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CHANNEL-FILL CONGLOMERATES IN THE MIDDLE MIOCENE KOTAMBETSU FORMATION, NORTHERN HOKKAIDO, JAPAN

by

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(with 12 text-figures, 1 table and 2 plates)

Abstract

The Middle Miocene Kotambetsu Formation consisting of turbidite and related coarse clastic sediments, attains to 2,000 meters in thickness. Conglomerates in this formation are channel-fill deposits with normal or inverse type graded-bedding and clast fabrics. The clast fabrics are characterized by inclining orientation of the long axes to the bedding plane. Analysis of the sedimentary structures suggests that the coarse clastic sediments of the Kotambetsu Formation were transported by the sediment gravity flows of turbidity currents.

Introduction

Turbidity currents transport coarse clastics into marine basins and accumulate graded-bedding deposits called turbidites. The turbidites in a narrow sense are made up of alternating beds of sandstone and mudstone with Bouma sequence (Bouma, 1962), which are called "classical turbidites" by Walker (1979). The "classical turbidites" are accompanied with massive sandstones, pebbly sandstones and conglomerates. This assemblage is called "turbidites and associated coarse clastic deposits" (Walker, 1979) which are considered to have been transported by sediment gravity flows (Middleton & Hampton, 1973).

Resedimented conglomerates of the "turbidites and coarse clastic deposits" were described by Walker & Mutti (1973), Hendry (1973, 1976) and Walker (1975a). From the sedimentary structures, the depositional environment (Walker, 1975b, 1979; Winn & Dott, 1979) and transporting mechanism of clasts (Davies & Walker, 1974; Walker, 1977) were discussed. Tateishi (1978) analyzed the turbidite of the Paleogene Muro Group in the Kii Peninsula and discussed the transportation and depositional processes of the conglomerate. Soh (1985) revealed the sedimentation process of channel-fill conglomerate of the Fujikawa Group in the southern Fossa Magna region situated at the junction of Southwest Japan and Izu-Bonin arcs. Many sedimentological studies in Japan are mainly concerned with the interpretation of the depositional environments and its related tectonics. Recently, it has been discussed that the studies of sedimentary facies and structures play an important role in sedimentary basin analysis and its tectonics.

Middle Miocene thick marine sediments are widely distributed running from north to south in the central Hokkaido. They are composed mostly of shallow marine facies or turbidite facies sediments (Hoyanagi et al., 1986). The sedimentological study of

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these Miocene clastics is very important to consider Cenozoic tectonics in Hokkaido. The Kotambetsu Formation of turbidite sediments distributed in northern part of the central Hokkaido has already been studied from the view point of environmental analysis (Hoyanagi & Ohkami, 1986). The conglomerates of the Kotambetsu Formation were described as the resedimented facies (Okada & Tandon, 1984). In this paper the writer describes the channel-fill conglomerates of the Kotambetsu Formation and further discusses their transportation mechanism and also the sedimentary environment where they were deposited.

Geologic setting

The central Hokkaido is situated at the junction of the Kurile and Northeast Japan arcs. The Miocene sedimentary basin of the central Hokkaido is divided into the four geological provinces from the distribution pattern of shallow marine and turbidite facies sediments (Text-fig. 1A); Rebun-Kabato, Ishikari-Teshio, Esashi-Hidaka and Mombetsu-Tokachi from west to east (Hoyanagi et al., 1986).

The several sedimentary basins in the Ishikari-Teshio Belt abruptly changed from shallow marine to turbidite facies sediments in the Middle Miocene. Thickness of the turbidites attains up to several thousand meters. These turbidite basins of trough-like shape extend about 400 kilometres from north to south in the central Hokkaido. Clastic materials were derived mainly from the eastern uplifting area situated in the northern part of the Esashi-Hidaka Belt. The upheaval of the Esashi-Hidaka Belt and subsidence of the Ishikari-Teshio Belt were resulted from the collision of the North American Plate with the Eurasian Plate (Hoyanagi et al., 1986; Kimura & Miyashita, 1986).

Outline of geology and stratigraphy

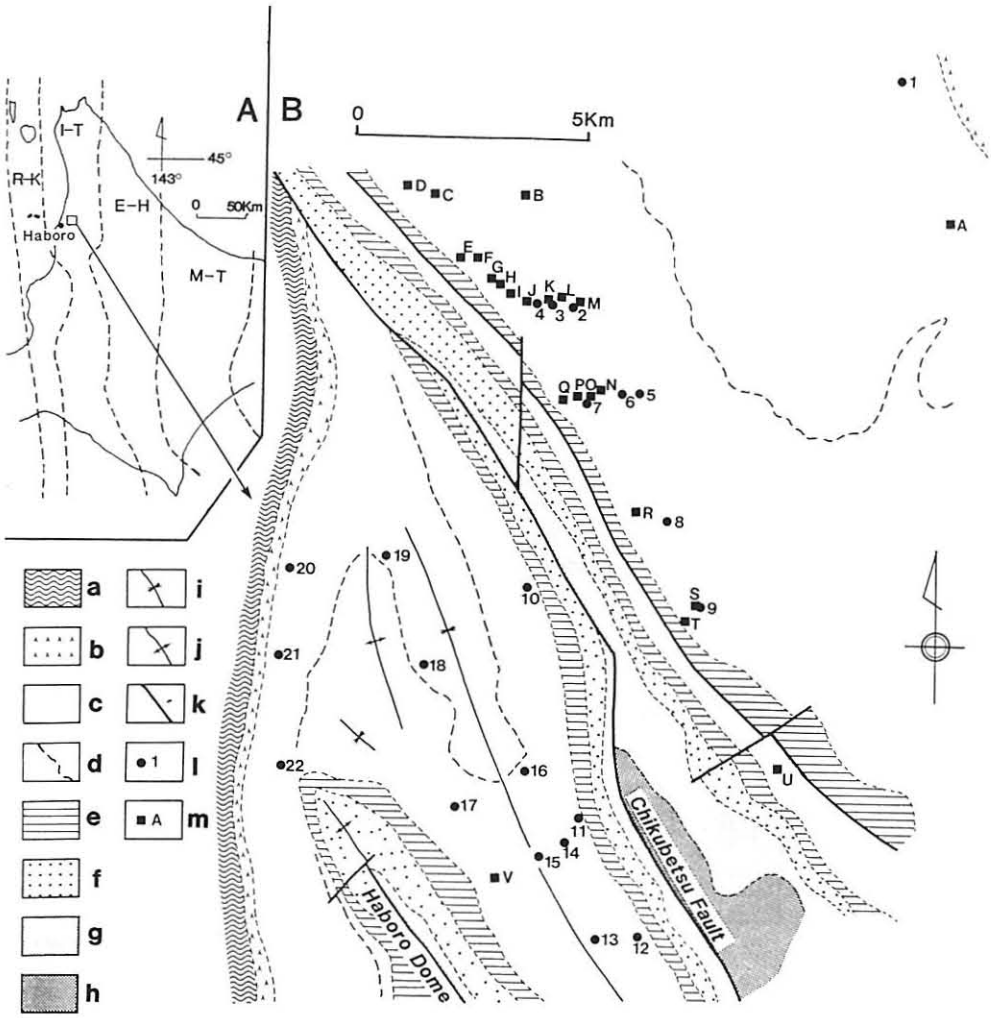
The Haboro area is situated in the northern part of the Ishikari-Teshio Belt (Text-fig. 1). The Miocene to Pliocene strata in the area are divided into the following six formations in ascending order; the Haboro, Sankebetsu, Chikubetsu, Kotambetsu, Chepotsunai and Embetsu Formations (Matsuno & Kino, 1960; Yamaguchi & Matsuno, 1963) (Text-fig. 2). These five formations except for the Kotambetsu were formed under a shallow-marine or non-marine condition.

