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Sedimentology and Basin Analysis of the Paleogene Muro Group in the Kii Peninsula, Southwest Japan

By

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Contents

Abstract

The Oligocene to lower Miocene Muro group in the Kii Peninsula represents the later stage of the Shimanto geosyncline which was widely extended along the Pacific coast of Southwest Japan from late Jurassic to earliest Miocene time. The Muro group is composed mainly of flysch-type alternations of sandstone and mudstone, intercalating conglomerates, thick-bedded sandstones and conglomeratic mudstones. These sequences are well exposed in the southern coast area in the peninsula.

Based on the analyses of the sedimentary features such as grading, stratification and clast fabric, and field occurrence as well, the conglomerates are referred to have been transported and deposited by grain flow and turbidity current combined. Thick-bedded sandstones are considered to have been transported and deposited by turbidity current. It is safely concluded that conglomeratic mudstones such as pebbly mudstone and angular fragment-bearing mudstone were transported and deposited by debris flow. All of these coarse sediments were deposited in proximal suit of deposition.

There are observed several channel-scours and -fills in the upper formation of the Muro group, which indicate the submarine fan deposition of the formation.

Paleocurrent analysis based on sole marks and clast fabrics shows that the provenances existed not only to the north, but also to the south of the basin. General trends of the channels and paleocurrents in channel fillings indicate the distributary channel system developed on the submarine fan in the southern side of the basin. The existence of the Kuroshio Paleoland estimated to the south of the Shimanto terrain by the Kishu Shimanto Research Group is strongly supported by the present study.

I. Introduction

The Shimanto terrain situated in the southernmost part of outer zone of Southwest Japan extends more than 1,000 km in length with a width of more than 200 km. Little has been known about the geology of the Shimanto terrain for long years. However, energetic surveys have been done for the past ten and several years, and the geology of the Shimanto terrain has been made fairly clear. In 1975, KISHU SHIMANTO RESEARCH GROUP summarized the geology of the Shimanto terrain in the Kii Peninsula, and discussed the development of the Shimanto geosyncline. In this paper the group attempted the paleogeographic reconstruction of the Shimanto geosyncline from the late Cretaceous to the early Miocene, and inferred that the source land must have existed not only to the north as generally considered, but also to the south of the Shimanto geosyncline. This hypothesis based mainly on the paleocurrent analysis and properties of coarser clastic sediments is important not only for the consideration of the geologic development of the Shimanto terrain, but also for the study of basement rocks of the Japanese Islands and furthermore of the development of the Philippine Sea. So it must be confirmed by the more detailed reconstruction of paleogeography.

The Oligocene to lower Miocene Muro group in the Kii Peninsula representing the later stage of the Shimanto geosyncline has been studied in detail stratigraphically and sedimentologically, and its paleo-environment has been made fairly clear (KISHU SHIMANTO RESEARCH GROUP, 1975). In order to clarify in more detail the sedimentary environment of the Muro group, the present writer examined the sedimentation of coarse sediments such as conglomerate and thick-bedded sandstone, and of channel-scours and -fills. Main purposes of the present paper are 1) to describe the sedimentary structures and fabrics of coarse sediments and to consider the sedimentary process of them, 2) to describe the channel structures and their sedimentation, and 3) to clarify the paleogeography and sedimentary environment of the Muro group.

The field-work was done mainly in the southern coast area of the Kii Peninsula where wave-cut terraces and cliffs are well developed and the various excellent sedimentary features can be observed.

II. Geologic Setting

Stratigraphy and geologic structure

The Shimanto terrain occupies the vast area south of the Butsuzo Tectonic Line. The Shimanto terrain in the Kii Peninsula is divided into three belts by the Gobo-Hagi tectonic line and the Hongu fault, namely, the Hidakagawa, the Otonashigawa and the Muro belts from north to south (Fig. 1). The Hidakagawa group (mainly late Cretaceous), having eugeosynclinal facies, distributed in the Hidakagawa belt. The Otonashigawa belt is occupied by the Eocene Otonashigawa group, and the Muro belt by the

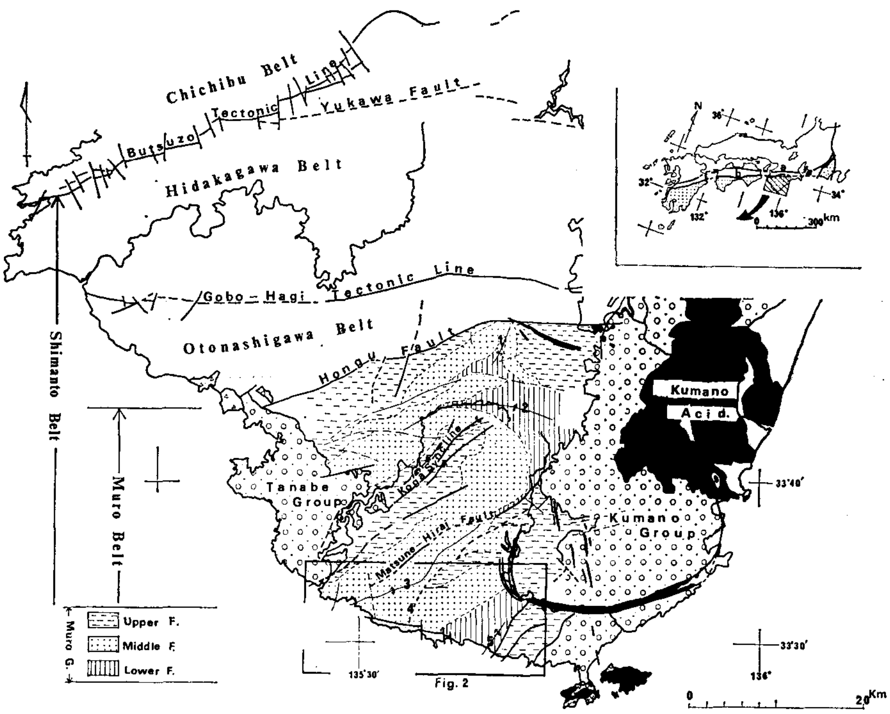


Fig. 1. Geologic outline of the Shimanto terrain in the Kii Peninsula.
a: Median Tectonic Line, b: Butsuzo Tectonic Line,
1: Kimidani Anticline, 2: Uchikoshi Anticline, 3: Susami Anticline,
4: Samoto Fault, 5: Wabuka Anticline.

Oligocene to lower Miocene Muro group, composed entirely of terrigenous sediments lacking in ophiolites and radiolarian cherts. The Otonashigawa and Muro groups are overlain with clino-unconformity by the middle Miocene Tanabe and Kumano groups in the west and east respectively.

Stratigraphic, structural and sedimentologic studies of the Muro group have been much advanced by the collaborative research group for the Shimanto terrain in the Kii Peninsula (KISHU SHIMANTO RESEARCH GROUP), of which the present writer is a member, for the past ten and several years. The results were summarized by KISHU SHIMANTO RESEARCH GROUP (1975). According to this paper, the stratigraphy and lithofacies of the Muro group are summarized as in the followings. The generalized geologic map of the Muro belt is shown in Fig. 1, and the generalized columnar section of the Muro group is shown in Fig. 3. The Muro group, of which total thickness attains to 7, 500 to 9, 000 m, is composed mainly of flysch-type alternations of sandstone and mudstone, often intercalating thick-bedded sandstones, conglomerates and conglomeratic mudstones. The geologic age of the Muro group is assigned as the Oligocene to the lower Miocene based on molluscan fossil evidence. The group is subdivided lithologically into the lower (A), the middle (B) and the upper (C to H) formations. The lower formation is composed mainly of mudstone and muddy flysch. The middle formation is composed predominantly of sandy flysch and thick-bedded sandstone. The upper formation is composed of various kinds of sediments such as mudstone, muddy flysch, conglomerate, thick-bedded sandstone, pebbly mudstone and angular fragment-bearing mudstone.

The Muro belt can be divided into northern and southern blocks by the Matsune-Hirai fault. Main folding structures in the Muro belt are the Uchikoshi anticline and the Kogawa synclinorium in the northern block and the Susami anticline and the Wabuka anticline in the south, although there exist many folds and faults in various scales.

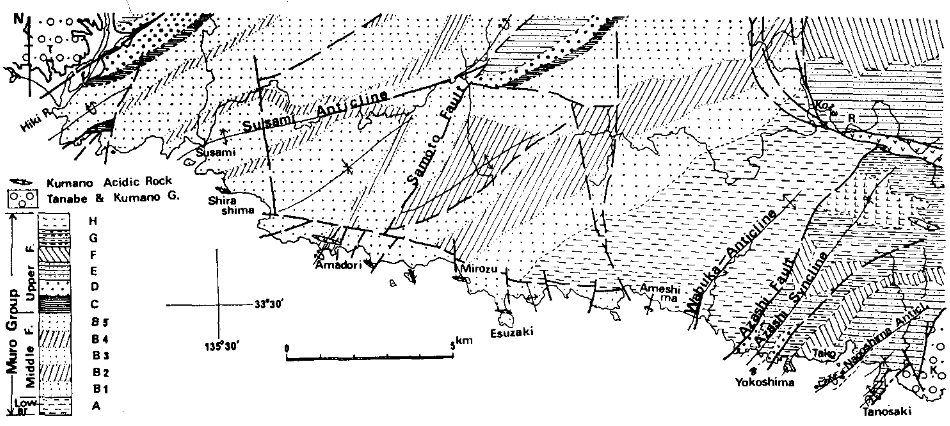


Fig. 2. Geologic map of the studied area, compiled from KISHU SHIMANTO RESEARCH GROUP (1969, 1973) and the present writer (TATEISHI, 1976).

The present study deals with the southern part of the Muro belt shown by a quadrangle in Fig. 1. The geology along the southern coast exceeding 30 km in length was reported in detail by KISHU SHIMANTO RESEARCH GROUP (1969, 1973) and the present writer (TATEISHI, 1976). The geologic map and columnar sections of this area are shown in Figs. 2 and 3 respectively. The Muro group in the present area attains to

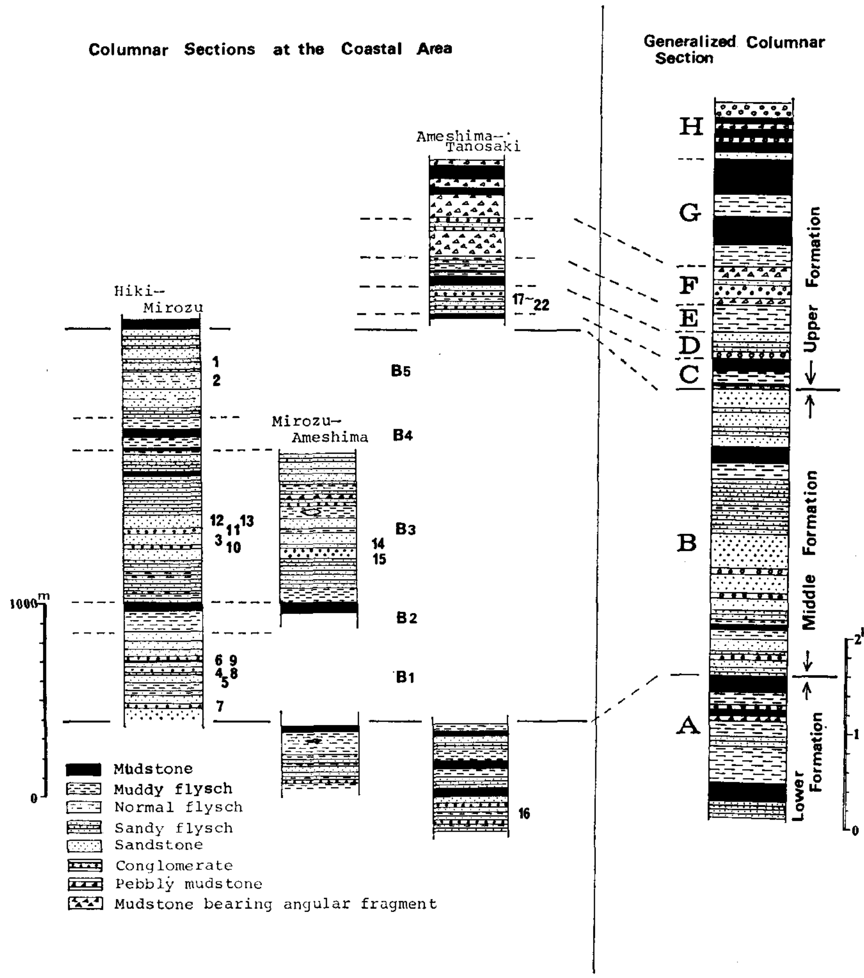


Fig. 3. Columnar sections of the Muro group. Each section was compiled from the followings; generalized section: KISHU SHIMANTO RESEARCH GROUP (1975), Hiki-Mirozu: TATEISHI (1976), Mirozu-Ameshima: KISHU SHIMANTO RESEARCH GROUP (1973), Ameshima-Tanosaki: KISHU SHIMANTO RESEARCH GROUP (1969).
The numbers at the right of sections show the horizons of localities examined sedimentologically.

3, 500 m in thickness, and obtained columns can be correlated to the generalized stratigraphy of the Muro group as shown in Fig. 3. The middle formation of the present area is subdivided into five members by intercalations of mudstone and muddy flysch is NE-SW to ENE-WSW in the western and eastern parts of the present coast area. On the other hand, that in the central coast area between Mirozu and Ameshima is N-S, being discordant to the regional trend of the Muro belt. The lithofacies of the Muro group is briefly described in the following section. Localities of conglomerates, thick-bedded sandstones and channel structures examined in detail in the present study are shown in Fig. 4.

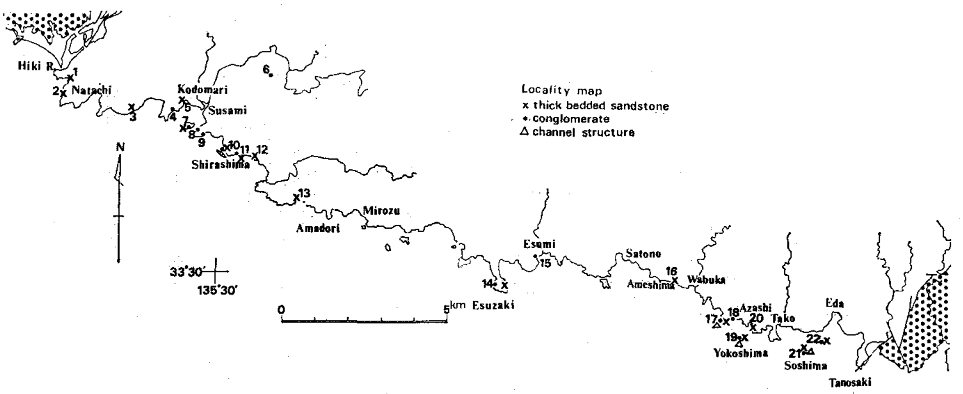


Fig. 4. Localities of conglomerates, thick-bedded sandstones and channel structures observed and examined.

Lithofacies

The lower formation: The lower formation is found in the axial part of the Wabuka anticline. It is about 600 m in thickness, showing a fining-upward sequence as a whole. The lower part is composed mainly of sandy to normal flysch, in which sole marks and ripple marks are well developed, and frequently intercalates thick-bedded sandstone and conglomerate. The upper part consists of muddy flysch and mudstone, rarely intercalating sandy flysch, thick-bedded sandstone and conglomerate. Thick-bedded sandstones and sandy flysch, that will be described later, are found in the west of Wabuka (loc. 16, Fig. 4).

The middle formation: The middle formation lies in the western half of the present area. It attains to 2, 500 to 3, 100 m in total thickness. It is composed mainly of sandy flysch and thick-bedded sandstone, intercalating mudstone, muddy flysch and conglomerate, and is subdivided into five members (B1 to B5 members) by mappable intercalations of mudstone and muddy flysch (B2 and B4 members). Molluscan fossils were discovered in mudstone of the B2 member at Mirozu.

The B1 member distributing around Susami Bay consists mainly of sandstone 1 to 3 m thick in bed. Graded bedding and parallel lamination are well developed in these thick-bedded sandstones. Several conglomerate beds are intercalated. These are mostly granule- to pebble-sized, and are mostly bedded 1 to 3 m, sometimes up to 5 m. Thick-bedded sandstone and conglomerate were well observed at five localities around Susami Bay (locs. 4, 5, 7, 8 and 9) and at one locality north of Magari (loc. 6).

The B3 member is composed mainly of sandy flysch and thick-bedded sandstone, frequently intercalating conglomerate. It shows a thickening- and coarsening-upward sequence in the lower part and a thinning- and fining-upward sequence in the upper part. Pebble conglomerates of 5 to 10 m thick are frequently intercalated in the middle part, which can be seen well at the east of Shirashima (locs. 10 to 13). Sandy flysch and thick-bedded sandstone are well developed at Esuzaki (loc. 14).

The B5 member is found around Natachi. It consists of thick-bedded sandstone and sandy flysch. Linguoid ripple marks and sole marks are well developed in these flysch beds. Pebble conglomerates are intercalated in the upper part. Thick-bedded sandstones were observed at locs. 1 and 2.

