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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 II: Eastern ("Higashiyama") oil belt and summary of the whole study area

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TOKUHASHI Shuichi and AGYINGI Christopher M. (1995) Heavy mineral composition of the Neogene turbidite sandstones in the middle part of the Niigata backarc oil basin, central Japan — Part II: Eastern ("Higashiyama") oil belt and summary of the whole study area. *Bull. Geol. Surv. Japan*, vol. 46 (3), p. 121-151, 13figs, 12tables.

**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, have been done to prove the applicability of heavy mineral composition as a useful marker to characterize or identify the individual turbidite sandstone bodies. In this paper, following the Western ("Nishiyama") and Central ("Chuo") oil belts (Part I), the results of the analysis of turbidite sandstones in the Eastern ("Higashiyama") oil belt are shown with discussions on some sedimentological problems through the whole study area and the effectiveness of heavy mineral analysis in deciphering such problems.

The main results of this study are summarized as follows:

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 generalized heavy mineral composition.

2) The turbidite sandstones in the study area can be classified at least into six types (four conventional types described in the former paper and two new types observed in this paper) 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 the study 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 the 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,

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each of which usually corresponds to a lithologic unit such as a formation or a member.

6) The heavy mineral analysis of turbidite sandstones often yields a very important key or a new information in disclosing their sedimentary process, especially when its results are combined with sedimentological data such as paleocurrent ones.

7) Therefore, the heavy mineral analysis is very valuable not only as a conventional tool to estimate the provenance, but also as a strong measure to estimate the original relationship of several sandstone bodies, to disclose the sedimentary process of these sandstone bodies with other sedimentary data, and to predict the three-dimensional extents of turbidite sandstone bodies both on the surface and subsurface by using samples from outcrops and from boring cores or cuttings.

## 1. Introduction

In the former paper (Part I; Agyingi and Tokuhashi, 1995), the results of heavy mineral analysis of the turbidite sanstones at 13 localities in the Western ("Nishiyama") oil belt and Central ("Chuo") oil belt were shown. The main results are as follows:

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 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 differenct 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 a lithologic unit such as a formation or a member.

In this paper, the authors first show the results of heavy mineral analysis at 12 localities in the Eastern ("Higashiyama") oil belt (Fig. 1) and then discuss on some sedimentological problems based on the results both of the present and former papers.

As the generalized geologic setting and the method of sampling and experimentary works for heavy mineral analysis are the same as those shown in the former paper, they are omitted in this paper.

The Eastern ("Higashiyama") oil belt is here subdivided into three parts, i.e. northern part, middle part and southern part. The stratigraphy and results of heavy mineral analysis in each part are shown below.

## 2. Results of heavy mineral analysis

### 2.1 Northern part of the Eastern ("Higashiyama") oil belt

#### 2.1.1 Stratigraphy in the northern part of the Eastern ("Higashiyama") oil belt

The stratigraphy of this area was mainly studied around the NNE-SSW trending Niitsu hill located southeast of Niitsu city, and a part of this hill is used to be called as "Niitsu oil field".

The southern central part of the Niitsu hill along the main anticline is occupied by the middle Miocene Gomadoyama formation and Takadateyama formation, which form the lowermost part of the outcropped succession in

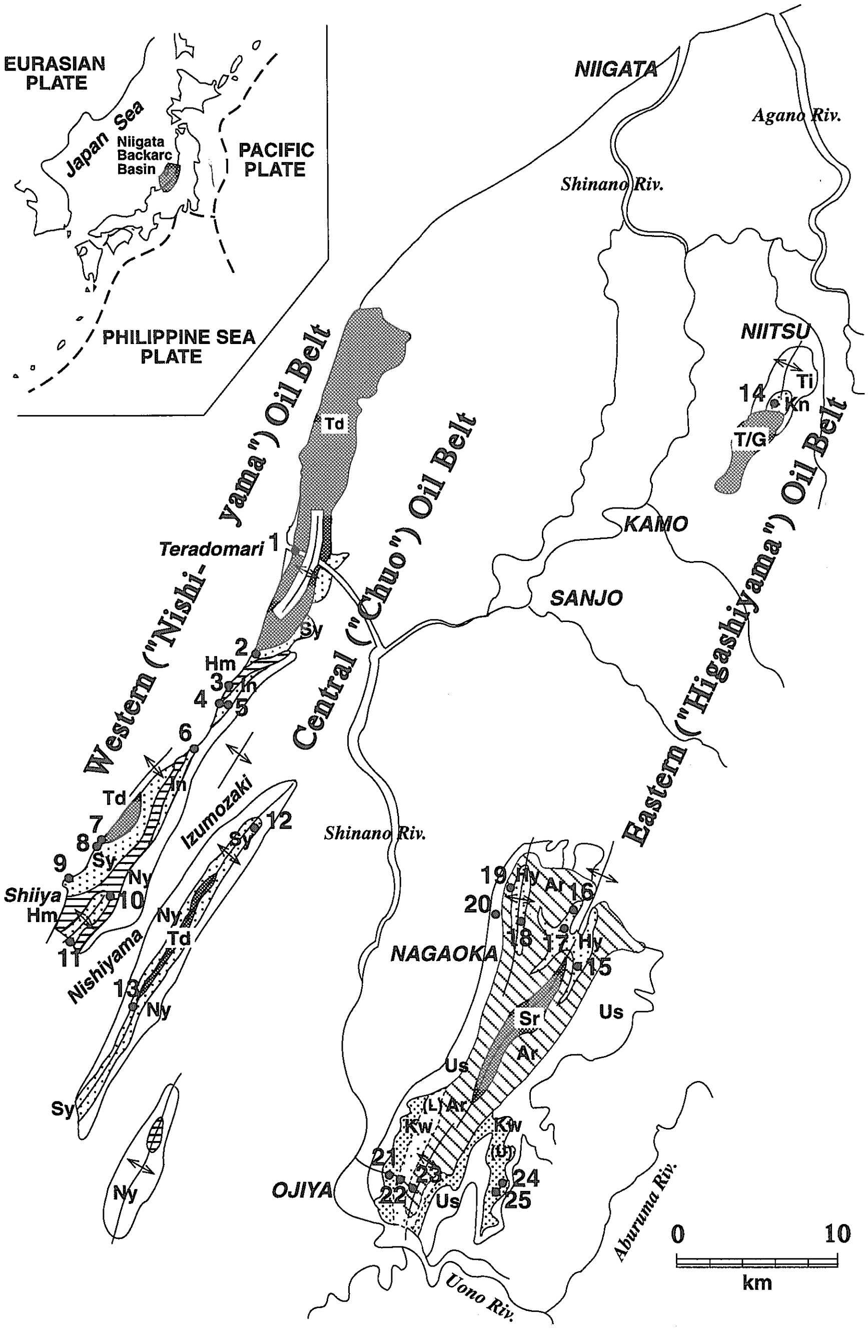



Fig. 1 Geologic sketch map of the study area and sampling localities. Alphabetic letters correspond to the names of formations and members in Fig. 2.

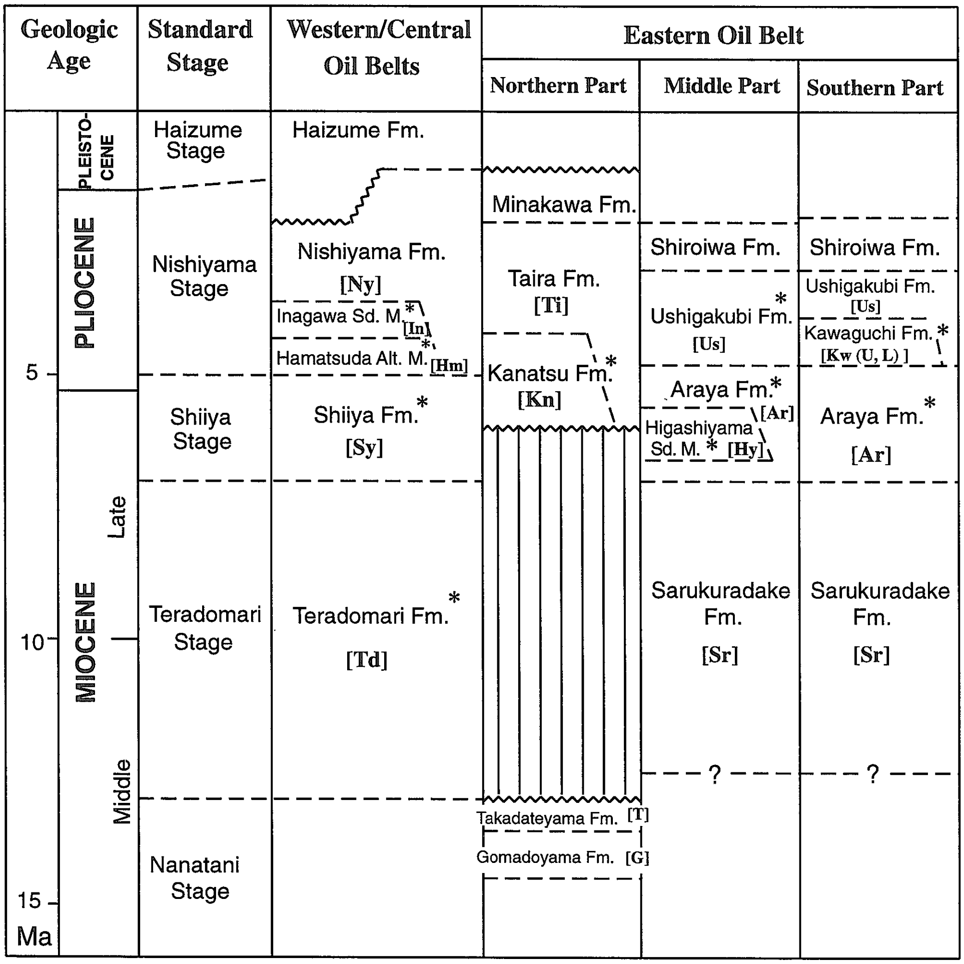



Fig. 2 Stratigraphy in the study area. Asterisks mean the formations and members of which turbidite sandstones were analyzed.

this area (Fig. 2). The Gomadoyama formation is mostly composed of dacitic tuff and partly of dacitic lava and tuff. It attains more than 300 meters in thickness. The Takadateyama formation which overlies the Gomadoyama formation is comprised mostly of basaltic tuff braccia and pillow lava, and partly basaltic tuff. It attains a maximum thickness of 300 meters (Hasegawa *et al.*, 1976).

The late Miocene to early Pliocene Kanatsu formation which unconformably overlies the Middle Miocene Gomadoyama and Takadateyama formations occurs as a lenticular body along the central anticline. The formation is made up of a flysch-type alternation and attains 450 meters in maximum thickness. The formation forms the main reservoir rocks in the Niitsu oil field. The Kanatsu formation is laterally changed to the lower part of the Taira formation and is conformably overlain by the upper part of the Taira formation. The Taira formation is mostly formed of massive grey mudstones and partly of pebbly mudstones. The formation is conformably overlain by the Minakawa formation, mostly composed of massive sandy siltstones. The lower Taira formation attains a maximum thickness of 300 meters and the total thickness of the upper Taira formation and the Minakawa formation is about 800 meters (Hasegawa *et al.*, 1976).

#### 2.1.2 Kanatsu formation (Loc. 14)

The Late Miocene to Early Pliocene Kanatsu formation, 450 meters in maximum thickness, unconformably overlies the Middle Miocene volcanic rocks and occurs as a lenticular body around the main anticline (Fig. 1 and Fig. 3). It is comprised of a sandstone-dominated alternation of sandstones and mudstones. Most sandstones are thick and almost composed of massive coarse-grained sandstones and often yields pebble-size gravels in the lower part and outsize mudstone clasts in the upper part. Thick pebbly sandy mudstones or debris flow deposits are often intercalated (Fig. 4B). These sandstones are interpreted as proximal turbidite sandstones or channel deposits in the submarine fan systems (Abe, 1978; Tateishi *et al.*, 1984). Many oil stains are observed in these sandstones (Fig. 5).

