3. Setogawa-Mineoka area

3-1. Historical review

3-1-1. Stratigraphy in the Mineoka area

Although there are many studies about the stratigraphy in the study area, the name or definition of the lithostratigraphic units differs among them. This is caused by the complicated geological structure and the ill outcrop conditions. Fig. 5 shows the correlation table of recent studies in the southern part of the Boso Peninsula.

Koike (1949) divided the strata in the study area into four groups, namely the Mineoka, Hota, Sakuma and Miura Groups, and supposed that these groups were in unconformable contact with each other. Kawai (1957) divided the strata in the eastern distributional area of the Hota Group into two groups, namely the Hota and Emi Groups. Nakajima et al. (1981) concluded that the Hota, Sakuma and Miura Groups were in conformable contact with each other and unified them into one group, that is, the Awa Group. Suzuki et al. (1990), however, divided the Awa Group into two groups, that is, the Hota and Miura Groups based on a structural difference and a finding of the outcrop showing unconformable contacts.

Although the stratigraphic divisions are mainly based on lithological characteristics as mentioned above, Saito (1992) established the stratigraphy using radiolarian fossil evidence. Saito (1992) subdivided the Miura Group into two groups, namely the Sakuma and Miura Groups again. Mohiuddin and Ogawa (1998b) divided the Mineoka Group into two groups, that is, the Mineoka and Kamogawa Groups, based on the lithological assemblage and their ages. Sakagami et al. (1997) compiled the stratigraphy of the southern part of the Boso Peninsula, and regarded serpentinite, basalt, mudstone and other constituents of the Mineoka Group as tectonic blocks protruding into the Hota Group.

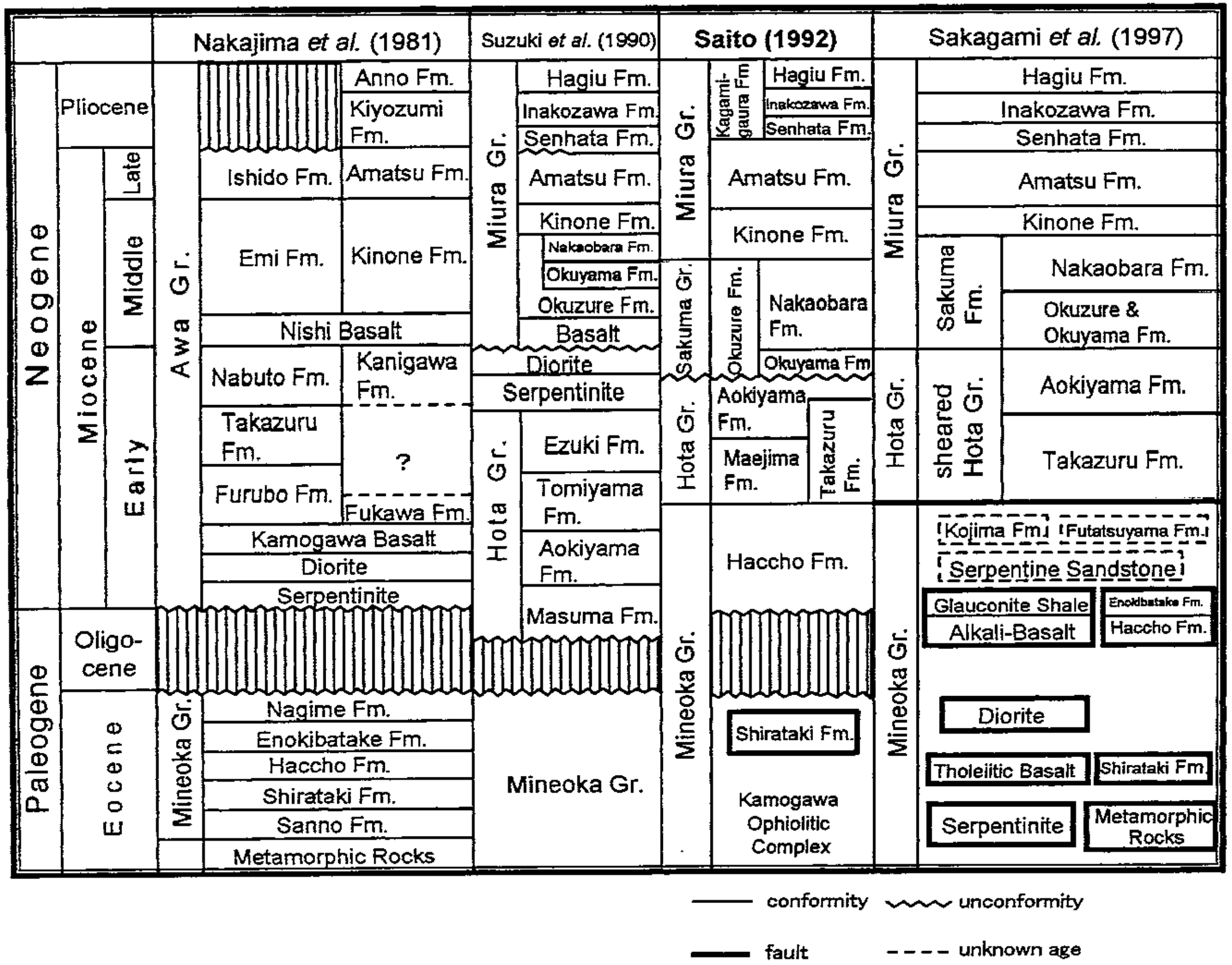


Fig. 5. Historical review of the stratigraphy of the southern part of the Boso Peninsula.
Modified from Sakagami et al. (1997)

3-1-2. Stratigraphy in the Setogawa area

In this study, four groups were investigated in the Setogawa area, namely, the Mikura, Setogawa, Kurami and Koma Groups. Because the age and sedimentary environment are different among them, they have been often studied independently. In this section, outlines of the historical review of each group was described separately.

Mikura Group

The systematic study of the Mikura Group can go back to the pioneer work of Chitani (1931). Saito and Isomi (1954) and Mochizuki (1956) revealed the lithology and distribution of this group. Matsumoto (1966) reported Oligocene molluscan fossils from this group. He regarded both the Mikura and Setogawa Groups as one group, namely, the Setogawa Group, and he divided his Setogawa Group into the Nabeshima and Takizawa Subgroups. Furthermore, he subdivided the Nabeshima Subgroup into four formations, namely Ikumi, Kamio, Wappazawa and Tentokuji Formations. Kimura and Tokuyama (1971) considered that the Mikura Group was correlated to the other formations in the Shimanto Belt in the Akaishi Mountains, and they lumped all the formations in the Akaishi Mountains together as the Shimanto Group. However, in 1980s, Cretaceous radiolarian fossils were reported by many authors from the Shirane and Akaishi Groups which are distributed to the northwest of the distribution area of the Mikura Group, and these fossil data and the stratigraphy in the Akaishi Mountains were compiled by Kano and Matsushima (1988).

Iijima et al. (1981) and Watanabe (1988) reported the Tertiary pollen and Early Miocene radiolarian fossils from the Mikura Group, respectively. Sugiyama and Shimokawa (1990) reported the occurrence of the Eocene benthic foraminifers. Kato et al. (1991) investigated the Mikura Group around the lower stream of the Oigawa River and divided the Mikura Group into three formations, namely Ikumi, Kamio and

Wappazawa Formations. They also reported an occurrence of the Eocene to Oligocene planktonic foraminifers, molluscs and trace fossils, and inferred the sedimentary environment of the Mikura Group.

Setogawa Group

The systematic study of the Setogawa Belt can go back to the pioneer work of Chitani (1931). He divided the Setogawa Group into three formations, namely Ichinose, Takisawa and Nakayama Formations. After his study, the stratigraphic and palaeontorogical studies of the southern part of the Setogawa Group distributional area have been carried out by some authors. The stratigraphic divisions of the southern part of the Setogawa Group distributional area were compiled by Sugiyama et al. (1982) and Sugiyama and Shimokawa (1990). Until the early 1980s, it had been supposed that the depositional process of the Setogawa Group was interpreted in the tectonic framework of a geosyncline. Naka (1985, 1988) investigated around the upper reaches of the Abe River, and considered that the greenstones in the Setogawa Group were the accreted seamount in origin. Osozawa (1986, 1988) divided the southern part of the Setogawa Group distributional area into five zones, and supposed that the Setogawa Group corresponded to an accretionary complex. Sugiyama and Shimokawa (1989, 1990) lumped the Setogawa Group with the Oigawa (Makiyama, 1950) and Takakusayama Group (Sugiyama et al., 1982) and they divided the southern part of the distribution are of the Setogawa Group into six thrust sheets extended in the direction of N-S; from west to east, the Odake, Takayama, Tawarazawa, Utsunoya, Oigawa and Ryuso sheets. Recently, Sugiyama (1995) investigated the northern part of the Setogawa Group distributional area. He divided the whole Setogawa Group into three subbelts, namely the Setogawa, Oigawa and Ryuso Subbelts, and he subdivided the Setogawa Subbelt into six thrust sheets, namely Odake, Umegashima, Takayama, Takizawa, Tawarazawa and Utsunoya Thrust Sheets.

From the Setogawa Group, the first occurrence of index fossils was reported by

Ishii and Makino (1946). They mentioned an occurrence of Paleocene to Eocene foraminifers from the limestone at Yokoyama, Shizuoka City. Mizuno (1956) found early Oligocene molluscs at Ashikubo, Shizuoka City, and it had been believed that the Setogawa Group was of the Paleogene until 1970's. However, Iijima et al. (1981) reported Early Miocene radiolarian fossils from shale of the Setogawa Group, and assigned that the most of the clastic rocks of the Setogawa Group to the Early Miocene.

Kurami Group

The stratigraphic study of the Kurami Group was started by Chitani (1926). Makiyama and Sakamoto (1957) divided the strata in the Kakegawa area into six groups; Ooigawa, Kurami, Saigo, Sagara, Kakegawa and Ogasa Groups in ascending order. They considered that the Ooigawa Group was unconformably overlain by the Kurami Group, and the Kurami Group was also unconformably overlain by the Saigo Group. However, Ujiie (1958) considered the Kurami and Saigo Groups were in conformable contact, and lumped them into one group, namely the Mikasa Group. After his study, some authors recognized the local unconformity between the Kurami and Saigo Groups (e.g. Ujiie, 1962; Tsuchi and Ibaraki, 1978). However, Ibaraki et al. (1983) and Ibaraki (1986a) used the name of the Kurami and Saigo Groups, while the other authors, that is, Ujiie (1962), Shimokawa and Sugiyama (1982), Osozawa (1988), and Sugiyama (1992) used the name of the Mikasa Group. Watanabe (1988) divided the strata of the Ibaraki (1986a)'s Kurami and Saigo Groups into three formations; Kamiohka, Matsuba, and Saigo Formations.

Matsumoto (1964) and Watanabe (1988) reported molluscan fossils from the Kurami Group, and Watanabe (1988) also reported radiolarian fossils. Ibaraki et al. (1983) and Ibaraki (1986a, 1986b) established the planktonic foraminiferal biostratigraphy of the Neogene in the Kakegawa area, including the Kurami Group.

Koma Group

The systematic study of the stratigraphy of the Koma Group can go back to the pioneer work of Otuka (1941). He divided the strata in the Koma Mountains into two formations, namely Kushigatayama and Momonoki Formations. The Koma Group was defined by Kosaka and Tsunoda (1969). They divided their Koma Group into two subgroups, namely Kushigatayama and Momonoki Subgroups, and subdivided the Kushigatayama and Momonoki Subgroup into six and two formations, respectively. After them, this stratigraphic division of the Koma Group was accepted by many authors, although the subdivisions of each subgroup are different among them (e. g. Tamura et al., 1984; Amano, 1986; Koyama, 1991, 1993).

Kosaka and Tsunoda (1969) reported an occurrence of ***Lepidocyclina*** sp. from the lowest part of the Kushigatayama Subgroup. Akimoto et al. (1990) inferred the age and paleobathymetry of the Koma Group based on the planktonic and benthic foraminifers. Aoike (1998) indicated an occurrence of calcareous nannofossils from the Kushigatayama Subgroup. Aoike (1999) compiled the microfossil data from the Koma Group, and concluded the sedimentary age of the Kushigatayama and Momonoki Subgroups as 15-16 Ma and 15-13.5 Ma, respectively.

3-1-3. Modal compositions of sandstone

There are a few literatures about modal or mineral compositions of the clastic rocks in the Mineoka-Setogawa area. Arai et al. (1983) described the serpentine sandstone and the leucocratic sandstone distributed at Mineokasengen and Hegurinaka, and analyzed the chemical compositions of detrital chromian spinels in those sandstones. According to them, the serpentine sandstone is frequently accompanied with the leucocratic sandstone which is similar to the sandstone of the Furubo Formation, the lower part of the Awa Group (Nakajima et al., 1981), and the chemical compositions of detrital chromian spinels are similar to those of chromian spinels in the serpentinites which occur in the Mineoka Mountains. Therefore, they considered the serpentinite in the Mineoka Mountains had protruded at the same time of the sedimentation of the Furubo Formation. Ogawa et al. (1985b) reported the modal compositions of the serpentine sandstone at Mineokasengen and the Mineoka Group sandstone. Watanabe and Iijima (1990) studied the modal compositions of sandstones of the Haccho Formation of the Mineoka Group, and compared them to those of the lower Miocene sandstones in the Kobotoke and Setogawa Terranes. They concluded that modal compositions of the lower Miocene turbidite sandstones were indistinguishable among those three terranes. Saito (1991) studied clast compositions of conglomerates of the Sakuma Group. He indicated that most clasts of conglomerate of the Sakuma Group had been derived from the Mineoka and Hota Groups.

In the Setogawa area, only two papers, namely Tokuoka and Kumon (1979) and Watanabe and Iijima (1990), reported the modal compositions of sandstones. Tokuoka and Kumon (1979) measured the modal composition of sandstone from the Inui (Cretaceous), Mikura, Setogawa and Oigawa Groups and showed that the sandstones from the Inui and Oigawa Groups contain more rock fragments than those from the Mikura and Setogawa Groups. Kimura (1992) proposed the Suruga-Sagami Petroprovince for sandstones of the Mikura and Sagamiko Groups using the data of the modal composition of sandstones shown by Tokuoka and Kumon (1979) and Sakai (1987).

3-1-4. The Circum-Izu Massif Serpentine Belt

The ophiolitic rocks such as serpentinite, basalt and gabbro occur in the Mineoka-Hayama-Kobotoke-Setogawa Belt (Fig. 3), and they are called as "Circum-Izu Massif Serpentine Belt" (Arai and Ishida, 1987). They are very important in terms of the interpretation of the Tertiary tectonics in this area (e.g. Sato et al., 1999). Concerning basaltic rocks in the Mineoka area, it had been inferred that basaltic rocks erupted in site (e.g. Nakajima et al., 1981). Ogawa and Taniguchi (1987) descrived that the basaltic rocks in the Mineoka area were of MORB-type, and insisted the presence of the Mineoka plate in the Eocene to Early Miocene. The idea of the Mineoka plate is based on both the reconstruction of plate arrangements and the formative age of Eocene basaltic rocks. The reconstruction of plate arrangements was indicated by Seno and Maruyama (1984), while the age of basaltic rocks was reported by Kaneoka et al. (1981; 40 to 50 Ma of Ar-Ar age) and Ogawa et al. (1985a; Eocene nannofossils from interpillow limestone). Furthermore, as a source rock of serpentinite, they supposed the obducted oceanic crust, namely the Mineoka plate. Arai et al. (1990) divided the serpentinites in the Circum-Izu Massif Serpentine Belt into two groups, namely Mineoka type and Hayama type. The Mineoka type serpentinites are composed of the serpentinites in the Mineoka and Kobotoke Belts, while the Hayama type serpentinites are composed of those in the Hayama and Setogawa Belts (Fig. 3). Arai (1991) insisted that these serpentinites originated from backarc basin peridotites because of similar mineralogical composition of serpentinites and similar chemistry of chromian spinel. Arai et al. (1983) and Arai and Okada (1991) studied serpentine sandstones in the Mineoka Belt, and they inferred that the peridotites, which were source rocks of serpentine sandstones, were emplaced along a transcurrent fault during an opening of Shikoku Basin, and accreted to the Honshu arc during an opening of Sea of Japan. Arai (1994a) explained the difference of the Mineoka type and the Hayama type by a degree of influence of fluid. Fujioka et al. (1995) concluded that the origin of serpentinites in the Mineoka Belt corresponded to serpentine seamounts, which could be observed in the Izu-Bonin and Mariana arc at present, based on the similarities of their lithological characteristics. Sato et al. (1999) compiled the data of chemical compositions and the ages of ophiolitic rocks in the Mineoka and Hayama Belts, and proposed that they were of the Mineoka plate origin again. They also considered the ophiolitic rocks in the Mineoka Belt were emplaced in the early Middle Miocene, because the age of the serpentine sandstones (Arai et al., 1983) is ambiguous and the early Middle Miocene Sakuma Group contains many clasts of the ophiolitic rocks.

3-2. Outline of geology

3-2-1. Mineoka area

In this section, the outline of geology in the Mineoka area is summarized based on Saito (1992). Saito (1992) established four groups, namely the Mineoka, Hota, Sakuma and Miura Groups in the study area (Fig. 6). The description of the Miura Group is excluded herein, because its sandstone has not been treated in this study. The undivided sedimentary rocks in the Mineoka Mountains are described in the next section.

Mineoka Group

The Mineoka Group is subdivided into three units, namely the Kamogawa Ophiolitic Complex, the Shirataki Formation and the Haccho Formation. The Kamogawa Ophiolitic Complex is composed of intensely serpentinized ultramafic rocks and tectonic blocks of basalt, gabbro, diorite, metamorphic rocks and hemi-pelagic sediments, and is distributed mainly in the Mineoka Mountains (Fig. 6). The ultramafic rocks are largely harzburgites with a small amount of dunites (e.g. Uhcida and Arai, 1978). The basaltic rocks are composed of tholeiitic pillow basalts and alkali basalts, and occupy the largest volume among the tectonic blocks in the Mineoka Mountains. The alkali basalts are considered to be of hot spot in origin (e.g. Takahashi, 1994). As for the origin of tholeiitic basalts, most of them are of MORB origin, though some of them are of arc in origin. Several Ar-Ar ages and K-Ar ages of basaltic rocks have reported. As mentioned above, Kaneoka et al. (1981) reported the Ar-Ar age of 40-50 Ma for the tholeiitic basalt, and Ogawa et al. (1985a) reported Eocene nannofossils from interpillow limestone. The gabbro occurs as dike or tectonic lens in the serpentinites. Saito (1992) showed the K-Ar age of 95.9±20.2 Ma for

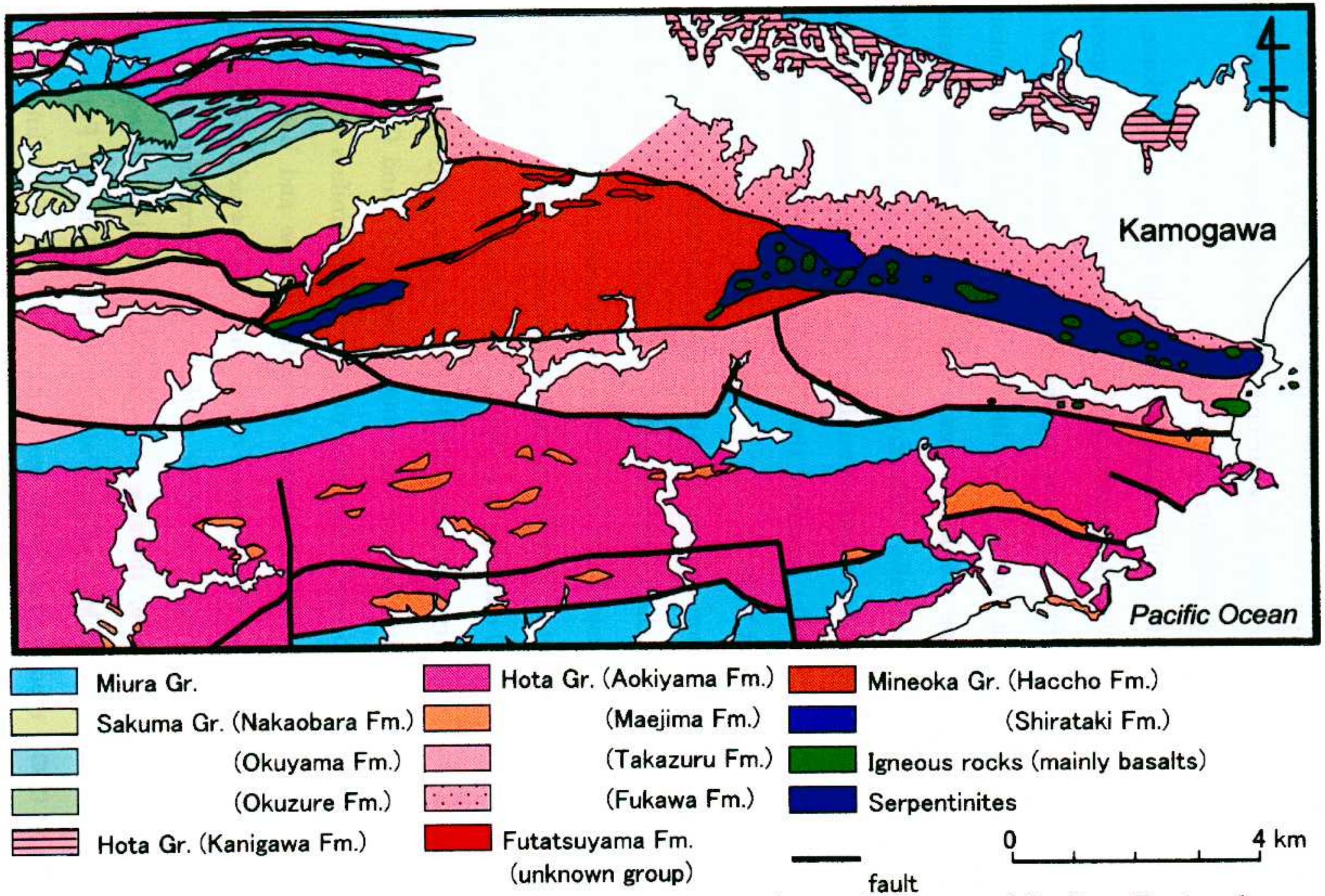


Fig. 6. Geological map around the Mineoka Mountains in the southern part of the Boso Peninsula. Modified from Nakajima et al. (1981) and Saito (1992).

amphibole gabbro. The metamorphic rocks are composed of amphibolite, quartz schist and biotite schist (e.g. Kanehira et al., 1968; Arai et al., 1983). Yoshida (1974) mentioned the K-Ar age of 38 Ma of biotite schist and 14 Ma of diorite. Recently, Shashida and Ogawa (2003) found an occurrence of red chert block at Yohka Beach and obtained early Cretaceous radiolarians from that.

The Shirataki Formation is distributed at Shirataki, Otashiro and Okune, and is composed of alternation of dark greenish tuffaceous mudstone and light greenish tuff and alternation of micritic limestone and bedded chert. The thickness of this formation is inferred as 80 m. Suzuki et al. (1984) and Iijima et al. (1984) mentioned occurrences of latest Eocene planktonic foraminifers and the Middle Eocene to Oligocene calcareous nannofossils, respectively. Mohiuddin and Ogawa (1998a) reported the Early Miocene planktonic foraminifers from this formation at Shirataki. Mohiuddin and Ogawa (1998b) described the Late Paleocene and Eocene sections from two limestone bodies at Nishi.

The Haccho Formation consists of basalt, basaltic conglomerate, glauconite bearing basaltic sandstone, shale yielding radiolarian, shale intercalated with white tuff, and alternation of sandstone and shale in ascending order. The thickness of this formation is inferred as 1000 m. This typical sequence is observed at Hegurinaka (e.g. Ogawa and Taniguchi, 1987) and Toge (e.g. Hirano and Okuzawa, 2002). Saito (1992) interpreted those sedimentary ages as earliest Miocene to early Early Miocene based on his radiolarian data from shale at Hegurinaka. Mohiuddin and Ogawa (1996) described middle Eocene to early Oligocene planktonic foraminifers from micritic limestone underlying shale at Hegurinaka. Recently, Eocene and Early Miocene radiolarians have been found from floats of calcareous nodule which probably came from the Haccho Formation, and the shale of the Haccho Formation, respectively (Kawakami, 2003). Therefore, there is a possibility that the Mineoka Group sandstone distributed around Mt. Atago is Paleogene to Early Miocene. Furthermore, Hirano et al. (2001) reported the Ar-Ar age of 19.62±0.9 Ma of alkaline basalt at Hegurinaka, though it is somewhat in discrepancy with fossil data.

In the distributional area of the Haccho Formation, some floats of conglomerate were found at Motona and Fusada in this study (Figs. 7 to 9). Because alternation of shale and white tuff of the Haccho Formation is distributed around the localities of the conglomerate floats, these conglomerates seem to have originally intercalated in the alternation of shale and white tuff.

Hota Group

The Hota Group is subdivided into three formations, namely the Maejima, Takazuru and Aokiyama Formations. The lowest part of the Maejima Formation consists of white to light greenish tuff, and the other parts are composed of medium to very fine-grained massive sandstone. The Maejima Formation is distributed to the south of the Sorogawa fault. The massive sandstones distributed to the north of the Sorogawa fault are called Takazuru Formation.

The Takazuru Formation consists of fine-grained, white to light greenish tuff, conglomerate, tuffaceous massive sandstone intercalated with white tuff or mudstone, and alternation of sandstone and mudstone in ascending order. The conglomerate is called Ishihata Conglomerate Member. The clasts of this member are rounded, and composed of chert, siliceous shale, siliceous sandstone and tuff. This conglomerate contains characteristically no clasts derived from the Mineoka Ophiolitic Complex.

The Aokiyama Formation conformably overlies the Maejima and Takazuru Formations. This formation is subdivided into lower, middle and upper parts. The lower part is composed mainly of tuffaceous sandstone and grayish green massive mudstone. The middle part consists of white tuff, tuffaceous sandstone and tuffaceous mudstone. The upper part is composed mainly of gray to bluish gray tuffaceous massive sandy mudstone with white tuff. In this formation, there is the thick white tuff intercalated with tuffaceous sandstone and mudstone. It is called Niemonjima Tuff Member.

