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Heavy mineral composition of the Neogene turbidite sandstones in the middle part of the Niigata backarc oil basin, central Japan — Part I: Western ("Nishiyama") and Central ("Chuo") oil belts

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Abstract : Detailed and systematic heavy mineral analysis of many Neogene turbidite sandstone bodies in the middle part of the Niigata backarc sedimentary basin, the most productive basin of oil and gas in Japan, had been carried out to prove the applicability of heavy mineral composition as a useful marker in characterizing or identifying the individual turbidite sandstone bodies. The results of the Western ("Nishiyama") and Central ("Chuo") oil belts are shown in this paper (Part I) and those of the Eastern ("Higashiyama") oil belt will be shown in the next paper (Part II) with discussion on some problems throughout the whole study area.

Results of this study reveal the followings:

1) The turbidite sandstones at each locality or at each outcrop has, more or less, the same or common characteristics of the heavy mineral composition, that is, those at each locality can be represented by the specific heavy mineral composition.

2) The turbidite sandstones in this area can be classified into, at least, four types based on the combination of the quantitatively major heavy minerals such as opaque minerals, hornblende, hypersthene, and augite.

3) The turbidite sandstones of one formation or one member are represented by one type or closely related two types.

4) The different formations or members in this area are often composed of the different heavy mineral composition. The different provenance or the different geologic event (e.g. the beginning of volcanic activities) at the same provenance may be suggested as a cause of such difference.

5) The heavy mineral composition of turbidite sandstones can be used as a very useful marker to characterize or to identify the individual turbidite sandstone bodies which correspond to the lithologic units such as formations or members.

1. Introduction

In the middle part of the Niigata backarc oil basin, central Japan, Middle Miocene to Pliocene turbidite sandstone bodies, some of which constitute the important reservoir rocks for oil and gas, are distributed on the hills and in the subsurface. As the exploration of strati-

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graphic traps becomes more important than structural traps, it is neccessary to improve the method of estimating the three dimensional extent or distribution pattern of each turbidite sandstone body, and to clarify the original or sedimentological relationship among the several proximate sandstone bodies.

Heavy mineral analysis of the sedimentary rocks, especially sandstones, is generally undertaken to investigate the characteristics of source rocks or to estimate the provenance area (Krumbein and Pettijohn, 1938, Pettijohn, 1975; Mange and Maurer, 1992). As the constituent grains of turbidite sandstones are completely mixed during transport, their heavy mineral composition is expected to retain the characteristics of source rocks or provenance area over long distances. Therefore, there is a high possibility that heavy mineral analysis is useful not only in estimating the provenance but also in characterizing or identifying each sandstone body itself and disclosing the original or sedimentological relationship among several closely disposed sandstone bodies. From this viewpoint, the detailed heavy mineral analysis of many turbidite sandstones outcroped in the middle part of the Niigata sedimentary basin was conducted in this study. Previously, the regional sedimentary basin analysis mainly based on the facies and paleaocurrent analyses of these sandstones had been done in the basin by several researchers (Morita *et al.*, 1973; Kageyama and Suzuki, 1974; Tsuda, 1978; Tateishi *et al.*, 1984; Suzuki, 1989; Kobayashi and Tateishi, 1992). However, basin analysis based on regional mineralogical analysis, especially regional heavy mineral analysis, has not been done yet except for some local areas (Sasaki and Ushijima, 1968; El Habab *et al.*, 1991; Tokuhashi, 1992; Tateishi *et al.*, 1992).

2. General Remarks on the Niigata Sedimentary Basin

The Niigata basin is surrounded onshore, except for the southern part, by older basement rocks mostly composed of Mesozoic rocks. The western end of the basin is bordered by the Itoigawa-Shizuoka Tectonic Line (I. S. T. L. in Fig. 1), which cross the central part of Honshu Island nearly north-southward from Japan sea coast to Pacific coast. The eastern end of the basin is bordered more irregularly, but one tectonic line, Shibata-Koide Tectonic Line is supposed. The location of Shibata and Koide is shown in Fig. 1. The sediments of the basin become thin towards the south, but it continue to the southern Shinshu or Nagano area. Therefore, the Niigata basin is sometimes included in a northern part of the Shin'etsu sedimentary basin.

The Neogene Niigata backarc basin is known as the most productive basin of oil and gas in Japan. The late Early Miocene to early Middle Miocene volcanic rocks and the Middle Miocene to Pliocene turbidite sandstones in the basin form the most important reservoir rocks of oil and gas. The late Early Miocene to early Middle Miocene thick volcanic rocks, basic to acidic rocks, constitute the basal part of the basin fills. They are interpreted as products of the opening of the Japan Sea during the late Early to early Middle Miocene time. The overlying Middle Miocene to Quaternary sedimentary rocks show, as a whole, an upward shallowing succession attaining more than 5,000 meters in maximum thickness, typically beginning with deep-water mudstone through thick turbidite-sandstone-bearing mudstone-sandstone alternation, to shallow-marine sandy mudstone, then nearshore sandstone and finally Quaternary transitional to terrestrial sediments. A number of volcanic ash layers are intercalated in these sedimentary rocks and many of them are used as local or regional markers and yield a very important tool for recent detailed stratigraphic works and chronologic dating. The fills of the basin have suffered east-westward compressional stress since the late Pliocene and resulted in many north-south trending folds and some thrusts. These deformations played a very important role in making up the present oil and gas traps in the basin.

The study area, the middle part of the Niigata sedimentary basin, is stratigraphically a very important area, because the most type localities of the standard stages for the succession of the Niigata sedimentary basin is located in this area (Fig. 2 and Fig. 3). For the

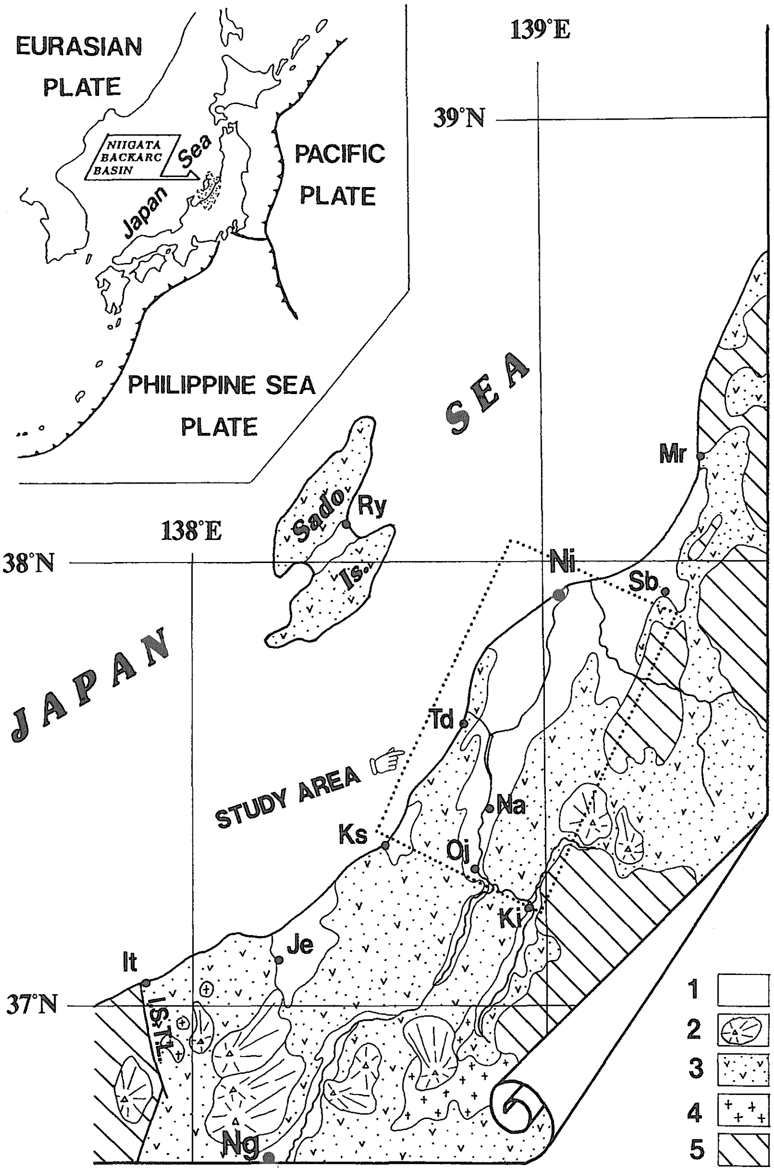

Fig. 1 Index map of the study area.
Ry: Ryotsu, Mr: Murakami, Ni: Niigata, Sb: Shibata, Td: Teradomari, Na: Nagaoka, Ks: Kashiwazaki, Oj: Ojiya, Ki: Koide, Je: Joetsu, Ng: Nagano, I. S. T. L. : Itoigawa-Shizuoka Tectonic Line. 1: Alluvium, 2: Late Quaternary volcanoes, 3: Miocene to Pleistocene sedimentary and volcanic rocks, 4: Miocene intrusive rocks, 5: Basement rocks (pre-Terciary sedimentary and intrusive rocks).

sedimentological study on the turbidite sandstones, the study area is very important, too, because many turbidite sandstone bodies of Middle Miocene to Pliocene age are outcropped in this area. This is the reason this area is selected for the present study. Outcrop localities are grouped here into three belts, Western ("Nishiyama") oil belt along the Japan Sea, Central ("Chuo") oil belt located east of Western oil belt, and Eastern ("Higashiyama") oil belt near the eastern end of the basin (Fig. 2). In this paper, results of heavy mineral analysis of

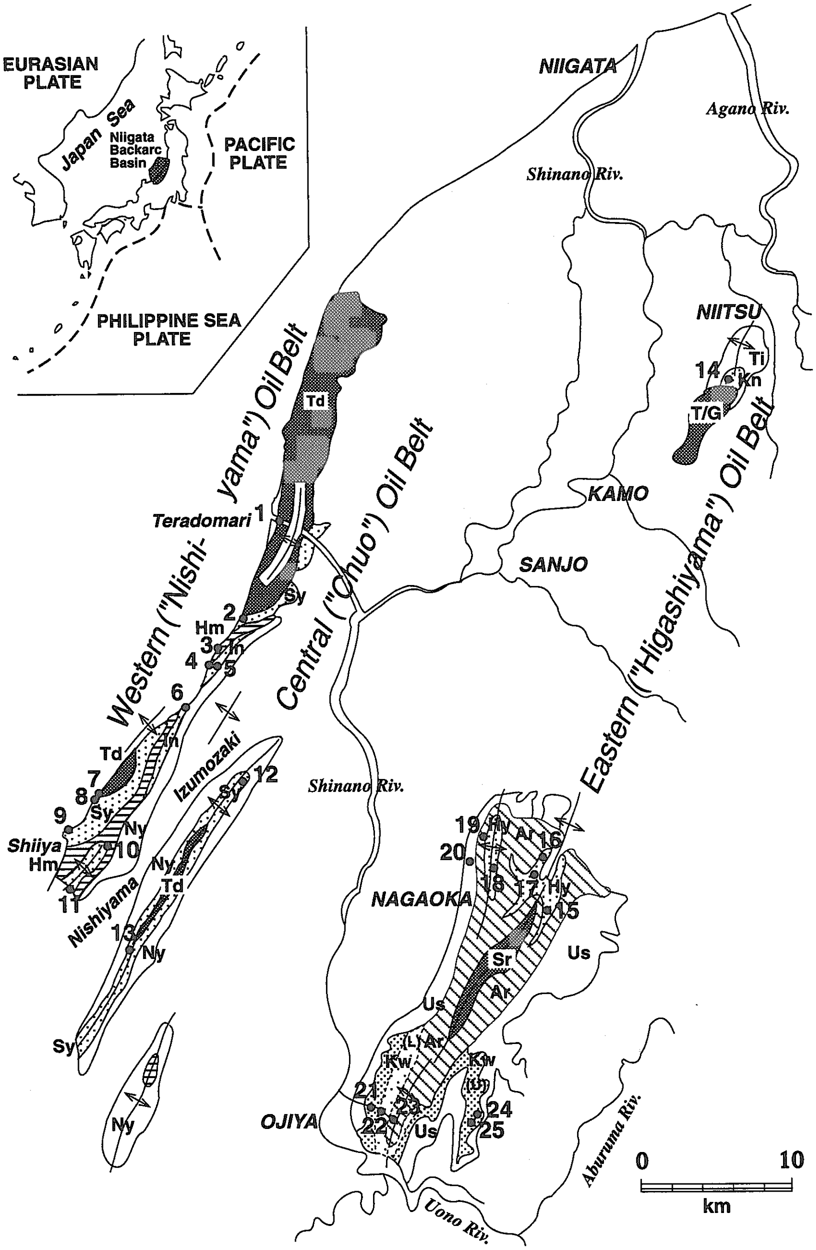

Fig. 2 Geologic sketch map of the study area and sampling localities. Alphabetic letters correspond to the names of the formation and member in Fig. 3.

samples collected in the Western ("Nishiyama") and Central ("Chuo") oil belts are shown. The results in the Eastern ("Higashiyama") oil belt will be shown in the next paper (Part II) with discussion on some problems related to the whole study area.

3. Stratigraphy at the Western ("Nishiyama") oil belt and Central ("Chuo") oil belt

The names of the standard stages for the sedimentary succession in the Niigata sedimen-

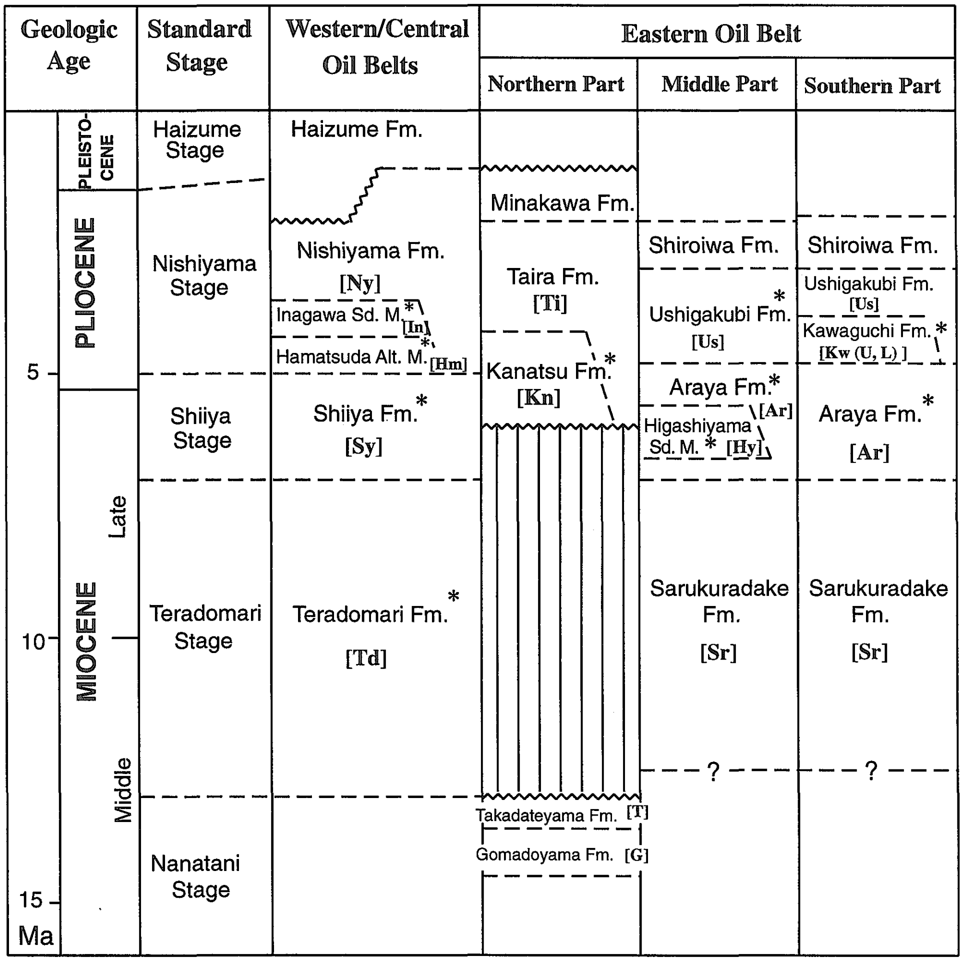

Fig. 3 Stratigraphy in the study area. Fm: Formation, Inagawa Sd. M.: Inagawa Sandstone Member, Hamatsuda Alt. M.: Hamatsuda Alternation Member, Higashiyama Sd. M.: Higashiyama Sandstone Member. Asterisks indicate the formations and members whose turbidite sandstones were analyzed.

tary basin were mostly derived from names of the formations in this area as shown in Fig. 3. Distributed in this area are Teradomari formation, Shiiya formation, Nishiyama formation, Haizume formation, and younger Quaternary formations in ascending order.