##### 2.1.2.1 Heavy mineral composition of the Kanatsu formation

Sampling of sandstones was carried out at 4 points (Fig. 3). The geologic column at Loc. 14a is shown in Fig. 4B.

The results of heavy mineral analysis are shown in Table 1. Opaque minerals occur dominantly or abundantly. Hypersthene usually occurs abundantly to commonly, while hornblende occurs more variably, i.e. abundantly to very rarely, but constantly observed. As minor contents, zircon, garnet and epidote are nearly constantly observed.

The most conspicuous characteristics is the absence of augite. The combination of opaque minerals, hypersthene and hornblende, but without augite is not observed in the turbidite sandstones of the Western ("Nishiyama") and Central ("Chuo") oil belts. This means that the sandstones of the Kanatsu formation are composed of a new type of heavy mineral composition, while conventional types are classified into four types as shown in the former paper (PartI; Agyini and Tokuhashi, 1995), i.e. Type I, Type I-II, Type II, and Type III, based on the combination of quantitatively major heavy minerals such as opaque minerals, hypersthene, hornblende and augite. This new type first observed here, at Loc. 14, is defined as "Type IV".

##### 2.1.2.2 Summary

The sandstones of the Kanatsu formation is characterized by a new type of heavy mineral composition, Type IV. Here, opaque minerals, hypersthene and hornblende occurs but augite is not observed. Epidote, zircon and garnet occurs constantly but as minor components.

### 2.2 Middle part of the Eastern ("Higashiyama") oil belt

#### 2.2.1 Stratigraphy in the middle part of the Eastern ("Higashiyama") oil belt

The middle to late Miocene Sarukuradake formation constitues the lowermost part of the outcropped succession and occurs in the central zone of the NNE-SSW trending Higashiyama mountain (Fig. 1 and Fig. 2). The formation is divided into three parts: usually stratified hard black shale more than 300 meters thick, andesitic volcanic rocks 400 to 500 meters thick mostly of volcanic breccia and tuff breccia, and dasitic volcanic rocks more than 500 meters thick mostly of massive lava and volcanic clastics. These three parts interfinger each other (Kobayashi *et al.*, 1991). The Sarukuradake formation is conformably overlain by the Late Miocene Araya formation.

The Araya formation is comprised mostly of massive black shale or mudstone and partly of intercalations of andesitic lava and volcanic breccia. The formation intercalate the Higashiyama sandstone member, formed of a sandstone-dominated flysch-type alternation of turbidite sandstones and mudstones, and attains about 700 to 900 meters in thickness. The formation is conformably overlain by the Pliocene Ushigakubi formation, mostly composed of gray to dark gray massive mudstone. The Pliocene Ushigakubi formation is conformably overlain by the Shiroiwa formation composed of massive sandy mudstone (Fig. 2; Kobayashi *et al.*, 1991).

#### 2.2.2 Higashiyama sandstone member

The Higashiyama sandstone member is formed of a few flysch-type sandstone bodies of different horizons and is intercalated in the lower to middle parts of the Araya formation.

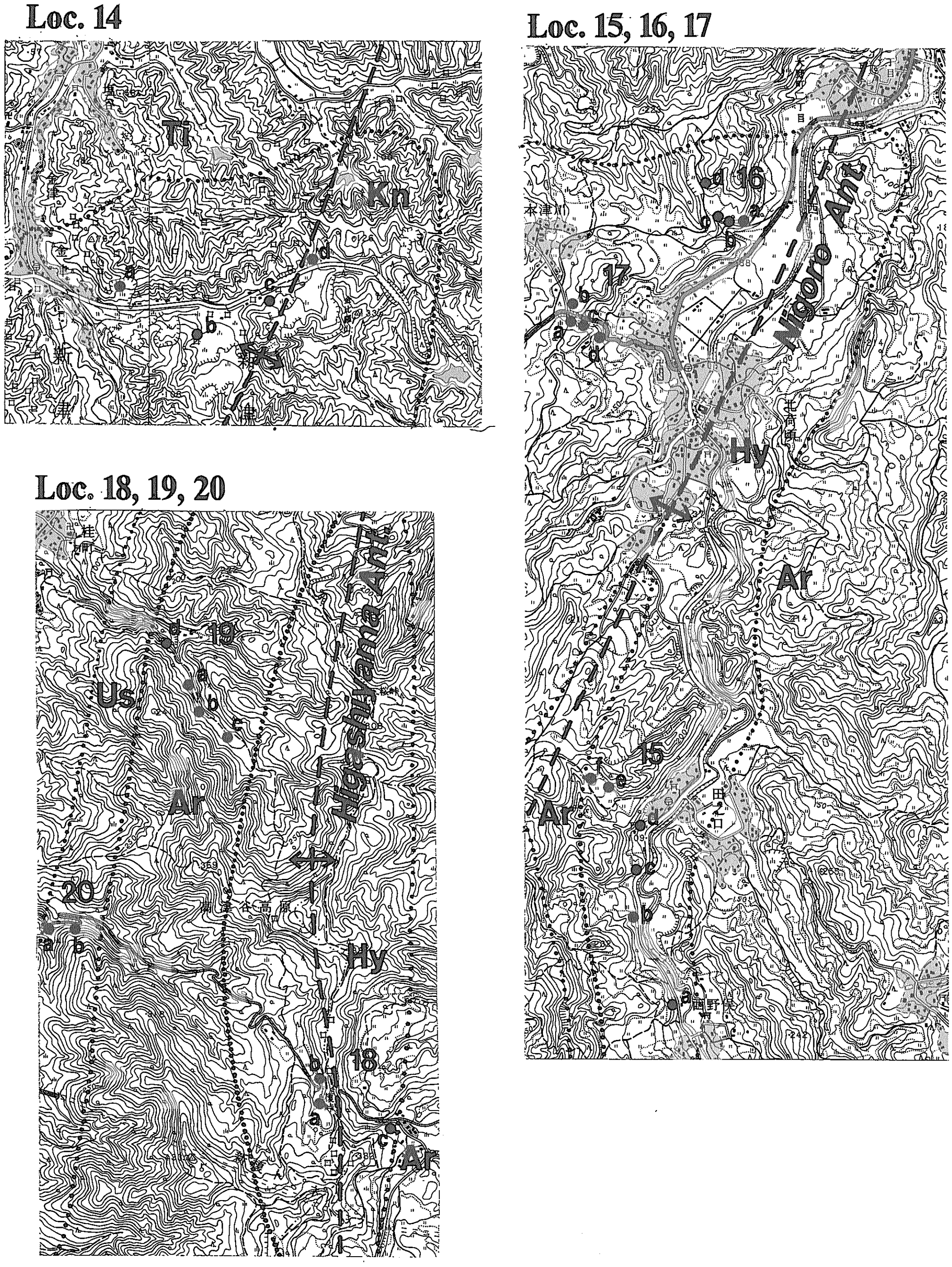
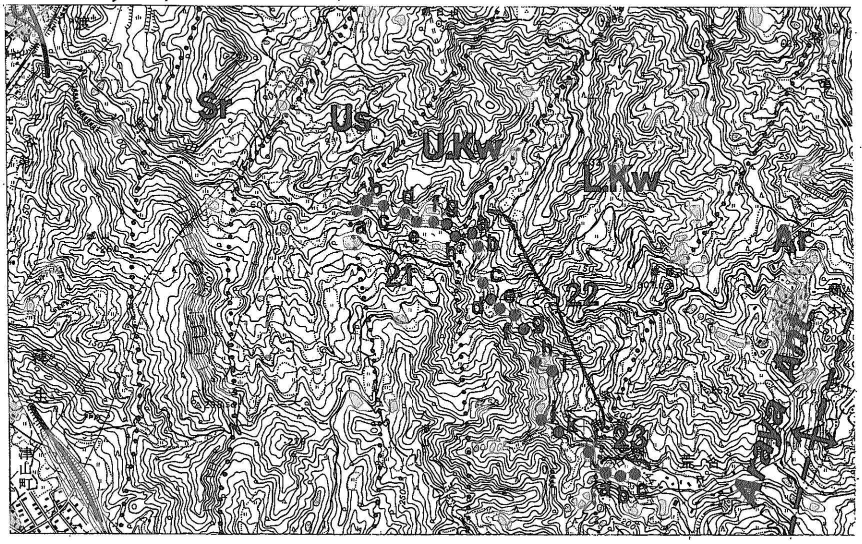



Fig. 3 Detailed sampling points at each locality. Alphabetic letters mean the name of formations and members shown in Fig. 2. Topographic maps are parts of 1:25,000 map sheets "Yashiroda", "Muramatsu", "Tochio", "Ojiya", and "Obiro" published by Geographical Survey of Institute.

**Loc. 21, 22, 23**




**Loc. 24, 25**


Fig. 3 (Continued)

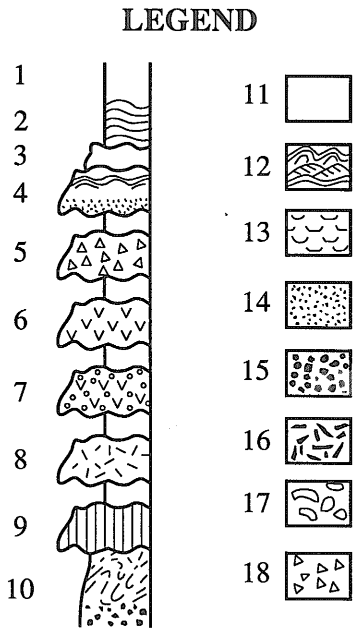



Fig. 4A Legend for geologic columns. 1: mudstone to siltstone, 2: banded mudstone to siltstone, 3: turbidite sandy mudstone to sandy siltstone, 4: turbidite sandstone, 5: pumice tuff or pumiceous sandstone, 6: andesitic tuff, 7: andesitic lapilli tuff, 8: fine-grained glassy tuff, 9: fine-grained white to grey tuff, 10: pebbly mudstone, 11: massive sandstone, 12: laminated sandstone (parallel lamination, current-ripple lamination, convolute lamination and so on), 13: dish structure, 14: granule-sized grains, 15: pebble-sized gravels, 16: carbonaceous fragments, 17: mudstone- or siltsone-clasts (rip-up clasts), 18: pumice grains.

These sandstones are mainly distributed around the Nigoro and Higashiyama anticlines (Fig. 1 and Fig. 3). The Higashiyama sandstone member is usually made up of a sandstone-dominated alternation of sandstones and mudstones. The sandstones are composed mostly of thick-bedded coarse-grained proximal turbidite sandstones, but partly of thin-bedded fine-grained distal turbidite sandstones (Fig. 6 and Fig. 7).

#### 2.2.2.1 Heavy mineral composition of the Higashiyama sandstone member

Sampling of the Higashiyama sandstone member for heavy mineral analysis was carried out at four localities, Loc. 15, 16, 17 and 18 (Fig. 1 and Fig. 3).

**Loc. 15**

This locality is located at the east limb of the Nigoro anticline. Sampling was carried out at 6 points mainly along the small river (Fig. 3). The results of heavy mineral analysis are shown in Table 2. Opaque minerals are dominant. No hypersthene and augite, and very few hornblende are observed. Zircon and garnet occur constantly as minor minerals. The characteristics of heavy mineral composition is the same as those of Type I defined in the former paper.

**Loc. 16**

Loc. 16 is located at the west limb of the Nigoro anticline. Sampling was carried out at 4 points (Fig. 3). The results of heavy mineral analysis are shown in Table 2. The heavy mineral composition is exactly the same as that at Loc. 15 and, therefore, belongs to Type I heavy mineral composition.

**Loc. 17**

Loc. 17 is located at the west limb of the Nigoro anticline. Sampling was carried out at 4 points (Fig. 3). The results of heavy mineral analysis are shown in Table 2. The heavy mineral composition at this locality is slightly different from that at Loc. 15 and Loc. 16. Because common to abundant hornblende are observed here, while very few hornblende is observed at Loc. 15 and Loc. 16. The type of heavy mineral composition based on the combination of quantitatively major minerals is characterized by Type I-II.

