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Sedimentological and mineralogical analysis of the Neogene turbidite sandstone beds at the eastern margin of the Niigata backarc oil basin, central Japan

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Abstract: Positive effort to combine mineralogical analysis, especially heavy mineral analysis, with sedimentological analysis of the Neogene turbidite sandstone beds at the eastern margin of the Niigata backarc basin, the most important oil-bearing basin in Japan, resulted in a new fact that two kinds of turbidite sandstones, a western submarine-fan turbidite sandstone and an eastern shelf turbidite sandstone, were deposited concurrently during the deposition of the upper part of the lower Pliocene Kawaguchi Formation. As the exploration for stratigraphic traps becomes more important in the basin, such combination of analytical data based both on detailed mineralogy and sedimentology is stressed in this paper to be very useful and inevitable.

INTRODUCTION

Around the Japanese Islands are distributed many sedimentary basins, such as forearc basins and backarc basins along the Chishima Arc, the Japan Arc and the Ryukyu Arc and some foreland basins in central Hokkaido (Fig. 1A). The genesis of the backarc basins along the Japan Arc is closely related with the opening of Japan Sea during the late Early Miocene to early Middle Miocene. Basic to intermediate, partly acidic, volcanic rocks of these ages widely occupy the lowermost part of the basin-fill rocks and are overlain by thick marine sediments. These lowermost volcanic rocks are more or less altered and often called "Green-tuff rocks". The distribution zone of these volcanic rocks or "Green-tuff rocks" is often called "Green-tuff region" in Japan. The distribution area of the Tertiary backarc basins along the Chishima Arc, Japan Arc and Ryukyu Arc is approximately equal to the "Green-tuff region".

The lowermost volcanic rocks or "Green-tuff rocks" in the Niigata backarc basin (Fig. 1A), the most important oil-bearing basin in Japan, are overlain by the Middle Miocene deep-marine mudstone and Late Miocene to Pliocene thick turbidite-bearing deep-marine sediments. Several turbidite sandstone bodies, which were closely spaced to each other but supplied from different source areas, were formed in the central deeper basin areas. During the Late Pliocene to Pleistocene, these sediments suffered from compressional stress field and were deformed to form many NNE-SSW trending folds and overlain by the upward-shallowing marine and non-marine sediments. The Late Pliocene to Pleistocene deformation of the basin-fill rocks resulted in the formation of the oil and gas traps in the basin. Now, the lowermost volcanic rocks or "Green-tuff rocks" and Late Miocene to Pliocene turbidite sandstones make up the two major reservoir rocks or play types in the basin (Watanabe *et al.*, 1990; Kikuchi *et al.*, 1991).

As the exploration for stratigraphic traps of the turbidite sandstone reservoir rocks becomes more important in place of the anticlinal structural traps, the prediction of the areal or spatial extent of individual turbidite sandstone bodies, that is, sedimentological and provenancial relationship between each turbidite sandstone body located here and there in the basin becomes necessary and inevitable. Though the paleogeographic reconstruction based on sedimentological analysis of turbidite sandstones such as paleocurrent analysis and sedimentary facies analysis have been tried by several previous workers (Kageyama and Suzuki, 1974; Tateishi *et al.*, 1984; Suzuki, 1989; Kobayashi and Tateishi, 1992), mineralogical analysis of these sandstones to clarify the sedimentological and provenancial relationship is very limited. However, the mineralogical analysis, especially heavy mineral analysis, is very important and useful not only to estimate the provenance characteristics and source area, but also to investigate the original relationship and areal or spatial extent of each turbidite sandstone body.

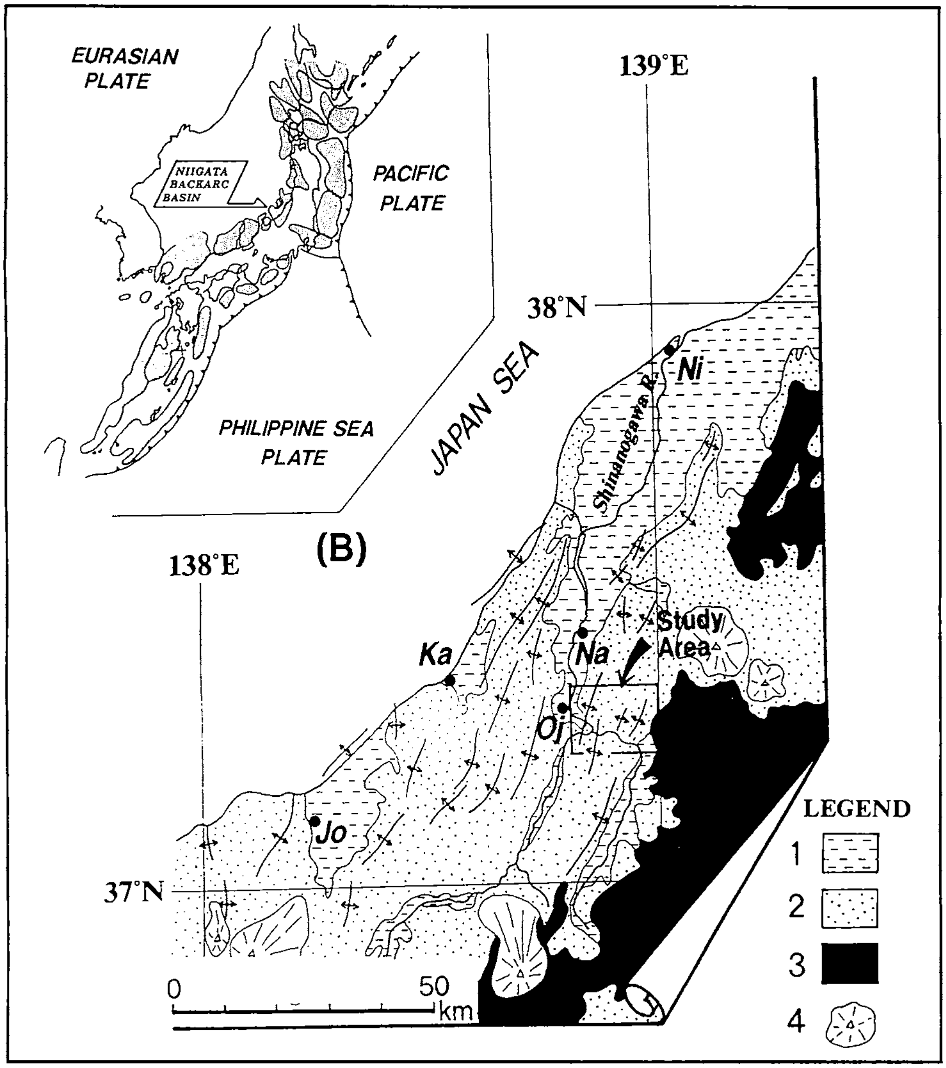


Figure 1. (A) Distribution of sedimentary basins around Japanese Islands and the location of Niigata backarc basin. Drawn based on Sumii *et al.* (1992). (B) The location of the study area in the Niigata backarc basin. Ni: Niigata City, Na: Nagaoka City, Oj: Ojiya City, Ka: Kashiwazaki City, Jo: Joetsu City. 1: Holocene alluvial deposits, 2: Neogene basin-fill sediments (partly includes volcanic rocks), 3: Pre-Tertiary basement rocks (Mesozoic sedimentary rocks and Cretaceous granitic rocks), 4: Late Quaternary volcanoes.