The upper formation: The upper formation is found in the east of the Azashi fault. It is composed of many kinds of sediments such as mudstone, muddy flysch, sandy flysch, thick-bedded sandstone, conglomerate, pebbly mudstone and angular fragment-bearing mudstone. It is 900 m in total thickness, and is subdivided into C to G members lithologically. The H member, the uppermost member of the Muro group, is not found in the present area. Not a few molluscan fossils were found in the D, E and G members, especially in the last one.

The C and E members consist of muddy flysch and mudstone. *The D member* is channel-fill sediments scouring out a part of the C member. It is made up of thinning- and fining-upward sequences from pebbly mudstone or conglomerate to muddy flysch through sandy flysch. The member is well observed at the east of Wabuka (loc. 17), the west of Azashi (loc. 18), Yokoshima Island (loc. 19), Azashi (loc. 20), Soshima Island (loc. 21) and Nagoshima Island (loc. 22) which will be described later.

The F member is composed of angular fragment-bearing mudstone in the lower part and of alternation of poorly sorted conglomerate and coarse sandstone in the upper. The former contains various-sized angular clasts quite randomly. The clasts are pebble-sized gravels to large blocks up to 8 m in diameter of conglomerate, sandstone and mudstone. It was called "Sarashi-kubi (gibbeted head) bed" as a field name by Kishu Shimanto Research Group (1969). The upper part of the formation contains non-turbidite sandstones which show a wedge-shaped large cross-lamination. Some kinds of trace fossils considered to show Cruziana facies are observed in the upper sequence.

The G member is composed of angular fragment-bearing mudstone, crudely bedded 1.5 to 2 m thick in the lower part, and of poorly sorted siltstone and mudstone in the upper. The former contains clasts smaller than those in the F member, and most of them are pebble- or cobble-sized.

III. Sedimentology of Conglomeratic rocks, Thick-bedded Sandstones and Flysch-type Alternations

The Muro group is composed mainly of flysch-type alternations, intercalating frequently coarse sediments such as thick-bedded sandstone, conglomerate and conglomeratic mudstones. Textural properties and mineral or gravel composition of sandstone and conglomerate in geosynclinal sediments have been examined especially to get information on source rocks and provenance. To examine the depositional process of coarse sediments is important for reconstructing the paleogeography and estimating the sedimentary environment of the geosyncline. The study of sedimentary process of coarse sediments is not as advanced as the study of flysch-type alternation, which has been remarkably developed for the last two decades since the turbidity current theory was presumed by KUENEN and MIGLIORINI (1950).

There have been papers on conglomerate such as FISHER and MATTISON (1968), WALKER and PETTIJOHN (1971), HENDRY (1973, 1976), ROCHELEAU and LAJOIE (1974), MRAKOVICH and COOGAN (1974) and WALKER (1975a). They have mainly described sedimentary structures such as grading and stratification, textural properties and clast fabrics. Recently DAVIES and WALKER (1974) and WALKER (1975b) proposed the methods how to describe the sedimentary features of conglomerate in geosyncline. As for massive and/or thick-bedded sandstone, there have been papers such as STAUFFER (1968), CHIPPING (1972), CORBETT (1972), TYLER (1972) and LINK (1975). They examined and discussed mainly the internal sedimentary structures and lateral changes of lithofacies. The process of transportation and deposition of coarse grains such as gravels and sand grains was discussed in detail by MIDDLETON and HAMPTON (1976).

In order to clarify their sedimentary process, it is important that sedimentary structures and clast or grain fabric are examined in detail. The present writer examined sedimentary structures and fabrics of conglomerate and thick-bedded sandstone at 22 localities along the coast area shown in Fig. 4. Conglomeratic mudstones and flysch-type alternations were also treated and are described briefly.

A. Sedimentary structures and fabrics

1. Conglomerates

Layers of conglomerate with sandy matrix are frequently intercalated in the Muro group, especially in the middle and upper formations (Fig. 3). The observed localities and their stratigraphical horizons are shown in Figs. 3 and 4. Internal sedimentary structures, especially grading and stratification, were observed on 70 beds. Clast fabrics were examined in 24 beds, and several beds were examined at plural points. Examined points on clast fabrics attained to 29 in total.

a. General occurrence

Conglomerate layers occur usually as a part of thick proximal sequence together with thick-bedded sandstones and sandy flysches. Typical successions composed mainly of conglomerate are shown in columnar sections (Fig. 5). Each layer of conglomerate is

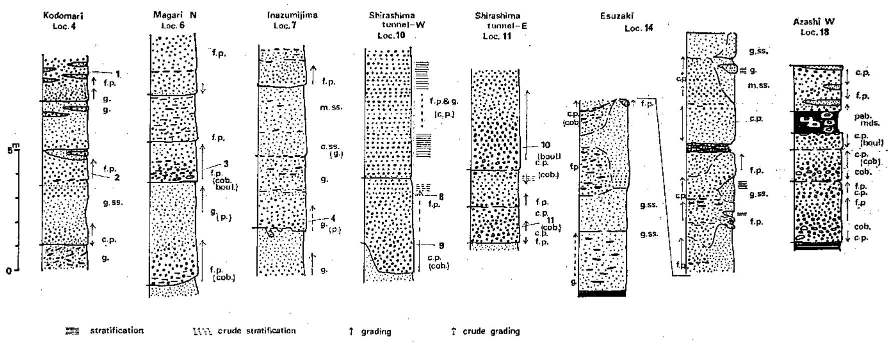


Fig. 5. Columnar sections of conglomerates showing internal sedimentary features and average gravel size.
g: granule, c.p.: coarse pebble, f.p.: fine pebble, cob.: cobble, boul.: boulder, g.ss.: granular sandstone, c.ss.: coarse sandstone, m.ss.: medium sandstone, ( ): associated gravel size.
Numerals at the right are the ones of clast fabric data (see Table 2).

generally 40 to 200 cm in thickness, and consistituting gravels are mostly fine pebbles, partially coarse pebbles and rarely cobbles. Granule conglomerates are also found frequently. These granule conglomerates are intercalated in thick-bedded sandstones as lens or lamina, and sometimes change gradually to sandstones without sharp boundary. The bottom of conglomerate generally shows erosional or irregular surface, but sometimes non-erosional planar surface.

b. Internal sedimentary structures

As shown in Fig. 6, Davies and Walker (1974) recognized seven sedimentary structure types in resedimented conglomerates of the Cambro-Ordovician Cap Enrage formation at Gaspe, Quebec. They examined the relationship between sedimentary structure type and gravel size, and made clear that sedimentary structures of conglomerate are related intimately to an average gravel size. That is, an inverse grading is found at the lower part of cobble conglomerate with or without boulder gravels. On the other hand, pebble and granule conglomerates are characterized by the normal grading and stratification. Adding much more observation on other conglomerate beds, Walker (1975b) proposed three descriptive models on the sedimentary structures of conglomerates, namely, i) inverse-to-normal grading model, ii) graded-stratified model, and iii) disorganized model (Fig. 7).

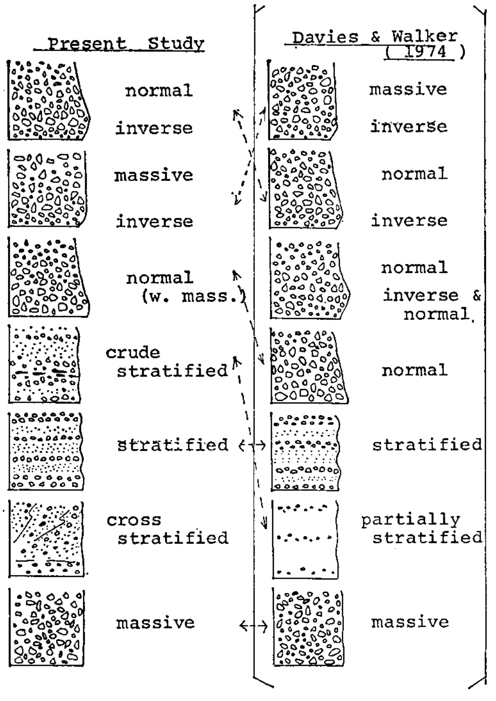


Fig. 6. Types of internal sedimentary features of conglomerates in the Muro group (present study) and in the Cap Enrage formation at Gaspe, Quebec (DAVIES and WALKER, 1974).

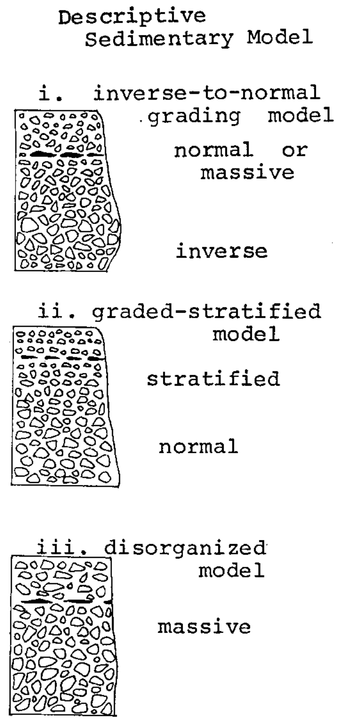


Fig. 7. Descriptive sedimentary models of conglomerates proposed by WALKER (1975b).

Conglomerates of the Muro group were examined on the basis of the same methods as their ones. First, conglomerates of the Muro group were classified into seven sedimentary structure types, which are different in a few points from their types (Fig. 6) ; that is, their 3rd type (lower: inverse and normal, upper: normal) is omitted and a cross-stratified type is newly added. Secondly, the relationship between each type and average gravel size was examined, and summarized in Table 1, which differs from that obtained by them in the following respects; i) the gravel size of conglomerates characterized by inverse grading in the Muro group is smaller than that of conglomerates in the Cap Enrage formation, ii) although the sedimentary structure types of conglomerates in the Cap Enrage formation are classified clearly by their mean gravel size, there are observed both types of inverse-to-normal grading and graded-stratified in the fine pebble conglomerates of the Muro group. It may be said, however, that the three descriptive sedimentary models, which were proposed by WALKER (1975b), are also recognized in

Type	of Sedi. Structure	cob.	c. peb.	f. peb.	gra.
1	normal inverse	3	8	4	
2	massive inverse		4	7	
3	normal (w. massive)		5	11	3
4	crude stratified		3	1	1
5	stratified			3	7
6	cross stratified			1	1
7	massive		5	3	3

Table 1. Frequency of internal feature types of 70 conglomerate beds classified according to clast size.

the conglomerates of the Muro group as a whole. Features of internal sedimentary structures, especially of grading and stratification, are described in the followings.

i. Inverse-to-normal grading model

Cobble conglomerates and most of coarse pebble conglomerates are characterized by distinctive inverse grading at the base. Inverse grading part is generally 10 to 20 cm in thickness. Usually a zone composed of larger clasts comes above the inverse grading part, of which thickness is generally 10 to 20 cm. Normal grading or massive division is found generally in the upper part. A typical example is observed at the west of Azashi (loc. 18 in Fig. 5, Plate I-1). A few conglomerate layers in which inverse grading develops throughout a bed are observed.

Stratification is generally indistinctive in this type of conglomerates. Sometimes there develops a crude stratification formed by arrangement of calcareous mudstone clasts of several to ten cm in diameter.

ii. Graded-stratified model

Fine pebble conglomerate is characterized by development of normal grading throughout a bed or by development of inverse grading at the base. Both features occur at the roughly equal rate in fine pebble conglomerates. Typical example of fine pebble conglomerate with normal grading is observed at the north of Magari (loc. 6 in Fig. 5). Granule conglomerate is characterized by development of normal grading throughout a bed, and there develops no inverse grading part. Most of granule conglomerates are transitional upward to sandstone as shown in Plate I-3.

Stratification is remarkably developed in this type of conglomerates. A typical example of stratification is observed at the west of Shirashima tunnel (loc. 10 in Fig. 5, Plate I-4).

iii. Disorganized model

There are found several conglomerates which do not show sedimentary features such as grading and stratification. These conglomerates are massive throughout a bed, and are usually 40 to 200 cm in thickness. Sometimes these are transitional laterally to conglomerate showing some sedimentary structures of sedimentary models i and ii.

c. Clast fabrics

Fabrics of conglomerate are represented by clast orientation and clast imbrication. Generally speaking, clast orientation means the preferred direction of long axis on bedding plane, while clast imbrication means the inclination of clasts observed at cross section vertical to the bedding plane. It is worth to say that secondary fabrics caused by later tectonic deformation may sometimes be observed in conglomerates, however, there is no possibility of such fabrics in the conglomerates of the Muro group. There can be found no rotation around each clast and no deformational structures at any observed localities. So all the clast fabrics treated here can safely assigned as primary ones.

Although the orientation of conglomerate cannot be found easily at a glance at the exposure because of bearing a large amount of spherical gravels, it can be detected by paying attention to elongated clasts that have a ratio of long axis to short axis greater than 1. 5 and by treating them statistically. Clast imbrication can be observed rather easily, because discoidal clasts also indicate the imbrication in the same way as rod-shaped ones. Clast fabrics were observed and measured in 24 beds, and at 29 points in total. The several points are shown in columnar sections in Figs. 5 and 10. The results of measurements is shown in Table 2.

i. Method and results of measurements

Clast orientation; After marking the strike of the bed, each exposure surface parallel or nearly parallel to the bedding plane was photographed. Only elongated clasts, having a ratio of long axis to short axis greater than 1. 5, were choosed and measured (Fig. 8). All elongated clasts in each photograph were measured. The measured numbers of clasts range between 35 and 65. The clast orientations are shown collectively in

Fig. 8. Clast orientation at Nagoshima (loc. 22). A measure indicates the strike (N 20° E) of bedding plane, and a rose diagram shows distribution of elongated 52 clasts.

a rose diagram, after rotating bedding plane around the strike horizontally. Several examples of rose diagrams are shown in Fig. 10.

It is worth to mention here that two types of clast orientation pattern are recognized. One is the type that only one preferred orientation is obtained, and the other is the type that two preferred directions are distinguished. In the latter type, more preferential direction can be detected by comparison of numbers of clasts arranged on each direction.

Clast imbrication; After marking the line parallel to the bedding plane, the exposure surface nearly vertical to the bedding plane was photographed. The angle between the marked line and the long axis of each clast was measured (Fig. 9). The measured numbers of clasts range from 23 to 56. Examples of rose diagrams representing clast imbrication are shown in Fig. 10 by small solid patterns. In order to obtain maximum angle of inclination, the measurements were corrected mathematically in considering the angle between the obtained orientation and the direction of the photographed exposure. Corrected values are shown in Table 2. There may be an intimate relation between mean angle of inclination and mean clast size. As shown clearly in Table 3, the larger the mean clast size is, the higher the mean angle is.

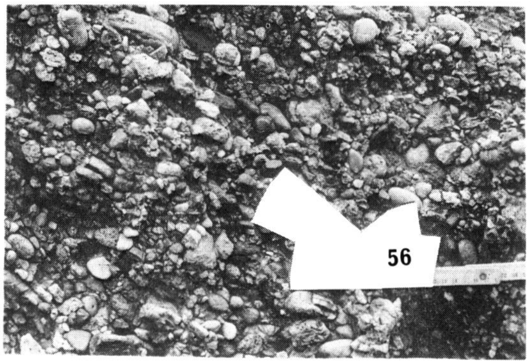


Fig. 9. Clast imbrication at Nagoshima (loc. 22). A measure is parallel to bedding plane, and a rose diagram shows distribution of elongated 56 clasts.

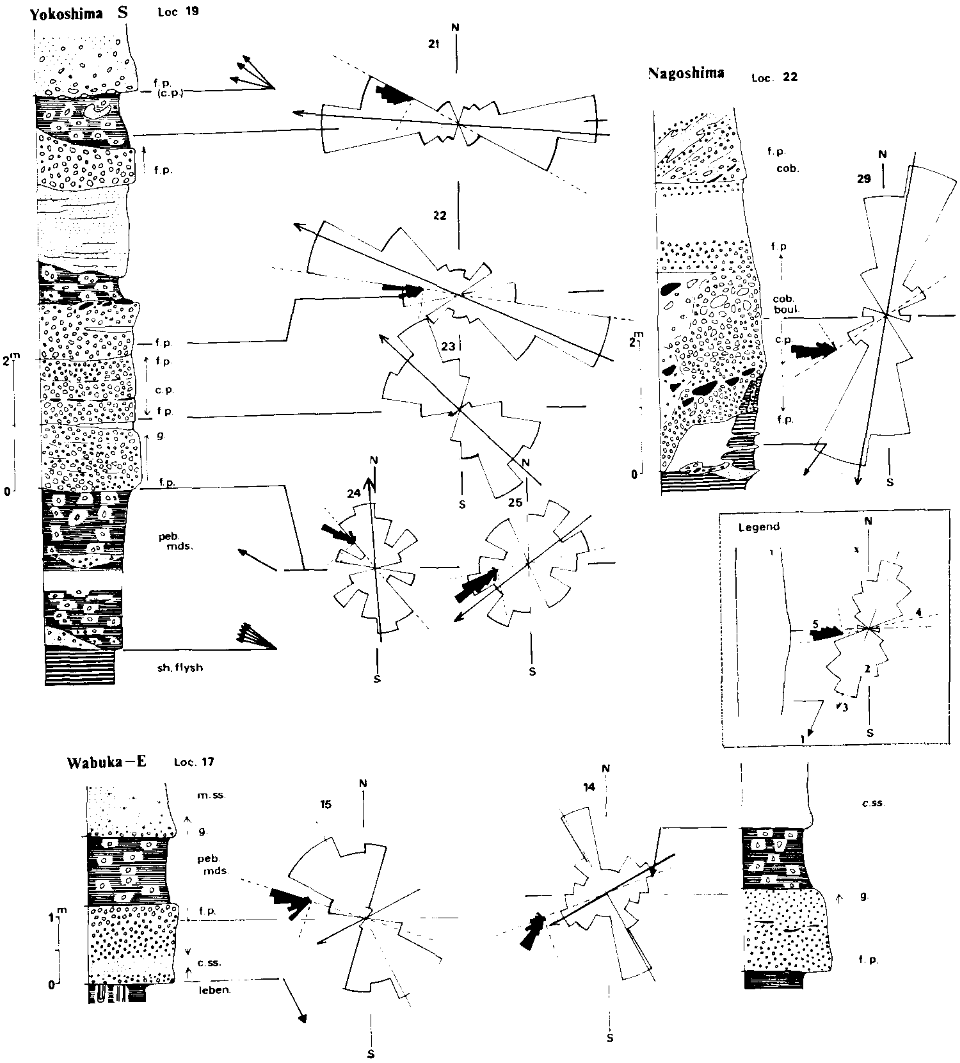


Fig. 10. Columnar sections and clast fabrics of conglomerates. Symbols for internal features and average gravel size are the same as in Fig. 5.
Legend 1: paleocurrent deduced from sole marks, 2: rose diagram of orientation, 3: paleocurrent deduced from clast fabric, 4: trend of section along which clast inclination was observed, 5: diagram of imbrication drawn in a first or fourth quadrant, x: number of clast fabric data (see Table 2).