**Loc. 18**

Loc. 18 is located near the axis of the Higashiyama anticline. Sampling was carried out at 3 points (Fig. 3). The results of heavy mineral analysis are shown in Table 3. The heavy mineral composition here is very similar to that at Loc. 17 and, therefore, belongs to Type I-II.

#### 2.2.2.2 Summary

The heavy mineral composition of the Higashiyama sandstone member is character-

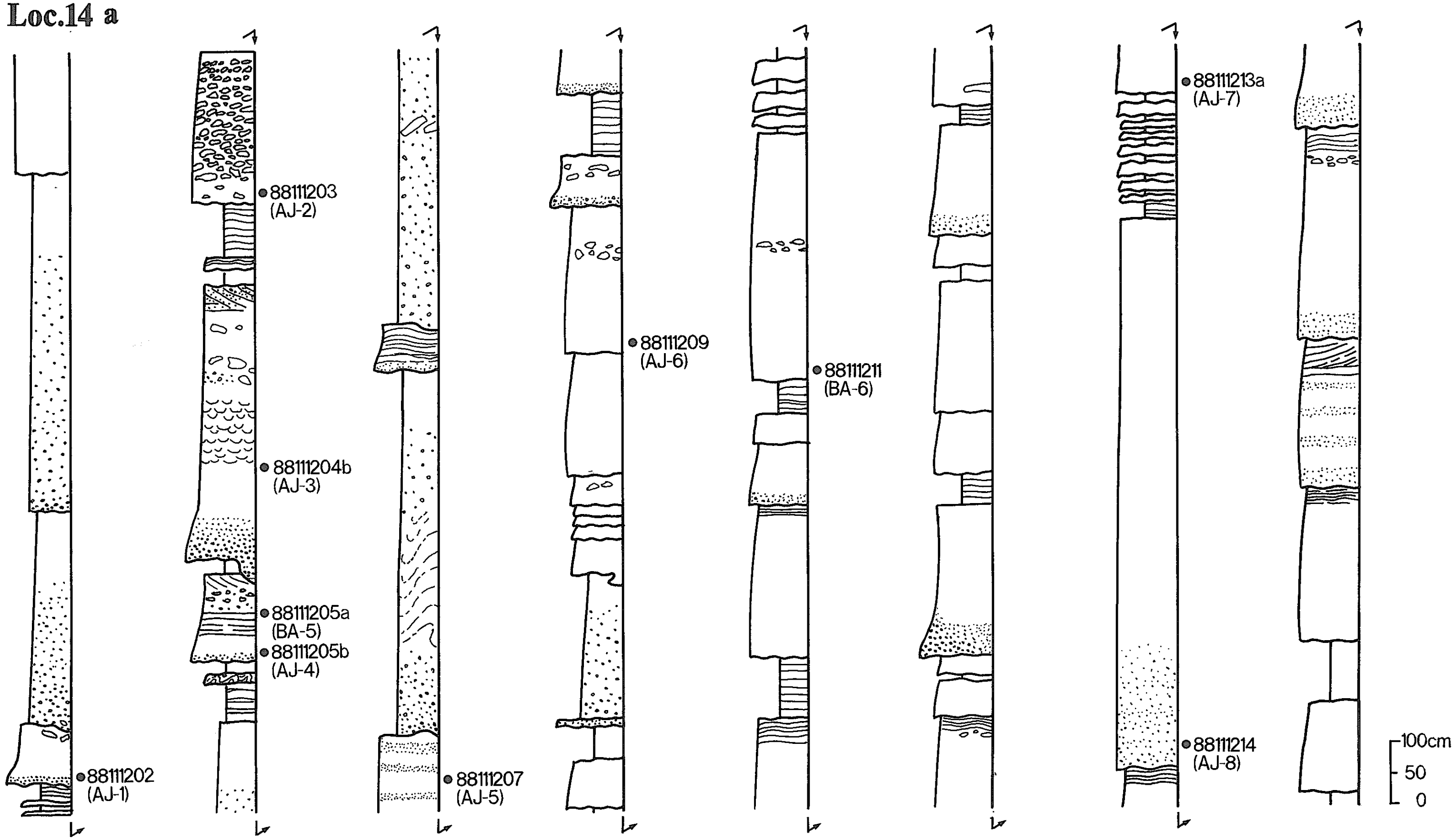



Fig. 4B Geologic columns at Loc. 14 (Kanatsu formation). Black circles correspond to the sampling positions for heavy mineral analysis.

Table 1 Results of heavy mineral analysis at Loc. 14 (Kanatsu formation).
Lithology (Tbss: turbidite sandstone, Tfss: tuffaceous sandstone, Sdtf: sandy tuff, Tf: tuff), Position (sampling position in a single 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: diopside, 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, Minerals of mica groups such as biotite and muscovite are excluded in this table.), 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

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14a | Tbss | 100 | LM | 88111202 | AJ-1 | ○ | ○ | | ○ | − | ○ | + | − | | | | − | | | | | − | | | | 1076 | 2.7 | 3.2 | <vc. sand> |
| 14a | Tbss | 250 | LM | 88111203 | AJ-2 | ○ | ○ | | ○ | − | ○ | + | − | | | | | | | | | | | | | 585 | 2.7 | 3.6 | <vc. sand> |
| 14a | Tbss | 450 | M | 88111204b | AJ-3 | ◎ | △ | | △ | − | △ | + | | | | | + | − | | | | | | | | 1303 | 2.8 | 4 | <m. sand> |
| 14a | Tbss | 150 | U | 88111205a | BA-5 | ◎ | + | | + | + | + | | | | | − | − | − | | | | | | | | 776 | 4.6 | 3.4 | <m. sand> |
| 14a | Tbss | 150 | LM | 88111205b | AJ-4 | ◎ | + | | + | ・ | + | − | | | | | + | − | | | | | | | | 2627 | 2.4 | 4.5 | <vc. sand> |
| 14a | Tbss | 200 | M | 88111207 | AJ-5 | ○ | ○ | | ○ | − | △ | + | − | | | | − | − | | | | | | | | 746 | 6.5 | 1.9 | <vc. sand> |
| 14a | Tbss | 250 | LM | 88111209 | AJ-6 | ○ | ◎ | | △ | − | △ | + | − | | | | − | − | | | | | | | | 1250 | 2.8 | 2 | <c. sand> |
| 14a | Tbss | 400 | LM | 88111211 | BA-6 | ◎ | ○ | | △ | + | △ | − | | | | − | − | − | | | | − | | | | 1344 | 2.5 | 2.4 | <c. sand> |
| 14a | Tbss | 230 | LM | 88111213a | AJ-7 | ◎ | ○ | | + | − | + | − | − | | | | − | − | | | | | | | | 659 | 3.6 | 3.9 | <c. sand> |
| 14a | Tbss | 900 | LM | 88111214 | AJ-8 | ○ | ◎ | | △ | − | + | − | − | | | | − | − | | | | | | | | 1116 | 1.2 | 2.2 | <vc. sand> |
| 14b | Tbss | 1100 | LM | 92100401a | AR-1 | ○ | ○ | | ○ | + | △ | + | − | | | − | − | − | | | | | | | | 771 | 2.9 | 2.7 | <vc. sand> |
| 14b | Tbss | 1100 | M | 92100401b | AR-2 | ○ | ○ | | ○ | + | △ | + | − | | | − | + | | | | | | | | | 993 | 3 | 2.5 | <c. sand> |
| 14b | Tbss | 400 | LM | 92100402a | AR-3 | ○ | ○ | | ○ | − | ○ | + | − | | | | − | | | | | | | | | 983 | 2.5 | 2.4 | <c. sand> |
| 14b | Tbss | 500+ | L | 92100403a | AR-4 | ◎ | + | | + | − | + | | | | | − | + | − | | ・ | | | | | | 2059 | 1.5 | 5.1 | <vc. sand(pebbly)> |
| 14b | Tbss | 500+ | M | 92100403b | AR-5 | ◎ | + | | + | − | + | | | | | − | − | − | | | | | | | | 2331 | 3.5 | 3.1 | <c. sand with granule> |
| 14c | Tbss | 300+ | L | 92100404 | AR-6 | ◎ | + | | △ | + | △ | | | | | + | △ | − | | | | | | | | 946 | 0.1 | 4.3 | <f. sand> |
| 14c | Tbss | 18 | L | 92100405 | AR-7 | ◎ | △ | | + | − | − | | | | | − | + | − | | | | | | | | 2742 | 0.7 | 2.2 | <f. sand> |
| 14c | Tbss | 50 | L | 92100406 | AR-8 | ◎ | △ | | + | − | − | − | | | | − | − | − | | | | | | | | 1245 | 0.6 | 1.7 | <m. sand> |
| 14d | Tbss | 700 | LM | 92100407a | AR-9 | ◎ | △ | | − | − | − | | | | | − | − | − | | | | | | | | 1817 | 3.1 | 2.2 | <vc. sand(pebbly)> |
| 14d | Tbss | 700 | M | 92100407b | AR-10 | ◎ | △ | | − | − | − | ・ | | | | − | ・ | ・ | | | | | | | | 2054 | 2.8 | 1.7 | <c. sand> |
| 14 | Tbss | | | general | | ◎○ | +◎ | | −○ | −+ | −○ | (−+) | (−) | | | (−) | −+ | − | | | | (−) | | | | | | | |

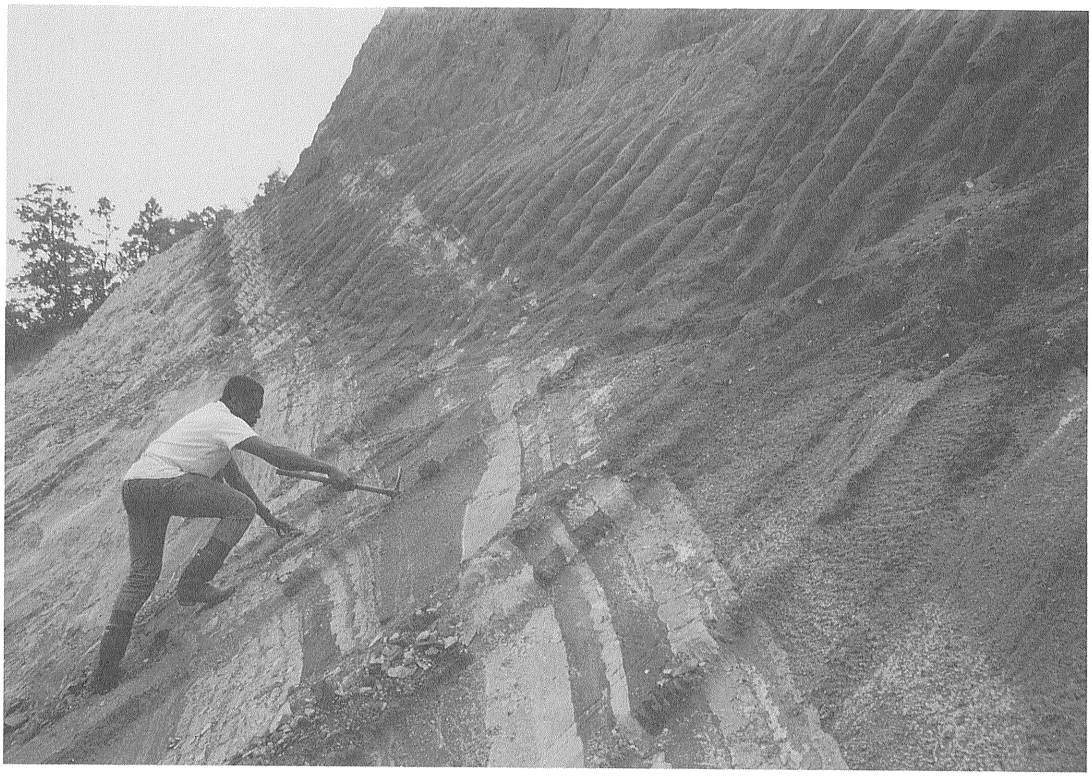


Fig. 5 An outcrop of the Kanatsu formation at Loc. 14a. Black parts and white parts correspond to turbidite sandstones and hemipelagic mudstone or pebbly mudstone, respectively. The surface of the turbidite sandstones is widely stained with oil.

ized by Type I to Type I–II. Opaque minerals are dominant and very few to abundant hornblende, but no hypersthene and augite are observed in these sandstones. Zircon and garnet occurs constantly but as minor minerals.