The marine Kotambetsu Formation attains a maximum thickness of more than 2,000 meters. Examination of coarse clastic sediments indicates that they were transported from the northern part of the Esashi-Hidaka Belt in the east (Takahashi, 1974; Hoyanagi & Ohkami, 1986). The sedimentary basin of the Kotambetsu Formation is considered to have been situated on the westward dipping slope formed by the rapid upheaval of the Esashi-Hidaka Belt during Miocene time (Hoyanagi & Ohkami, 1986).

Description of the conglomerates

Facies and sequence

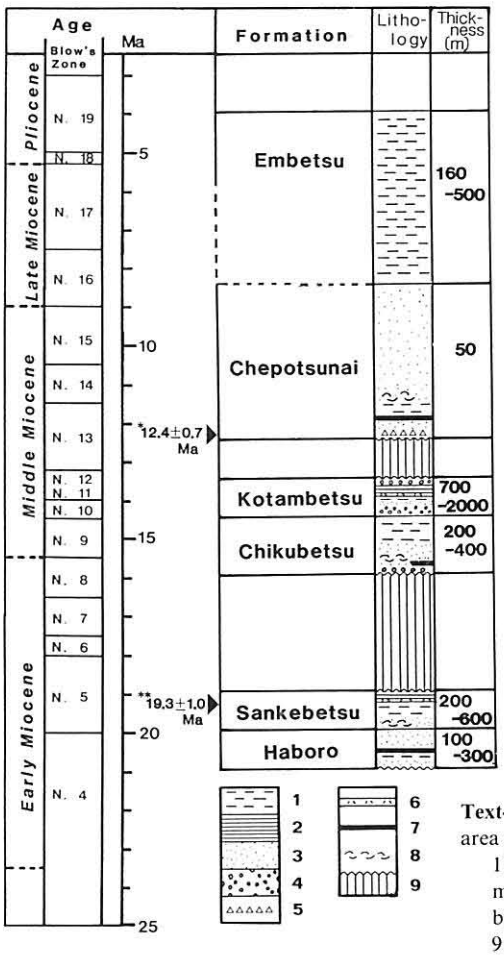
Facies: The Kotambetsu Formation consists of turbidite and related coarse clastic



Text-fig. 1 A; Geotectonic division of central Hokkaido in the Miocene (after Hoyanagi et al., 1986). R-K: Rebun-Kabato Belt, I-T: Ishikari-Teshio Belt, E-H: Esashi-Hidaka Belt, M-T: Mombetsu-Tokachi Belt.

B; Geological map and locality index (geological map simplified from Hoyanagi & Ohkami, 1986). a: Embetsu Formation, b: Chepotsunai Formation, c: Kotambetsu Formation, d: Kotambetsu Formation (tuff), e: Chikubetsu Formatiion, f: Sankebetsu Formation, g: Haboro Formation, h: Cretaceous, i: syncline, j: anticline, k: fault, l: locality where clast size and roundness measured, m: locality where clast fabric measured.

rocks of the following facies; conglomerate, pebbly sandstone, sandstone, turbidite (alternating beds of sandstone and mudstone), mudstone, slump and pebbly mudstone facies. Two types of facies associations are indentified as follows; one is *Coarse clastic beds* defined as the association of conglomerate, pebbly sandstone and sandstone in



Text-fig. 2 Stratigraphic succession of the Haboro area (after Hoyanagi & Ohkami, 1986).
1: mudstone, 2: alternating beds of sandstone and mudstone, 3: sandstone, 4: conglomerate, 5: volcanic breccia, 6: tuff, 7: coal bed, 8: molluscan fossils, 9: hiatus, *: Shibata & Tanai (1982), **: Hoyanagi & Matsui (1985).

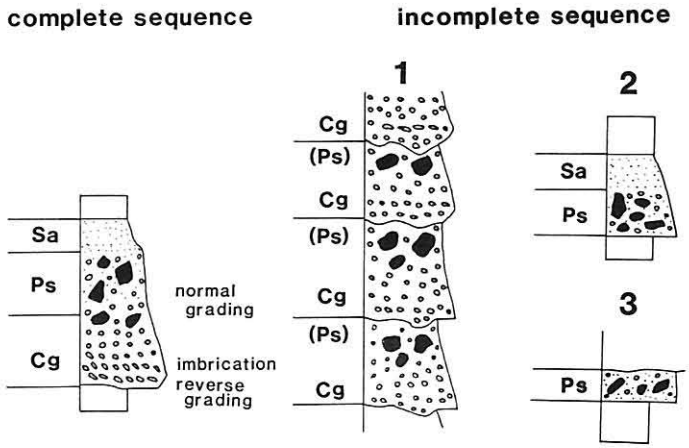
ascending order (Hoyanagi & Ohkami, 1986), and the other is the association of turbidite and mudstone facies. The former and the latter associations are considered to be channel-fill and inter-channel deposits, respectively (Hoyanagi & Ohkami, 1986).

Sequence of the coarse clastic bed: The coarse clastic beds with grading structure attain up to 70 meters in a maximum thickness. These beds are classified into the complete sequence and incomplete sequence types. The latter is subdivided into the following three types; truncate, base cut-out and truncate base cut-out types (Hoyanagi & Ohkami, 1986) (Text-fig. 3).

The feature of the complete sequence type is as follows (Plate 1);

(1) The bottom of the bed shows an erosional or non-erosional planar surface.

(2) The lower part of the bed generally consists of pebbles and/or cobbles and grades upward into sandstone.