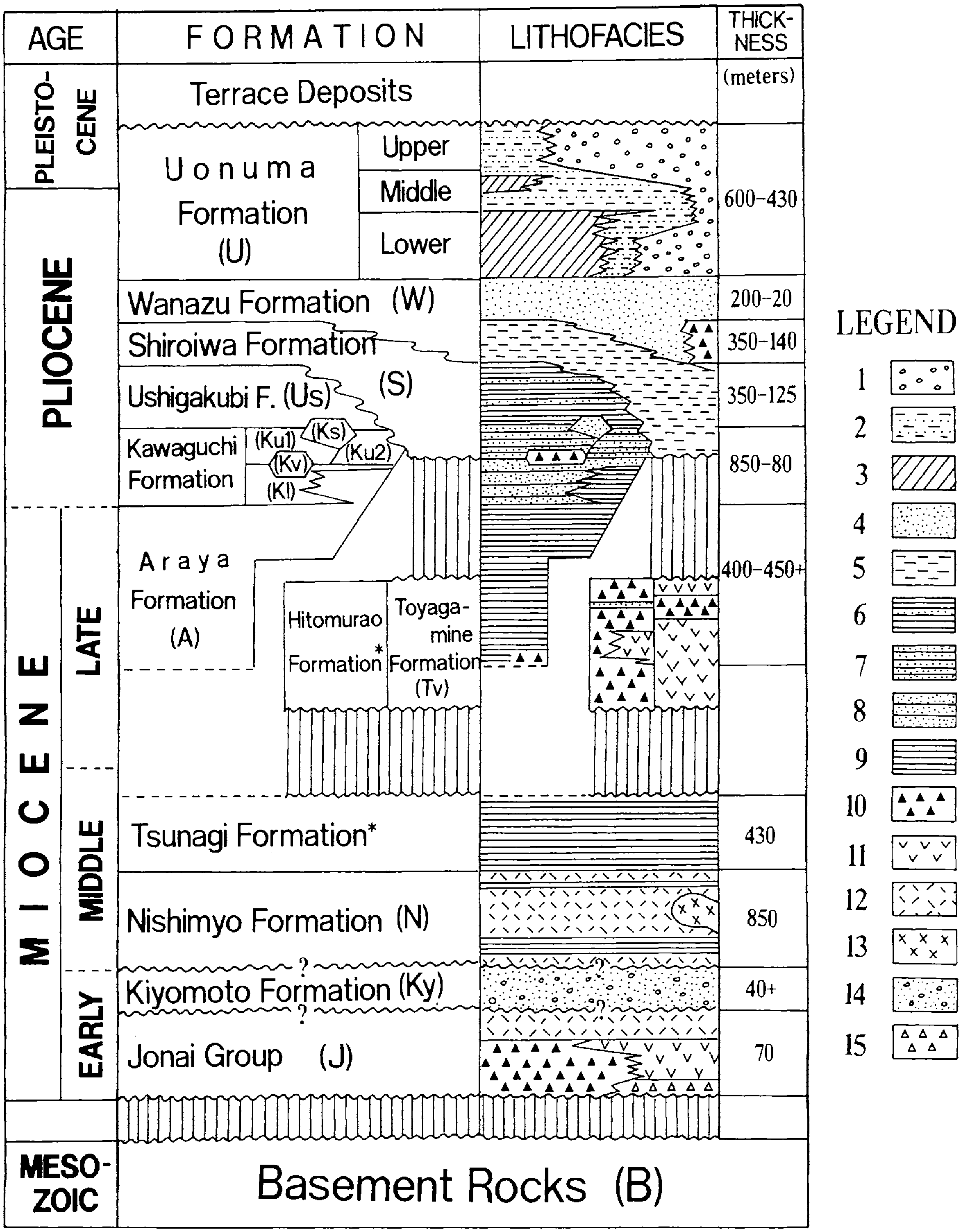
This paper will show the very good example that the combination of the detailed sedimentological and mineralogical analysis discloses new facts and guides to a completely different interpretation. As the study area is located at the eastern margin of the Niigata backarc basin, sedimentological phenomena at the transitional area from deep-marine to shallow-marine environments become the main topics. However, the method practiced here should be useful and inevitable to clarify the mutual relationship between many turbidite sandstone bodies and to establish more high-resolutional paleogeographic reconstruction of these sandstones.

STRATIGRAPHY IN THE STUDY AREA

The study area is located at the eastern margin of the Niigata backarc basin, and partly includes the area of the basement composed of pre-Tertiary rocks (Fig. 1B). The lowermost part of the basin-fill rocks consists mostly of Early to Middle Miocene intermediate to acidic volcanic rocks. During the Late Miocene to Pleistocene, an upward shallowing sequence from deep-marine through shallow-marine to terrestrial deposits partly with volcanic rocks was formed in the study area (Fig. 2). Since the Late Pliocene, these rocks have been deformed to form NNE-SSW trending folds. The Late Miocene to Pleistocene sedimentary rocks are repeatedly distributed under the control of these folds in the study area (Fig. 3).

The Late Miocene to Pliocene marine sediments in the study area are divided into several formations; Araya Formation (deep-marine mudstone), Kawaguchi Formation (turbidite sandstone-mudstone alternation), Ushigakubi Formation (deep-marine mudstone), Shiroiwa Formation (shallow-marine sandy mudstone), and Wanazu Formation (shallow-marine sandstone) in ascending order. These marine sediments are overlain by the Late Pliocene to Pleistocene terrestrial to near shore Uonuma Formation (Fig. 2).

Many thin volcanic ash layers are intercalated in the marine sediments in the study area.



* Not distributed in the study area.

Figure 2. Stratigraphy in the study area. After Yanagisawa *et al.* (1986). 1: gravel (terrestrial), 2: sand and silt (fresh water), 3: silt and sand (marine), 4: sand, 5: sandy mudstone, 6: mudstone with intercalation of thin sandstone beds, 7: mudstone-dominated alternation of turbidite sandstone and mudstone, 8: sandstone-dominated alternation of turbidite sandstone and mudstone, 9: mudstone, 10: andesitic and dacitic volcanic breccia, 11: andesitic and dacitic lava, 12: dacitic pyroclastic rocks, 13: rhyolitic lava, 14: sandstone and conglomerate, 15: andesitic pyroclastic rocks.