No	Locality	Hori-zon	Type	Size	Orientation	Imbri-cation	Paleo-current
1	Kodimari-W	B1	A	f.p.	N78°E (82.5)* (39)**	20° (42)**	78°E
2	Kodomari-W	B1	A	f.p.	N26°E (91.3) (44) N74.5°W (93.4) (13)	27° (48)	26°E
3	Magari-N	B1	A	f.p.	N72°E (79.7) (31)	22° (24)	72°E
4	Inazumijima	B1	B	g.	N45°W (90.3) (45) N48°E (97.8) (9)	21° (29)	135°W
5	Susami-I	B1	A	f.p.	N85.5°E (95.0) (36) NS (96.3) (5)	21° (44)	85.5°E
6	Susami-II	B1	A	f.p.	N32.5°E (86.4) (44)	45° (45)	32.5°E
7	Susami-II	B1	B	g.	N57°W (89.0) (26) N46°E (96.1) (8)	33° (30)	33°E
8	Shirashima-I	B3	A	c.p.	N10°E (78.7) (65)	48° (32)	10°E
9	Shirashima-I	B3	A	f.p.	N14°E (89.4) (54)	40° (30)	14°E
10	Shirashima-II	B3	B	c.p.	N60°E (91.5) (38)	32° (29)	150°E
11	Shirashima-II	B3	A	c.p.	N11°E (88.6) (27) N80°E (96.9) (10)	49° (33)	169°W
12	Esuzaki	B3	A	g.	N13°E (86.9) (54)	20° (34)	167°W
13	Esuzaki	B3	A	f.p.	N37°E (88.4) (24) N40°W (94.8) (11)	31° (38)	143°W
14	Wabuka-E	D	B	f.p.	N29°W (95.1) (24) N61°E (90.2) (22)	37° (35)	61°E
15	Wabuka-E	D	B	f.p.	N25°W (89.2) (45)	35° (41)	65°E
16	Azashi-W	D	A	c.p.	N60.5°W (78.1) (51)	30° (32)	119.5°E
17	Azashi-W	D	A	c.p.	N23°W (84.2) (50)		157°E
18	Azashi-W	D	A	c.p.	N20°W (73.0) (47)	46° (23)	160°E
19	Yokoshima-N	D	A	f.p.	N 4°W (96.4) (25) N85°E (88.9) (17)	37° (44)	176°E
20	Yokoshima-N	D	A	f.p.	N35°W (79.1) (43)	23° (38)	145°E
21	Yokoshima-S	D	A	c.p.	N85.5°W (89.4) (45)	27° (35)	94.5°E
22	Yokoshima-S	D	A	c.p.	N62°W (92.1) (45) N35°E (95.7) (10)	21° (27)	118°E
23	Yokoshima-S	D	A	c.p.	N47°W (85.1) (47)		133°E
24	Yokoshima-S	D	A	c.p.	N 1°W (74.4) (40)	30° (25)	179°E
25	Yokoshima-S	D	A	c.p.	N52°E (86.9) (35) N41°W (96.1) (14)	34° (39)	52°E
26	Soshima	D	A	c.p.	N83°W (82.6) (40)	46° (35)	97°E
27	Soshima	D	A	c.p.	N17°W (87.1) (40)	28° (43)	163°E
28	Soshima	D	A	c.p.	N36°E (77.2) (37)	13° (41)	144°W
29	Nagoshima	D	A	c.p.	N11°E (86.7) (31)	55° (48)	11°E

Table 2. Clast fabric and paleocurrent.
* consistency ratio ** the number of clasts measured
Shirashima-I: Shirashima tunnel-W Shirashima-II: Shirashima tunnel-E

clast size	number	incli- nation
c. peb.	13	37°
f. peb.	11	31°
gra.	3	25°

Table 3. Inclination of imbricated clasts. The larger the average gravel size is, the higher the inclination is.

ii. Relationship between clast orientation and imbrication

Two types of clast fabrics, which are shown diagramatically in Fig. 11, can be recognized in the conglomerates of the Muro group. The one is a type that the long axes arrange parallel to imbrication (type A), the other is a type that the long axes arrange transverse to imbrication (type B). Typical examples of both types are shown in Fig. 10, in which two examples at the east of Wabuka (loc. 17) are of type B, and five examples at the south of Yokoshima (loc. 19) and an example at Nagoshima (loc. 22) are of type A. The type of all clast fabrics measured is collectively shown in Table 2, in which only five examples belong to type B, and the remaining to type A. The relationship between the type of clast fabric and clast size is shown collectively in Table 4. It can be inferred that there is a tendency that type B occurs more in finer conglomerates.

type	c. peb.	f. peb.	gra.
A	14/15	9/11	1/3
B	1/15	2/11	2/3

Table 4. Relationship between clast fabric type and average gravel size. The denominaters are the total numbers of conglomerates having each clast size. The smaller the average gravel size is, the higher the ratio of B-type fabric is.

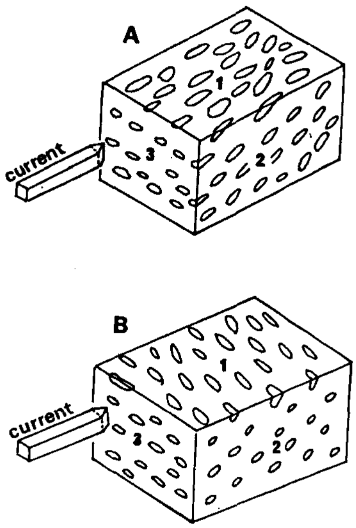


Fig. 11. Diagrams showing clast fabric types A and B.
1: bedding plane or plane parallel to bedding plane (orientation)
2: plane vertical to bedding plane and parallel to current direction (imbrication)
3: plane vertical to bedding plane and current direction.

iii. Relationship between clast fabrics and sole marks

It is well known that the actual dip of clasts deposited in fluvial or beach environment indicates the direction of transport of clasts, namely the direction of paleocurrent (JOHANSSON, 1965; POTTER and PETTIJOHN, 1963). That relationship is considered to be realized in conglomerates deposited in geosynclinal environment (DAVIES and WALKER, 1974; MRAKOVICH and COOGAN, 1974). The paleocurrent direction inferred from clast fabrics is shown in Fig. 10, and that deduced by sole marks are also shown in the same figure. As shown in the examples (Yokoshima-S and Nagoshima in Fig. 10), there is good relationship between the paleocurrents from clast fabrics and those by sole marks. On the other hand, there are a few cases that these directions are oblique each other, the examples of which can be observed at Wabuka-E in Fig. 10. Such cases occur in type-B conglomerates.

2. Thick-bedded sandstones

Thick-bedded sandstones are frequently intercalated in the Muro group, especially in the middle formation. Sandstone beds exceeding 80 cm in thickness are treated here as "thick-bedded". Mineral composition and size distribution of these sandstones in the present area were reported by the present writer (TATEISHI, 1976). These are poor in matrix (mostly less than 15%), and are mostly medium- to fine-grained, although sometimes there are granular to coarse sandstones. These have two modes in general, and show moderate to poor sorting. Most of them belong to feldspathic arenite, and a part of them to feldspathic wacke. Internal sedimentary structures and grain fabrics of thick-bedded sandstones are described in the followings.

a. General occurrence

There are two types of occurrence of thick-bedded sandstones. One is the sandstones that make thick sequences in which several thin beds of mudstone, flysch bed and conglomerate are intercalated. These sequences vary in thickness from 40 to 200 m, and sometimes contain a thick sandstone bed up to 10 m. Such sequences are the most wave resistant rocks, making most of promontries. The other is the sandstones intercalate solely within muddy flysch beds or mudstones. These sandstones vary in thickness along strike, and are lenticular-shaped in general. Typical occurrence of sequences mainly composed of thick-bedded sandstone are shown in Fig. 12. Their horizons and localities are shown in Figs. 3 and 4 respectively.

b. Classification based on internal sedimentary structures

In total, 100 beds of thick-bedded sandstones were examined. Three types, namely, i. composite bed (type 1), ii. structureless bed with parallel lamination at the top (type 2) and iii. laminated bed (type 3), are distinguished on the basis of internal sedimentary structures (Fig. 13). In 100 beds of thick-bedded sandstones, 17 beds belong to type 1, 52 beds to type 2 and 28 beds to type 3. Most of sandstones belonging to type 1 are considered to be composed of thick-bedded sandstones belonging to type 2 or 3. There exist 22 beds having the intermediate feature between types 2 and 3.

i. Composite bed

This type is composed of plural sandstone layers, although these look like a single bed apparently. This type of sandstone was reported as to have been formed by amalga-

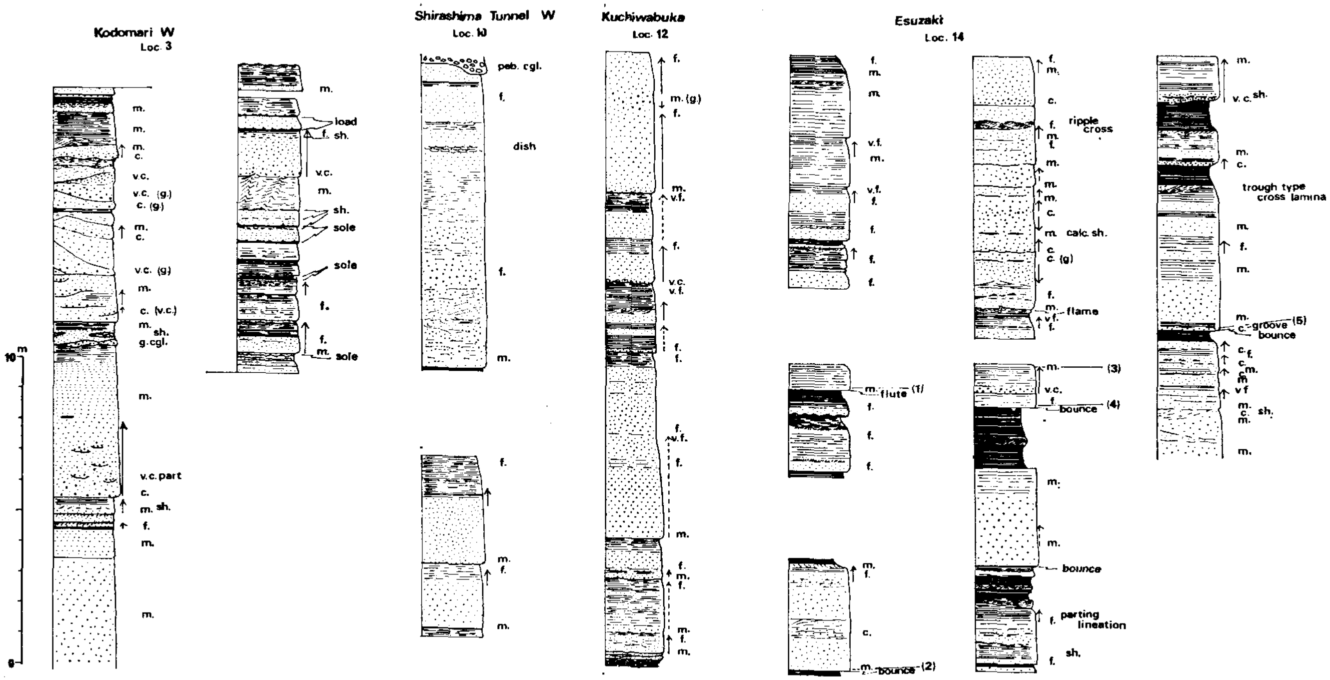


Fig. 12. Columnar sections of sequences composed mainly of thick-bedded sandstone. These show the grain size, internal sedimentary feature (grading and lamination) and external sedimentary structure. Symbols of grain size are same as in Fig. 5, though the symbol of sandstone (ss.) is omitted. Numerals at the right of section (Esuzaki, loc. 14) show the sample numbers of sandstones collected in order to examine grain fabrics (see Fig. 16).

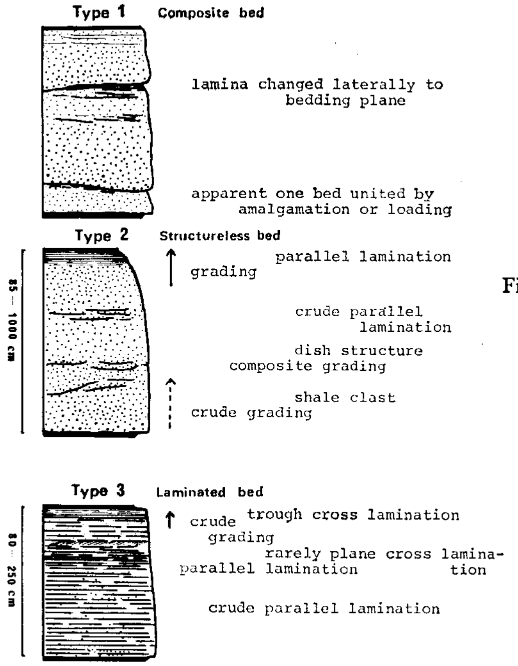


Fig. 13. Sedimentary types of thick-bedded sandstone based on internal sedimentary features.

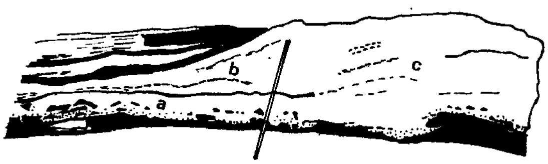


Fig. 14. Lateral change of amalgamated bed into two thin beds observed at Wabuka-W (loc. 16). Scale bar is 1 m in length (see Plate II-1).

mation sometimes accompanied with loading by WALKER (1967) and CORBETT (1972). In the typical example shown in Fig. 14 and Plate II-1, two beds (beds a and b) can be distinguished clearly with intercalation of thin mudstone in the left of the figure, while they change suddenly to an amalgamated bed (bed c) in the right. There the boundary between the two original beds is indicated only as lamination. Bed-a is 30 to 32 cm thick, and its base is very irregular. Clasts of calcareous mudstone are contained in the basal part. Grading can be observed throughout the bed from very coarse in the base to medium sandstone in the upper. Bed-b is thinning leftward from 58 to 18 cm thick. It is composed of medium sandstone, and is associated with thin muddy laminations at the top. Grading is indistinctive excepting a transitional zone from sandstone to mudstone. Two zones of mudstone patches are observed in the bed. Bed-c is 89 cm thick, and its base is irregular. The flame structures are found there. It is composed mostly of medium sandstone having some laminations of calcareous mudstone patch. The basal part consists of very coarse sandstone having clasts of calcareous mudstone. Thin muddy laminations are found at the top. Grading is indistinctive excepting the basal part and the top of the bed.

Another example shown in Fig. 15 shows clearly that a contemporaneous loading must have played an important role together with amalgamation for uniting plural layers.

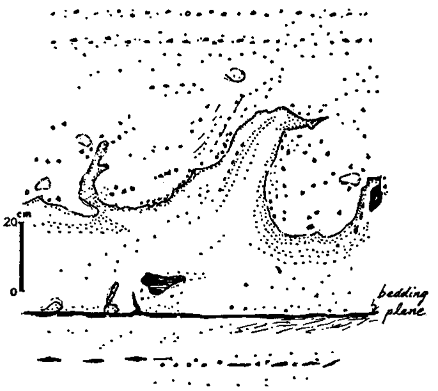


Fig. 15. Lower part of an amalgamated sandstone about 180 cm thick (scale bar is 20 cm length) observed at Kodomari (loc. 5). The boundary is shown clearly by the difference of grain size, and the loading structure is developed.

ii. Structureless bed with parallel lamination at the top

There are many sandstones which consist of structureless division in the lower part and parallel-laminated division in the upper. These sandstones are treated here as type 2. The lower division is predominant in general, and the upper one may be developed only along the top of the bed as shown in Plate II-2 and -3. Grading is usually indistinct, although it develops well at a transitional zone between the two divisions. This type attaining to 8 to 10 m thick, and is thicker in general than type-3 sandstone.

iii. Laminated bed

Parallel laminations develop dominantly throughout this type of sandstone. It is usually 80 to 150 cm thick. A typical example is shown in Plate II-4. Although laminations are mostly parallel, cross laminations and convolute laminations are sometimes observed. In cross laminations, there are three types, such as trough (Plate III-1), plane and ripple-drift types (Plate III-2).

c. Relationship between grain fabrics and sole marks

The relationship between grain fabrics and sole marks in flysch-type alternations was examined by STAUFFER (1967) and COLBURN (1968). The relationship in thick-bedded sandstone, however, has not been reported yet. The relationship gives an efficient clue to discuss sedimentary process of thick-bedded sandstones.