Text-fig. 3 Types of the sequence of *coarse clastic bed* (after Hoyanagi & Ohkami, 1986).
Cg: conglomerate, Ps: pebbly sandstone, Sa: sandstone, Tu: thin bedded turbidite, Mu: mudstone, ( ); rare, 1: incomplete sequence truncate type, 2: incomplete sequence base cut-out type, 3: incomplete sequence truncate base cut-out type.

(3) In the lower part the reverse grading and clast fabric are frequently observed.
(4) The middle part of the bed includes blocks (rip-up clasts) of mudstone, sandstone and alternating beds of them derived from the Kotambetsu Formation. These blocks range from ten centimeters up to several meters in diameter.
(5) The upper part of the beds consists mainly of sandstone which grades upward into mudstone.

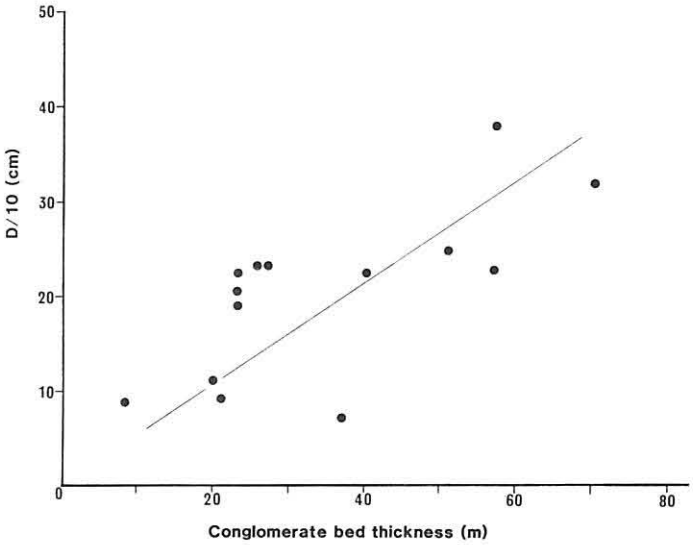
In the incomplete sequence the truncate type lacks sandstone facies with an erosional surface at the top of the bed. The base cut-out type lacks conglomerate facies with a non-erosional planar surface at the bottom of the bed, and the truncate base cut-out type is composed of only pebbly sandstone facies with a planar surface at the bottom of the bed and with an erosional or planar surface at the top.

Bed thickness and clast size

The complete sequence type and truncate type beds consist of conglomerate in the lower part. Text-fig. 4 shows the relationship between clast size and bed thickness of the complete sequence type bed. The clast size (D/10) is represented by the mean value of long axis of the 10 largest clasts selected in one bed. Clast size (D/10) has a high correlation with the bed thickness.

Feature of gravels

Diameter: Text-fig. 5 shows the mean diameter of one hundred gravels collected from the one square meter outcrop at each locality. The mean values for 22 localities



Text-fig. 4 Graph of coarse clastic bed thickness versus mean of the ten largest clasts (D/10).

(Text-fig. 1) range from 3.0 to 4.0 centimeters.

Roundness: Text-fig. 5 indicates roundness grade of gravels at the 22 localities shown in Text-fig. 1. Subangular and subrounded gravels are dominant in all localities without any exception.

Internal sedimentary structures

Grading structure: There are five types of grading structure within a coarse clastic bed as follows, though it shows normal grading as a whole; inverse grading to massive (non-grading), inverse to normal grading, massive to normal grading, normal grading, and massive (Text-fig. 6). Text-fig. 6 represents the frequency of the five types of grading structures based on clast size. Normal grading can be found frequently in pebble-size parts.

Clast fabric: Fabrics of conglomerate are represented by clast orientation and

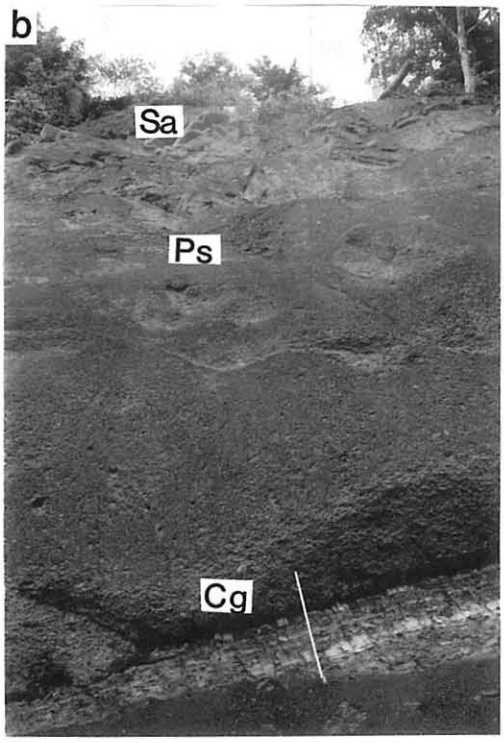
Explanation of Plate 1.

a : Basal part of a coarse clastic bed. Clast fabric, inverse grading and normal grading are observed. Scale is 1 m.