The Teradomari formation is characterized by relatively thin-bedded fine-grained turbidite sandstones intercalated with black to dark grey mudstones. The overlying Shiiya formation is mostly formed of an alternation of thick-bedded coarse-grained turbidite sandstones and thin-bedded dark-gray mudstones. The Nishiyama formation, on the other hand, are mostly composed of thick bluish grey to light grey mudstones, although in the Western ("Nishiyama") oil belt the lower part of the formation is composed of the Hamatsuda alternation member and Inagawa sandstone member (Fig. 3). The Hamatsuda alternation member is made up of thin-bedded fine-grained turbidite sandstones intercalated with light grey mudstones. The Inagawa sandstone member is comprized mostly of an alternation of thick-bedded coarse-grained turbidite sandstones and thin-bedded light gray mudstones, and partly of debris flow deposits.

The Haizume formation overlies the Nishi-

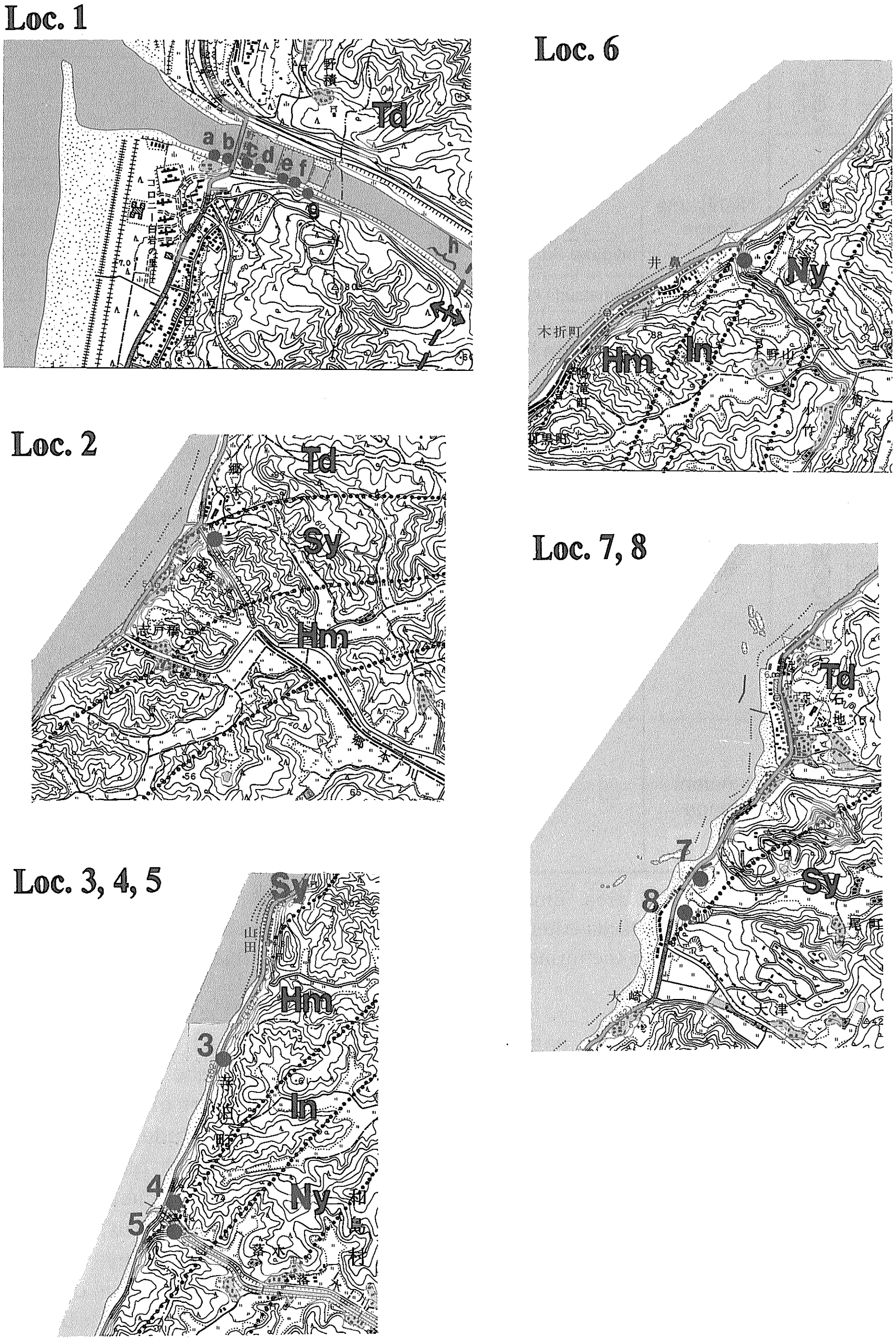

Fig. 4 Detailed sampling points at each locality. Alphabetic letters mean the name of formations and members shown in Fig. 3. Topographic maps are parts of 1:25,000 map sheets "Miyagawa", "Nishiyama", "Nagaoka", "Izumozaki", "Yoita" and "Teradomari" published by Geographical Survey of Institute.

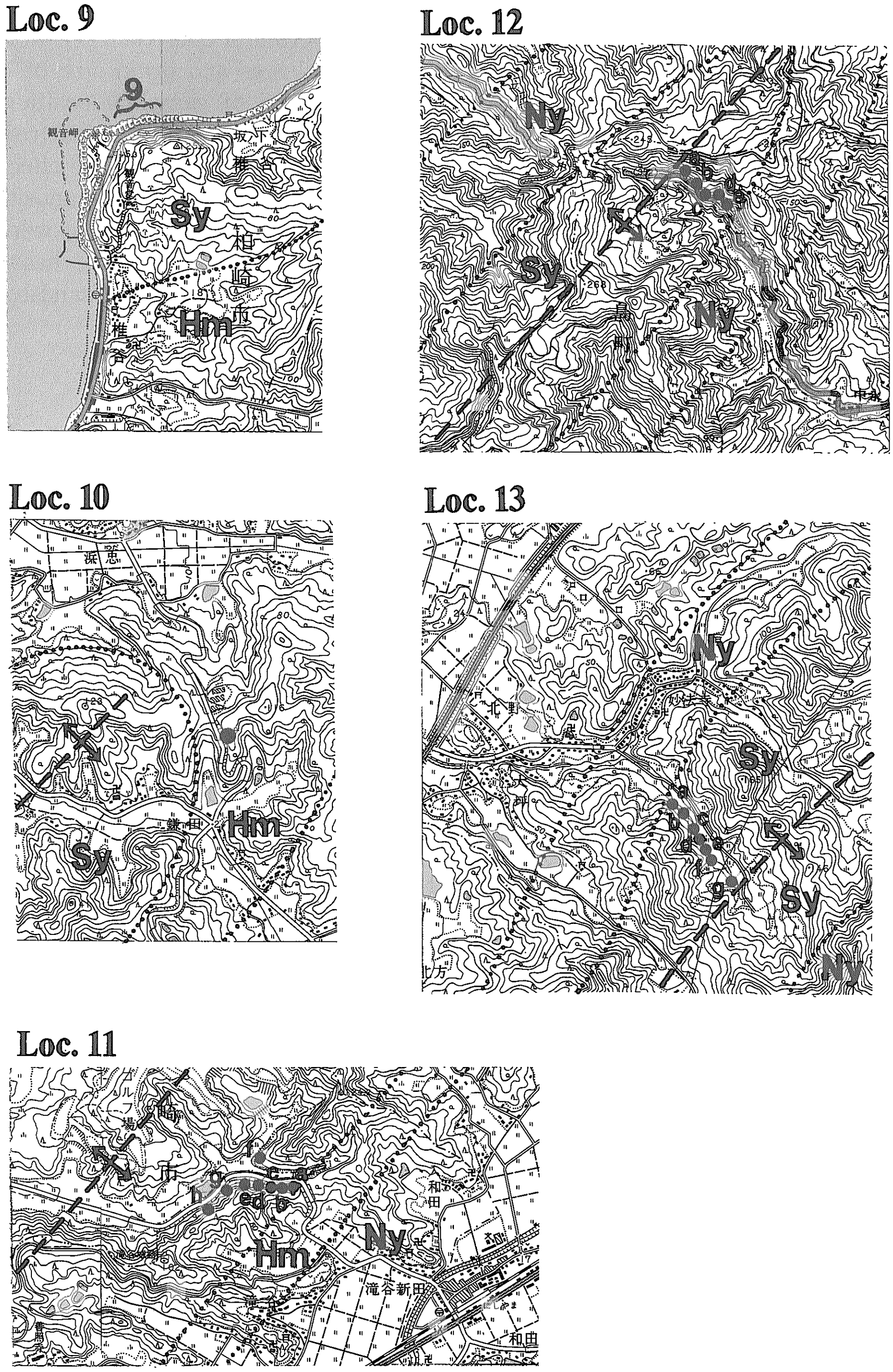

Fig. 4 (continued)

yama formation partly unconformably and partly conformably and composed mostly of massive sandy mudstone with many molluscan and trace fossils. Sandstone samples from the Teradomari formation, Shiiya formation, Hamatsuda alternation member, Inagawa sandstone member are collected and analyzed with the results presented in this paper.

4. Method

4.1 Method of sampling

All samples were collected from turbidite sandstone outcrops. Sampling points at each locality are shown in Fig. 4. In the most localities, geologic columns for the outcropped successions were first constructed with description of the thickness and grain size of each sandstone bed, and of sampling position within a bed. Sometimes, a few samples from a single bed were collected to check the effects of grain size to the heavy mineral composition. Some volcanic ashes in the successions were collected and analyzed to compare the heavy mineral composition with that of the sandstones.

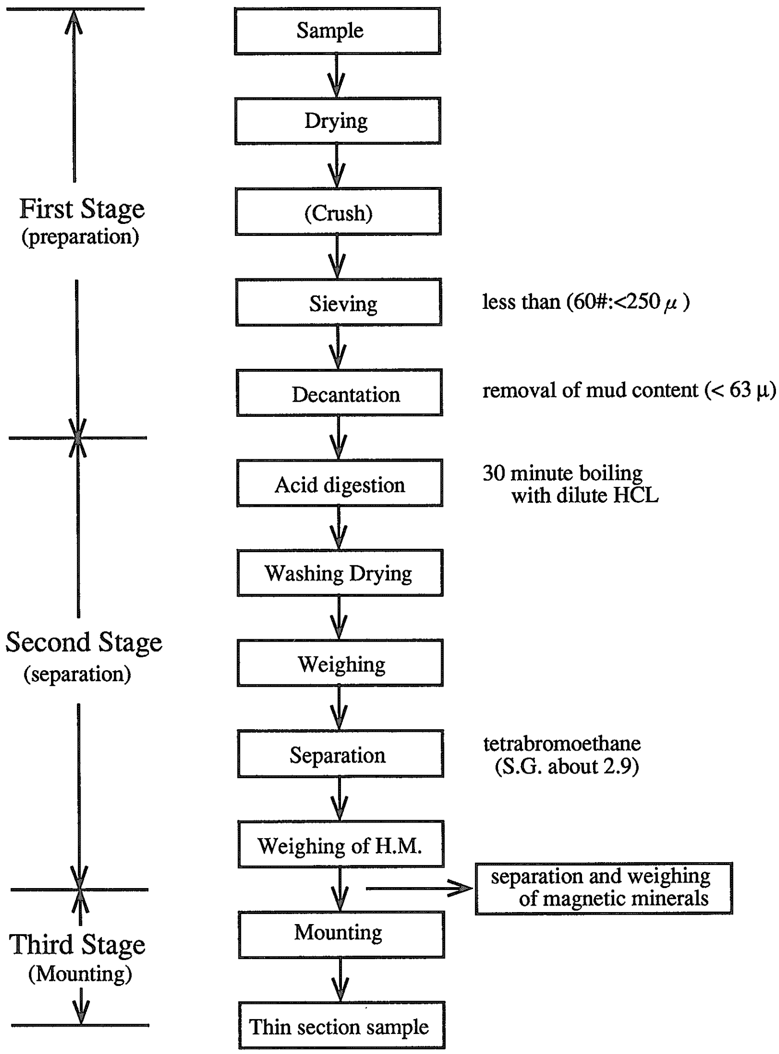

Fig. 5 Flow chart of the laboratory work for heavy mineral analysis.

4.2 Method of experiment

A flow chart of sample preparation procedures to make thin sections for heavy mineral analysis is shown in Fig. 5. Samples for heavy mineral analysis were first dried and then disaggregated in order to liberate individual grains from coherent sediments. Most of the samples were friable and were crushed with the fingers. Weakly consolidated samples were crushed by gentle pounding in an iron mortar using an up-and-down motion to avoid distorting the original shape and size of the grains.

The crushed samples were then sieved by a spray of water (wet sieving) to obtain the less 0.25mm fraction. This was followed by washing and decantation of the clay and silt fraction, leaving a grain-size range from which optimal results had been obtained in test runs.

Acid digestion was then applied to the extracted grain size range in order to rid the grains of coatings of carbonates and iron oxides. For this purpose, the samples were placed in dilute HCl and warmed over a hot plate in a fume cupboard with intermittent stirring for about thirty minutes. The samples were then allowed to cool followed by decantation of the acid and a thorough wash with water to remove all soluble substances and remaining clays and silts. The washed samples were then oven dried at about 80°C.

Heavy mineral separation was achieved by gravity settling using the heavy liquid tetrabromoethane (acetylene tetrabromide) with specific gravity of about 2.9. The heavy liquid was poured into separating funnels and weighed dry samples (maximum 15g) were then added to the liquid and stirred to ensure that the grains were thoroughly wetted. The contents of the separating funnels were stirred intermittently until maximum separation was obtained (normally after 4-6 hours separating time). The

Fig. 6 An outcrop of the Teradomari formation at the type locality (Loc. 1).

pinch clips at the bottom of the separating funnels were released slowly allowing the heavy mineral fraction to pour into crucibles and followed by washing with ethanol to remove the heavy liquid from the samples. The washed samples were dried at about 40°C in the oven.

The heavy minerals were then weighed and recorded. The magnetic heavy mineral fraction of each sample was separated from the none magnetic fraction using a horse shoe magnet followed by further weighing to obtain the weight of the magnetic and none magnetic heavy mineral fractions.

Grain mounts of the none magnetic heavy minerals were then made using resin as the mounting medium. For each mount the grains were evenly distributed on the glass slide to avoid overlapping and dense packing of grains.

The heavy mineral content of each grain mount was identified by observation under a petrological microscope. The relative abundance of heavy minerals in each sample was determined by point counting using the ribbon counting technique. All minerals were counted, but the flake minerals such as biotite and muscovite, though they are included only as minor components in this area, were omitted at the caluculation of the relative abundance of indidual heavy minerals, because the abundance of such flake minerals is sometimes influenced by a very small difference of experimental conditions such as specific gravity of heavy liquid and so on. Therefore mica minerals such as biotite and muscovite are omitted in the following tables showing the results of heavy mineral analysis.

5. Results of heavy mineral analysis

5.1 Teradomari formation

The Teradomari formation is the eldest formation outcropped in this area and distributed mainly along the west coast in the Western ("Nishiyama") oil belt and partly along the main anticlinal axis in the Central ("Chuo") oil belt (Fig. 2). The formation is mostly composed of a mudstone-dominated alternation of thin-bedded sandstones (mostly less than 30 cm in thickness) and thin- to medium-bedded black to dark grey mudstones (mostly less than 50 cm in thickness) (Fig. 6). The sandstones are characteristic of fine-grained, graded, distal turbidite with parallel, convolute, and current ripple laminations. The formation is interpreted to have been deposited in the anoxic condition as the mudstone is rich in organic matter and the formation yields very few trace fossils as shown in the very well preserved sedimentary structures of the turbidite sanstones. Several thick (a few to 10 meters) acidic volcanic ash layers including lapilli pumice tuff are intercalated in the formation. The formation attains maximum thickness more than 350 m in this area.

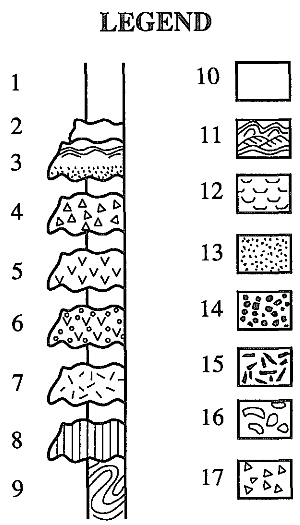

Fig. 7A Legend for geologic columns. 1: mudstone to siltstone, 2: turbidite sandy mudstone to sandy siltstone, 3: turbidite sandstone, 4: pumice tuff or pumiceous sandstone, 5: andsitic tuff, 6: andesitic lapilli tuff, 7: fine-grained glassy tuff, 8: fine-grained white to grey tuff, 9: slumped mudstone, 10: massive sandstone, 11: laminated sandstone (parallel lamination, current-ripple lamination, convolute lamination and so on), 12: dish structure, 13: granule-sized grains, 14: pebble-sized gravels, 15: carbonaceous fragments, 16: mudstone- or siltstone-clasts (rip-up clasts), 17: pumice grains.

5.1.1 Heavy mineral composition of the Teradomari formation

Turbidite sandstones of the Teradomari formation, taken at three localities, i.e. Loc. 1, Loc. 7, and Loc. 8 in Fig. 2, were analyzed.