The Hota Group to the north of the Mineoka Mountains is not described by

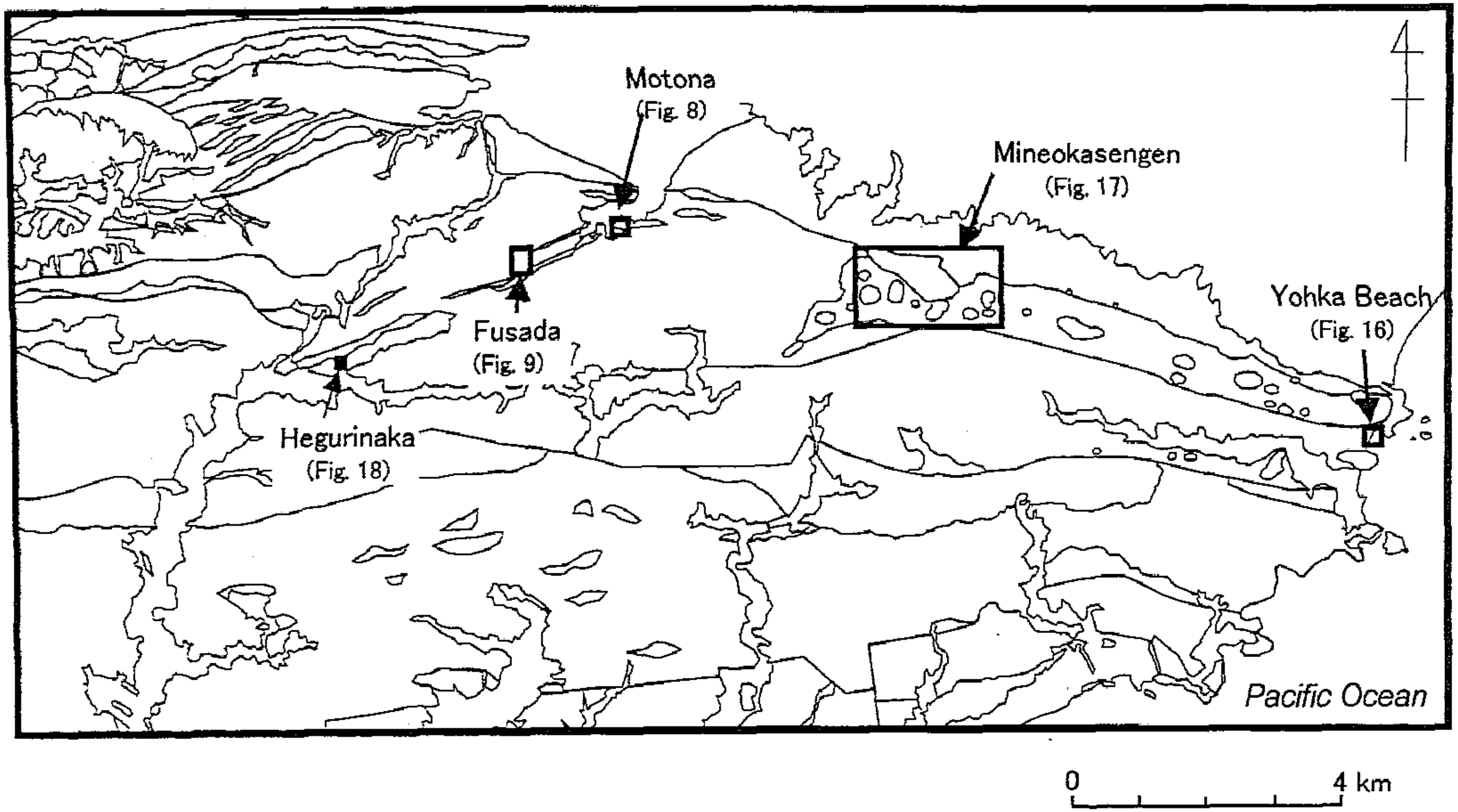


Fig. 7. Locations of route map in the Mineoka area.

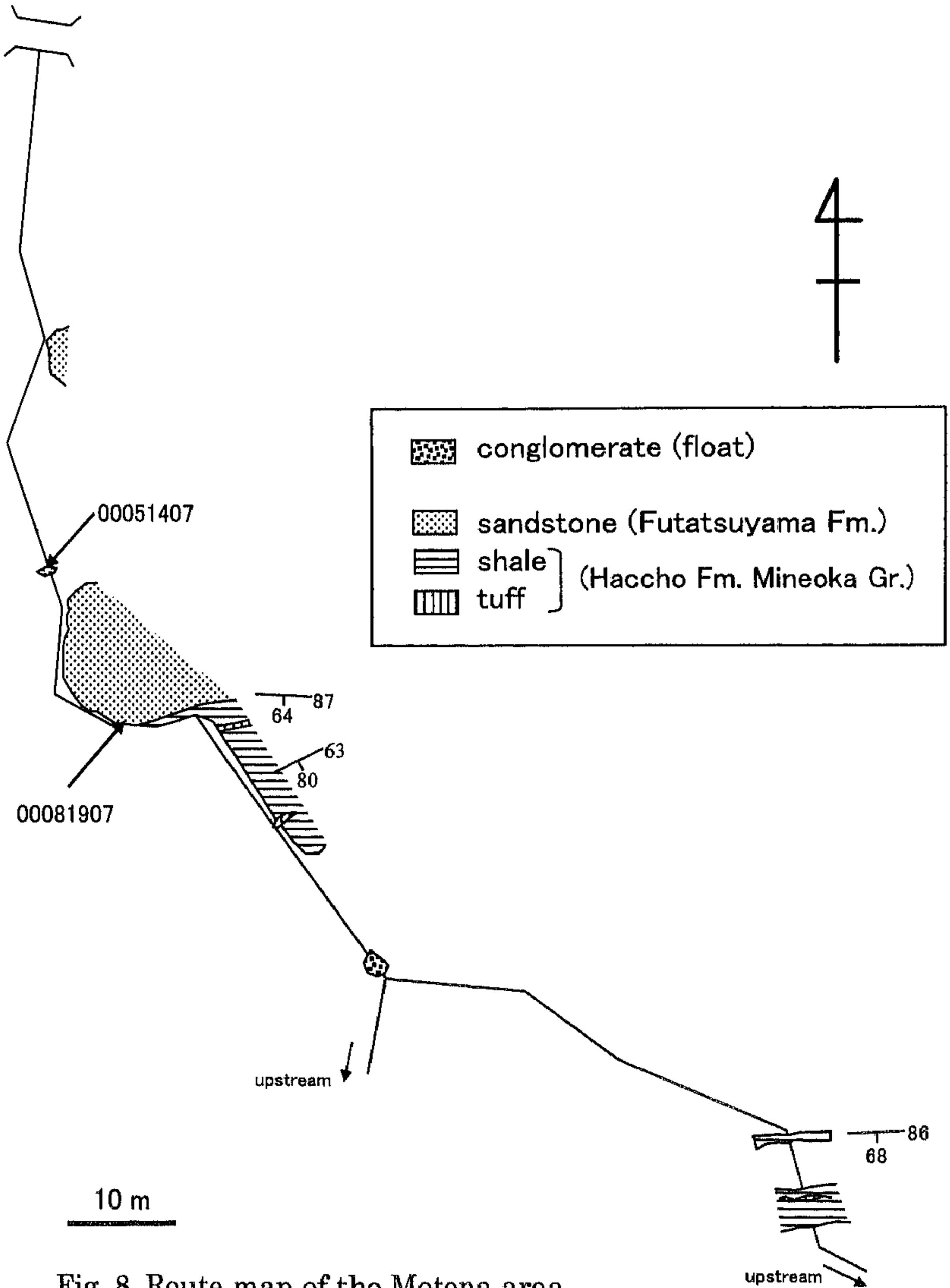


Fig. 8. Route map of the Motona area.
The site of this route map is shown in Fig. 7.

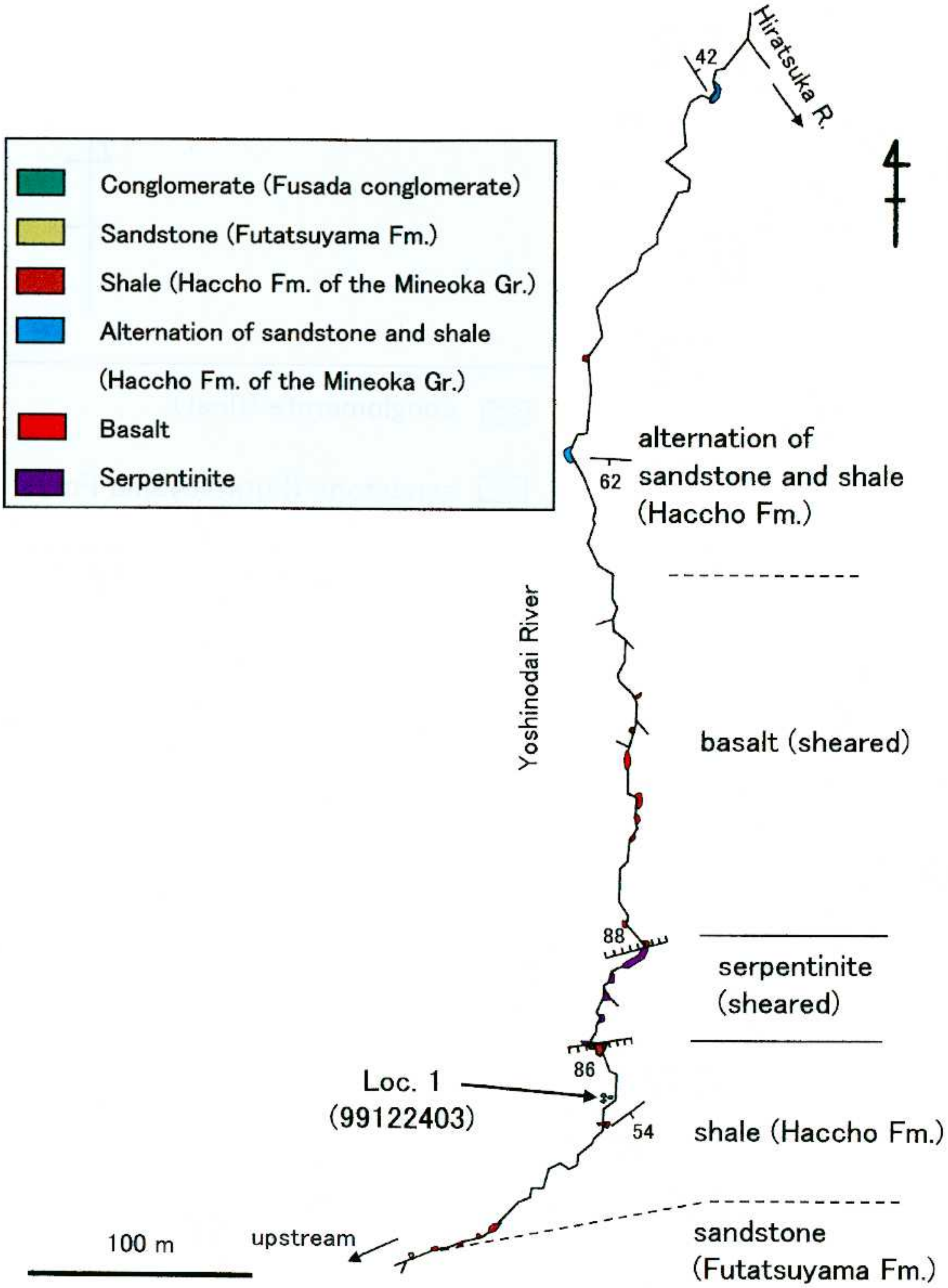


Fig. 9. Route map of the Yoshinodai River, branch of the Hiratsuka River, in the Fusada area.
The locality of this route map is shown in Fig. 7.

Saito (1992). Nakajima et al. (1981) subdivided it into two formations, namely the Fukawa and Kanigawa Formations, though they treated these formations as the belongings to the Awa Group. The Fukawa Formation comprises the lowest part of the Hota Group in the north of the Mineoka Mountains. It is composed of fine- to medium-grained massif arkosic sandstone and is distributed along the northern edge of the Kamogawa Ophiolitic Complex (Kawai, 1957). The Kanigawa Formation is distributed on the north side of the Fukawa Formation's distribution area, though the relationship with the Fukawa Formation is unsettled (Nakajima et al., 1981). The Kanigawa Formation is composed of gray massive fine to very fine-grained sandstone and massive sandy siltstone. This formation is conformably overlain by the Kinone Formation of the Miura Group (Nakajima et al., 1981; Watanabe and Takahashi, 2000).

Hatai and Koike (1957) reported the molluscan fauna of the Hota Group, and concluded that its age was Oligocene. Furthermore, they correlated that a part of the Hota Group, which yielded molluscs, to the Asagai Formation in Fukushima Prefecture. Noda et al. (2002) described the *Mytilus tichanovichi* from the northernmost part of the dictributional area of the Hota Group, and inferred the sedimentary environment as shallow marine. The strata at the occurrence site of *Mytilus tichanovichi* are inferred to be Early Miocene based on the molluscan fauna (Kurihara, Y., pers. comm.). On the other hand, Ogasawara et al. (1994) reported the occurrence of *Calyptogena* sp. from the southernmost part of the distributional area of the Hota Group, and they inferred the sedimentary environment as deep sea.

Saito (1992) established the radiolarian biostratigraphy, and according to him, the Hota Group is early Early to late Early Miocene. Furthermore, Saito (1992) concluded that the Hota Group was deposited at the depth near CCD or deeper based on the benthic foraminifers. Suzuki et al. (1996) reported the occurrence of latest Oligocene diatoms and silicoflagellates from the Maejima Formation.

Sakuma Group

The Sakuma Group is defined as the strata which are distributed in the Sakuma area, and is characterized by fining-upward sequence. This group consists of the Okuzure, Okuyama, Nakaobara and Kojima Formations, and unconformably overlies on the Hota Group. Although Saito (1992) considered that the Futatsuyama Formation belonged to the Sakuma Group, the Futatsuyama Formation is excluded from the Sakuma Group in the present study. The following are reasons; 1) distribution of the Futatsuyama Formation is separated from that of the other formations of the Sakuma Group (Fig. 6). 2) lithology of the Futatsuyama Formation is different from that of the other formations of the Sakuma Group. 3) sedimentary age of the Futatsuyama Formation is still ambiguous due to the absence of index fossils. The Futatsuyama Formation is described later.

The Okuzure Formation consists of unsorted conglomerate. The clasts of conglomerate are composed of constituents of the Mineoka and Hota Groups and of the probably Paleozoic-Mesozoic strata in the adjacent area. Saito (1991) reported that the clasts were pebble to boulder in size and angular.

The Okuyama Formation consists of medium to coarse bluish gray sandstone. This formation interfingers with the Okuzure Formation.

The Nakaobara Formation consists of alternation of sandstone and mudstone. The sandstone presents bluish gray, and the mudstone is grayish green. This formation conformably overlies on the Okuzure and Okuyama Formations or it is in interfingering relationship with them.

The Kojima Formation consists of bluish green andesitic tuff, and is correlative with the Tateishi Tuff Member of the Abuzuru Formation in the Miura Peninsula (Eto, 1986). This formation occurs intermittently in the southern part of the Mineoka Mountains.

Otuka and Koike (1948) and Koike (1949) reported the molluscan fossils from the Sakuma Group. Saito (1992) described calcareous nonnofossils, planktonic foraminifers and radiolarians from the Nakaobara Formation, and concluded its age as the early Middle Miocene. Furthermore, Saito (1992) inferred that the sedimentary depth of the Sakuma Group was the lower part of the middle bathyal zone.

Saito (1991) considered that the Okuzure, Okuyama and Nakaobara Formations were deposited in the pull-apart basin due to the right-lateral faulting in the early Middle Miocene caused by right-lateral faulting.

3-2-2. Setogawa area

Four groups, namely the Mikura, Setogawa, Kurami and Koma Groups in the Akaishi Mountains have been investigated in this study. Figs. 10 and 11 show a correlation diagram and distributions of these groups, respectively.

Mikura Group

The Mikura Group occupies the most southern part of the Shimanto Belt in the Akaishi Mountains (e. g. Kano and Matsushima, 1988). The distribution of this group is elongated in the direction of NE-SW (Fig. 11), and it is distributed from the Ikawa Lake, Shizuoka City to Mori Town, Shizuoka Prefecture. The maximum width of the distribution of this group is about 15 km in the south, and in the north, this group thins out to the east of the Ikawa Lake.

This group consists of sandstone, shale and alternation of sandstone and shale (Fig. 12). Kato et al. (1991) divided the southern part of the distribution area of this group into three formation; Ikumi, Kamio and Wappazawa Formations in ascending order. The outline of geology of these formations described by Kato et al. (1991) is as follows.

The Ikumi Formation consists mainly of green to dark gray shale, and is often intercalated with thin beds of fine-grained sandstone.

The Kamio Formation is composed mainly of sandstone-rich alternation of sandstone and shale. The sandstone and conglomerate are distributed in some places.

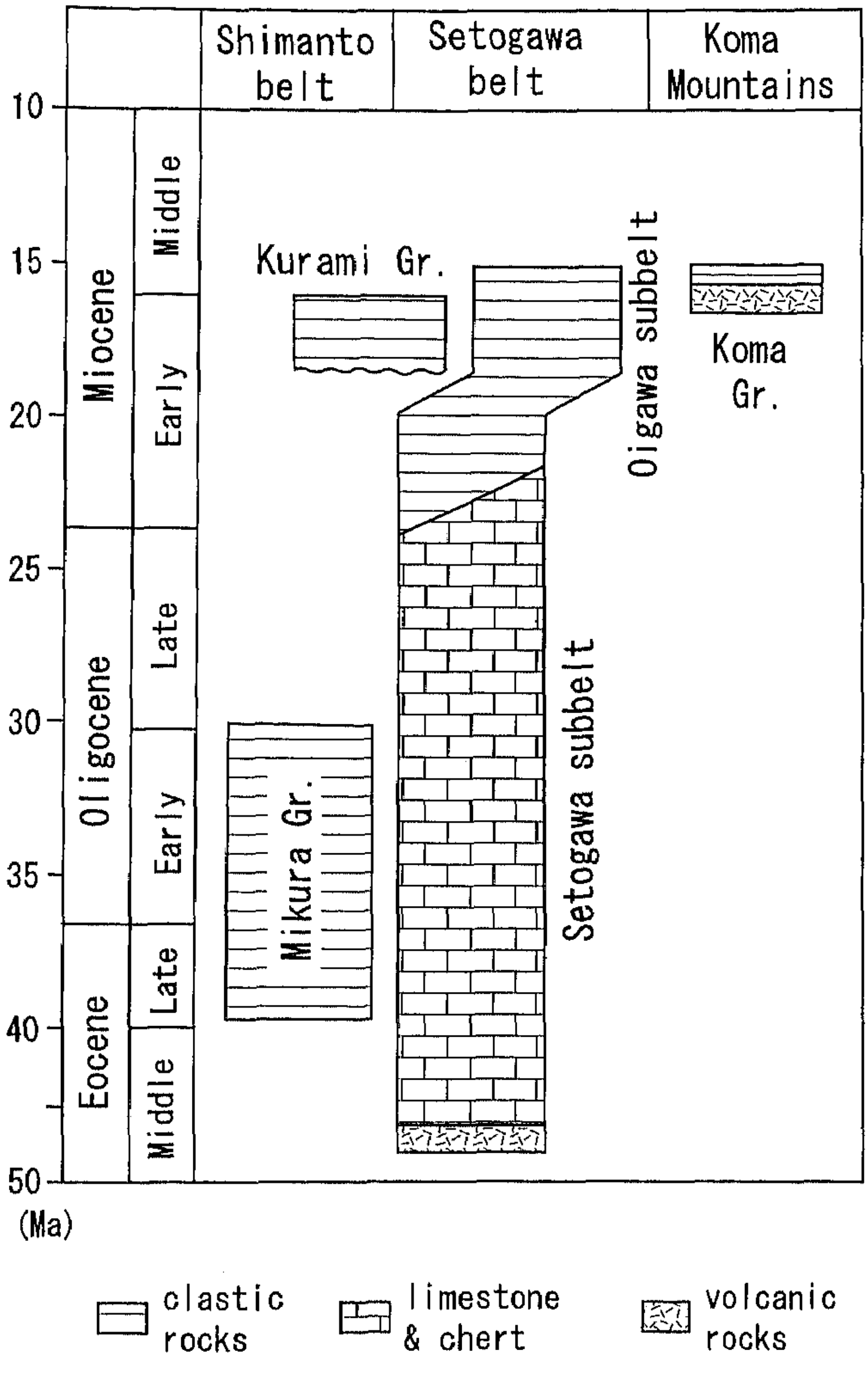


Fig. 10. Correlation diagram of the groups in the Set
Compiled from Ibaraki (1986a), Sugiyama (1992) and Koyama

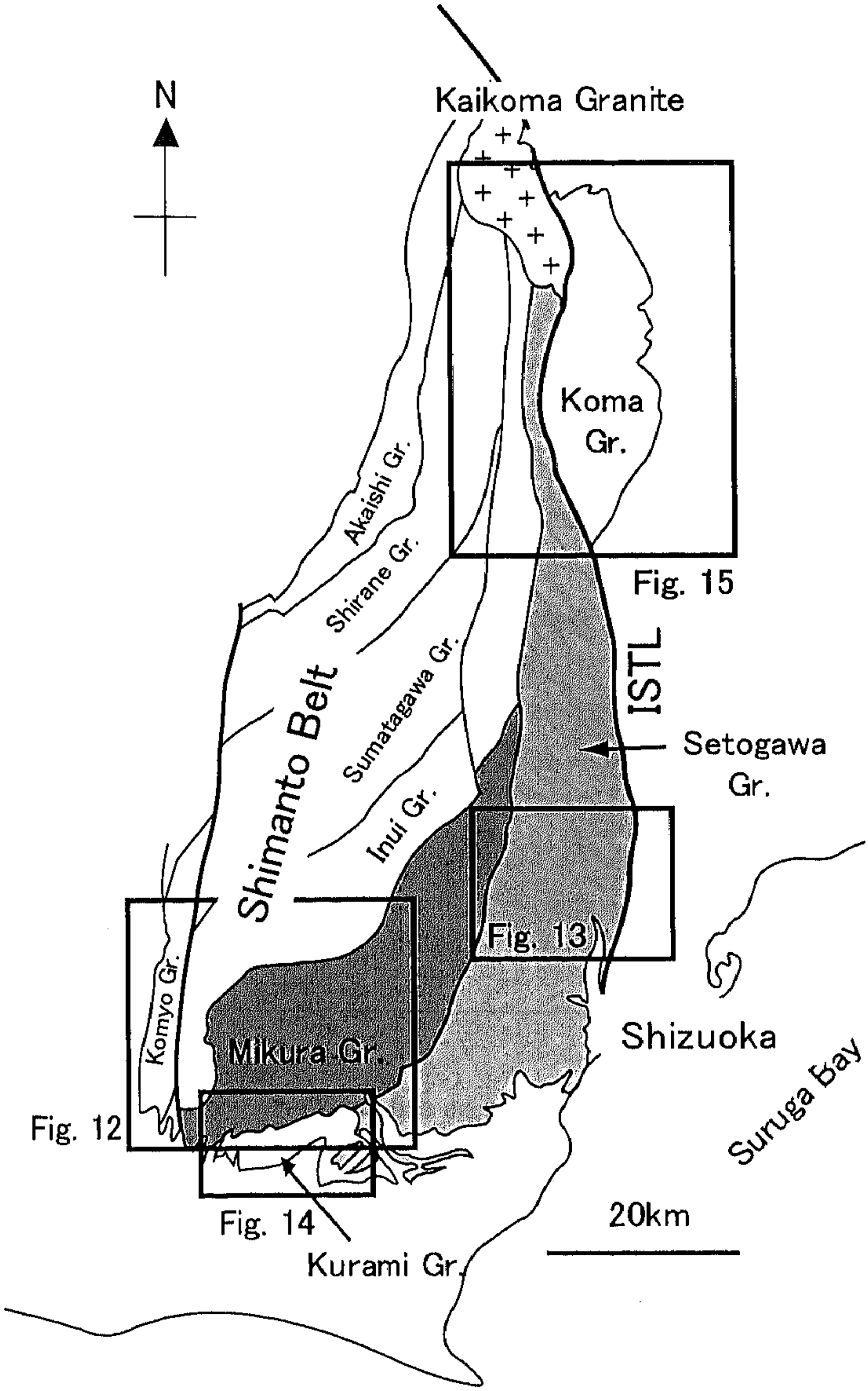
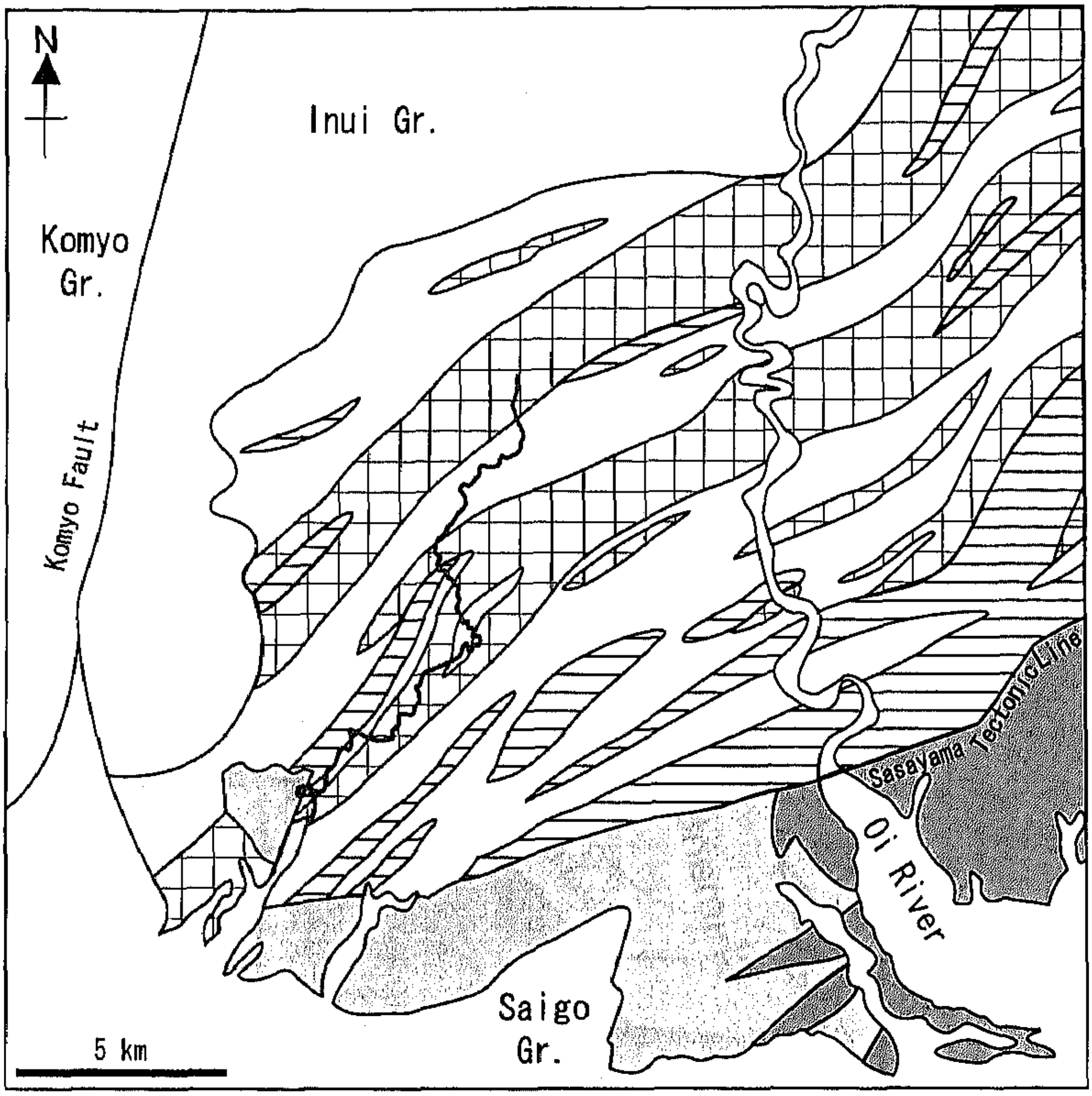


Fig. 11. Simplified geological map of the Setogawa area.
Simplified from Sugiyama (1995). ISTL: Itoigawa-Shizuoka Tectonic Line.



Mikura Group (alternation of sandstone and shale)

Mikura Group (disturbed sandstone and shale)

Mikura Group (shale)

Main survey route (Yoshi River)

Kurami Group

Se

The conglomerate contains clasts of chert, sandstone, shale, limestone and felsic volcanics. The slump structure is developed in the upper part of this formation. The calcareous shale yielding molluscan fossils is intercalated in the upper part of this formation.

The Wappazawa Formation consists mainly of dark gray shale and shale-rich alternation of sandstone and shale, and often contains calcareous nodules. The nodules in the lower part of this formation often contain molluscan fossils.

The strata of this group have a general strike of NE-SW to ENE-WSW and dip to NE. This group is in fault contact with the Inui and Setogawa Groups and is unconformably overlain by the Kurami Group. The fault between the Mikura and Setogawa Groups is called Sasayama Tectonic Line (Mochizuki, 1956).

Matsumoto (1966) reported Oligocene molluscan fossils from this group. Iijima et al. (1981) and Watanabe (1988) mentioned the Tertiary pollen and Early Miocene radiolarian fossils, respectively. Sugiyama and Shimokawa (1990) indicated an occurrence of the Eocene benthic foraminifers. Kato et al. (1991) described Eocene to Oligocene planktonic foraminifers and molluscs, and inferred that the sedimentary depth of the Mikura Group was deeper than the bathyal zone or CCD based on the benthic foraminifers and trace fossils.