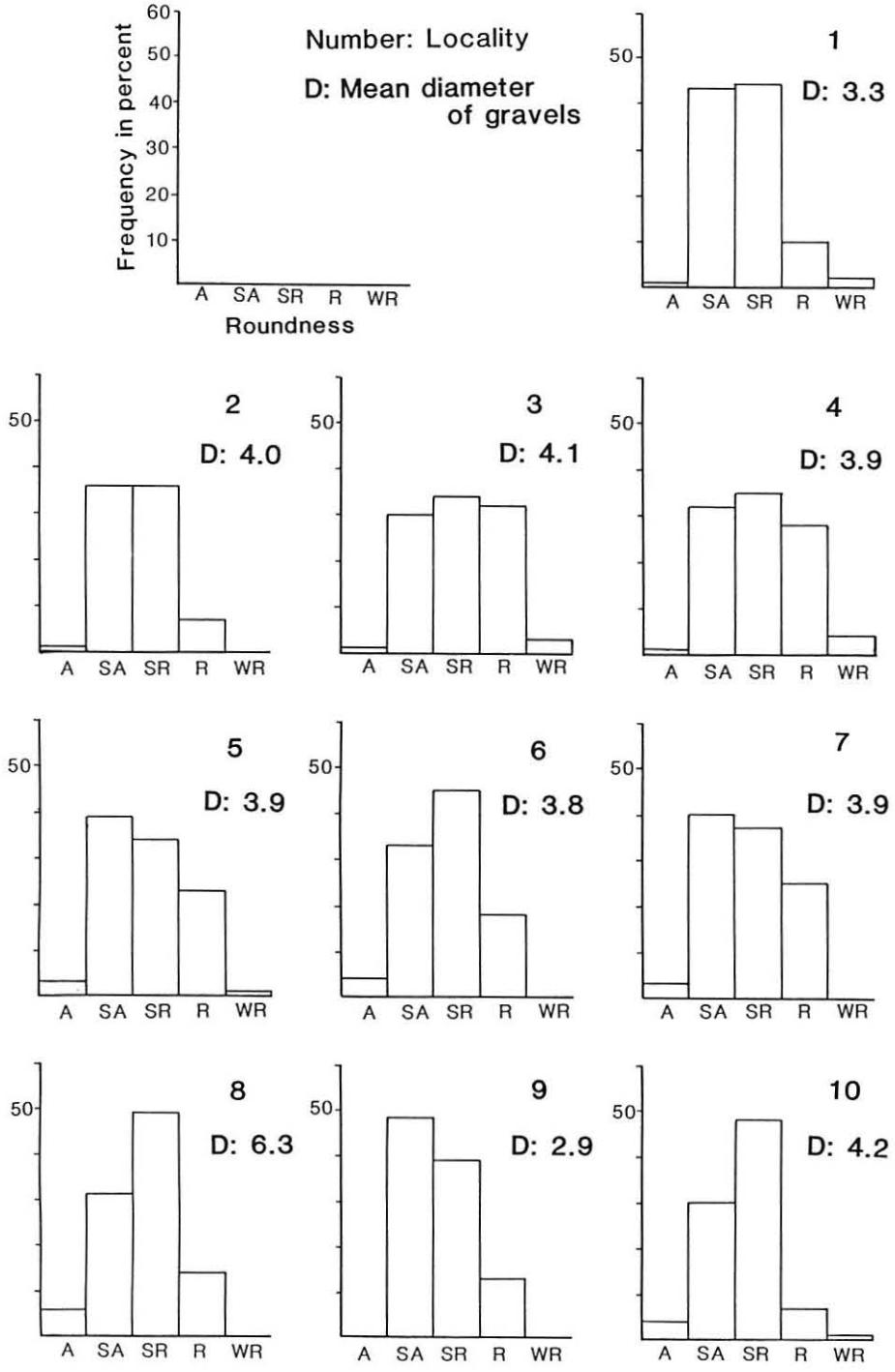
b : Sequence of a coarse clastic bed. Conglomerate facies (Cg) grades upward into snadstone facies (Sa) through pebbly sandstone facies (Ps). Scale is 1 m.

c : Middle part of a coarse clastic bed. Pebbly sandstone facies with rip-up clast of alternating beds of sandstone and mudstone. Scale is 1 m.

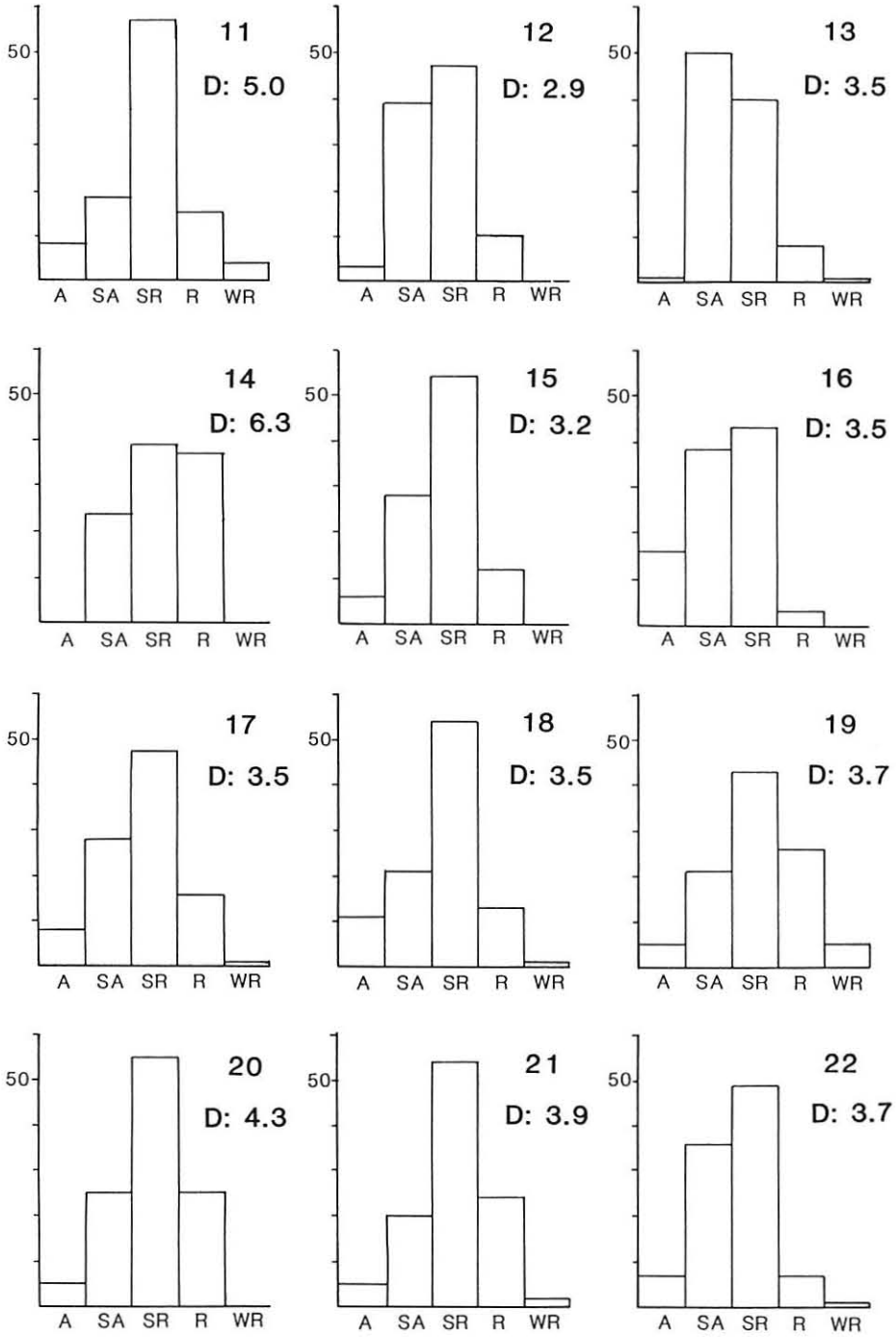

a


b
Sa
Ps
Cg


c



Text-fig. 5 Mean diameter of gravels (cm) and the frequency distribution of roundness grades. A: angular, SA: subangular, SR: subrounded, R: rounded, WR: well rounded.