Loc. 1

Loc. 1 is the type locality of the Teradomari formation and is located along the Okotsu channel, a short-cut channel of the Shinano river and sometimes called New-Shinano river. In this locality, samples were collected at several points along the Okotsu channel as shown in Fig. 4. The geologic columns at individual points are shown in Fig. 7B. Heavy mineral composition at this locality is shown in Table 1. Thickness of all turbidite sandstone beds analyzed is less than 40 cm. All sandtone samples show similar composition each other. Opaque minerals extremely dominate. Zircon and garnet are the most common components among the non-opaque minerals. A few tourmaline and allanite are present, with very few hyperthene, augite, and hornblende.

Loc. 7

Sedimentary facies of the successions at this locality is the same as that as at Loc. 1 (Fig. 8). Heavy mineral composition at this locality is shown in Table 2. Thickness of analyzed sand-

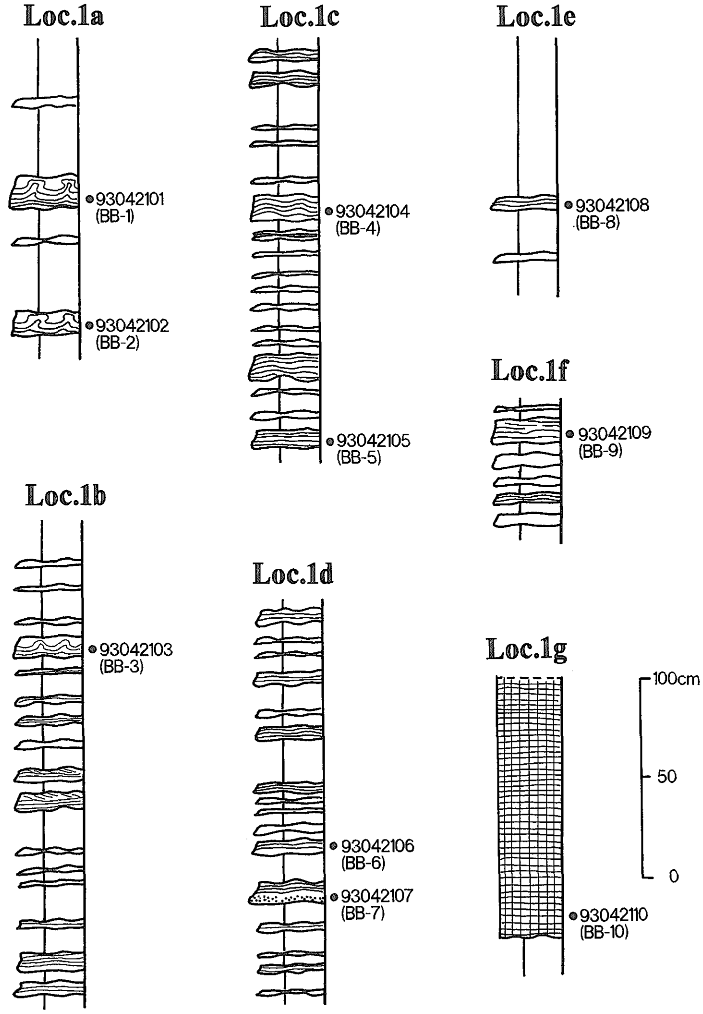

Fig. 7B Geologic columns at Loc. 1 (Teradomari formation). Solid circles mean the sampling positions for heavy mineral analysis.

Table 1 Results of heavy mineral analysis at Loc. 1 (Teradomari formation).
Lithology (Tbss: turbidite sandstone, Tfss: tuffaceous sandstone, Sdtf: sandy tuff, Tf: tuff), Position (sampling position in a sinble bed, LM: lowermost part, L: lower part, M: middle part, U: upper part, UM: uppermost part, A: whole part), Run No (identification number at laboratory work), Heavy minerals (Opq: opaque minerals, Hyp: Hypersthene, Aug: augite, Hor: hornblende, brn.: brown, blu.grn.: bluish green, Oxy-Hor: oxyhornblende, Dio: diolite, Tre-Act: tremolite-actinolite, Epi: epidote, Zir: zircon, Gar: garnet, Sph: sphene, Ana: anatase, Rut: rutile, Tou: tourmaline, Al: allanite, Gla: glaucophene, Oth: other minerals), Total CHMG: total number of counted heavy mineral grains, Hy: weight contents of heavy minerals, Mg: weigt contents of magnetic minerals in heavy minerals, ◎: dominant, ○: abundant, △: common, +: rare, − : very rare, ·: trace. general: generalized heavy mineral composition of the taubidite sandstone at each locality. As mentioned in the text, mica minerals such as biotite and muscovite are omitted in the table.

Loc. No.	Litho- logy	Thick- ness (cm)	Posi- tion	Sample No	Run No	Opq	Hyp	Aug	Hor total	brn.	green	blu. grn.	Oxy- Hor	Dio	Tre- Act	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total CHMG	Hy %	Mg %	Lithologic feature
1a	Tbss	15	L	93042101	BB-1	◎											−	−				·				3668	1.5	1.5	<vf-f. sand>
1a	Tbss	12	L	93042102	BB-2	◎	−										△	+								5185	0.4	0.5	<vf-f. sand>
1b	Tbss	10	L	93042103	BB-3	◎	−		·		·						△	+				+	−			4074	0.8	6	<vf-f. sand>
1c	Tbss	12	L	93042104	BB-4	◎											+	+				−	−			3385	0.4	3.4	<f-vf. sand>
1c	Tbss	7	A	93042105	BB-5	◎	−	+	·		·					·	△	+				−	−			3656	0.2	18	<vf. sand>
1d	Tbss	7	A	93042106	BB-6	◎			−		−						△	+				+				2904	0.1	5.2	<vf-f. sand>
1d	Tbss	10	L	93042107	BB-7	◎			·	·							+	+				−				2439	0.7	3.6	<c-m. sand>
1e	Tbss	5	A	93042108	BB-8	◎			−		−						○	△				+				1455	0.1	11	<vf. sand>
1f	Tbss	12	L	93042109	BB-9	◎											○	△				+	−			782	0.1	3.8	<vf-f. sand>
1g	Tf	130+	LM	93042110	BB-10	◎											△	−				·				2290	0.3	7.9	<f. white grey tuff>
1h	Tbss	40	L	8701	AV-7	◎											−	−				·	−			2320	0.8	0.7	<f-vf. sand>
1h	Tbss	20	L	8702	AV-8	◎			−	−	−						+	+				−	−			2818	0.2	2.2	<vf-f. sand>
1h	Tbss	20	L	8703	AV-9	◎	−		·	·							+	+				·				3071	0.7	0.3	<vf-f. sand>
1h	Tbss	35	L	8704	AV-10	◎											△	+				−	−			3253	1.1	4.2	<f-vf. sand>
1	Tbss			general		◎	(−)		(· −)		(· −)						△	+				· +	(−)						

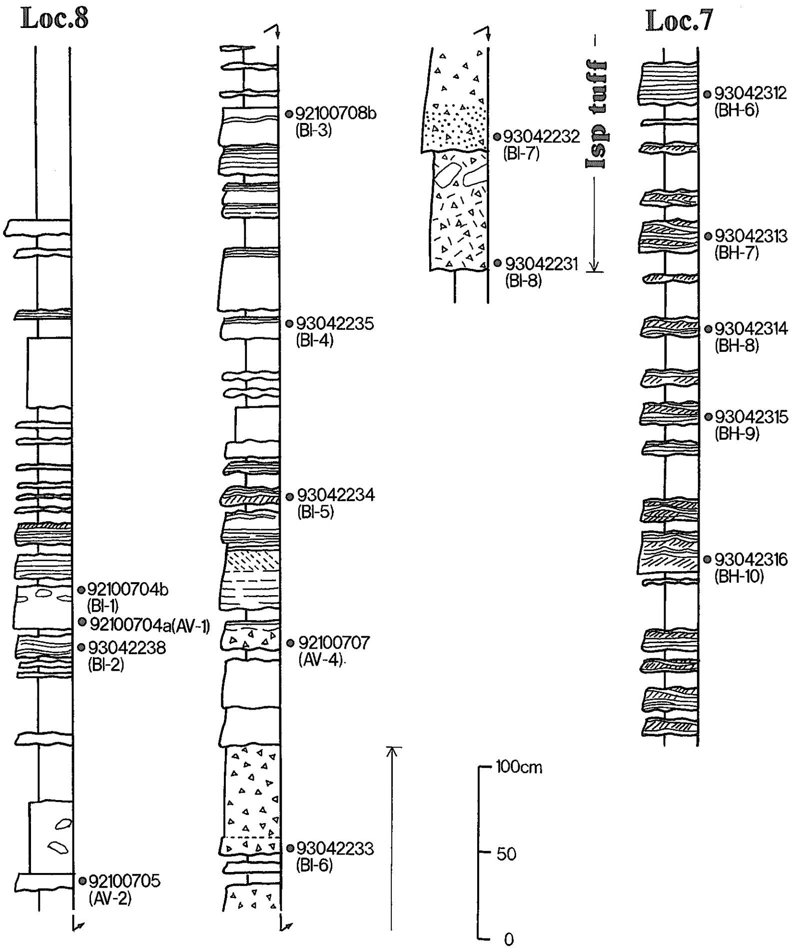

Fig. 8 Geologic columns at Loc. 7 and Loc. 8 (the upper and uppermost Teradomari formation). For the legend, see Fig. 7A.

stone beds is less than 25 cm. Heavy mineral composition shows very similar assemblage as that as at Loc. 1. Opaque minerals are extremely dominant with common to rare garnet. Tourmaline is very rare and a very few glaucophane are newly observed in this assemblage.

Loc. 8

At this locality are outcropped the uppermost Teradomari formation. The sedimentary facies at this locality shows transitional facies between the Teradomari formation and the overlying Shiiya formation, as relatively thick turbidite sandstones about 50 cm thick with coarse-grained, graded or massive parts in the lower parts are also observed in the succession as well as thin-bedded turbidite sandstones only with fine-grained laminated part (Fig. 8). Some acidic or pumiceous tuff or pumiceous sandstones are also intercalated in the succession.

The heavy mineral composition of the turbidite sandstones is principally as like as those at Loc. 1 and Loc. 7 as shown in Table 3. A little higher ratio of hornblende and very rare but constant inclusion of tremolite-actinolite show a little different features compared with heavy mineral composition at Loc. 1 and Loc. 7. These different features reflect the characteristics of turbidite sandstones of the overlying Shiiya formation.

Heavy mineral composition of the pumice

Table 2 Results of heavy mineral analysis at Loc. 7 (the upper Teradomari formation). For the legend, see Table 1.

Loc. No.	Litho-logy	Thick-ness (cm)	Posi-tion	Sample No	Run No	Opq	Hyp	Aug	Hor total	brn.	green	blu. grn.	Oxy-Hor	Dio	Tre-Act	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total CHMG	Hy %	Mg %	Lithologic feature
7	Tbss	22	L	93042312	BH-6	◎	—		—	—	—		—			—	○	+		·		—		—		3237	0.1	8	<vf-f. sand>
7	Tbss	18	L	93042313	BH-7	◎	·		—	—	—				—	·	△	+				—				3161	0.1	14.9	<f-vf. sand>
7	Tbss	10	A	93042314	BH-8	◎	—		—	—	—						△	+		—		—		·		4325	0.1	15.5	<vf-f. sand>
7	Tbss	12	L	93042315	BH-9	◎	+	—	—	—	—		—		—		△	+		·		—		·		3343	0.2	20.2	<vf-f. sand>
7	Tbss	24	L	93042316	BH-10	◎	—	—	—	—	—		—				△	+				—		—		1738	20	0.1	<vf-f. sand>
7	Tbss			general		◎	—	(—)	—	—	—		(—)		(—)	(—)	△	+		(—)		—		(—)					

Table 3 Results of heavy mineral analysis at Loc. 8 (the uppermost Teradomari formation). For the legend, see Table 1.

Loc. No.	Litho-logy	Thick-ness (cm)	Posi-tion	Sample No	Run No	Opq	Hyp	Aug	Hor total	brn.	green	blu. grn.	Oxy-Hor	Dio	Tre-Act	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total CHMG	Hy %	Mg %	Lithologic features
8	Tf	600	LM	92100709a	AV-5	◎	·		△	+	△	—	·		·	—	—	—								2387	0.9	16	Pumice tuff (Ndp tuff)
8	Tf	600	M	92100709b	AV-6	○	—		○	—	○	—	—		—	—	—						·			2190	0.4	11.3	Pumice tuff (Ndp tuff)
8	Tbss	25	UM	92100704b	BI-1	◎	—		+	—	—		·		—	—	○	+		·		—		—		2875	0.2	21.3	<vf-f. sand>
8	Tbss	13	M	93042238	BI-2	◎			—	·	—				—	—	△	+		·		—		—		3621	0.2	18.5	<f-vf. sand>
8	Tbss	10	L	92100705	AV-2	◎			+	—	+				—	—	+	—				—	—	—		2035	0.1	7.8	<m. sand>
8	Tbss	20	UM	92100708b	BI-3	◎	·		—	—	—				—	—	△	+		—		—		—		3790	0.1	13	<vf-f. sand>
8	Tbss	12	U	93042235	BI-4	◎			+	—	+				—	—	△	+				—				3060	0.2	11.6	<f-vf. sand>
8	Tbss	8	A	93042234	BI-5	◎	—	—	△	+	△				—	·	△	+		·		—		—		2275	0.1	18.3	<f-vf. sand>
8	Tbss	35	L	92100706	AV-3	◎			△	+	△	—			—	—	△	+		—		—	—	—		2243	0.2	16.2	<f. sand>
8	Tfss	16	L	92100707	AV-4	◎			○	△	○	—			—	—	+	+					—			1382	0.1	13.6	<pumic. f. sand>
8	Tfss	10	L	93042233	BI-6	◎			○	+	○	—			—	—	—	—								1797	0.4	7.3	<pumic. c-m. sand>
8	Tfss	78	LM	93042232	BI-7	◎	—	—	○	+	○	—			—		—	—								1212	0.2	8.3	<pumic. vc-c. sand>
8	Tf	70	LM	93042231	BI-8	◎	—		○	—	○	—			—	—	—	—								1926	0.3	7.3	<f. pumic. glassy tuff>
8	Tbss			general		◎	(—)	(—)	—△	—+	—△	(—)			—	—	△	+		(—)		—	(—)	—					

tuffs or pumceous sandstones, on the other hand, is different by the existence of abundant hornblende (mostly green hornblende) as well as abundant opaque minerals, and by the absence of tourmaline and glaucophane.

5.1.2 Summary

Heavy mineral composition of the turbidite sandstones of the Teradomari formation is characterized by extremely dominant opaque minerals, common to very rare but constant zircon and garnet, very rare tourmaline, and a trace of glaucophane. Very few hypersthene, augite, and hornblende are included except for some sandstones in the uppermost Teradomari formation at Loc. 8, which include rare to common hornblende and show more similiar characteristics as those of the turbidite sandstones in the overlying Shiiya formation.

5.2 Shiiya formation

The Shiiya formation conformably overlies the Teradomari formation and is distributed in the Western ("Nishiyama") oil belt and in the Central ("Chuo") oil belt surrounding the distribution area of the Teradomari formation (Fig. 2).

The Shiiya formation in the Western ("Nishiyama") oil belt is mostly comprized of a sandstone-dominated alternation of sandstones and mudstones. Most sandstones show the features of proximal turbidite sandstones, usually less than 200 cm in thickness, the lower parts of which are more or less occupied by the coarse-grained, graded or massive sandstones. Granule to pebbles are often observed concentrated in the basal part or randomly distributed in the lower part of these sandstones. These graded or massive sandstones are overlain by laminated structures including parallel, wavy, convolute, and current ripple laminations. Thin-bedded and fine-grained distal turbidite sandstones, usually composed only of laminated sandstones, are also included in the formation. The thickness of turbidite sandstone beds and grain size of sandstones tend to increase towards the south. Mudstones in the formation, usually less than 50 cm in thicness, made up of dark grey to light grey mudstone. Mudstones and sandstones commonly yield trace fossils in their cross section. Slumps, debris flow deposits and volcanic ash layers are also intercalated in the formation. The total thickness of the formation increases towards the south and attains more than 1,000 m in maximum thickness (Suzuki *et al.*, 1974; Kurokawa *et al.*,1992).

In the Central ("Chuo") oil belt, the turbidite sandstones are generally less thick and finer-grained than those in the Western ("Nishiyama") oil belt. The formation often includes slumped deposits and volcanic ash layers. The formation thickens southward and attains more than 400 m in maximum thickness (Suzuki *et al.*, 1974).

5.2.1 Heavy mineral composition of the Shiiya formation

Turbidite sandstones of the Shiiya formation were sampled and analyzed at three localities, i.e. Loc. 2, Loc. 9 and Loc. 11 in the Western ("Nishiyama") oil belt, and at two localities, i.e. Loc. 12 and Loc. 13, in the Central ("Chuo") oil belt.

Loc. 2

This locality is located at the mouth of the Ochimizu river and here outcropped the lowermost part of the Shiiya formation. As many pumiceous tuff layers are also intecalated in the succession as well as turbidite sandstone beds, both of turbidite sandstones and pumiceous tuffs were sampled and analyzied (Fig. 9). The results of the analysis are shown in Table 4. As to three sandstone beds, two samples, one from the lower to lowermost part and the other from the upper or uppermost part, were anlyzed for each sandstone bed.