Grain fabrics of thick-bedded sandstones were tentatively examined at four points. After marking the strike of the bed, hand-specimens were sampled from four thick-bedded sandstone bed which have sole marks on the bottom. Their horizons are shown in Fig. 12. Grain orientation was measured microscopically on thin sections cut parallel to bedding plane and, then, grain imbrication was determined on newly made thin sections cut vertical to bedding plane and parallel to the grain orientation.

The results are shown in Fig. 16. It is apparent that long axes of sand-sized grains are arranged well in a preferred direction, and that grains show imbricated structures although these are indistinct. Paleocurrents deduced by sole marks are also shown in the same figure. It is clear that there exists a good relationship between paleocurrents obtained by means of grain fabrics and that by sole marks.

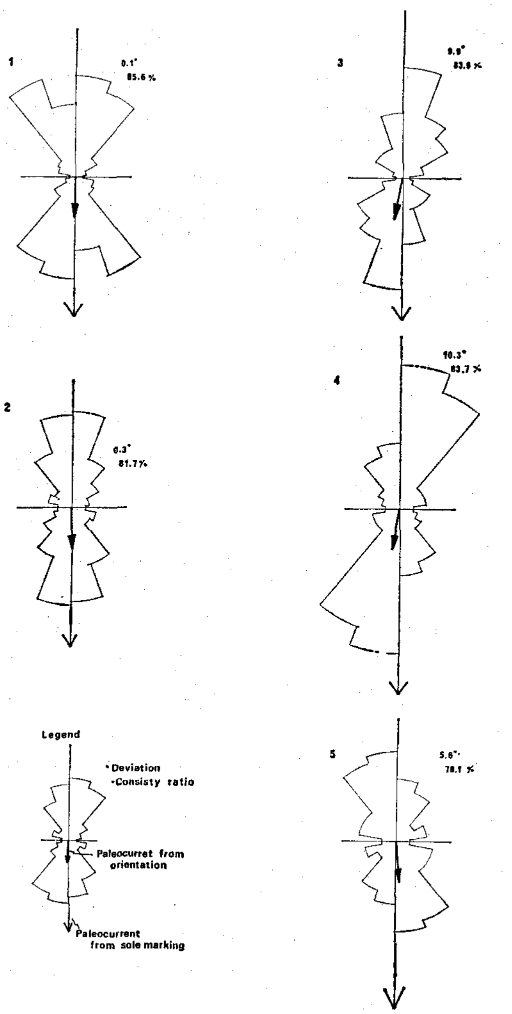


Fig. 16. Relationship between paleocurrents from grain fabric and sole marks in the thick-bedded sandstone collected at Esuzaki (loc. 14) (see Fig. 12). Both of paleocurrents are well coincided.

3. Conglomeratic mudstones

There exist two kinds of conglomeratic mudstones, that is, pebbly mudstone and angular fragment-bearing mudstone, in the Muro group. Pebbly mudstones are frequently intercalated within the upper formation. Thick layers of pebbly mudstone (usually 6 to 10 m thick) occur in the basal part of the channel filling sediments which will be described later (Figs. 18, 19 and 20). Thinner layers (1 to 3 m thick) are intercalated within flysch sequences and sequences composed of thick-bedded sandstone and conglomerate. The pebbly mudstones consist of predominant dark-grey mudstone and scattered clasts in the matrix. The mudstone matrix is massive and structureless in general. Clasts are pebble- to granule-sized, rounded to subangular gravels of acidic volcanic rocks, orthoquartzite, greywacke, mudstone and chert. In general, these gravels are randomly scattered through the matrix, though they are sometimes aligned making laminae (Fig. 18b). The large blocks of conglomerate and sandstone, sometimes reaching 3 m in diameter, are contained in pebbly mudstone which forms the basal part of channel-fill (Figs. 18 and 19). These rocks are identical in lithology to those of stratigraphically lower horizon. These blocks show sometimes contorted shape similar to slumping.

The angular fragment-bearing mudstones are an important constituent of the F and G members. These in the lower part (about 200 m thick) of the F member are called "Sarashi-kubi (gibbeted head) bed" as a field name by KISHU SHIMANTO RESEARCH GROUP (1969). Dark-grey mudstone matrix occupies more than 90 per cent and clasts are scattered throughout the matrix. Although the muddy matrix is apparently massive and structureless, if observed in detail, it is formed by assemblage of small fragments of mudstone, which suggests the secondary fragmentation during transportation. The clasts are composed of various sized, subangular to angular sedimentary rocks, such as mudstone, sandstone, flysch-type alternation and conglomerate, all of which are identical in lithology to those of stratigraphically lower horizon. Some clasts are up to 5 to 8 m in diameter. These clasts are randomly scattered in the matrix in general, but in the lower part of the F member, are aligned with long axis parallel to general trend of the neighbourhood.

Angular fragment-bearing mudstones forming the lower part (about 100 m thick) of the G member are different from those of the F member: smaller clasts than cobble-size; crude bedding; and are called "Ko-sarashi bed (ko- means small)" as a field name by KISHU SHIMANTO RESEARCH GROUP (1969). These angular fragment-bearing mudstone in the F and G members are considered to be endolistostrome (ELTER andRAGGI, 1965).

4. Flysch-type alternation

The Muro group is composed predominantly of flysch-type alternation of sandstone and mudstone. The flysch-type alternation of the Muro group has been examined sedimentologically (HARATA, 1965; SHIKI et al., 1968; KUROKAWA, 1972; KISHU SHIMANTO RESEARCH GROUP, 1970, 1972, 1976). The flysch beds are classified in this paper as sandy flysch (sandstone>mudstone), normal flysch (sandstone=mudstone), and muddy flysch (sandstone<mudstone) on the basis of approximate ratio of sandstone to mudstone. Typical examples of these flysch beds are shown in Plate IV. In general, the bottom of sandy part is sharp and distinctive, and alternatively the boundary between sandy part and overlying muddy part is transitional and indistinctive. Most of the flysch beds have internal sedimentary structures such as parallel lamination and ripple cross lamination. Grading structure is sometimes observed in the lower part of the bed. These internal sedimentary features have a good correspondance with those in Bouma's flysch sequences (BOUMA, 1962). Most of sandy flysch beds are Tb-e or Tc-e sequences of Bouma's sequence. A part of sandy flysch beds begins from grading division, and consists of complete sequence (Ta-e). On the other hand, normal flysch and muddy flysch show predominantly Tc-e or Td-e sequence, and there are few beds with grading and lower parallel lamination divisions.

There are observed many kinds of external sedimentary structures such as directional sole marks, load casts and ripple marks in the flysch beds. There are also observed many kinds of trace fossils such as *Helminthopsis*, *Cosmorhaphe*, *Nereites*, *Paleodictyon*. These structures play important roles to reconstruct sedimentary environment of the Muro group, and several studies were already reported as mentioned above.

B. Transportation and deposition

On the basis of the above-mentioned data, the mechanism of transportation and deposition of conglomerate, thick-bedded sandstone, conglomeratic mudstone and flysch-type alternation will be discussed in the following.

1. Conglomerates

It is well known that large gravels which are rolled on the bottom are finally aligned with their long axes transverse to flow direction and with their intermediate axes dipping upstream (JOHANSSON, 1965; REES, 1968; RUST, 1972). Most of conglomerates of the Muro group show the preferred fabric. Two types (types A and B) can be recognized in their clast fabrics (Fig. 11). Type A is that long axes of elongated clasts are arranged parallel to direction of clast imbrication, in other words, parallel to direction of current. Type B is that long axes are aligned transverse to current. B-type fabric, which occurs not so many, implies that constituting clasts were rolled for appreciable distance. A-type fabric, which is most common in the conglomerates of the Muro group, clearly indicates that clasts were not rolled for a long distance, but were transported in state of suspension and deposited in accordance with the decrease of energy. Concerning to the current that is able to transport coarse detritus in state of suspension, there have been proposed turbidity current (WALKER, 1967), grain flow (STAUFFER, 1967) and submarine debris flow. The sediments deposited by submarine debris flow are not sorted well and are scarcely organized. The conglomerates in the Muro group show mostly imbrication, inverse and/or normal gradings and sometimes stratification. So the submarine debris flow can be eliminated safely, and the other two cases remain logically as a transportation mechanism of the conglomerates of the Muro group. Large clast-bearing conglomerates are characterized by development of inverse grading in the lower part (Model i). It is known that the inverse grading structure is formed by the effect of the dispersive pressure arised from clast collision under shear, namely, by the so-called Bagnold's effect (BAGNOLD, 1954). It is most probable that transportation and deposition of conglomerate, especially composed of large clasts, are attributed to grain flow that supports the clasts above the bed by dispersive pressure caused by clast collision. Small clast-bearing conglomerates are characterized by development of normal grading and stratification (Model ii). Their sedimentary features indicate that these conglomerates were transported and deposited mainly by turbidity current. The mechanism of turbidity current is distinguished theoretically from that of grain flow. However, it is likely that the relationship between the two mechanisms is transitional in real flows (MIDDLETON and HAMPTON, 1976; WALKER, 1975b), and most of the gravels are transported and be deposited by the currents combining two types of mechanisms. The dispersive pressure by clast collision plays the important role to transport a lot of larger gravels, and forms the inverse grading. The turbulence plays an important role to transport small gravels, and forms the normal grading and stratification.

It is most likely that the disorganized model of conglomerates, which is not sorted and stratified so well, deposited in the most proximal suite where the current is not developed to segregate clasts (WALKER, 1975b).

As for the B-type fabric in the conglomerate of the Muro group, it is possible that the rolling of clasts took place at the last stage of the turbidity current. It may be likely that the normal bottom current acts to retransport clasts at that stage.

2. Thick-bedded sandstones

Three types (1. composite bed, 2. structureless bed with parallel lamination at the top, and 3. laminated bed) are distinguished in the thick-bedded sandstones of the Muro group (Fig. 13). As the first type is assigned to have been formed secondarily by amalgamation, the present writer would like to treat here the second and third types. There

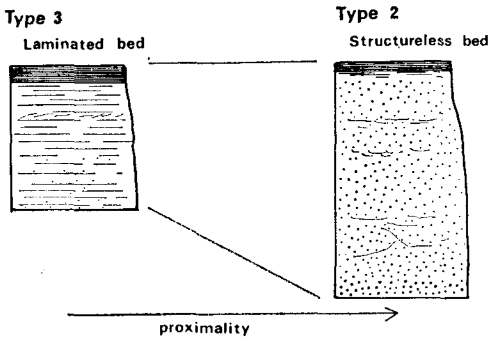


Fig. 17. Inferred relationship between sedimentary types 2 and 3 of thick-bedded sandstones. It is probable that type 2 beds are located in more proximal suits than type 3 beds.

are many thick-bedded sandstones of intermediate type, and the relationship between the two types is gradational (Fig. 17). Sedimentary features such as grading and various kinds of laminations are similar to those in typical "turbidite" sequences reported by BOUMA (1962), KUENEN (1967) and WALKER (1967). These facts suggests that the origin of thick-bedded sandstones of the Muro group must be same as in typical turbidite sequences. The present writer examined the grain-size distribution of thick-bedded sandstones of the Muro group, and drew the C-M diagram (PASSEGA and BYRAMJEE, 1969) of which pattern suggests that these sandstones might have been transported and deposited by turbidity current (TATEISHI, 1976). The grain fabrics of thick-bedded sandstone support that sand grains were transported by the currents which made the directional sole marks.

There exist some different features between thick-bedded sandstones and flysch-type alternations. Compared with flysch-type sandstone, thick-bedded sandstone is generally coarser, and poorly sorted. Furthermore, structureless division is thicker, and grading is not so remarkable in thick-bedded sandstone. These features in the thick-bedded sandstones of the Muro group coincide well with the characteristic features in proximal turbidites reported by WALKER (1967).

The sedimentary process of thick-bedded sandstones in a geosyncline, has been argued extensively for the last decade. Most of sedimentologists considered that these were transported and deposited by a kind of sediment gravity flows (MIDDLETON and HAMPTON, 1976), although there has been a controversy whether sand grains could be deposited by turbidity current or by grain flow. Theoretically turbidity current and grain flow can be distinguished from each other, however, the sediments yielded by them cannot be distinguished practically (MIDDLETON and HAMPTON, 1976). The characteristic features of grain flow assigned by STAUFFER (1967) cannot be found in the thick-bedded sandstones in the Muro group except for dish structures. Dish structure itself cannot be assigned as one of the features of grain flow, but as a secondary water-escaped structure (LOWE and LOPICCOLO, 1974; RAUTMAN and DOTT, Jr., 1977). It is probable that the grain flow did not play main role in emplacement of sandstones of the Muro group, and that most of thick-bedded sandstones of the Muro group were deposited in proximal site by turbidity currents.

3. Conglomeratic mudstone

There exist pebbly mudstone and angular fragment-bearing mudstone in the Muro group. CROWELL (1957) examined the pebbly mudstone in California ranging from Jurassic to Pliocene in age, and assigned the origin of pebbly mudstone to subaqueous sliding or slumping. Thereafter, sedimentation of tilloids or pebbly mudstones in sedimentary sequences was examined by several workers and was assigned to be of the submarine mass movement such as sliding, slumping, or mudflow (SCHERMERHORN and STANTON, 1963; DOTT, 1963). MIDDLETON and HAMPTON (1976) summarized the mechanisms and deposits of various kinds of sediment gravity flows, and called the flow including the flows of above-mentioned mechanisms the debris flow. The summary of the type of sedimentary features that might be found in beds deposited by debris flow is presented by HAMPTON (1972) and MIDDLETON and HAMPTON (1976).

The pebbly mudstones in the Muro group have the following features; i. clasts are scattered at random throughout the matrix, ii. grading is scarcely observed, iii. contorted blocks of sandstone or conglomerate are frequently included. Judging from these features, the origin of pebbly mudstones in the Muro group is ascribed safely to the debris flow.

Angular fragment-bearing mudstones in the Muro group have quite similar features to the above-mentioned pebbly mudstones and are also considered to have been transported and deposited by the debris flow. However, they differ from the pebbly mudstones in having angular clasts of various sizes and various degrees of consolidation which are derived from the lower beds of the Muro group, and are certainly referred to as endolistostrome. Olistostrome has been reported from geosynclinal sediments in various places (ABBATE, et al., 1970; KAY, 1976; De JONG, 1974), and is generally considered to be of submarine slide or submarine mudflow origin (ABBATE, et al., 1970). The organized arrangement of clasts are observed in some parts of the angular fragment-bearing mudstones of the F member. This indicates that the mass movement was advanced, and the segregation of clasts took place in the flow. The crude bedding in the G member suggests that the small-scale mass movement occurred frequently at short intervals. Source materials of the angular fragment-bearing mudstones differ from those of pebbly mudstones as mentioned already. They must have been caused by the breakdown of the geanticlinal upheaval within the basin. On the other hand, pebbly mudstones are derived from the exotic provenance same as the other turbidite sequences. WALKER and MUTTI (1973) attempted to classify several turbidite facies. According to them, the pebbly mudstone and olistostrome are grouped in the slope-channel facies association. The conglomeratic mudstones in the Muro group are considered to be deposited in the lower part of submarine slope, and in the major channels or canyons incised into the slope.

4. Flysch-type alternations

There have been reported numerous papers as for the sedimentology of the flysch sequences, characterized by rhythmic alternations of sandstone and mudstone. Since KUENEN and MIGLIORINI (1950) put forward the suggestion that turbidity flow causes a graded bedding, the concept of turbidite has been greatly elaborated and popularized. Diagnostic characteristics of turbidites were summarized by BOUMA and BROWER (1964), POTTER and PETTIJOHN (1963), KUENEN (1967), SELLEY (1970), etc. Turbidites can be identified by many kinds of sedimentary structures, such as external and internal structures. The former are current scours, obstacle scours and tool marks, and the latter are graded bedding, parallel lamination and cross lamination. The typical sequence of internal structures in turbidites was established for the first time by BOUMA (1962). It has been called as Bouma's sequence, being considered as one of the most important features of turbidites. The flysch sequences of the Muro group show the excellent rhythmic bedding as shown in Plate IV. External sedimentary structures such as flute mark, groove mark and current crescent mark can be abundantly observed. Although the beds possessing the idealized Bouma's sequence (complete sequence) are not so many, most of the flysch beds show the Tb-e or Tc-e sequences of Bouma's sequence. These facts indicate apparently that the flysch-type alternations of the Muro group were mostly transported and deposited by turbidity currents.