11
D: 5.0
12
D: 2.9
13
D: 3.5
14
D: 6.3
15
D: 3.2
16
D: 3.5
17
D: 3.5
18
D: 3.5
19
D: 3.7
20
D: 4.3
21
D: 3.9
22
D: 3.7
50
A SA SR R WR

Grading \ Size	B-C	C	C-P	F-P
Massive / Inverse	1		1	
Normal / Inverse	2		2	2
Normal / Massive	2	2	1	
Normal		1	8	26
Massive		3		4

Text-fig. 6 Five types of grading with their frequency in each clast size.
B-C: boulder-cobble, cobble (6.5-25 cm), but boulder (25 cm-) scattered, C: cobble (6.5-25 cm), C-P: coarse pebble (1.5-6.5 cm), F-P: fine pebble (0.4-1.5 cm)

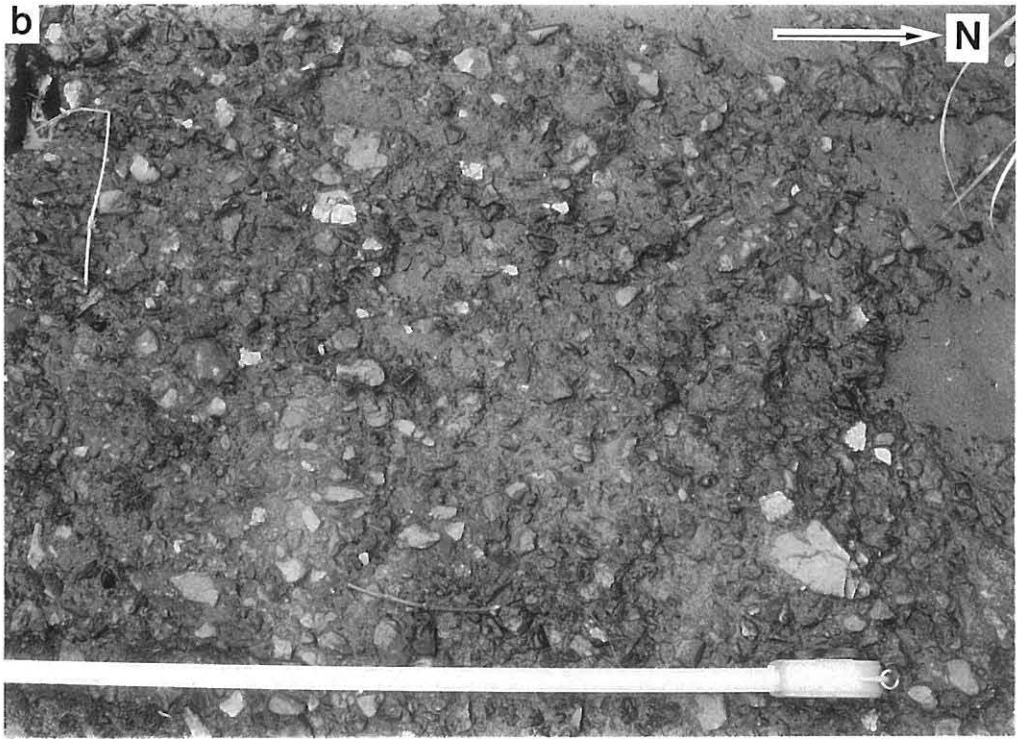
clast imbrication. Clast orientation means a preferred direction of the long axis on the bedding plane, while clast imbrication means an inclination of clasts to the bedding plane. All the clast fabrics in the Kotambetsu Formation are considered to be primary, since the secondary fabrics caused by later tectonic deformation are not apparent.

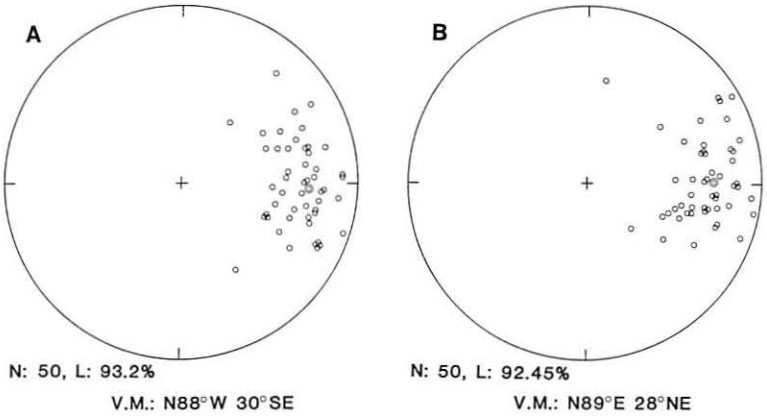
The clast fabrics observed in the lowest part of the coarse clastic bed of the Kotambetsu Formation are characterized by the well-oriented long axes inclined to the bedding plane (Plate 2). Clasts greater than 1.5 in a ratio of long to short axes were selected to examine the fabrics of conglomerate. Fifty clasts were measured at the localities A and B, respectively (Text-fig. 1). The long axis directions and inclinations of clasts are shown in a Schmidt net at each locality, after bedding correction to the initial horizontal position (Text-fig. 7). Rose diagrams in Text-fig. 8 also show orientations and imbrications at the same localities. Preferred orientations show an east to west direction. The preferred imbrications dip eastward with 30 degrees in a mean vector angle.

Strikes and dips of ab-plane (plane of long axis and medium axis) were measured in the same fabrics where the direction and inclination studies had been already done. These two sets of the measurements are plotted in a Schmidt net (Text-fig. 9). The poles of ab-plane sit at 90 degrees from the direction and inclination of long axis. The strike and dip of ab-plane were measured to obtain the direction and inclination of the

Explanation of Plate 2.
a : Clast imbrication observed on the outcrop surface vertical to the bedding plane.
b : Bedding-plane view of clast orientation.


a
parallel to bedding plane


b
N

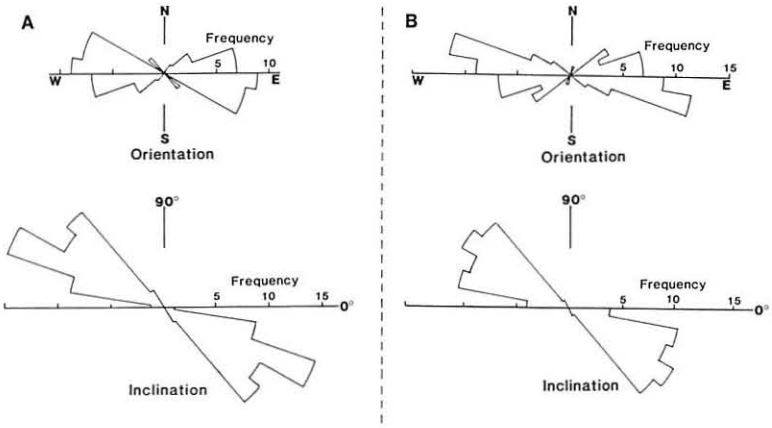


Text-fig. 7 Schmidt net (lower hemisphere) plots for clast long axes.
open circle: orientation and inclination of long axis. double circle: vector mean of long axes, A,B: localities, in Text-fig. 1, N: measured numbers, L: consistency ratio, V.M.: vector mean.

