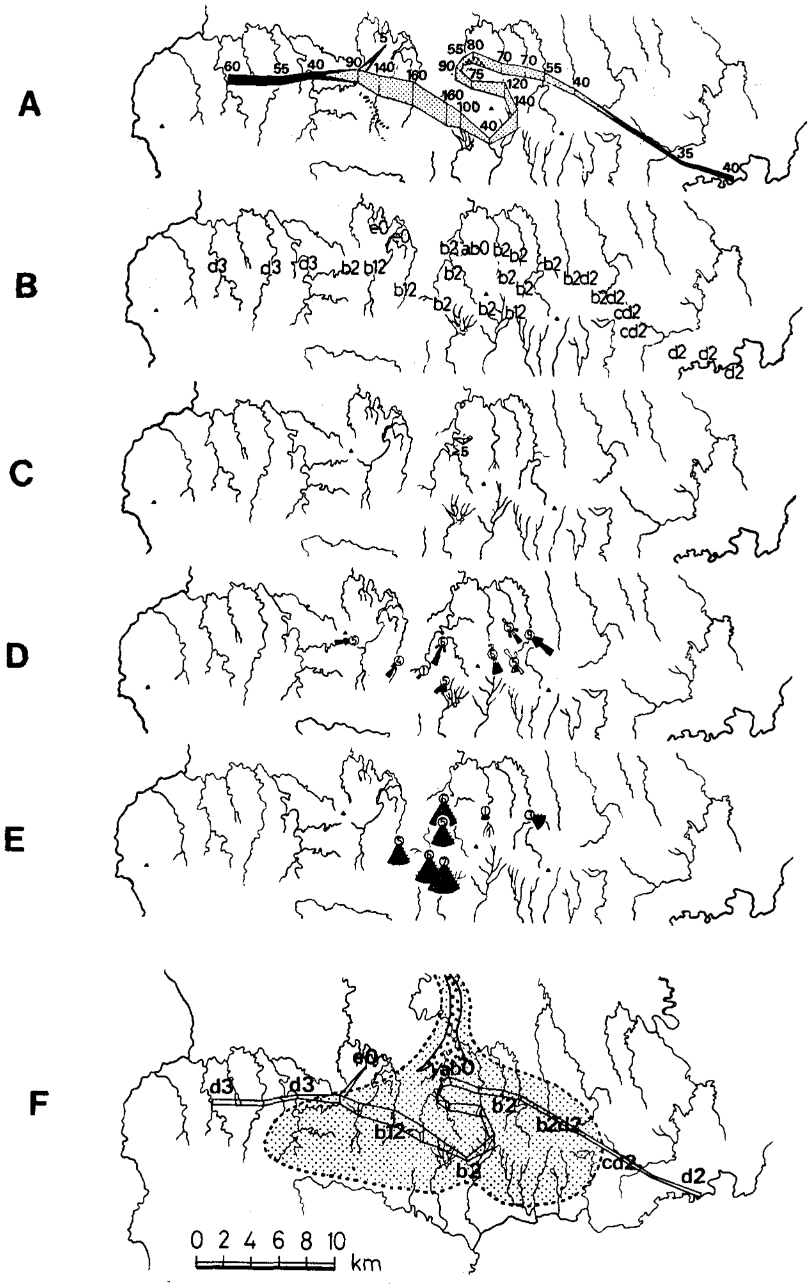


Fig. 20. Summary of some basic sedimentological data on the Hk-Km unit (A–E) and an inferred depositional pattern of the unit (F).

For explanation see the text.

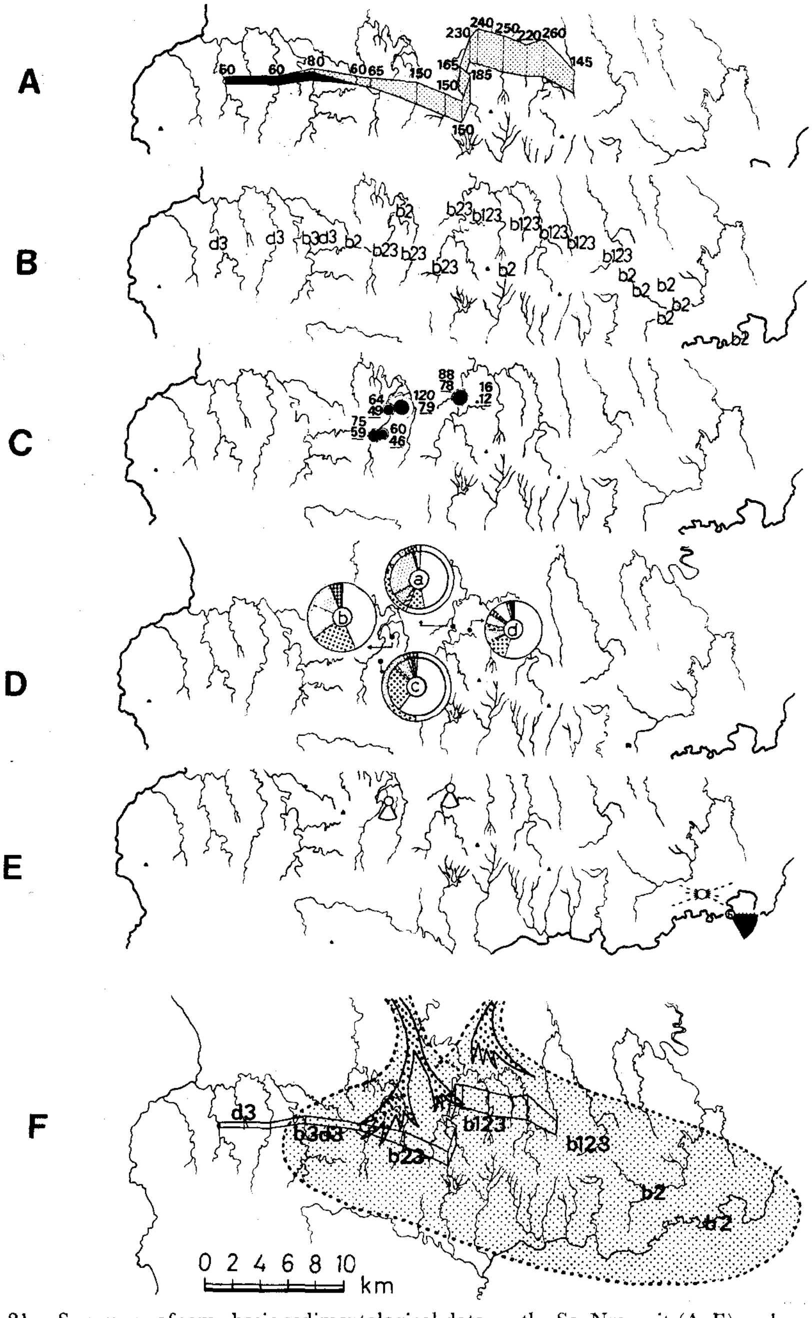


Fig. 21. Summary of some basic sedimentological data on the Sa–Nm unit (A–E) and an inferred depositional pattern of the unit (F).

For explanation see the text.

units further regressed toward north. But the other new channel was formed at the western side of the older one and seems to have stretched to the more southern areas than the older one.

C. Depositional Process of the Kiyosumi Formation

Depositional process of the overall Kiyosumi Formation can be drawn by the successive figures of the depositional patterns of individual units.

The following two assumptions play the very important roles to infer the process. Firstly, the pebbly sandstone facies (facies "a") is channel deposits. The main reasons of this assumption are as follows.

(1) A large trough-like erosive morphology is observed at the base of the pebbly sandstone facies of each unit.

(2) Pebbly sandstone facies disappears rapidly in a few kilometers in the lateral directions.

(3) In the area downcurrent of the pebbly sandstone facies are developed the thick sandy-flysch facies (facies "b").

Secondary, the channel deposits and their downcurrent deposits debauched from the almost same outlet located at the northern portion, except for those of the uppermost Sa–Nm unit which contain the larger gravels and include no crystalline schist gravels. Therefore, the discontinuous migration of the pebbly sandstone facies from the Tk–Kr unit to the Hk–Km unit through the Km–Tk unit was caused by the shifting of the channel (Fig. 8). The main reasons of the second assumption are as follows.

(1) Constitution of gravels in the pebbly sandstones of these units closely resemble each other (Fig. 14, Table 2).

(2) The thickness of the channel deposits is much larger than the depth of the trough-like erosive morphology formed at the base of the units (Figures 8 and 11).

(3) The channel deposits indicate an upward thinning cycle from the thick pebbly sandstone facies at the base to the thin siltstone-dominated alternations at the top through the sandstone-dominated alternations.

(4) The migration of the pebbly sandstone facies from one unit to the overlying unit is discontinuous and complete.

On the basis of these assumptions the depositional process of the Kiyosumi Formation is shown in Fig. 22 and interpreted as follows.

Tk–Kr unit (see Fig. 17)

The channel of this unit was extended toward southeast and passed through the eastern part of the investigated area, and then turned toward west. Downcurrent

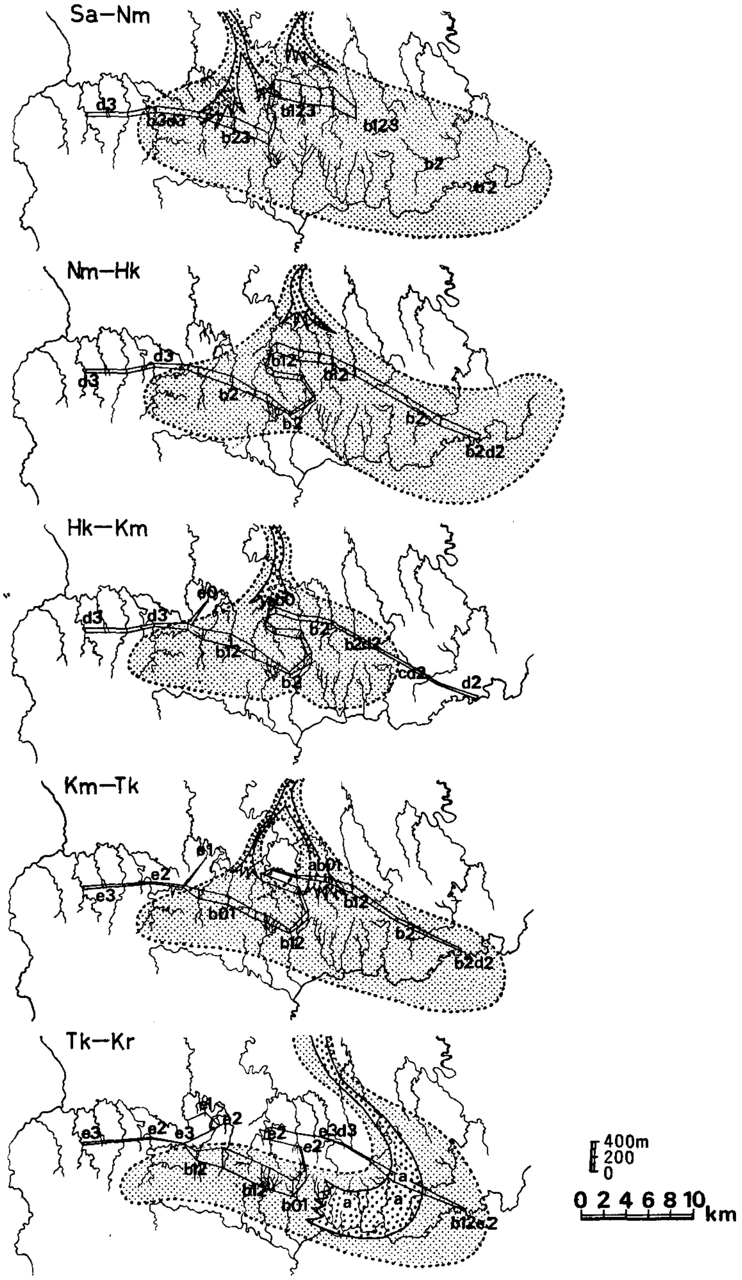


Fig. 22. Inferred depositional process of the Kiyosumi Formation.