### 2.2.3 Araya formation

As well as the Higashiyama sandstone member intercalated in the lower to middle part of the Araya formation, which is composed mostly of massive black shale or mudstone, turbidite sandstones are sporadically interbedded also in the upper part of the formation. Sampling of these sandstones were carried out at Loc. 19 along the small river located in the west limb of the Higashiyama anticline.

#### 2.2.3.1 Heavy mineral composition of the Araya formation

**Loc. 19**

Sandstones were sampled at 4 points along the river (Fig. 3 and Fig. 8). The results of heavy mineral analysis are shown in Table 4. Two types of heavy mineral composition are recognized. One is characterized by abundant hypersthene and hornblende but very rare augite. This type associates oxyhornblende and zircon as minor components. This type is nearly the same as that of the sandstones of the Kanatsu formation at Loc. 14, i.e. Type IV. The other type is characterized by abundant hypersthene and augite but actually no hornblende. This type associates very few minor components such as zircon, garnet and so on, and contents of heavy minerals are very high in these sandstones. This type, a fresh type which is not observed before, is named "Type V".

Fig. 6 An outcrop of the Higashiyama sandstone member at near Loc. 15a.

#### 2.2.3.2 Summary

As described above, two new types of heavy mineral composition, i.e. Type IV and Type V, which are not present in the Western ("Nishiyama") and Central ("Chuo") oil belts (see Part I), are observed in the sandstones at this locality.

### 2.2.4 Ushigakubi formation

The Ushigakubi formation conformably overlies the Araya formation and is comprised mostly of massive gray to dark gray mudstone but partly of an alternation of turbidite sandstones and mudstones. The formation attains a thickness of about 500 to 600 meters. Sandstones were collected at Loc. 20 located at the west limb of the Higashiyama anticline.

#### 2.2.4.1 Heavy mineral composition of the Ushigakubi formation

**Loc. 20**

Sampling was carried out at two points along the river (Fig. 3 and Fig. 9) and the results of heavy mineral analysis are shown in Table 5. The heavy mineral composition is characterized by dominant to abundant hypersthene and augite, but very few hornblende. Oxyhornblende occurs as a minor component. Very high contents of heavy mineral composition is notable. The characteristics of heavy mineral composition is nearly the same as those of Type V, observed in some sandstones in the upper part of the Araya formation at Loc. 19.

#### 2.2.4.2 Summary

As mentioned above, nearly the same type of heavy mineral composition as Type V, observed in some sandstones at Loc. 19, is observed here.

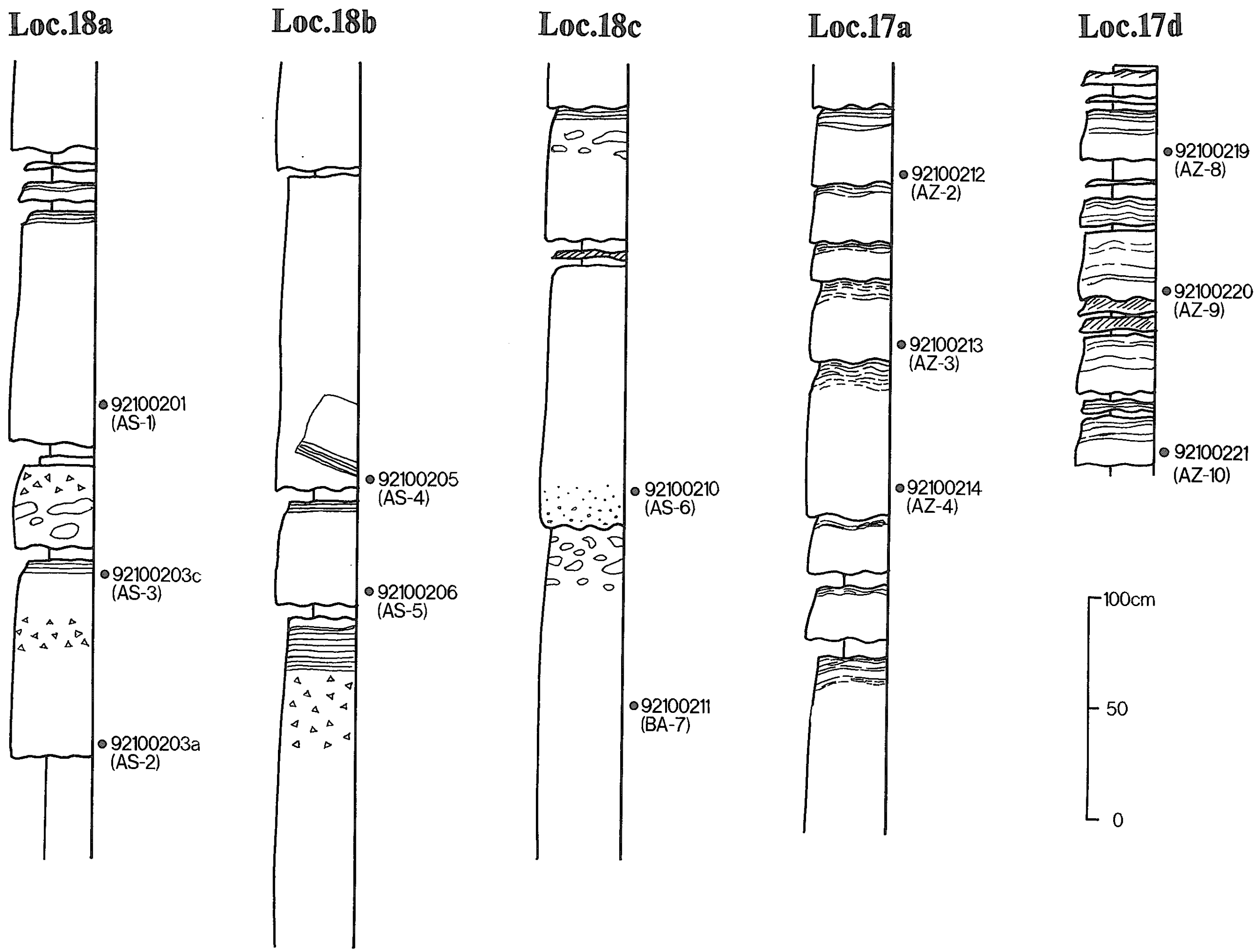



Fig. 7 Geologic columns at Loc. 17 and Loc. 18 (Higashiyama sandstone member). For the legend see Fig. 4A.

Table 2 Results of heavy mineral analysis at Loc. 15, 16 and 17 (Higashiyama 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15a | Tbss | | | 88111307 | AI-4 | ◎ | | | − | − | − | | − | | | | + | − | | | | | | | | 2947 | 0.6 | 3.4 | <vc. sand> |
| 15b | Tbss | | | 88111305 | AI-6 | ◎ | | | | | | | | | | | − | − | | | | | | | | 748 | 1 | 3.9 | <vc. sand> |
| 15c | Tbss | | | 88111303 | AI-7 | ◎ | | | − | − | − | | − | | | | △ | − | | | | | − | | | 5793 | 0.2 | 2.1 | <vc. sand> |
| 15d | Tbss | | | 88111302 | AI-8 | ◎ | | | | | | | | | | | + | · | | | | | | | | 3359 | 0.9 | 2.9 | <vc. sand> |
| 15e | Tbss | | | 88111501 | AI-9 | ◎ | | | | | | | | | | | + | − | | | | | | | | 2088 | 0.3 | 7 | <vc. sand> |
| 15f | Tbss | | | 88111502 | AI-10 | ◎ | | | | | | | | | | | + | − | | | | − | − | | | 1359 | 0.7 | 9.7 | <vc. sand> |
| 15 | Tbss | | | general | | ◎ | | | (−) | (−) | (−) | | (−) | | | | + | − | | | | | (−) | | | | | | |
| 16a | Tbss | 800 | LM | 92100301b | AS-7 | ◎ | | | − | − | · | | | | | | + | − | | | | | | | | 2472 | 0.1 | 7.5 | <vc. sand> |
| 16b | Tbss | 300 | M | 92100302 | AS-8 | ◎ | | | | | | | | | | | − | − | | | | | | | | 2429 | 1.1 | 0.9 | <vc. sand> |
| 16c | Tbss | 300+ | L | 92100303 | AS-9 | ◎ | | | − | | − | | | | | | + | − | | | | | | | | 1482 | 0.5 | 2.5 | <vc. sand> |
| 16d | Tbss | 100 | LM | 92100304 | AS-10 | ◎ | | | − | − | − | | | | | | + | − | | | | | | | | 1826 | 1.6 | 10 | <vc. sand> |
| 16 | Tbss | | | general | | ◎ | | | − | (−) | (−) | | | | | | + | − | | | | | | | | | | | |
| 17a | Tbss | 35 | LM | 92100212 | AZ-2 | ◎ | | | + | − | + | | | | | − | + | − | | | | | | | | 1818 | + | △ | <m-c. sand> |
| 17a | Tbss | 35 | L | 92100213 | AZ-3 | ◎ | | | △ | + | △ | | | | · | | + | + | | | | | | | | 2021 | − | △ | <m-c. sand> |
| 17a | Tbss | 70 | L | 92100214 | AZ-4 | ◎ | | | △ | + | △ | | | | | · | + | + | | | | | | | | 2015 | − | △ | <m-c. sand> |
| 17b | Tbss | 50 | L | 92100216 | AZ-5 | ◎ | | | △ | + | △ | | | | − | | − | − | | | | | | | | 1719 | + | + | <c. sand> |
| 17b | Tbss | 50 | L | 92100217 | AZ-6 | ◎ | | | ○ | △ | ○ | | | | | | + | − | | | | | | | | 1635 | − | △ | <m. sand> |
| 17c | Tbss | 400+ | L | 92100218a | AZ-7 | ○ | | | ◎ | − | ◎ | − | − | | | | − | − | | | | | | | | 1861 | + | + | <m-c. sand> |
| 17d | Tbss | 23 | L | 92100219 | AZ-8 | ◎ | | | △ | △ | + | − | | | | | + | − | | | | | | | | 1948 | − | ○ | <m. sand> |
| 17d | Tbss | 32 | L | 92100220 | AZ-9 | ◎ | | | ○ | + | ○ | | | | | | + | + | | | | | | | | 1800 | − | △ | <m. sand> |
| 17d | Tbss | 22 | L | 92100221 | AZ-10 | ◎ | | | △ | + | + | | | | | | + | − | | | | | | | | 1866 | + | △ | <m. sand> |
| 17 | Tbss | | | general | | ◎ | | | △◎ | −△ | +◎ | (−) | | | | | −+ | −+ | | | | | | | | | | | |

Table 3 Results of heavy mineral analysis at Loc. 18 (Higashiyama 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18a | Tbss | 100 | L | 92100201 | AS-1 | ◎ | | | △ | — | △ | — | | | | — | △ | — | — | | | — | | | | 1714 | 0.8 | 3.3 | <m. sand> |
| 18a | Tbss | 85 | LM | 92100203a | AS-2 | ◎ | | | △ | + | △ | — | | | | — | + | — | | | | | | | | 929 | 0.6 | 4.6 | <m. sand> |
| 18a | Tbss | 85 | UM | 92100203c | AS-3 | ◎ | | | + | — | + | | | | | — | △ | — | | | | | | | | 1586 | 0.1 | 2.8 | <vf. sand> |
| 18b | Tbss | 140 | LM | 92100205 | AS-4 | ◎ | | | △ | — | △ | | | | | — | + | — | | | | | | | | 1078 | 1.4 | 1.7 | <m. sand> |
| 18b | Tbss | 45 | LM | 92100206 | AS-5 | ○ | + | | ◎ | + | ◎ | — | — | | | | + | — | | | | | | | | 1116 | 1.1 | 1.1 | <m. sand> |
| 18c | Tbss | 120 | L | 92100210 | AS-6 | ○ | | | ○ | + | ○ | | | | | | + | — | | | | | | | | 1021 | 1.2 | 2.4 | <c. sand> |
| 18c | Tbss | 150+ | M | 92100211 | BA-7 | ◎ | | | — | — | · | | — | | | | + | — | | | | | | | | 2476 | 0.4 | 4.9 | <m. sand> |
| 18 | Tbss | | | general | | ◎○ | | | +◎ | —+ | +◎ | (—) | (—) | | | (—) | +△ | — | | | | | | | | | | | |