Setogawa Group

The Setogawa Group is distributed in the southeasternmost part of the Akaishi Mountains. The distribution of this group is elongated in the direction of northeast to southwest in the southern part, and north to south in the northern part (Fig. 11). It is exposed from the north, Minami-Alps City (former Ashiyasu Village), Yamanashi Prefecture to the south, Kayana Town, Shizuoka Prefecture. The width of the distribution of this group is about 15 km in the south, and less than 5 km in the northernmost part.

This group consists mainly of sandstone, shale, limestone, chert, basalt, serpentinite and dacite. Sugiyama and Shimokawa (1989, 1990) divided the southern part of the Setogawa Belt into two subbelts, that is, Setogawa and Oigawa Subbelts. They subdivided the Setogawa Group in the Setogawa Subbelt into four thrust sheets; from west to east, the Odake, Takayama, Tawarazawa and Utsunoya Subbelts (Fig. 13). They also subdivided the Setogawa Group in the Oigawa Subbelt into two thrust sheets; Oigawa and Ryuso Thrust Sheets (Fig. 13). The outline of the geology of these thrust sheets described by Sugiyama and Shimokawa (1990) is as follows.

The Odake Thrust Sheet is composed mainly of black shale, greenish tuffaceous shale, alternation of sandstone and shale and bedded chert. The bedded chert is generally muddy, and presents black to dark gray in color. It comprises the lowest part of the Odake Thrust Sheet. Black shale and greenish tuffaceous shale are intercalated with greenish and white tuff and volcaniclastic rocks. They also include mafic to ultramafic rocks (Arai and Uchida, 1979; Ohashi, 1980). Ultramafic rocks are composed of serpentinized harzburgite, dunite, chromitite, clinopyroxenite, wehrlite and websterite (e.g. Arai et al., 1978). Serpentinite occurs as intrusive rocks or clasts in shale. Mafic rocks are composed mainly of basalts. Some basalts in the Odake Thrust Sheet occur as in-situ basalt (e.g. Osozawa et al., 1990). In the northern part of the Setogawa Group, the in-situ basalt occurs along the Sasayama Tectonic Line (Sugiyama, 1995). In this thrust sheet, blocks or clasts of gabbro, dolerite, diorite and andesite occur in shale near serpentinite or basalt. From this thrust sheet, Ohashi and Shiraki (1981) also reported the occurrence of high-magnesian andesite and basalt which were similar to the boninite in the Bonin Islands in terms of chemistry and mineralogy.

The Takayama Thrust Sheet is composed mainly of shale, sandstone, alternation of sandstone and shale, chert, basalt and limestone. Around the Takayama area, the lowest part of this thrust sheet is composed of basaltic lava, calcareous and tuffaceous (basaltic) sandstone and shale, bedded limestone-chert and bedded chert in ascending order. Sugiyama (1995) regarded the basalt at Takayama as a seamount in origin based on the chemistry of basalt. A picrite basalt dike also

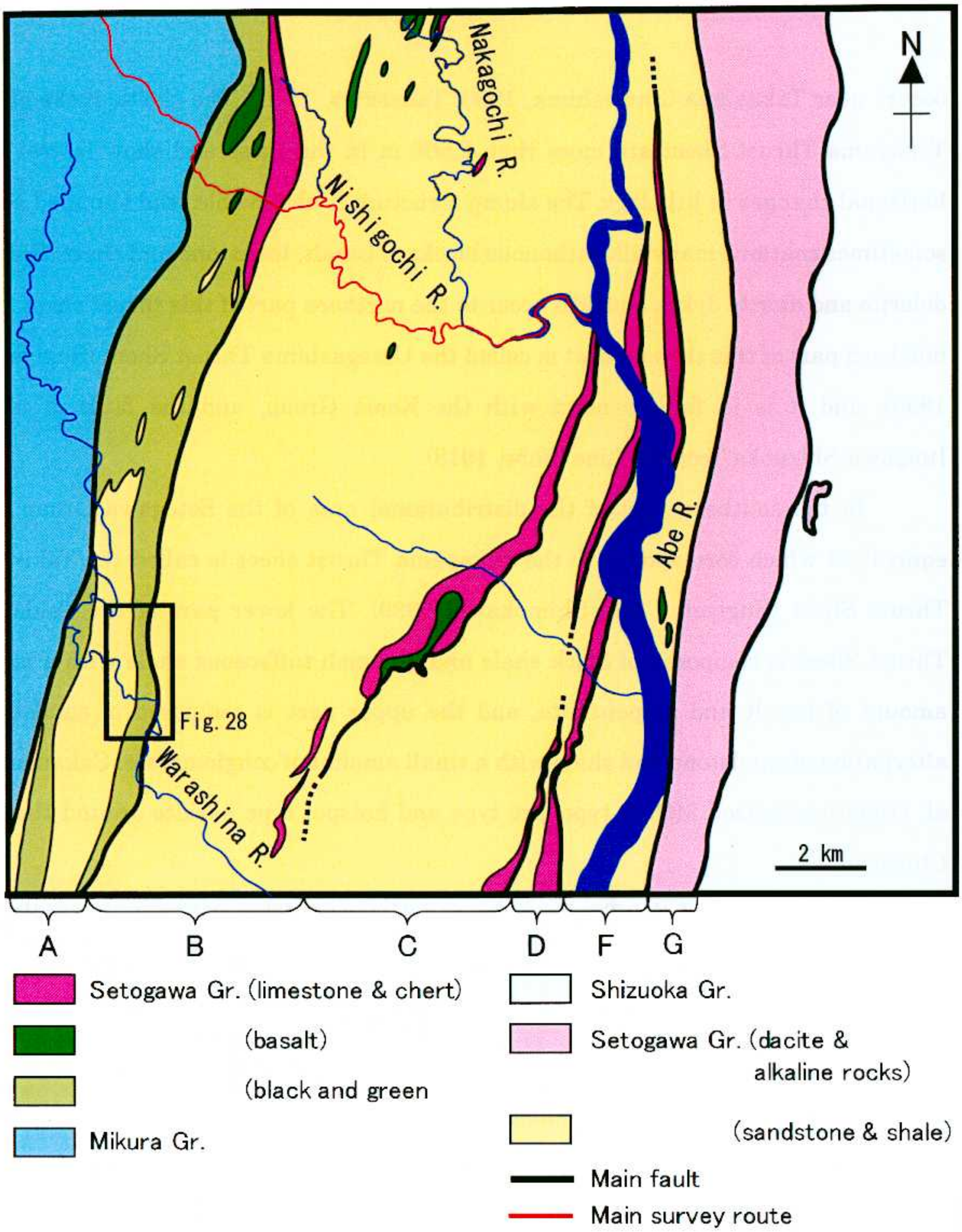


Fig. 13. Geologic map of the Setogawa Group in the middle reaches of the Abe River. Simplified from Sugiyama and Shimokawa (1990). A: Ohdake Thrust Sheet. B: Takayama Thrust Sheet. C: Tawarazawa Thrust Sheet. D: Utsunoya Thrust Sheet. F: Oigawa Thrust Sheet. G: Ryuso Thrust Sheet. ISTL: Itoigawa-Shizuoka Tectonic Line.

occurs near Takayama (Sameshima, 1960; Takasawa, 1976). The clastic rocks of the Takayama Thrust Sheet are more than 2,500 m in thickness and show lateral and horizonal changes in lithology. The slump structure is observable, and slumped shale sometimes contains many allochthonous blocks of basalt, limestone and chert. Gabbro, dolerite and diorite dykes and sills occur in the northern part of this thrust sheet. The northern part of this thrust sheet is called the Umegashima Thrust Sheet (Sugiyama, 1995), and it is in fault contact with the Koma Group, and the fault is called Itoigawa-Shizuoka Tectonic Line (Yabe, 1918).

In the southern part of the distributional area of the Setogawa Group, the equivalent which corresponds to the Takayama Thrust sheet is called the Takisawa Thrust Sheet (Sugiyama and Shimokawa, 1989). The lower part of the Takisawa Thrust Sheet is composed of black shale and greenish tuffaceous shale with a minor amount of basalt and serpentinite, and the upper part is composed of sandstone, alternation of sandstone and shale with a small amount of conglomerate. Sakamoto et al. (1993) recognized MORB type, arc type and hotspot type basalts around the Mt. Chibasan.

The lithology of the Tawarazawa and Utsunoya Thrust Sheets is similar to each other. The lowest part of these thrust sheets is composed of basaltic lava, calcareous tuffaceous (basaltic) sandstone and shale, bedded micritic limestone and bedded chert in ascending order. The clastic rocks of these thrust sheets are composed of alternation of sandstone and shale, shale with a small amount of conglomerate, pebbly shale and tuffaceous siliceous shale, and chert. The slump structure is also observable in these thrust sheets. The blocks of basalt, chert and limestone are contained in the slumped bed.

The Oigawa Thrust Sheet is composed mainly of sandstone, shale and alternation of sandstone and shale with a minor amount of felsic tuff and tuffaceous siliceous shale. Pebbly shale and conglomerate also occur in the southern part of this thrust sheet. The slump structure is also observable and the slumping bed and pebbly shale contain many allochthonous blocks of basalt, limestone and chert. These allochthonous blocks are interpreted as olistolith derived from the Setogawa Subbelt (Sugiyama, 1980, 1995). Most of the Dolerite dykes occur in the northern part of this thrust sheet. The basaltic rocks around the Mt. Takakusa (e.g. Watanabe and Iijima, 1983; Shimokawa and Sugiyama, 1983) are also contained in this thrust sheet. The boundary fault with the Ryuso Thrust Sheet is called the Jumaiyama Tectonic Line (Tokuyama, 1972).

The Ryuso Thrust Sheet is composed mainly of alkaline dacite with a minor amount of rhyolite, alkaline dolerite, intrusive gabbro and granophyre, mudstone and sandstone. The boundary fault between this thrust sheet and the Shizuoka Group is the Itoigawa-Shizuoka Tectonic Line (Yabe, 1918).

The radiolarian data from shale in the Odake, Takayama, Tawarazawa and Utsunoya Thrust Sheets show the Early Miocene (e.g. Iijima et al., 1981; Sugiyama and Shimokawa, 1990; Yagi et al., 1996). The planktonic foraminifers and radiolarians from the Oigawa Thrust Sheet indicate a slightly younger age (late Early Miocene to early Middle Miocene: e.g. Ibaraki, 1981; Iijima et al., 1981; Kato et al., 1992). The mudstone which is intercalated with the basalt around Mt. Takakusa contains early Middle Miocene planktonic foraminifers and radiolarians (Sugiyama et al., 1982; Sugiyama, 1995). From the bedded limestone just above the basaltic rocks, middle to late Eocene planktonic foraminifers (e.g. Ibaraki, 1983, 1984) and radiolarians (Iijima, et al., 1981; Sugiyama and Shimokawa, 1990) have been described. From the bedded chert and siliceous shale which conformably overlie the bedded limestone, Oligocene to Early Miocene radiolarians have been reported (Osozawa, 1986; Sugiyama and Shimokawa, 1990).

Kurami Group

The Kurami Group occupies the northern part of the Kakegawa Hills. This group is exposed in the Kakegawa City, Kanaya Town and Mori Town, Shizuoka Prefecture.

This group consists of sandstone, siltstone, alternation of sandstone and siltstone with a minor amount of basal conglomerate. Ibaraki (1986a) divided this group into five formations; the Haramishi Conglomerate, Amakata Sandstone, Todo Alternation of Sandstone and Siltstone, Towata Siltstone and Matsuba Siliceous Siltstone in ascending order (Fig. 14). The outline of geology of these formations described by Ibaraki (1986a) is as follows.

The Haramishi Conglomerate is the basal conglomerate of the Kurami Group. This formation overlies the Mikura Group and the strata of the Takisawa Thrust Sheet of the Setogawa Group unconformably. It consists mainly of rounded pebble- and cobble-sized sandstone clasts. Maximum thickness of this formation is 90 m. It changes upward into the Amakata Sandstone.

The Amakata Sandstone is massive, bluish gray, medium-grained sandstone. This is 100 to 300 m in thickness. It changes upward to the Towata Siltstone and the Todo Alternation of Sandstone and Siltstone.

The Todo Alternation of Sandstone and Siltstone is composed of alternating bluish grayish, medium-grained sandstone and dark gray siltstone. This is about 400 m in thickness in the west. This formation interfingers with the lower part of the Towata Siltstone and thins out to the east. It also grades upward to the Towata Siltstone.

The Towata Siltstone is composed of massive, dark gray siltstone. Maximum thickness of this formation is 600m. This formation grades upward into the Matsuba Siliceous Siltstone.

The Matsuba Siliceous Siltstone is composed mainly of dark greenish, bedded siliceous siltstone and tuffaceous siltstone. This formation is 700 m in thickness. Several lenses of greenish tuffaceous medium-grained sandstone which is called the Awagatake Sandstone (Makiyama, 1941) are included in the lower and middle parts of this formation around Mt. Awagatake. This formation becomes less siliceous in the upper part, and is overlain by the Saigo Group in a locally unconformable contact.

Watanabe (1988) indicated the occurrence of molluscan fossils from the Todo

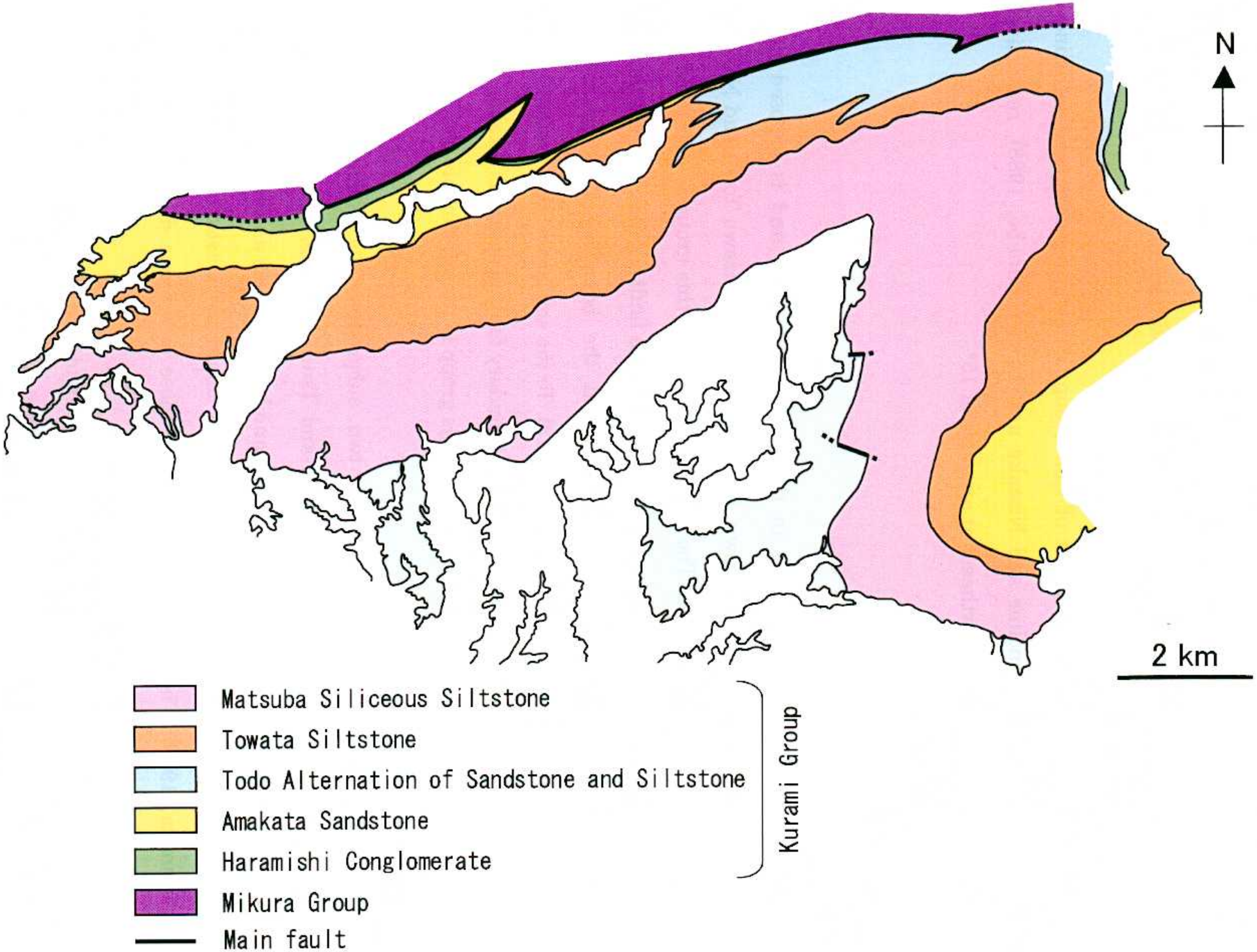


Fig. 14. Geologic map of the Kurami Group. Simplified from Ibaraki (1986a).

Alternation of Sandstone and Siltstone. Saito (1960) and Ibaraki (1986b) described the planktonic foraminifers from the Towata Siltstone. These fossils are assigned to the Early Miocene. From the Matsuba Siliceous Siltstone, the occurrence of the late Early Miocene planktonic foraminifers had been reported by Saito (1960), Ujiie and Inoue (1980) and Ibaraki (1986b).

In the distributional area of this group, a set of syncline and anticline is developed; Kurami syncline and Nissaka anticline (Watanabe, 1988), respectively. Fold axes plunge to the northeast at an angle of 15°.

Koma Group

The Koma Group occurs in the Koma Mountains, and is exposed in the Minami-Alps City, Hayakawa Town, Masuho Town, Kajikazawa Town and Nakatomi Town, Yamanashi Prefecture. The distribution area of this group is elongated in the direction of N-S (Fig. 15). To the west, this group is in fault contact with the Setogawa Group and the Kaikomagatake Granite and the boundary fault is called as Itoigawa-Shizuoka Tectonic Line (Yabe, 1918). To the southeast, this group is in fault contact with the Fujigawa Group and the boundary fault is called as Akebono Thrust (Otuka, 1938). To the east and northeast, this group is unconformably overlain by the Quaternary.

The Koma Group consists of two subgroups; the Kushigatayama and Momonoki Subgroups (Fig. 15; Kosaka and Tsunoda, 1969). The Kushigatayama Subgroup is composed mainly of andesitic and basaltic lavas and volcaniclastic rocks, while the Momonoki Subgroup is composed mainly of clastic rocks (Kosaka and Tsunoda, 1969). The outline of geology of these subgroups described by Koyama (1993) is as follows.

The Kushigatayama Subgroup was subdivided into the lower part upper parts (Fig. 15; Koyama, 1993). The lower part of this subgroup is composed mainly of andesitic to basaltic tuff and volcaniclastic rocks, and is intercalated with andesitic to

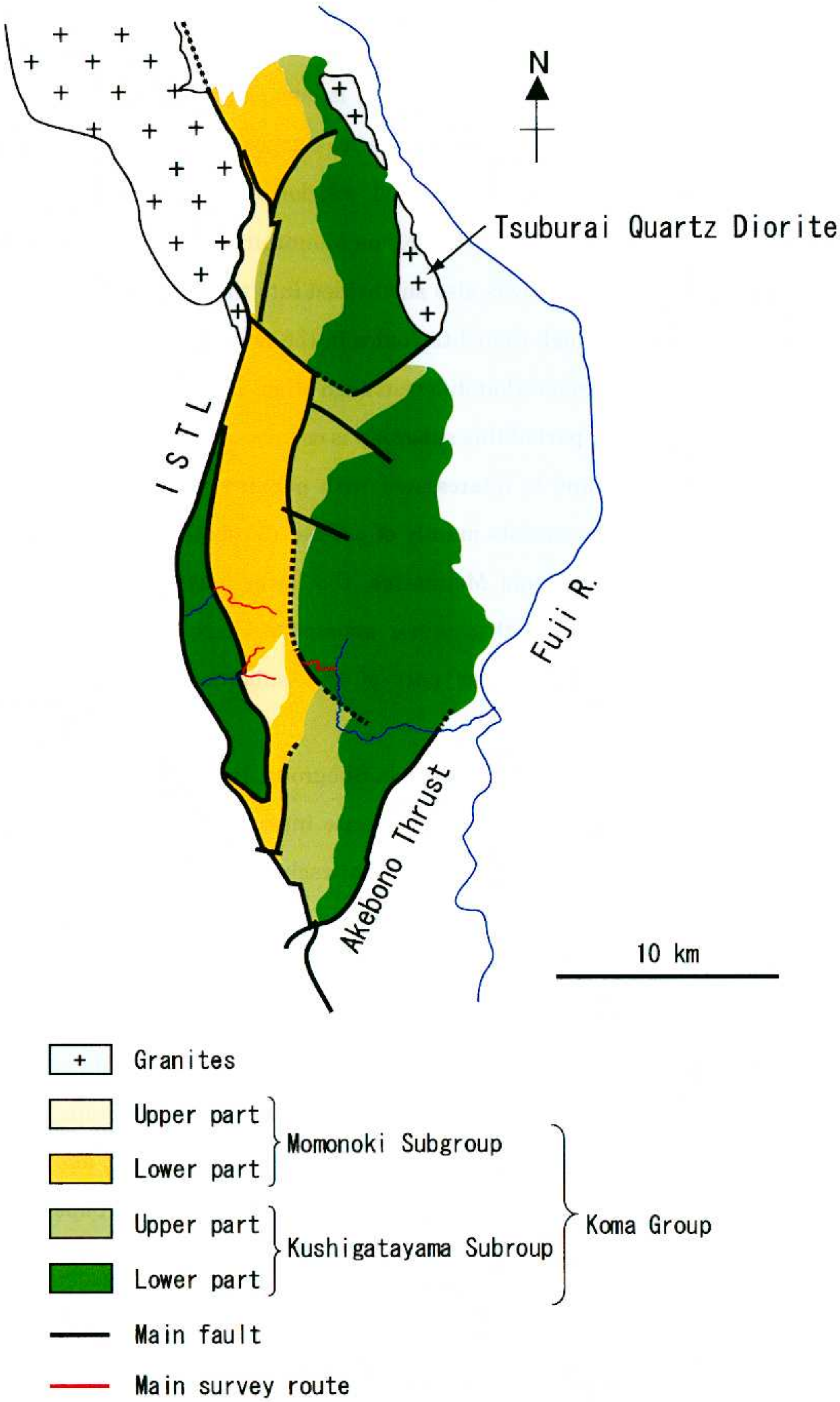


Fig. 15. Geologic map of the Koma Mountains.
Simplified from Koyama (1993). ISTL: Itoigawa-Shizuoka Tectonic Line.

basaltic lava. The upper part of this subgroup is composed mainly of tuff, and is intercalated with clastic rocks. The clastic rocks are composed of mudstone, sandstone, alternation of sandstone and mudstone, and conglomerate. The conglomerate is observable only in the southern part of the Koma Mountains.

The Momonoki Subgroup was also subdivided into the lower part upper parts (Fig. 15; Koyama, 1993), though their lithologies in the northern and southern parts of the Koma Mountains are somewhat different each other. In the southern part of the Koma Mountains, the lower part of this subgroup is composed mainly of alternation of sandstone and mudstone, and is intercalated with pebble-sized conglomerate. The upper part of this subgroup consists mainly of pebble- to cobble-sized conglomerate. In the northern part of the Koma Mountains, the lower part of this subgroup is composed mainly of mudstone with a minor amount of chert, siliceous mudstone, sandstone and felsic tuff. The upper part of this subgroup consists mainly of alternation of sandstone and mudstone.

Porphyrite dykes occur in the Momonoki Subgroup. In the northeastern part of the Koma Mountains, the Tsuburai Quartz Diorite intruded to the Kushigatayama Subgroup (Fig. 15). 15 ± 0.6 Ma of the fission-track age was obtained from the Tsuburai Quartz Diorite (Ito et al., 1989).

Akimoto et al. (1990) mentioned the occurrence of planktonic and benthic foraminifers from this group, and inferred that the sedimentary depth of the Kushigatayama and Momonoki Subgroups was the lower bathyal and abyssal zones, respectively. Aoike (1998) reported occurrence of the calcareous nannofossils from the Kushigatayama Subgroup. Aoike (1999) compiled these microfossil data, and inferred that the sedimentary ages of the Kushigatayama and Momonoki Subgroups were 15 to 16 Ma and 15 to 13.5 Ma, respectively.

3-3. Description of undivided unit of sedimentary rocks in the Mineoka area

As shown in earlier lines, tectonic blocks of clastic rocks occur in the Mineoka Mountains. These tectonic blocks have been treated as the Mineoka Group by Saito (1992) and Sakagami et al. (1997). They are treated separately from the Mineoka Group in this study owing to unknown depositional ages or belongings of tectonic blocks, and described in this section. The undivided clastic rocks are named three units, that is, the Futatsuyama Formation, serpentine sandstone and leucocratic sandstone.

3-3-1. Futatsuyama Formation

The Futatsuyama Formation, so-called hard sandstone, defined by Saito (1992) is distributed in the western part of the Mineoka Mountains. This formation consists of light green to light gray medium- to coarse-grained massive sandstone. Moreover, this formation forms characteristic topographies called knockers, and these knockers make linear arrangements in the ENE-WSW direction (Fig. 6). The occurrence of index fossils has not been reported from this formation. Moreover, the relationship between the Futatsuyama Formation and its surrounding strata had not been known because of the lack of outcrops. Mitsunashi et al. (1979) included this formation into the Mineoka Group, while Saito (1992) and Suzuki et al. (1990) included this formation into the Sakuma Group. Recently, Sakagami et al. (1997) supposed this as tectonic blocks in the Mineoka Mountains.

3-3-2. Serpentine sandstone

The serpentine sandstone occurs as tectonic blocks in the sheared serpentinite or basalts in the Mineoka Mountains. Those blocks are distributed at Yohka Beach (Fig. 16), Mineokasengen (Fig. 17, Ogawa, 1981; Arai et al., 1983) and Hegurinaka (Fig. 18, Arai et al., 1983). In this study, the outcrops of the serpentine sandstone at

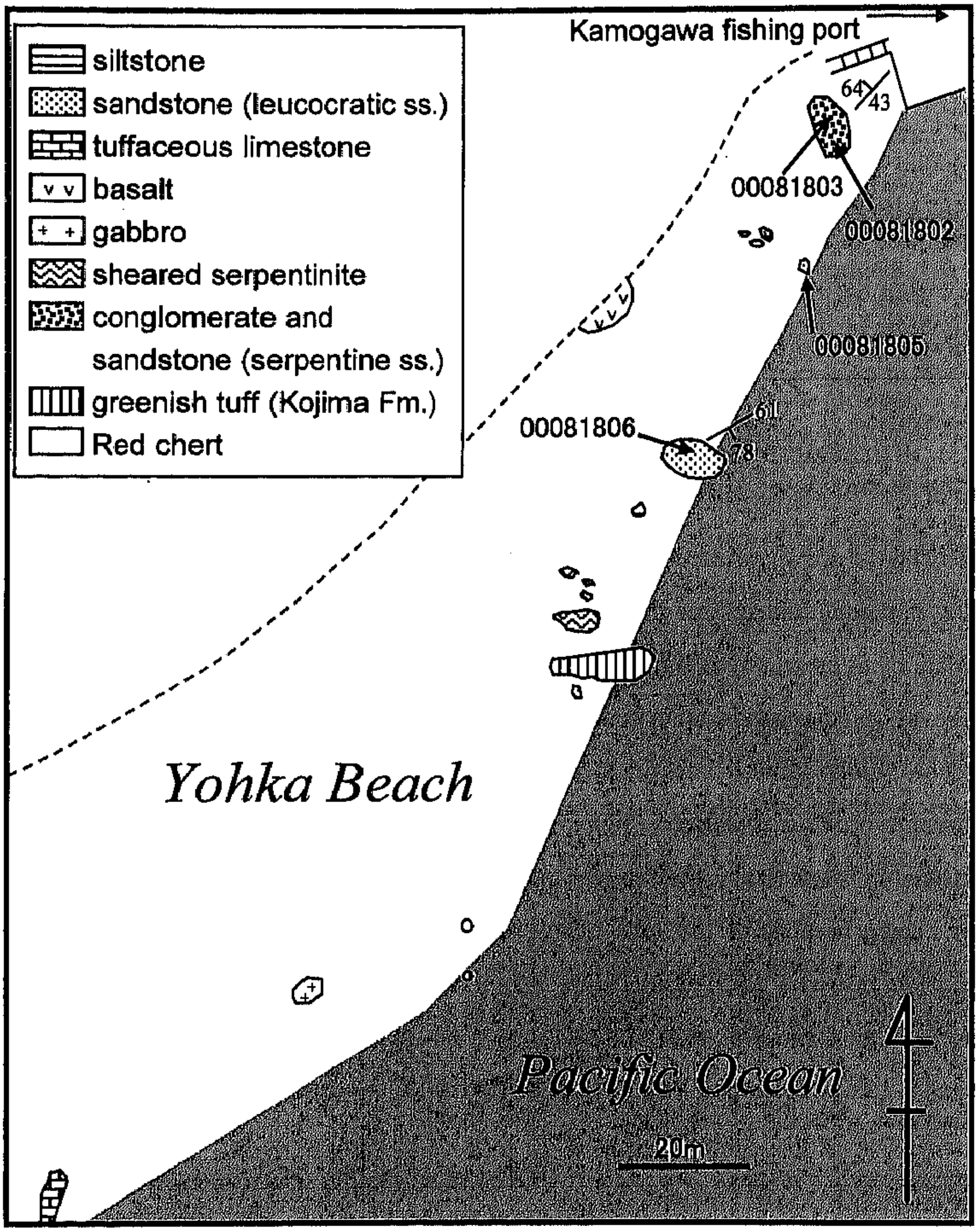


Fig. 16. Route map along the Yohka Beach.
These outcrops or blocks are observable only while the tidal level is low. The site of this Route map is shown in Fig. 7.