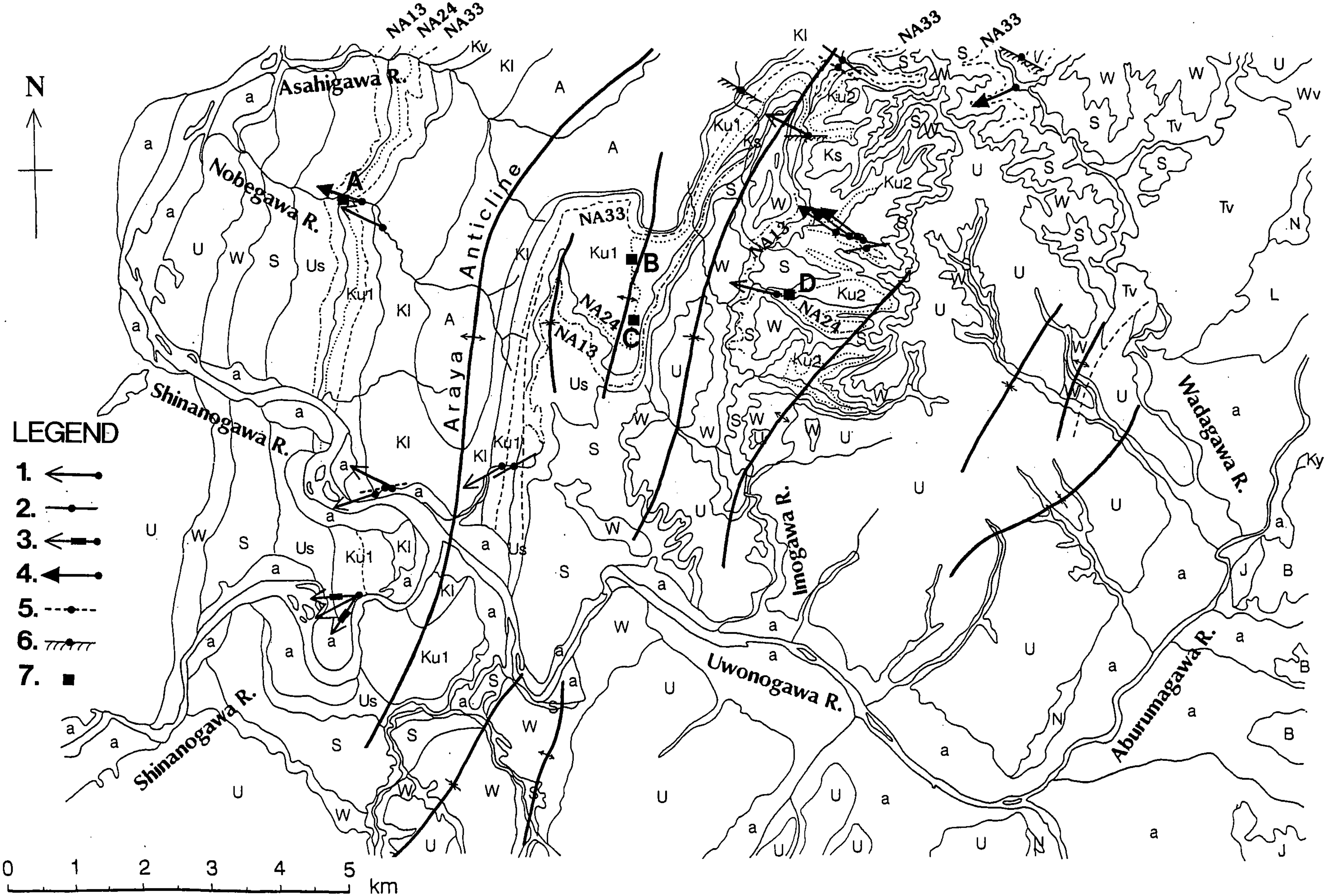


Figure 3. Geologic sketch map of the study area (after Yanagisawa *et al.* (1986) and direction of paleocurrent measured from various sedimentary structures associated with turbidite sandstones in the Kawaguchi Formation. Each formation is represented by the same alphabetical symbol shown in Figure 2. a: Holocene fluvial deposits, L: Pleistocene landslide deposits. 1: sole mark, 2: sole mark (sense is unknown), 3: preferred orientation of gravels in the turbidite sandstone beds, 4: current ripple lamination, 5: preferred orientation of wood fragments in the turbidite sandstone beds (sense is unknown), 6: orientation of the wall of small channels (sense is unknown), 7: location of lithologic columns shown in Figure 6.

Tokuhashi (1985) gave these volcanic ash layers systematic names to use them as tuff marker beds and traced them around the Araya anticline in the western part of the study area (Fig. 4). Yanagisawa *et al.* (1986) traced these tuff marker beds through the whole study area and found that the western deep-marine formations are gradually replaced by the shallow-marine formations eastward (Fig. 5).

SEDIMENTOLOGICAL CHARACTERISTICS OF THE KAWAGUCHI FORMATION

In the western part of the study area, the Kawaguchi Formation is divided into the lower and upper parts (Tokuhashi, 1985; Yanagisawa *et al.*, 1986). The Lower Kawaguchi Formation (K1) is characterized by sandstone-dominated alternation of turbidite sandstone and mudstone, and is distributed almost exclusively in the western part of the study area (Fig. 3, Fig. 5). Yanagisawa *et al.* (1986) divided the Upper Kawaguchi Formation into the western and eastern parts. The western Upper Kawaguchi Formation (Ku1) is composed of mudstone-dominated alternation of turbidite sandstone and mudstone, while the eastern Upper Kawaguchi Formation (Ku2) is made up of sandy mudstone dominated alternation of turbidite sandstone and sandy mudstone with abundant trace fossils (see vertical section, Fig. 5). Turbidite sandstone beds in the western part of the study area (K1 and Ku1) are thicker and commonly more than a few meters in thickness. They attain approximately 10 meters in maximum thickness, and tend to occur more or less collectively in vertical section. Tokuhashi (1985) named each set of turbidite sandstone beds "Depositional Tongue (DT)" and interpreted these turbidite sandstones as submarine-fan deposits. The turbidite sandstones in the eastern part of the study area (Ku2), on the other hand, are thinner and usually less than several tens of centimeters, and tend to occur more randomly in the vertical section (Fig. 6).

The paleocurrent direction measured from sedimentary structures of the turbidite sandstones of the Kawaguchi Formation indicates that the transportation of these sediments is westward, that is, from east toward west both in western (K1 and Ku1) and eastern parts (Ku2) of the study area (Fig. 3). To investigate the original or sedimentological relationship of the turbidite sandstones distributed in the western and eastern parts of the study area, heavy mineral analysis of many samples collected from these turbidite sandstones was carried out.

RESULTS OF HEAVY MINERAL ANALYSIS

Tokuhashi (1990) analyzed the heavy mineral composition of sandstones sampled from Araya Formation to Wanazu Formation in ascending order along the Nobegawa River, type section of the Late Miocene to Late Pliocene marine sediments in the western part of the study area. Tokuhashi (1990) distinguished at least four types of heavy mineral composition, i.e., Type I, Type I-II, Type II and Type III (Fig. 7). Type I is characterized by the dominance of opaque minerals (opaque minerals > 50% of all heavy minerals) and other minor minerals include zircon, garnet, epidote and zoisite. In Type I-II, opaque minerals and hornblende are both abundant, but the former is more abundant than the latter (opaque minerals > hornblende), but other minor heavy minerals are the same as those in Type I. In Type II, hornblende is dominant but opaque minerals are still abundant (hornblende > opaque minerals). Other minor heavy minerals in Type II are the same as those as in Type I and Type I-II. Type III is fundamentally different from other Types as it contains abundant hypersthene and augite besides hornblende, epidote and opaque minerals.