Detailed explations are given in the text. Outlines of areal variations of facies and thickness of each unit are also shown in this figure.

of the pebbly sandstones filling a large channel are extensively developed thick sandstone-dominated alternations.

Km–Tk unit

In this unit braided channels were created at the northern part of the investigated area. The main reasons are as follows.

(1) Trough-like erosive morphology is observed at the two areas apart from each other at the base of this unit (Fig. 11).
(2) Deposits filling these two erosive morphologies were formed concurrently in the same period.
(3) The thickness of the unit in the area between these two morphologies is very small (Fig. 8).

Two depositional tongues composed of the sandstone-dominated alternations were formed and incorporated with each other in the area downcurrent of each braided channel.

Hk–Km unit (see Fig. 20)

The braided channels of the Km–Tk unit were replaced by a single new channel extended from north to the northernmost portion of the investigated area. A single depositional tongue composed of the sandstone-dominated alternations was formed downcurrent of the channel. Further downcurrent in the eastern and western parts of the peninsula were deposited the siltstone-dominated alternations.

Nm–Hk unit

The channel of the Hk–Km unit gave place to a new one formed in the neighbourhood. Its terminus retreated further northward, because pebbly sandstone facies (facies "a") are not exposed anywhere in this unit within the investigated area. The depositional tongue composed of the sandstone-dominated alternations stretched beyond the east coast of the peninsula.

As already mentioned, current ripple cross laminations indicating the currents from south are observed in the Nm–Hk unit at only one locality in the eastern part of the peninsula (Fig. 16B). But these sandstone beds are all thin and composed only of laminated sandstones. On the other hand, the orientation of currents at the same locality obtained from sole markings and preferred wood fragments of thick sandstone beds containing massive sandstone are concordant with the NWW–SEE current directions in the central part of the peninsula (Fig. 16A). Moreover, at the east coast near that locality, current cross laminations of both thick and thin sandstone beds in the same unit are all concordant with those, too (Fig. 16B). Therefore, the author attributes such northward current cross laminations to shifting of current directions controlled by microreliefs on the basin floor and not to direct supply from the southern area.

Sa–Nm unit (see Fig. 21)

The terminus of the surviving channel deposits also did not reach to the investigated area and the depositional tongue composed of the sandstone-dominated alternations successively stretched beyond the east coast. The new channel coming from a different outlet intruded to the more southern area than the older one on the western side of it. The new channel deposits contain a little different gravels from those of the older channel deposits. In the area downcurrent of the new channel deposits was also formed the depositional tongue of the sandstone-dominated alternations. Therefore, in the central part of the peninsula, two tongues were formed overlapping with each other.

From this depositional process, it is clear that each unit is composed of channel deposits, depositional tongue of sandstone-dominated alternations, and surrounding siltstone-dominated alternations or massive siltstones. The Kiyosumi Formation is formed by superposition of several pairs of the channel deposits and depositional tongue. Therefore, the migration of the channel and depositional tongue has played the most important role in vertical facies variation of the Kiyosumi Formation.

D. Depositional Model of Turbidite Bed and Facies

TOKUHASHI (1976) traced the sandstone-dominated alternations constituting the upper half of the Hk–Km unit widely for 40 km in E–W direction throughout the peninsula along the folding axis and for 5 km in N–S direction across it. He correlated many individual sandstone beds in the alternations by means of many thin tuff marker-beds in the siltstone beds (Fig. 23). He reconstructed schematically a three-dimensional geometry of each sandstone bed (Fig. 24A) and illustrated a common lateral change of sedimentary structures and textures in each turbidite bed along the downcurrent direction (Fig. 24B). But these models lack the most upcurrent part, because the sediments in the exactly upcurrent area such as pebbly sandstones are not included in the upper half of the Hk–Km unit.

However in the overall Kiyosumi Formation are also observed such thick pebbly sandstones as channel deposits filling a large-scale erosive morphology, that is, a large channel. Therefore, a more complete diagramatic model of the lateral change of sedimentary structures and textures in each turbidite bed can be illustrated now (Fig. 25A). Characteristics of sedimentary structures and textures of each division in the model are summarized in Table 3. Depositional models of the turbidite sequence corresponding to individual units in the Kiyosumi Formation are illustrated in Figures 25B and C with facies symbols in Table 1.

The depositional model of each turbidite bed illustrated here relatively well

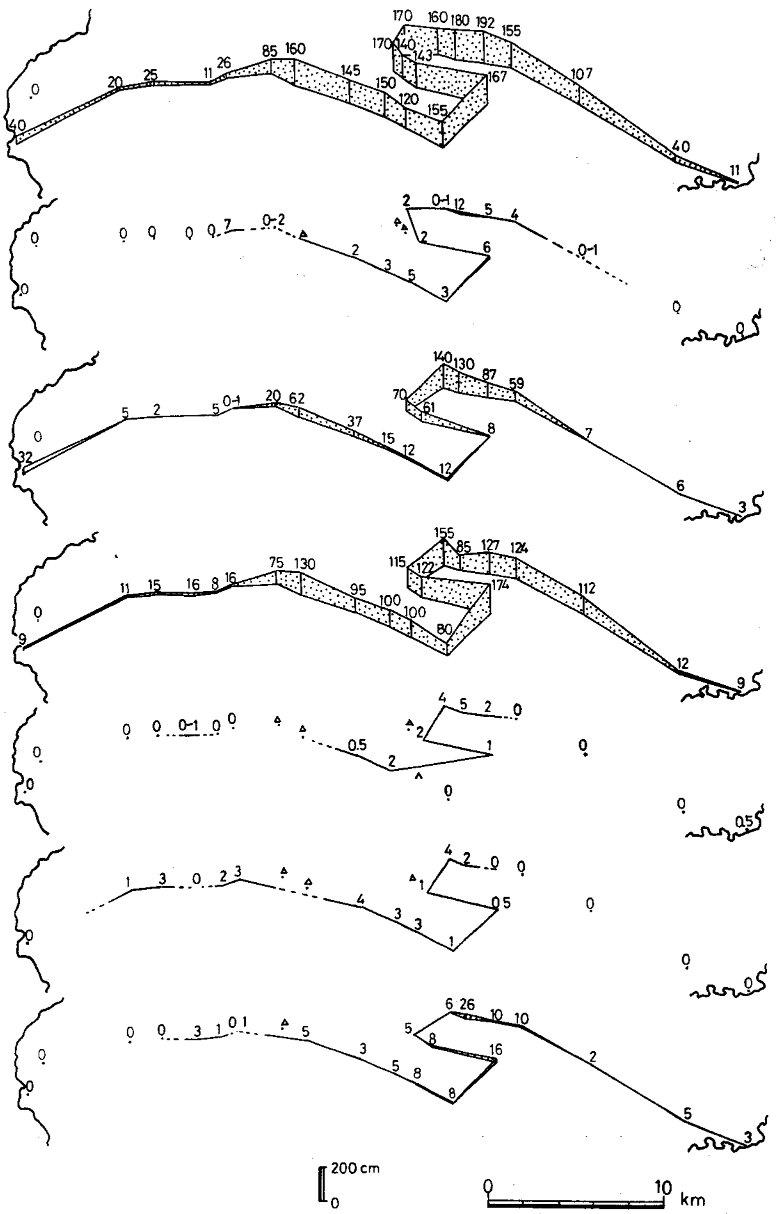


Fig. 23. Geometry of individual sandstone beds in the upper half of the Hk–Km unit (TOKUHASHI, 1976).

Each number means thickness in cm at each locality. The lower point of each section corresponds to each locality. Triangles mean the absence of beds due to erosion by the overlying thick sandstone beds.

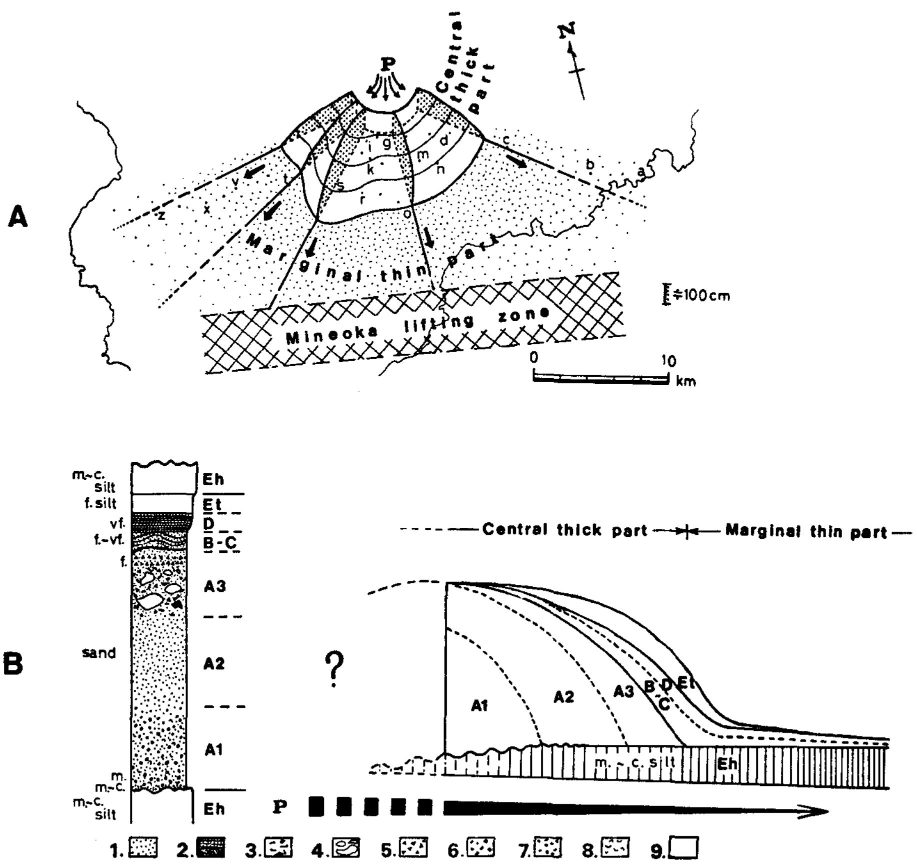


Fig. 24. Depositional model of individual turbidite beds in the Kiyosumi Formation (TOKUHASHI, 1976; partly modified). Vertical scale is remarkably exaggerated.

A. Geometric model of a moderately thick sandstone bed.

B. Schematic model of the lateral variation of sedimentary structures and textures in a considerably thick sandstone bed along the current direction.

1. Massive sandstone, 2. Laminated sandstone, 3. Wood fragments, 4. Siltstone clasts, 5. Pumice grains, 6. Scoria grains, 7. Small pebbles of basement rocks, 8. Shell fragments, 9. Siltstone. For description of symbols see Table 3.

Fig. 25. Depositional model of individual trubidite beds and facies in the Kiyosumi Formation along the current direction. Vertical scale is remarkably exaggerated.

A. Schematic model of the lateral variation of sedimentary structures and textures in a considerably thick sandstone bed. For description of symbols see Table 3.

B. Schematic profile model of the lateral facies change of flysch sequence corresponding to an upward thinning cycle unit.