The heavy mineral composition of turbidite sandstones is almost occupied by dominant opaque minerals and dominant hornblende, composed mostly of green hornblende. Oxyhornblende and zircon are rare to very rare but constantly included. Tremolite-actinolite, epidote, garnet are very rare but constantly included. A trace of glaucophane in one sample. Very few hypersthene and augite are included in the sandstones except for one sandstone bed (87O8b) which include common hypersthene but

Loc.2

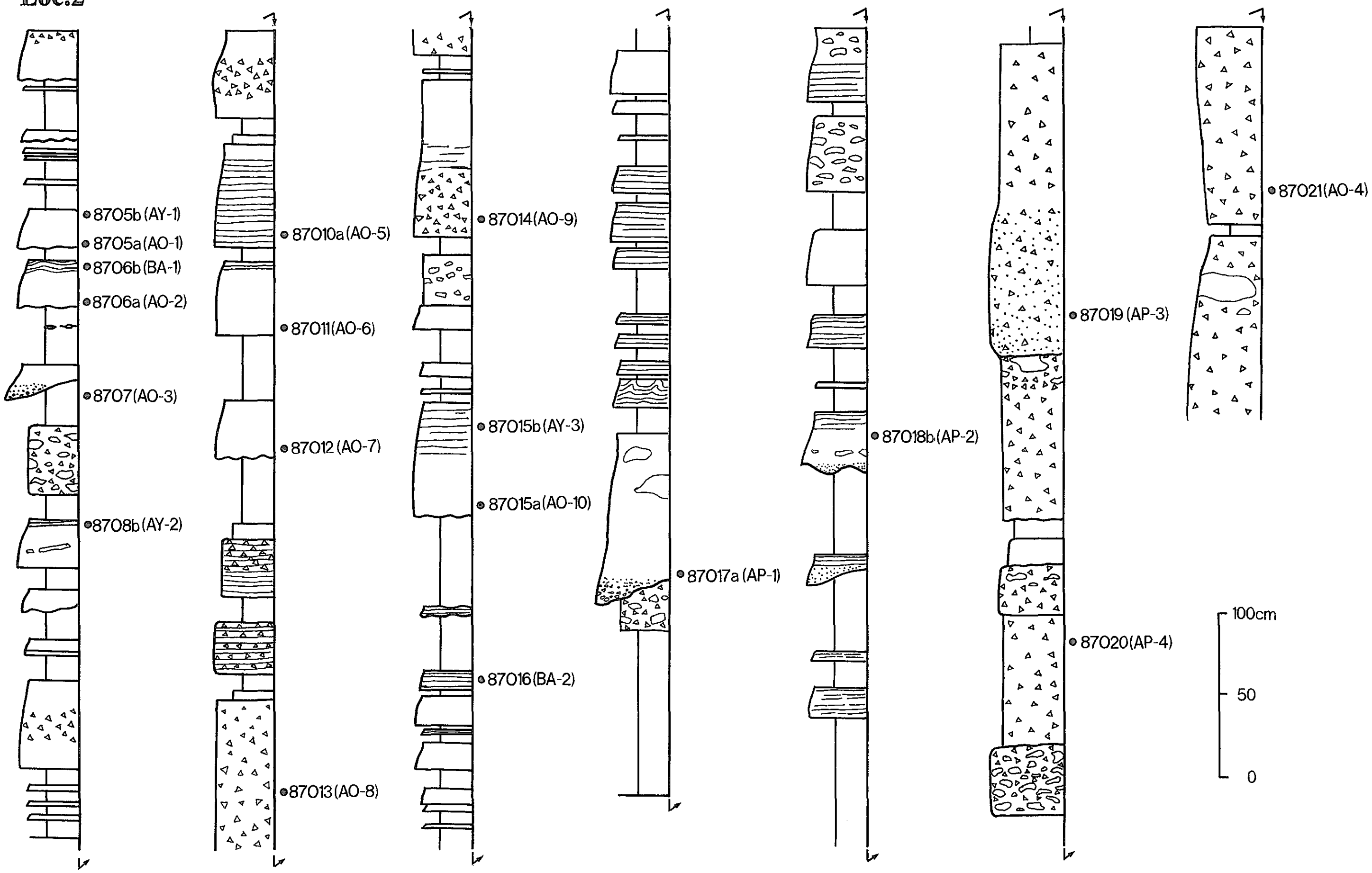

Fig. 9 Geologic column at loc. 2 (the lowermost Shiiya formation). For the legend see Fig. 7A.

Table 4 Results of heavy mineral analysis at Loc. 2 (the lowermost Shiiya formation). For the legend, see Table 1.

Loc. No.	Litho-logy	Thick-ness (cm)	Posi-tion	Sample No	Run No	Opq	Hyp	Aug	Hor total	brn.	green	blu. grn.	Oxy-Hor	Dio	Tre-Act	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total CHMG	Hy %	Mg %	Lithologic feature
2	Tbss	23	L	87O5a	AO-1	○			◎	△	○	−	−		−	−	−	−								1605	1.6	4.9	<m. sand>
2	Tbss	23	UM	87O5b	AY-1	◎			○	+	○	−	+			−	△	−								2562	0.6	4.2	<f-vf. sand>
2	Tbss	29	L	87O6a	AO-2	○			◎	+	◎	+	−		+	−	−	−				−				1387	0.7	6.8	<m. sand>
2	Tbss	29	UM	87O6b	BA-1	○			◎	+	◎	−	+		−		+	−								1386	1.2	3.2	<f. sand>
2	Tbss	20	L	87O7	AO-3	○			◎	+	◎	−	−		−	−	−	−								1290	2.1	4.4	<v.c. sd. with granules>
2	Tbss	29	UM	87O8b	AY-2	○	○		○	△	○	−	−			−	△	−								1158	0.8	2.1	<f-vf. sand>
2	Tf	63	LM	87O10a	AO-5	○	○	+	◎	△	○	+	+			−	−									1041	0.7	1.6	Wht. glassy tuf. <m. tuff>
2	Tbss	45	LM	87O11	AO-6	○			◎	△	◎	−	−		−	−	−	−	+							1061	0.7	3	<m. sand>
2	Tbss	35	L	87O12	AO-7	○			◎	△	○	−	−		−	−	+	−	−							1287	0.6	6.9	<m. sand>
2	Tf	108	M	87O13	AO-8	○	+		◎	△	◎	−	+		−	−	+	−				−				983	0.2	3.3	Pum. tuf. <w. pu. ball>
2	Sdtf	95	LM	87O14	AO-9	○	+	−	◎	+	○	−	−		−	−	+	−								1489	0.4	5.9	Sandy pu. tuf. or Pu tuff.
2	Tbss	70	LM	87O15a	AO-10	○			◎	+	○	−	+		−	−	+	−								1492	0.9	3.5	<m. sand>
2	Tbss	70	U	87O15b	AY-3	○			◎	+	○		+				+	−				−				1258	0.8	4.1	<f.sand>
2	Tbss	12	M	87O16	BA-2	○			○	+	○	−	−		−	·	+	+						−		2346	0.4	5	<vf. sand>
2	Tbss	90	LM	87O17a	AP-1	◎		−	○	+	○	−	+		−	−	−	−								1285	0.4	5.6	<vc. sd. with granules>
2	Tbss	40	M	87O18b	AP-2	○			○	+	○	−	−		−	−	+	−	−							1844	0.6	4.7	<m. sand>
2	Tf	175	LM	87O19	AP-3	○	◎	△	+	−	+		−				−									1222	5.2	1	Pu.tuf.<c.-vc. with gran.>
2	Tf	80	U	87O20	AP-4	○	◎	△	+	−	+		−				−									1012	5.7	0.6	Pum. tuf. <c-vc. pmice>
2	Tf	120	L	87O21	AO-4	○	○	△	○	+	○	−	+			−	−									1111	0.3	2.2	Pumice tuff <f. pumice>
2	Tbss			general		○			◎○	+△	◎○	−	−+		−	−	−△	−				(−)							

no augite. No significant differences are detected between the two samples collected from the different positions of a single bed. Heavy mineral composition of some tuffs are basically different from that of sandstones, but some others show similar features to that of sandstones.

Loc. 9

This locality, the type locality of the Siiya formation, is located along the coastal cliff at the Cape Kan'non (Fig. 10). The succession is made up of a sandstone-dominated alternation of turbidite sandstones and mudstones. The turbidite sandstones are mostly composed of proximal turbidite sandstones, usually less than 2 meters in thickness, composed of thick, graded, coarse-grained sandstones, and overlying thin laminated fine-grained sandstones. Granule to small pebbles are often included in the basal to the lower part of the graded sandstones. Rip-up clasts of mudstones are often observed in the upper part of the graded sandstones. Distal turbidite sandstones composed of thin-beded fine-grained laminated sandstones are also intercalated in the succession (Fig. 11). Samples were collected both from the several proximal turbidite sandstones, some of which were collected at a few positions within single beds, and from several distal turbidite sandstones. The results of heavy mineral analysis are shown in Table 5.

Heavy minerals are like those of the sandstones at locality 2, which are dominated by the two main components, opaque minerals and hornblende, the latter being composed mostly of green horblende and partly of brown and bluish green hornblende. Tremolite-actinolite and zircon are rare to very rare, but constantly included, and epidote, garnet, tourmaline and glaucophane are very rare to traceable in the most sandstone samples.

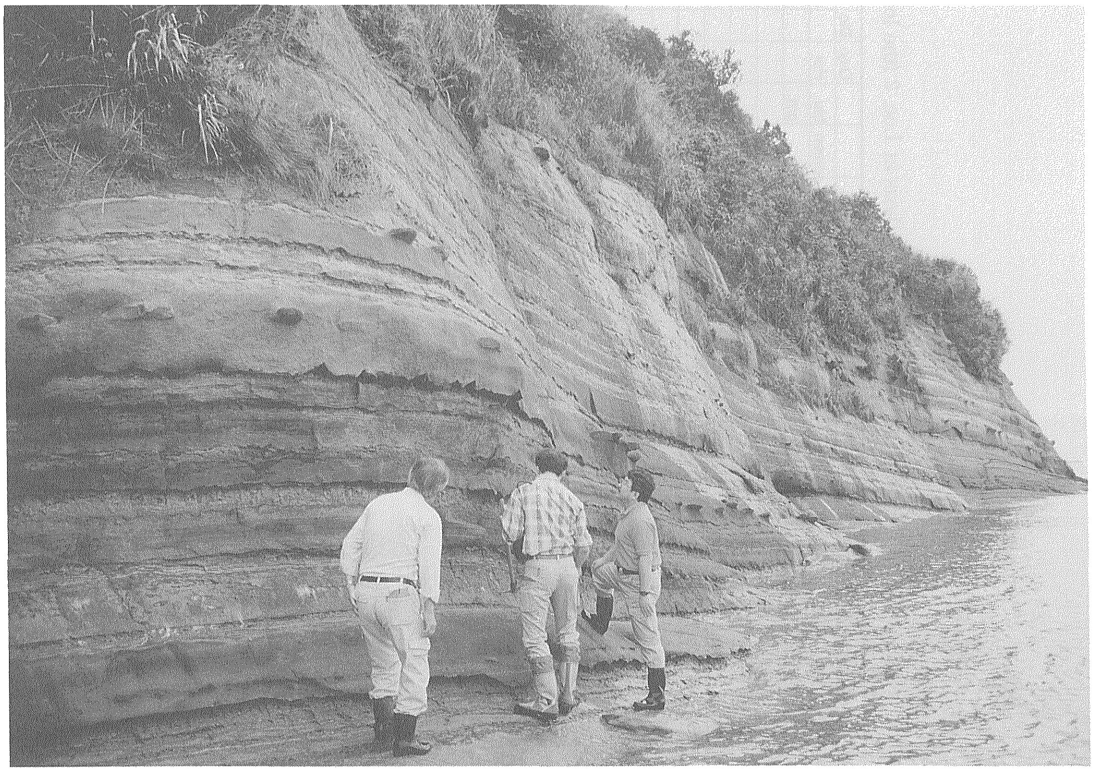

Fig. 10 An outcrop of the Shiiya formation at the type locality (Loc. 9).

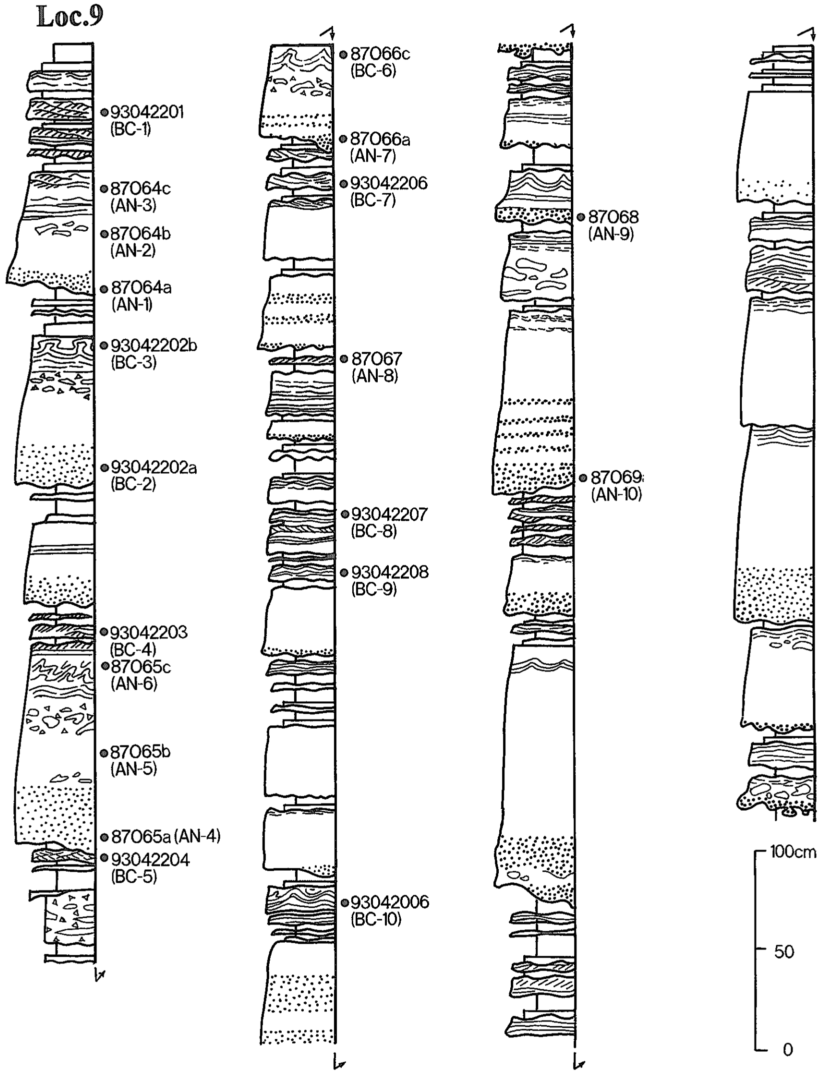

Fig. 11 Geologic column at Loc. 9 (the upper Shiiya formation). For the legend see Fig. 7A.

Loc. 11

This locality occupies the east wing of a local anticline and is located along the road stretched westward from Nishiyama town (Fig. 2) and the upper part of the Shiiya formation is outcropped here. Samples were collected from several successions along the road (Fig. 4 and Fig. 12). Sedimentary facies of the formation at this locality is nearly same as that of Loc. 9 except that proximal and distal turbidites tend to occur more collectively and alternatively in the vertical successions. Heavy mineral composition at this locality is summarized in Table 6.

Like the sandstones at Loc. 2 and Loc. 9, heavy minerals are almost occupied by the two components, i.e. opaque minerals and hornblende, the latter is mostly green hornblende and partly brown and bluish green hornblende. Tremmolite-actinolite is common to rare. Oxyhornblende, epidote, zircon and garnet are rare to very rare but constantly included. Glaucophane is very rarely observed in some fine-grained sandstones.

Loc. 12

This locality occupies the east wing of the main anticline at the Central ("Chuo") oil belt

Table 5 Results of heavy mineral analysis at Loc. 9 (the upper Shiiya formation). For the legend, see Table 1.