Type I heavy minerals are shown in the thin turbidite sandstones in the uppermost part of the Araya Formation. Turbidite sandstones, both thick and thin, in the Lower Kawaguchi Formation (K1) contain Type I and Type I-II heavy minerals. Most turbidite sandstones in the Upper Kawaguchi Formation (Ku1) contain Type II heavy mineral composition. Turbidite sandstones partly intercalated in the upper part of the Ushigakubi Formation are made up of Type I or Type II. Shallow-marine sandstones in the Wanazu Formation, on the other hand, are composed of Type III (Fig. 7). Therefore, along the Nobegawa River, the type section in the western part of the study area, abundant hypersthene- and augite-bearing Type III heavy mineral composition is observed only in the shallow-marine sandstones in the Wanazu Formation and not observed in the turbidite sandstones in the underlying formations. All these turbidite sandstones are formed of Type I, Type I-II and Type II heavy mineral composition (Figs. 4 and 7).

Tokuhashi (1992) analyzed the heavy mineral composition of a large number of sandstone samples gathered both in the western and eastern parts of the study area and identified the types of heavy mineral composition of these samples (Fig. 8). In the western part of the study area, that is, both

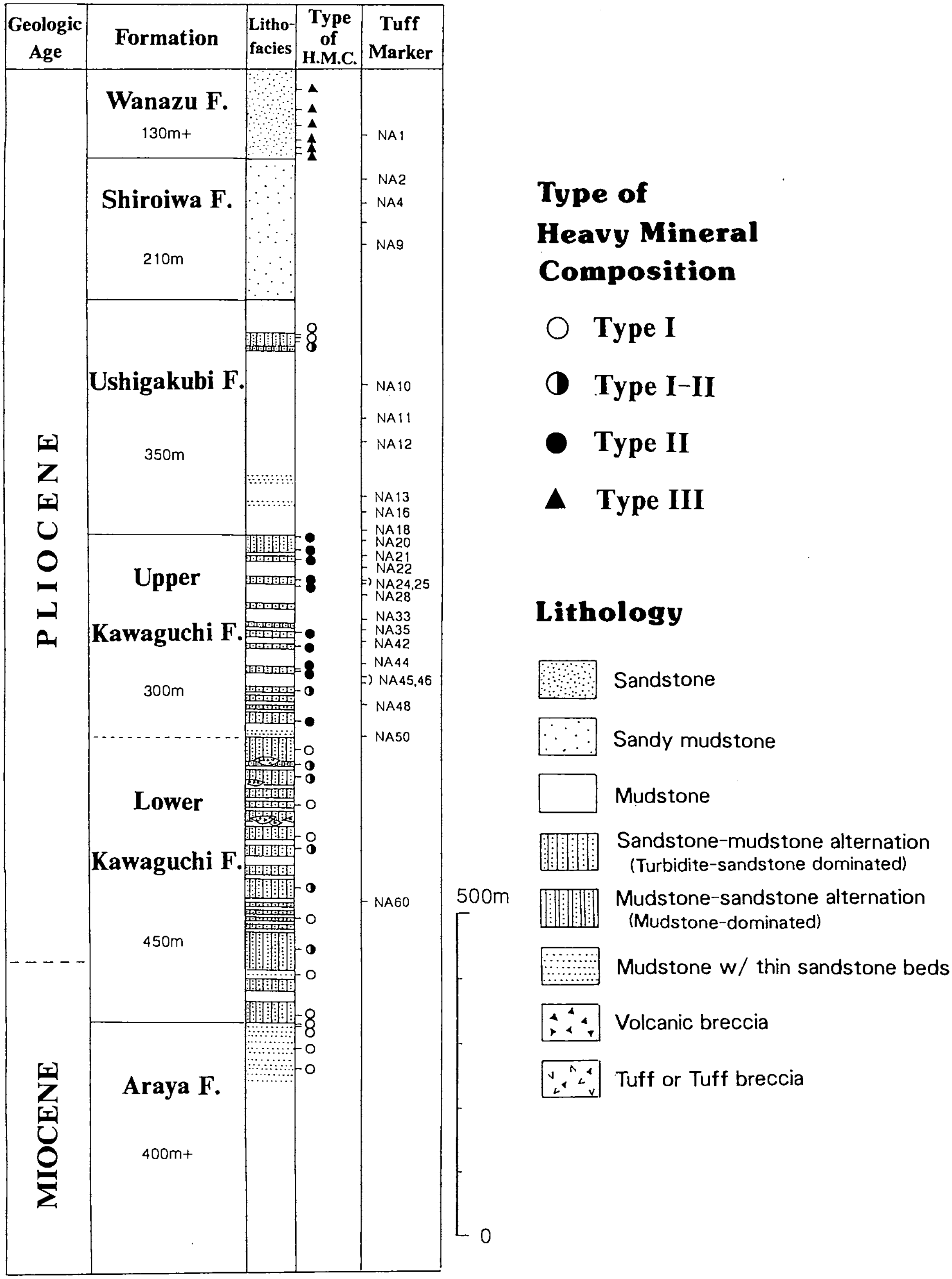


Figure 4. Lithologic column with types of heavy mineral composition of sandstones and the position of main tuff markers along the Nobegawa River in the western part of the study area.