C. Schematic plan model of the same unit as B. For description of symbols in B and C see Table 1.

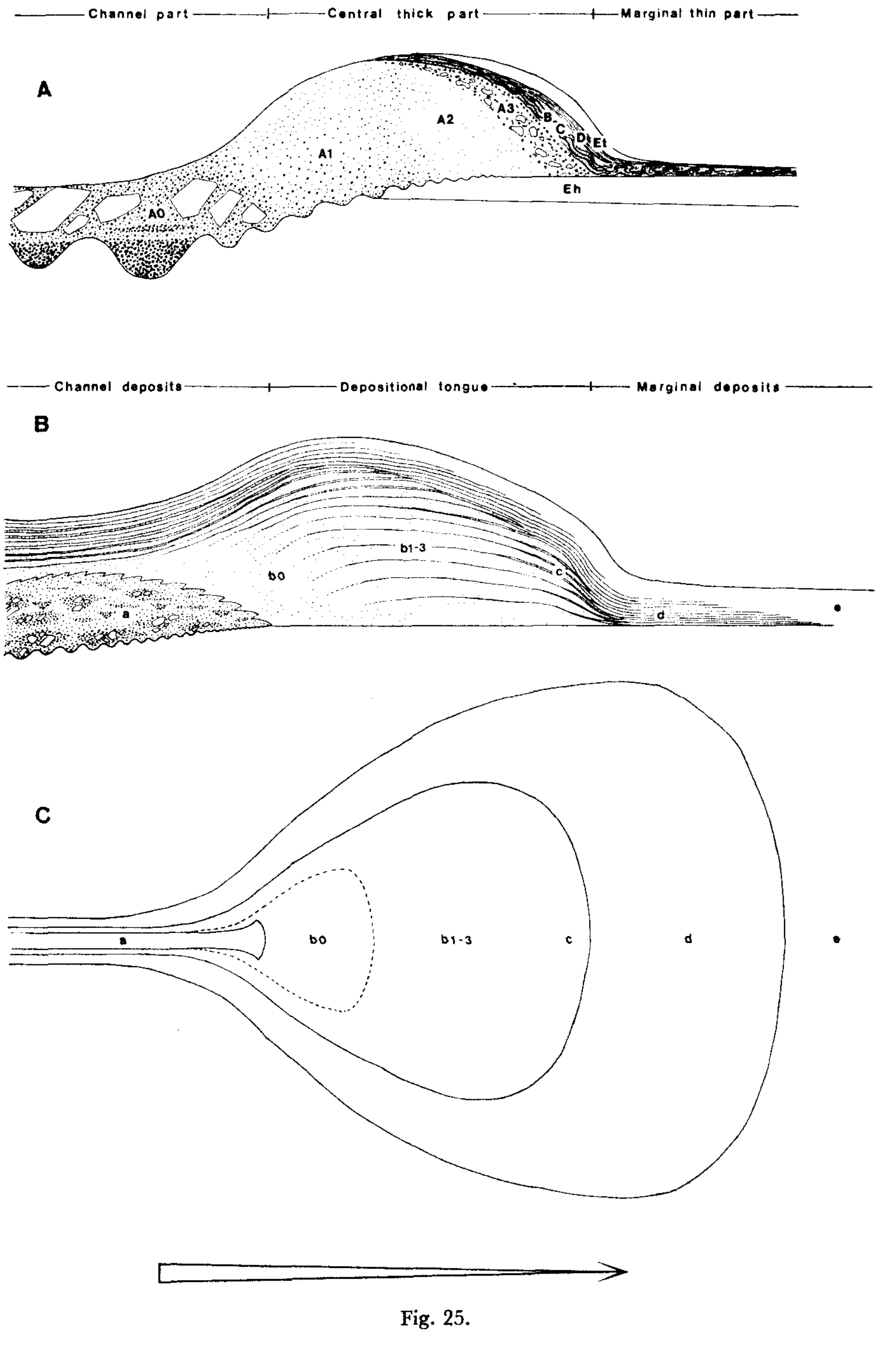

Channel part
Central thick part
Marginal thin part
A
A0
A1
A2
A3
B
C
D
Et
Eh
Channel deposits
Depositional tongue
Marginal deposits
B
a
b0
b1-3
c
d
e
C
a
b0
b1-3
c
d
e

Fig. 25.

Table 3. Characteristics of each division of turbidite beds and hemipelagic siltstone beds in the Kiyosumi Formation

Symbol	Characteristics	Grain size of matrix	Occurrence
A0	Pebbly sandstone division Small hard pebbles occur crowdedly, contacting with each other. They occur filling small channel-like scours, enclosing very large angular siltstone-clasts or forming elongated lenses in the massive sandstones.	very coarse- to medium-grained sands	channel deposits
A1	Lower massive sandstone division (Bouma's a division) Small hard pebbles and hard scoria grains and shell fragments occur scattering in the massive sandstones. Grading and imbrication of these pebbles and grains are often observed. Dish structures are sometimes developed.	coares- to medium-grained sands	lower to middle parts of thick-bedded sandstones
A2	Middle massive sandstone division (Bouma's a division) Well sorted sandstone with few conspicuous grains in it. Dish structures are sometimes developed.	medium- to fine-grained sands	middle to upper parts of thick-bedded sandstones and lower part of sandstone beds thinner than about 1 m.
A3	Upper massive sandstone division (Bouma's a division) Massive sandstone with scattering rounded siltstone-clasts, wood fragments of various sizes but smaller than siltstone clasts, and pumice grains. Pumice grains are sometimes parallel aranged in the uppermost part of the division. Preferred orientation of wood fragments are sometimes observed.	fine-grained sands	upper or uppermost part of relatively thick-bedded sandstones
B–C	Laminated sandstone division (Bouma's b and c division) Various sedimentary structures with carbonaceous wood flakes, such as parallel, wavy, convoluted, current-ripple-cross laminations occur. Division into lower-parallel-lamination part (Bouma's b division) and overlying current-ripple-cross-lamination part (Bouma's c division) is very difficult so they are treated as a single B–C division here.	fine- to very fine-grained sands	upper or uppermost part of thick-bedded sandstones and lower part of thin-bedded sandstones
D	Finely laminated silty sandstone division (Bouma's d division) Very fine sedimentary structures such as thinly-alternated parallel laminations and other minute laminations with very small wood flakes and micas are observed. Weathered surface is protruded as in the case of overlying siltstone bed.	very fine-grained sands to coarse-grained silts	uppermost part of thick-bedded sandstones and upper part of thin-bedded sandstones
Et	Turbiditic siltstone division (lower part of Bouma's e division) Turbiditic siltstone is easily distinguished from overlying hemipelagic siltstone (Eh) by finer-grained and better sorting and sharp contact with the latter. Distinct grading is observed in the case of thick turbiditic siltstone.	medium- to fine-grained silts	usually accompanied wtih relatively thick-bedded sandstones
Eh	Hemipelagic siltstone division (upper part of Bouma's e division) This siltstone is usually ill sorted and often contains scoria and pumice grains randomly. Many continuous tuff beds are included in the division. Grading is not observed. Trace-fossils are sometimes observed.	mostly of medium- to coarse-grained silts	lying on the sandstone beds or turbiditic siltstone beds

coincides with that hypothetically proposed by MEISCHNER (1964). But the lowermost pre-face underlying the main face in the MEISCHNER's model is not observed here. In addition, not only hemipelagic siltstone but also turbiditic siltstone are both observed on the relatively thick sandstone beds and they are easily distinguished from each other. Generally the turbiditic siltstone is finer-grained and better-sorted than the overlying hemipelagic siltstone. Detailed differences between the turbiditic and hemipelagic siltstones are discussed in O'BRIEN *et al.* (in press).

The depositional model of the turbidite sequence illustrated here (Figures 25B and C) fundamentally coincides with the hypothetical lithologic variation proposed by DZULYNSKI and WALTON (1965) with symbols such as "a" to "e" used to express the characteristic facies commonly occurring in flysch. But in the present model, the concept of upward thinning cycle are also incorporated (Fig. 25B) and pebbly sandstone facies (facies "a") is distinguished and stressed as channel deposits by their narrow distribution and large basal erosion (Figures 25B and C).

V. Discussion

A. Comparison of the Depositional Process of the Kiyosumi Formation with that of the Submarine Fan Model

The prevailing submarine fan model is as follows. A submarine fan which stretches from a mouth of a submarine canyon is generally divided into three segments, that is, upper or inner fan, middle fan and lower or outer fan. In the upper fan, is developed a submarine valley or channel with natural levees which debouches from the mouth of the submarine canyon. When tubbidity currents flow down through the valley or channel and arrive at an intersection zone (HANER, 1971), they release and deposit a large quantity of suspended loads on the surrounded area. Consequently a depositional lobe or suprafan (NORMARK, 1970) is formed downcurrent of the zone, that is, on the middle fan segment. Therefore the middle fan is characterized by the active deposition and by a convex-upward segment on a radial profile. The lower fan has a very smooth and nearly flat surface with no channels. Uniform parallel bedding is observed on reflection profiles. The shifting of channel in the upper fan is followed by the migration of the suprafan in the middle fan. Submarine fan model shows that the repetition of these processes makes a fan to grow up (NELSON *et al.*, 1970; NORMARK, 1970; HANER, 1971; NORMARK and PIPER, 1972; NELSON and KULM, 1973; WALKER and MUTTI, 1973; SAKURAI *et al.*, 1974; NORMARK, 1974; NELSON and NILSEN, 1974; CLEARY and CONOLLY, 1974; RICCI-LUCCHI, 1975; PIPER *et al.*, 1978; NORMARK, 1978).

On the other hand, the inferred depositional process of the Kiyosumi Formation is fundamentally the same as that of the submarine fan model. Because, as already mentioned, the Kiyosumi Formation was formed by the superposition of depositional tongues or lobes which were deposited in the area downcurrent of the termini of channel deposits. The terminus of the channel deposits seems to correspond accurately to the intersection zone of the submarine fan model.

Submarine channel deposits in the Kiyosumi Formation are characterized by accompanying a trough-like erosive morphology at the base and by an upward thinning cycle beginning with thick pebbly sandstones and ending with thin siltstone-dominated alternations or massive siltstones. Pebbly sandstone facies are very narrow laterlaly and rapidly change into siltstone-dominated alternations. Three stages are recognized in the formation of the channel deposits.

First stage

The period of growth of an channel morphology by the passage of a large quantity of sediments and concurrent erosion of the underlying layers.

Second stage

The period of deposition of pebbly sandstones in the channel and consequent disappearence of the channel morphology on account of the regression of the intersection zone, which follows the reduction of the power and magnitude of turbidity currents.

Third stage

The period of burial of the pebbly standstones in the channel by deposition of sandstone- and siltstone-dominated alternations on them, due to the further regression of the intersection zone.

When the magnitude and power of turbidity currents were recovered again, a new channel of the first stage was formed at a different site. That is, the rejuvenation of turbidity currents seems to have been the most important factor to cause the shift of the channel. The characteristics of the depositional site of these channel deposits coincide well with those of the upper fan especially of the lower half of the upper fan of the submarine fan model.

On the other hand, the depositional tongue, consisting of thick sandstone-dominated alternations developed in the area downcurrent from the terminus of the channel deposits, must have formed a convex-upward depositional bulge on the surface with the negligible erosion at the base of the tongue. Therefore, the depositional tongue seems to correspond exactly to the suprafan of the submarine fan model.

The suprafans in the Kiyosumi Formation extend more than 20 km in E–W direction and they overlap most parts of their extents with each other (Fig. 22). Moreover each suprafan of the unit occupies the most part of the main depositional area. Because of these features, the depositional process or pattern of the Kiyosumi Formation does not completely coincide with that of the current submarine fan model. In the case of the submarine fan model, each suprafan occupies only a portion of the overall surface of a fan (NORMARK, 1970; RICCI-LUCCHI, 1975; MUTTI, 1977). As a result, the lateral extent of individual turbidite beds on the suprafan are remarkably underestimated such as 1 to 2 km wide (WALKER and MUTTI, 1973). But in the case of the Kiyosumi Formation, the individual thick sandstone beds extend consistently in thickness at least over 10 to 20 times as wide as the estimated value (TOKUHASHI, 1976a; HIRAYAMA and NAKAJIMA, 1977). Accordingly, in the case of the Kiyosumi Formation, the remarkably large-scale turbidity currents seem to have occurred forming remarkably wider suprafans than those in the current submarine fan model.