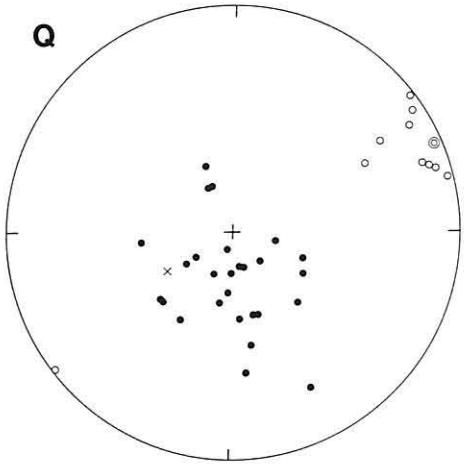
fabrics because of the difficulty to obtain the latter set of data in consolidated conglomerates as in the Kotambetsu Formation. The pole position of ab-plane is shown in a Schmidt net, after the bedding correction around the strike (Text-fig. 10). Ten to fifty measurements of ab-plane were carried out at 19 localities shown in Text-fig. 1.

Reconstruction of paleocurrent from clast fabrics

Text-fig. 11 shows that the long axes of clasts are parallel to the flow direction de-



Text-fig. 8 Rose diagram for the orientation and inclintion of clast long axes.
A,B: localities in Text-fig. 1



Text-fig. 9 Schmidt net (lower hemisphere) plots for clast long axes and ab-plane poles.
open circle: clast long axis, double circle: vector mean of long axes, solid circle: pole of ab-plane, cross: vector mean of poles, Q: locality in Text-fig. 1.

termined from solemarkings. These long axes or ab-planes dip eastward, of which direction is upstream side of paleocurrent. This relationship has been already suggested in the resedimented conglomerate by Walker (1979).

Therefore, flow directions are determined from the clast fabrics shown in Text-figs. 7, 9 and 10, except for data of Loc. G, L and V, which show a low angle imbrication in the former and low consistency ratios in the latter two (Table 1). Text-fig. 12 summarizes both the clast fabrics and solemarkings with the general trend of paleocurrent direction in this area. This direction is generally from east to west in the east of the Chikubetsu Fault, while solemarkings suggest the direction from north to sourth in the west.