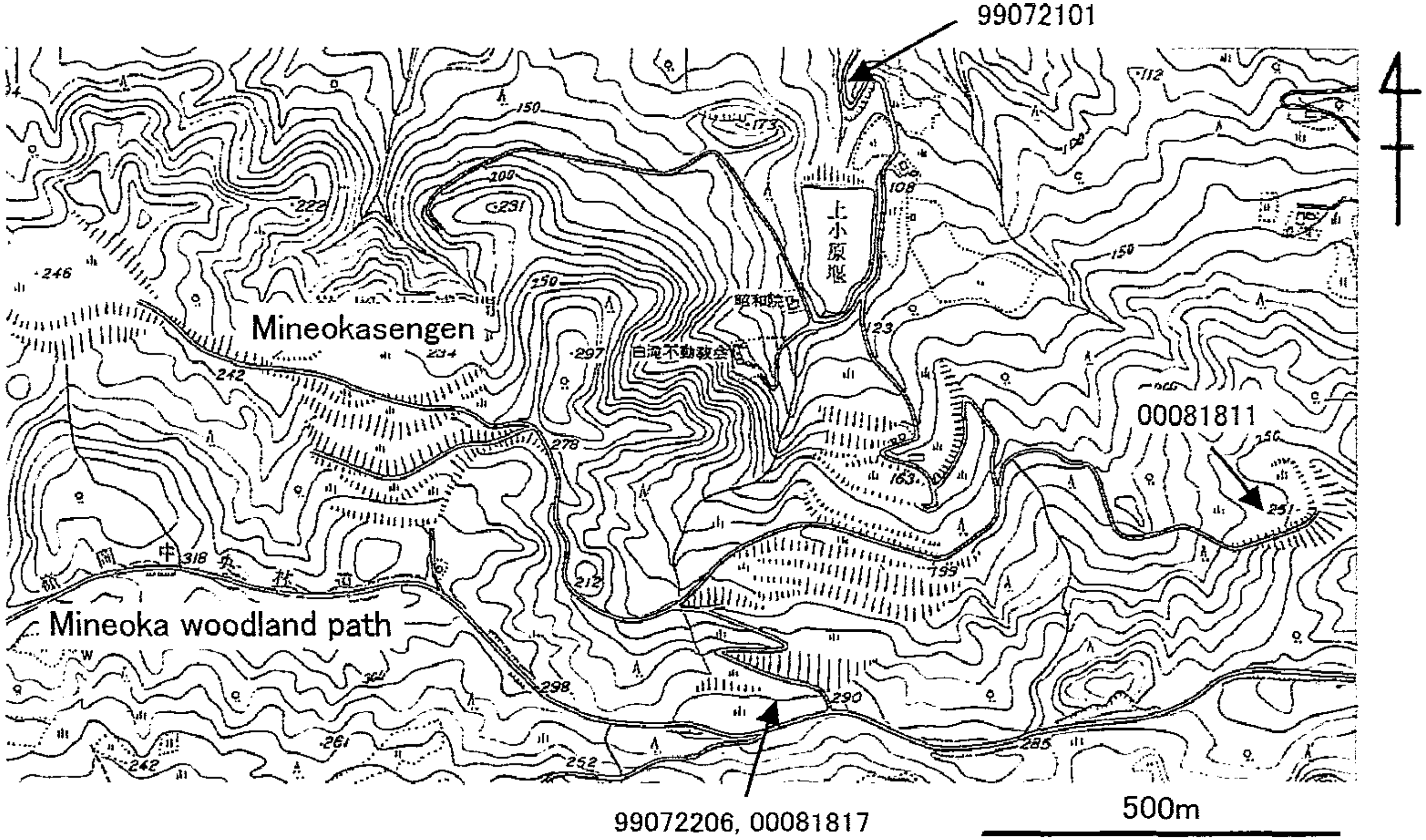


Fig. 17. Locations of tectonic blocks at Mineokasengen. The base map is cited from 1/10,000 of Kamogawa City Whole Map published by the Kamogawa City. The site of this map is shown in Fig. 7 . The tectonic blocks at 99072206 and 00081817 correspond to the serpentine sandstone and leucocratic sandstone described by Arai et al. (1983), respectively. The sample 00081811 is collected from the outcrop of serpentine sandstone found newly in this study. The sample 99072101 is the Fukawa Formation sandstone.

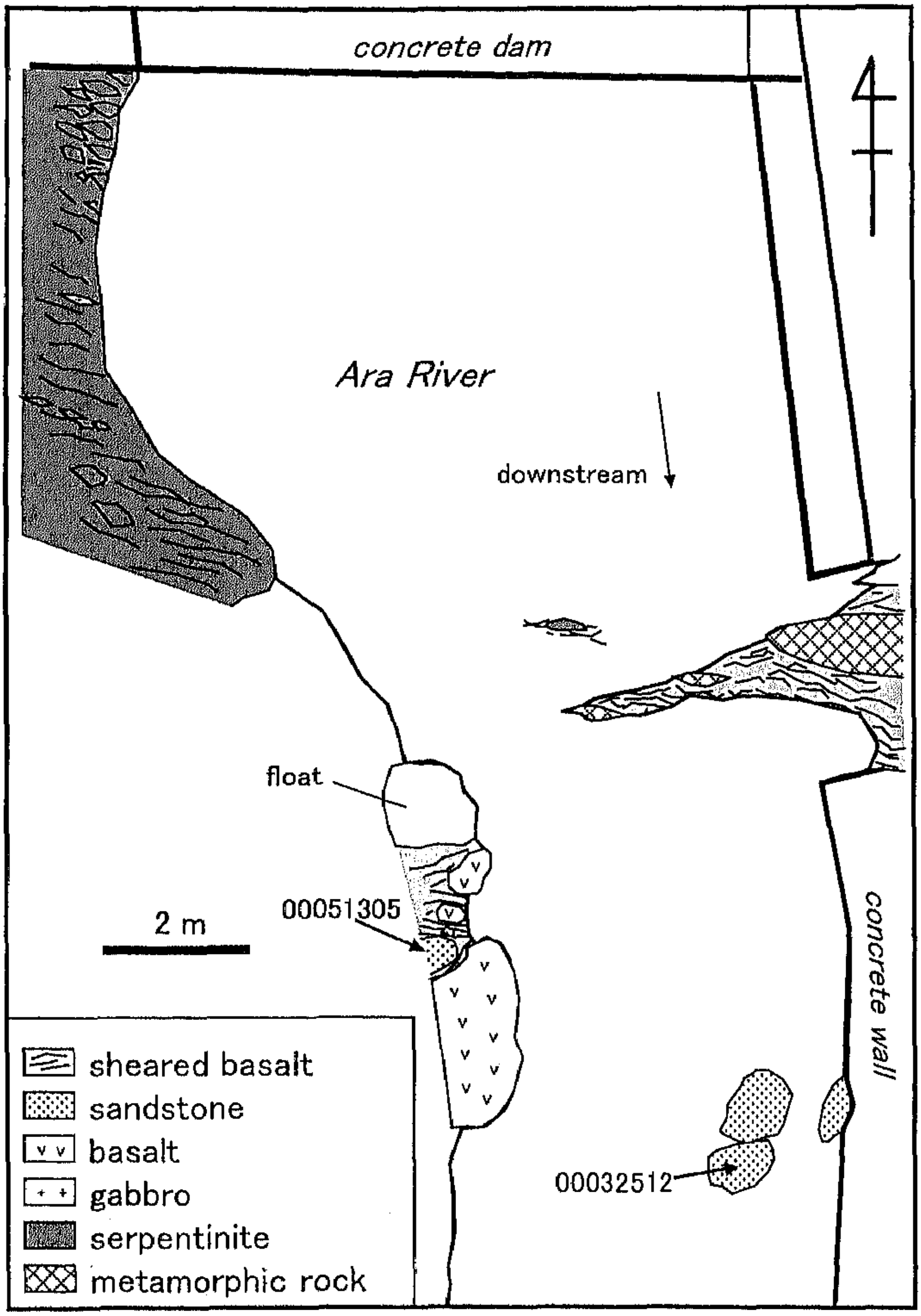


Fig. 18. Sketch map of tectonic blocks along the Ara River at Hegurinaka.
The locality of this outcrop is shown in Fig. 7.

Mineokasengen and Hegurinaka (Arai et al., 1983) were not found, however, a new outcrop was found at near the Mineokasengen (Fig. 17). The serpentine sandstones are composed mainly of fragments of mafic to ultramafic rocks and mudstone, and present grayish green and brown color. The serpentine sandstones at near Mineokasengen are massive and medium- to very coarse-grained, and those tectonic blocks in the sheared basalt are rounded and 10 to 15 cm in size. At Yohka Beach, the serpentine sandstone is composed of only one tectonic block which consists of sandstones and conglomerates. The size of this block is more than 9 meters. The conglomerates are unsorted and clast supported, and its clasts are angular and pebble to cobble in size. The clasts are composed of sandstone, siltstone, basalt, gabbro, serpentinite and limestone. The matrixes of conglomerate are coarse sandstone. The sandstones are greenish gray, medium- to very coarse-grained, parallel laminated or graded, and are sometimes intercalated with siltstone.

3-3-3. Leucocratic sandstone

The leucocratic sandstones also occur as tectonic blocks in the sheared serpentinite or basalt in the Mineoka Mountains. Those blocks are accompanied with serpentine sandstones and are distributed at Yohka Beach (Fig. 16), Mineokasengen (Fig. 17, Arai et al., 1983), Hegurinaka (Fig. 18; Arai et al., 1983) and Fukihara (Arai, 1981). The outcrop of the leucocratic sandstone at Fukihara (Arai, 1981), was not found in this study. These sandstones present gray to light green color, and are fine- to medium-grained. Most of them are massive, however some of them are parallel laminated. The tectonic blocks of leucocratic sandstones are 10 cm to 8 m in size.

3-4. Modal composition of sandstone and conglomerate

3-4-1. Mineoka area

The sampling localities and lithologies of the sandstone samples are shown in Appendix, and the selected micro photomicrographs of sandstones are shown in Plates 1 to 3. Twenty-four sandstones, comprising nine samples from the Mineoka Group, Futatsuyama Formation and Sakuma Group (three samples from each units), nine samples from the Hota Group, and six samples from the tectonic blocks, were measured based on both the Gazzi-Dickinson method and traditional method. The modal composition data from Mineoka area are listed in Tables 1 and 2, and are plotted on the diagrams in Figs 19 and 20. The data in Table 1 were calculated on the traditional method such as Okada (1971), while Table 2 is based on the Gazzi-Dickinson method (Ingersoll et al., 1984).

The sandstones of the Mineoka Group consists mainly of monocrystalline quartz, plagioclase and felsic volcanic fragment, and characteristically contain many polycrystalline quartz (Plates 1a and 1b). The sandstones of the Hota Group are subdivided into two types, namely the Fukawa Formation (Kawai, 1957) sandstone and the sandstone from the other Hota Group (= the other formation of the Hota Group). The Fukawa Formation sandstone is composed mainly of quartz, K-feldspar, plagioclase and felsic volcanic fragments (Plates 1c and 1d). These amounts of quartz, K-feldspar and granitic rocks differ from those of the sandstones from the other Hota Group. The sandstones of the other Hota Group consist mainly of volcaniclastic fragments, plagioclase and quartz (Plates 2a and 2b). There is a possibility that they can be subdivided into two groups in terms of an amount of mafic volcaniclastic fragments. The Sakuma Group sandstones characteristically contain sedimentary rock fragments such as mudstone fragments (Plates 2c and 2d). The other characteristics are similar to those of the Hota Group excluding the Fukawa Formation. Namely, they contain many volcaniclastic fragments, plagioclase and quartz. The leucocratic sandstones at Hegurinaka, Mineokasengen and Yohka Beach consist mainly of monocrystalline quartz, plagioclase, K-feldspar and felsic volcaniclastic (Plates 2e and 2f).

Table 1. Modal composition of sandstones in the Mineoka area based on traditional method (Okada, 1971).

Group	Formation	sample	MQz (%)	PQz	K-fel.	Pl.	Vf	Vi	Plut.	Se.	Ot	H.M.	S.M.	If & aut.	Mtx & Cem.	total	A. D. (mm)
Mineoka	Haccho	99082701	26.2	9.0	5.6	12.4	13.2	1.6	4.2	3.8	0.0	0.2	0.2	0.0	23.6	100.0	0.424
		00021201	33.0	9.0	0.0	25.6	11.4	0.2	1.4	6.2	0.0	0.6	0.0	0.0	12.6	100.0	0.134
		99122404	28.2	3.4	2.4	21.6	16.2	0.6	1.6	5.6	0.0	0.4	0.0	0.4	19.6	100.0	0.166
Hota	Fukawa	99072101	40.6	2.8	12.6	13.2	7.0	0.2	7.4	0.2	0.2	0.2	0.4	0.0	15.2	100.0	0.222
		00032508	29.2	2.4	11.8	32.8	8.0	0.0	5.2	0.4	0.2	1.4	0.0	0.0	8.6	100.0	0.175
		99072212	33.8	3.2	14.8	16.4	7.8	0.2	4.8	2.0	0.2	0.8	0.8	0.0	15.2	100.0	0.201
	Aokiyama	99122302	9.6	1.0	1.2	27.6	12.2	15.6	0.8	2.0	0.2	6.4	0.0	0.0	23.4	100.0	0.226
		99072111	20.4	4.8	3.2	9.2	25.6	0.6	0.6	2.2	0.0	0.2	0.6	0.2	32.4	100.0	0.148
		99072114	10.2	0.6	0.4	27.6	14.4	13.4	2.0	0.8	0.4	3.2	1.6	0.8	24.6	100.0	0.148
		99082801	14.0	2.6	2.0	19.4	12.6	18.4	4.0	1.6	0.2	4.8	0.0	0.2	20.2	100.0	0.329
		99072307	14.0	2.2	6.4	20.2	22.4	3.6	2.4	3.4	0.0	0.2	1.0	0.0	24.2	100.0	0.171
	Maejima	99122304	11.0	1.8	3.8	13.2	12.0	7.2	0.6	5.0	3.2	0.8	0.4	0.0	41.0	100.0	0.152
Sakuma	Okuyama	00021109	9.6	0.6	0.4	20.0	8.0	13.6	0.4	31.4	4.4	4.8	0.0	0.2	6.6	100.0	0.334
	Nakaobara	00082101	3.6	0.4	3.0	17.4	10.2	12.6	0.8	27.0	3.8	2.8	0.6	2.8	15.0	100.0	0.426
		00021206	16.6	2.2	3.0	17.4	25.8	1.0	1.0	7.6	0.0	0.4	0.4	0.0	24.6	100.0	0.155
	Futatsuyama	99082805	8.6	1.6	1.4	29.6	10.8	19.4	0.8	4.2	0.8	1.6	0.0	0.0	21.2	100.0	0.362
		99072112	16.6	1.0	5.4	21.0	13.2	7.6	5.4	3.8	3.6	1.0	0.4	0.0	21.0	100.0	0.446
		00040907	12.6	3.0	5.0	22.8	16.2	2.2	8.8	2.6	1.0	1.8	0.8	0.2	23.0	100.0	0.401
	Serpentine sandstone	99072206	0.2	0.0	0.0	1.0	0.0	27.0	6.2	0.8	48.0	5.0	0.6	0.6	10.6	100.0	0.472
		00081802	1.6	0.0	0.0	4.6	2.4	1.0	0.0	30.0	43.6	1.2	0.2	0.0	15.4	100.0	0.497
	Leucocratic sandstone	00081805	31.6	1.8	7.0	29.6	8.0	0.0	1.0	0.6	0.2	0.4	4.6	0.0	15.2	100.0	0.159
		00032512	40.2	1.0	4.2	25.8	3.2	0.0	0.0	0.4	0.0	1.6	2.4	0.0	21.2	100.0	0.076

MQz: monocrystalline quartz, PQz: polycrystalline quartz, K-fel.: K-feldspar, Pl.: plagioclase, Vf: felsic volcanics, Vi: intermediate to mafic volcanics, Plut.: plutonic rock fragment, Se.: sedimentary rock fragments (including chart), Ot: other rock fragments, H.M.: heavy minerals, S.M.: secondary minerals, If & aut.: intra-basinal fragment and authigenic minerals, Mtx & Cem.: matrix and cement, A.D.: average of grain diameter. The plutinic rock fragments of tectonic block at Mineokasengen are fragments of gabbro, and the other plutonic fragments are granitic rock fragment.

Table 2. Modal composition of sandstones in the Mineoka area based on Gazzi-Dickinson method (Ingersoll et al., 1984)

Group	Formation	sample	Qm (%)	Qp	K-fel.	Pl.	Lvf	Lvi	Ls	Ot	H.M.	S.M.	If & aut.	Mtx & Cem.	total	A. D. (mm)
Mineoka	Haccho	99082701	36.4	3.8	5.8	14.0	12.4	1.6	1.8	0.0	0.4	0.2	0.0	23.6	100.0	0.424
		00021201	37.8	6.6	0.0	26.6	11.4	0.2	4.2	0.0	0.6	0.0	0.0	12.6	100.0	0.134
		99122404	32.6	3.8	2.4	23.0	15.4	0.6	1.8	0.0	0.4	0.0	0.4	19.6	100.0	0.166
Hota	Fukawa	99072101	46.6	0.2	13.6	17.4	6.0	0.2	0.0	0.2	0.2	0.4	0.0	15.2	100.0	0.222
		00032508	33.4	0.4	12.2	35.8	7.8	0.0	0.2	0.2	1.4	0.0	0.0	8.6	100.0	0.175
		99072212	38.6	2.0	15.8	18.4	7.6	0.2	0.4	0.2	0.8	0.8	0.0	15.2	100.0	0.201
	Aokiyama	99122302	10.6	1.0	1.4	30.0	11.4	14.4	1.2	0.2	6.4	0.0	0.0	23.4	100.0	0.226
		99072111	24.0	3.4	3.2	10.0	24.6	0.6	0.8	0.0	0.2	0.6	0.2	32.4	100.0	0.148
		99072114	12.6	0.6	0.4	31.6	12.4	11.6	0.4	0.2	3.2	1.6	0.8	24.6	100.0	0.148
		99082801	18.4	1.8	2.0	23.8	10.6	17.2	0.8	0.2	4.8	0.0	0.2	20.2	100.0	0.329
		99072307	16.6	1.2	6.4	22.8	21.4	3.6	2.6	0.0	0.2	1.0	0.0	24.2	100.0	0.171
	Maejima	99122304	13.0	0.8	3.8	14.2	11.6	6.8	4.4	3.2	0.8	0.4	0.0	41	100.0	0.152
Sakuma	Okuyama	00021109	17.8	1.8	3.0	18.8	25.2	1.0	7.0	0.0	0.4	0.4	0.0	24.6	100.0	0.155
	Nakaobara	00082101	10.0	1.6	0.4	22.4	7.2	12.6	29.8	4.4	4.8	0.0	0.2	6.6	100.0	0.334
		00021206	4.4	1.6	3.2	18.4	9.6	12.2	25.6	3.8	2.8	0.6	2.8	15	100.0	0.426
	Futatsuyama	99082805	11.0	0.2	1.4	31.6	10.2	18.0	4.0	0.8	1.6	0.0	0.0	21.2	100.0	0.362
		99072112	18.6	2.0	8.0	24.8	11.0	7.2	2.4	3.6	1.0	0.4	0.0	21	100.0	0.446
		00040907	18.6	2.2	8.6	25.6	15.6	2.0	0.6	1.0	1.8	0.8	0.2	23	100.0	0.401
	Serpentine sandstone	99072206	0.2	0.0	0.0	3.2	0.0	26.2	0.8	47.8	6.0	0.6	0.6	10.6	96.0	0.472
		00081802	1.6	0.0	0.0	4.6	2.4	1.0	30.0	43.6	1.2	0.2	0.0	15.4	100.0	0.497
	Leucocratic sandstone	00081805	33.8	0.6	7.0	30.2	8.0	0.0	0.0	0.2	0.4	4.6	0.0	15.2	100.0	0.159
		00032512	40.4	1.0	4.2	25.8	3.2	0.0	0.2	0.0	1.6	2.4	0.0	21.2	100.0	0.076

Qm: monocrystalline quartz, Qp: polycrystalline quartz (including chart), Lvf: felsic volcanics, Lvi: intermediate to mafic volcanics, Ls: sedimentary lithics. The other symbols are same to those in Table 1.

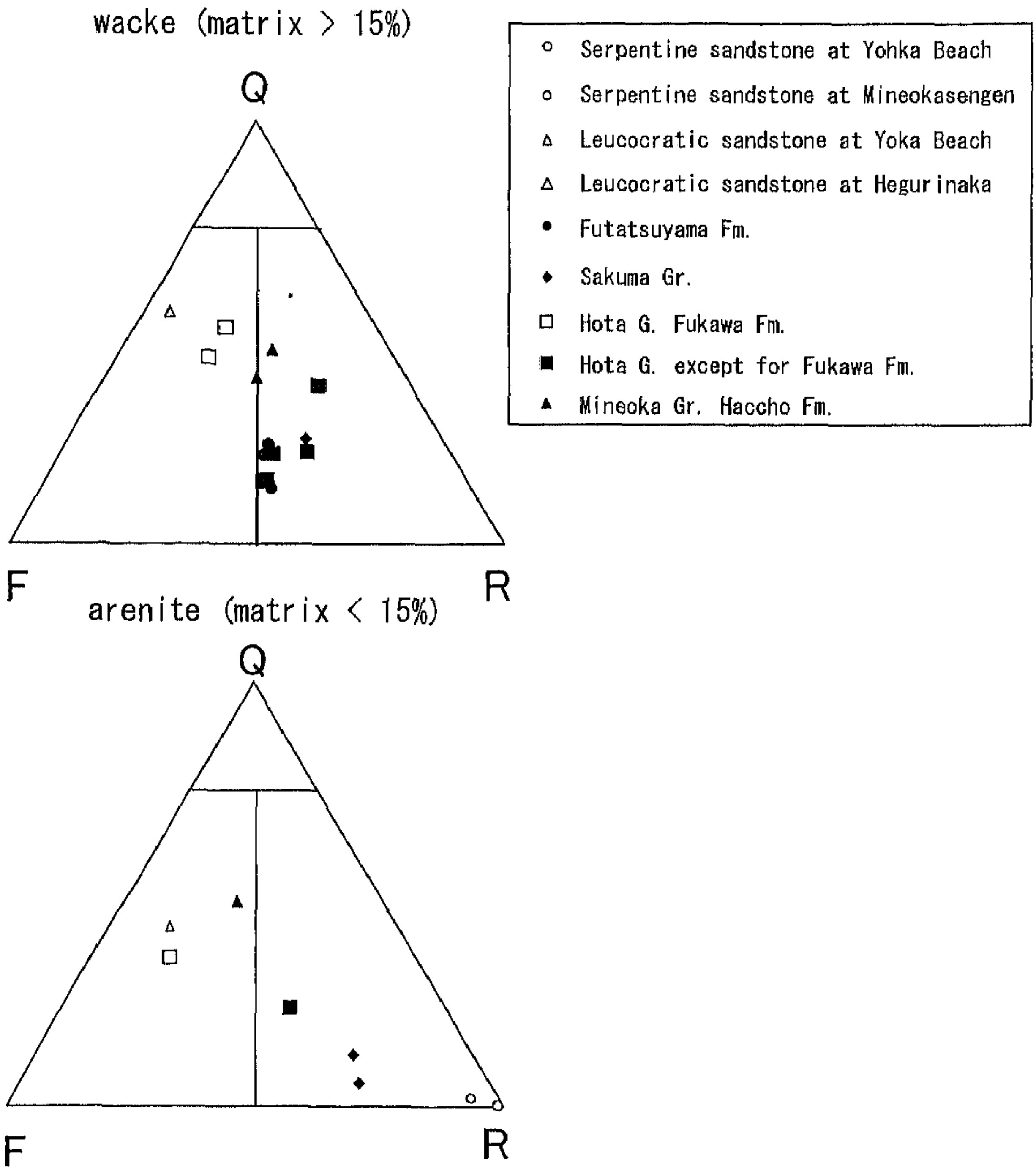


Fig. 19. Q-F-R diagrams of the sandstones in the Mineoka area. Data from Table1. The subdivision scheme is after Okada (1971). Q: total quartz (MQz+PQz), F: total feldspar, R: total rock fragments.