Siltstone-dominated alternations and successive siltstones which are distributed in the areas downcurrent of the sandstone-dominated alternations (suprafan) seem to have formed the lower fan deposits and/or basin floor deposits.

B. Early Stage of Fan Sedimentation

One of the most serious shortcomings of the prevailing submarine fan model is that it makes no reference to the early stage of the submarine fan sedimentation. That is, it refers only to the depositional process on the surface of the adequately matured submarine fan. Here the author will discuss the early stage of the depositional process of the Kiyosumi Formation which corresponds to the early stage of fan sedimentation.

When the inferred depositional process of the Kiyosumi Formation is examined, the peculiar behaviour of the lowermost Tk–Kr unit should be first noticed (Fig. 22). Why does such a peculiar behaviour occur only in the lowermost Tk–Kr unit? What does it mean in forming the submarine fan? Of course, the configuration of a basin and the site of a feeder canyon obviously have an overall influence over the growth of a fan. As already mentioned, the Kiyosumi Formation was formed by lateral supply from north into a restricted basin elongated in the E–W direction on the continental slope. The Mineoka uplift zone formed an outer ridge along the southern side of the basin and dammed up the sediments supplied from north.

On the other hand, the bottom topography such as general slope and relief of the basin before the incoming of turbidity currents seems to have had an important influence on the depositional process in the early stage of fan sedimentation.

Bottom topography of the basin in the depositional period of the uppermost part of the Amatsu Formation, which underlies the Kiyosumi Formation and is composed mainly of hemipelagic siltstones, seems to have been formed mainly under the influence of tectonic movements for a long time. Especially in the case of the slope basins in the geologically active region, the bottom topography mainly reflects the tectonic movements, and the tectonic topography is dominant unless differential deposition occurs to bury the relief. Therefore, on the bottom of the basin just before the beginning of the deposition of the Kiyosumi Formation, some tectonic topography seems to have been developed. The first group of turbidity currents which flowed into the basin from north must have necessarily been controlled by the configulation of the basin and the bottom tectonic topography.

The Mineoka uplift zone on the southern side must have changed the direction of turbidity currents of the lowermost Tk–Kr unit from southward to westward. The southern area in the basin floor must have been deeper than the northern area, because the thick sandstone-dominated alternations of the Tk–Kr unit are distributed only in the southern area in the basin.

The turbidite sandstones of the Tk–Kr unit seem to have smoothed the preexisting relief to attain an equilibrium profile of slope-fan-basin. Therefore, it may be said that the lowermost Tk–Kr unit showing the peculiar depositional process exhibits the deposits of "a preparatory stage" of fan sedimentation, or the deposits of "a pre-fan-sedimentation stage". Such stage must always exist, although the sedimentary features may not be same due to the characteristics of the various basins in the various geologic frameworks.

C. Further Problems

The Kiyosumi Formation occupies the lower half of a turbidite suite, and therefore, reveals the process of fan sedimentation of the first-half stage including the early stage. The Kiyosumi Formation consisting of a large sandy-flysch body formed the fundamental framework of a submarine fan on the basin floor made of the Amatsu Formation or Amatsu Mudstone. The Inakozawa Formation or Inakozawa Mudstone, the western equivalent of the Kiyosumi Formation, was formed on the lower fan or the basin floor around the fan. On the submarine fan composed of the Kiyosumi Formation was deposited the Anno Formation, which is composed of several small-scale sandstone-dominated alternations surrounded respectively with siltstone-dominated alternations both laterally and vertically. To understand the process of fan sedimentation of the later-half stage including the last stage, the depositional process of the Anno Formation must be analyzed. Then the depositional process of the overall fan sedimentation or of a complete turbidite suite can be clarified.

On the other hand, the origin of upward thinning cycles observed in the Kiyosumi Formation seems to be the most important problem to be further discussed, because they not only play such a substancial role as channel shifting in fan sedimentation but also may reflect the chronologic and geologic events in those days.

At least the two different orders of upward thinning cycles are recognized in the Kiyosumi Formation. An upward thinning cycle of the first order is detected throughout both the Kiyosumi Formation and the overlying Anno Formation. As already mentioned, these two formations together form a positive or transgressive or recessional turbidite suite (RICCI-LUCCHI, 1975). In the case of the Kiyosumi Formation, a phased retreat of the terminus of the channel deposits is clearly recognized unit by unit from the bottom to the top as shown in Fig. 22.

Upward thinning cycles of the second order are clearly recognized at the ancient submarine channel sites of the individual units. Each of them may correspond to a positive or transgressive turbidite megasequence or subsuite (RICCI-LUCCHI, 1975). These cycles were repeated several times in the Kiyosumi Formation. The rejuvenation of turbidity currents, which means a new start of the next unit or cycle, played the most important role to form a new channel at a different site.

What caused such upward thinning cycles of the first and second orders in the Kiyosumi Formation? These phenomena might reflect the eustatic movements, that is, a general tendency of gentle rise of sea level with small-scale oscillations. Obviously the level of the sea surface effects the possibility for the coastal sediments to reach the canyon heads or the shelf break, and therefore, the frequency and magnitude of turbidity currents. Generally the lower level of the sea surface is considered to permit more frequent and larger turbidity currents (DALY, 1936; KUENEN, 1950; HAND and EMERY, 1964; CALSON and NELSON, 1969; NORMARK and PIPER, 1972; NELSON and KULM, 1973).

Therefore, the gentle ascention of the sea level reduces the frequency and magnitude of turbidity currents and may produce the upward thinning cycle in the depositional area. The following relatively rapid descent of the sea level may produce, on the contrary, the rejuvenation of turbidity currents. Therefore, the tendency of a general rise of the sea level with such small-scale fluctuation might have produced such upward thinning cycles of the first and second orders as observed in the Kiyosumi Formation. If the idea is correct, we can read the ancient eustatic movements or glacial activities by analyzing the upward thinning cycles in flysch sequences.

However, a different way of thinking may be possible. The depositional processes in the depositional basin are no more than the reflection of the destructive processes in the source area. That is, the turbidity current action is the process to attain a new stable equilibrium occuring on a large scale in the submarine realm. An abrupt destructive fall of the unconsolidated metastable sediments at the first stage may occur on the largest scale and form a new canyon head on the uppermost part of the slope. As the canyon head grows forward, each quantity of sediments produced by a single destructive fall may decrease gradually and then the magnitude of turbidity currents may become smaller than that at the earlier stage. In response to this, the upward thinning megasequence or cycle may be formed in the depositional area.

The formation of a new canyon head at a different site due to a next new large destructive fall of the unconsolidated sediments may be responsible for the rejuvenation of turbidity currents or the shift of channel site in the depositional area. FELIX and GORSLINE (1971) pointed out the lateral shifts of the Newport Submarine Canyon off California in response to the changing point of input of sand to the canyon system. The constructive process of a transgressive or recessional turbidite suite may correspond to a general destructive process of a large body of the unconsolidated sediments such a delta through the formation of a canyon system of the dendritic tributaries on the upper slope.

Moreover, the tectonic movements including a change of lifting rate at the provenance may have sensibly controlled the rate of supply of sediments to the canyon heads. In this case, the tectonic movement may be a main factor to have produced the upward thinning cycle.

Of course, the combination of these factors may have produced the first- and second-order upward-thinning cycles in the Kiyosumi Formation. Accumulation of the data on the eustatic movements in those days and on the initiation of turbidity currents at the canyon heads will help to analyze the generation of such cycles. Anyway, the clarification of origin of the upward thinning cycles demands the broader knowledge and background as in the case of the other cyclic sedimentation.

It may be very important to recognize that any submarine fan sedimentation and its sediments reflect and are characterized by not only the geologic setting such as size, configuration and depth of basin, and rate of sediment supply, but also the chronologic events such as eustatic movements. Geologic time is an important factor in changing growth patterns and differing sedimentary regimes during the depositional history of fans (NELSON and KULM, 1973).

At last, we can't forget the facts that the detailed and fundamental work on the recent submarine topographies and sediments has made a great advance in interpreting the genesis of various facies in flysch sequences on land. But unfortunately, as correctly pointed out by WALKER and MUTTI (1973), only a little is known about the detailed topographies, sediments and their interrelationships of the trenches, troughs, slope basins, borderland basins and marginal-sea basins around the island arcs including Japan Island Arcs. Urgent and vigorous work on them is demanded. Such work will bring further useful informations in interpreting the depositional processes of flysch and other sediments which were deposited in ancient geosynclines and other various basins and are now exposed on land.

VI. Conclusive Remarks

Three dimensional analysis of the Mio-Pliocene Kiyosumi Formation with the aid of many tuff marker-beds disclosed the depositional process of the formation and enabled it to be compared with the current submarine fan model. Main results are as follows.

(1) The Kiyosumi Formation or the Kiyosumi Sandstone is composed of a lenticular sandy-flysch body attaining 850 m in maximum thickness and distributed more than 20 km in E–W direction along the folding axis and more than 6 km in N–S direction in the central and eastern parts of the Boso Peninsula and interfingers with the Inakozawa Mudstone in the western part of the peninsula.

(2) The turbiditic sediments were supplied laterally from north into a restricted slope basin elongated in E–W direction. Supply from north is supported not only by paleocurrent evidences of turbidites but also by composition of gravels in the formation. The Mineoka uplift zone on the southern side of the basin is considered not to have been a source area of the formation, but a submarine outer ridge of the basin.

(3) The depositional depth of the Kiyosumi Formation is inferred from benthonic foraminifera in the interbedded hemipelagic sediments as middle to upper bathyal environments (Aoki, 1968; Hatta, unpublished data). Hemipelagic sediments are composed mostly of medium- to coarse-grained siltstone.

(4) Submarine channels played the most important role in forming the Kiyosumi Formation as passage ways for the large quantity of turbiditic sediments. Channel deposits are characterized by an upward thinning cycle beginning with thick pebbly sandstones and ending with thin siltstone-dominated alternations or massive siltstones and by accompanying a basal trough-like erosive morphology up to 50 m in maximum depth and more than 5 km in maximum width.

(5) In the area downcurrent of the channel deposits were deposited a large depositional tongue composed of thick sandstone-dominated alternations with negligible erosion at the base. Siltstone-dominated alternations are distributed in the area further downcurrent of it.

(6) The Kiyosumi Formation was formed by shifting the submarine channel several times. Such depositional process of the Kiyosumi Formation is essentially the same as that of the current submarine fan model (Normark, 1970; Haner, 1971; Walker and Mutti, 1973; Ricci-Lucchi, 1975; *etc.*) The shift of the submarine channel is related most intimately to the beginning of a new upward thinning cycle, that is, to the rejuvenation of turbidity currents.

(7) Depositional environment of the channel deposits seems to have been an upper-fan segment. The terminus of the channel deposits probably corresponds to an intersection zone (Haner, 1971) between the upper- and middle-fan segments.

(8) The depositional tongue of thick sansdtone-dominated alternations seems to have been an ancient suprafan (Normark, 1970) on the middle fan segment. Siltstone-dominated alternations deposited in the area downcurrent of the depositional tongue seems to have formed the outer-fan deposits and/or the surrounding basin floor deposits.

(9) The extent of the individual depositional tongues in the Kiyosumi Formation is much larger than that of the suprafan estimated based on the current submarine fan model. The depositional tongues in the Kiyosumi Formation cover most of the middle-fan segment, so they largely overlap each other. The extent of the constituent individual sandstone beds is also much larger than that estimated based on the current submarine fan model (TOKUHASHI, 1976a, b). This seems to reflect the much larger-scale turbidity currents in the depositional period of the formation.