Table 4 Results of heavy mineral analysis at Loc. 19 (Araya 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19a | Tbss | 130 | LM | 92100506a | AT-4 | ○ | ○ | + | ○ | — | ○ | | + | | | | — | | | — | | | | | | 1374 | 2.8 | 3 | <c. sand> |
| 19a | Tbss | 90 | L | 92100507a | BA-9 | △ | ○ | + | ○ | + | ○ | | — | | | | — | | | | | | | | | 875 | 2.9 | 2.2 | <c. sand> |
| 19a | Tbss | 60 | LM | 92100508a | AT-5 | △ | ○ | △ | ○ | △ | ○ | | + | | | | — | | | | | | | | | 1029 | 2.4 | 1.9 | <c. sand> |
| 19b | Tbss | 110 | LM | 92100511 | AT-6 | + | ◎ | ○ | | | | | | | | | | | | | | | | | | 894 | 25 | 1.4 | <c. sand> |
| 19b | Tbss | 30 | L | 92100512 | AT-7 | + | ◎ | ○ | | | | | | | | | | | | | | | | | | 857 | 16 | 1.3 | <m-c. sand> |
| 19c | Tbss | 300+ | M | 92100514 | AT-8 | ○ | △ | — | ◎ | + | ◎ | | — | | | | — | — | | | | | | | | 1275 | 1.6 | 1 | <c. sand> |
| 19d | Tbss | 120 | LM | 92100515 | AT-9 | + | ◎ | ○ | — | — | | | — | | | | | | | | | | | | | 850 | 20 | 1.5 | <m. sand> |
| 19d | Tbss | 17 | L | 92100516 | BA-10 | + | ◎ | ○ | | | | | | | | | — | | | | | | | | | 670 | 1.8 | 11 | <m. sand> |
| 19d | Tbss | 25 | L | 92100518 | AT-10 | + | ◎ | ○ | | | | | | | | | — | | | | | | | | | 1000 | 20 | 1.1 | <m. sand> |
| 19 | Tbss | | | general-1 | | + | ◎ | ○ | | | | | | | | | (—) | | | | | | | | | | | | |
| | | | | general-2 | | ○△ | ○ | —+ | ◎○ | —△ | ◎○ | | —+ | | | | — | | | | | | | | | | | | |

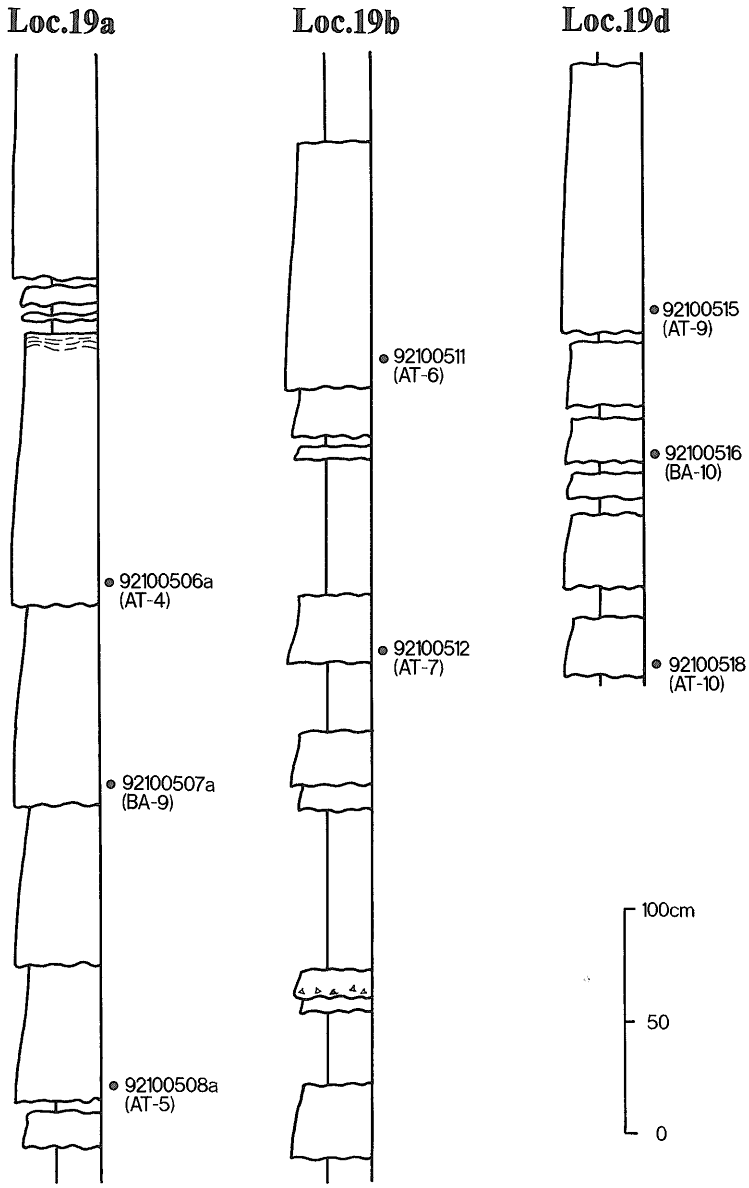



Fig. 8 Geologic columns at Loc. 19 (Araya formation). For the legend see Fig. 4A.

### 2.3 Southern part of the Eastern ("Higashiyama") oil belt

#### 2.3.1 Stratigraphy in the southern part of the Eastern ("Higashiyama") oil belt

The late Miocene Araya formation occurs around the Araya anticline and conformably overlies the middle to late Miocene Sarukuradake formation, which is described in 2.2.1. In this area, the Araya formation is mostly composed of massive dark gray shale or mudstone, but fine-grained, thin-bedded turbidite sandstones are intercalated in the uppermost part of the formation. It attains a thickness of more than 450 meters and conformably overlain by the Kawaguchi formation. The early Pliocene Kawaguchi formation is formed of alternation of turbidite sandstone and hemipelagic mud-

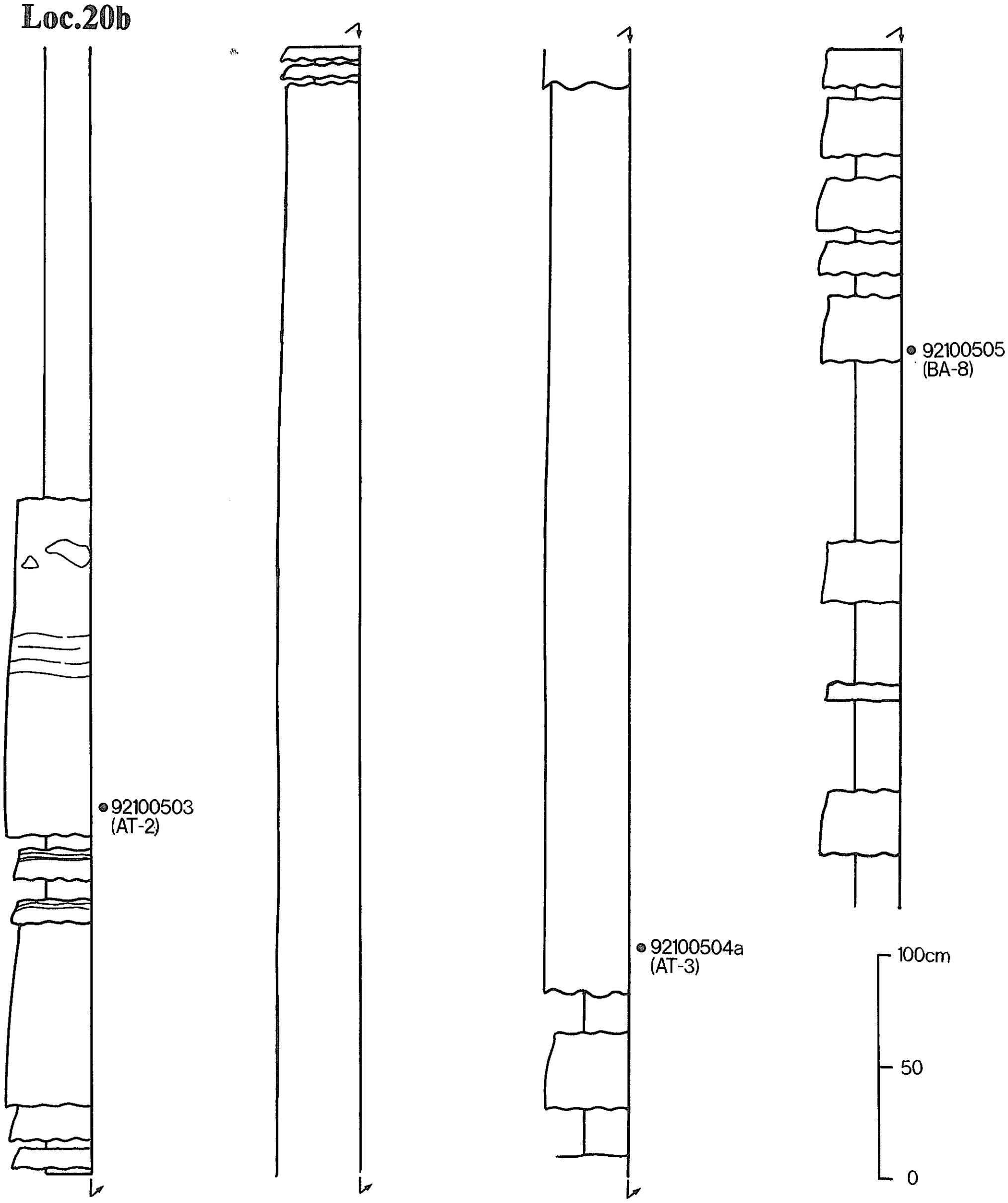



Fig. 9 Geologic columns at Loc. 20 (Ushigakubi formation). For legend see Fig. 4A.

stone and attains about 850 meters in maximum thickness. The Kawaguchi formation is conformably overlain by the Ushigakubi formation, which is mostly composed of massive gray to dark gray mudstone with a maximum thickness of 350 meters. The Pliocene Shiroiwa formation conformably overlies the Ushigakubi formation and made up mostly of sandy siltstone (Yanagisawa *et al*., 1986; Fig. 2).

**2.3.2 Araya formation**

As mentioned above, the Araya formation is formed mostly of massive dark gray shale, but in the uppermost part of the Araya formation are intercalated thin-bedded fine-grained turbidite sandstones. Sandstone samples were col-

Table 5 Results of heavy mineral analysis at Loc. 20 (Ushigakubi 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20a | Tbss | 50 | L | 92100502 | AT-1 | + | ◎ | ○ | + | − | − | | + | | | | | | | | | | | | | 859 | 22.2 | 2.6 | <m. sand> |
| 20b | Tbss | 150 | LM | 92100503 | AT-2 | △ | ◎ | ○ | · | | | | − | | | | | | | | | | | | | 918 | 26.3 | 2.4 | <c. sand> |
| 20b | Tbss | 400 | LM | 92100504a | AT-3 | △ | ◎ | ○ | · | | | | − | | | | | | | | | | | | | 900 | 30.5 | 2 | <c. sand> |
| 20b | Tbss | 30 | LM | 92100505 | BA-8 | △ | ◎ | ○ | + | + | − | | + | | | | | | | | | | | | | 642 | 22.5 | 1.3 | <c. sand> |
| 20 | Tbss | | | general | | +△ | ◎ | ○ | (+) | (−+) | (−) | | −+ | | | | | | | | | | | | | | | | |

Table 6 Results of heavy mineral analysis at Loc. 23 (Araya 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23a | Tbss | 10 | L | 87A58.4 | E-1 | ◎ | | | | | | | | | | − | △ | ○ | + | − | | − | − | | − | 1016 | 0.2 | 6.3 | <f-vf. sand> |
| 23a | Tbss | 20 | L | 87A58.5 | D-3 | ◎ | | | − | | − | − | | | | ○ | − | + | + | | | − | − | | − | 809 | 0.2 | 16 | <f-vf. sand> |
| 23b | Tbss | 30 | L | 87A59 | D-4 | ◎ | | | − | − | − | | | − | | + | − | + | − | | | − | − | | − | 1846 | 0.2 | 12 | <f-vf. sand> |
| 23c | Tbss | 10 | L | 87A60 | E-2 | ◎ | | | | | | | | | | + | + | − | + | | | | − | | − | 1306 | 1.2 | 1.1 | <f-vf. sand> |
| 23 | Tbss | | | general | | ◎ | | | (−) | | (−) | | | | | −○ | −△ | −○ | −+ | | | (−) | − | | − | | | | |

Fig. 10 An outcrop of the upper Kawaguchi formation at Loc. 21d. A measure is one meter long.

lected at Loc. 23 located at the west limb of the Araya anticline.