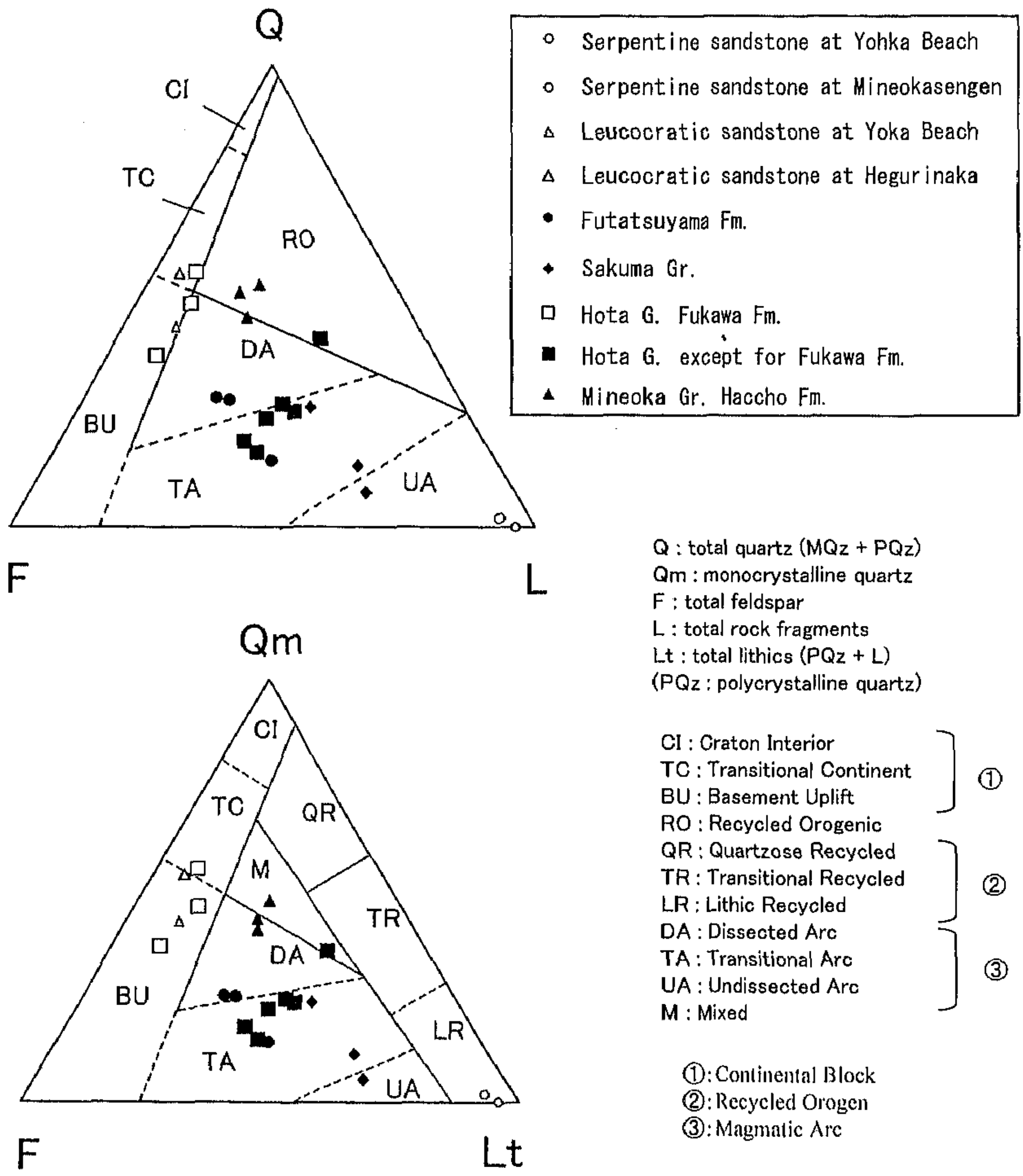


Fig. 20. Q·F·L and Qm·F·Lt diagrams of the sandstones in the Mineoka area based on the Gazzi-Dickinson method. Data from Table 2. The subdivision scheme is after Dickinson et al. (1983).

The sandstones of the Futatsuyama Formation consist mainly of plagioclase, volcaniclastic fragments and quartz with a minor amount of granitic rocks and K-feldspar (Plates 3a and 3b). The serpentine sandstones at Mineokasengen are composed mainly of mafic and ultramafic rock fragments, and contain a minor amount of quartz, feldspar and metamorphic rock fragments (Plates 3c and 3d). The serpentine sandstone at Yohka Beach consists mainly of mudstone fragments and ultramafic rock fragments (Plates 3e and 3f).

According to the Okada's scheme (1971), almost all the sandstones in the Mineoka area were plotted in lithic wacke or arenite fields, while the sandstones from the Fukawa Formation and leucocratic sandstones are plotted in feldspathic wacke or arenite field (Fig. 19).

The clast composition of one sample from the conglomerate intercalates in the shale of the Haccho Formation, Mineoka Group at Fusada was measured. The sampling locality is locality 1 shown in Fig 9. The whole volume of measured sample was 2240 cm^3. The clasts, whose longest axis is more than 1.2 cm, were extracted, and the total number of the clasts is 227. The clast composition is shown in Table 3 and Fig. 21. These clasts consist of fine-grained gabbro (including dolerite), basalt, gabbro, rhyolite (including dacite), serpentinite, tuff, andesite and metamorphic rocks with a small amount of granite, limestone and pure polycrystalline quartz. The gabbro and fine-grained gabbro characteristically contain hornblende like the gabbro occurring in the Mineoka Mountains at present. Some dolerites have ophitic texture. Most basalts are aphyric, while some contain porphyroclasts of plagioclase, and present black to green, and red. The rhyolites present light gray to light green, and some of them contain porphyroclasts of quartz, K-feldspar and plagioclase. The tuffs present greenish color, and are comparatively altered. The andesites contain porphyroclasts of plagioclase, and some of them are vesicular. Those vesicles are filled with secondary minerals. The metamorphic rocks have no schistosity, and seem to have been mafic rocks as a protolith. The granite is composed of quartz, K-feldspar, plagioclase, altered mafic minerals and opaque minerals.

Table 3. Clast composition of the conglomerate of the Haccho Formation at Fusada.

	number	(%)	mean of (a) axis	mean of (b) axis	mean of (c) axis	roundness
gabbro (including dolerite)	64	28.2	1.61	1.23	0.84	0.18
basalt	32	14.1	1.48	1.06	0.71	0.19
gabbro	30	13.2	1.70	1.26	0.90	0.17
rhyolite	27	11.9	1.51	1.19	0.86	0.15
serpentinite	25	11.0	1.44	1.04	0.74	0.14
tuff	20	8.8	1.64	1.21	0.87	0.25
andesite	16	7.0	1.71	1.18	0.84	0.19
metamorphic rocks	10	4.4	2.08	1.51	1.01	0.19
pure chart	1	0.4	1.31	1.19	0.64	0.20
granite	1	0.4	1.22	1.09	0.89	0.10
limestone	1	0.4	1.30	0.94	0.87	0.20
total	227	100.0	1.60	1.19	0.83	0.18

(a) axis is the longest axis of the clast. (b) axis is the intermediate axis of the clast. (c) axis is the short axis of the clast. . The longest and intermediate axes define the maximum projection area (plane) of a pebble; the intermediate and short axes define the minimum projection area of a pebble (Krumbein, 1939).

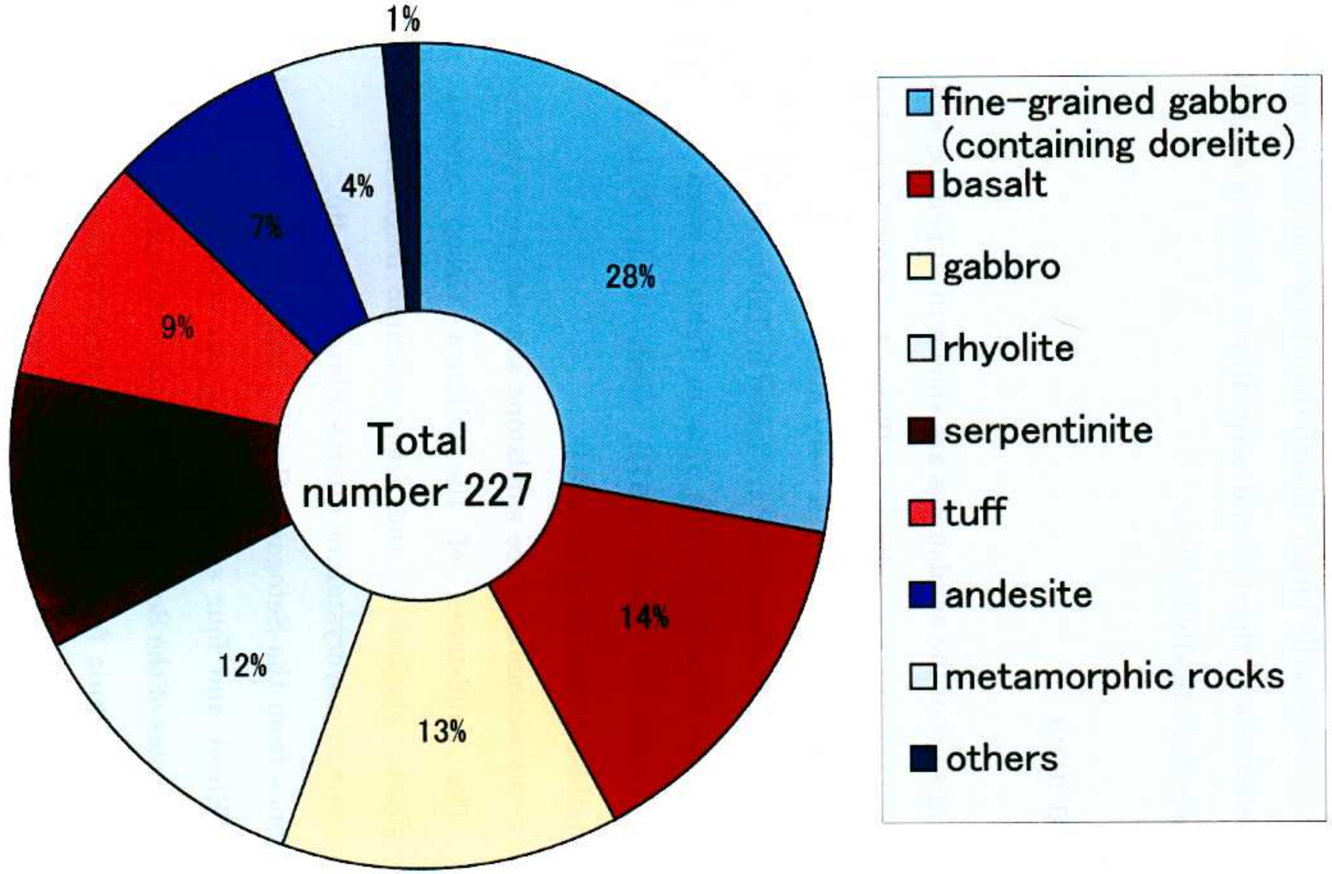


Fig. 21. The clasts composition of the conglomerate of the Haccho Formation at Fusada.
Sampling locality is shown in Fig.9.

The clasts of basalt and serpentinite are somewhat small, and the clasts of metamorphic rocks are especially larger though their total number is small (10 out of 227 clasts). The roundness of rhyolite and serpentinite clasts is slightly lower, and those of tuff are characteristically higher.

3-4-2. Setogawa area

The sampling sites of the sandstones are shown in Appendix, and the selected photomicrographs of sandstones are shown in Plates 4 and 5. The modal composition of 21 sandstones from the Setogawa area were measured in this study. The modal composition data from the Setogawa area are listed in Tables 4 and 5 and are plotted on the diagrams in Figs 22 and 23. The data in Table 4 were calculated on the traditional method such as Okada (1971), while Table 5 is based on the Gazzi-Dickinson method (Ingersoll et al., 1984).

The modal compositions of three sandstone samples were measured from the Mikura Group. The sandstones of the Mikura Group consist mainly of monocrystalline quartz, plagioclase and felsic volcanic fragments with a minor amount of K-feldspar and polycrystalline quartz (Plates 4and 4b).

Six sandstones from the Setogawa Group, comprising two samples from the Takayama Thrust Sheet and four samples from the Oigawa Thrust Sheet, were measured. The sandstones of the Setogawa Group are also composed mainly of quartz, plagioclase and felsic volcanic fragments with a minor amount of K-feldspar and polycrystalline quartz (Plates 4c and 4d). The proportion of these grains varies widely in each sample (Figs. 22 and 23), though no horizontal change of the sandstone composition was observed in this group.

The modal compositions of three sandstone samples from the Kurami Group were measured. The sandstones of the Kurami Group contain characteristically sedimentary rock fragments such as mudstone (Plates 4e and 4f). The other characteristics are similar to those of the sandstone from the Mikura and Setogawa

Table 4. Modal composition of sandstones in the Setogawa area based on traditional method (Okada, 1971).

Group	Formation	sample	MQz (%)	PQz	K-fel.	Pl.	Vf	Vi	Plut.	Se.	Ot	H.M.	S.M.	If & aut.	Mtx & Cem.	total	A. D. (mm)
Mikura		02122701	28.2	4.0	6.2	16.2	27.2	0.0	2.8	1.4	0.0	0.0	1.2	1.2	11.6	100.0	0.340
		02122705	23.2	3.6	1.6	13.0	25.6	0.0	1.4	0.2	0.2	1.0	0.4	1.0	28.8	100.0	0.204
		02122706	16.4	1.2	2.2	16.4	31.2	0.0	1.0	2.0	0.2	1.0	0.8	0.4	27.2	100.0	0.320
Setogawa	Takayama	02093005	33.4	3.4	7.6	17.0	14.6	0.0	3.0	0.0	0.0	0.4	0.8	0.0	19.8	100.0	0.251
		02093008	14.2	0.4	1.4	23.2	30.6	0.0	0.0	0.4	0.0	0.4	2.0	1.4	26.0	100.0	0.117
	Oigawa	02122603	20.6	1.8	2.0	14.0	27.8	0.0	0.4	0.8	0.0	0.4	1.0	0.0	31.2	100.0	0.137
		02122604	32.0	2.8	3.4	9.6	32.0	0.0	0.0	0.4	0.0	0.4	0.4	0.0	19.0	100.0	0.150
		02122606	36.0	4.0	6.6	14.8	11.6	0.0	1.4	0.0	0.0	2.6	1.2	0.0	21.8	100.0	0.197
		02122609	31.8	4.4	4.2	14.4	22.2	0.0	0.2	0.4	0.0	0.2	1.8	0.0	20.4	100.0	0.159
Kurami	Amakata	02122803	17.6	7.2	4.0	10.8	23.0	0.0	0.8	20.4	0.0	0.8	0.0	0.0	15.4	100.0	0.200
	Towata	02122807	11.0	2.2	5.0	12.0	20.8	0.8	0.0	10.2	0.0	1.2	0.0	0.0	36.8	100.0	0.103
	Todo	02122810	19.2	4.8	5.0	6.4	27.2	0.0	0.4	18.8	0.0	0.4	0.2	0.0	17.6	100.0	0.159
Koma	Kushigatayama	02102501	1.4	1.0	0.2	8.8	27.0	17.4	0.0	2.6	0.0	5.6	4.4	0.0	31.6	100.0	0.242
		02102503	9.0	1.0	2.8	22.8	29.6	4.0	0.8	5.8	0.0	0.0	0.0	9.2	15.0	100.0	0.537
		02102504	13.4	0.6	6.8	24.2	24.2	1.4	0.2	5.2	0.0	1.2	1.0	0.0	21.8	100.0	0.154
		02102506	16.0	1.6	0.4	17.0	13.4	0.6	0.0	13.4	0.0	0.6	0.2	0.0	36.8	100.0	0.147
	Momonoki	02102101	25.0	2.2	1.6	14.8	24.0	0.0	0.4	0.6	0.0	0.2	0.4	0.0	30.8	100.0	0.150
		02102207	29.8	5.6	5.2	11.6	25.0	0.6	0.6	4.0	0.0	0.2	0.2	0.0	17.2	100.0	0.147
		02102208	10.8	2.6	1.8	10.8	23.6	5.8	0.2	13.2	0.0	0.8	1.0	0.2	29.2	100.0	0.223
		02102303	13.4	6.8	4.4	6.6	39.4	0.2	0.6	14.0	0.0	0.4	0.4	0.2	13.6	100.0	0.328

The symbols are same to those in Table 1.

Table 5. Modal composition of sandstones in the Setogawa area based on Gazzi-Dickinson method (Ingersoll et al., 1984)

Group	Formation	sample	Qm (%)	Qp	K-fel.	Pl.	Lvf	Lvi	Ls	Ot	H.M.	S.M.	If & aut.	Mtx & Cem.	total	A. D. (mm)
Mikura		02122701	35.0	0.4	7.2	17.4	24.6	0.0	1.4	0.0	0.0	1.2	1.2	11.6	100.0	0.34
		02122705	28.4	0.0	1.6	13.8	24.6	0.0	0.2	0.2	1.0	0.4	1.0	28.8	100.0	0.204
		02122706	19.4	0.0	2.6	17.4	29.0	0.0	2.0	0.2	1.0	0.8	0.4	27.2	100.0	0.32
Setogawa	Takayama	02093005	38.0	0.0	8.6	18.6	13.8	0.0	0.0	0.0	0.4	0.8	0.0	19.8	100.0	0.251
		02093008	14.8	0.0	1.4	23.8	29.8	0.0	0.4	0.0	0.4	2.0	1.4	26	100.0	0.117
	Oigawa	02122603	22.6	0.6	2.0	15.0	26.6	0.0	0.6	0.0	0.4	1.0	0.0	31.2	100.0	0.137
		02122604	35.2	0.8	3.4	10.0	30.8	0.0	0.0	0.0	0.4	0.4	0.0	19	100.0	0.15
		02122606	41.2	0.0	7.0	15.4	10.8	0.0	0.0	0.0	2.6	1.2	0.0	21.8	100.0	0.197
		02122609	36.4	0.2	4.2	16.2	20.2	0.0	0.4	0.0	0.2	1.8	0.0	20.4	100.0	0.159
Kurami	Amakata	02122803	22.4	4.6	4.0	11.2	22.4	0.0	19.2	0.0	0.8	0.0	0.0	15.4	100.0	0.2
	Towata	02122807	11.6	2.2	5.0	12.0	20.8	0.8	9.6	0.0	1.2	0.0	0.0	36.8	100.0	0.103
	Todo	02122810	21.0	3.6	5.0	7.0	26.8	0.0	18.4	0.0	0.4	0.2	0.0	17.6	100.0	0.159
Koma	Kushigatayama	02102501	1.6	0.8	0.2	8.8	27.0	17.4	2.6	0.0	5.6	4.4	0.0	31.6	100.0	0.242
		02102503	9.6	0.6	2.8	25.2	27.8	4.0	5.8	0.0	0.0	0.0	9.2	15	100.0	0.537
		02102504	14.2	0.6	6.8	24.6	23.6	1.4	4.8	0.0	1.2	1.0	0.0	21.8	100.0	0.154
		02102506	17.6	0.4	0.4	17.2	13.2	0.6	13.0	0.0	0.6	0.2	0.0	36.8	100.0	0.147
	Momonoki	02102101	27.6	0.0	1.6	15.4	23.4	0.0	0.6	0.0	0.2	0.4	0.0	30.8	100.0	0.15
		02102207	36.6	0.2	5.2	12.4	23.6	0.6	3.8	0.0	0.2	0.2	0.0	17.2	100.0	0.147
		02102208	13.8	0.2	1.8	12.6	21.4	5.8	13.2	0.0	0.8	1.0	0.2	29.2	100.0	0.223
		02102303	19.4	5.8	4.8	9.4	35.8	0.2	10.0	0.0	0.4	0.4	0.2	13.6	100.0	0.328

The symbols are same to those in Table 2.

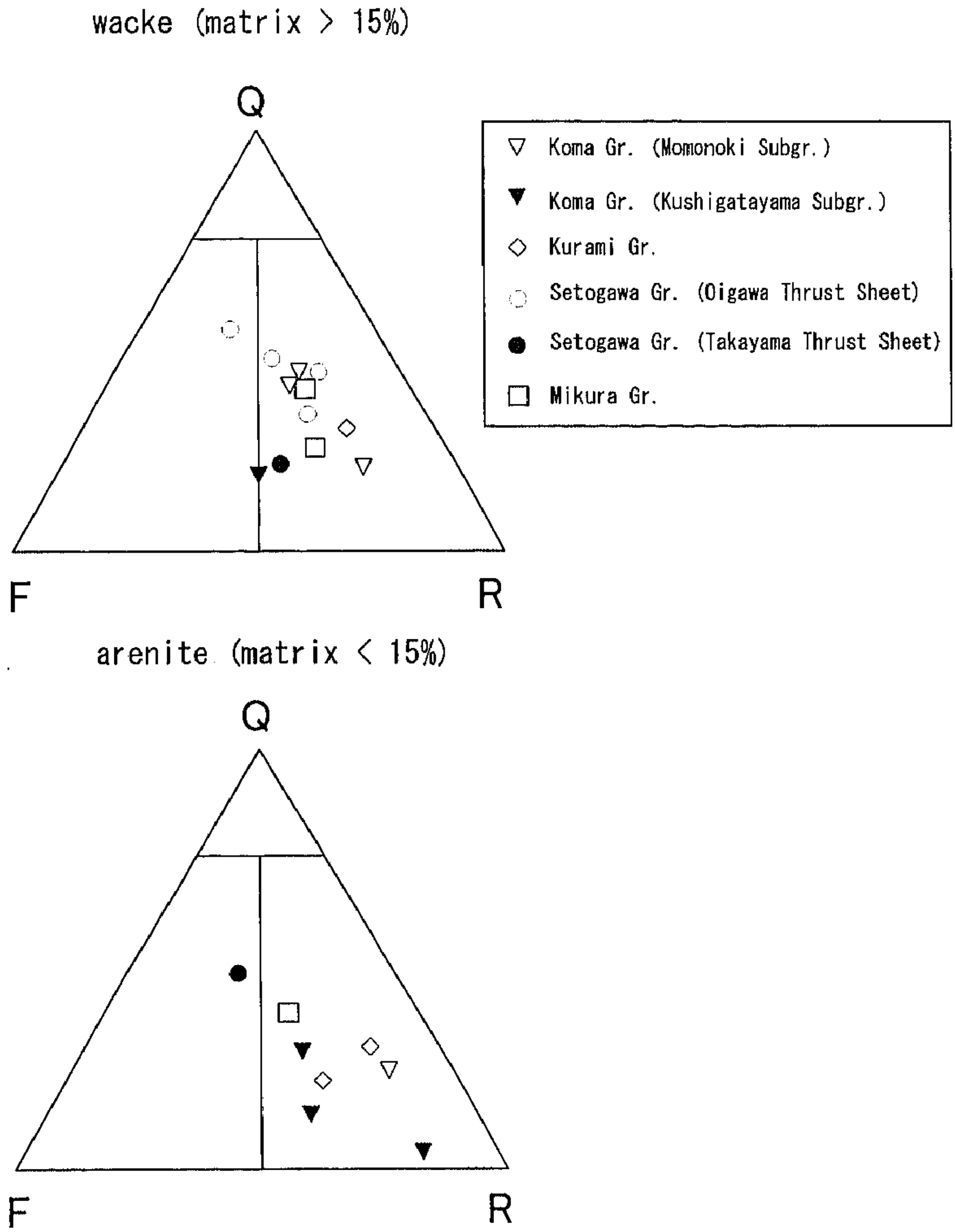


Fig. 22. Q·F·R diagrams of the sandstones in the Setogawa area. Data from Table 3. The subdivision scheme is after Okada (1971). Q: total quartz (MQz+PQz), F: total feldspar, R: total rock fragments.

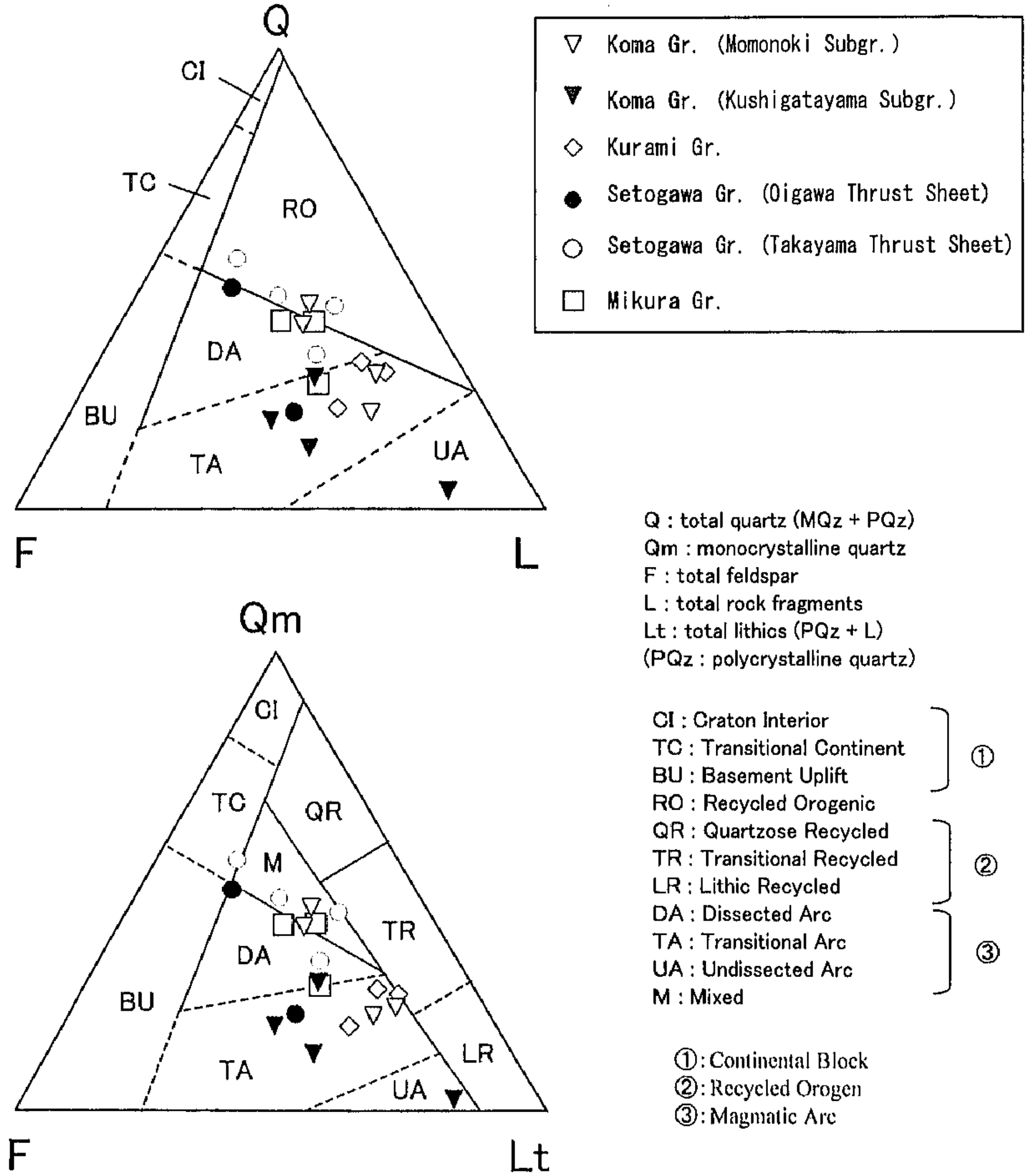


Fig. 23. Q-F-L and Qm-F-Lt diagrams of the sandstones in the Setogawa area based on the Gazzi-Dickinson method.Data from Table 5. The subdivision scheme is after Dickinson et al. (1983).

Groups.

Eight sandstones from the Koma Group, comprising four samples collected respectively from the upper part of the Kushigatayama and Momonoki Subgroups, were measured. The composition of sandstones from both the Kushigatayama and Momonoki Subgroups shows horizontal changes. The sandstone from the lower part of the upper Kushigatayama Subgroup comprises mainly of felsic to mafic volcanic fragments and plagioclase (Plates 5a and 5b). However, the sandstones from the uppermost part of the Kushigatayama Subgroup consist mainly of plagioclase, felsic volcanic fragments and quartz (Plates 5c and 5d), and these characteristics are similar to those of the Mikura and Setogawa Groups. The sandstones from the lower part of the Momonoki Subgroup are composed mainly of quartz, felsic volcanic fragments and plagioclase with a minor amount of K-feldspar and polycrystalline quartz (Plates 5e and 5f), and these characteristics are also similar to those of the sandstones from the Mikura and Setogawa Groups. The sandstones from the upper part of the Momonoki Subgroup consist mainly of felsic volcanic fragments, plagioclase, quartz and mudstone fragment, and these characteristics are similar to those of the Kurami Group sandstone.

According to the Okada's scheme (1971), most of the sandstones in the Setogawa area were plotted in lithic wacke and arenite fields, while two sandstones from the Setogawa Group are plotted in feldspathic wacke and arenite fields (Fig. 22).

3-5. Detrital chromian spinel

3-5-1. Occurrence and petrographic description

The occurrence of detrital chromian spinel is very important to consider the timing of subaerilal and/or suboceanic exposure of ophiolitic rocks; therefore the occurrences of detrital chromian spinels from the Setogawa-Mineoka area are described herein.