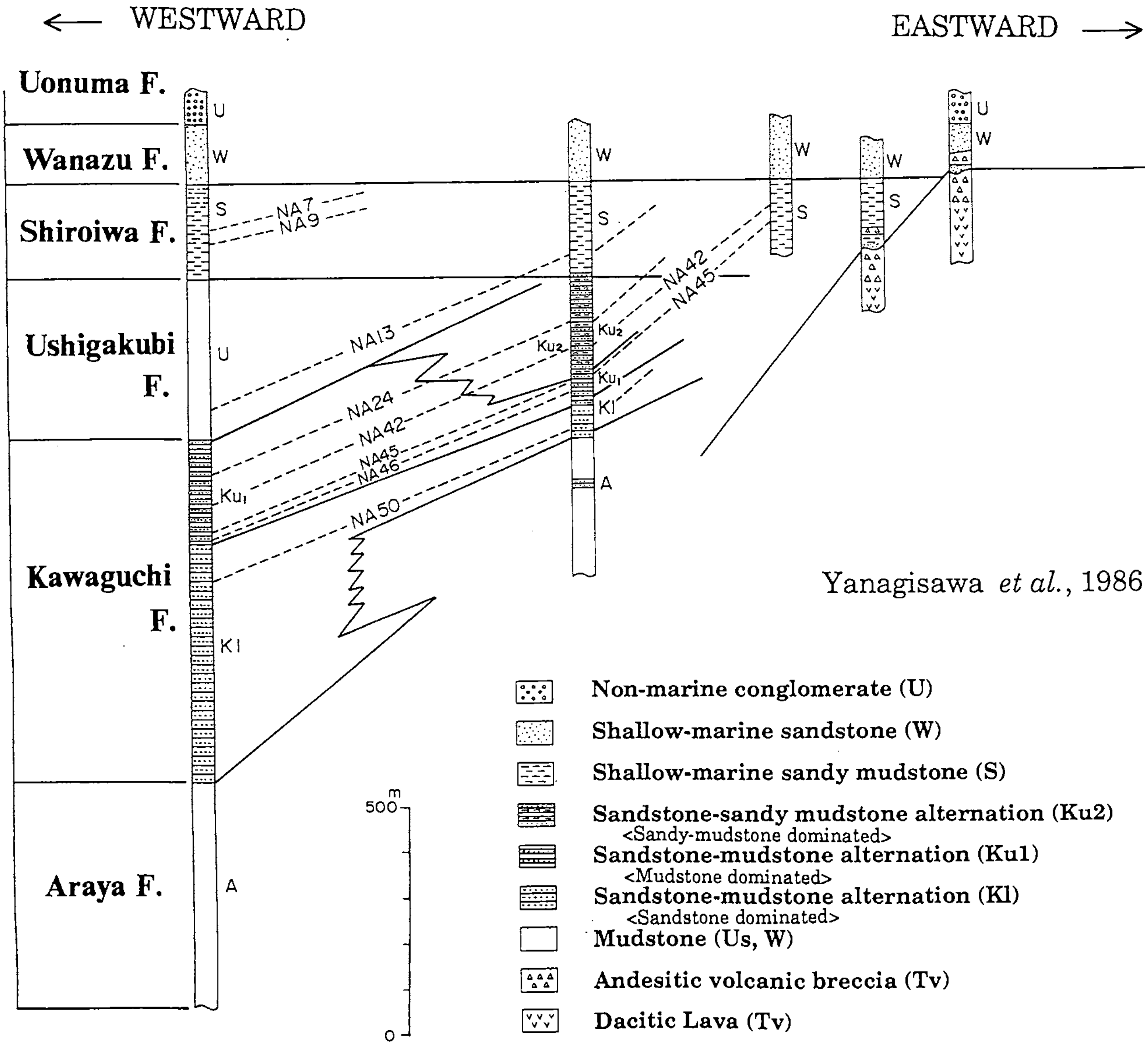


Figure 5. Lateral relationship of each formation in the east-west cross section with main tuff markers. After Yanagisawa *et al*, 1986.

sides of the Araya Anticline, the types of heavy mineral composition of the turbidite sandstones in the Kawaguchi Formation are the same as those along the Nobegawa River (Fig. 8). Turbidite sandstones in the Lower Kawaguchi Formation (K1) are composed of Type I and Type I-II, and those in the Upper Kawaguchi Formation (Ku1) mostly of Type II. Type III is not observed in these sandstones in the western part of the study area.

In the eastern part of the study area, on the other hand, the turbidite sandstones in the Upper Kawaguchi Formation (Ku2) are all made up of Type III heavy mineral composition, not of Type II as in the western Upper Kawaguchi Formation (Ku1) (Fig. 8). This interesting phenomenon is observed in turbidite sandstones, both in the western and eastern parts, in strictly the same horizon, that is, NA24 tuff marker horizon as shown in Fig. 6. In this case, turbidite sandstones of the NA24 horizon, both thick and thin, in the western area (Loc. A) all consist of Type II heavy mineral composition. Turbidite sandstones of the same horizon, both thick and thin, in the eastern area (Loc. B, C and D), on the other hand, are all composed of Type III. As Type I, Type I-II and Type II are fundamentally different from Type III, the results of heavy mineral analysis strongly indicate the new conclusion that the turbidite sandstones in the western Kawaguchi Formation (K1, Ku1) and the turbidite sandstones in the eastern Upper Kawaguchi Formation (Ku2) were supplied from different source areas through different routes and deposited in the different sedimentary environments to each other.

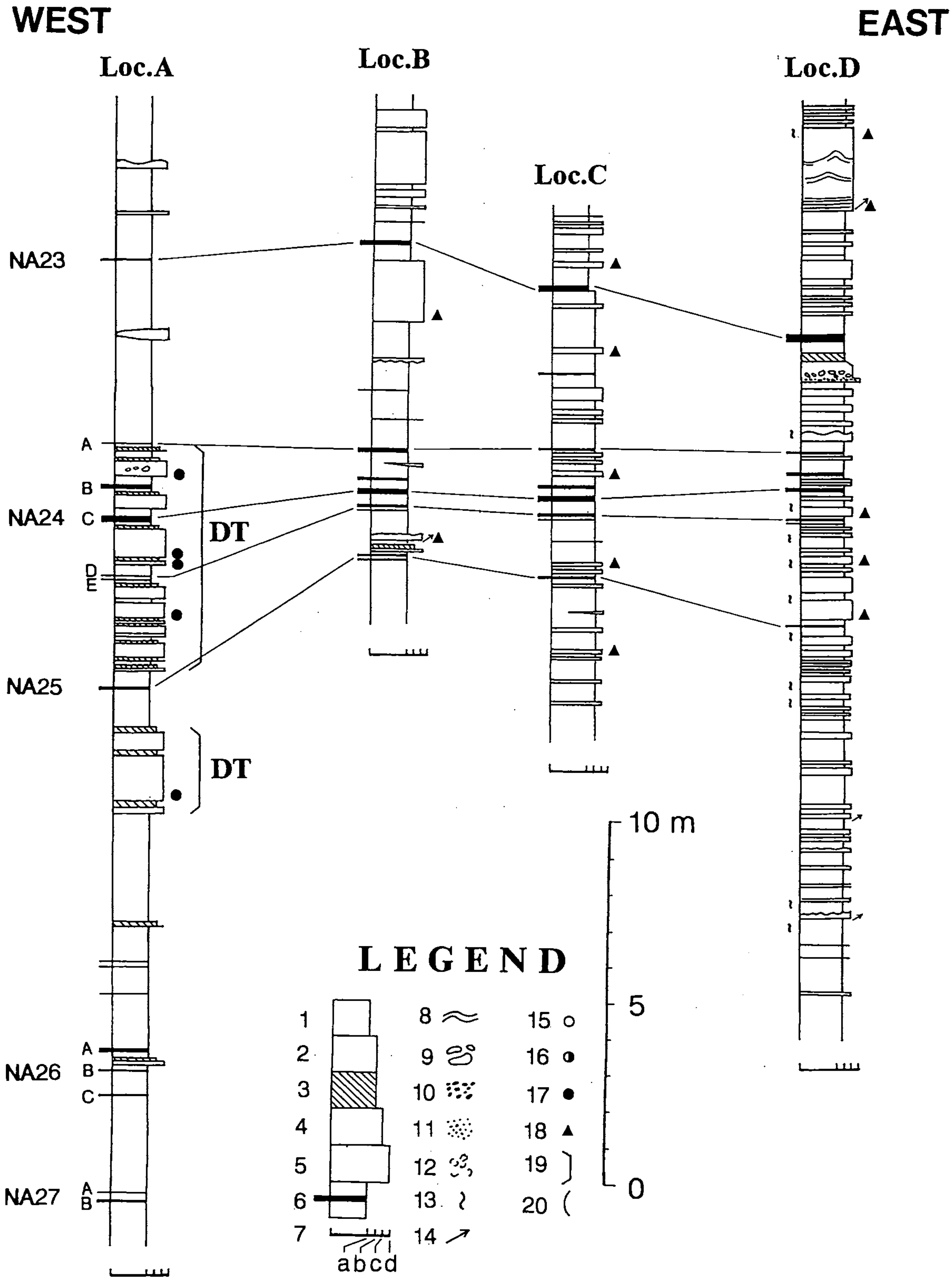
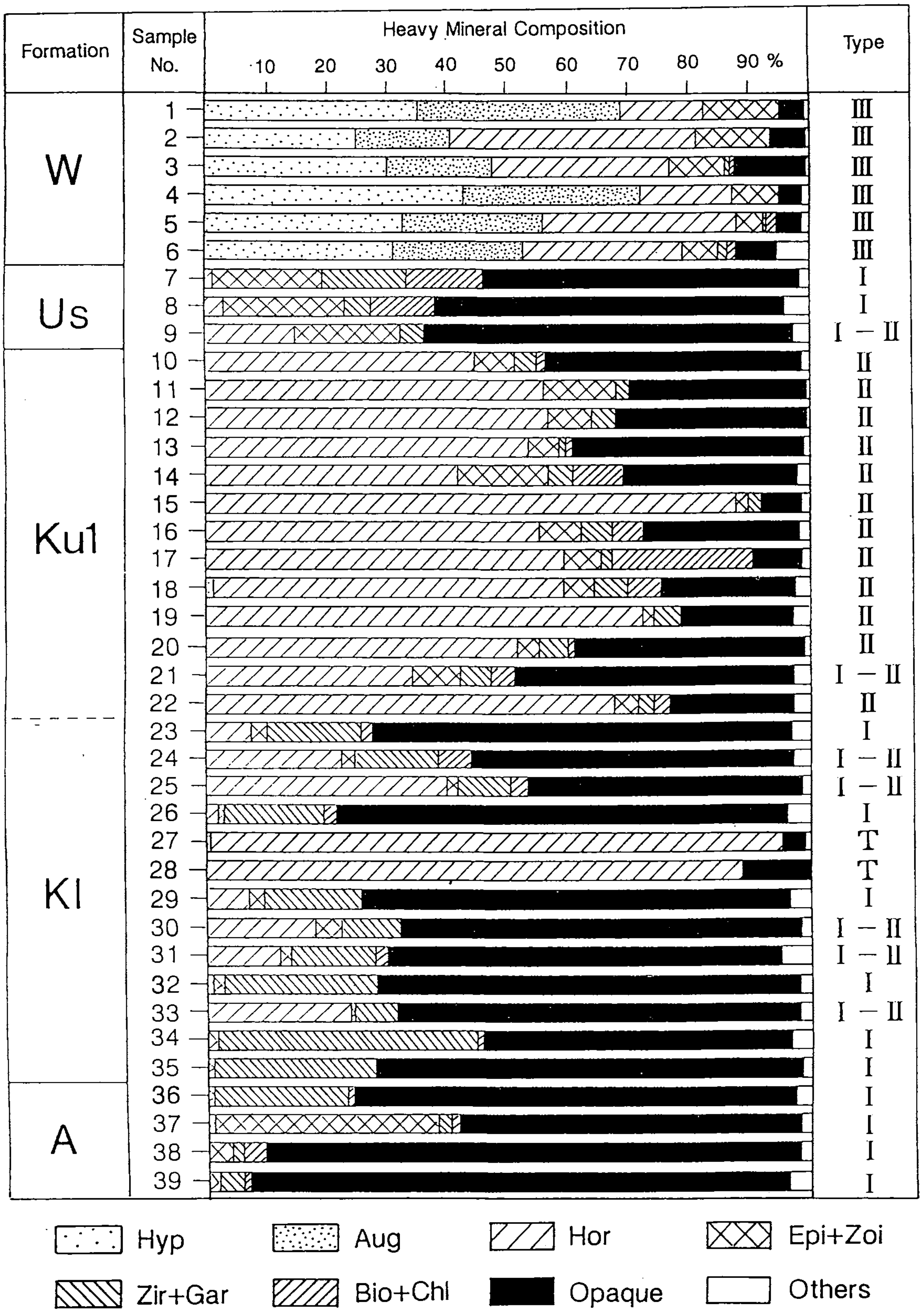