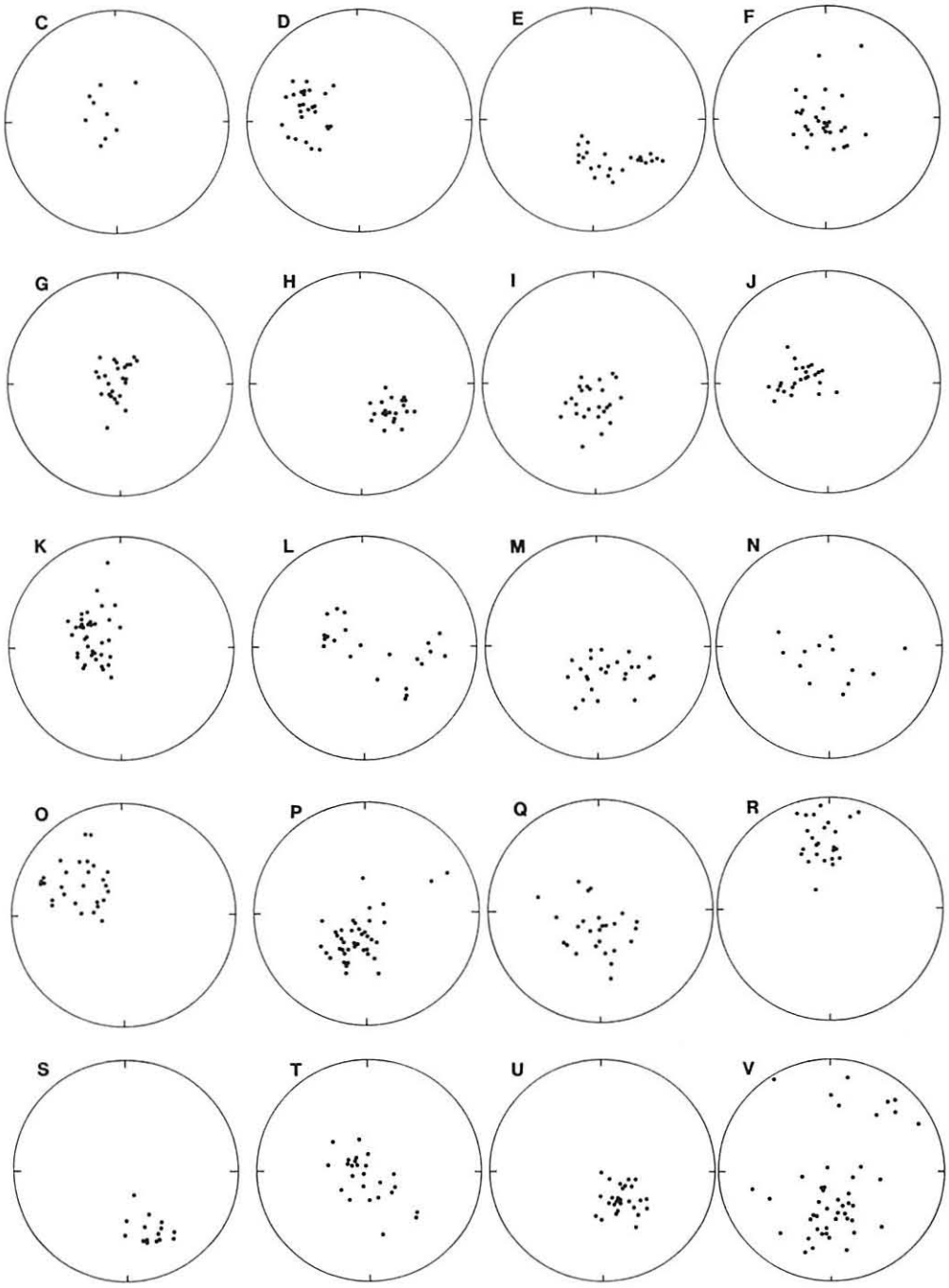
Discussion

Transportation and deposition of the coarse clastic bed

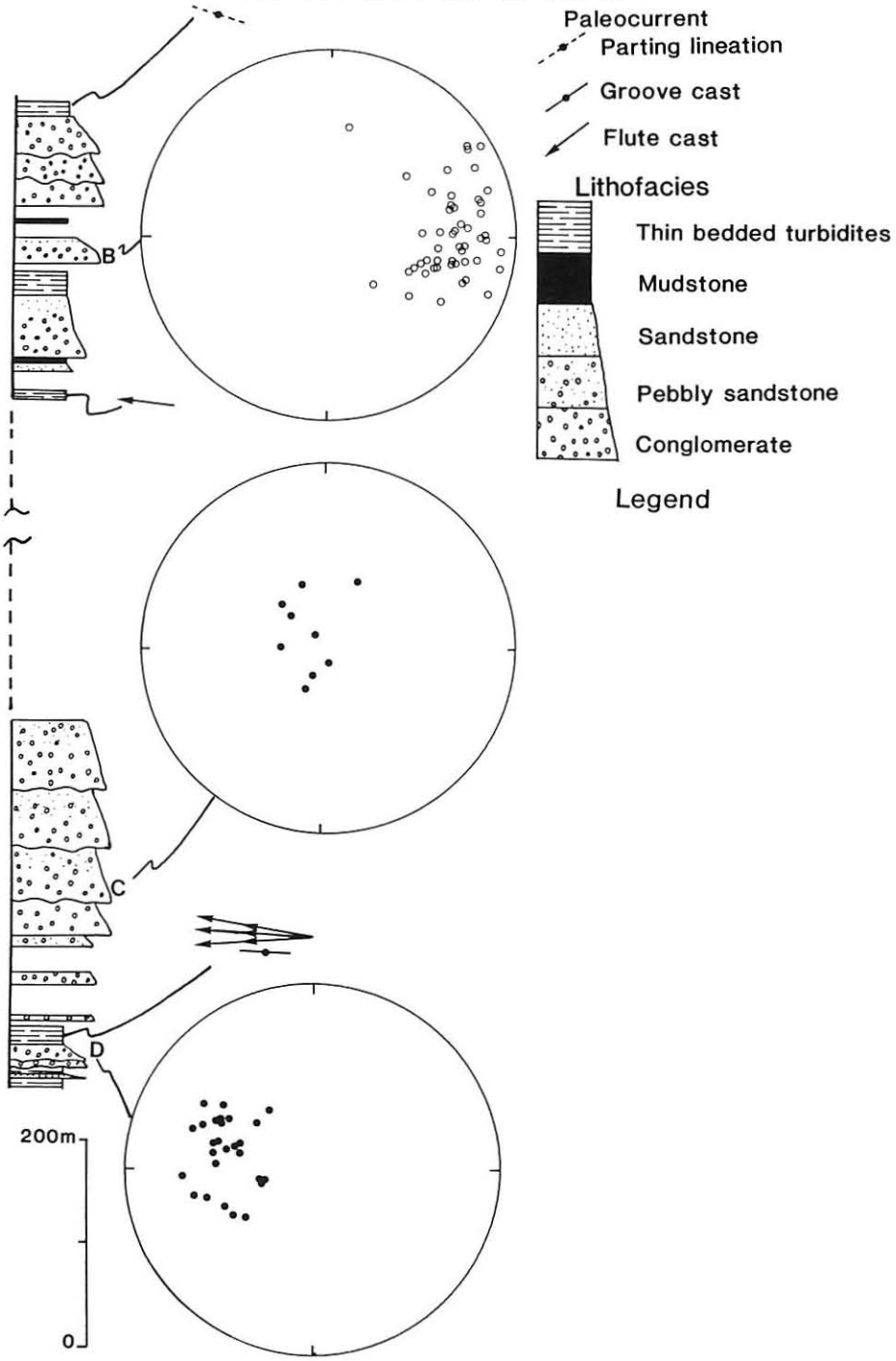
Middleton and Hampton (1973) stated that clastic materials of turbidites and coarse clastic deposits were transported by sediment gravity flows. In the Kotambetsu Formation clastic materials are considered to have been also transported by these flows.

Text-fig. 4 suggests that the thickness and grain size of the bed increase with increasing scale of the flow and that each coarse clastic bed was formed by only one flow event but not the result of successive conglomeratic flows. If a thick bed is a result of multiple flows, one would not expect a good correlation between the size of large clasts and the thickness of conglomerate beds as shown in Text-fig. 4. Since the thickness of coarse clastic beds attains a maximum of 70 meters, the large scale flow might have transported large quantities of sediments of the Kotambetsu Formation.

Middleton & Hampton (1973) classified sediment gravity flows into the following four types on the basis of the dominant sediment-support mechanism; (1) turbidity



Text-fig. 10 Schmidt net (lower hemisphere) plots for poles of ab-plane.
C to V: localities, refer to text-fig. 1.



Text-fig. 11 Relationship between clast fabrics and paleocurrents near Loc. B,C,D in Text-fig. 1. open and solid circles: Schmidt net (lower hemisphere) plots for orientation and inclination of clast long axes and for ab-plane poles.

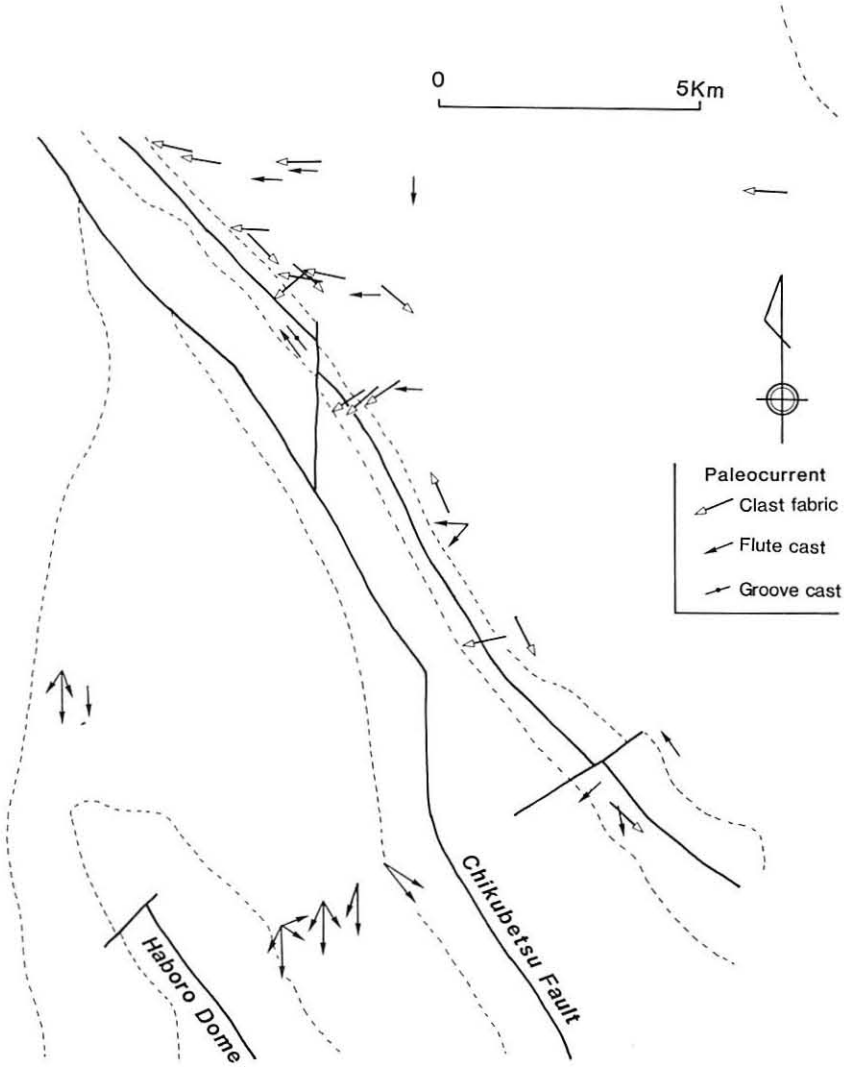
Table 1 Clast fabric data with paleocurrent direction from them.