Mineoka area

In this study, detrital chromian spinels were obtained from the sandstone and conglomerate from the Mineoka, Hota and Sakuma Groups and tectonic blocks of serpentine sandstone and leucocratic sandstone. Table 6 shows the number of detrital chromian spinels per one usual thin-section and per 1 gram of original sandstone sample. Numerous detrital chromian spinels are found in usual thin-sections of the conglomerate intercalated in the shale of the Haccho Formation, Mineoka Group and serpentine sandstones at Yohka Beach and Mineokasengen (Table 6), which also contain numerous fragments of serpentinite. The other chromian spinels were mainly collected with heavy liquid separation from sandstones of other formations. It should be noticed that detrital chromian spinel has not been found from the sandstone of the Takazuru Formation defined by Saito (1992), but from the Fukawa Formation defined by Kawai (1957).

The detrital chromian spinel grains obtained from the Mineoka, Hota and Sakuma Group sandstones present reddish brown to black (Plates 6a to 6d). The detrital chromian spinels from the serpentine sandstone at Yohka Beach present yellowish brown to black (Plate 6e). The detrital chromian spinels from the serpentine sandstone at Mineokasengen are brownish yellow to dark reddish brown (Plate 6f).

The spinel grains in sandstones, which yield many chromian spinels from usual thin-section, are generally angular to subrounded, and their diameters vary with the grain size of sandstone. The detrital chromian spinel, which has the maximum diameter among the detrital chromian spinels found in this study, is obtained from the conglomerate intercalated in the shale of the Haccho Formation, and its diameter is 0.6 mm (Plate 6b). The detrital chromian spinels in these conglomerates sometimes concentrate along a lamination. The tendency of diameter or roundness of the detrital chromian spinels obtained with heavy liquid separation is

Table 6. Frequency of occurrence of detrital chromian spinels in the Mineoka area.

group / tectonic block	formation / area	sample no.	usual thin sections (number / one thin section)	original sample* (number /1g)
Serpentine sandstone	Yoka Beach	00081802	40	—
		00081803	3	—
	Mineokasengen	99072206	28	—
		00081811	62	—
Leucocratic sandstone	Yohka Beach	00081806	0	0.54
	Mineokasengen	00081817	—	1.27
	Hegurinaka	00051303	1	1.09
Sakuma Gr.	Nakaobara Fm.	00040902	0	0.16
	Okuyama Fm.	00080702	1	0.56
Hota Gr.	Kanigawa Fm.	02092301	0	1.38
	Fukawa Fm.	99072212	0	0.23
		00040908	0	0.77
	Aokiyama Fm.	99072114	0	0.25
	Maejima Fm.	99122601	0	0.04
Mineoka Gr. (sandstone)	Haccho Fm.	00021202	2	1.03
		00121002	—	2.19
		01042101	—	1.28
Mineoka Gr. (conglomerate)	Haccho Fm. (Fusada)	99122403	109	—
	Haccho Fm. (Motona)	00051407	44	—

* The number of detrital chromian spinels per 1 gram of original sandstone samples is calculated based on the number of spinels in mounted thin sections and lost weight at each step of heavy liquid separation such as panning.

ambiguous. That is because many grains might be crushed before the heavy liquid separation.

Chromian spinels in a basaltic clast from the Sakuma Group were also analyzed for the comparison with other detrital chromian spinels. This clast is especially large (longest axis from appearance is 1.7m) compared with the other clasts. Chromian spinels occur as inclusions in the serpentinized phenocryst. These chromian spinels are black and idiomorphic.

Setogawa area

Detrital chromian spinels were obtained from the sandstones of all the groups investigated in this study. Only the sandstones of the lower part of the upper Kushigatayama Subgroup are barren of the detrital chromian spinel. Table 7 shows the number of detrital chromian spinels per one usual thin-section and per 1 gram of original sandstone sample. Numerous detrital chromian spinels were found in usual thin-sections of conglomerate beds of the Odake Thrust Sheet of the Setogawa Group and conglomerate blocks in the shale of the upper part of the upper Kushigatayama Subgroup. The detrital chromian spinels obtained from the other sandstones in the Setogawa area were collected using heavy liquid separation.

Detrital chromian spinel grains obtained from the Mikura and Kurami Groups and most of the Setogawa Group present reddish brown to black (Plates 6g to 6l). The detrital chromian spinel grains from the sandstone of the Odake Thrust Sheet of the Setogawa Group and the Koma Group present yellowish brown to black (Plates 6i and 7a to 7c).

The spinel grains from the conglomerate beds of the Odake Thrust Sheet and conglomerate blocks of the upper Kushigatayama Subgroup are generally angular to subrounded, and their diameters are 0.03 to 0.33 mm and 0.03 to 0.48 mm, respectively.

Table 7. Frequency of occurrence of detrital chromian spinels in the Setogawa area.

group	formation	sample no.	usual thin sections (number / one thin section)	original sample* (number /1g)
Koma Gr.	Momonoki Subgr.	02102101	1	0.63
		02102303	0	0.18
	Kushigatayama Subgr.	02122504	0	1.21
		02122509	46	—
Kurami Gr.	Amakata Ss.	02122803	3	1.00
	Todo Alt. Ss. and Cs.	02122810	0	0.75
Setogawa Gr.	Oigawa Thrust Sheet	02071601	1	0.64
		02122603	0	1.52
		02122605	1	0.44
		02122608	0	0.48
	Takayama Thrust Sheet	02092604	0	0.72
		02093005	0	0.30
		02093008	1	0.14
	Odake Thrust Sheet	03081201	0	1.07
		02061401	30	—
Mikura Gr.		02082401	0	0.50
		02092902	0	0.17
		02122701	0	0.71

* The number of detrital chromian spinels per 1 gram of original sandstone samples is calculated based on the number of spinels in mounted thin sections and lost weight at each step of heavy liquid separation such as panning.

3-5-2. Chemical compositions

A total of 1,097 chemical analyses of detrital chromian spinels were obtained from the Mineoka and Setogawa areas in this study. The tendencies of chemical compositions of detrital chromian spinels vary with each formation or block. Figs. 24 to 33 show the chemical compositions of spinels from each formation or block.

Mineoka area

178 chemical analyses of chemical compositions of detrital chromian spinels were obtained from sandstones of the Haccho Formation. The composition varies widely without a strong concentration. Cr# range is 0.33 to 0.92. Mg# is 0.36 to 0.76, and that of one grain is exceptionally 0.24 (Fig. 24). Fe^{3+}3# (= $Fe^{3+}/(Fe^{3+}+Cr+Al)$) range is 0.00 to 0.18, mostly below 0.12. TiO_2 wt% range is mostly 0.00 to 0.50, and 14 out of 178 grains have TiO_2 wt%>1.0. These six grains are reddish brown to black, like the other detrital spinels from the Mineoka Group. One grain has a high ZnO content of 1.65 wt%.

154 chemical analyses of detrital chromian spinel were obtained from the conglomerate intercalated in the shale of the Haccho Formation at Fusada and Motona. The ranges of those spinels from the conglomerates at Fusada and Motona are similar to each other (Fig. 25). Cr# range is mostly 0.31 to 0.90. Mg# range is 0.16 to 0.78, and concentrates in the range 0.35 to 0.7. Fe^{3+}3# range is mostly 0.00 to 0.17. TiO_2 wt% range is 0.02 to 0.66.

73 chemical analyses of detrital chromian spinels were obtained from the Hota Group. As shown in Table 6, the sandstones of the Fukawa and Kanigawa Formations yield more detrital chromian spinels than those of the other formations of the Hota Group. 16 and 51 chemical analyses were obtained from the Fukawa and Kanigawa Formations, respectively, while six chemical analyses were obtained from the other formations of the Hota Group. The plots of the chromian spinels from these

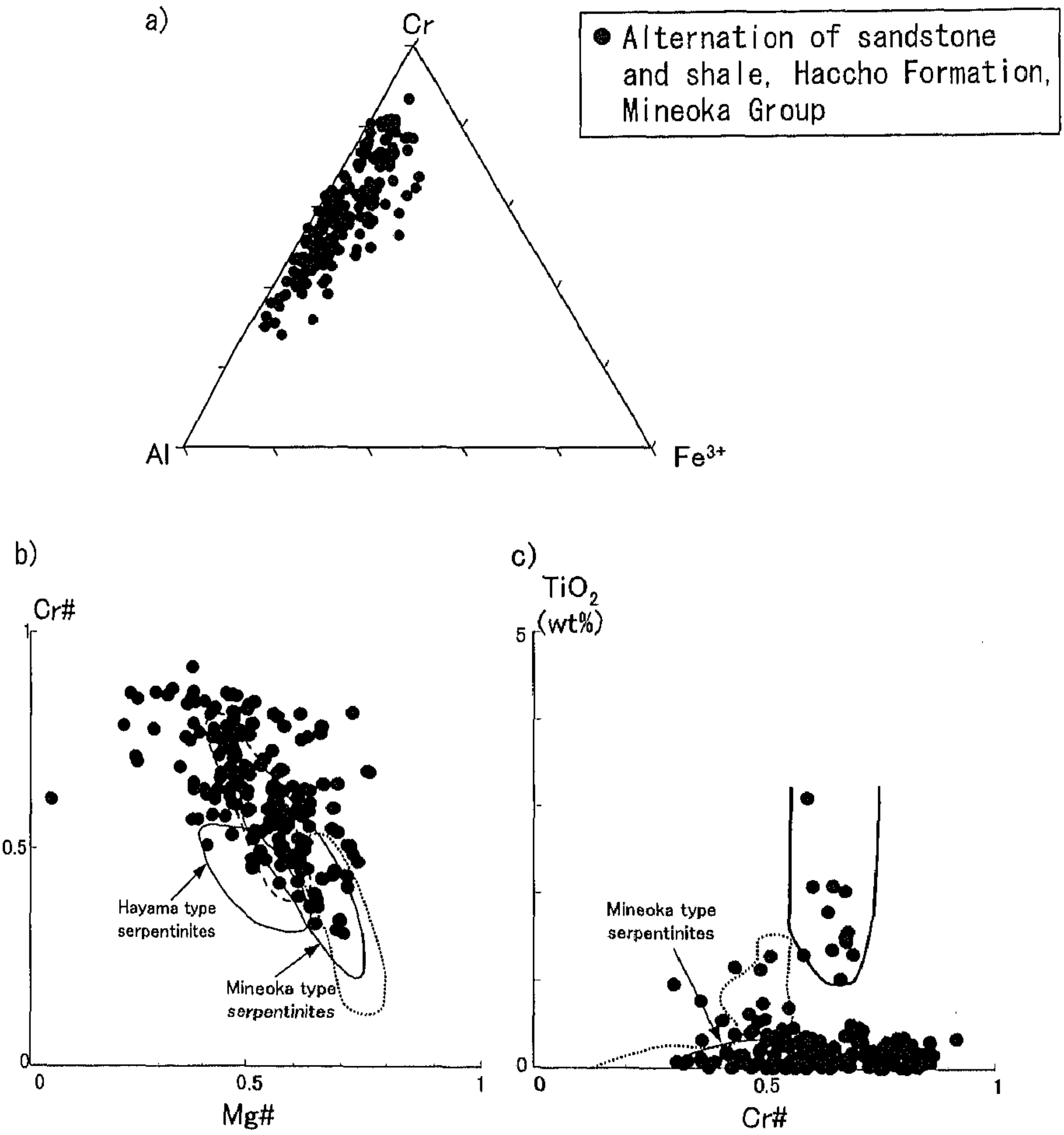


Fig. 24. Chemical compositions of detrital chromian spinels from sandstones of the Haccho Formation of the Mineoka Group. a) Cr-Al-Fe^{3+} diagram, b) Mg# vs. Cr# diagram, c) Cr# vs. TiO_2 diagram. The range of the serpentinites in the Circum-Izu Massif serpentine belt is surrounded by thin lines (Arai et al., 1990). The range of the alkaline and picrite basalts in the Circum-Izu Massif serpentine belt is surrounded by a thick line (compiled after Tazaki, 1975; Tazaki and Inomata, 1980; Ishida et al., 1988; 1990; Taniguchi and Ogawa, 1990). The range of the abyssal peridotites is surrounded by dotted lines (Dick and Bullen, 1984). The range of the forearc peridotites is surrounded by a broken line (Ishii et al., 1992).

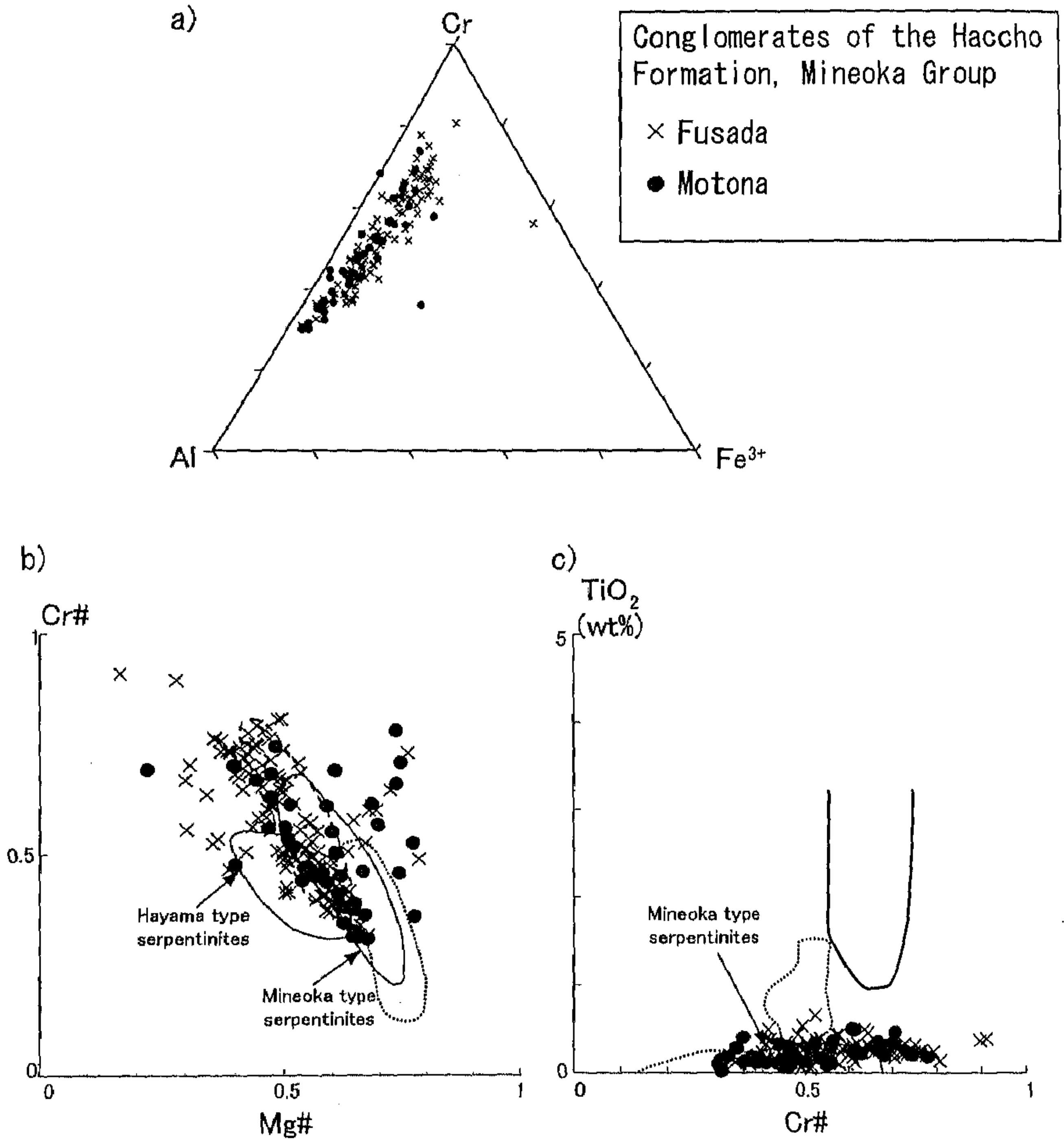


Fig. 25. Chemical compositions of detrital chromian spinels from conglomerates of the Haccho Formation of the Mineoka Group. a) Cr-Al-Fe^{3+} diagram, b) Mg# vs. Cr# diagram, c) Cr# vs. TiO_2 diagram. The range of the serpentinites in the Circum-Izu Massif serpentine belt is surrounded by thin lines (Arai et al., 1990). The range of the alkaline and picrite basalts in the Circum-Izu Massif serpentine belt is surrounded by a thick line (compiled after Tazaki, 1975; Tazaki and Inomata, 1980; Ishida et al., 1988, 1990; Taniguchi and Ogawa, 1990). The range of the abyssal peridotites is surrounded by dotted lines (Dick and Bullen, 1984). The range of the forearc peridotites is surrounded by a broken line (Ishii et al., 1992).

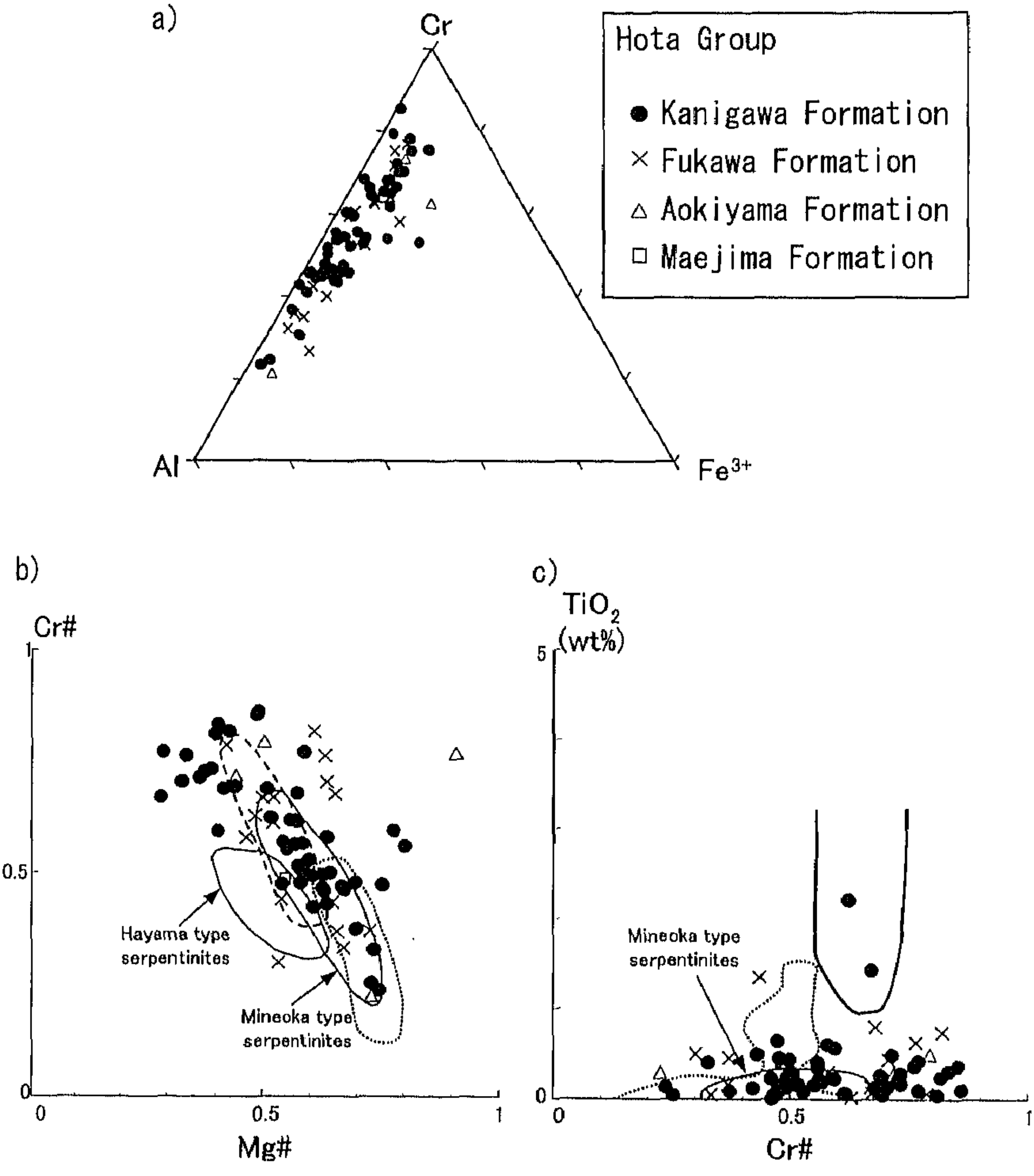


Fig. 26. Chemical compositions of detrital chromian spinels from the Hota Group. a) Cr-Al-Fe^{3+} diagram, b) Mg# vs. Cr# diagram, c) Cr# vs. TiO_2 diagram. The range of the serpentinites in the Circum-Izu Massif serpentine belt is surrounded by thin lines (Arai et al., 1990). The range of the alkaline and picrite basalts in the Circum-Izu Massif serpentine belt is surrounded by a thick line (compiled after Tazaki, 1975; Tazaki and Inomata, 1980; Ishida et al., 1988, 1990; Taniguchi and Ogawa, 1990). The range of the abyssal peridotites is surrounded by dotted lines (Dick and Bullen, 1984). The range of the forearc peridotites is surrounded by a broken line (Ishii et al., 1992).

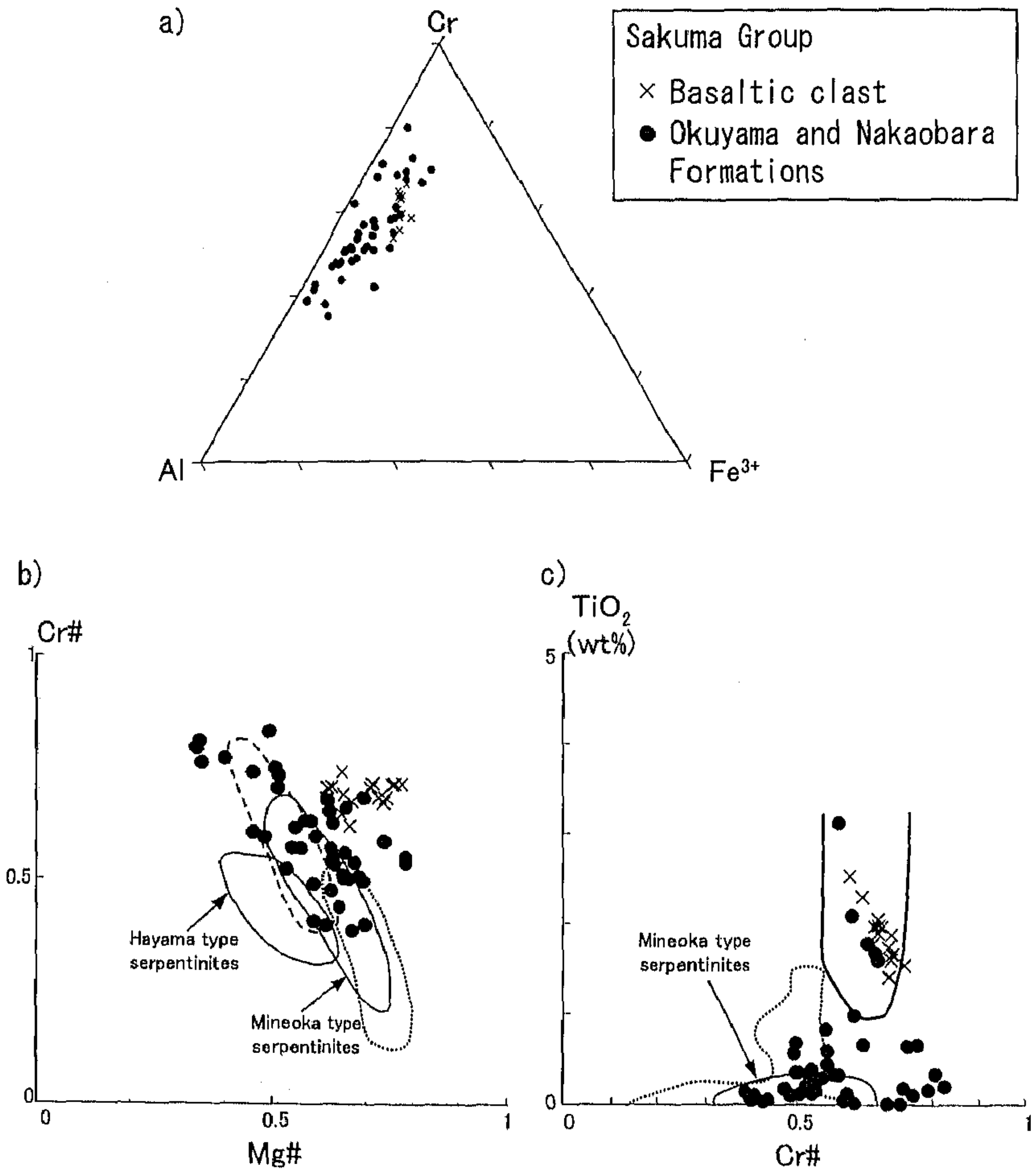


Fig. 27. Chemical compositions of detrital chromian spinels from the Sakuma Group. a) Cr-Al-Fe^{3+} diagram, b) Mg# vs. Cr# diagram, c) Cr# vs. TiO_2 diagram. The range of the serpentinites in the Circum-Izu Massif serpentine belt is surrounded by thin lines (Arai et al., 1990). The range of the alkaline and picrite basalts in the Circum-Izu Massif serpentine belt is surrounded by a thick line (compiled after Tazaki, 1975; Tazaki and Inomata, 1980; Ishida et al., 1988, 1990; Taniguchi and Ogawa, 1990). The range of the abyssal peridotites is surrounded by dotted lines (Dick and Bullen, 1984). The range of the forearc peridotites is surrounded by a broken line (Ishii et al., 1992).

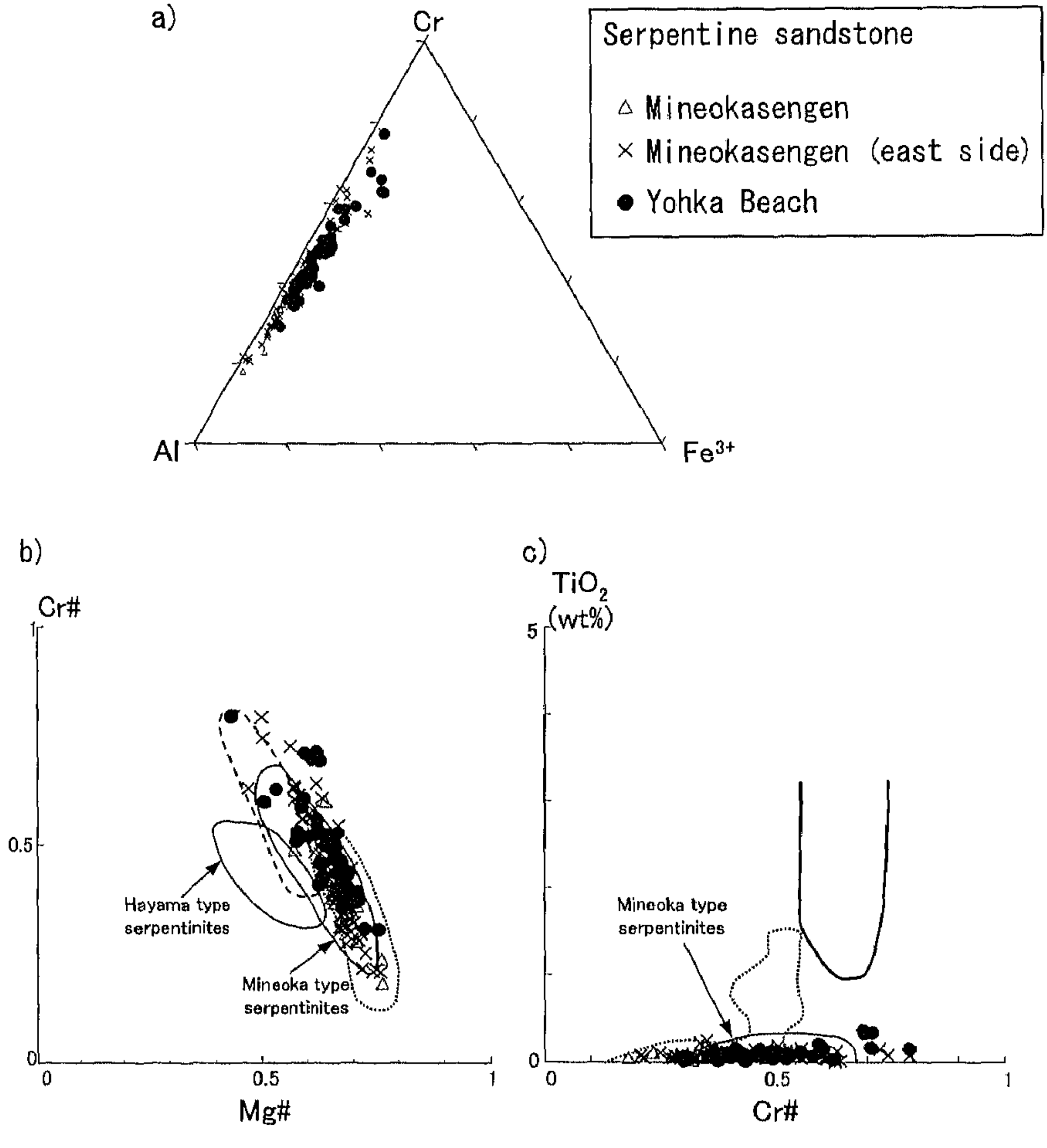


Fig. 28. Chemical compositions of detrital chromian spinels from the serpentine sandstone. a) Cr-Al-Fe^{3+} diagram, b) Mg# vs. Cr# diagram, c) Cr# vs. TiO_2 diagram. The range of the serpentinites in the Circum-Izu Massif serpentine belt is surrounded by thin lines (Arai et al., 1990). The range of the alkaline and picrite basalts in the Circum-Izu Massif serpentine belt is surrounded by a thick line (compiled after Tazaki, 1975; Tazaki and Inomata, 1980; Ishida et al., 1988, 1990; Taniguchi and Ogawa, 1990). The range of the abyssal peridotites is surrounded by dotted lines (Dick and Bullen, 1984). The range of the forearc peridotites is surrounded by a broken line (Ishii et al., 1992).