IV. Submarine Fan Sedimentation

Facies analysis of sediments deposited on ancient submarine fan has been reported by many sedimentologists (NORMARK, 1970; SMITH, 1971; NILSEN and SIMONI, Jr., 1973; WALKER and MUTTI, 1973; MUTTI, 1974, 1977; NELSON and NILSEN, 1974; CARTER and LINDQVIST, 1975; WALKER, 1975c). Channel-scours and -fills of various scales are observed in the Muro group, suggesting submarine fan deposition. In order to make clear the sedimentary environment of the Muro group these channel-scours and -fills were examined in detail.

A. Channel-scours and -fills

A number of channel-scours and -fills of various scales are observed in the coast area. Most of these channel structures belong to the middle and upper formations. Typical channel structures which belong to the D member are well observed at the east of Wabuka (loc. 17), Yokoshima Island (loc. 19) and Soshima Island (loc. 21).

1. East of Wabuka (loc. 17)

The channel structure is well exposed at the sea cliff of 25 m in width and 10 m in height (Plate V). The geologic map and a brief sketch of the channel are shown in Fig. 18. The sequence underlying the channel structure consists of thin-bedded muddy flysch in the lower part and pebble conglomerate in the upper. The former, in which bioturbations are well developed, is alternations of fine sandstone or siltstone (less than 1 cm thick) and mudstone (2 to 3 cm thick). The latter overlying conformably the former is 2 m in thickness. Mudstone clasts up to 30 cm in diameter are scattered in the upper part. The pebble conglomerate has N 30°E strike, dipping 40° southward at point B. The channel cut into the underlying conglomerate and even muddy flysch as well about 4 m in depth at point A. There, the bottom surface of the channel has N 10°E strike, dipping 20° eastward. The channel-fill consists of pebbly mudstone about 10 m thick. It contains pebble gravels and large blocks of sandstone, granule conglomerate and muddy flysch in the basal part, and intercalates two medium sandstone beds in lenticular shape. Pebble conglomerate overlies the pebbly mudstone. Flute marks are found on its bottom surface, indicating the paleocurrent from NNW to SSE.

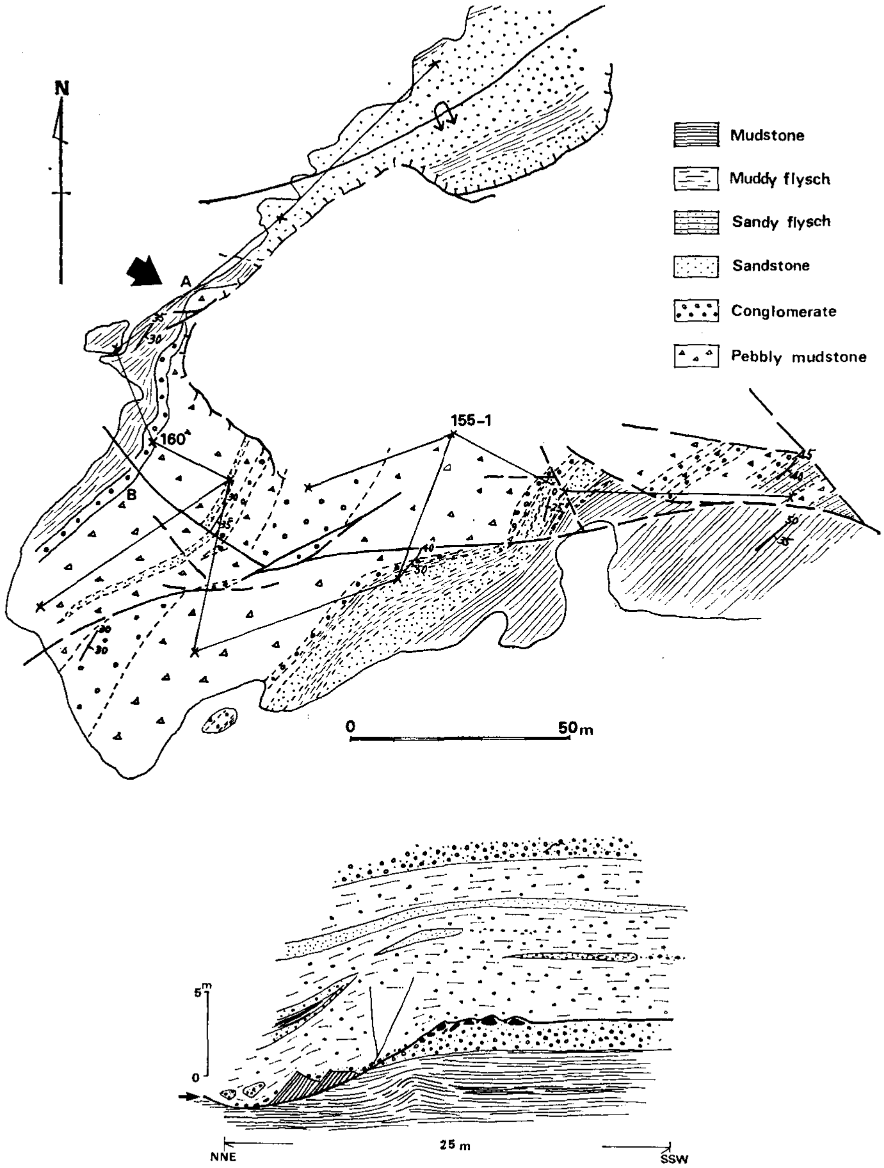


Fig. 18. Channel structure at Wabuka-E (loc. 17). See Plate V.
A: Geologic map (after KISHU SHIMANTO RESEARCH GROUP, 1969). The arrow shows the point of channel structure.
B: A brief sketch of the channel structure. The arrow shows the channel base.

2. Yokoshima Island (loc. 19)

Two large channels (lower and upper ones) are observed. The geologic map and a brief sketch of the upper channel are shown in Fig. 19.

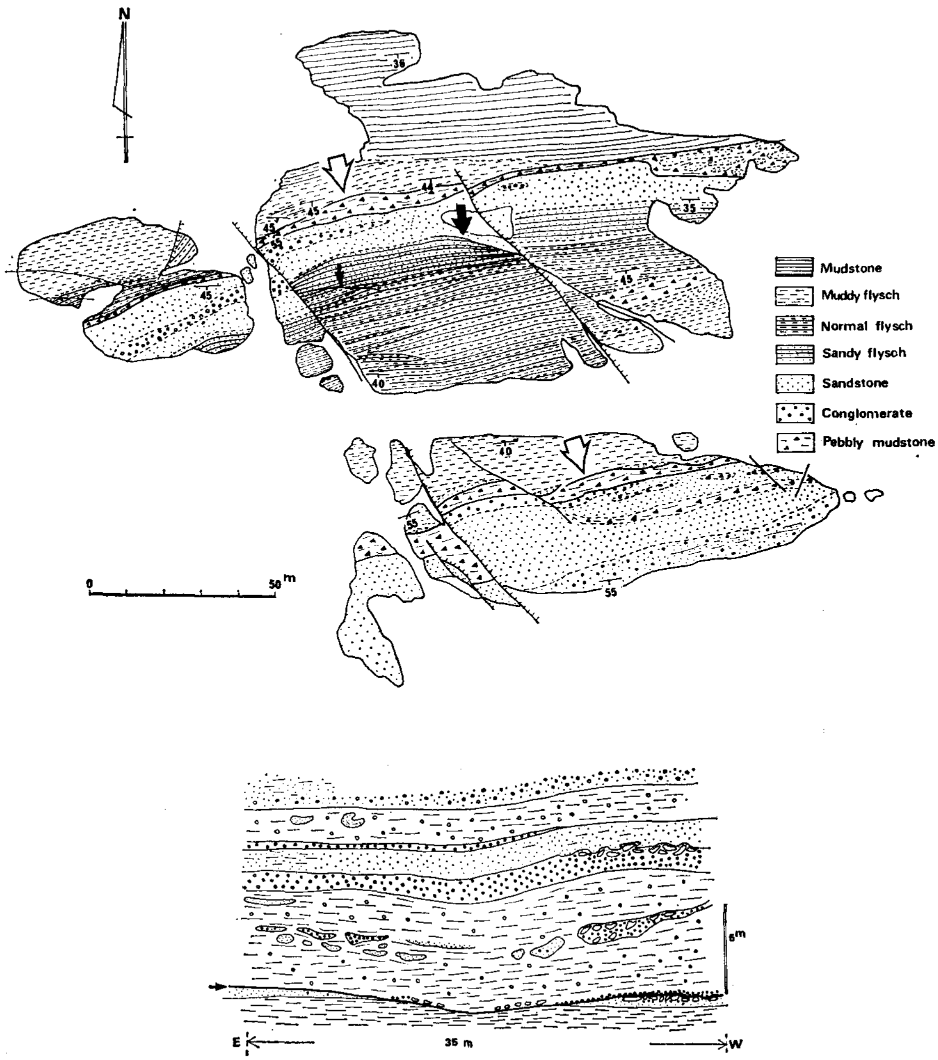


Fig. 19. Channel structures at Yokoshima Island (loc. 19) (see Plate VI).

A: Geologic map (after KISHU SHIMANTO RESEARCH GROUP, 1970). White arrows show the large channel structures, and black arrows show the small channel structures.

B: A brief sketch of the upper large channel. The black arrow shows the channel base.

a. Lower channel

The sequence underlying the channel consists of bedded mudstone, muddy flysch and normal flysch in ascending order. These have N 50°W to EW strike, dipping 45° to 65° southward, and are deeply scoured out by the channel. At the east of the island, normal and muddy flysch are entirely scoured out. Unfortunately the eastern part of the channel wall is not exposed. The western half of the channel is 20 m deep and 200 m wide. Bottom surface of the channel has N 60° to 80°E strike, dipping 55° southward. The channel is filled with pebbly mudstone, pebble conglomerate, thick-bedded sandstone, sandy to normal flysch and muddy flysch in ascending order. The filling sediments as a whole comprise typical thinning- and fining-upward sequence as shown in Fig. 20. The lowest pebbly mudstone, of which thickness varies from 150 to 450 cm, contains blocks of sandstone and mudstone. Several small channels can be seen in the filling sediments. The thick-bedded sandstones are scoured at least 8 m in depth by overlying sandy flysch, and the sandy to normal flysch beds are also scoured, forming small channels (Plate VI).

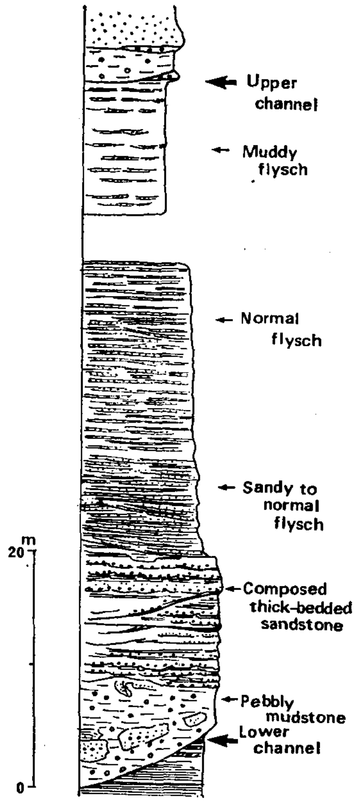


Fig. 20. Columnar section of filling sediments of the lower channel at Yokoshima Island (loc. 19).

b. Upper channel

The sequence underlying the channel consists of muddy flysch and granule sandstone. It has generally N 80°E strike, dipping 40° southward. The granule sandstone is about 40 cm in thickness, and contains mudstone clasts up to 20 cm in diameter in the upper. The channel scours out the underlying sequence in a scale of 1 m in depth and 10 m in width. The bottom surface has EW strike, dipping 30° southward. The channel is filled with pebbly mudstone, pebble conglomerate and thick-bedded sandstone. The lowest pebbly mudstone is 6 to 7 m in thickness, and contains blocks of pebble to granule conglomerate and sandstone in the middle horizon of the bed. Sole marks are observed on the bottom of conglomerates, indicating paleocurrents from ESE.

3. Soshima Island (loc. 21)

The geologic map of Soshima Island is shown in Fig. 21. The sequence underlying the channel consists of muddy flysch of sandstone or siltstone (0.5 to 5 cm thick) and mudstone (3 to 15 cm thick). It has N 75°E strike, dipping reversely 50° to 60° northward. The channel scours out these beds in 25 m in depth and 150 m in width. Bottom surface of the channel has N 50 °W strike, dipping 50° northward, though it is overturned. The filling sediments, attaining to 80 m in total thickness, are subdivided into the lower and the upper parts. The lower part is composed of pebble conglomerate of 30 m thick, intercalating thick-bedded sandstone which thin out towards the channel wall. The upper part is composed of pebbly mudstone, pebble conglomerate and thick-bedded sandstone. Current marks are observed on the bottom surfaces of these filling sequences,

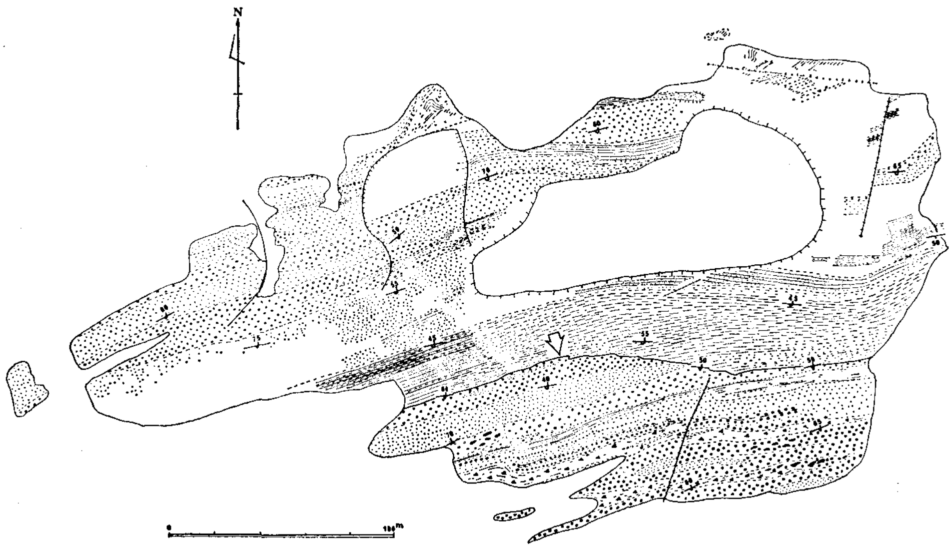


Fig. 21. Geologic map of Soshima Island (loc. 21) (after KISHU SHIMANTO RESEARCH GROUP, 1969) Legend of lithofacies is as same as in Fig. 19. The arrow shows the channel base.

indicating paleocurrents from ESE or E.

B. Channel directions and paleocurrents in channel-fills

The directions of elongated channels and paleocurrents found in channel-fills are examined in the following.

1. The direction of elongated channels

In order to reconstruct a dispersal pattern of a submarine fan, it is important to obtain the direction of elongated channels. Although the channel-wall and -base have different geometries from place to place, the general trend of an elongated channel can be obtained by averaging some measurements of strikes of channel-wall and -base (Fig. 22). In order to obtain original strikes and dips of channel-wall and -base, it is necessary to correct data for tilt. The compensations were done by means of the same methods as the tilt correction of cross-bedding (POTTER and PETTIJOHN, 1963; p. 259-260). Using the strike-line as a hinge line, the bed under channel structure is rotated back to horizontal position. By means of the rotation, original strike and dip of the bottom surface of channel can be obtained. Example of compensation is shown in Fig. 23. It shows the compensation about the lower channel at Yokoshima Island. The data

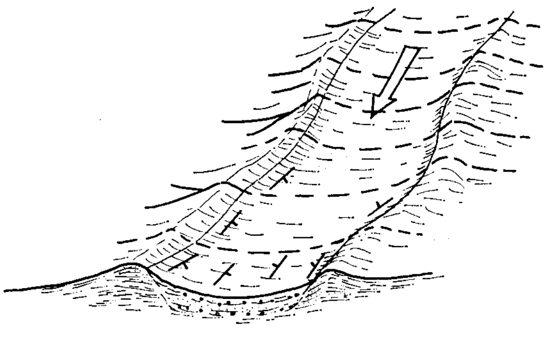


Fig. 22.

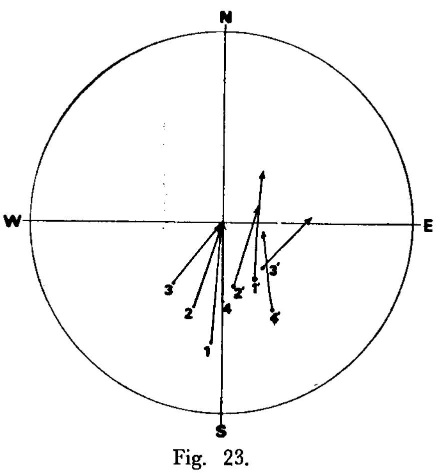


Fig. 23.

Fig. 22. Illustration of channel structure. General trend of channel (white arrow) can be obtained by averaging some strike measurements of channel-base and -wall, though the strike and dip of them are differed from place to place.