Loc.	Litho-	Thick-	Posi-	Sample No	Run No	Opq	Hyp	Aug	Hor				Oxy-	Dio	Tre-	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total	Hy	Mg	Lithologic feature
No.	logy	ness	tion						total	brn.	green	blu.	Hor		Act											CHMG	%	%	
		(cm)										grn.																	
9	Tbss	10	L	93042201	BC-1	○			◎	−	◎	+	−		+	+	+	+				−		−		1639	0.7	2	<vf-f. sand>
9	Tbss	50	LM	87064a	AN-1	○			○	△	○	+	−		+	−	+	−	−	−		−	−			1605	1.4	9.8	<vc. sand>
9	Tbss	50	M	87064b	AN-2	○			◎	△	○	+	−		+	−	+	−	−					−		1752	1	5	<c. sand>
9	Tbss	50	U	87064c	AN-3	○			◎	△	○	△	−		△	−	−	−				−	−			1971	0.3	5	<f. sand>
9	Tbss	74	LM	93042202a	BC-2	○			○	−	○	−	−		−	−	+	−				−	−			1447	1.3	7.8	<c. sand>
9	Tbss	74	UM	93042202b	BC-3	◎			○	−	○	−			+	−	+	−				−				3513	0.5	3.9	<vf-f. sand>
9	Tbss	5	A	93042203	BC-4	+			◎		◎	+			△	−	+	−				−		−		1477	0.2	4.7	<vf-f. sand>
9	Tbss	100	L	87065a	AN-4	○			◎	△	○	+	−		+	−	+	−		−						1776	0.8	10.8	<vc. sand>
9	Tbss	100	M	87065b	AN-5	○			◎	△	○	+			△	−	−	−						−		1213	0.3	7.9	<c. sand>
9	Tbss	100	UM	87065c	AN-6	◎			○	+	○	+			+	−	−	−								1805	0.6	4	<f. sand>
9	Tbss	50	LM	87066a	AN-7	○			◎	○	○	+	·		+	−	·	−			·	·	·	·		2433	1.3	10.9	<c. sand>
9	Tbss	5	A	93042204	BC-5	○			◎		◎	−			△	−	+	+				−		−		1707	0.7	2.6	<vf-f. sand>
9	Tbss	50	UM	87066c	BC-6	◎			○		○	−			+	−	+	−				−		−		1798	0.4	3.7	<f-vf. sand>
9	Tbss	6	A	93042206	BC-7	◎			○	−	○	−			+	−	+	+				−		·		3458	0.2	7.1	<vf-f. sand>
9	Tbss	3	A	87067	AN-8	◎			○	+	○	+			+	−	+	−			·		−	·		2478	0.8	16.9	<f. sand>
9	Tbss	5	A	93042207	BC-8	◎			○	−	○	−			−	−	+	−						·		4238	0.5	3 9	<vf-f. sand>
9	Tbss	8	A	93042208	BC-9	◎			△		△	−			+	·	+	−				−	·	−		3143	0.3	5.7	<vf-f. sand>
9	Tbss	15	L	93042006	BC-10	○			◎	+	◎	+			+	−	+	−				−	−	−		1751	0.3	5.3	<f-vf. sand>
9	Tbss	26	LM	87068	AN-9	◎			○	+	○	−	·		+	−	+	+								2019	2.2	14.6	<vc. sand>
9	Tbss	90	LM	87069	AN-10	○			◎	△	◎	+			+		−	−								1444	1.1	8.4	<vc. sand>
9	Tbss			general		◎○			◎○	−△	◎○	−+	(−)		+△	−	−+	−	(−)	(−)		(−)	(−)	(−)					

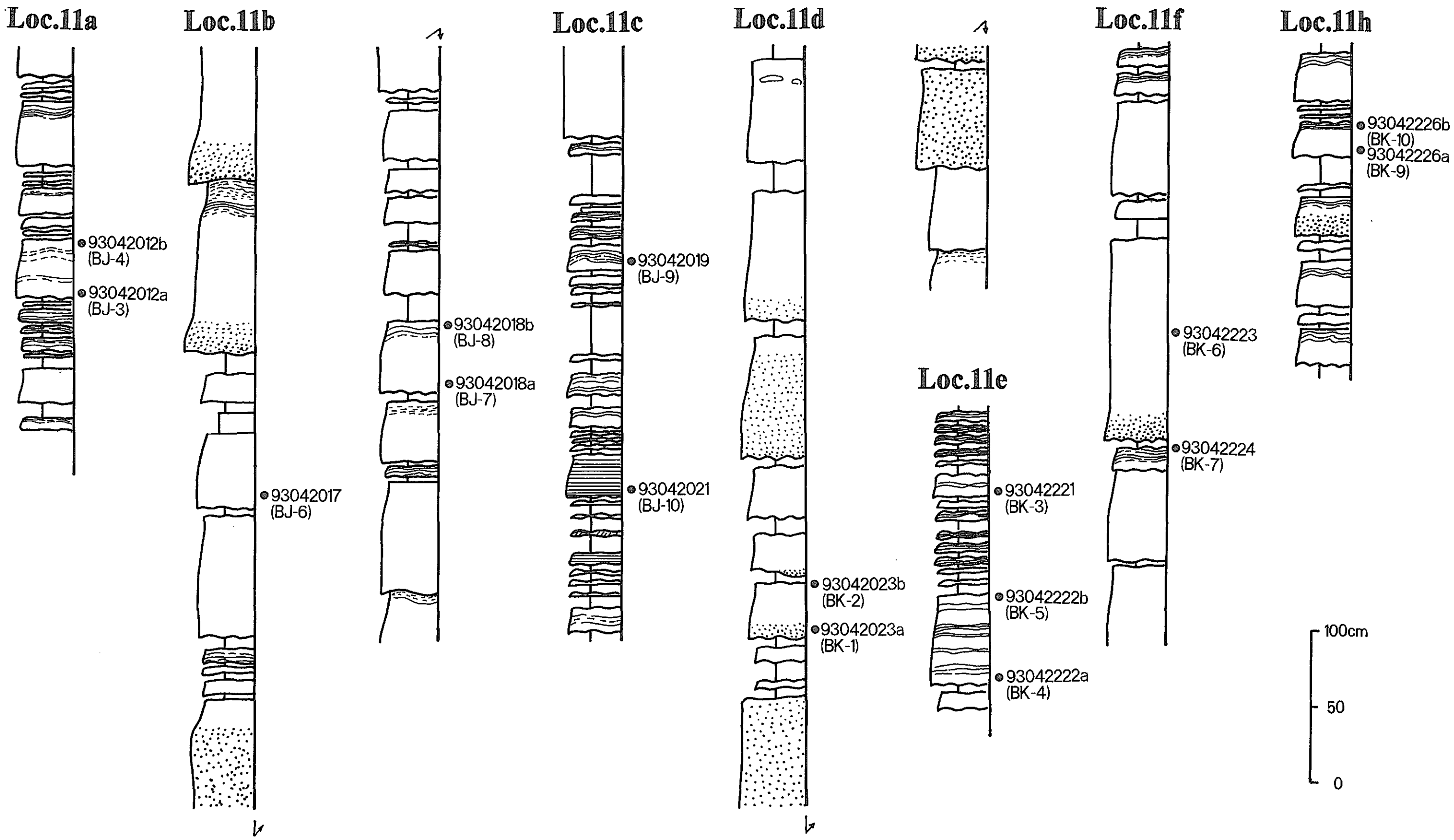

Fig. 12 Geologic columns at Loc. 11 (the upper Shiiya formation). For the legend see Fig. 7A.

Table 6 Results of heavy mineral analysis at Loc. 11 (the upper Shiiya formation). For the legend, see Table 1.

Loc. No.	Litho- logy	Thick- ness (cm)	Posi- tion	Sample No	Run No	Opq	Hyp	Aug	Hor total	brn.	green	blu. grn.	Oxy- Hor	Dio	Tre- Act	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total CHMG	Hy %	Mg %	Lithologic feature
11a	Tbss	40	LM	93042012a	BJ-3	○			◎	+	○	○			△	−	−	−								1217	1.7	5.9	<m. sand>
11a	Tbss	40	UM	93042012b	BJ-4	○			◎	+	◎	△	−		△	−	−	−				−				1262	0.7	8.8	<v. sand>
11b	Tbss	32	LM	93042014	BJ-5	○			◎	+	○	△	−		△	−	−	−								1058	1.5	9	<c-m. sand>
11b	Tbss	50	LM	93042017	BJ-6	○			◎	+	○	△	−		△	−	−						−			1105	2.1	7.4	<c-m. sand>
11b	Tbss	48	LM	93042018a	BJ-7	○			○	−	○	△	−		+	−	−	−								1327	1.8	8.3	<c-m. sand>
11b	Tbss	48	UM	93042018b	BJ-8	◎			○	−	○	+	−		+	−	−	·								2089	0.7	3.8	<vf-f. sand>
11c	Tbss	17	L	93042019	BJ-9	◎			○	+	○	+	+		+	+	+	−						−		1057	0.8	2.9	<f-vf. sand>
11c	Tbss	28	LM	93042021	BJ-10	+			◎	+	◎		△				−									1418	4.4	8.7	<m. sand>
11d	Tbss	36	LM	93042023a	BK-1	○			◎	+	◎	+	−		△	−	−	−								1459	1.4	9.6	<c-m. sand>
11d	Tbss	36	UM	93042023b	BK-2	○			◎	+	◎	+	−		+	+	−	−								1397	0.9	4.8	<f-vf. sand>
11e	Tbss	15	L	93042221	BK-3	○			◎	△	◎	+	−		+	−	+	−								1005	1	9.5	<f-vf. sand>
11e	Tbss	60	LM	93042222a	BK-4	◎		−	○	△	○	−	−		+	−	−	−								1250	6	18.6	<c-m. sand>
11e	Tbss	60	UM	93042222b	BK-5	○			◎	△	○		+		+	+	+	−				−		−		1350	1	10.5	<vf-f. sand>
11f	Tbss	130	M	93042223	BK-6	○			◎	△	◎		−		△	+	+	−								929	1.3	4.9	<c. sand>
11f	Tbss	15	U	93042224	BK-7	○			◎		◎		−		+	−	+	−		−				−		1165	0.7	6.2	<f. sand>
11g	Tbss	300+	M	93042225	BK-8	○		−	◎	△	◎	+	−		+	−	+	−		−						1220	0.7	5	<m-c. sand>
11h	Tbss	24	LM	93042226a	BK-9	○			◎	△	◎	−	−		+	−	+	−								1186	0.7	3	<c. sand>
11h	Tbss	24	UM	93042226b	BK-10	○			◎		◎		−		+	−	+	−								1133	20.2	0.1	<vf. sand>
11	Tbss			general		◎○			◎○	+△	◎○	+△	−+		+△	−+	−+	−		(−)		(−)		(−)					

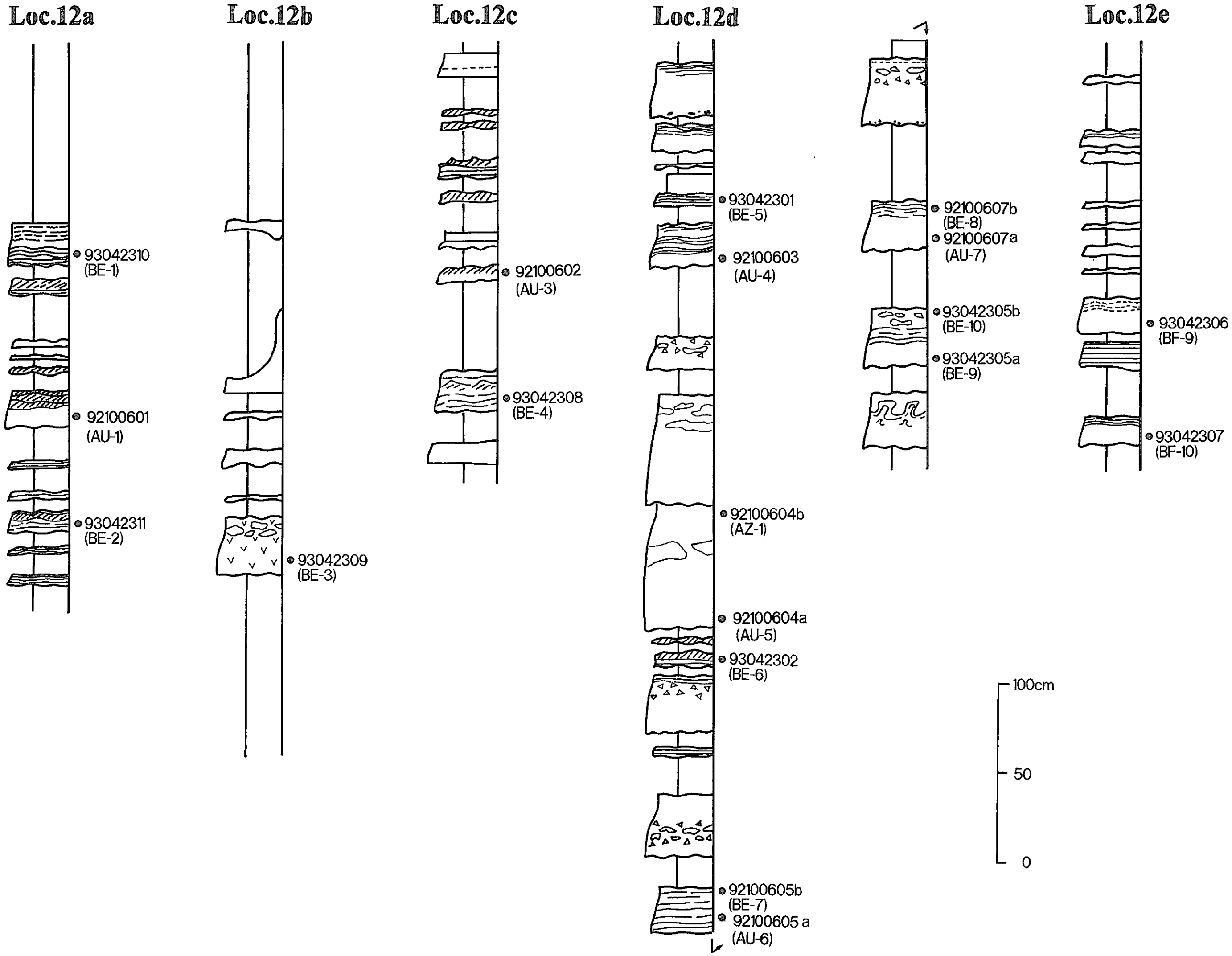

Fig. 13 Geologic columns at Loc. 12 (Shiiya formation). For the legend see Fig. 7A.

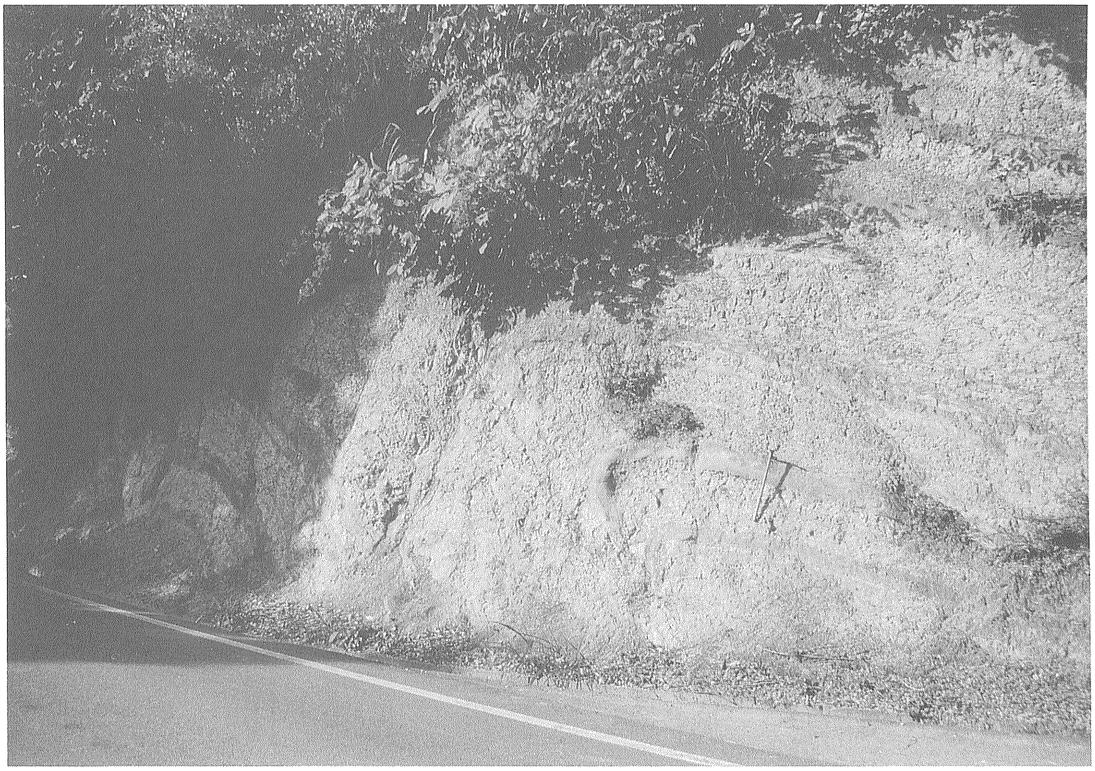

Fig. 14 An outcrop of the Shiiya formation at Loc. 12.

and each outcrop is located along the road traverse the Central ("Chuo") oil belt (Fig. 2 and Fig. 4). Samples were collected from several successions along the road (Fig. 13), one of which (Loc. 12a) shows slumped deposits (Fig. 14). Although the sandstones are composed both of proximal and distal turbidite sandstones like those at the Western ("Nishiyama") oil belt, the proximal turbidite sandstones seems to be thinner-bedded and finer-grained compared with those at the Western ("Nishiyama") oil belt.

The heavy mineral composition of sandstones at this locality is basically different from those at the localities along the Western ("Nishiyama") oil belt (Table 7). Because the latter sandstones, as mentioned above, are characterized by dominant to abundant opaque minerals and hornblende but very few hyperthene and augite; however, the sandstones at Loc. 12 in the Central ("Chuo") oil belt include not only opaque minerals and hornblende, but also dominant to abundant hypersthene and augite. Other minor minerals such as oxy-hornblende, tremolite-actinolite, epidote, zircon, garnet, tourmaline and glaucophane are also included.