Loc. A-V are shown in Text-fig. 1., n: number of clasts measured, L (%): consistency ratio, V.M.: vector means of ab-plane poles (* vector means of long axes orientation and inclination).
Three data of less than 90% in consistency ratio and less than 20° in imbrication angles were excluded for paleocurrent reconstruction.

Loc.	n	L (%)	V.M.	Paleocurrent
A	50	93.2	N88°W 30°SE*	92°E
B	50	92.5	N89°E 28°NE*	89°E
C	10	93.8	N10°E 24°E	100°E
D	25	95.8	N13°E 42°E	103°E
E	26	93.0	N47°E 43°W	43°W
F	28	92.2	N 2°E 23°E	92°E
G	25	96.4	N12°E 16°E	—
H	20	98.0	N36°E 32°W	54°W
I	25	96.0	N37°W 25°E	53°E
J	25	96.8	N11°E 25°E	101°E
K	38	93.7	N12°E 30°E	102°E
L	25	81.0	N15°E 42°W	—
M	25	93.0	N41°E 31°W	49°W
N	12	90.9	N25°W 28°E	68°E
O	26	93.4	N34°E 44°E	56°E
P	40	92.5	N40°W 31°E	50°E
Q	25	92.5	N33°W 27°E	57°E
R	25	94.5	N67°E 57°E	157°E
S	15	97.1	N63°E 52°W	27°W
T	25	90.6	N 8°W 26°E	82°E
U	26	97.2	N45°E 29°W	45°W
V	43	66.8	N11°E 50°W	—

currents, (2) fluidized sediment flows, (3) grain flows, (4) debris flows. The coarse clastic beds in the Kotambetsu Formation have normal grading structure with minor inverse grading at the lower part of the beds. Since normal grading is characteristic of turbidity currents (Middleton & Hampton, 1973), apparently clastic materials of the coarse clastic beds of the Kotambetsu Formation were transported mainly by turbidity currents. Massive beds of the truncate base cut-out type are not common in those beds, which are considered to be formed by another type of sediment gravity flows such as debris flows. Further works are necessary for the truncate base cut-out type structure in the coarse clastic beds.

Inverse grading and clast fabric are often observed in the basal part of the coarse clastic bed of the Kotambetsu Formation. Bagnold (1968) proposed that inverse grading might be produced by dispersive pressure caused by collision of grains. High concentration flows proposed by Fisher (1971) can be deduced from the presence of inverse grading. Davies & Walker (1974) and Walker (1975b, 1977) proposed theoretically that clast orientation of long axes dipping to the upstream could be formed by collision of clasts during the transportation. This proposal was based on the theory of Rees (1968). The presence of inverse grading and clast fabric suggests that coarse clas-



Text-fig. 12 Paleocurrent of the Kotambetsu Formation in the same are of Text-fig. 1.

tic grains were highly concentrated in the flow which formed the coarse clastic beds of the Kotambetsu Formation.

Depositional environments of coarse clastic beds

The coarse clastic bed is mainly of complete sequence type and truncate type in the Kotambetsu Formation (Text-fig. 3). The truncate type bed is considered to have been produced by the erosion of the upper part of the complete sequence type bed caused by the succeeding flow. Owing to the submarine fan environmental model proposed by Walker & Mutti (1973) and Walker (1978, 1979), conglomerate beds were deposited in

an upper-fan channel, and pebbly sandstone and sandstone beds were accumulated in a relatively downstream side of the mid-fan channel. The facies of coarse clastic bed of the Kotambetsu Formation is quite different from that in the submarine fan environmental model. This bed is considered to be deposited under a sudden speed reduction of strong sediment gravity flow caused by the blockade owing to the presence of swell in the basin (Cfr. Fig. 13, Hoyanagi & Ohkami, 1986). This swell corresponds to the NNW-SSE trending upheaval of Haboro dome (Text-fig. 1), which was discussed by Takahashi & Kiminami (1983) and Hoyanagi & Ohkami (1986).

Gravels and basin analysis

Hoyanagi & Ohkami (1986) suggested that the clastics of the Kotambetsu Formation were derived from the eastern hinterland in the northern part of Esashi-Hidaka Belt. In this area are distributed pre-Tertiary sedimentary rocks, granitic rocks and serpentinites. A gradual increase of the diameter of gravels to the eastward is expected, if the gravels were transported from the east hinterland. However, such as an evidence has not been observed in the studied area. Complete sequence of the coarse clastic bed contains conglomerate with normal and inverse grading, and the grain size of gravels varies from part to part within one bed. The random sampling of the gravels within a coarse clastic bed can not show the average size distribution. No definite trend in the change of grain size toward east can be expected by such a sampling method herein employed.

Gravels are not rounding off in the sediment gravity flows, differeing from the usual transportation in the water. The predominance of subangular and subrounded gravels indicates short distance transportation in the river before coming down into the marine environment. This is consistent with the rapid upheaval of the hinterland in Middle Miocene time as was suggested by Hoyanagi et al. (1986).

Concluding remarks

The following remarks are concluded from the studies of resedimented conglomerate of the Kotambetsu Formation.

(1) One coarse clastic bed was generally formed by one sediment gravity flow even in the case of the bed 70 meters thick. Most of the flows were of turbidity current with high concentration of grains.

(2) The clast fabrics indicate that the gravels of the Kotambetsu Formation were transported from the east. This conclusion is consistent with the flow direction deduced from solemarkings.

(3) A rapid upheaval followed by the denudation of the hinterland east of the sedimentary basin during Middle Miocene time is suggested from the examination of roundness grade of the gravels in the Kotambetsu Formation.

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