Figure 6. Lithologic columns of NA24 tuff marker horizon in the Upper Kawaguchi Formation. Locality of each column is shown in Figure 3. 1: mudstone, 2: sandy mudstone, 3: turbidite mudstone (sandy mudstone), 4: sandstone, 5: conglomerate, 6: tuff marker (volcanic ash layer), 7: lithology indicator (a: mudstone, b: sandy mudstone, c: sandstone, d: conglomerate), 8: lamination in sandstone bed, 9: mudstone clasts, 10: gravel (pebble to cobble), 11: very coarse sand to granule, 12: shell fragments, 13: trace fossil in vertical section, 14: reverse grading, 15: Type I heavy mineral composition, 16: Type I-II, 17: Type II, 18: Type III, 19: depositional tongue (DT), 20: banded alternation of sandstone and mudstone (BA).



Type I	**: Opaque>>Gar,Zir,Epi,Zoi,Hor**
Type I-II	**: Opaque>Hor>Gar,Zir,Epi,Zoi**
Type II	**: Hor>Opaque>>Gar,Zir,Epi,Zoi**
Type III	**: Hyp,Aug,Hor>>Epi,Opaque>Gar,Zir,Zoi**

Figure 7. Results of heavy mineral analysis of sandstones collected along the Nobegawa River in the western part of the study area.