(10) The channel deposits and depositional tongue in the lowermost unit of the Kiyosumi Formation indicate a peculiar distribution as fan sedimentation. This unit seems to have been allotted to smooth a preexisting relief on the basin floor largely caused by tectonic movements for a long time and to attain an equilibrium profile of slope-fan-basin. Such "a preparatory stage" of fan sedimentation or "a pre-fan-sedimentation stage" must have an especially important meaning when a fan is formed in such a geologically active basin as a slope basin.

(11) The Kiyosumi Formation occupies the lower half of a positive or transgressive or recessional turbidite suite (RICCI-LUCCHI, 1973) and so discloses the depositional framework of a fan. To clarify the depositional process of the later-half stage including the last stage, the overlying Anno Formation must be analyzed. This formation contains several small-scale sandstone-dominated alternations surrounded with siltstone-dominated alternations both laterally and vertically.

(12) The first-order and second-order upward thinning cycles are recognized in the Kiyosumi Formation. The first-order upward thinning cycle is detected throughout the whole Kiyosumi Formation. It was formed by a phased retreat of the terminus of channel deposits or the intersection zone on the fan from the lowermost unit to the uppermost unit. The second-order upward thinning cycle is clearly observed in the channel deposits of each unit. It is repeated several times in the Kiyosumi Formation. This cycle caused not only the formation and disappearence of the channel morphology but also the shift of the channel site.

(13) As causes of the multiple upward thinning cycles are considered an eustatic rise of sea level with small-scale fluctuations, a general destructive process of a large unconsolidated sediments such as a delta through the development of a canyon system on the uppermost slope, a change of rate of sediment supply due to the tectonic movements at the provenance area and/or the combination of these factors. It may be very important to recognize that fan sedimentation and its deposits may reflect not only the geologic setting such as size and configulation of the basin and the rate of sediment supply in the provenance and so on but also the worldwide chronologic events such as eustatic movements in the Miocene-Pliocene time.

(14) Recent submarine geology has played the most important role to establish

the overall turbidite facies association based on the submarine fan sedimentation. Many detailed and fundamental works on submarine topography and sediments in the basins around the island arcs including the Japan Island Arc, such as marginal-sea basins, troughs, trenches and so on are needed not only to fill the gap of informations on them (WALKER and MUTTI, 1973), but also to promote the further marked development of studies on flysch sequences which were deposited in the ancient geosynclines and other basins.

Acknowledgements

The author wishes to express his sincere thanks to Prof. Keiji NAKAZAWA and Associate Prof. Tsunemasa SHIKI, Kyoto University, for their appreciated supervision and permanent encouragement. He must extend his hearty thanks to Drs. Jiro HIRAYAMA and Terumasa NAKAJIMA, Geological Survey of Japan, for their initial and continuing encouragement and support to undertake the sedimentological study in the Boso Peninsula.

He is much indebted to Prof. Keiichiro KANEHIRA, Chiba University, Drs. Naotoshi YAMADA, Sadahisa SUDO and Hiroshi MAKIMOTO, Geological Survey of Japan, for their examination of many thin sections of gravels in the Kiyosumi Formation. He also thanks Mr. Akio HATTA, Kisarazu-higashi High School, for his information on the benthonic foraminiferal fauna in the siltstone bed just below the Hk tuff.

He expresses his deep gratitude to Profs. Tadao KAMEI and Sadao SASAJIMA, Associate Prof. Shiro ISHIDA, Drs. Daikichiro SHIMIZU and Takao TOKUOKA, Kyoto University, for their critical and repeated reading of the rough drafts and their helpful advice to them. He also expresses it to Prof. Neal O'BRIEN, State University of New York, Potsdam, for refining the manuscript.

He is also grateful to Messrs. Kinzo YOSHIDA and Hisao TSUTSUMI, Kyoto University, for preparing many thin sections of gravels, and to the colleagues of Department of Geology and Mineralogy, Kyoto University, for their useful discussion and kindly consideration.

References

AOKI, N. (1968): Benthonic foraminiferal zonation of the Kazusa Group, Boso Peninsula. *Trans. Proc. Palaeont. Soc. Japan, N. S.*, **70**, 238–266.

ASANO, K. (Ed.) (1970): *Micropaleontology (Bikoseibutsugaku) Part I.* 278 p., Asakura-shoten, Tokyo. (in Japanese)

BERGGREN, W. A. (1973): The Pliocene time scale; Calibration of planktonic foraminiferal and calcareous nannoplankton zones. *Nature*, **243**, 391–397.

BOSO PENINSULA RESEARCH COLLABORATING GROUP (1965): On the erosion of the Kurotaki Unconformity between the Pliocene and Miocene Series, and its significance. *Earth Sci. (Chikyu Kagaku)*,

19, 88–99. (in Japanese with English Abstr.)

BOUMA, A. H. (1962): *Sedimentology of some flysch deposits: a graphic approach to facies interpretation.* 159 p., Elsevier, Amsterdam.

CARLSON, P. R. and NELSON, C. H. (1969): Sediments and sedimentary structures of the Astoria submarine canyon-fan systems, northeast Pacific. *Jour. Sediment. Petrol.*, **39**, 1269–1282.

CLEARY, W. J. and CONOLLY, J. R. (1974): Hatteras deep-sea fan. *Jour. Sediment. Petrol.*, **44**, 1140–1154.

CORBETT, K. D. (1972): Features of thick-bedded sandstones in a proximal flysch sequence, upper Cambrian, southwest Tasmania. *Sedimentology*, **19**, 99–114.

DALY, R. A. (1936): Origin of submarine "canyons". *Amer. Jour. Sci.*, **31**, 401–420.

DZULYNSKI, S., KSIAZKIEWICZ, M. and KUENEN, PH. H. (1959): Turbidites in flysch of the Polish Carpathians. *Bull Geol. Soc. Amer.*, **70**, 1089–1118.

——— and WALTON, E. K. (1965): *Developments in sedimentology*, 7: *Sedimentary features of flysch and greywackes.* 265p., Elsevier, Amsterdam.

GEOLOGICAL SURVEY OF JAPAN (1976): Geological map of Tokyo Bay and adjacent areas (scale 1: 100,000). *Misc. map series* (20).

GORSLINE, D. S. and EMERY, K. O. (1959): Turbidity-current deposits in San Pedro and Santa Monica basins off southern California. *Bull. Geol. Amer.*, **70**, 279–290.

HAND, B. M. and EMERY, K. O. (1964): Turbidites and topography of north end of San Diego trough, California. *Jour. Geol.*, **72**, 526–542.

HANER, B. E. (1971): Morphology and sediments of Redondo submarine fan, southern California. *Bull. Geol. Soc. Amer.*, **82**, 2413–2432.

HARATA, T. (1965): Some directional structures in the flysch-like beds of the Shimanto terrain in the Kii Peninsula, southwest Japan. *Mem. Coll. Sci., Kyoto Univ., Ser. B*, **32**, 103–176.

———, SUZUKI, H., TERASHIMA, E. and TOKUOKA, T. (1967): The study of the Shimanto terrain in the Kii Peninsula, Japan — The Muro Group in Hongu-cho and Nakaheji-cho district —. *Earth Sci. (Chikyu Kagaku)*, **21**, 1–9. (in Japanese with English abstr.)

HIRAYAMA, J. (1973): The historical review of the flysch studies. *Mar. Sci. (Kaiyo Kagaku)*, **5**, 394–402. (in Japanese with English abstr.)

———, FUJII, K. and NAKAJIMA, T. (1969): Granulometric distribution within a single sandstone bed composing flysch. *Bull. Geol. Surv. Japan*, **20**, 669–684. (in Japanese with English abstr.)

——— and NAKAJIMA, T. (1977): Analytical study of turbidites, Otadai Formation, Boso Peninsula, Japan. *Sedimentology*, **24**, 747–779.

——— and SUZUKI, Y. (1965): On the forms and textures of each layer composing the flysch-type alternations of sandstone and mudstone. *Bull. Geol. Surv. Japan*, **16**, 1–15.

——— and SUZUKI, Y. (1968): Analysis of layers: an example in flysch-type alternations. *Earth Sci. (Chikyu Kagaku)*, **22**, 43–62. (in Japanese with English abstr.)

ICHIKAWA, K., FUJITA, Y. and SHIMAZU, M. (Eds.) (1970): *The geologic development of the Japanese Islands.* 232 p., Tsukiji-shokan, Tokyo. (in Japanese)

IDA, K., MITSUNASHI, T. and KAGEYAMA, K. (1956): On the new stratigraphic division of Upper Cenozoic in Tokyo district. *Bull. Geol. Surv. Japan*, **7**, 435–436. (in Japanese with English abstr.)

IIJIMA, A. and IKEYA, N. (1976): Geology of the Tokyo University Forest in Chiba. *Misc. Inf., Tokyo Univ. Forest (Enshurin)*, **20**, 1–38. (in Japanese)

IKEBE, N. (1948): On the Amatsu Group in the Boso Peninsula. *Jour. Japan. Assoc. Petrol. Technol.*, **13**, 132–133. (in Japanese)

ISHII, M. (1962): Basement of the Kwanto Plain. *ibid.*, **27**, 405–430. (in Japanese)

ISHII, T. (1973): Wavelength of turbidite ripples. *Mar. Sci. (Kaiyo Kagaku)*, **5**, 402–407. (in Japanese with English abstr.)

KANEHIRA, K. (1976): Modes of occurrence of serpentinite and basalt in the Mineoka district, southern Boso Peninsula. *Mem. Geol. Soc. Japan* (13): *Studies on the boundary area between east and west Japan.* 43–50. (in Japanese with English abstr.)

———, OKI, Y., SANADA, S., YANO, M. and ISHIKAWA, F. (1968): Tectonic blocks of metamorphic rocks at Kamogawa, southern Boso Peninsula. *Jour. Geol. Soc. Japan*, **74**, 529–534. (in Japanese with English abstr.)

KAWAI, K. (1957): Geology of the Kamogawa district, Chiba Prefecture. *Jour. Japan. Assoc. Petrol. Technol.*, **22**, 190–197. (in Japanese with English abstr.)

——— (1961): Economic geological study on the southern Kanto gas-producing region. *ibid.*, **26**, 212–266. (in Japanese with English abstr.)

KIKUCHI, Y. (1964): Biostratigraphy of the Neogene and Quaternary deposits based upon the smaller foraminifera in the southern Kanto region. *Contr., Inst. Geol. Pal., Tohoku Univ.*, **59**, 1–36. (in Japanese with English abstr.)

KIMURA, M. (1976): Geology and tectonics around the southern Kanto region. In: *Marine geology* (Ed. by N. NASU), 155–181, Tokyo Univ. Press, Tokyo, 215 p. (in Japanese)

KISYU SHIMANTO RESEARCH GROUP (1968): The study of the Shimanto terrain in the Kii Peninsula, southwest Japan (Part 2) — The present status of the research and the southern former-land in the Pacific Ocean —. *Earth Sci. (Chikyu Kagaku)*, **22**, 224–231. (in Japanese with English Abstr.)

——— (1970): Sedimentological and paleontological studies of the Muro Group at the southern coastal region of the Kii Peninsula — The study of the Shimanto terrain in the Kii Peninsula, southwest Japan (Part 4) —. *Mem. Fac. Educ., Wakayama Univ., Natural Sci.*, **20**, 75–102. (in Japanese with English abstr.)

KOIKE, K. (1949): Geology of the middle part of the Boso Peninsula (II). *Bull. Physiogr. Sci. Research Inst., Tokyo Univ.*, **3**, 1–6. (in Japanese with English abstr.)

——— (1951): On "the Kurotaki Unconformity". *Jour. Geol. Soc. Japan*, **57**, 143–156. (in Japanese with English abstr.)