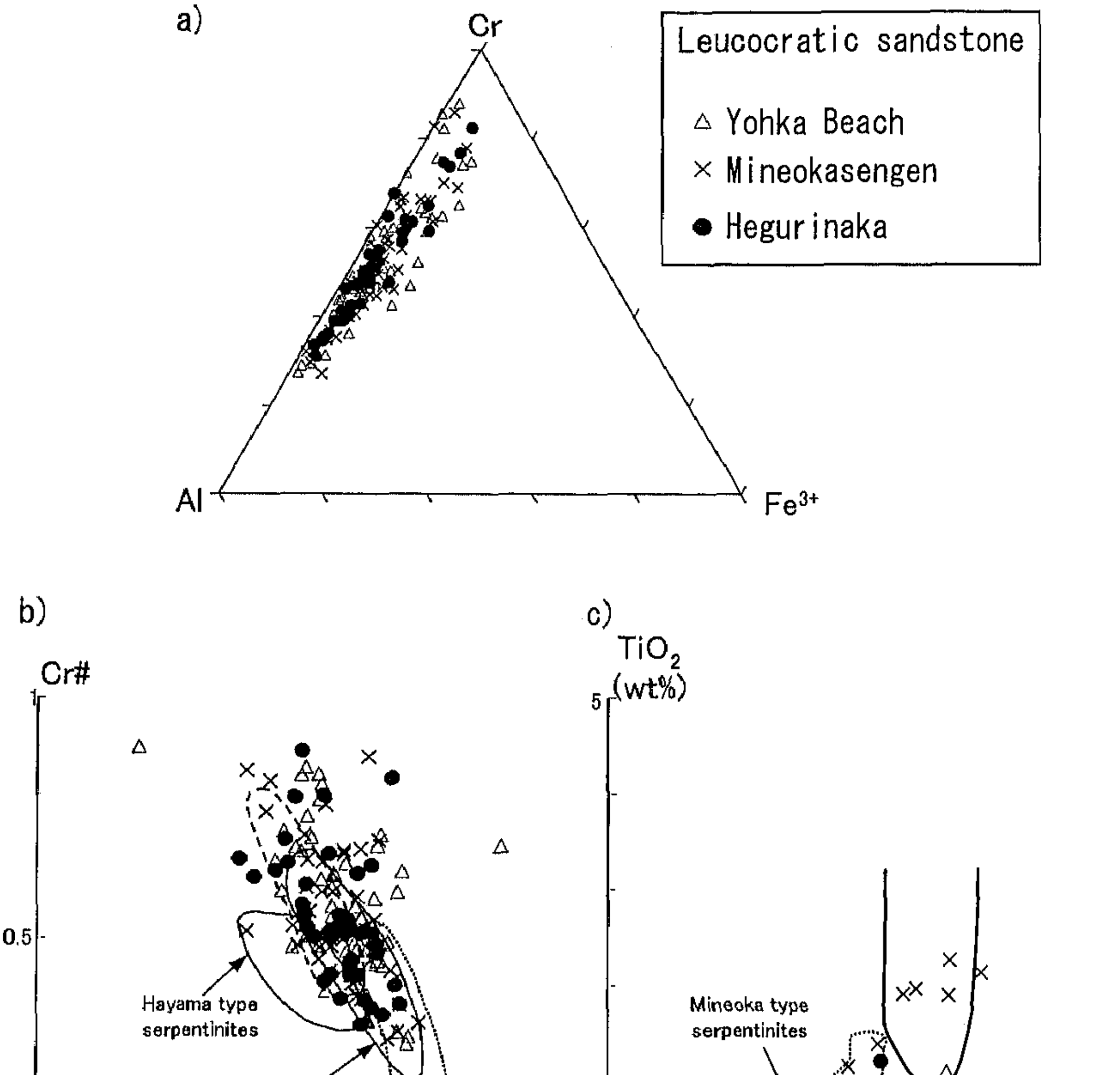


Fig. 29. Chemical compositions of detrital chromian spinels from the leucocratic sandstone. a) Cr-Al-Fe^{3+} diagram, b) Mg# vs. Cr# diagram, c) Cr# vs. TiO_2 diagram. The range of the serpentinites in the Circum-Izu Massif serpentine belt is surrounded by thin lines (Arai et al., 1990). The range of the alkaline and picritic basalts in the Circum-Izu Massif serpentine belt is surrounded by a thick line (compiled after Tazaki, 1975; Tazaki and Inomata, 1980; Ishida et al., 1988, 1990; Taniguchi and Ogawa, 1990). The range of the abyssal peridotites is surrounded by dotted lines (Dick and Bullen, 1984). The range of the forearc peridotites is surrounded by a broken line (Ishii et al., 1992).

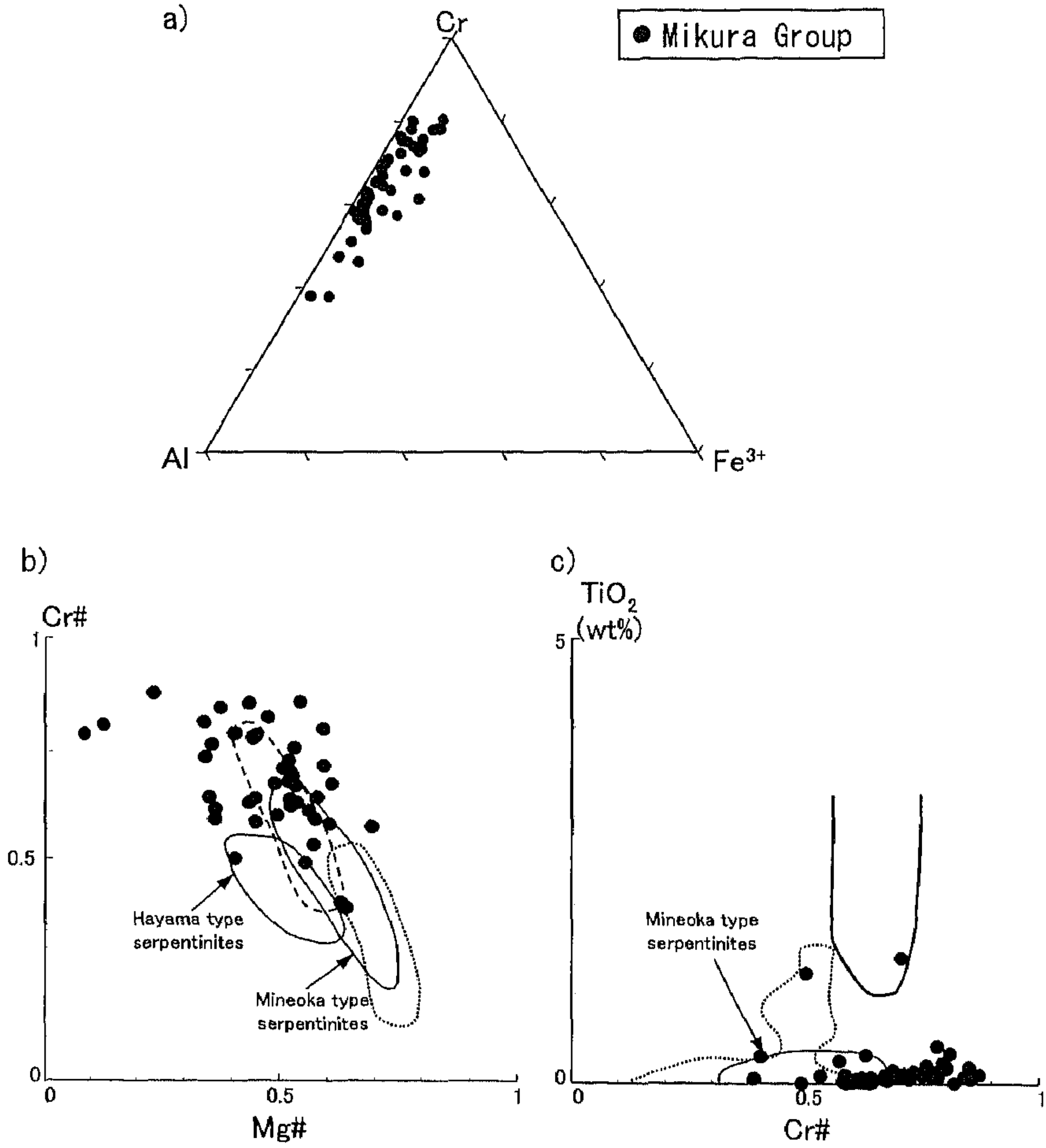


Fig. 30. Chemical compositions of detrital chromian spinels from the Mikura Group. a) Cr-Al-Fe^{3+} diagram, b) Mg# vs. Cr# diagram, c) Cr# vs. TiO_2 diagram. The range of the serpentinites in the Circum-Izu Massif serpentine belt is surrounded by thin lines (Arai et al., 1990). The range of the alkaline and picrite basalts in the Circum-Izu Massif serpentine belt is surrounded by a thick line (compiled after Tazaki, 1975, Tazaki and Inomata, 1980, Ishida et al., 1988, 1990; Taniguchi and Ogawa, 1990). The range of the abyssal peridotites is surrounded by dotted lines (Dick and Bullen, 1984), and The range of the forearc peridotites is surrounded by a broken line (Ishii et al., 1992).

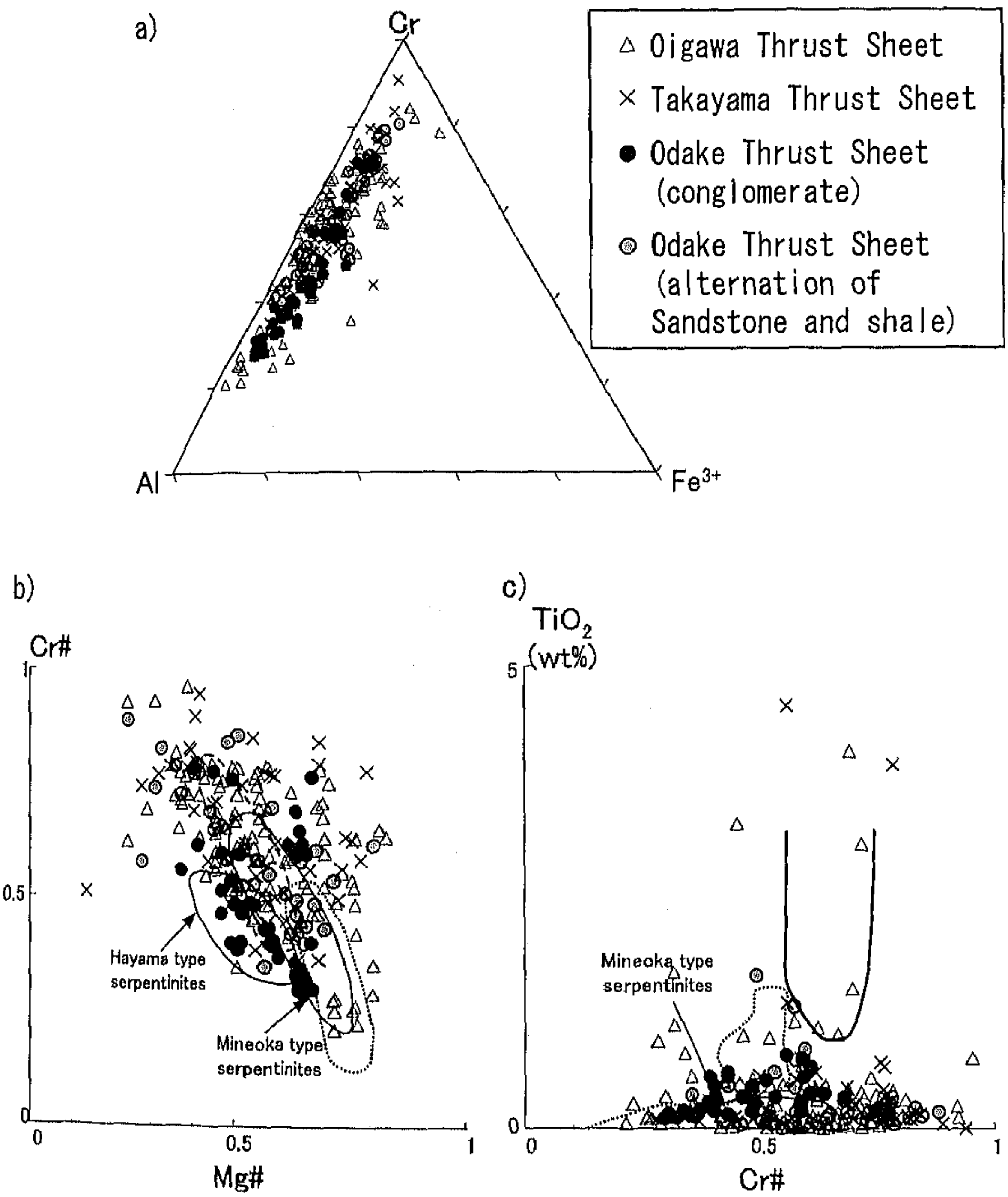


Fig. 31. Chemical compositions of detrital chromian spinels from the Setogawa Group. a) Cr-Al-Fe^{3+} diagram, b) Mg# vs. Cr# diagram, c) Cr# vs. TiO_2 diagram. The range of the serpentinites in the Circum-Izu Massif serpentine belt is surrounded by thin lines (Arai et al., 1990). The range of the alkaline and picrite basalts in the Circum-Izu Massif serpentine belt is surrounded by a thick line (compiled after Tazaki, 1975; Tazaki and Inomata, 1980; Ishida et al., 1988, 1990; Taniguchi and Ogawa, 1990). The range of the abyssal peridotites is surrounded by dotted lines (Dick and Bullen, 1984). The range of the forearc peridotites is surrounded by a broken line (Ishii et al., 1992).

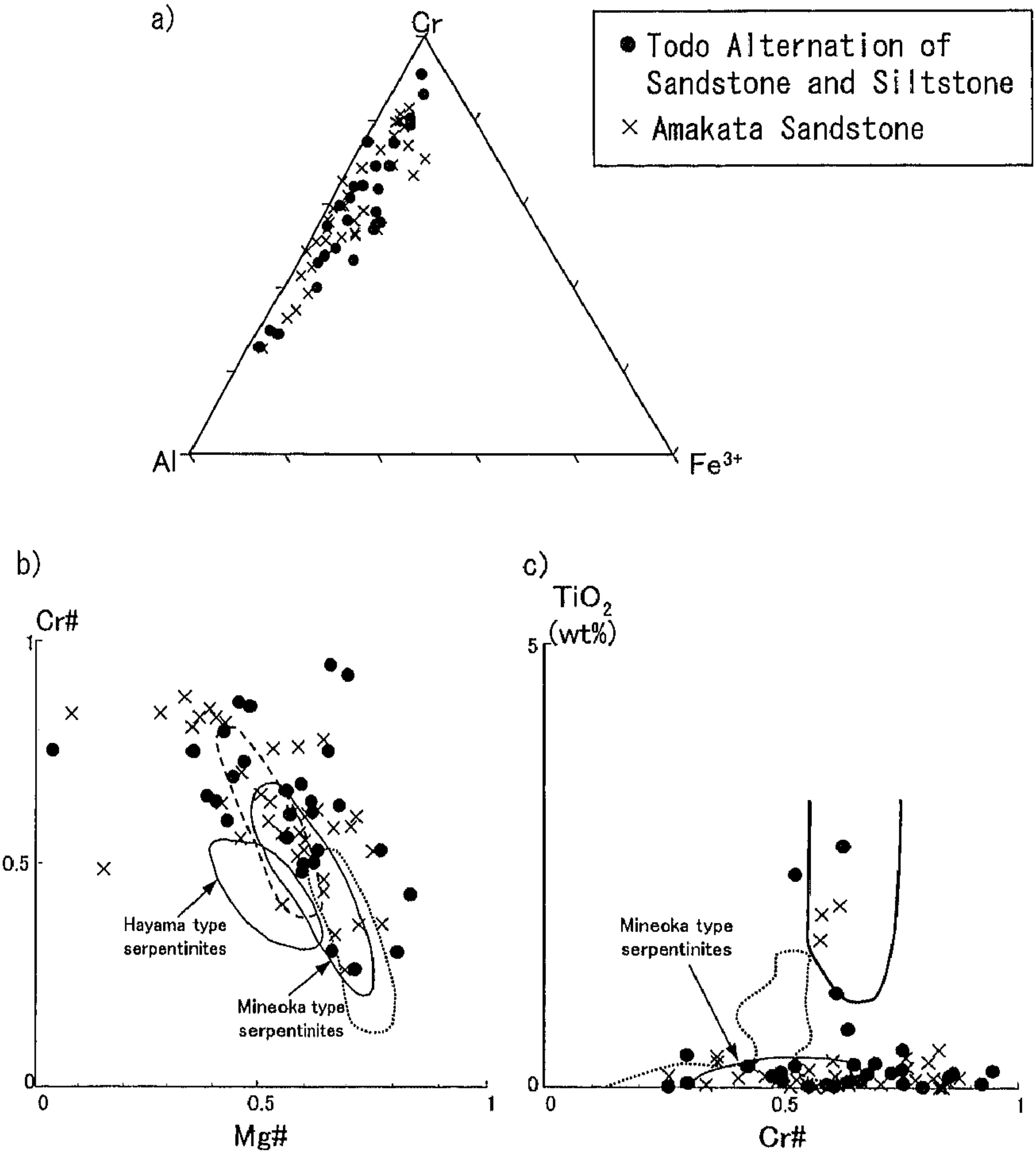


Fig. 32. Chemical compositions of detrital chromian spinels from the Kurami Group. a) Cr-Al-Fe^{3+} diagram, b) Mg# vs. Cr# diagram, c) Cr# vs. TiO_2 diagram. The range of the serpentinites in the Circum-Izu Massif serpentine belt is surrounded by thin lines (Arai et al., 1990). The range of the alkaline and picrite basalts in the Circum-Izu Massif serpentine belt is surrounded by a thick line (compiled after Tazaki, 1975; Tazaki and Inomata, 1980; Ishida et al., 1988, 1990; Taniguchi and Ogawa, 1990). The range of the abyssal peridotites is surrounded by dotted lines (Dick and Bullen, 1984). The range of the forearc peridotites is surrounded by a broken line (Ishii et al., 1992).

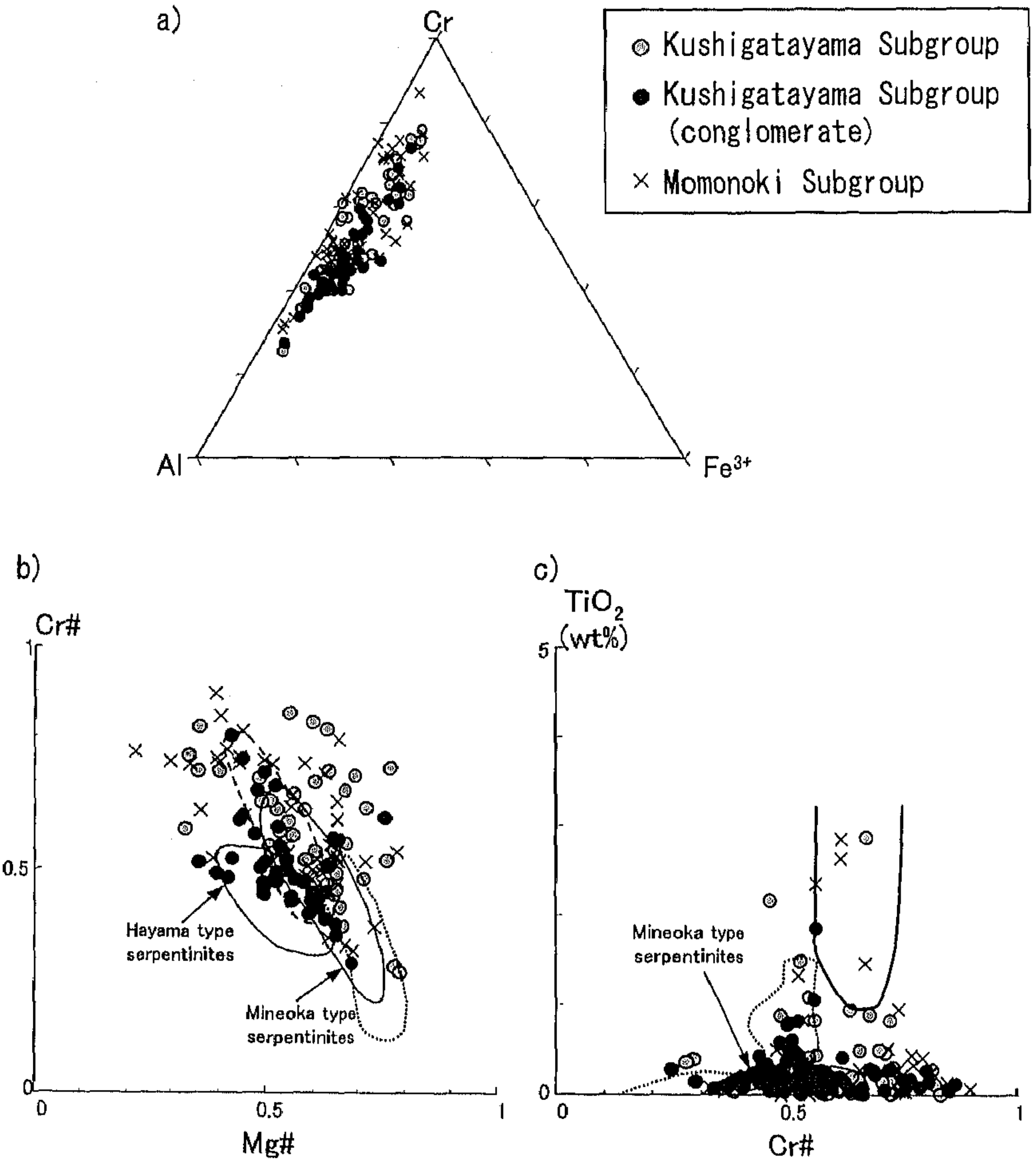


Fig. 33. Chemical compositions of detrital chromian spinels from the Koma Group. a) Cr-Al-Fe^{3+} diagram, b) Mg# vs. Cr# diagram, c) Cr# vs. TiO_2 diagram. The range of the serpentinites in the Circum-Izu Massif serpentine belt is surrounded by thin lines (Arai et al., 1990). The range of the alkaline and picrite basalts in the Circum-Izu Massif serpentine belt is surrounded by a thick line (compiled after Tazaki, 1975; Tazaki and Inomata, 1980; Ishida et al., 1988, 1990; Taniguchi and Ogawa, 1990). The range of the abyssal peridotites is surrounded by dotted lines (Dick and Bullen, 1984). The range of the forearc peridotites is surrounded by a broken line (Ishii et al., 1992).

formations show similar distribution (Fig. 26). Cr# range is 0.22 to 0.86, while Mg# is mostly 0.30 to 0.75. One grain from has high Mg# and Cr#, 0.91 and 0.77, respectively. Fe^{3+}3# range is 0.02 to 0.21, mostly below 0.10. TiO_2 wt% range is 0.02 to 1.40, though three grain have TiO_2 wt% > 0.8. One grain from the Kanigawa Formation has a high ZnO content of 1.04 wt%.

43 chemical analyses of detrital chromian spinels were obtained from the Sakuma Group sandstone, and 16 chemical analyses were obtained from the basaltic clast of the Okuyama Formation. Cr# range of the spinels from the Sakuma Group sandstone is 0.38 to 0.81, and its lower limit is comparatively higher (Fig. 27). On the other hand, Cr# range of the spinels from the basaltic clast is concentrated in 0.64 to 0.74. Mg# range from sandstone is 0.34 to 0.79, while Mg# range from the basaltic clast is also concentrated in 0.62 to 0.78. Fe^{3+}3# range from the Sakuma Group sandstone is 0.02 to 0.15, while Fe^{3+}3# range from the basaltic clast is also concentrated in 0.09 to 0.15. TiO2 wt % range from the sandstone is mostly 0.00 to 0.99, and only five grains have TiO2 wt% >1.00. These five grains are plotted near plots of the grains from the basaltic clast. However the color of these grains is brown to black, and these characteristics differ from those of the spinels from the basaltic clast in terms of the color.

133 detrital chromian spinels, comprising 43 grains from the conglomerate and sandstone at Yohka Beach, 28 grains from the float at Mineokasengen which Arai (1981) reported the occurrence of serpentine sandstone, and 64 grains from tectonic blocks in the newly found outcrop at Mineokasengen, were obtained. These are categorized as serpentine sandstone. The tendency of the chemistry of chromian spinels from the conglomerate and sandstone at Yohka Beach is different from those of the serpentine sandstone at the other two locations (Fig. 28). Cr# range is 0.30 to 0.79. Mg# range is 0.44 to 0.76. Cr#-Mg# diagram shows a negative tendency. Fe^{3+}3# range is 0.02 to 0.10 (Fig. 22). TiO_2 wt% range is comparatively lower, mostly 0.01 to 0.20.

Tendencies of the chemistry of chromian spinels from the serpentine sandstones at two localities in Mineokasengen are similar to each other (Fig. 28). Cr# range is comparatively wider, namely 0.18 to 0.79 (Fig. 23). Cr# - Mg# diagram shows clear negative trend. Fe^{3+}3# range is comparatively lower, mostly 0.00 to 0.05. TiO_2 wt% range is also lower, 0.00 to 0.19.

139 detrital chromian spinels, comprising 42 grains respective from the sandstones at Mineokasengen and Hegurinaka and 55 grains from the sandstone at Yohka Beach, were obtained from the leucocratic sandstones. As shown in Fig. 29, the range of the chemistry of the those spinels show a similar distribution. Cr# range is 0.28 to 0.90, and is mostly 0.30 to 0.70. Mg# is mostly 0.40 to 0.75. One grain from the sandstone at Yohka Beach has high Mg# and Cr#, 0.90 and 0.69, respectively. Fe^{3+}3# range is 0.00 to 0.13, mostly below 0.10. TiO_2 wt% range is mostly 0.00 to 1.00, nine out of 139 grains have TiO_2 wt% > 1.0. Four grains have a high ZnO content of 1.24 to 12.44 wt%.