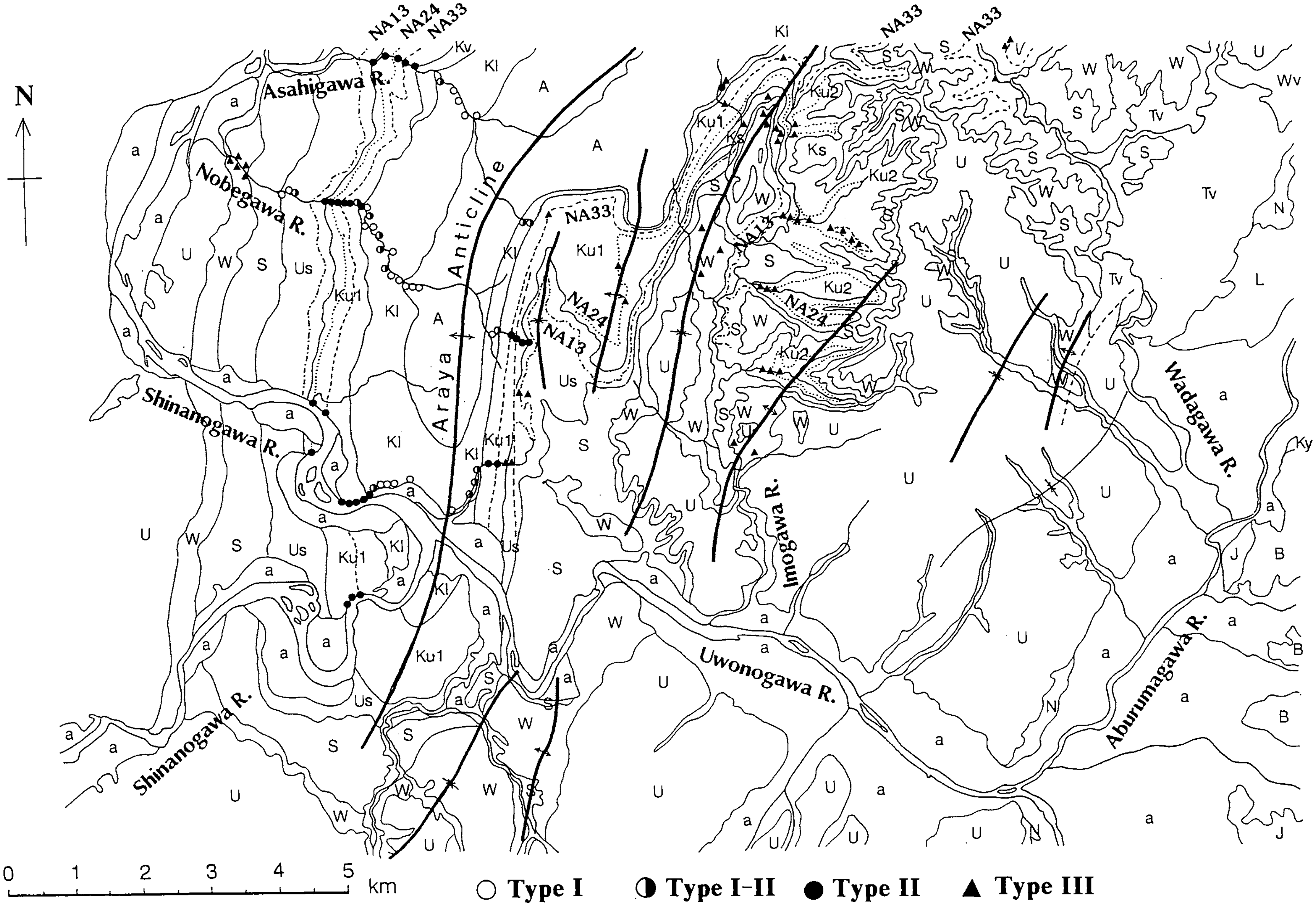


Figure 8. Areal distribution of types of heavy mineral composition of sandstones collected both in the western and eastern parts of the study area.

INFERRED SEDIMENTARY PROCESS OF THE KAWAGUCHI FORMATION

The results of heavy mineral analysis lead to a new and interesting idea that two kinds of turbidite sandstones were formed concurrently and closely juxtaposed to each other, one in the western part and the other in the eastern part of the study area, at the eastern margin of the Niigata backarc basin during the deposition of the Upper Kawaguchi Formation.

The turbidite sandstones in the western Kawaguchi Formation (K1, Ku1) are interpreted as submarine-fan turbidite deposits. The non-turbiditic mudstone beds among the turbidite sandstone beds indicate deep-marine environments, because they are composed of finer-grained sediments (fine silt to clay particles) and are homogeneous, yielding very few trace fossils in vertical section. Sometimes, thick and composite coarser-grained turbidite sandstone facies with gravels, indicating feeder-channel or valley-fill deposits, are observed near the boundary area between the western and eastern areas. These sandstones are composed of the same types of heavy mineral composition as turbidite sandstones in the western area. Depositional tongues observed in the western Kawaguchi Formation must be made up of sandstones supplied through these feeder channels or valleys. A submarine fan was formed by the continuous deposition of turbidite sandstones at the same area, forming depositional tongues, and by the intermittent migration of depositional tongues from place to place.

The turbidite sandstones in the eastern Kawaguchi Formation (Ku2) must have been deposited on the shelf area below the storm wave base. The mudstones among the turbidite sandstones are coarser-grained and ill-sorted (sandy siltstone to sandy mudstone), yielding abundant trace fossils in vertical section. The sandstones interbedded with these sandy mudstones might have been deposited as storm deposits. However, these sandstones are here referred to as turbidite sandstones, as their sedimentary structures in their vertical section are similar to those of the Bouma sequence and the HCS (Hummocky cross stratification), a typical sedimentary structure of storm deposits (Harms *et al.*, 1975), are not observed in these sandstone beds.

The sedimentary environments and deposition of these two kinds of turbidite sandstones are schematically shown in Figure 9. The fact that hypersthene and augite in the eastern shelf turbidite sandstones often show mechanically broken hacksaw edges and are sometimes surrounded by glass and commonly occur together with oxyhornblende strongly indicates that these sandstones were mainly supplied from volcanic rocks, that is, the lowermost intrabasinal volcanic rocks or so-called "Green tuff" rocks. Western submarine-fan turbidite sandstones, on the other hand, are inferred to have been supplied mainly from the basement area where Mesozoic sedimentary rocks, mostly composed of shale and chert, and partly of green rock and sandstone, and Cretaceous granitic rocks are present, because these turbidite sandstones do not contain such volcanic-origin minerals as hypersthene and augite. The composition of gravels sporadically included in these turbidite sandstones also support this interpretation. The western submarine-fan turbidite sandstones and eastern shelf turbidite sandstones form the juxtaposition of two kinds of sandstone-mudstone alternations in the study area. The difference in characteristics of the western alternation (K1, Ku1) and the eastern alternation (Ku2) are summarized in Table 1.

CONCLUDING REMARKS

Heavy mineral analysis is generally known as a useful method to determine the provenance or source rock characteristics (Pettijohn, 1957; Pettijohn *et al.*, 1987; Blatt *et al.*, 1972). However, as mentioned by Mange and Maurer (1992), the heavy mineral analysis has the potentiality, in combination with sedimentological analysis, to produce a new understanding and a completely different interpretation of the sedimentary process, as shown in this study (Fig. 10). Not only sedimentological analysis but also mineralogical analysis of these sandstone bodies are very important. Especially for the purpose of disclosing the sedimentological or original relationship of closely spaced sandstone bodies, that is, to estimate the extent of each sandstone body which was supplied from the same provenance and deposited at the same sedimentary environments through the same mechanism. It is stressed that the positive combination of sedimentological analysis and mineralogical analysis yields one of the useful methods to promote the exploration for future stratigraphic traps.

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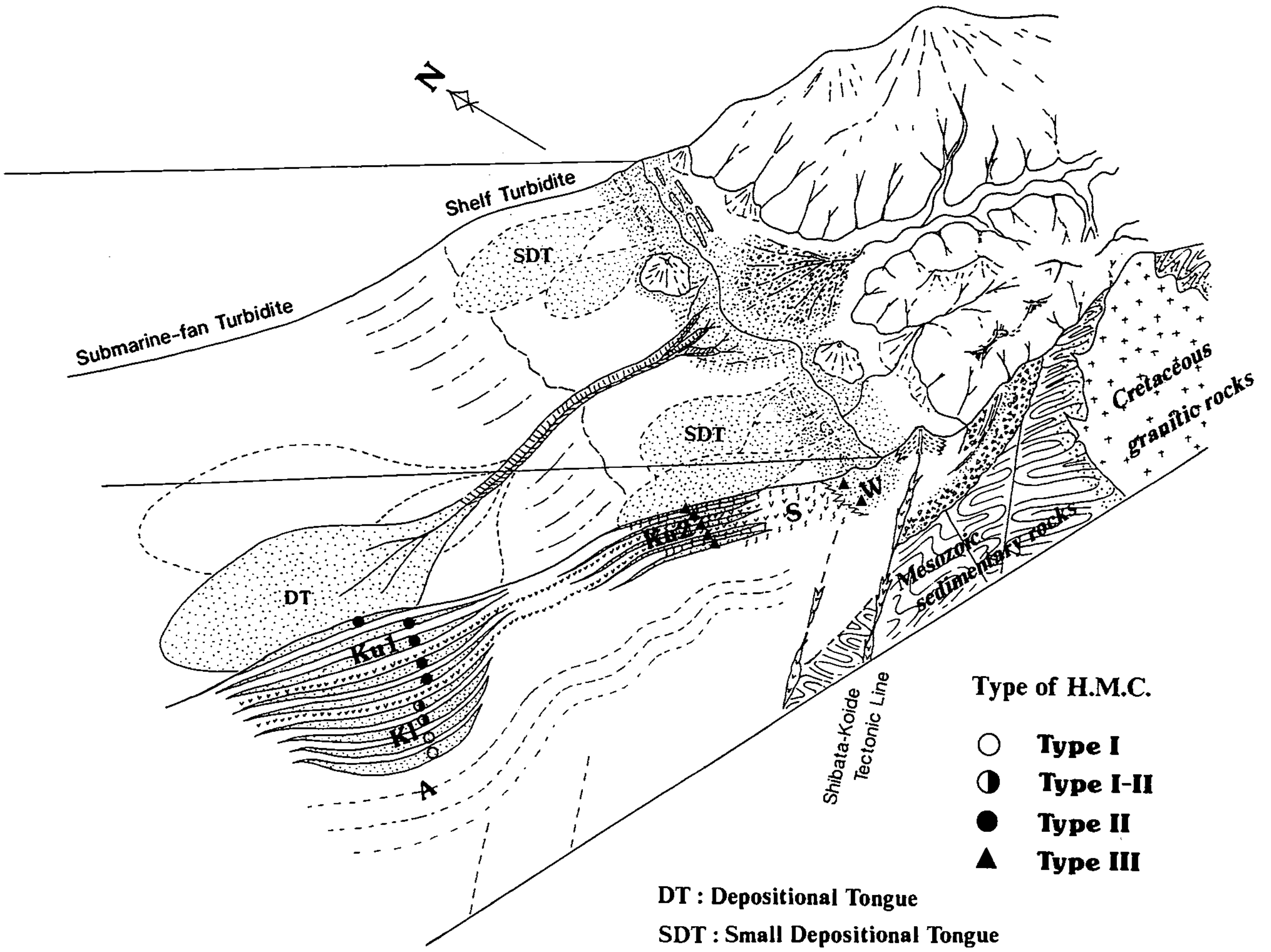