——— (1952): Structural evolution of southern Kanto. *Bull. Physiogr. Sci. Research Inst., Tokyo Univ.*, **10**, 5–11. (in Japanese with English abstr.)

——— (1957): Geotectonic development of the southern Kanto region, Japan. *Earth Sci. (Chikyu Kagaku)*, **24**, 1–18. (in Japanese with English abstr.)

——— and NISHIKAWA, Y. (1955): The geological structure of the Tokyo University Forest in Chiba. *Misc. Inf., Tokyo Univ. Forest (Enshurin)*, **10**, 1–6. (in Japanese)

KOMATSU, N. (1958): On the depositional conditions of sandstone-rich alternations. *Studies on Sedimentology (Taisekigaku-kenkyu)*, **18**, 1–3. (in Japanese)

KRUMBEIN, W. C. (1941): Measurement and geological significance of shape and roundness of sedimentary particles. *Jour. Sediment. Petrol.*, **11**, 64–72.

KUENEN, PH. H. (1950): *Marine geology*. 568p., John Wiley & Sons. Inc., New York.

——— (1967): Emplacement of flysch-type sand beds. *Sedimentology*, **9**, 203–243.

——— and HUBERT, F. L. (1964): Bibliography of turbidity currents and turbidites. In: *Development in sedimentology*, 3: *Turbidites* (Ed. by A. H. BOUMA and A. BROUWER), 222–256, Elsevier, Amsterdam, 264 p.

——— and MIGLIORINI, C. I. (1950): Turbidity currents as a cause of graded bedding. *Jour. Geol.*, **58**, 91–127.

MAIYA, S. (1972): Planktonic foraminifera from the Nishizaki, Chikura and Toyofusa Formations of the southern part of the Boso Peninsula. *Prof. J. Iwai Mem. Vol.*, 649–656. (in Japanese with English abstr.)

MATSUDA, T. (1962): Crustal deformation and igneous activity in the south Fossa Magna, Japan. *Crust of the Pacific Basin, Geophysical Monograph*, **6**, 140–150.

MEISCHNER, K. D. (1964): Allodapiche Kalke, Turbidite in Riff-nahen Sedimentations-Becken. In: *Development in sedimentology*, 3: *Turbidites* (Ed. by A. H. BOUMA and A. BROUWER), 156–191, Elsvier, Amsterdam, 264 p.

MENARD, H. W. (1955): Deep-sea channels, topography and sedimentation. *Bull. Amer. Assoc. Petrol. Geol.*, **39**, 236–255.

MITSUNASHI, T. (1954): Geology of the southern district of Kinadayama, Boso Peninsula — Notes on the extention of rock facies in time and space —. *Jour. Geol. Soc. Japan*, **60**, 461–472. (in Japanese with English abstr.)

MITSUNASHI, T. (1968): Stratigraphic outline. In: *Geotectonics and sedimentary structures in the Miura and Boso Peninsula, A pamphlet for geologic excursing in 75th Ann. Meeting of Geol. Soc. Japan*, 4–13, *Tokyo*, 45 p. (in Japanese)

——— and YAZAKI, K. (1958): The correlation between the Cenozoic strata in Boso and Miura Peninsulas by the pyroclastic key bed (no. 1). *Jour. Japan. Assoc. Petrol. Technol.*, **23**, 16–22. (in Japanese with English abstr.)

———, ———, KAGEYAMA, K., SHIMADA, T., ONO, E., YASUKUNI, N., MAKINO, T., SHINADA, Y., FUJIWARA, K. and KAMATA, S. (1961): Futtsu-Otaki (scale 1: 50,000). *Geological maps of the oil and gas field of Japan* 4, Geol. Surv. Japan.

MOGI, A. and SATO, T. (1975): Submarine topography and geology of the continental margin around Japan (Part I). *Science (Kagaku)*, **45**, 551–559. (in Japanese)

MUTTI, E. (1974): Examples of ancient deep-sea fan deposits from circum-Mediterranean geosynclines. In: *Modern and Ancient Geosynclinal Sedimentation* (Ed. by R. H. DOTT and R. H. SHAVER) *Spec. Publ. Soc. Econ. Paleont. Miner.* (19), 92–105.

——— (1977): Distinctive thin bedded turbidite facies and related depositional environments in the Eocene Hecho Group (south-central Pyrenees, Spain). *Sedimentology*, **24**, 107–131.

NAKAJIMA, T. (1972 MS): Sedimentological study on the Anno Formation, Boso Peninsula. *Tohoku Univ., Doctoral Dissertation.*

——— (1973): Cyclic sedimentation of flysch-type sediments, Boso Peninsula, Japan. *Mar. Sci. (Kaiyo Kagaku)*, **5**, 408–413. (in Japanese with English abstr.)

——— (1977): Grain orientation in turbidite sandstones — An experimental study and its application to some field data —. *Jour. Geol. Soc. Japan*, **83**, 617–629. (in Japanese with English abstr.)

——— (1978): Sedimentary environment of flysch sediments in Boso Peninsula, Japan — Relationship between flysch and its marginal facies of the Kiwada, Kurotaki and Anno Formations —. *ibid.* **84**, 645–660. (in Japanese with English abstr.)

NARUSE, Y. (1968): Quaternary crustal movements in the Kanto Region. *Mem. Geol. Soc. Japan*, **2**, 27–32. (in Japanese with English abstr.)

———, SUGIMURA, A. and KOIKE, K. (1951): Zur Geologie des sudlichsten Teils der Halbinsel Boso in Honsiu, Japan. *Jour. Geol. Soc. Japan*, **57**, 511–526. (in Japanese with German abstr.)

NATLAND, M. L. and KUENEN, PH. H. (1951): Sedimentary history of the Ventura Basin, California, and the action of turbidity currents. In: *Turbidity currents and the transportation of coarse sediments to deep water* (Ed. by J.L. HOUGH), *Spec, Publ. Soc. Econ. Paleont. Miner.* (2), 76–107.

NELSON, C. H., CARLSON, P. R., BYRNE, J. V. and ALPHA, T. R. (1970): Development of the Astoria canyon-fan physiography and comparison with similar systems. *Marine Geology*, **8**, 259–291.

——— and KULM, L. D. (1973): Submarine fans and deep-sea channels. In: *Turbidites and deep water sedimentation*, 39–78. Pacific Section, Soc. Econ. Paleontol. Mineral., Los Angeles.

——— and NILSEN, T. H. (1974): Depositional trends of modern and ancient deep-sea fans. In: *Modern and Ancient Geosynclinal Sedimentation* (Ed. by R. H. DOTT and R. H. SHAVER), *Spec. Publ. Soc. Econ. Paleont. Miner.* (19), 68–91.

NIITSUMA, N. (1976): Magnetic stratigraphy in the Boso Peninsula. *Jour. Geol. Soc. Japan*, **82**, 163–181. (in Japanese with English abstr.)

———, KIMURA, K. and SAKAI, T. (1972): On the Neogene paleomagnetic stratigraphy in the oil and gas fields of Japan. *Jour. Japan. Assoc. Petrol. Technol.*, **37**, 411–415. (in Japanese)

NORMARK, W. R. (1970): Growth patterns of deep-sea fans. *Bull. Amer. Assoc. Petrol. Geol.*, **54**, 2170–2195.

——— (1974): Submarine canyons and fan valleys; factors affecting growth patterns of deep-sea fans. In: *Modern and Ancient Geosynclinal Sedimentation* (Ed. by R. H. DOTT and R. H. SHAVER), *Spec. Publ. Soc. Econ. Paleont. Miner.* (19), 56–68.

——— (1978): Fan valleys, channels and depositional lobes on modern submarine fans: characters for recognition of sandy turbidites environments. *Bull. Amer. Assoc. Petrol. Geol.*, **62**, 912–931.

——— and PIPER, D. J. W. (1969): Deep-sea fan-valleys, past and present. *Bull. Geol. Soc. Amer.*,

80, 1859–1866.

——— and ——— (1972): Sediments and growth pattern of Navy deep-sea fan, San Clemente basin, California Borderland. *Jour. Geol.*, **80**, 198–223.

O'BRIEN, N. R., NAKAZAWA, K. and TOKUHASHI, S. (in press): Use of clay fabric to distinguish turbiditic and hemipelagic siltstones and silts. *Sedimentology.*

ODA, M. (1975): A chronological interpretation of the paleomagnetic polarity records of the Upper Cenozoic of the Boso Peninsula based upon planktonic Foraminifera. *Jour. Geol. Soc. Japan*, **81**, 645–647. (in Japanese)

OKUDA, Y. (1977): Geological map off outer zone of southwest Japan (scale 1: 1,000,000). Geol. Surv. Japan.

OMORI, M. (1960): On the geological meaning of the "Fossa Magna". *Earth Sci. (Chikyu Kagaku)*, **50–51**, 75–82. (in Japanese with English abstr.)

OTUKA, Y. and KOIKE, K. (1949): Geology of the middle part of the Boso Peninsula. *Bull. Physiogr. Sci. Research Inst., Tokyo Univ.*, **2**, 31–32. (in Japanese with English abstr.)

PIPER, D. J. W., PANAGOS, A. G. and PE, G. G. (1978): Conglomeratic Miocene flysch, western Greece. *Jour. Sediment. Petrol.*, **48**, 117–126.

RADOMSKI, A. (1961): On some sedimentological problems of the Swiss flysch series. *Eclogae Geol. Helv.*, **54**, 451–459.

RESEARCH GROUP FOR NEOGENE TECTONICS OF THE KANTO DISTRICT (1977): On the geologic development of the Kanto district, central Japan, in the Late Neogene and Quaternary. *Mon., Assoc. Geol. Collab. Japan* (20), 241–256. (in Japanese with English abstr.)

RICCI-LUCCHI, F. (1975): Depositional cycles in two turbidite formations of northern Apennines (Italy). *Jour. Sediment. Petrol.*, **45**, 3–43.

SAKURAI, M., SATO, T., IKEDA, K. and NAGANO, M. (1974): Deep sea fans off the Shimokita Peninsula, Northeast Japan. *Jour. Geol. Soc. Japan*, **80**, 411–419. (in Japanese with English abstr.)

SAMEJIMA, T. (1950): Ultrabasic rocks and their associated rocks in the Boso and Miura Peninsula (abstract). *Jour. Geol. Soc. Japan*, **56**, 260. (in Japanese)

SASAKI, K. and USHIJIMA, N., (1966): Sedimentation of graded sandstones in Shiiya and Nishiyama formations, Higashiyama oil belt, Niigata Prefecture. *Jour. Japan. Assoc. Min. Petr. Econ. Geol.*, **56**, 161–182. (in Japanese with English abstr.)

SAWADA, H. (1939): Geology of Katsuura, Okitsu and Ueno areas in the Isumi district and Kominato and Amatsu areas in the Awa district. *Jour. Geol. Soc. Japan*, **46**, 445–450. (in Japanese)

SCHLAGER, W. and SCHLAGER, M. (1973): Clastic sediments associated with radiolarites (Tauglboden-Schichen, Upper Jurassic, Eastern Alps). *Sedimentology*, **20**, 65–89.

SHEPARD, F. P., DILL, R. F. and VON RAD, U. (1969): Physiography and sedimentary processes of La Jolla submarine fan and fan-valley, California. *Bull. Amer. Assoc. Petrol. Geol.*, **53**, 390–420.

SHIKI, T. (1961): Studies on sandstones in the Maizuru Zone, southwest Japan II — Graded bedding and mineral composition of sandstones of the Maizuru Group —. *Mem. Coll. Sci., Kyoto Univ., Ser. B*, **27**, 293–308.