#### 2.3.2.1 Heavy mineral composition of the Araya formation

**Loc. 23**

Sampling was carried out at three points along the river (Fig. 3) and the results of heavy mineral analysis are shown in Table 6. The heavy mineral composition is characterized by the dominant opaque minerals but no or very few hypersthene, augite, and hornblende. Epidote, zircon, and garnet occurs usually as minor components but sometimes as major components. Sphene, tourmaline and allanite occur as minor components. According to the classification defined in the former paper (Part I), the heavy mineral composition here belongs to Type I.

#### 2.3.2.2 Summary

Type I heavy mineral composition is observed in these sandstones intercalated in the uppermost part of the Araya formation. The details are described above.

### 2.3.3 Kawaguchi formation

The Kawaguchi formation is formed of an alternation of turbidite sandstones and hemipelagic mudstones and attains a maximum thickness of 850 meters. It is divided into the lower and upper parts. The lower Kawaguchi formation, about 450 meters in its maximum thickness, is composed mainly of sandstone-dominated alternation and distributed exclusively in the western part of the area. Thick-bedded coarse-grained turbidite sandstones, often thicker than a few meters, are intercalated in it. The lithologic characteristics of the upper Kawaguchi formation are slightly different between the western part and the eastern part of the area. In the western area, the upper Kawaguchi formation, about 300 meters in maximum thickness, is made up of an alter-

Fig. 11 An outcrop of the upper Kawaguchi formation at Loc. 25. A measure is about 60 centimeters long.

nation of turbidite sandstones and mudstones, yielding very few trace fosils in vertical section (Fig. 10). On the other hand, in the eastern area, it, about 300 meters in maximum thickness, is made up of an alternation of turbidite sandstones and sandy mudstones, and it yields abundant trace fossils in vertical section (Fig. 11).

### 2.3.3.1 Heavy mineral composition of the Kawaguchi formation

Sandstone samples were collected at Loc. 22 (lower Kawaguchi formation) and Loc. 21 (upper Kawaguchi formation) along the river located at the west limb of the Araya anticline, and Loc. 24 (upper Kawaguchi formation) and Loc. 25 (upper Kawaguchi formation) along the small rivers in the eastern part of the area (Fig. 3).

**Loc. 22**

Samples of the lower Kawaguchi formation were collected at 12 points along the small river (Fig. 3) and the results of heavy mineral analysis are shown in Table 7. Two types of heavy mineral composition are observed in the sandstones of the lower Kawaguchi formation. One is characterized by dominant opaque minerals, no hypersthene and augites, and rare to very rare hornblende, similar to those of turbidite sandstones of the underlying Araya formation at Loc. 23. The other is characterized by dominant opaque minerals, no hypersthene and augites, and abundant to common hornblende. As associated minerals, epidote, zircon, garnet, sphene and tourmaline are constantly included in both types. Sometimes tremolite-actinolite, anatase, rutil and allanite are also observed. According to the classification of heavy mineral composition based on the quantitatively major minerals (see Part I), the former belongs to Type I and the latter belongs to Type I–II.

**Loc. 21**

Samples of the upper Kawaguchi formation were collected at 8 points along the small river (Fig. 3) and the results of heavy mineral analy-

Table 7 Results of heavy mineral analysis at Loc. 22 (lower Kawaguchi 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. | | | | | | | | | | | | | | | | | |
| 22a | Tbss | 130 | LM | 87A41 | C-2 | ◎ | | | △ | − | △ | + | | | | + | + | △ | + | | | − | − | | − | 566 | 0.1 | 16.9 | <c-m. sand> |
| 22b | Tbss | 30 | LM | 87A42 | E-4 | ◎ | | | ○ | + | ○ | + | | | − | + | △ | △ | − | | | − | + | | | 800 | 0.3 | 13.3 | <m-c. sand> |
| 22c | Tbss | 500 | LM | 87A44a | C-3 | ○ | | | ○ | + | ○ | + | | | | + | + | △ | + | | | − | | | | 700 | 0.1 | 15.8 | <c-vc. sand> |
| 22d | Tbss | 50 | LM | 87A46 | E-5 | ◎ | | | + | − | − | − | | | − | + | △ | △ | − | − | − | − | + | | − | 1066 | 0.2 | 18.6 | <m-c. sand> |
| 22e | Tf | 100 | LM | 87A47 | C-4 | + | | − | ◎ | △ | ◎ | | ○ | | | − | | | | | | | | | − | 408 | 12.6 | 6.7 | <m-f. dacitic tuff> |
| 22e | Tf | 300 | M | 87A48 | C-5 | △ | | | ◎ | + | ◎ | | + | | | | | | | | | | | | | 568 | 11.7 | 4.9 | <c-vc. andesitic tuff> |
| 22f | Tbss | 500 | LM | 87A50c | C-6 | ◎ | | | △ | − | + | + | | | | + | + | △ | + | | − | − | | | − | 676 | 0.1 | 16.3 | <c-vc. sand> |
| 22g | Tbss | 100 | LM | 87A52 | C-7 | ◎ | | | ○ | + | △ | + | − | | − | + | + | △ | − | | | − | | | − | 803 | 0.1 | 16.3 | <m-c. sand> |
| 22h | Tbss | 600 | LM | 87A53 | E-6 | ◎ | | | △ | + | △ | + | | | − | + | + | △ | + | − | | + | | | + | 516 | 0.1 | 12.8 | <c-vc. sand> |
| 22i | Tbss | 500 | LM | 87A54 | C-8 | ◎ | | | − | − | − | | | | | + | + | ○ | − | | − | + | | | − | 590 | 0.1 | 12.9 | <c-m. sand> |
| 22j | Tbss | 200 | LM | 87A56a | C-9 | ◎ | | | ○ | + | ○ | + | − | | | − | − | △ | − | | | − | − | | | 846 | 0.2 | 19.2 | <m-c. sand> |
| 22k | Tbss | 20 | L | 87A57 | E-7 | ◎ | | | | | | | | | | + | + | ○ | + | − | | − | − | | − | 450 | 0.1 | 21.5 | <f-vf. sand> |
| 22l | Tbss | 200 | LM | 87A58 | C-10 | ◎ | | | | | | | | | | − | + | ○ | − | − | | − | | | − | 593 | 0.1 | 13.2 | <c-m. sand> |
| 22 | Tbss | | | general-1 | | ◎ | | | (−+) | (−) | (−+) | (−) | | | | −+ | +△ | △○ | −+ | (−) | (−) | − | | | − | | | | |
| | | | | general-2 | | ◎ | | | △○ | −+ | △○ | + | (−) | | | −+ | −△ | △ | −+ | | | − | −+ | | − | | | | |



Table 8 Results of heavy mineral analysis at Loc. 21 (upper Kawaguchi 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 features |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | logy | ness | tion | | | | | | total | brn. | green | blu. | Hor | | Act | | | | | | | | | | | CHMG | % | % | |
| | | (cm) | | | | | | | | | | grn. | | | | | | | | | | | | | | | | | |
| 21a | Tbss | 400 | LM | 87A21a | B-1 | ○ | | | ○ | + | ○ | △ | − | | − | △ | + | + | − | | | − | − | | − | 717 | 0.3 | 6.5 | <c-m. sand> |
| 21a | Tbss | 400 | M | 87A21b | D-1 | ○ | | | ◎ | + | ◎ | − | − | | | △ | − | + | − | | | | − | | − | 962 | 0.3 | 7.1 | <m-c. sand> |
| 21a | Tbss | 400 | UM | 87A21c | D-2 | ○ | | | ◎ | + | ◎ | + | − | | − | △ | + | + | − | | | | − | | − | 1024 | 0.2 | 10.5 | <f-vf. sand> |
| 21b | Tbss | 300 | LM | 87A23a | B-2 | ○ | − | | ◎ | + | ○ | + | | | | △ | − | + | | | | | − | | | 617 | 0.4 | 2.6 | <c-m. sand> |
| 21b | Tbss | 200 | LM | 87A24a | B-3 | ○ | − | − | ○ | − | ○ | △ | − | | − | ○ | + | + | − | | | − | − | | − | 753 | 0.3 | 10.3 | <c-m. sand> |
| 21c | Tbss | 80 | LM | 87A27 | B-4 | △ | − | | ◎ | + | ◎ | + | − | − | | + | | − | − | − | | | | | − | 836 | 0.9 | 2.2 | <m-c. sand> |
| 21c | Tbss | 120 | LM | 87A29a | B-5 | ○ | − | | ◎ | + | ○ | △ | − | − | − | △ | + | + | − | | | − | − | | − | 1008 | 0.5 | 4.3 | <c-m. sand> |
| 21d | Tbss | 120 | LM | 87A33a | B-6 | △ | − | | ◎ | + | ◎ | △ | − | | − | △ | − | + | − | | | | | | − | 439 | 0.4 | 8.6 | <c-m. sand> |
| 21e | Tbss | 50 | LM | 87A35a | B-7 | ○ | − | | ◎ | + | ○ | △ | | | + | △ | + | + | − | − | − | | − | | − | 843 | 0.2 | 6.7 | <m-c. sand> |
| 21f | Tbss | 70 | LM | 87A36 | B-8 | ○ | | | ◎ | − | ◎ | + | − | − | + | + | + | + | − | − | | − | − | | − | 864 | 1.1 | 3.8 | <m-c. sand> |
| 21f | Tbss | 80 | LM | 87A37a | B-9 | ○ | | − | ◎ | + | ○ | + | − | − | − | + | + | + | − | | − | − | | | | 910 | 0.6 | 8.1 | <c-m. sand> |
| 21g | Tbss | 250 | LM | 87A38a | C-1 | ○ | | − | ○ | + | ○ | △ | | | − | △ | + | + | | | | | + | | − | 635 | 0.2 | 7.1 | <c-vc. sand> |
| 21h | Tbss | 500 | LM | 87A39 | E-3 | ○ | | | ◎ | △ | ◎ | + | | | + | + | + | + | − | | | | | | + | 625 | 0.2 | 6.4 | <c-vc. sand> |
| 21 | Tbss | | | general | | ○△ | (−) | (−) | ◎○ | −△ | ◎○ | −△ | − | (−) | −+ | +△ | −+ | + | − | (−) | (−) | (−) | − | | − | | | | |