Loc. 13

This locality occupies the west wing of the main anticline at the Central ("Chuo") oil belt and outcrops are along the small river across the Central ("Chuo") oil belt (Fig. 2 and Fig. 4). Samples were collected from several successions along the river (Fig. 15), one of which (Loc. 13g) is mostly composed of andesitic tuffs. Thick-bedded, coarse-grained, and thin-bedded, fine-grained turbidite sandstones are both observed in this locality; however, the occurrence of these turbidite sandstones is not so frequent compared with those along the Western ("Nishiyama") oil belt.

The characteristics of heavy mineral composition of the turbidite sandstones at this locality are very similar to those at Loc. 12 and, there-

Table 7 Results of heavy mineral analysis at Loc. 12 (Shiiya formation). For the legend, see Table 1.

Loc. No.	Litho-logy	Thick-ness (cm)	Posi-tion	Sample No	Run No	Opq	Hyp	Aug	Hor total	brn.	green	blu. grn.	Oxy-Hor	Dio	Tre-Act	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total CHMG	Hy %	Mg %	Lithologic feature
12a	Tbss	24	L	93042310	BE-1	△	○	△	○	−	○	△	+		−	−	−	−								662	3	1.7	<vf-f. sand>
12a	Tbss	20	L	92100601	AU-1	+	◎	○	△	−	△	−	−				−	−								1031	3.3	2.6	<f-vf. sand>
12a	Tf	12	L	93042311	BE-2	△	○	○	○	−	○	+	−		−	−	−					−		−		809	2.5	2	<vf-f. sand>
12b	Tbss	32	L	93042309	BE-3	+	◎	○																		984	21.8	1.1	<c-m. andesitic tuff>
12c	Tbss	6	M	92100602	AU-3	△	◎	△	○	+	○	−	−			−	−									1410	3.5	3.1	<vf-f. sand>
12c	Tbss	22	L	93042308	BE-4	+	○	△	○		○		−													998	10.1	2.8	<f-vf. sand>
12d	Tbss	5	A	93042301	BE-5	△	△	○	◎	+	○	○	−				−							−		792	2.3	2.3	<vf-f. sand>
12d	Tbss	24	LM	92100603	AU-4	+	◎	○	○	+	○		−			−	−									1049	3.4	2.3	<f-vf. sand>
12d	Tbss	75	LM	92100604a	AU-5	○	◎	△	△	+	△	−	−				−					−				1229	4.5	1.8	<c. sand>
12d	Tbss	75	UM	92100604b	AZ-1	△	◎	△	○	+	○		−				−									933	0.8	0.2	<f-vf. sand>
12d	Tbss	6	A	93042302	BE-6	+	○	○	○	+	○		−		−											918	3	2.4	<vf-f. sand>
12d	Tbss	25	LM	92100605a	AU-6	○	+	△	○	△	○	−	+.			+	+	−								1223	1.2	1.3	<f-vf. sand>
12d	Tbss	25	UM	92100605b	BE-7	○	○	△	○	+	○		+		+	−	+	−				−		−		710	2.8	2.4	<vf-f. sand>
12e	Tbss	28	LM	92100607a	AU-7	△	◎	△	△	+	△		−			−	−	−								1045	8	2.6	<c. sand>
12e	Tbss	28	UM	92100607b	BE-8	+	◎	○	△	−	△		−			−	−									1123	4	3.1	<f-vf. sand>
12e	Tbss	32	LM	93042305a	BE-9	△	◎	○	+	+	+		−				−									701	17.4	2.3	<f-m. sand>
12e	Tbss	32	UM	93042305b	BE-10	△	○	○	○	+	○		−				+	−								852	3.5	2.6	<vf-f. sand>
12f	Tbss	20	L	93042306	BF-9	△	○	○	△		△		−			−		−								830	6.1	7.3	<f-m. sand>
12f	Tbss	16	L	93042307	BF-10	△	○	◎	△		△		−			−	−							−		1111	3	2.2	<f-m. sand>
12	Tbss			general		+○	◎○	○△	○△	−+	○△	−○	−		(−)	(−)	−+	(−)						(−)					

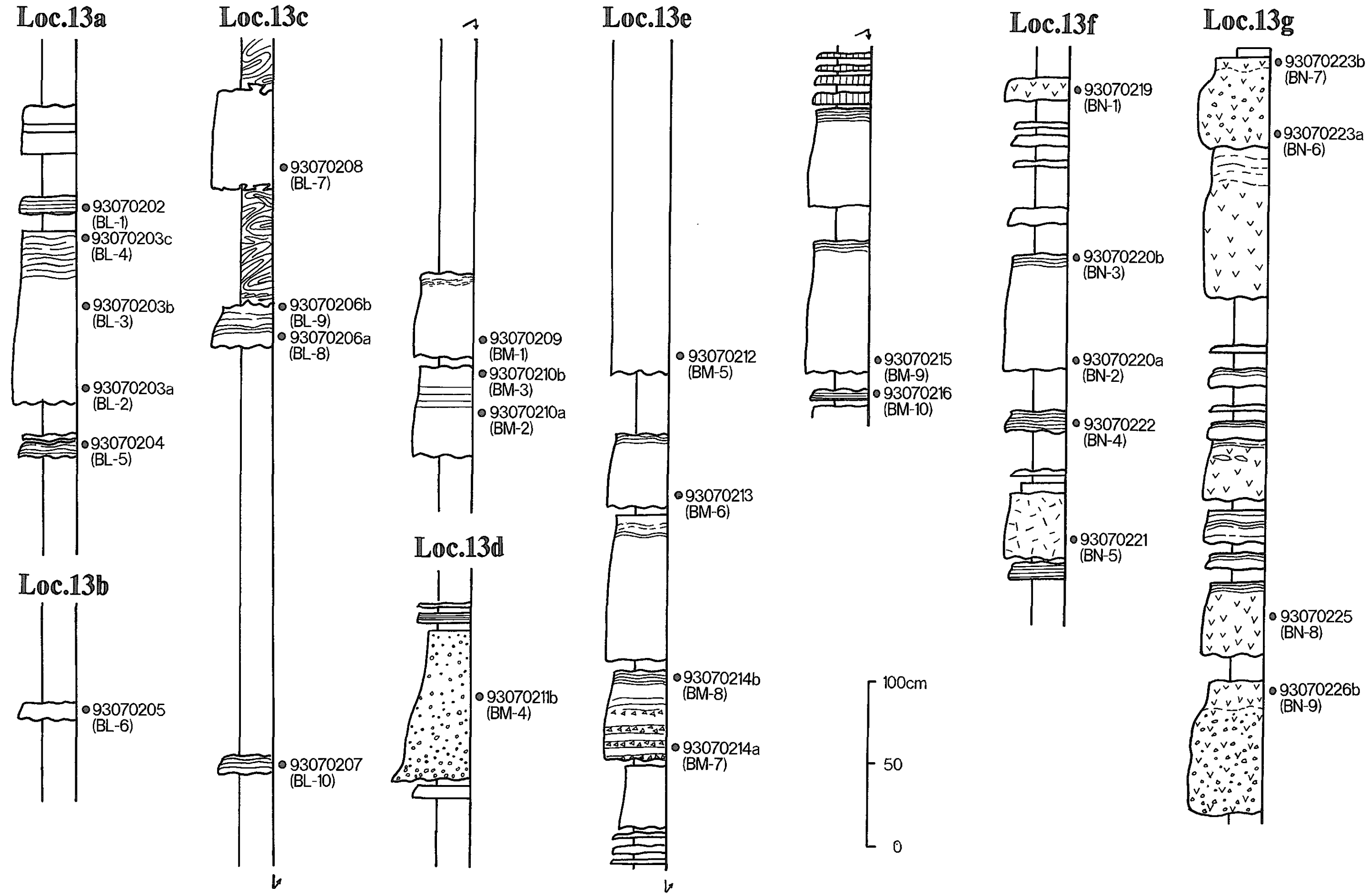

Fig. 15 Geologic columns at Loc. 13 (Shiiya formation). For the legend see Fig. 7A.

Table 8 Results of heavy mineral analysis at Loc. 13 (Shiiya formation). For the legend, see Table 1.

Loc. NO.	Litho.	Thick-ness (cm)	Posi-tion	Sample No	Run No	Opq	Hyp	Aug	Hor total	brn.	green	blu. grn.	Oxy-Hor	Dio	Tre-Act	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total CHMG	Hy %	Mg %	Lithologic feature
13a	Tbss	10	L	93070202	BL-1	+	○	△	◎	+	◎	−	+		−		−									1018	26.3	21.2	<f-vf. sand>
13a	Tbss	100	LM	93070203a	BL-2	+	○	△	◎	−	◎		+				−									1341	29.5	18.3	<m-c. sand>
13a	Tbss	100	M	93070203b	BL-3	+	○	△	○	+	○		△			−										1006	10.1	6.9	<f. sand>
13a	Tbss	100	UM	93070203c	BL-4	+	○	△	◎	+	◎		+													1027	13.5	8.4	<f-vf. sand>
13a	Tbss	12	M	93070204	BL-5	+	○	○	○	+	○	△				−										586	2.4	2.2	<f-vf. sand>
13b	Tbss	10	M	93070205	BL-6	○	○	△	○	△	△		−			−	−									828	1.9	1.4	<f-vf. sand>
13c	Tbss	60	L	93070208	BL-7	○	○	○	○	+	○		−				−									1065	3.2	4.7	<c-m. sand>
13c	Tbss	25	LM	93070206a	BL-8	△	○	○	○	+	△		−			−	−									820	3.4	3	<c. sand>
13c	Tbss	25	UM	93070206b	BL-9	△	○	○	○	+	○		−			−	−	−						−		989	0.7	3.9	<vf-f. sand>
13c	Tbss	10	M	93070207	BL-10	+	○	○	△	+	△		−			−										660	2.7	2	<vf-f. sand>
13c	Tbss	50	L	93070209	BM-1	○	○	○	○	+	○		−		−	−	−	−								1748	1.6	3.9	<m-f. sand>
13c	Tbss	55	M	93070210a	BM-2	○	◎	○	△	−	+		−		−	−										1553	3.4	1.5	<f. sand>
13c	Tbss	55	UM	93070210b	BM-3	○	○	○	△	−	△	−	−			−	−							−		1559	2.9	0.9	<vf-f. sand>
13d	Tbss	90	M	93070211b	BM-4	○	○	○	△	−	+		−		−											1048	4.7	2	<m-c. sand>
13e	Tbss	200+	LM	93070212	BM-5	○	○	○	○	+	○		−		−	−	−	−								1111	1.7	3.6	<m. sand>
13e	Tbss	45	L	93070213	BM-6	○	○	○	○	+	○	−	−		−	−	−	−								1057	1.9	4.4	<m. sand>
13e	Tbss	55	LM	93070214a	BM-7	+	◎	○	+	−	+		−													766	16.8	0.7	<m. sand>
13e	Tbss	55	UM	93070214b	BM-8	△	○	○	△	+	△		−			−	−									755	2.3	1.5	<vf. sand>
13e	Tbss	80	LM	93070215	BM-9	○	○	△	○	−	○	−	−		−	−	−	−								1360	1.6	6.6	<m. sand>
13e	Tbss	5	A	93070216	BM-10	◎	−	−	○	−	○		−		+	−	−	−								3882	2.4	1.2	<vf. sand>
13f	Tf	13	A	93070219	BN-1	○	○	△	△	+	△						−									1373	6.9	4	<andesitic c. tuff>
13f	Tbss	70	LM	93070220a	BN-2	○	○	+	△	+	△	−	−		−	−	−	−								1229	4.8	2.2	<c-m. sand>
13f	Tbss	70	UM	93070220b	BN-3	○	○	△	○	+	△	−	−		−	−	−	−								1412	4	2.3	<f-vf. sand>
13f	Tbss	12	A	93070222	BN-4	○	○	△	○	+	○	−	−		−	−	−	−								1905	1.9	1.2	<f-vf. sand>
13f	Tf	40	L	93070221	BN-5	○	○	△	○	+	△		+		−	−	−									1323	3.3	1.7	<f-vf. glassy tuff>
13g	Tf	50	L	93070223a	BN-6	○			◎	−	◎	−	−		−											1576	3	17.4	<andesitic vc-gr. tuff>
13g	Tf	50	UM	93070223b	BN-7	○			○	−	○	−	−		−	−	−									1287	0.9	8.1	<andesitic f. tuff>
13g	Tf	45	M	93070225	BN-8	△			◎		◎	−	−		−		−	−								1241	0.6	3.9	<andesitic f-m. tuff>
13g	Tf	80	U	93070226b	BN-9	◎	−	+	○	+	○				−	−	−									1281	7.4	28.2	<andesitic f-m. tuff>
13	Tbss			general		+○	○	○△	△◎	−+	△◎	(−)	−+		(−)	−	−	(−)						(−)					

fore, basically different from those along the Western ("Nishiyama") oil belt. Andesitic tuffs at Loc. 13g are characterized by dominant to abundant opaque minerals and hornblende, and very few hypersthene and augite (Table 8).

5.2.2 Summary

In the Western ("Nishiyama") oil belt, the heavy mineral composition of turbidite sandstones of the Shiiya formation is fairly different from those of the underlying Teradomari formation. The former sandstones include both of opaque minerals and hornblende dominantly to abundantly, while the latter sandstones include dominant opaque minerals but very few hornblende. However, some sandstones of the uppermost Teradomari formation (Loc. 8) show some similarity to those of the overlying Shiiya formation, because they include rare to very rare hornblende.

The heavy mineral composition of turbidite sandstones of the Shiiya formation in the Western ("Nishiyama") oil belt are basically different from those in the Central ("Chuo") oil belt, though they both belong to the same horizon and the same formation, i.e. the Shiiya formation. The former sandstones are characterized by dominant to abundant opaque minerals and hornblende, and very few hypersthene and augite. On the other hand, the latter sandstones include not only opaque minerals and hornblende, but also dominant to abundant hypersthene and augite.

5.3 Nishiyama formation

The main part of the formation is comprized mostly of massive light grey to greysh green siltstone and partly of interbedded acidic to andesitic volcanic ash layers or tuffs. The main part, which is distributed in the Western ("Nishiyama") and Central ("Chuo") oil belts, attains more than 400 meters in maximum thickness and decreases its thickness both eastward and southward (Suzuki *et al.*, 1974; Kurokawa *et al.*, 1992).

In the Western ("Nishiyama") oil belt, the main part of the formation is underlain by two members, i.e. the Hamatsuda alternation member and the Inagawa sandstone member.

Hamatsuda alternation member

This alternation, which conformably overlies the Shiiya formation, is made up mostly of an alternation of fine-grained and thin-bedded, i.e. distal turbidite sandstones, and light grey to greysh green siltstones, and partly of massive siltstones. Some acidic tuffs are intercalated in the alternation. The alternation attains more than 250 meters or about 400 meters in maximum thickness (Suzuki *et al.*, 1974; Kurokawa *et al.*, 1992).

Inagawa sandstone member

This sandstone conformably overlies the Hamatsuda alternation member and is formed mostly of thick-bedded coarse-grained, proximal turbidite sandstones and partly of interbedded light gray siltstones. The sandstone often includes pebbles and rip-up siltstone clasts. The sandstone thickens northward and attains about 120 meters in maximum thickness (Suzuki *et al.*, 1974; Kurokawa *et al.*, 1992).

5.3.1 Heavy mineral composition of the Nishiyama formation

Heavy mineral analysis of the Nishiyama formation was conducted for the turbidite sandstones both of the Hamatsuda alternation member (Loc. 10, Loc. 3 and Loc.4) and the Inagawa sandstone member (Loc. 5 and Loc. 6).

Loc. 10

This locality is located near the type locality of the Hamatsuda alternation member. Here occurs the lower part of the member and distal turbidite sandstones, i.e. thin-bedded fine-grained turbidite sandstones, are intercalated in the light gray mudstones (Fig. 16).

Sandstones at this locality include abundant to dominant opaque minerals and hornblende (mostly green hornblende) ; and oxyhornblende, tremolite-actinolite, epidote, zircon and garnet are rare to very rare, but constant. They sometimes include tourmaline and glaucophane (Table 9). The characteristics of the heavy mineral composition is very similar to those of the underlying Shiiya formation (e.g. Loc. 9 and Loc. 11).