Fig. 23. Tilt correction to obtain original strike and dip of channel-base and -wall. The method is the same as correction for cross-bedding by POTTER and PETTIJOHN (1963). Points shown by numerals are the strike and dip of the beds underlying channel structures, and points shown by dashed numerals are the ones of the channel-base and -wall. Data are of lower channel at Yokoshima Island (loc. 19) (see Table 5).

		sequence underlied channel structure	bottom surface of channel	compensated value
East of Wabuka		N70°E, 15°S	N10°E, 30°E	N20°E, 25°E
lower at Yokoshima	1	N55°W, 65°S	N65°E, 38°S	N52°W, 38°N
	2	N72°W, 50°S	N80°E, 38°S	N25°W, 24°E
	3	N52°W, 45°S	N48°E, 36°S	N 3°W, 50°E
	4	EW , 45°S	N60°E, 55°S	N10°E, 25°E
			vector mean	N17°W
upper at Yokoshima		N85°E, 40°S	N75°W, 60°S	N50°W, 25°S
Soshima	1	N65°E, 85°N(O)	N80°E, 20°N(O)	N16°E, 20°W
	2	N54°E, 74°N(O)	N55°W, 80°N(O)	N17°W, 78°W
	3	N75°E, 60°N(O)	N80°W, 50°S	N55°E, 74°N
	4	N74°E, 70°N(O)	N60°W, 70°S	N55°W, 60°N
	5	N80°E, 55°N(O)	N68°W, 35°N(O)	N40°E, 30°E
	6	N80°W, 50°N(O)	N75°W, 65°N(O)	N65°W, 15°N
	7	N80°E, 70°N(O)	N75°E, 60°N(O)	N76°W, 10°S
	8	EW , 65°N(O)	N55°W, 80°N(O)	N16°W, 35°E
	9	N65°E, 80°N(O)	N70°W, 70°N(O)	N 8°W, 45°E
	10	N75°E, 70°N(O)	N85°W, 80°N(O)	N40°W, 20°E
	11	N55°E, 70°N(O)	N35°W, 55°E(O)	N 2°W, 78°E
	12	N60°E, 55°N(O)	N80°E, 70°N(O)	N68°W, 25°N
	13	N55°E, 80°N(O)	N86°W, 74°N(O)	N22°W, 38°E
			vector mean	N 4°W

Table 5. General trends of channels. These can be obtained by averaging the compensated values, or can be shown by the compensated value.

and compensated values are shown in Table 5 about 4 channels. Vector mean of compensated values for strike of the bottom surface of channel indicates a general trend of the channel. General trends of four channels are shown in the followings.

east of Wabuka:	N 20°E
lower one at Yokoshima Is.:	N 17°W
upper one at Yokoshima Is.:	N 50°W
Soshima Is.:	N 4°W

2. Paleocurrents in channel-fills

Although the general trend of elongated channel is obtained by the above-mentioned method, its sense cannot be known. The sense of channel trend can be deduced indirectly by paleocurrent analysis of filling sediments.

The general trends of channels and the paleocurrents of filling sediments are shown in rose diagrams in Fig. 24. These show that the filling sediments excepting one example flowed down from southeast, suggesting that the mouth of submarine canyon existed to the south.

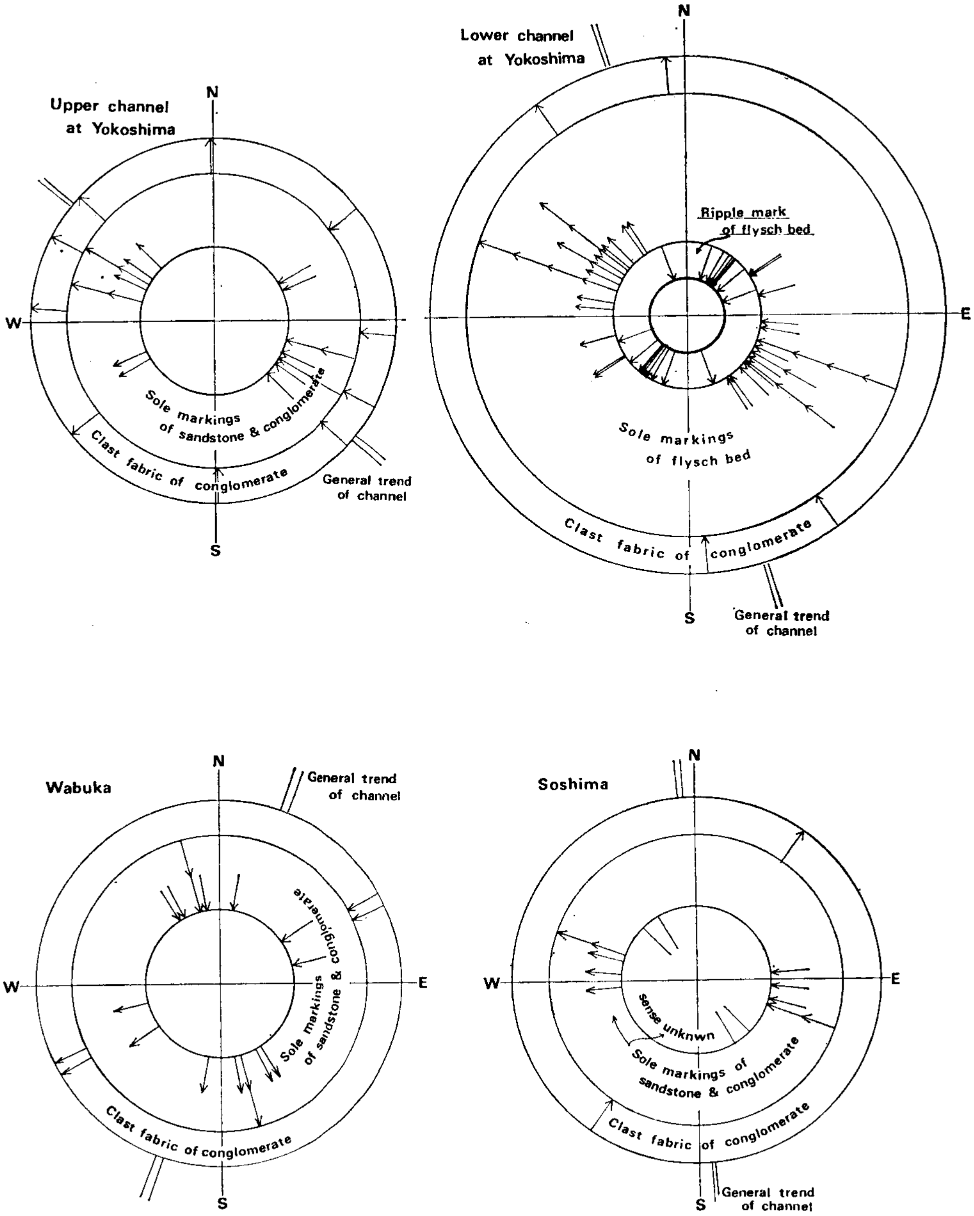


Fig. 24. General trends of channels and paleocurrents in each channel-filling sediments.

V. Basin Analysis of the Muro Group

The sedimentary environment of the Muro group was reconstructed mainly on the basis of stratigraphical study, paleocurrent analysis and petrographical examination of conglomerates (KISHU SHIMANTO RESEARCH GROUP, 1975). In order to make clear the environment in more detail, the present writer examined sedimentary structures of conglomerates and thick-bedded sandstones, and sedimentary features of channel structures. Adding these new data, the paleogeographical reconstruction is attempted in the following.

A. Lithostratigraphic features

Stratigraphy and lithofacies of the Muro group were described in some papers (KISHU SHIMANTO RESEARCH GROUP, 1969, 1972, 1973; TATEISHI, 1976), and were summarized by KISHU SHIMANTO RESEARCH GROUP (1975). Based on these papers, the lithostratigraphic features of the Muro group is summarized as the followings.

The Muro group is composed predominantly of marine sequences of terrigenous clastic rocks, but lacking in greenstones and radiolarian chert of oceanic origin. Such lithofacies indicates the miogeosynclinal environment. The Muro group is divided into three formations, namely the lower, middle and upper formations. The lower formation is composed mainly of muddy flysch and mudstone, intercalating sandy flysch and thick-bedded sandstone. The middle formation is composed mainly of sandy flysch and thick-bedded sandstone, frequently intercalating conglomerate. The upper formation consists predominantly of alternations of coarse sediments such as conglomerate, conglomeratic mudstone and thick-bedded sandstone. The Muro group shows an upward coarsening sequence as a whole (Fig. 3). Such sequence suggests that filling up of the sedimentary basin was more rapid than its subsidence, and that the basin gradually became shallow as a result.

B. Properties of coarse sediments

Sedimentary petrologic examination of conglomerate and sandstone gives us valuable informations for the source rocks. Such studies on the Muro group have been done by TOKUOKA (1967, 1970), KISHU SHIMANTO RESEARCH GROUP (1970, 1976) and the present writer (TATEISHI, 1976). Based on these papers, the compositional properties of their coarse sediments are summarized as the followings.

Conglomerates of the Muro group are polymictic, and consists of gravels of various kinds of rocks predominated by acidic volcanic rocks, greywacke-type sandstone, orthoquartzitic sandstone, chert, shale, granitic rocks and muddy limestone. Orthoquartzite gravels are commonly contained in conglomerates, especially more in the upper formation. Exotic gravels in pebbly mudstone and angular fragment-bearing mudstone are the same kinds of rocks as those of conglomerate.

Sandstones of the Muro group are mostly poor in matrix, and mostly medium to fine grain-sized. These belong mostly to feldspathic arenite, and partially to feldspathic wacke. Main constituents are quartz, K-feldspar, plagioclase and rock fragments.

C. Sedimentation of coarse sediments

Transportation and deposition of the coarse sediments such as conglomerate, conglomeratic mudstone, thick-bedded sandstone and flysch-type alternation were examined in Chap. III, based on sedimentary features such as internal sedimentary structure and fabric. The sedimentation of these sediments is summarized as the followings.

It is apparent that the flysch-type alternation in the Muro group are considered to be mostly typical turbidite. Thick-bedded sandstone can also be assigned as turbidite in origin. Although there are some differences of sedimentary features between flysch-type alternation and thick-bedded sandstone, these are mainly due to the difference of depositional environment, that is, flysch-type alternations are deposited in the more distal site, and on the contrary, thick-bedded sandstones in the more proximal one.

Most of gravels of conglomerates are considered to be transported in suspension and deposited by the flows combining two mechanisms of turbidity current and grain flow. Grain flow is resulted from dispersive pressure by clast collision under shear. That pressure plays a more important role than turbulence when a lot of large clasts exist in the flow, and forms the inversive grading of gravels in the lower part of conglomerate bed. The turbulence being an agency of turbidity current plays an important role to transport fine gravels, and forms the normal grading and stratification. Conglomerates are considered to be deposited in the more proximal environment. Conglomeratic mudstones such as pebbly mudstone and angular fragment-bearing mudstone were deposited by the mechanism of debris flow in the lower part of submarine slope, that is, in the most proximal site. Angular fragment-bearing mudstone is endolistostrome, and is considered to have been deposited from the breakdown of the geanticlinal upheaval within the basin.

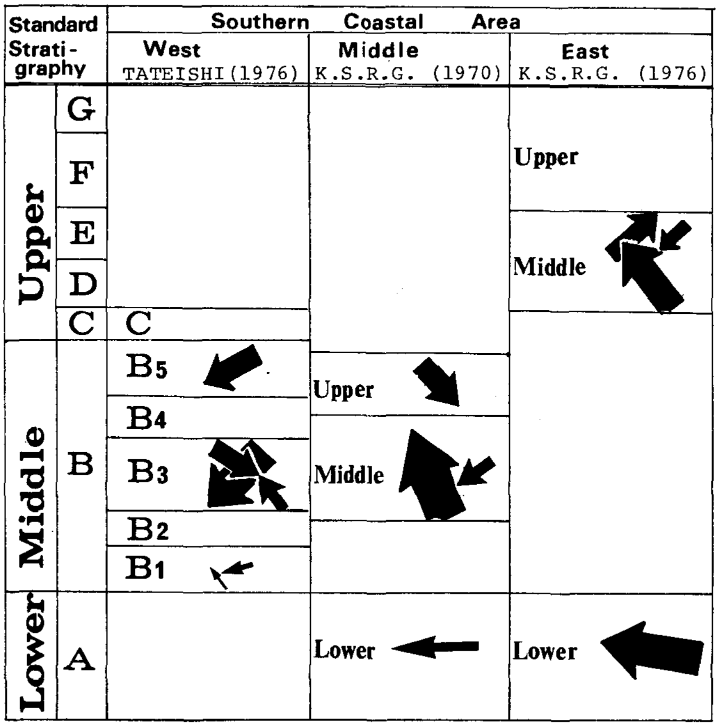
D. Paleocurrent analysis

Paleocurrent and channel direction play an important role to estimate the situation of provenance. In this section, the paleocurrents decided by directional sole marks and clast fabrics of conglomerate are examined.

Many kinds of directional sole marks can be found in the Muro group. Paleocurrent analysis of the Muro group was made by HARATA (1965) for the first time, and thereafter many data were obtained by KISHU SHIMANTO RESEARCH GROUP (1968, 1970, 1973, 1976) and the present writer (TATEISHI, 1976). These are summarized in Fig. 25, and the following conclusive results can be shown.

i. Lower formation: Eastern longitudinal currents predominant.

ii. Middle formation: Current systems vary in horizons. Eastern longitudinal and



K.S.R.G.: Kishu Shimanto Research Group

Fig. 25. Paleocurrent system of the Muro group at the coast area. The arrows represent the directions of currents. The upside in figure shows the north. The scale of arrow is proportionate to the measured numbers.

southern lateral currents are predominant in the lower and middle horizons, while in the upper, northern lateral currents become common, though several eastern longitudinal currents are found in the top.

iii. Upper formation: Southern lateral currents are predominant, and northeastern longitudinal ones are observed partially.

There are two types of clast fabrics in conglomerates of the Muro group, in which A-type indicates the direction of currents transported in suspension gravels. Paleocurrents deduced from clast fabrics of conglomerates are shown collectively in Fig. 26. The results are summarized as the followings.

i. Longitudinal currents from the northeast are observed in the B member, while in the B member, lateral currents from the north-northeast and south-southwest exist together.

ii. Lateral currents from the southeast are predominant in the D member.

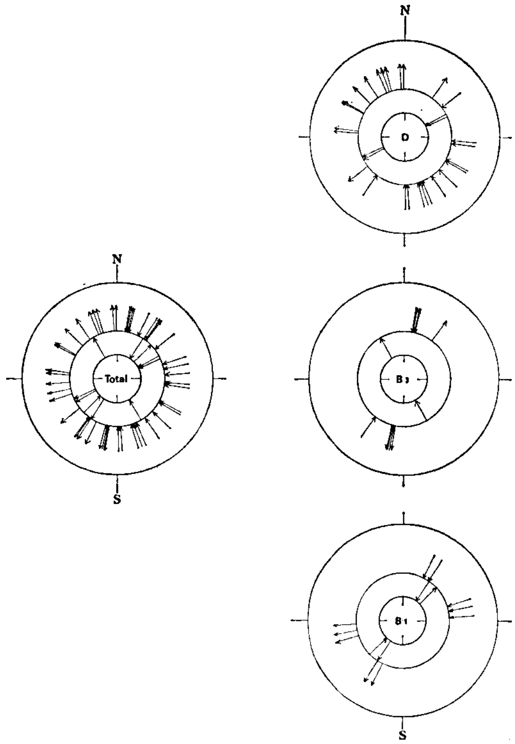


Fig. 26. Paleocurrent system deduced from clast fabrics of conglomerates. The arrows in outer circle show the direction of currents from A-type fabric, and the ones in inner circle the ones from B-type fabric.

It can be safely concluded from the above-mentioned paleocurrent analysis that the sediments were transported mainly by northeastern longitudinal and southern lateral currents. The southern lateral currents occurred for the first time in the middle formation, and became predominant in the upper formation.

E. Submarine fan sedimentation

Four large channels found in the D member along the coast area were examined in detail. Their localities, general trends and paleocurrent in filling sediments are collectively shown in Fig. 27. The channel at the east of Wabuka is correlated stratigraphically to the lower one at Yokoshima Island, both of which belong to the lower part of the D member. The other two channels belong to the upper part of the D member. Considering their stratigraphical relation, the distributary systems of channels as shown in the upper right of Fig. 27 are obtained.

The filling sediments in each channel show the thinning- and fining-upward sequence, of which typical example is shown in Fig. 19. Thinning- and fining-upward sequences are known from many channel filling sediments, and have been considered to result from vertical accretion (aggradation) upon gradual channel abandonment (MUTTI,

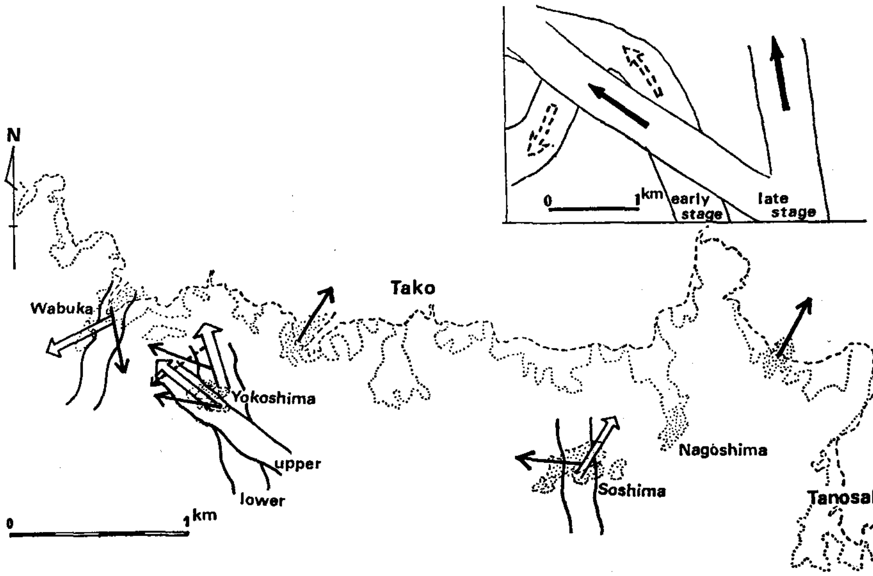


Fig. 27. General trends of channels, and paleocurrents deduced from sole marks (black arrows), ripple marks (dotted arrow) and clast fabric (white arrows). Dotted areas show the distribution of the D member. Illustration in the upper right show the distributary channel system inferred from considering of these channel's stratigraphy.