Table 9 Results of heavy mineral analysis at Loc. 24 and 25 (upper Kawaguchi 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | Tbss | 10 | A | 90080412 | O-10 | ○ | ○ | ○ | ○ | + | ○ | – | | | | – | – | – | | | | | | | | 767 | 1.2 | 6.5 | <f-vf. sand> |
| 24 | Tbss | 18 | L | 90080411 | O-9 | △ | ○ | ○ | ○ | – | ○ | – | – | | | – | – | – | | | | | | | | 799 | 0.9 | 1.6 | <m-f. sand> |
| 24 | Tbss | 25 | L | 90080410 | O-8 | ○ | ○ | ○ | ○ | – | ○ | – | – | | | – | – | – | | | | | | | | 1001 | 0.7 | 2 | <f-vf. sand> |
| 24 | Tbss | 35 | L | 90080409 | O-7 | ○ | ○ | ○ | ○ | – | ○ | | | | | | – | – | | | | | | | | 753 | 7.1 | 8.4 | <f. sand> |
| 24 | Tbss | 16 | L | 90080408 | O-6 | △ | ○ | ○ | ○ | – | ○ | – | – | | | – | – | | | | | | | | | 751 | 3.5 | 3.6 | <f. sand> |
| 24 | Tbss | 150 | L | 90080406 | O-5 | △ | ◎ | ○ | ○ | – | ○ | | – | | | | – | – | | | | | | | | 740 | 2.8 | 2 | <m-f. sand> |
| 24 | Tbss | | | general | | △○ | ○ | ○ | ○ | – | ○ | (–) | (–) | | | – | – | – | | | | | | | | | | | |
| 25 | Tbss | 200 | LM | 89O1601a | J-9 | △ | ◎ | △ | ○ | + | ○ | | – | | | – | | – | | | | | | | | 728 | 1.9 | 9.8 | <f-m. sand> |
| 25 | Tbss | 200 | UM | 89O1601c | J-10 | ○ | ◎ | △ | △ | – | △ | – | – | | | – | – | – | | | | | | | | 966 | 3.5 | 12.4 | <f. sand> |
| 25 | Tbss | 25 | L | 89O1602 | I-4 | + | ○ | △ | ◎ | – | ◎ | | | | | – | | | | | | | | | | 684 | 1.8 | 5.9 | <f. sand> |
| 25 | Tbss | 22 | L | 89O1603 | J-8 | △ | ○ | △ | ○ | + | ○ | – | – | | | – | | – | | | | | | | | 835 | 1.5 | 7.5 | <f. sand> |
| 25 | Tbss | 55 | LM | 89O1604 | I-5 | △ | ○ | △ | ◎ | + | ◎ | – | – | | – | – | – | – | | | | | | | | 665 | 1.3 | 7.5 | <m-f. sand> |
| 25 | Tbss | | | general | | +○ | ◎○ | △ | △◎ | –+ | △◎ | (–) | – | | | – | (–) | – | | | | | | | | | | | |

sis are shown in Table 8. The heavy mineral composition of these sandstones is characterized by abundant opaque minerals, dominant to abundant hornblende, but very few hypersthene and augite. The same kinds of associated minerals observed in the sandstones at Loc. 22 (lower Kawaguchi formation) are also constantly or sometimes included. According to the classification of heavy mineral composition based on the quantitatively major minerals (see Part I), sandstones of the upper Kawaguchi formation at Loc. 21 belong to Type II.

**Loc. 24**

This locality is located along a small river in the eastern part of the area (Fig. 3) and the results of heavy mineral analysis are shown in Table 9. The heavy mineral composition of turbidite sandstones of the upper Kawaguchi formation is characterized by abundant opaque minerals, hypersthene, augite and hornblende. As minor components, epidote, zircon and garnet are observed. According to the classification of heavy mineral composition based on the quantitatively major minerals (see Part I), sandstones of the upper Kawaguchi formation at Loc. 24 belong to Type III.

**Loc. 25**

This locality is located along an another small river near Loc. 24 in the eastern part of the area (Fig. 3) and the results of heavy mineral analysis are shown in Table 9. The heavy mineral composition of turbidite sandstones is nearly the same as those at Loc. 24. It is characterized by the common to dominant occurrence of opaque minerals, hypersthene, augite and hornblende, and belongs to Type III heavy mineral composition.

#### 2.3.3.2 Summary

At Loc. 22 and Loc. 21 in the western limb of the Araya anticline, the sandstones of the lower Kawaguchi formation are composed of Type I and Type I-II heavy mineral composition, and the sandstones of the upper Kawaguchi formation are composed of Type II heavy mineral composition. It is the most important characteristics common to these types to include actually no or very few hypersthene and augite. On the other hand, the sandstones of the upper Kawaguchi formation at Loc. 24 and Loc. 25 in the eastern part of the area are composed of Type III heavy mineral composition, which includes abundant hypersthene and augite. Therefore, the heavy mineral composition of turbidite sandstones of the upper Kawaguchi formation is basically different each other between in the western part and in the eastern part. The same kind of difference of the heavy mineral composition between the western and eastern parts is widely recognized throughout the area (Tokuhashi, 1992). Tokuhashi (1992, 1994) attributed the difference to the different sources located in the east, and suggested the juxtaposition of two kinds of turbidite sandstones, i.e. submarine-fan turbidite sandstones in the western area and shelf turbidite sandstones in the eastern area during the deposition of the upper part of the Kawaguchi formation.

## 3. Discussion

In the former paper (Part I), with the results of heavy mineral analysis of turbidite sandstones at the Western ("Nishiyama") and Central ("Chuo") oil belts, four types of heavy mineral composition, Type I, Type I-II, Type II and Type III, were suggested based on the combination of the quantitatively major heavy minerals such as opaque minerals, hypersthene, augite and hornblende. These types are also recognized in the turbidite sandstones at the Eastern ("Higashiyama") oil belt as shown in this paper. However, as mentioned above, two new types of heavy mineral composition, i.e. Type IV and Type V, are recognized at the Eastern ("Higashiyama") oil belt. Herein, a new classification which consists of 6 types, i.e. four conventional types and two fresh types, is suggested here (Table 10). The generalized heavy mineral composition and type of heavy mineral composition at each locality at the Eastern ("Higashiyama") oil belt are summarized at Table 11. The generalized heavy mineral composition and type of heavy mineral composition at all localities, i.e. from Loc. 1 to Loc. 25, at the Western ("Nishiyama"), Central ("Chuo"), and Eastern ("Higashiyama") oil belts are summarized at Table 12 and Fig. 12.

Table 10 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 | ○ | ○ | ○ | ○ | |
| IV | ○ | ○ | ○ | × or − | |
| V | ○ | × or − | ○ | ○ | |

The same kind of vertical change for types of the heavy mineral composition, i.e. from Type I through Type I-II to Type II upward, are recognized both from the Teradomari formation to the overlying Shiiya formation at the Western ("Nishiyama") oil belt, and from the Araya formation to the overlying Kawaguchi formation in the western part of the southern Eastern ("Higashiyama") oil belt. This vertical change reflects the addition and increase of hornblende upward. In these types, hypersthene and augite are actually not observed.

On the other hand, the occurrence of different types of heavy mineral composition for the sandstones from the same formation but from the different areas are observed in the plural formations, i.e. the presense of Type I-II or Type II in one area and Type III in another area observed both in the Shiiya formation between at the Western ("Nishiyama") and the Central ("Chuo") oil belts, and in the upper Kawaguchi formation between at the western and eastern areas at the Eastern ("Higashiyama") oil belt. According to the paleocurrent data of the turbidite sandstones in the study area (Fig. 13), the turbidite sandstones of the upper Kawaguchi formation, at the western and eastern areas, were supplied both from the east. Tokuhashi (1992, 1993, 1994) interpreted that these turbidite sandstones were supplied from the different sources and deposited in the different sedimentary environments, i.e. turbidite sandstones at the western area as submarine fan deposits and those at the eastern area as shelf turbidite sandstones.

The major paleocurrent direction of the Shiiya formation at the Western ("Nishiyama") oil belt is northward to northwestward, and at the Central ("Chuo") oil belt northward to northeastward (Fig. 13). From these data both of paleocurrent and of heavy mineral composition, it is probable that these sandstones were supplied from different source areas, and transported apart from each other nearly parallel to the anticlinal axes.

Therefore, the heavy mineral composition yields not only an important identification marker for each turbidite sandstone body, but also a valuable key in clarifying the sedimentary relationship or formation process of tur-

Table 11 Generalized heavy mineral composition and Type at each locality at the Eastern ("Higashiyama") oil belt.

| Regional name | Loc. no. | Formation | Opq | Hyp | Aug | Hor | Oxy-Hor | Tre-Act | Epi | Zir | Gar | Sph | Ana | Tou | Al | Gla | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Eastern Oil Belt | Loc.14 | Kanatsu F. | ◎○ | +◎ | | −○ | (−) | | (−) | −+ | − | | | (−) | | | IV |
| | Loc.15 | Higashiyama Sd. M. | ◎ | | | (−) | (−) | | | + | − | | | | (−) | | I |
| | Loc.16 | Higashiyama Sd. M. | ◎ | | | − | | | | + | − | | | | | | I |
| | Loc.17 | Higashiyama Sd. M. | ◎ | | | △◎ | | | | −+ | −+ | | | | | | I-II |
| | Loc.18 | Higashiyama Sd. M. | ◎○ | | | +◎ | (−) | | (−) | +△ | − | | | | | | I-II |
| | Loc.19 | U. Araya F. | + | ◎ | ○ | | | | | (−) | | | | | | | V |
| | | | ○△ | ○ | −+ | ◎○ | −+ | | | − | | | | | | | IV |
| | Loc.20 | Ushigakubi F. | +△ | ◎ | ○ | (+) | −+ | | | | | | | | | | V |
| | Loc.23 | Um. Araya F. | ◎ | | | (−) | | | −○ | −△ | −○ | −+ | | (−) | − | | I |
| | Loc.22 | L. Kawaguchi F. | ◎ | | | (−+) | | | −+ | +△ | ○△ | −+ | (−) | − | | | I |
| | | | ◎ | | | ○△ | (−) | | −+ | −△ | △ | −+ | | − | −+ | | I-II |
| | Loc.21 | U. Kawaguchi F. | ○△ | (−) | (−) | ◎○ | − | −+ | +△ | −+ | + | − | (−) | (−) | − | | II |
| | Loc.24 | U. Kawaguchi F. | ○△ | ○ | ○ | ○ | (−) | | − | − | − | | | | | | III |
| | Loc.25 | U. Kawaguchi F. | +○ | ◎○ | △ | △◎ | − | | − | (−) | − | | | | | | III |

(LEGEND)

- 50.0%≦◎
- 15.0%≦○<50.0%
- 5.0%≦△<15.0%
- 1.0%≦+<5.0%
- 0.1%≦−<1.0%
- · <0.1%

Table 12 Generalized heavy mineral composition and Type at each locality in the whole study area.

| Regional name | Loc. no. | Formation | Opq | Hyp | Aug | Hor | Oxy-Hor | Tre-Act | Epi | Zir | Gar | Sph | Ana | Tou | Al | Gla | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Western Oil Belt | Loc.1 | Teradomari F. | ◎ | (−) | | (・−) | | | | △ | + | | | ・+ | (−) | | I |
| | Loc.7 | U. Teradomari F. | ◎ | − | (−) | − | (−) | (−) | (−) | △ | + | | (−) | − | | (−) | I |
| | Loc.8 | Um. Teradomari F. | ◎ | (−) | (−) | −△ | | − | − | △ | + | | (−) | − | (−) | − | I, I-II |
| | Loc.2 | L. Shiiya F. | ○ | | | ◎○ | −+ | − | − | −△ | − | − | | (−) | | | II |
| | Loc.9 | U. Shiiya F. | ◎○ | | | ◎○ | (−) | △+ | − | −+ | − | (−) | (−) | (−) | (−) | (−) | I-II, II |
| | Loc.11 | U. Shiiya F. | ◎○ | | | ◎○ | −+ | △+ | −+ | −+ | − | | (−) | (−) | | (−) | I-II, II |
| | 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 Oil Belt | Loc.12 | Shiiya F. | +○ | ◎○ | ○△ | ○△ | − | (−) | (−) | −+ | (−) | | | | | (−) | III |
| | Loc.13 | Shiiya F. | +○ | ○ | ○△ | △◎ | −+ | (−) | − | − | (−) | | | | | (−) | III |
| Eastern Oil Belt | Loc.14 | Kanatsu F. | ◎○ | +◎ | | −○ | (−) | | (−) | −+ | − | | | (−) | | | IV |
| | Loc.15 | Higashiyama Sd. M. | ◎ | | | (−) | (−) | | | + | − | | | | (−) | | I |
| | Loc.16 | Higashiyama Sd. M. | ◎ | | | − | | | | + | − | | | | | | I |
| | Loc.17 | Higashiyama Sd. M. | ◎ | | | △◎ | | | | + | −+ | | | | | | I-II |
| | Loc.18 | Higashiyama Sd. M. | ◎○ | | | +◎ | (−) | | (−) | +△ | − | | | | | | I-II |
| | Loc.19 | U. Araya F. | + | ◎ | ○ | | | | | (−) | | | | | | | V |
| | | | ○△ | ○ | −+ | ◎○ | −+ | | | − | | | | | | | IV |
| | Loc.20 | Ushigakubi F. | +△ | ◎ | ○ | (+) | −+ | | | | | | | | | | V |
| | Loc.23 | Um. Araya F. | ◎ | | | (−) | | | −○ | −△ | −○ | −+ | | (−) | − | | I |
| | Loc.22 | L. Kawaguchi F. | ◎ | | | (−+) | | | −+ | +△ | ○△ | −+ | (−) | − | | | I |
| | | | ◎ | | | ○△ | (−) | | −+ | −△ | △ | −+ | | − | −+ | | I-II |
| | Loc.21 | U. Kawaguchi F. | ○△ | (−) | (−) | ◎○ | − | −+ | +△ | −+ | + | − | (−) | (−) | − | | II |
| | Loc.24 | U. Kawaguchi F. | ○△ | ○ | ○ | ○ | (−) | | − | − | − | | | | | | III |
| | Loc.25 | U. Kawaguchi F. | +○ | ◎○ | △ | △◎ | − | | − | (−) | − | | | | | | III |