Loc. 3

At this locality occurs the middle part of the

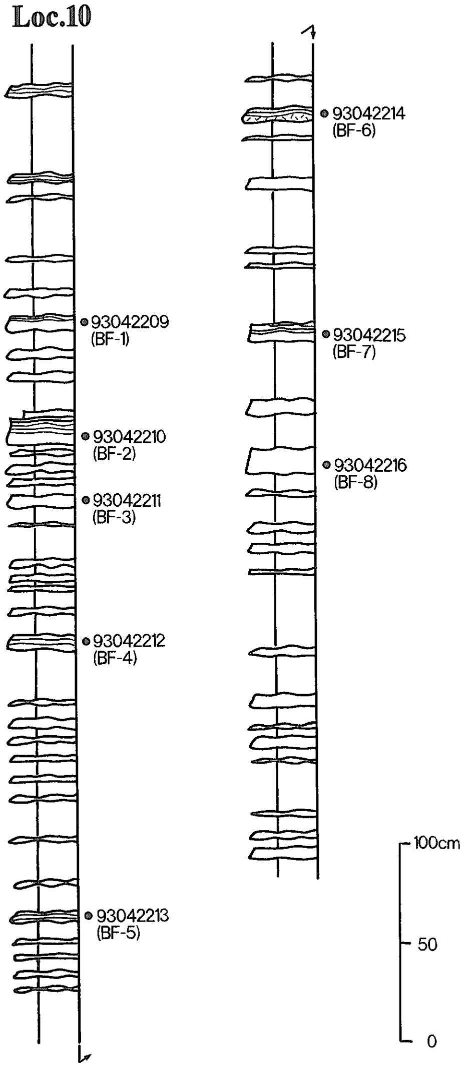

Fig. 16 Geologic column at Loc. 10 (the lower Hamatsuda alternation member). For the legend see Fig. 7A.

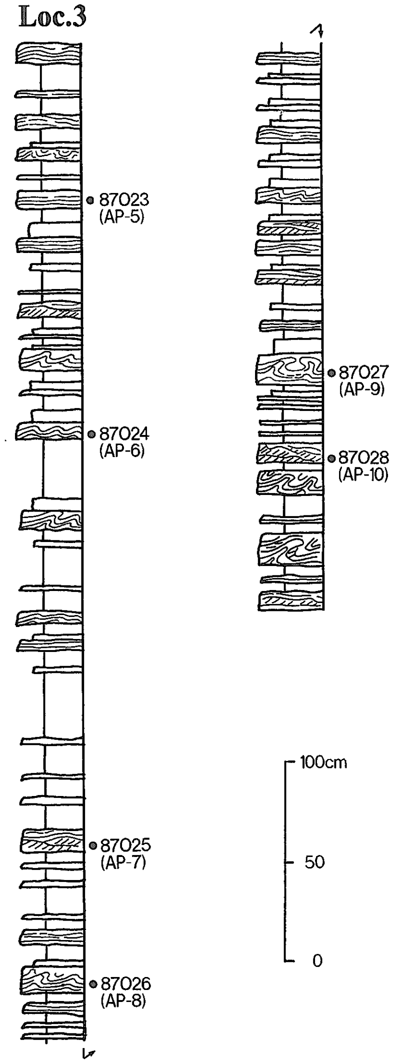

Fig. 17 Geologic column at Loc. 3 (the middle Hamatsuda alternation member). For the legend see Fig. 7A.

Hamatsuda alternation member. The sandstones are all thin-bedded and fine-grained turbidite sandstones. They yield various kinds of laminations such as parallel lamination, convolute lamination, and current-ripple lamination (Fig. 17).

The characteristics of the heavy mineral composition of these sandstones are nearly the same as those of the lower part of the Hamatsuda alternation member at Loc. 10. Glaucophane is constantly observed here (Table 10).

Loc. 4

The uppermost part of the Hamatsuda alternation member is observed here. Most sandstones are composed of thin-bedded fine-grained turbidite sandstones, but some sandstones exceed 50 cm in thickness (Fig. 18 and Fig. 19). Many laminated structures are also observed in these sandstones like those at Loc. 3.

Here, a slightly different heavy mineral composition is observed compared to those of the middle and lower parts of the Hamatsuda alter

Table 9 Results of heavy mineral analysis at Loc. 10 (the lower Hamatsuda alternation member). For the legend, see Table 1.

Loc. No.	Litho-logy	Thick-ness (cm)	Posi-tion	Sample No	Run No	Opq	Hyp	Aug	Hor total	brn.	green	blu. grn.	Oxy-Hor	Dio	Tre-Act	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total CHMG	Hy %	Mg %	Lithologic feature
10	Tbss	7	A	93042209	BF-1	○			○	△	○	+	+		+	+	△	+	−			−		−		1028	1.1	0.9	<vf-f. sand>
10	Tbss	12	L	93042210	BF-2	○			◎	+	◎		−		+	−	+	−								1122	0.8	3.8	<vf-f. sand>
10	Tbss	5	A	93042211	BF-3	○			◎	+	◎		−		+	−	+	−								1149	0.9	1.8	<vf-f. sand>
10	Tbss	5	A	93042212	BF-4	○			◎	+	◎	−	−		+	−	+	−								1036	0.8	2.1	<vf-f. sand>
10	Tbss	5	A	93042213	BF-5	○			◎	+	◎		−		+	−	+	−		−		−		−		1690	0.5	2.7	<vf-f. sand>
10	Tfss	7	A	93042214	BF-6	△	◎	+	○	+	○	−	+		−	−	−	−								1019	0.9	4.4	<f-vf. tuffa. sand>
10	Tbss	8	A	93042215	BF-7	○			◎	+	◎		−		+	+	+	−								1086	0.5	21	<f-vf. sand>
10	Tbss	12	L	93042216	BF-8	○			◎	−	◎	−	−		+	+	+	−								808	0.7	1.1	<f-vf. sand>
10	Tbss			general		○			◎	+	◎	(−)	−		+	−+	+	−				(−)		(−)					

Table 10 Results of heavy mineral analysis at Loc. 3 (the middle Hamatsuda alternation member). For the legend, see Table 1.

Loc. No.	Litho-logy	Thick-ness (cm)	Posi-tion	Sample No	Run No	Opq	Hyp	Aug	Hor total	brn.	green	blu. grn.	Oxy-Hor	Dio	Tre-Act	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total CHMG	Hy %	Mg %	Lithologic feature
3	Tbss	9	M	87023	AP-5	△	−	−	◎	+	◎	−	+			−	+	−						−		1921	1	2.8	<vf. sand>
3	Tbss	8	M	87024	AP-6	△	−	−	◎	+	◎	−	−			+	+	−						−		1775	0.9	8.1	<vf. sand>
3	Tbss	12	M	87025	AP-7	△	−	−	◎	△	◎	+	+			+	+	−						+		1181	0.8	1.7	<vf. sand>
3	Tbss	15	M	87026	AP-8	○	−	−	◎	△	◎	−	+			+	+	−						−		1815	0.8	1.7	<vf. sand>
3	Tbss	15	M	87027	AP-9	○	−	−	◎	△	◎	−	+			+	+	−				−		−		1817	0.5	5.2	<vf. sand>
3	Tbss	10	M	87028	AP-10	○	−	−	◎	△	◎	+	+			+	△	+						+		1988	0.3	5.4	<vf. sand>
3	Tbss			general		△○	−	−	◎	+△	◎	−+	+			+	+	−						−+					

Fig. 18 An outcrop of the Hamatsuda alternation member (Loc. 4).

nation member at Loc. 10 and Loc. 3, because abundant to common hypersthene and augite are observed as well as opaque minerals and hornblende in some sandstones at Loc. 4 (Table 11). This characteristics are observed in the sandstones of the overlying Inagawa sandstone member.

Loc. 5

Here occurs the lower part of the Inagawa sandstone member. Many thick-bedded coarse-grained turbidite sandstones as well as thin-bedded fine-grained turbidite sandstones form the sandstone-dominated alternation (Fig. 20 and Fig. 21).

Heavy minerals of these sandstones are characterized by dominant to abundant opaque minerals and hornblende, and abundant to common hypersthene and augite. Abundant oxyhornblende are included in some sandstones. Rare to very rare epidote, zircon and garnet are included in some sandstones (Table 12).

Loc. 6

The lowermost part of the Inagawa sandstone member is observed at Loc.6. Thick-bedded and coarse-grained turbidite sandstones are dominant (Fig. 22). The characteristics of heavy mineral composition of these sandstones are the same as those at Loc. 5. Hypersthene and augite as well as opaque minerals and hornblende are dominant. Oxyhornblende, epidote, zircon, garnet are rare to very rare but nearly constant. Very rare glaucophane are observed in some sandstones (Table 13).

5.3.2 Summary

The sandstones of the Hamatsuda alternation member, conformably overlying the Shiiya formation, have nearly the same characteristics as those of the underlying Shiiya formation, except for some sandstones in the uppermost part of the Hamatsuda formation, which show some similarity with the overlying Inagawa sandstone member. The sandstones of the Ina-

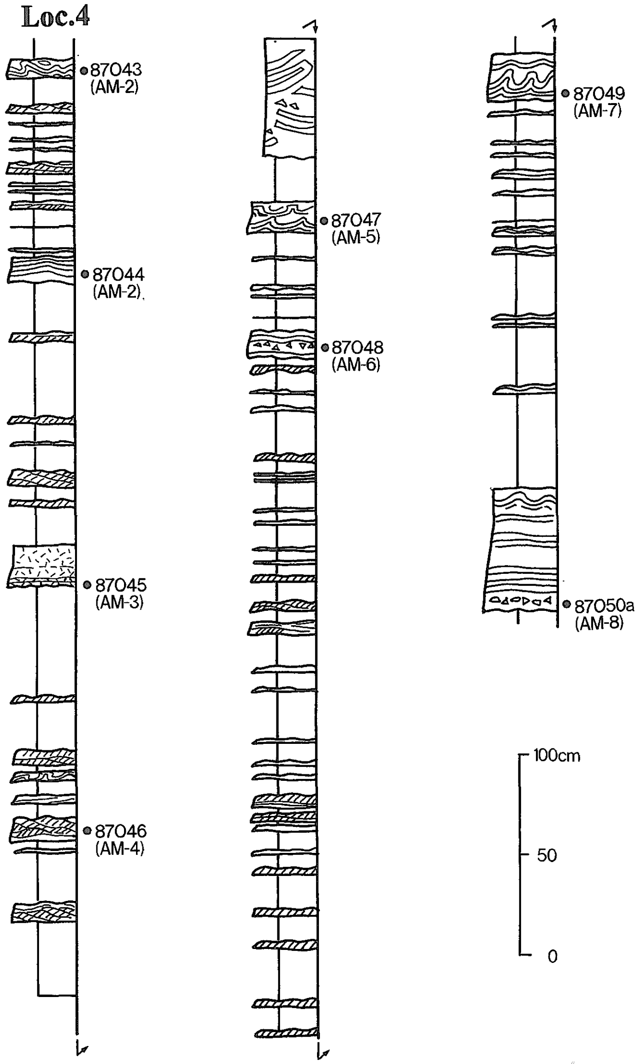

Fig. 19 Geologic column at Loc. 4 (the uppermost Hamatsuda alternation member). For the legend see Fig. 7A.

gawa sandstone member have different characteritics of heavy mineral composition from those of the underlying Hamatsuda alternation member. The former sandstones include dominant to common hypersthene and augite as well as dominant to common opaque minerals and hornblende. On the other hand, the latter sandstones includes dominant to abundant opaque minerals and hornblende, but very few hypersthene and augite.

6. Discussion

The results of heavy mineral analysis of turbidite sandstones and volcanic ash layers (tuffs) of the Teradomari formation, Shiiya formation, Hamatsuda alternation member and Inagawa sandstone member of the Nishiyama formation sampled at 13 localities in the Western ("Nishiyama") and Central ("Chuo") oil belts were shown before. Sampling position, thickness, and grain size of the analysed samples were also

Table 11 Results of heavy mineral analysis at Loc. 4 (the uppermost Hamatsuda alternation member). For the legend, see Table 1.

Loc.	Litho-	Thick-	Posi-	Sample No	Run No	Opq	Hyp	Aug	Hor				Oxy-	Dio	Tre-	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total	Hy	Mg	Lithologic feature
No.	logy	ness	tion						total	brn.	green	blu.	Hor		Act											CHMG	%	%	
		(cm)										grn.																	
4	Tbss	10	L	87043	AM-1	△	+	+	◎	+	◎	+	△			−		−								1190	1.7	1.8	<f-vf. sand>
4	Tbss	12	L	87044	AM-2	△	+	+	◎	−	◎	+	−				−									1498	1.7	2.9	<f. sand>
4	Tf	9	L	87045	AM-3	△	◎	○	−		−															1229	5.2	2.2	Glassy tuff<m-vf.>
4	Tbss	12	L	87046	AM-4	○	△	△	○	△	○	+	△			+	+	−		−				−		1429	1.9	3.1	<f. sand>
4	Tbss	16	L	87047	AM-5	△	+	△	◎	△	○	△	△			−	−	−						−		1067	1.3	4.7	<f-vf. sand>
4	Tfss	13	L	87048	AM-6	○	△	○	△	+	△		−			−	−									1667	0.4	5.6	<m. pumic. sand>
4	Tbss	23	LM	87049	AM-7	△	○	○	○	△	○	+	+			+	−	−						−		1054	1.6	4.2	<f. sand>
4	Tbss	62	LM	87050a	AM-8	△	△	△	○	△	○	−	○													1529	1 2	3.1	<m-c. sand>
4	Tbss			general		○△	○△	+○	◎○	+△	◎○	+	△−			−+	−	(−)						(−)					

Table 12 Results of heavy mineral analysis at Loc. 5 (the lower Inagawa sandstone member). For the legend, see Table 1.

Loc.	Litho-	Thick-	Posi-	Sample No	Run No	Opq	Hyp	Aug	Hor				Oxy-	Dio	Tre-	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total	Hy	Mg	Lithologic features
No.	logy	ness	tion						total	brn.	green	blu.	Hor		Act											CHMG	%	%	
		(cm)										grn.																	
5	Tfss	100+	LM	87036	AL-1	△	○		◎	−	◎	−	−				·					·				2014	3.8	27.9	<vc. sand with granule>
5	Tfss	240	L	87037b	AL-2	△	○		◎	−	◎	−	−				−	−								1474	1.7	34.4	Pumiceous sand
5	Tf	80	L	87037a	AL-3	◎	+		○	−	○	+	−			·	+	+								2462	0.1	28.1	Glassy tuff <f. tuff>
5	Tbss	90	LM	87038a	BA-3	○	○	○	○	+	○	+	+		−	−	+	+								772	1.1	7.5	<vc. sand with granule>
5	Tbss	90	U	87038b	AL-4	△	○	+	◎	△	○	○	+				−					−				866	0.5	5.8	<m. sand>
5	Tbss	200	U	87039b	AL-5	○	△	+	◎	△	○	○	+													727	0.5	5	<f. sand>
5	Tbss	200	LM	87039a	AL-6	○	+	+	◎	+	○	○	+				−									806	0.6	6.2	<m. sand>
5	Tbss	50	LM	87040	AL-7	○	△	○	○	+	△	△	○				−									1412	2.9	7.3	<m. sand>
5	Tbss	45	L	87040.5	AL-8	○	△	△	○	△	○	○	+				−	−								899	0.8	9.9	<m. sand>
5	Tbss	100	L	87041	AL-9	○	△	△	○	+	○	○	△			−		−								922	0.7	7.8	<m. sand>
5	Tbss	80	L	87042a	AL-10	○	○	○	○	△	△	+	○			−	−	−								1784	5.2	9.1	<gravelly sand>
5	Tbss	80	U	87042b	AY-4	△	○	○	○	+	○	−	○				−	−								845	2.5	2.5	<vf. sand>
5	Tbss			general		○△	○△	+○	◎○	+△	△◎	+○	+○			(−)	−	(−)											

Fig. 20 An outcrop of the Inagawa sandstone member (Loc. 5).

shown on the geologic columns and table at each locality. The following discussion is based on these data.

Tokuhashi (1992) classified the turbidite sandstones distributed in the southern part of the Eastern ("Higashiyama") oil belt into four types, i.e. Type I, TypeI-II, Type II and Type III, based on the combination of the quantitatively major heavy minerals such as opaque minerals, hornblende, hypersthene, and augite. The definition of these types are summarized in Table 14. The same types can be recognized in the turbidite sandstones in the Western ("Nishiyama") and Central ("Chuo") oil belts (Table 15).

Opaque minerals, hornblende, hypersthene, and augite constitute the quantitatively major heavy minerals in this area. Zircon and garnet are quantitatively minor heavy minerals, but occur constantly. Oxyhornblende, tremolite-actinolite, epidote, tourmaline, allanite, and glaucophane occur as quantitatively minor minerals, but not so constantly.

The heavy mineral composition of volcanic ash layers is usually different from that of the turbidite sandstones at the same locality. However, the heavy mineral composition of turbidite sandstones at each locality has, more or less, the same or common characteristics, that is, turbidite sandstones at each locality can be represented by the specific generalized heavy mineral composition.