1974; RICCI LUCCHI, 1975; WALKER, 1975b). This interpretation is based on a comparison with recent submarine fans. In recent deep-sea fans, many channels in middle fan area are now abandoned due to shifting of the distributary systems along with rapid vertical accretion in the interchannel area (NORMARK, 1970). As shown in Fig. 27, the shifting of the distributary channel systems are considered to have taken place in the sedimentary basin of the Muro group. This shifting seems to cause the thinning- and fining-upward sequences in channel-fillings of the Muro group.

F. Paleogeographic reconstruction

KISHU SHIMANTO RESEARCH GROUP (1975) proposed the hypothesis that in addition to the northern provenance, the source land must have located to the south of the Shimanto geosyncline and is named *Kuroshio Paleoland*. This hypothesis was based on the paleocurrent analysis by sole marks and the occurence of orthoquartzite gravels. On the basis of petrographic studies on coarse sediments, the southern source land was presumed to be consisted of Precambrian sedimentary quartzite, various kinds of covering rocks such as sandstone, shale, chert, acid volcanic rocks, etc., and granitic plutonic rocks (KISHU SHIMANTO RESEARCH GROUP, 1975). The existence of the southern former-land can be confirmed strongly by paleocurrents deduced from clast fabrics of conglomerates

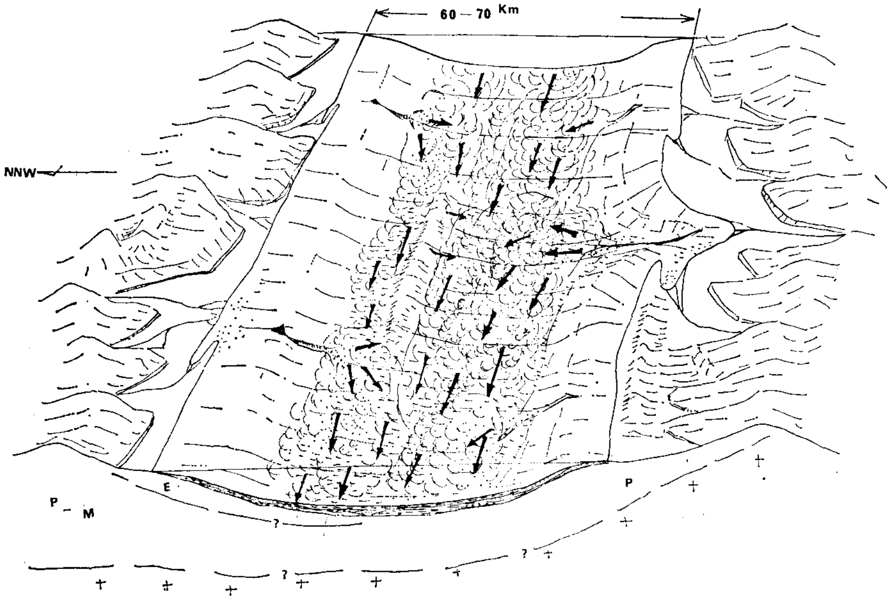


Fig. 28. Reconstructed illustration of the Shimanto geosyncline at the stage when the middle formation of the Muro group deposited (TATEISHI, 1976). The arrows represent the turbidity current or grain flow.

and the submarine fan-channel system reconstructed in the present paper.

The present writer (TATEISHI, 1976) reconstructed and illustrated the sedimentary basin at the stage when the middle formation of the Muro group deposited (Fig. 28). The important points of his reconstruction are: the sediments were transported and deposited mainly by turbidity currents and partially by grain flow; the provenances existed not only to the north, but also to the south of the basin; the lateral currents from the south deposited the proximal sequences; the normal bottom currents might have retransported and redeposited a part of sediments.

The basin at the stage of the D member of the upper formation is reconstructed as shown in Fig. 29. At this stage, the basin became shallower and narrower than that at the stage of the middle formation. Geanticlinal upheaval movement seems to have taken place, and yielded the differentiation of the basin. This is inferred by the facts that orthoquartzite gravels cannot be found northward beyond the Uchikoshi anticline, and that there are observed complicated paleocurrents in the basin (KISHU SHIMANTO RESEARCH GROUP, 1975). The marginal part of the basin at the stage of the middle formation was upheaved and changed partially into the shelf. At the stage of the F and G members the Muro group was exposed partially by a certain fault movement, and supplied angular fragments to the basin. The upheaval movement grew intense, and the Precambrian

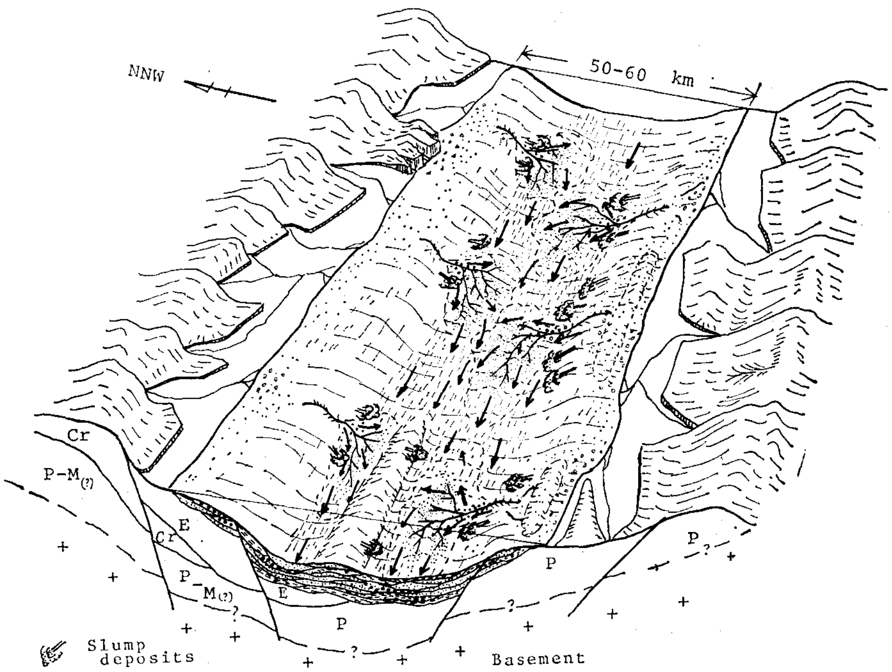


Fig. 29. Reconstructed illustration of the Shimanto geosyncline at the stage of the D member of the Muro group. The arrows represent the turbidity current or grain flow.

basement containing orthoquartzite sandstones was exposed extensively in the southern provenance. This is suggested from the increase of orthoquartzite gravels in the upper formation (KISHU SHIMANTO RESEARCH GROUP, 1976). Coarse clastics such as gravels and coarse sands were supplied abundantly and were deposited at marginal part of the basin. Several submarine fans were developed at the margin of the basin, and distributary channel systems were formed on these fans. Conglomerates, conglomeratic mudstones and thick-bedded sandstones were deposited there as proximal sequences by southern lateral currents, which are inferred apparently by sole marks and clast fabrics of conglomerates. These sediments were deposited mainly by turbidity currents, and partially by grain flows or debris flows. The distal sediments such as a part of sandy flysch, muddy flysch and mudstone were deposited on outer fan or on basin plain. These were transported and deposited mainly by turbidity currents from the east and from the southeast.

VI. Summary and Conclusion

The sedimentary structures of conglomeratic rocks, thick-bedded sandstone and flysch-type alternation were described, and the sedimentary processes of these sediments were discussed. Furthermore, channel-scours and -fills observed in the upper formation were examined. On the basis of sedimentological data, the sedimentary environment of the Muro group was reconstructed. The results are summarized as the followings.

1. Three descriptive sedimentary models of the conglomerates, which were proposed by WALKER (1975b) are also recognized in the Muro group; namely, i. inverse-to-nomal grading model, ii. graded-stratified model, iii. disorganized model. Two types of clast fabrics are distiguished; Type A - long axis of clasts arranged parallel to current direction, Type B - long axis arranged transverse to current direction. Most of conglomerates of the Muro group show the Type-A fabric. Paleocurrent directions deduced from clast fabrics showing Type-A coincide well with paleocurrent directions indicated by sole marks.

2. Conglomeratic mudstones such as pebbly mudstone and angular fragment-bearing mudstone consist of predominant dark-grey mudstone and scattered clasts in the matrix. These rocks are massive and structureless, and clasts are scattered randomly within matrix mudstone. Angular fragment-bearing mudstone is an endolistostrome.

3. There are three sedimentary types of thick-bedded sandstones; i. composite bed ii. structureless bed with parallel lamination at the top, iii. laminated bed. There are abundant sandstones showing intermediate type between the latter two. Paleocurrent directions deduced from grain fabrics show an excellent coincidence with sole marks trends.

Most of flysch-type beds show the succession of internal sedimentary structures similar to the Bouma's sequence (BOUMA, 1962).

4. Most of the sediments excepting conglomeratic mudstones are concluded to be transported and deposited mainly by turbidity current and partially by grain flow. In the real flow, the relation between turbidity current and grain flow is transitional. The grain flow may have played an important role for emplacement of conglomerate composed of large clasts. Conglomeratic mudstones are concluded to be deposited by debris flow.

5. Large channels are observed in the upper formation. These channels show nearly N-S trend in general, and the filling sediments were transported from the south. These channels are referred to constitute a distributary system. The filling sediments show the thinning- and fining-upward sequences, suggesting progressive abandonment of channels due to shifting of the distributary system.

6. The Muro group is composed of miogeosynclinal sediments of 3,500 m in thickness, and contains abundantly proximal sediments such as conglomeratic rocks and thick-bedded sandstone. The Muro group make the coarsening- and thickening-upward sequence as a whole. The sedimentary basin of the Muro group was filled up progressively, and became shallower.

7. The hypothesis that the provenance existed to the south of the Shimanto geosyncline in addition to the north, which proposed by the KISHU SHIMANTO RESEARCH GROUP

(1975), was supported by paleocurrents deduced from clast fabrics of conglomerates and the occurrence of channel structures. Especially, the supplies from the southern source land became remarkable at the stage when the upper formation deposited.

8. Reconstruction of sedimentary environment at the stage when the upper formation deposited was attempted and illustrated (Fig. 29). At the latest stage of the Shimanto geosyncline, the sedimentary basin was filled up by sediments that were supplied by intensive and intermittent upheaval of provenance, and dissapeared in the Early Miocene.

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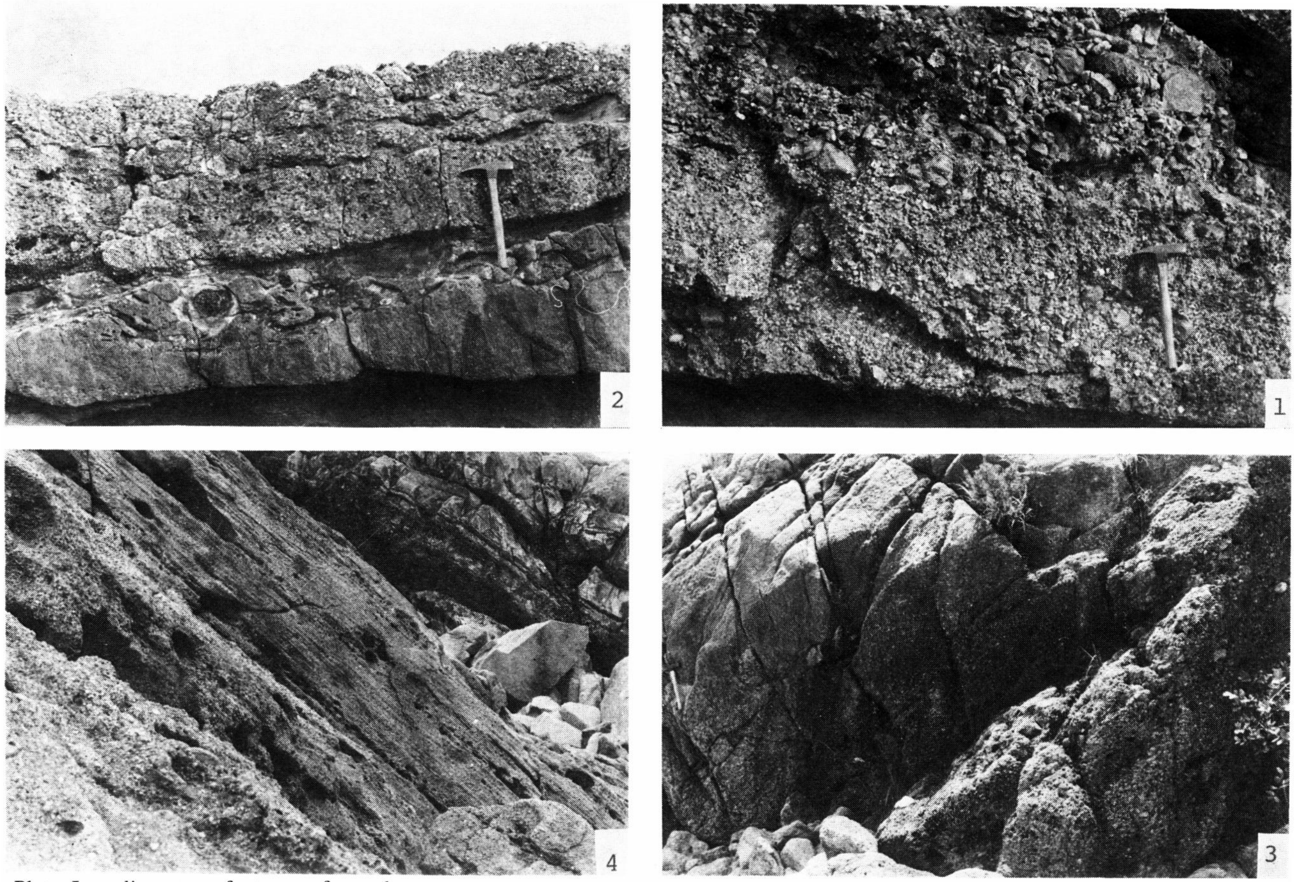


Plate I sedimentary features of conglomerates

1: Inverse-graded conglomerate, of which basal part is composed of coarse pebble-sized gravels, and upper part is cobble-sized. This is stratigraphically the lowest bed at Azashi-W (loc. 18) (see Fig. 5).

2: Fine pebble conglomerate with cobble-sized calcareous mudstone clasts. It shows a crude stratification formed by arrangement of mudstone clast (Azashi, the east of loc. 18).

3: Conglomerate graded from coarse pebble-sized to medium sandstone (Shirashima tunnel-E, loc. 11).

4: Normal-graded conglomerate (lower left) and stratified conglomerate (middle). The latter is 5 m thick, and is composed of laminations of fine pebble-sized gravels and granule-sized gravels (shirashima tunnel-W, loc. 10) (see Fig. 5).