(LEGEND)
50.0%≦◎
15.0%≦○<50.0%
5.0%≦△<15.0%
1.0%≦+<5.0%
0.1%≦−<1.0%
・<0.1%

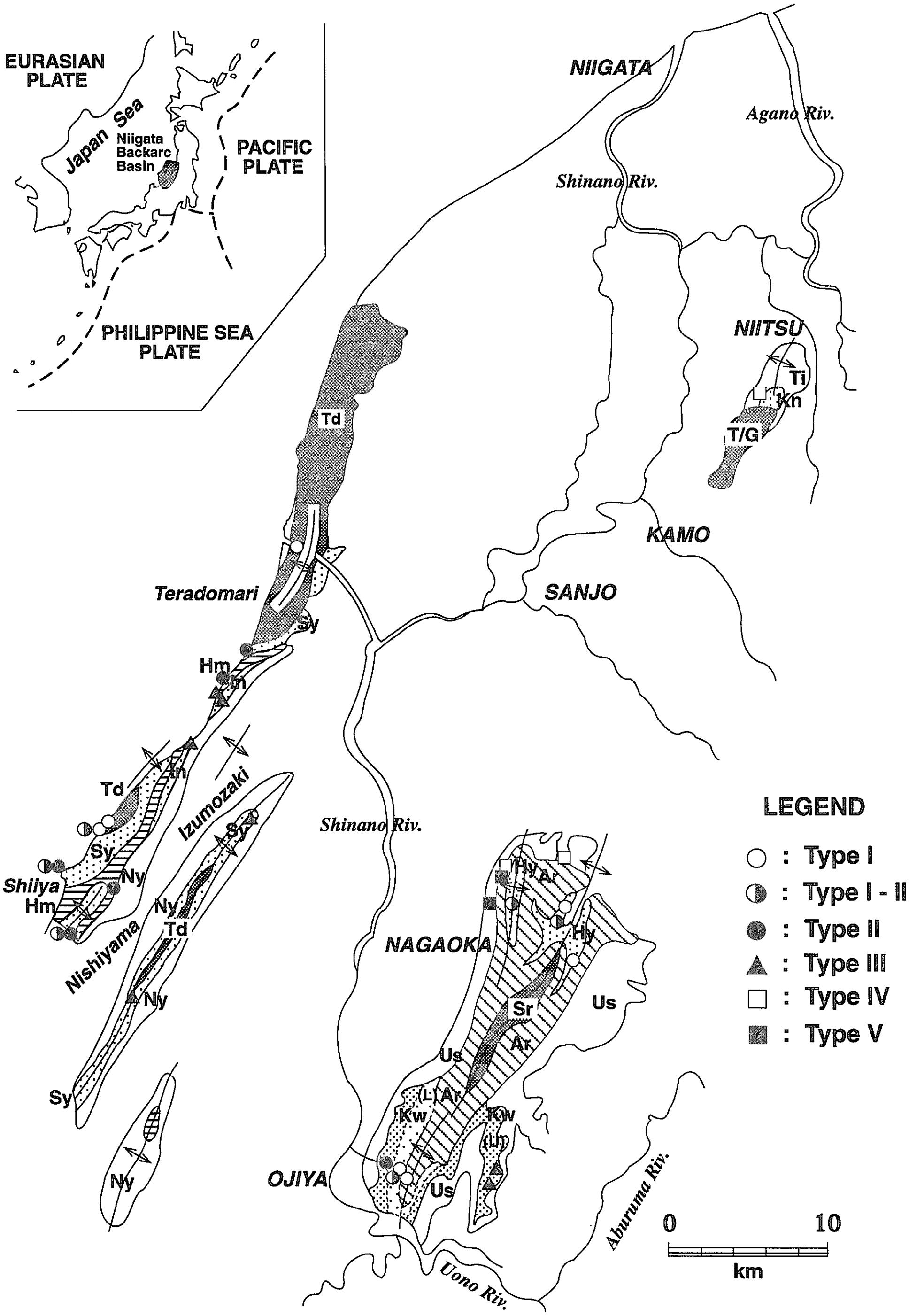



Fig. 12 Distribution of types of heavy mineral composition at each locality in the study area.

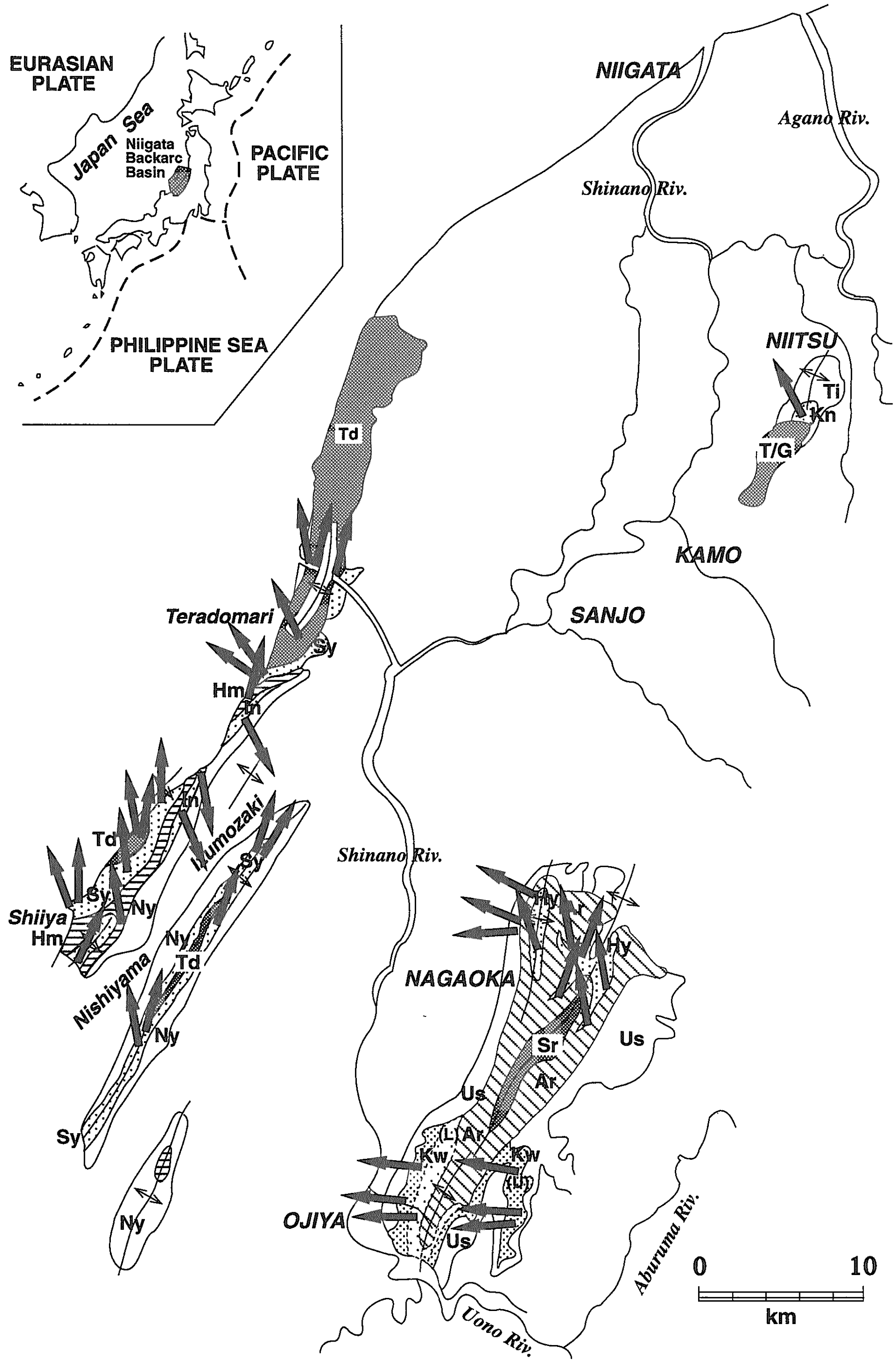



Fig. 13 Summary of paleocurrent data on turbidite sandstones in the study area. Main papers, to which paleocurrent data are refferred, are as follows: Sasaki and Ushijima, 1969; Morita *et al.*, 1973; Kageyama and Suzuki, 1974; Tateishi *et al.*, 1984; Tokuhashi, 1992.

bidite sandstone bodies, together with other sedimentary data, especially paleocurrent data of individual sandstone bodies.

To disclose the origin of 6 types from Type I to Type V of heavy mineral composition, which are recognized in the turbidite sandstones in the study area (Table 10), more detailed or quantitative data based on geochemical analysis using some equipments such as EPMA or EDX, are needed.

## 4. Conclusions

Based on the discussion above, the authors come up with the following conclusions:

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

2) The turbidite sandstones in the study area can be classified at least into six types (four conventional types described in the former paper and two new types recognized in this paper) 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 differenct formations or members in the study area are often composed of 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 the 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 a lithologic unit such as a formation or a member.

6) The heavy mineral analysis of turbidite sandstones yields a very important key or a new information to disclose the sedimentary process, especially when its results are combined with other sedimentological data such as paleocurrent data.

7) Therefore, the heavy mineral analysis is very valuable not only as a conventional tool to estimate the provenance, but also as a strong measure to estimate the original relationship of several sandstone bodies, to disclose the sedimentary process of these sandstone bodies in conjunction with the sedimentary data, and to predict the three-dimensional extents of turbidite sandstone bodies both on the surface and subsurface by using samples from outcrops and from boring cores or cuttings.

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(* Written in Japanese with English abstract and caption)

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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2：東山油帯及び全体のまとめ―

**徳橋秀一・クリストファー M. アギンギー**

### 要　旨

その1では，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について報告したが，その2では，東山油帯において12地点で行った重鉱物分析の結果について報告するとともに，全体のまとめを行った．主な結論は次の通りである．

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，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，その1(西山及び中央油帯)でみられた4つのタイプの他に，今回(東山油帯)，新しく2つのタイプが見つかり，本地域には，あわせて少なくとも6つのタイプが存在することが明らかになった．

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．

6) タービダイト砂岩の重鉱物分析の結果は，古流向といった堆積学的データと結びつくことによって，堆積作用の解明にも重要な役割を果たすことが期待される．

7) したがって，重鉱物分析は，供給源の推定という従来の手法としてのみならず，いくつかのタービダイト砂岩体相互の成因的関係やそれらの堆積様式の解明，そしてそれらの三次元的分布様式の解明にも大変有用な手段となりうることを示している．