STANLEY, D. J. and BOUMA, A. H. (1964): Methodology and paleogeographic interpretation of flysch formations: a summary of studies in the Maritime Alps. In: *Development in sedimentology* 3: *Turbidites* (Ed. by A. H. BOUMA and A. BROUWER), 34–64, Elsevier, Amsterdam, 264 p.

STAUFFER, P. H. (1967): Grain-flow deposits and their implications, Santa Ynez Mountains, California. *Jour. Sediment. Petrol.*, **37**, 487–508.

SUDO, S. (1976): Geology of the Katashina area, Gunma Prefecture, central Japan. *Mem. Geol. Soc. Japan* (13): *Studies on the boundary area between east and west Japan.* 229–240. (in Japanese with English abstr.)

SUYARI, K. (1966): Studies on the Izumi Group in the eastern Asan Mountain range, Shikoku (1). *Jour. Sci., Tokushima Univ.*, **1**, 9–14. (in Japanese with English abstr.)

——— *et al.* (1968): *ditto* (2). *ibid.*, **2**, 7–16. (in Japanese with English abstr.)

TAKAHASHI, S. (1954): Notes on a minor structure and a bone-bed on the coast near Kanaya Village, Boso Peninsula. *Sci. Rep. Yokohama Nat. Univ., Sec. II, Biol. Geol. Sci.*, **3**, 109–120. (in Japanese with English abstr.)

TANAKA, K. (1965): Izumi Group in the central part of the Izumi Mountain range, southwest Japan, with special reference to its sedimentary facies and cyclic sedimentation. *Rep. Geol. Surv. Japan* (212), 1–33. (in Japanese with English abstr.)

———— (1970): Sedimentation of the Cretaceous flysch sequence in the Ikushumbetsu area, Hokkaido, Japan. *ibid.*(236), 1–102.

TANAKA, K. and KAWADA, K. (1971): On the volcanic pebbles in the Upper Cretaceous conglomerates of the Nakaminato-Oarai area, Ibaraki Prefecture, Japan. *Bull. Geol. Surv. Japan*, **22**, 655–660. (in Japanese with English abstr.)

TERAOKA, Y. (1970): Cretaceous formations in the Onogawa Basin and its vicinity, Kyushu, southwest Japan. *Rep. Geol. Surv. Japan* (237), 1–84. (in Japanese with English abstr.)

TOKUHASHI, S. (1976a): Sedimentological study of the flysch-type alternation of Hk horizon in the Kiyosumi Formation (part I) — Constitution of the alternation and form of individual sandstone bed —. *Jour. Geol. Soc. Japan*, **82**, 729–738. (in Japanese with English abstr.)

———— (1976b): *Ditto*, (part II) — Dipositional processes and circumstances of sandstone beds —. *ibid.* **82**, 757–764. (in Japanese with English abstr.)

———— and IWAWAKI, T. (1975): Areal sedimentary analysis of flysch-type alternations. *Earth Sci. (Chikyu Kagaku)*, **29**, 262–274. (in Japanese with English abstr.)

TSUDA, K. and NAGATA, H. (1969): Problems on flysch-type alternations in Cenozoic sequence in Niigata Prefecture — Studies of the so-clled "Nanbayama Formation" (part 3) —. In: *Problems on green tuff*, 275–282, A memoir for total discussion in 76th Ann. Meeting of Geol. Soc. Japan, Niigata, 282 p. (in Japanese)

WAKIMIZU, T. (1901): Preliminary reports on geology of the Agricultural College (Nohka-daigaku) Forest in Chiba Prefecture. *Jour. Geol. Soc. Japan*, **8**, 411–424, 465–476. (in Japanese)

WALKER, R. G. (1966): Shale grit and Grindslow shales; transition from turbidite to shallow water sediments in the Upper Carboniferous on northern England. *Jour. Sediment. Petrol.*, **36**, 90–114.

———— (1967): Turbidite sedimentary structures and their relationship to proximal and distal depositional environments. *ibid.* **37**, 25–43.

———— (1973): Mopping up the turbidite mess. In: *Evolving concepts in sedimentology* (Ed. by R. N. GINSBURG), 1–37, Johns Hopkins Univ. Press, Baltimore and London, 191 p.

———— and MUTTI, E. (1973): Turbidite facies and facies associations. In: *Turbidites and deep-water sedimentation*, 119–157. Pacific Section, Soc. Econ. Paleontol. Mineral., Los Angels.

YAMAMOTO, H. (1971): On the convolute lamination occuring in the flysch-type sandstones. *Jour. Geol. Soc. Japan*, **77**, 23–36. (in Japanese with English abstr.)

YOSHIDA, T. (Ed.) (1975): *An outline of the geology of Japan.* Third Edition, Geol. Surv. Japan, 61 p.

Explanation of Plate 1

Six main tuff marker-beds

1. Sa : Reverse grading is prominant in this bed.
2. Nm: This bed is composed of two-layered "gomashio" tuff and is often overlain by the slump-structured, very fine white tuff.
3. Hk : This bed is composed of thick "gomashio" tuff ranging about 130 to 150 cm in thickness. Various sedimentary structures are observed in it. The current ripple cross lamination in this figure indicates the southward current.
4. Km: This bed is very thin measuring about 5 cm in thickness and composed of small lapilli scoria and associated with thin white "gomashio" tuff-bed below it. A thick sandstone bed is usually developed just above the bed.
5. Tk : This bed is characterized by the three-layered structure; the lower finer-grained scoria tuff, the middle coarser-grained scoria tuff and the upper fine to very fine sandstone.
6. Kr : This bed is also characterized generally by the three-layered structure; the lower finer-grained black scoria tuff band, the middle coarser-grained dark brown scoria tuff zone and the upper coarser-grained brown scoria tuff zone.

Explanation of Plate 2

Small channel-like scours in pebbly sandstone facies (facies "a").

1. A cutting outcrop beside a forest-land path named Higashi-Fukurokura Line in the Tokyo University Forest around Mt. Kiyosumi. Tk–Kr unit.
2. An enlarged view of the same outcrop.

3–5. Wall outcrops along a small tributary near the locality D in Fig. 12. Tk–Kr unit.

Explanation of Plate 3

Other sedimentary facies in the Kiyosumi Formation.

1–2. Wall outcrops along the Sasa River composed of thin-bedded sandstones (facies "b3") in the Sa–Nm unit. Siltstone-dominated alternations (facies "d") is partly included in the latter outcrop.

3. A cutting outcrop beside the Kamogawa Toll Road composed of relatively thick-bedded sandstones (facies "b2") in the Hk–Km unit.
4. A cliff outcrop near the east coast composed of siltstone-dominated alternation (facies "d") with many tuff-beds in the Hk–Km unit. This succession is the eastern equivalent of the succession in Fig. 3.
5. A cutting outcrop near the Mt. Kiyosumi composed of the lower massive siltstones of the Amatsu Formation and the upper thick-bedded sandstones (facies "bl") of the Tk–Kr unit. The contact between the Amatsu Formation and the Kiyosumi Formation is very sharp.

Explanation of Plate 4

Sedimentary structures of sandstone beds indicating paleocurrent.

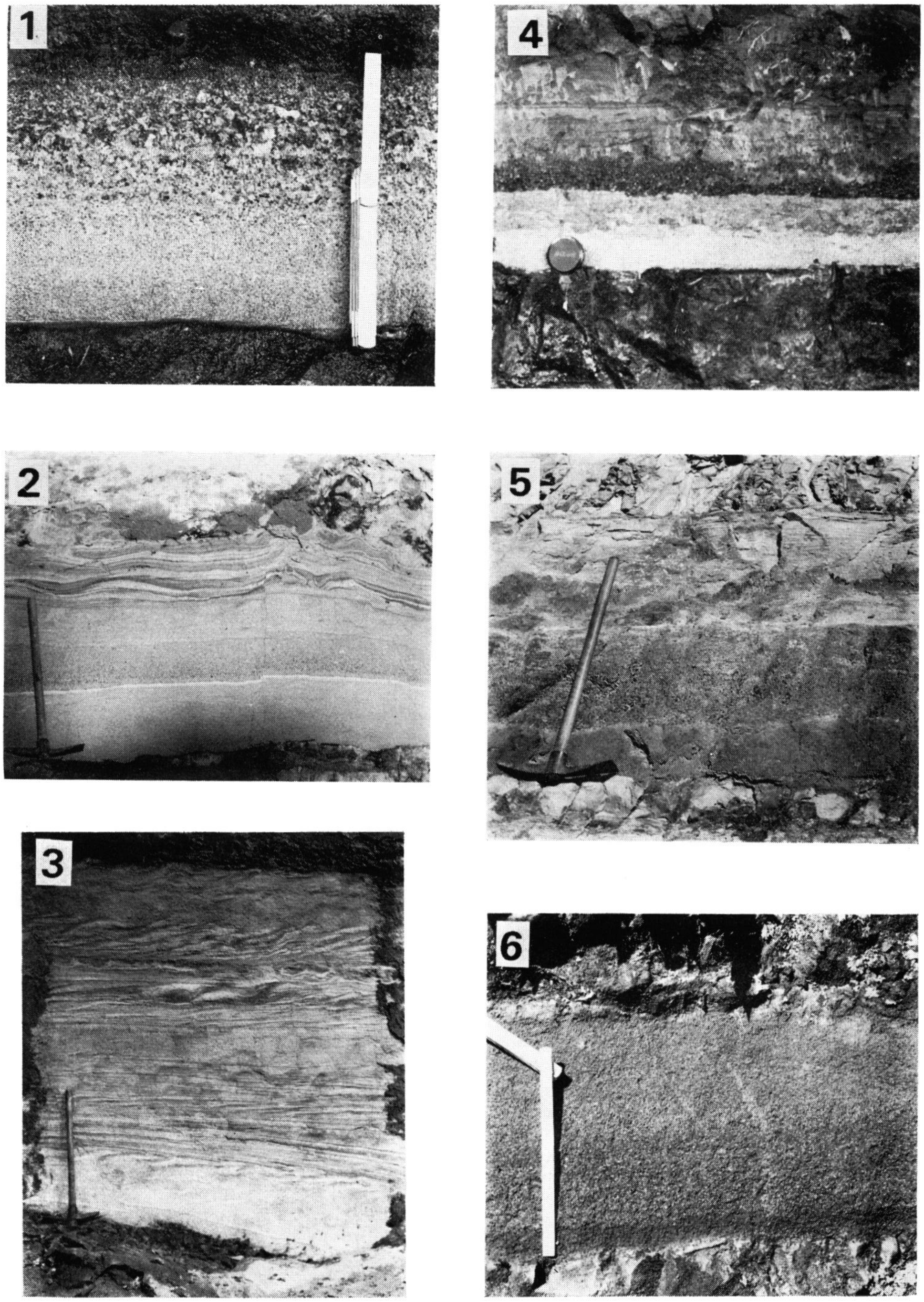
1. Current ripple cross lamination (locality i in Fig. 24A).
2. Current ripple cross lamination (locality k in Fig. 24A).

3. Groove cast imprinted on the underlying siltstone bed (locality n in Fig. 9A).
4. Flute cast imprinted on the underlying siltstone beds (locality f in Fig. 24A). Current directions of adjacent sandstone beds coincide well with each other.