As shown in Table 15, the turbidite sandstones of one formation or one member are represented by one type or closely related two types. For example, the turbidite sandstones of the main part of the Teradomari formation are represented by Type I, though those of the uppermost part by Type I and Type I-II. Those of the Shiiya formation are represented by Type II or Type I-II. Those of the main body of the Hamatsuda alternation member of the Nishiyama formation can be marked by Type II, though those of the uppermost part by Type

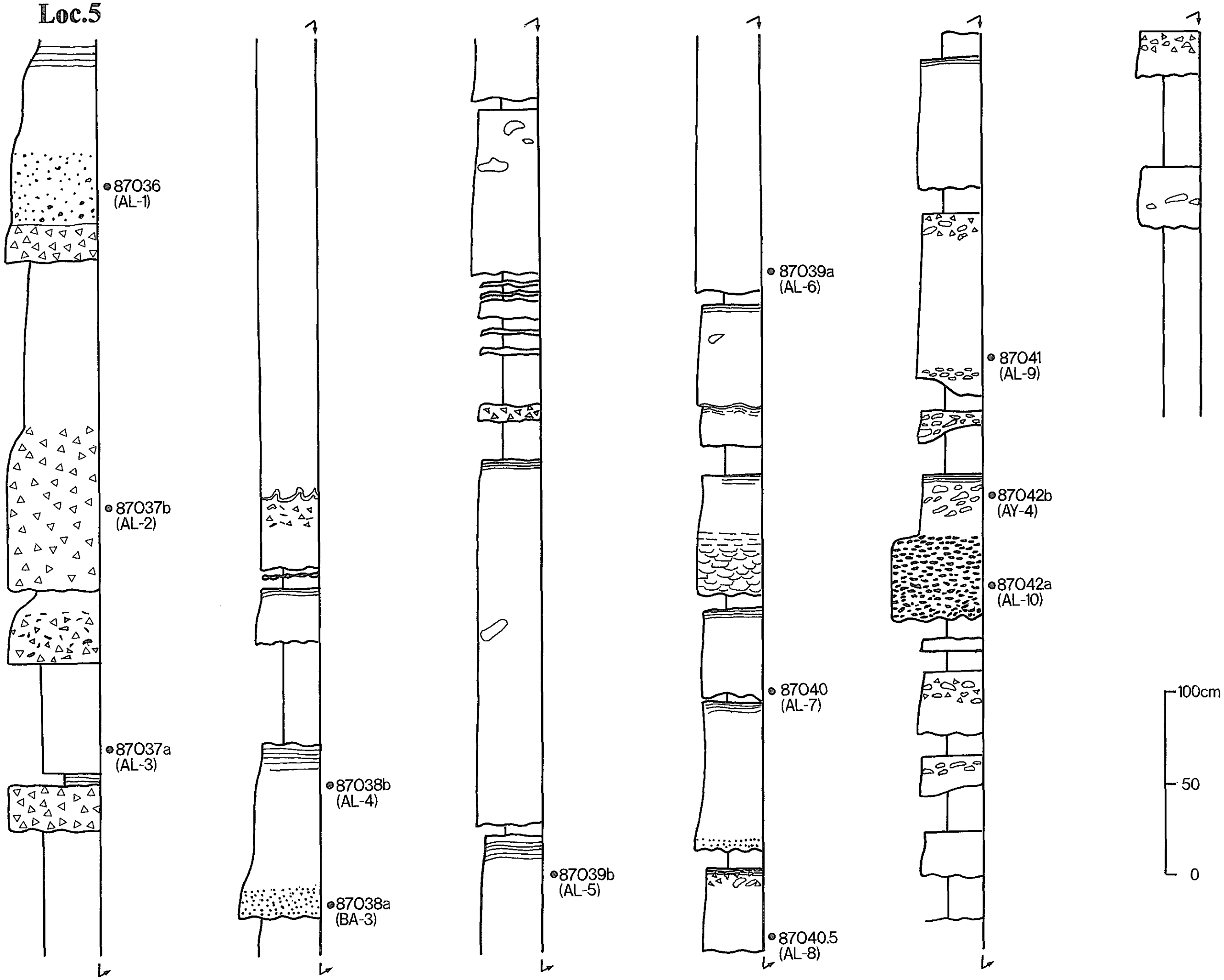

Fig. 21 Geologic column at Loc. 5 (the lower Inagawa sandstone member). For the legend see Fig. 7A.

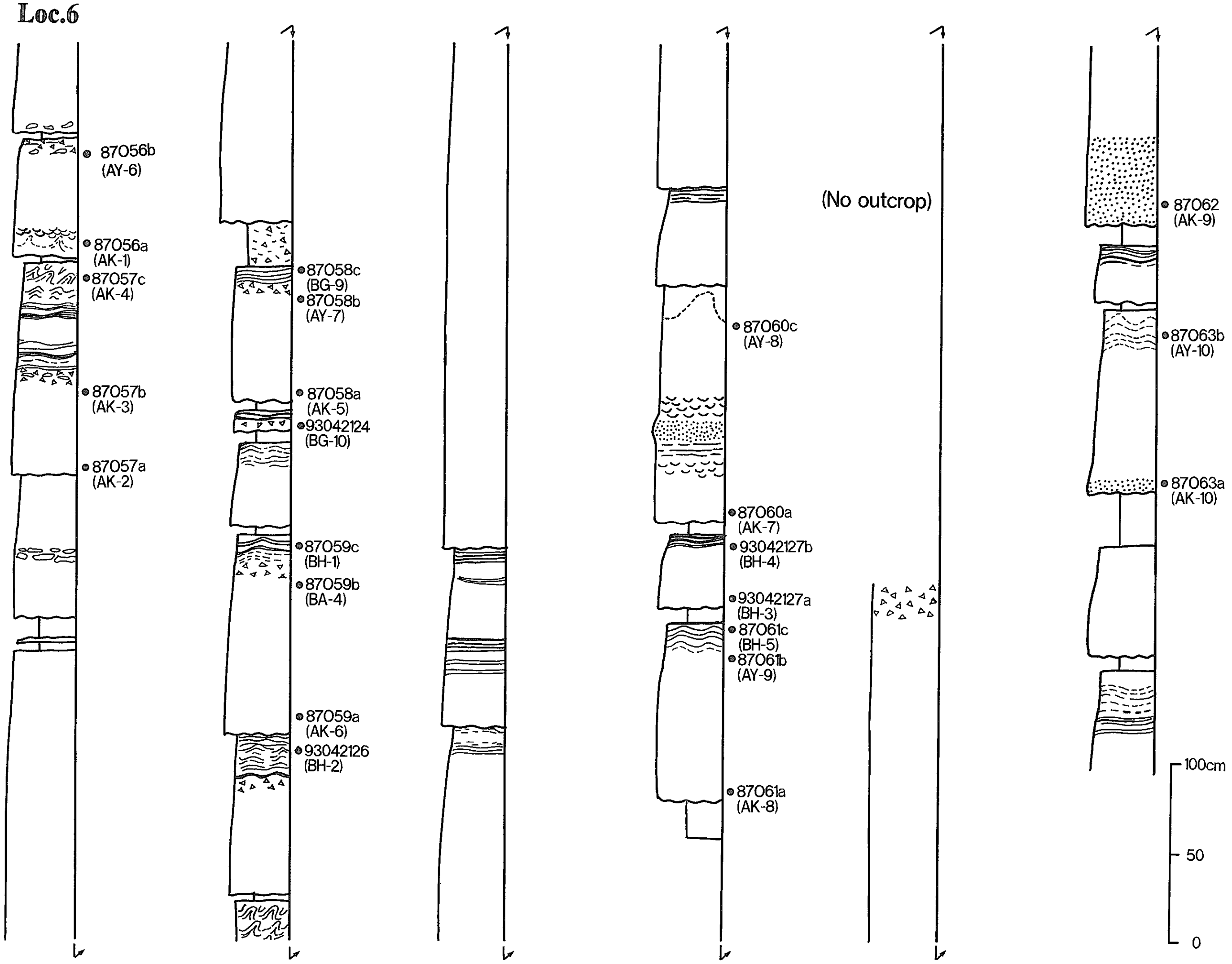

Fig. 22 Geologic column at Loc. 6 (the lower Inagawa sandstone member). For the legend see Fig. 7A.

Table 13 Results of heavy mineral analysis at Loc. 6 (the lower Inagawa sandstone member). For the legend, see Table 1.

Loc. No.	Litho-logy	Thick-ness (cm)	Posi-tion	Sample No	Run No	Opq	Hyp	Aug	Hor total	brn.	green	blu. grn.	Oxy-Hor	Dio	Tre-Act	Epi	Zir	Gar	Sph	Ana	Rut	Tou	Al	Gla	Oth	Total CHMG	Hy %	Mg %	Lithologic feature
6	Tbss	65	LM	87056a	AK-1	△	○	○	○		△	△	+			−	+									923	2.2	4	<m. sand>
6	Tbss	65	UM	87056b	AY-6	△	○	○	○	+	○	−	+			+	−	−								895	1.2	4.1	<f. sand>
6	Tbss	120	LM	87057a	AK-2	△	○	○	○	+	○	△	+			−	−									911	1.3	2.5	<m. sand>
6	Tbss	120	M	87057b	AK-3	○	○	○	○	+	△	△	+			−	−									1645	1.6	2.1	<f. sand>
6	Tbss	120	UM	87057c	AK-4	△	+	○	○	+	○	+	+			+	−							−		1071	1.7	2	<vf. sand>
6	Tbss	75	LM	87058a	AK-5	○	○	○	○	+	○	△	−			−	−									1196	2.3	3.8	<m. sand>
6	Tbss	75	U	87058b	AY-7	○	○	○	△	+	△	−	−			−	−									739	1.7	2.6	<f. sand>
6	Tbss	75	UM	87058c	BG-9	△	○	○	○	+	○		−			−	−									688	0.8	1.9	<vf-f. sand>
6	Tbss	12	L	93042124	BG-10	○	○	○	○	+	○		−		−	+	−	−								555	0.8	6.5	<f-vf. sand>
6	Tbss	110	LM	87059a	AK-6	○	○	○	○	+	△	△	+			−	+	−								713	2.1	7.5	<c. sand>
6	Tbss	110	U	87059b	BA-4	△	○	○	○	△	○	+	−				−	−			−					933	1.5	4.9	<f. sand>
6	Tbss	110	UM	87059c	BH-1	○	+	△	◎	+	◎		+		+	+	+	−						−		795	0.7	2.8	<vf-f. sand>
6	Tbss	90	UM	93042126	BH-2	△	+	○	◎		◎		−			+	−									677	1.8	1.6	<vf-f. sand>
6	Tbss	130	LM	87060a	AK-7	△	◎	○	○	+	△	+	+					−								994	7.7	13.7	<c. sand>
6	Tbss	130	U	87060c	AY-8	○	○	○	△	+	△	−	−			−	−									880	6.3	6.8	<m. sand>
6	Tbss	40	LM	93042127a	BH-3	△	○	○	△	−	△	−	+			−	−									956	3.3	3.6	<m. sand>
6	Tbss	40	UM	93042127b	BH-4	○	○	○	○	+	○		+		−	−	−	−								642	0.7	4	<vf-f. sand>
6	Tbss	100	LM	87061a	AK-8	△	○	○	○	+	△	+	+			−										726	5.1	9.2	<m. sand>
6	Tbss	100	U	87061b	AY-9	△	○	○	△	+	△		−			−	−									775	2.5	6.6	<f. sand>
6	Tbss	100	UM	97061c	BH-5	△	○	○	△	+	△	−	−		−	−	−	−								664	2.6	2.6	<f-vf. sand>
6	Tbss	300	LM	87062	AK-9	○	○	○	△	+	△	+	−				−									759	7.1	10.8	<vc. sand>
6	Tbss	100	LM	87063a	AK-10	○	○	○	△	+	△	+	+			−	−	−								969	5.6	13.7	<c. sand>
6	Tbss	100	U	87063b	AY-10	△	○	○	△	+	△		+			−	+	−								771	3.2	6.2	<vf. sand>
6	Tbss			general		○△	○	○	△◎	+	△○	−△	−+		(−)	−+	−+	(−)						(−)					

Table 14 Classification of turbidite sandstones based on the combination of quantitatively major heavy minerals.

TYPE	Opq (Opaque minerals)	Hor (Hornblende)	Hyp (Hypersthene)	Aug (Augite)	
I	◎	× or −	× or −	× or −	(LEGEND) ◎: Dominant ○: Abundant −: Very rare ×: None
I - II	◎	○	× or −	× or −	
II	○	◎	× or −	× or −	
III	○	○	○	○	

III. Those of the overlying Inagawa sandstone member are by Type III. Thus, the turbidite sandstones in the Western ("Nishiyama") oil belt change their types of heavy mineral composition upward from Type I through Type I-II and Type II to Type III. The same kind of vertical change is observed in the southern part of the Eastern ("Higashiyama") oil belt (Tokuhashi, 1989, 1992).

These facts strongly suggest that the difference of facies or the unit of lithology such as a formation or a member may reflect the difference of heavy mineral composition. The different provenance or the different geologic event (e.g. the beginning of volcanic activities) at the same provenance may be suggested as a cause of the difference of heavy mineral composition.

The turbidite sandstones of the Shiiya formation in the Western ("Nishiyama") oil belt are represented by Type I-II or Type II, but those in the Central ("Chuo") oil belt are represented by Type III. The difference between these two turbidite sandstones of the same formation may suggest that they have been supplied from the different provenances. This problem will be discussed in the next paper (Part II) with data on the paleocurrent of these sandstones.

7. Conclusions

1) The turbidite sandstones at each locality or at each outcrop in the Western ("Nishiyama") and Central ("Chuo") oil belts has, more or less, the same or common characteristics of the heavy mineral composition, that is, those at each locality can be represented by the specific generalized heavy mineral composition.

2) The turbidite sandstones in this area can be classified at least into four types based on the combination of the quantitatively major heavy minerals such as opaque minerals, hornblende, hypersthene, and augite.

3) The turbidite sandstones of one formation or one member are represented by one type or closely related two types.

4) The different formations or members in this area are often composed of the different heavy mineral composition. The different provenance or the different geologic event (e.g. the beginning of volcanic activities) at the same provenance may be suggested as a cause of such difference.

5) Heavy mineral composition of turbidite sandstones can be used as a very useful marker to characterize or identify the individual turbidite sandstone bodies which correspond to the lithologic units such as formations or members.

Table 15 Generalized heavy mineral composition and Type at each locality.

Regional name	Loc. no.	Formation	Opq	Hyp	Aug	Hor	Oxy-Hor	Tre-Act	Epi	Zir	Gar	Sph	Ana	Tou	Al	Gla	Type	(LEGEND)
Western	Loc.1	Teradomari F.	◎	(−)		(· −)				△	+			· +	(−)		I	50.0%≦◎
Oil Belt	Loc.7	U. Teradomari F.	◎	−	(−)	−	(−)	(−)	(−)	△	+		(−)	−		(−)	I	15.0%≦○<50.0%
	Loc.8	Um. Teradomari F.	◎	(−)	(−)	−△		−	−	△	+		(−)	−	(−)	−	I, I-II	5.0%≦△<15.0%
	Loc.2	L. Shiiya F.	○			◎○	−+	−	−	−△	−	−		(−)			II	1.0%≦+<5.0%
	Loc.9	U. Shiiya F.	◎○			◎○	(−)	△+	−	−+	−	(−)	(−)	(−)	(−)	(−)	I-II, II	0.1%≦−<1.0%
	Loc.11	U. Shiiya F.	◎○			◎○	−+	△+	−+	−+	−		(−)	(−)		(−)	I-II, II	· <0.1%
	Loc.10	L. Hamatsuda Alt. M.	○			◎	−	+	−+	+	−			(−)		(−)	II	
	Loc.3	M. Hamatsuda Alt. M.	○△	−	−	◎	+		+	+	−					−+	II	
	Loc.4	Um. Hamatsuda Alt. M.	○△	○△	+○	◎○	△−		−+	−	(−)					(−)	III	
	Loc.5	Inagawa Sd. M.	○△	○△	+○	◎○	+○		(−)	−	(−)						III	
	Loc.6	Inagawa Sd. M.	○△	○	○	△◎	−+	(−)	−+	−+	(−)					(−)	III	
Central	Loc.12	Shiiya F.	+○	◎○	○△	○△	−	(−)	(−)	−+	(−)					(−)	III	
Oil Belt	Loc.13	Shiiya F.	+○	○	○△	△◎	−+	(−)	−	−	(−)					(−)	III	

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新潟含油背弧堆積盆中部域に分布する新第三系タービダイト砂岩の重鉱物組成
—その１：西山及び中央油帯—

クリストファー M. アギンギー・徳橋秀一

要　旨

新潟堆積盆中部域の西山油帯と中央油帯に分布する中期中新世から鮮新世のタービダイト砂岩体の重鉱物組成を，13地点で詳細かつ系統的に検討した結果，次のような一般的結論を得た．

1) 個々の地点，個々の露頭でみられるタービダイト砂岩は，重鉱物組成上共通の特徴を有し，一般化された特定の重鉱物組成で表現することができる．

2) この地域に分布するタービダイト砂岩は，不透明鉱物，ホルンブレンド，ハイパーシン，オージャイトといった量的に主要な重鉱物の組合せによって，少なくとも4つのタイプに分類することが可能である．

3) 同一累層，同一部層中のタービダイト砂岩は，一つないし密接に関連した二つの重鉱物組成タイプによって，表現することができる．

4) 異なった累層や部層のタービダイト砂岩は，しばしば異なった重鉱物組成から構成されている．異なった供給源からの供給や同じ供給源での新しい地質現象(例えば，火山活動の始まりなど)を反映していることが考えられる．

5) 重鉱物組成は，部層や累層に相当する個々のタービダイト砂岩体を特徴づけたり，同定するための指標として，大変有用である．