Figure 9. Schematic diagram of sedimentary process and environments of the Late Pliocene Upper Kawaguchi Formation. Alphabetical symbols in the cross section correspond to the formations shown in Figure 2.

Table 1: Summary of the difference of sedimentological and mineralogical characteristics of sandstone-mudstone alternations in the Kawaguchi Formation in the western and eastern parts of the study area.

	WESTERN ALTERNATION	EASTERN ALTERNATION
MUDSTONE	Finer-grained (silt to clay)	Coarser-grained (sandy silt)
TURBIDITE MUDSTONE	Common	Rare
TRACE FOSSIL	Rare	Common
SANDSTONE		
Thickness	10 meters to a few centimeters (sandstone>1m:common)	A few meters to a few centimeters (sandstone>1m:rare)
Texture	Medium- to fine-grained Well-sorted	Medium- to fine-grained Well-sorted
Sedimentary structure	Turbidite sequence	Turbidite sequence (reverse grading at the lower part of some beds)
Vertical occurrence	Collectively (forming "depositional tongue")	Randomly (forming "small depositional tongue"?)
Paleocurrent	Westward	Westward
Heavy mineral composition	Type I, I-II, II	Type III
Supply system	Point source	Line source
SEDIMENTARY ENVIRONMENT	Submarine fan	Shelf (deeper than storm wave base)

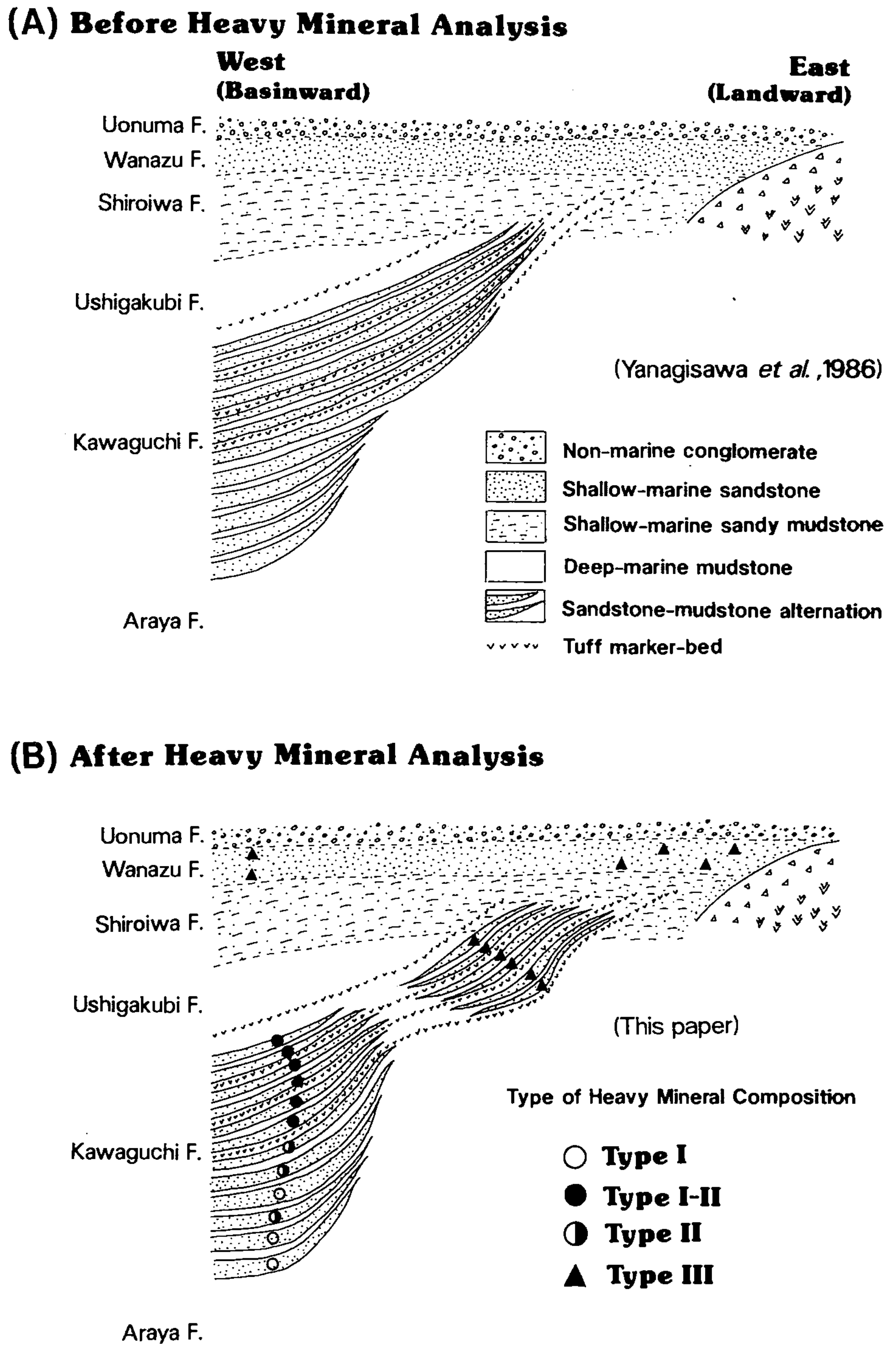

Figure 10. Diagram showing the change of interpretation for the sedimentological relationship of the sandstone-mudstone alternations in the Upper Kawaguchi Formation in the western and eastern parts of the study area between before and after the practice of heavy mineral analysis.

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