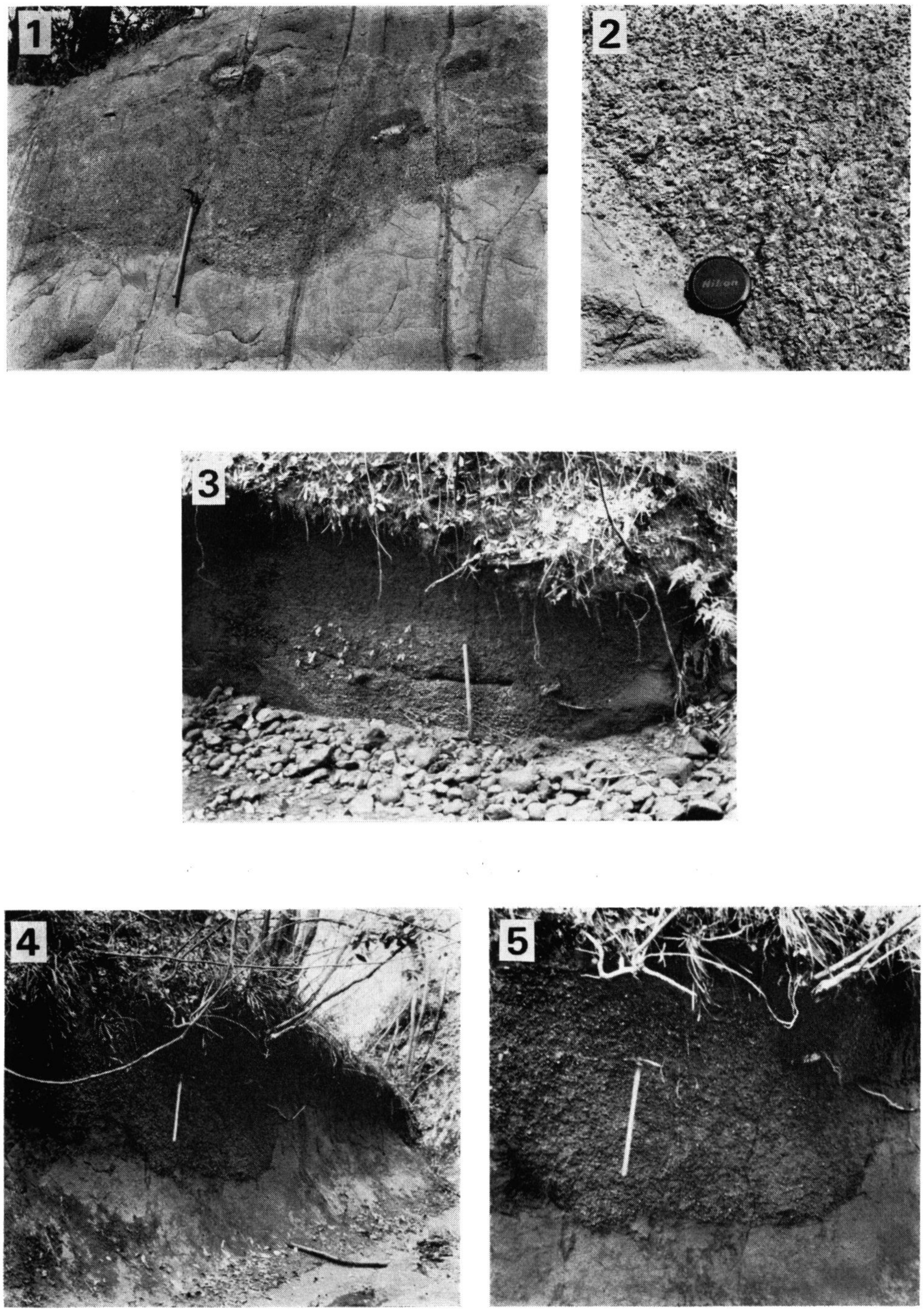
Explanation of Plate 5

Imbrication of siltstone clasts in pebbly sandstone facies.

1. A wall outcrop of the Sasa River (locality a in Fig. 14). Transport direction is from right to left (southward).
2. An enlarged view of the same outcrop.
3. A wall outcrop of a small tributary of the Koito River (locality b in Fig. 14). Transport direction is from right to left (southward).
4. An enlarged view of the same outcrop.
5. A cutting outcrop beside a small path (locality i in Fig. 14). Transport direction is from right to left (southward).
6. An enlarged view of the same outcrop.



TOKUHASHI: Large Sandy-Flysch Body



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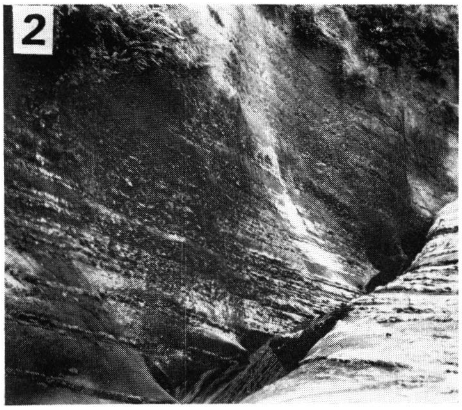

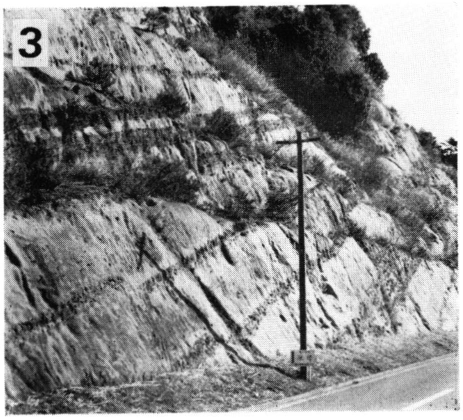

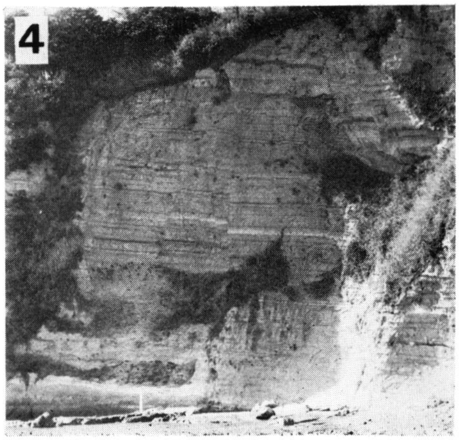

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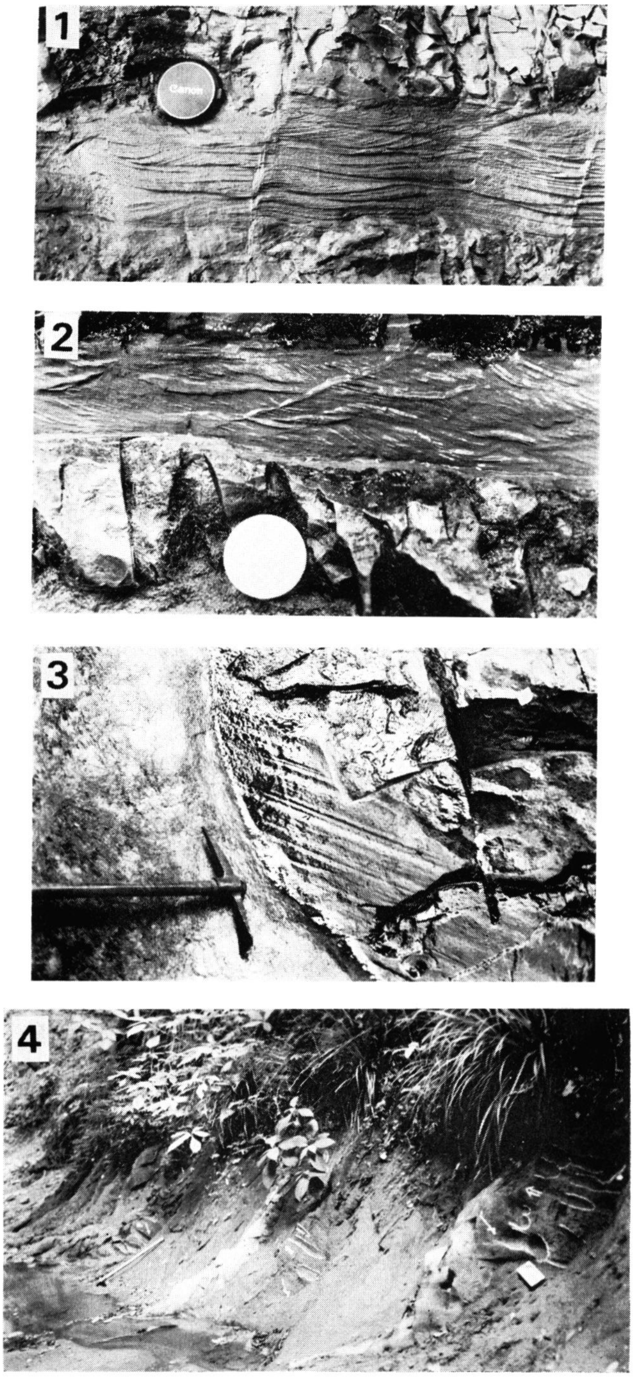

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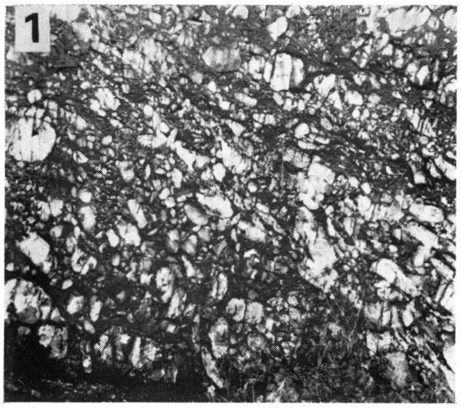

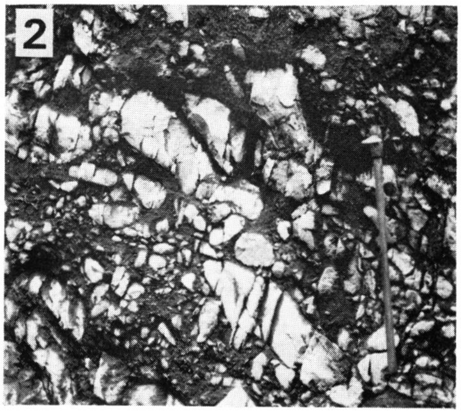

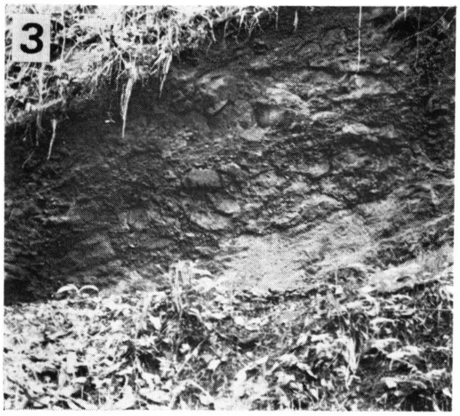

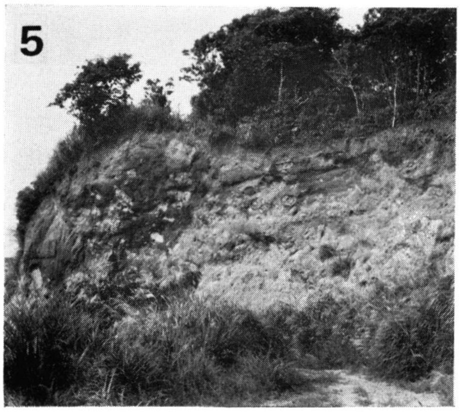

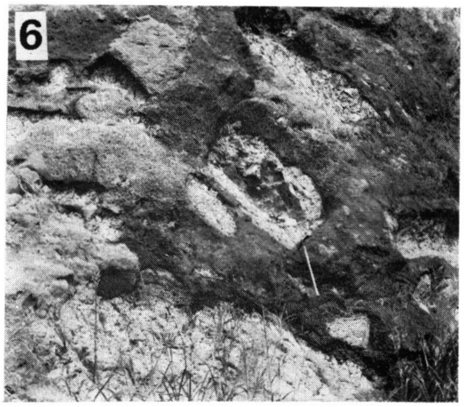

TOKUHASHI: Large Sandy-Flysch Body