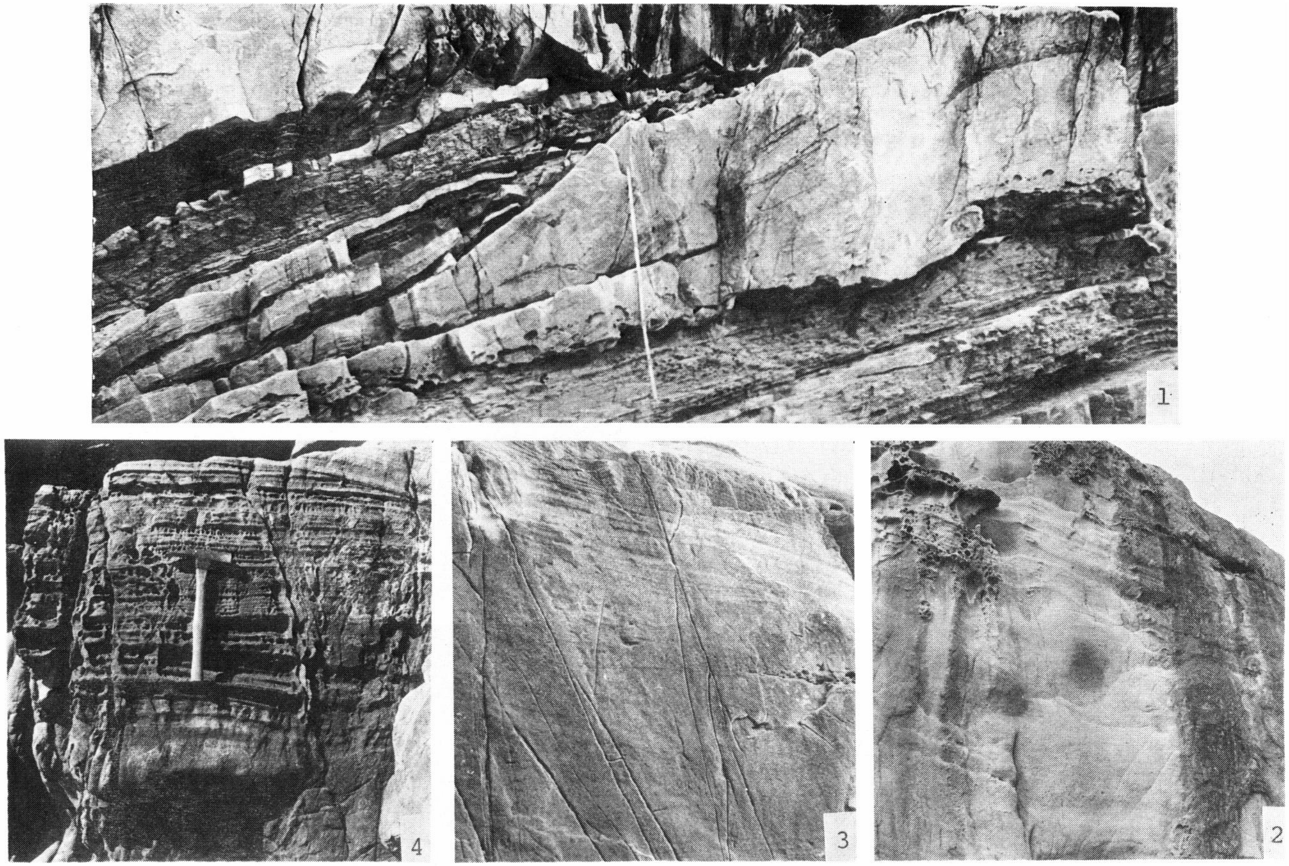


Plate II Sedimentary features of thick-bedded sandstones

1: Composite bed formed by amalgamation, a sketch of which is shown Fig. 14 (Wabuka-W, loc. 16).

2: Structureless bed partially with parallel lamination. It is about 8 m thick (Inazumijima, loc. 7).

3: Thick-bedded sandstone in which structureless division of parallel lamination is observed at the upper part. It is about 4 m thick (Kuchiwabuka, loc. 12).

4: Laminated bed of 90 cm thick. Its lowest part is massive (Esuzaki, loc. 14).

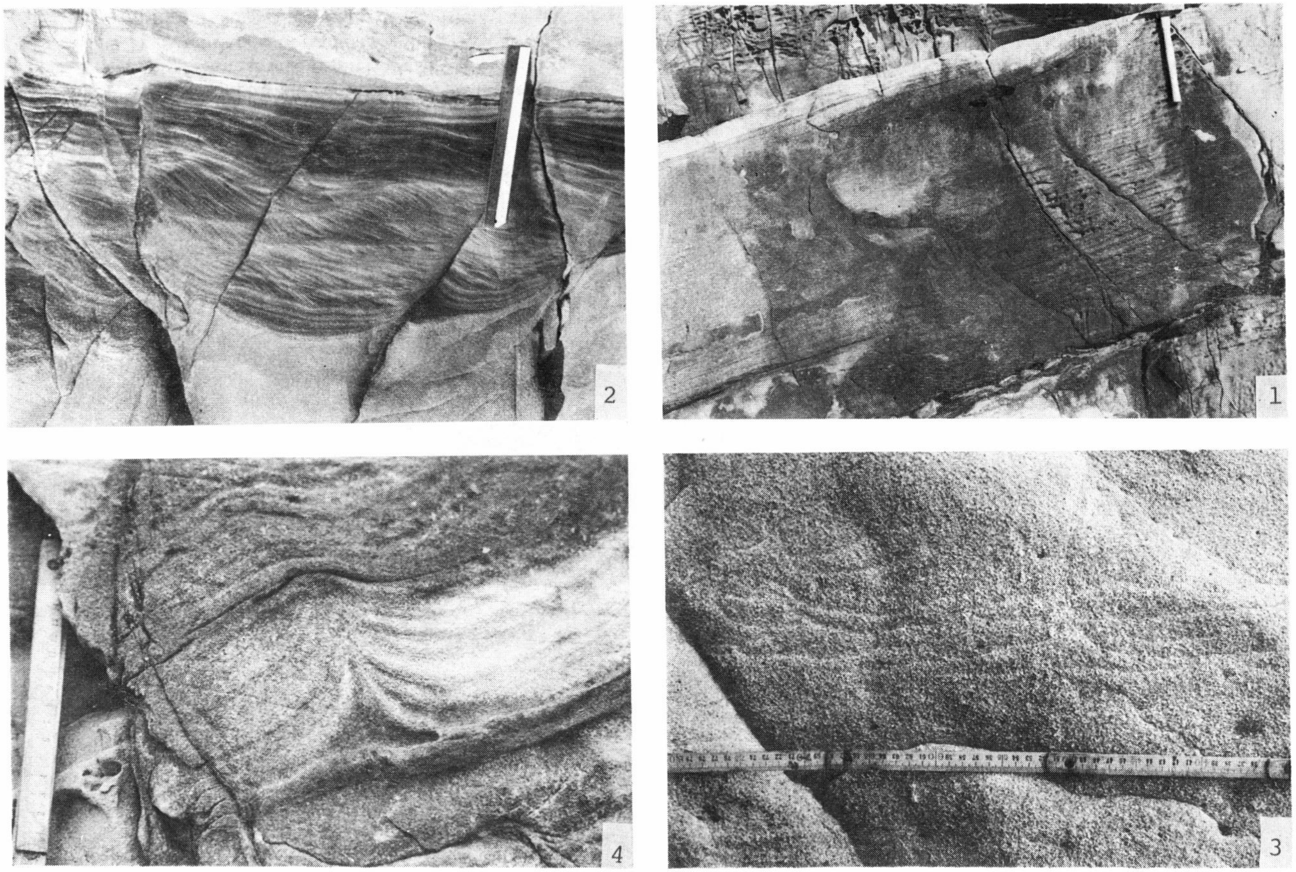


Plate III Internal sedimentary structures of thick-bedded sandstones

1: Trough-type cross lamination developed at the top of laminated thick-bedded sandstone (Natachi, loc. 2).

2: Ripple-drift cross lamination developed at the middle part of thick-bedded sandstone (Esuzaki, loc. 14).

3: Dish structure developed with in massive part of thick-bedded sandstone (Shirashima tunnel-W. loc. 10) (see Fig. 12).

4: Pillar structure developed within laminated part of amalgamated bed (Kodomari-W, loc. 3) (see Fig. 12).

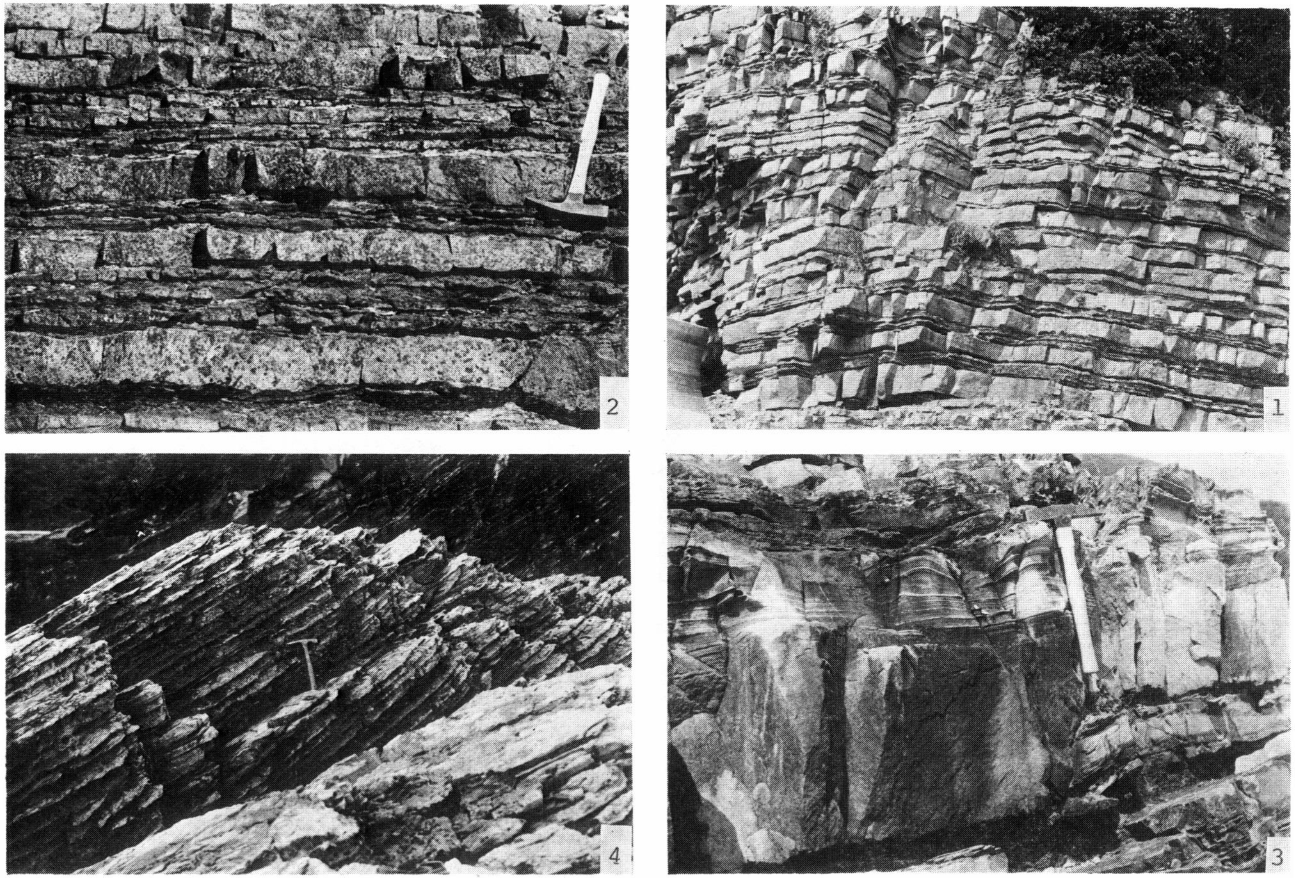


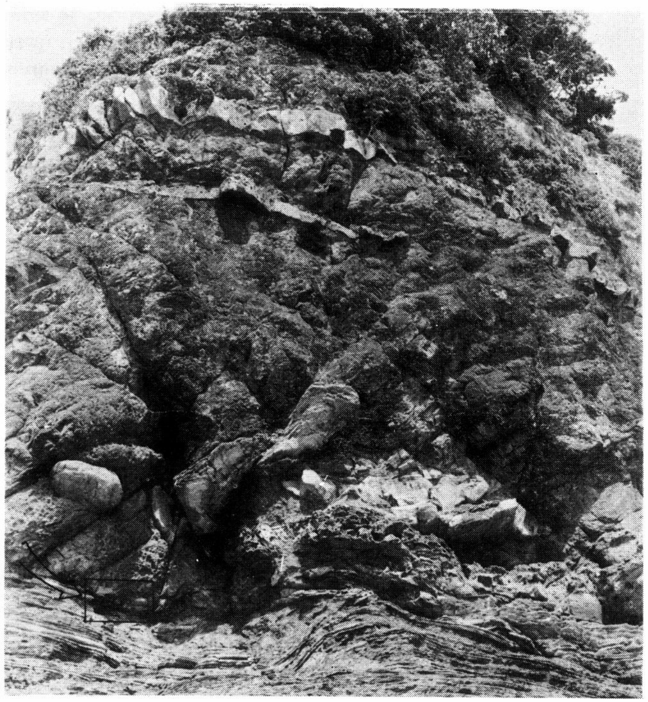
Plate IV Flysch-type alternation

1: Sandy flysch; alternation of sandstones (7 to 50 cm thick) and mudstones (2 to 5 cm thick) (Wabuka-W, loc. 16).

2: Normal flysch; alternation of sandstones (usually 3 to 5 cm thick, often 20 cm thick) and mudstones (3 to 5 cm thick) (shirashima tunnel-W, loc. 10).

3: Ta-e sequence of sandstone bed 45 cm thick (Wabuka-W, loc. 16).

4: Muddy flysch; alternation of sandstones or siltstones (2 to 3 cm thick) and mudstones (3 to 5 cm thick) (Kuchiwabuka-S, the south of loc. 12).



1

Plate V Channel structures and filling sediments at Wabuka-E (loc. 17)

1: Channel-base and filling sediments. Filling sediments are composed of pebbly mudstones of about 10 m thick, in which two sandstone layers are involved in lens shape and large blocks of sandstone and conglomerate are contained. The quadranglar part is magnified into Plate V-2.

2: Basal part of channel structure magnified the quadranglar part of Plate V-1. Gravels are concentrated into the basal part of filling sediments.

3: Conglomerate bed underlying the channel structure (right) and the pebbly mudstone (left) near Point 160 (see Fig. 18). A lot of pseudo-clasts of calcareous mudstone is contained in the upper part of conglomerate bed, of which bedding plane is irregular and indistinct.

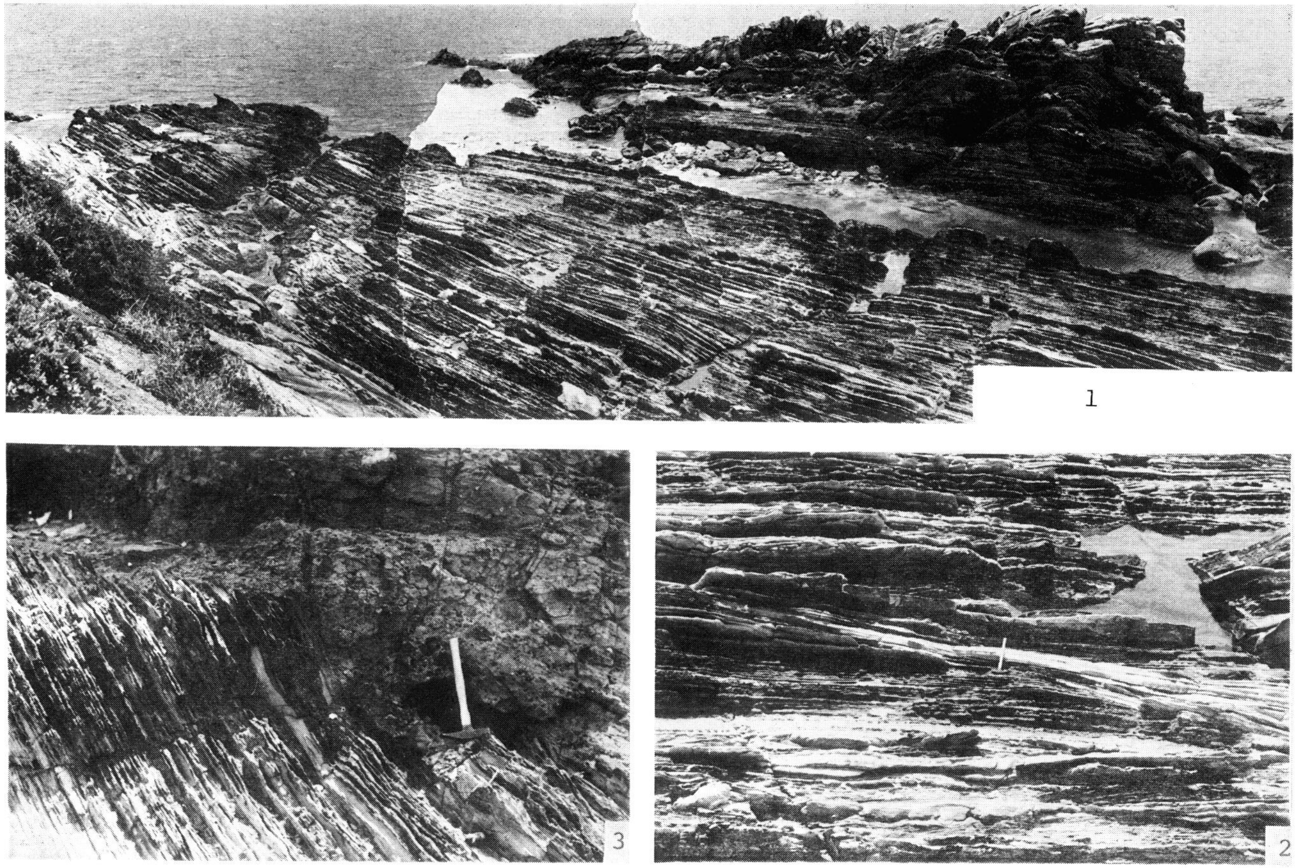


Plate VI Channel structure and channel filling sediments at Yokoshima Island (loc. 19)

1: Sandy to muddy flysch sequences filled the lower channel (lower) and the upper channel structure (upper right).

2: Minor scour and fill observed within the filling sediments of the lower channel.

3: Channel base of the lower channel. The sequences underlying the base (lower) is consist of muddy flysch, and filling sediments (upper) is pebbly mudstone.