Setogawa area

46 chemical analyses of chemical compositions of detrital chromian spinels were obtained from the sandstones of the Mikura Group (Fig. 30). Cr# range is 0.38 to 0.88, and most of the spinel grains have Cr# > 0.55. Mg# is mostly 0.34 to 0.70, and 3 out of 46 grains have Mg# < 0.25. Fe^{3+}3# range is 0.01 to 0.13, mostly below 0.10. TiO_2 wt% range is mostly 0.00 to 0.50, and two out of 46 grains have TiO_2 wt% > 1.0. Two grains have a high ZnO content of 1.38 and 1.88 wt%, respectively.

236 detrital chromian spinels grains, comprising 44 grains from the conglomerates of the Odake Thrust Sheet, 36 grains from the alternation of sandstone and shale of the Odake Thrust Sheet, 45 grains from the sandstone of the Takayama Thrust Sheet, and 111 grains from the Oigawa Thrust Sheet, were obtained from sandstones of the Setogawa Group. The chemistry of chromian spinels from these thrust sheets are somewhat different among them. The spinels obtained from the conglomerates of the Odake Thrust Sheet can be divided into three groups in terms of

their chemistry (Fig. 31). The first group is composed of 33 grains and clearly shows a negative tendency on the Mg#-Cr# diagram (Fig. 31). Cr# range is 0.28 to 0.62. Mg# is 0.36 to 0.68. Fe^{3+}3# range is 0.04 to 0.14, mostly below 0.10. TiO_2 wt% range is 0.11 to 0.79. The second group is composed of 3 grains. This group spinels have a relatively high Cr#, and Cr# range is 0.75 to 0.78. Mg# is 0.40 to 0.50. Fe^{3+}3# range is 0.04 to 0.08. TiO_2 wt% range is 0.17 to 0.20. The third group is composed of 8 grains. This group spinels are characterized by a high Mg# and Cr#. Cr# range is 0.59 to 0.76. Mg# is 0.62 to 0.67. Fe^{3+}3# range is 0.06 to 0.09. TiO_2 wt% range is 0.21 to 0.75.

The chemistries of the spinels obtained from the Takayama Thrust Sheet and from the alternation of sandstone and shale of the Odake Thrust Sheet have similar tendencies (Fig. 31). Cr# range is 0.35 to 0.94. Mg# is mostly 0.28 to 0.80. Fe^{3+}3# range is 0.01 to 0.21, mostly below 0.10. TiO_2 wt% range is mostly 0.00 to 0.85.

The chemistries of the spinels obtained from the Oigawa Thrust Sheet are characterized by a wide range of Cr# (Fig. 31), that is, 0.20 to 0.96. Mg# range is 0.24 to 0.83. Fe^{3+}3# range is 0.00 to 0.21, mostly below 0.10. TiO_2 wt% range is mostly 0.00 to 0.70, 12 out of 111 grains have TiO_2 wt% > 0.8.

43 detrital chromian spinels, comprising 13 grains from the Amakata Sandstone and 30 grains from the Todo Alternation of Sandstone and Siltstone, were obtained from the Kurami Group. The tendencies of chemistries of spinels obtained from those are similar to each other (Fig. 32). Cr# range is 0.26 to 0.95. Mg# is mostly 0.29 to 0.84, and 3 out of 43 grains have Mg# < 0.16. Fe^{3+}3# range is 0.00 to 0.16, mostly below 0.10. TiO_2 wt% range is mostly 0.00 to 0.50, and six out of 43 grains have TiO_2 wt% > 1.0. Two grains have a high ZnO content of 1.46 and 2.45 wt%, respectively.

132 detrital chromian spinels, comprising 42 grains from the uppermost part of the Kushigatayama Subgroup, 46 grains from the conglomerate clast in the shale of the lower part of the upper Kushigatayama Subgroup, and 44 grains from the Momonoki Subgroup, were obtained from the Koma Group. The tendencies of chemistries of spinels obtained from these except for the conglomerate clast in the

Kushigatayama Subgroup are similar to each other (Fig. 33). Cr# range is 0.26 to 0.90. Mg# is mostly 0.29 to 0.79. Fe^{3+}3# range is 0.00 to 0.16, mostly below 0.10. TiO_2 wt% range is mostly 0.00 to 0.50, and 16 out of 86 grains have TiO_2 wt% > 0.50.

The chemistries of the spinels obtained from the conglomerate clast in the Kushigatayama Subgroup are characterized by relatively low Mg# and Cr# (Fig. 33). Cr# range is mostly 0.35 to 0.75. Mg# range is mostly 0.35 to 0.69. Fe^{3+}3# range is 0.02 to 0.12. TiO_2 wt% range is mostly 0.09 to 0.50, 7 out of 46 grains have TiO_2 wt% > 0.5. Higher TiO_2 content chromian spinels have Cr# of about 0.5.

3-6. Detrital garnet

3-6-1. Occurrence and petrographic description

Mineoka area

The strata and tectonic blocks yielding the detrital garnets are limited compared with those yielding detrital chromian spinel. The Fukawa Formation and leucocratic sandstones yield abundantly detrital garnets. The sandstones of the Haccho Formation of the Mineoka Group, the Kanigawa Formation of the Hota Group, the Sakuma Group and the Futatsuyama Formation yield detrital garnets using the heavy liquid separation. From the Hota Group except for the Fukawa and Kanigawa Formations, several detrital garnets were obtained with heavy liquid separation. The serpentine sandstones yield no detrital garnet.

The detrital garnets from the Fukawa and Kanigawa Formations and the leucocratic sandstones are colorless to light pink (Plates 7e, 7f and 7j), while those from the Sakuma Group and the Futatsuyama Formation are colorless to light pink or light brown (Plates 7g and 7i). The detrital garnets obtained from the Haccho Formation and the Hota Group except for the Fukawa and Kanigawa Formations are colorless to light brown (Plates 7d and 7g).

The detrital garnets obtained from the Fukawa, Kanigawa and Futatsuyama Formations are angular to rounded, while the other detrital garnets are angular to sub-rounded.

Setogawa area

Almost all the strata in the Setogawa area which were dealt in this study yield detrital garnets. Only conglomerates of the Odake Thrust Sheet and conglomerates and sandstones of the lower part of the upper Kushigatayama Subgroup yield no detrital garnets. All the detrital garnets are obtained using the heavy liquid separation.

Most of the detrital garnets from the Setogawa area are colorless, and some of them from the Setogawa and Kurami Groups are light pink or light brown (Plates 7k and 7l and 8a to 8e).

3-6-2.Chemical compositions

A total of 532 chemical analyses of detrital garnets were obtained from the Mineoka and Setogawa areas in this study. The tendencies of chemical compositions of detrital garnets vary with each formation or block. Figs. 34 to 42 show the chemical compositions of garnets from each formation or block obtained in this study.

Mineoka area

23 grains of detrital garnet was obtained from sandstones of the Haccho Formation of the Mineoka Group. 18 grains correspond to pyrope-rich almandine (Pyr = 12 to 42 mol. %), two gains to spessartine-rich almandine (Sps = 19 and 20 mol. %) and two grains to Ca-rich almandine (Ugr = 14 and 27 mol. %) (Fig. 34).

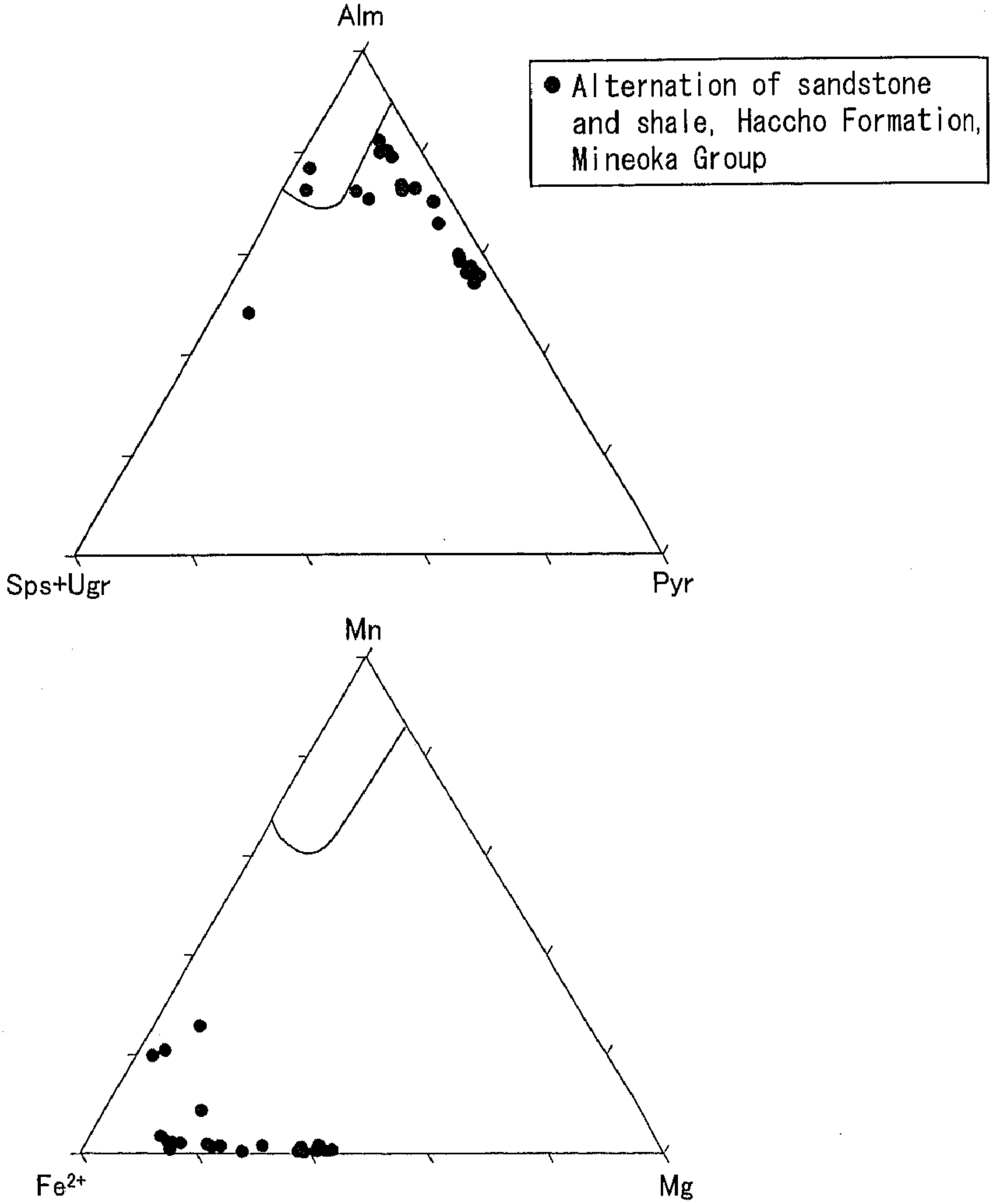


Fig. 34. Chemical compositions of detrital garnets from the Haccho Formation of the Mineoka Group. a) Alm-Sps+Ugr-Pyr diagram, b) Mn-Fe^{2+}-Mg diagram. The range of the metamorphic rocks in the Mineoka Mountains is surrounded by lines (Ogo and Hiroi, 1991). Alm: almandine, Sps: spessartine, Ugr: Ugrandite, Pyr: pyrope.

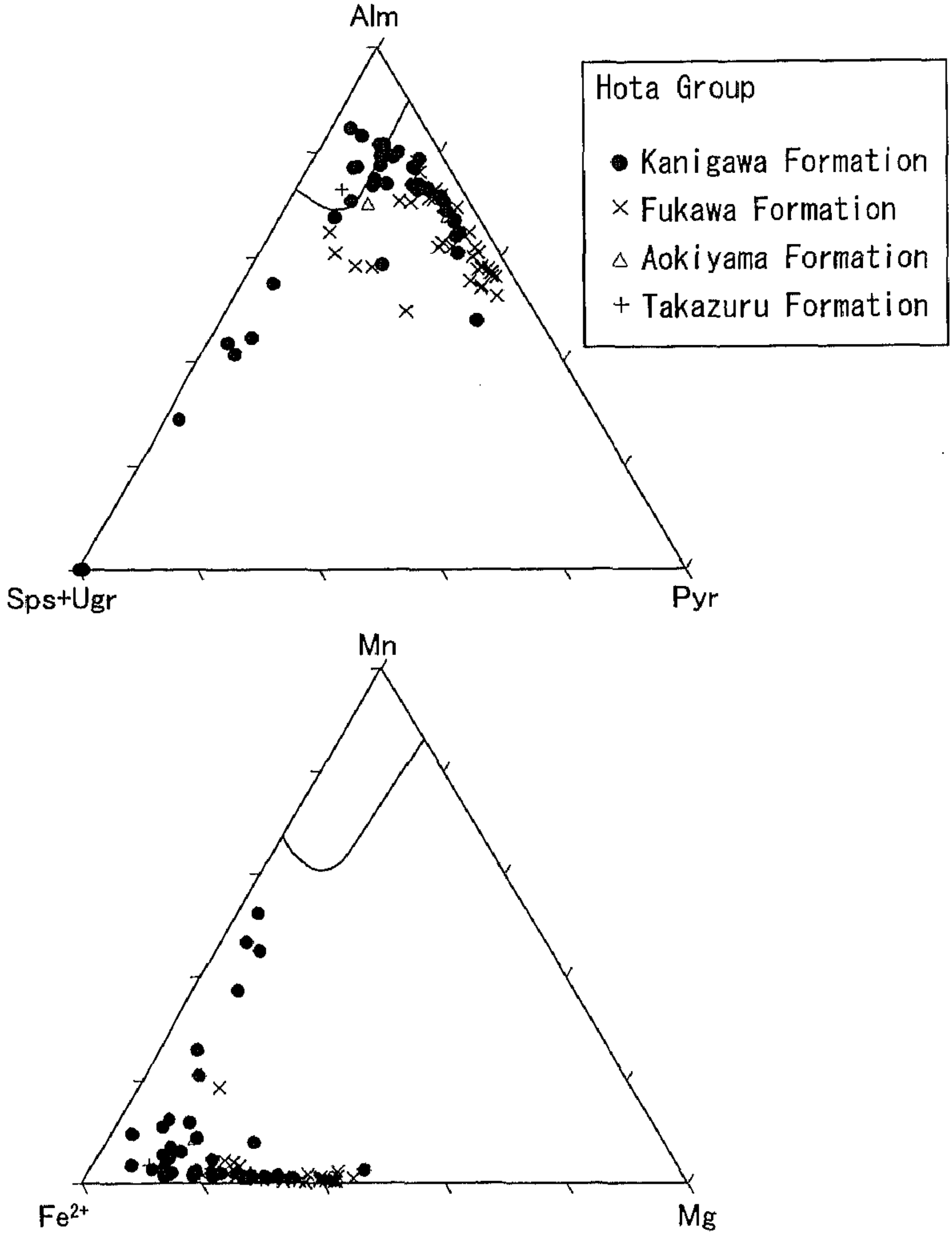


Fig. 35. Chemical compositions of detrital garnets from the Hota Group. a) Alm-Sps+Ugr-Pyr diagram, b) Mn-Fe^{2+}-Mg diagram. The range of the metamorphic rocks in the Mineoka Mountains is surrounded by lines (Ogo and Hiroi, 1991). Alm: almandine, Sps: spessartine, Ugr: Ugrandite, Pyr: pyrope.

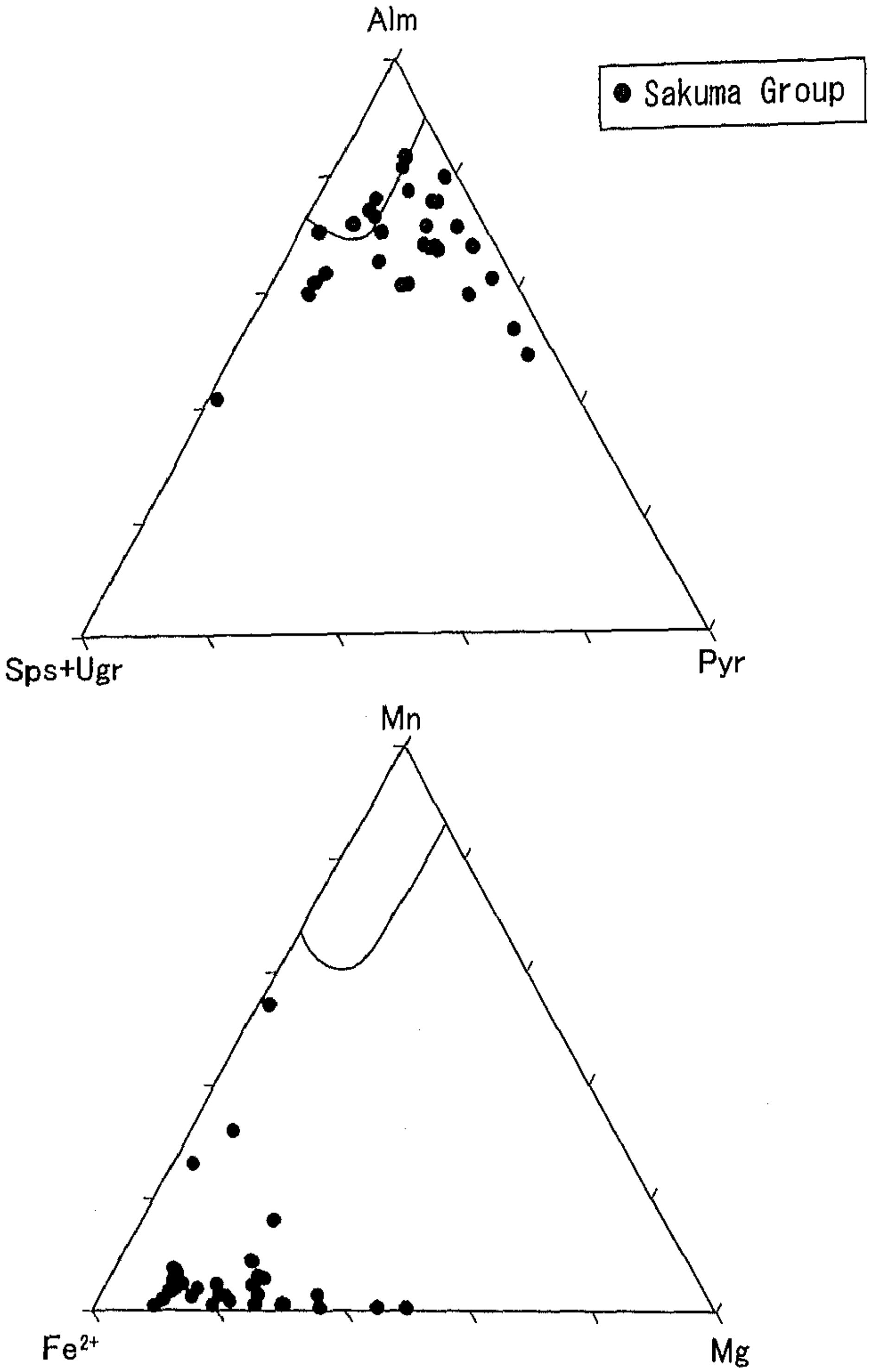


Fig. 36. Chemical compositions of detrital garnets from the Sakuma Group. a) Alm-Sps+Ugr-Pyr diagram, b) Mn-Fe^{2+}-Mg diagram. The range of the garnets in the Tethys and Higher Himalayas is surrounded by a thin line. The range of the metamorphic rocks in the Mineoka Mountains is surrounded by lines (Ogo and Hiroi, 1991). Alm: almandine, Sps: spessartine, Ugr: Ugrandite, Pyr: pyrope.

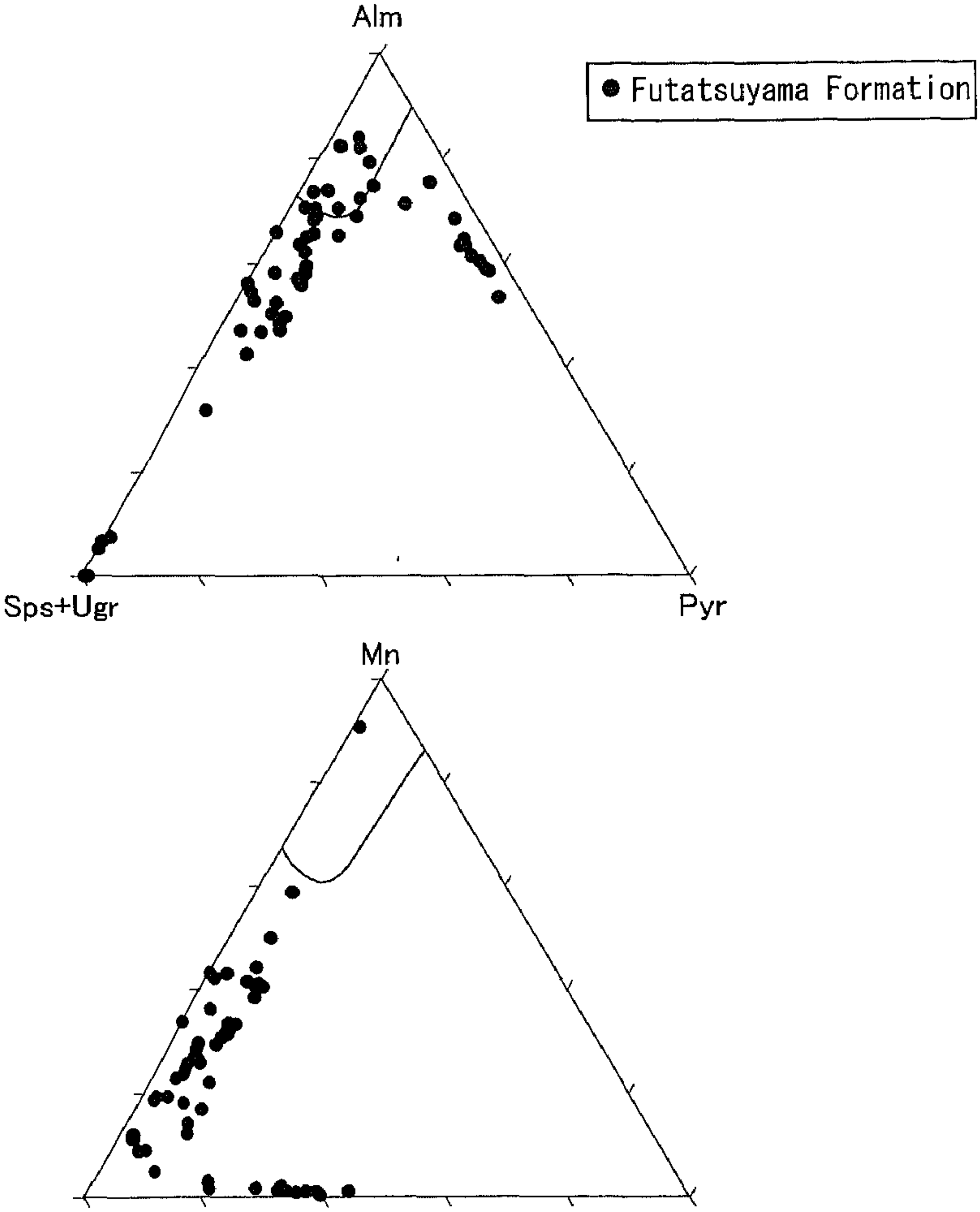


Fig. 37. Chemical compositions of detrital garnets from the Futatsuyama Formation. a) Alm-Sps+Ugr-Pyr diagram, b) Mn-Fe^{2+}-Mg diagram. The range of the metamorphic rocks in the Mineoka Mountains is surrounded by lines (Ogo and Hiroi, 1991). Alm: almandine, Sps: spessartine, Ugr: Ugrandite, Pyr: pyrope.

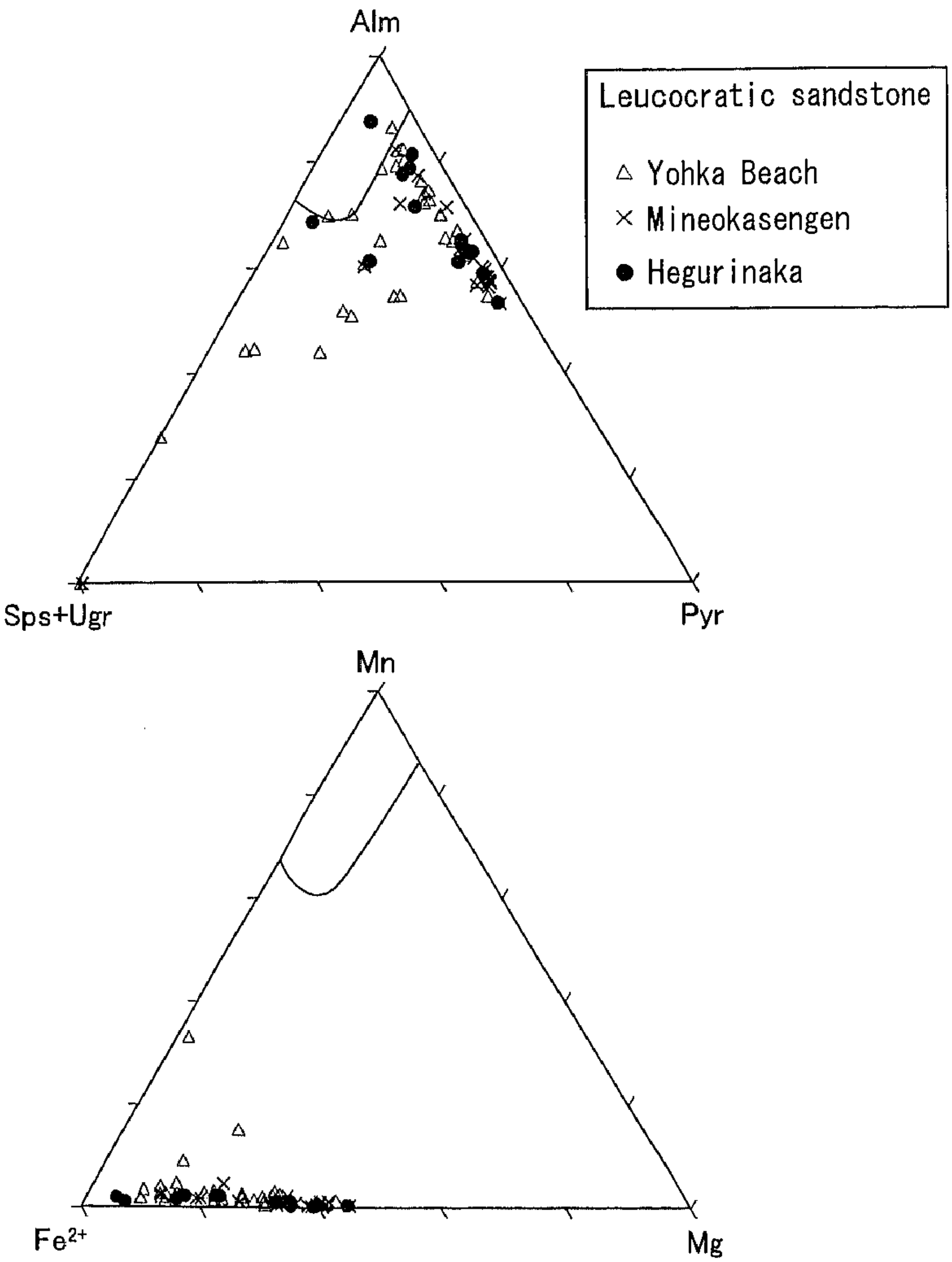


Fig. 38. Chemical compositions of detrital garnets from the leucocratic sandstone. a) Alm-Sps+Ugr-Pyr diagram, b) Mn-Fe^{2+}-Mg diagram. The range of the metamorphic rocks in the Mineoka Mountains is surrounded by lines (Ogo and Hiroi, 1991). Alm: almandine, Sps: spessartine, Ugr: Ugrandite, Pyr: pyrope.

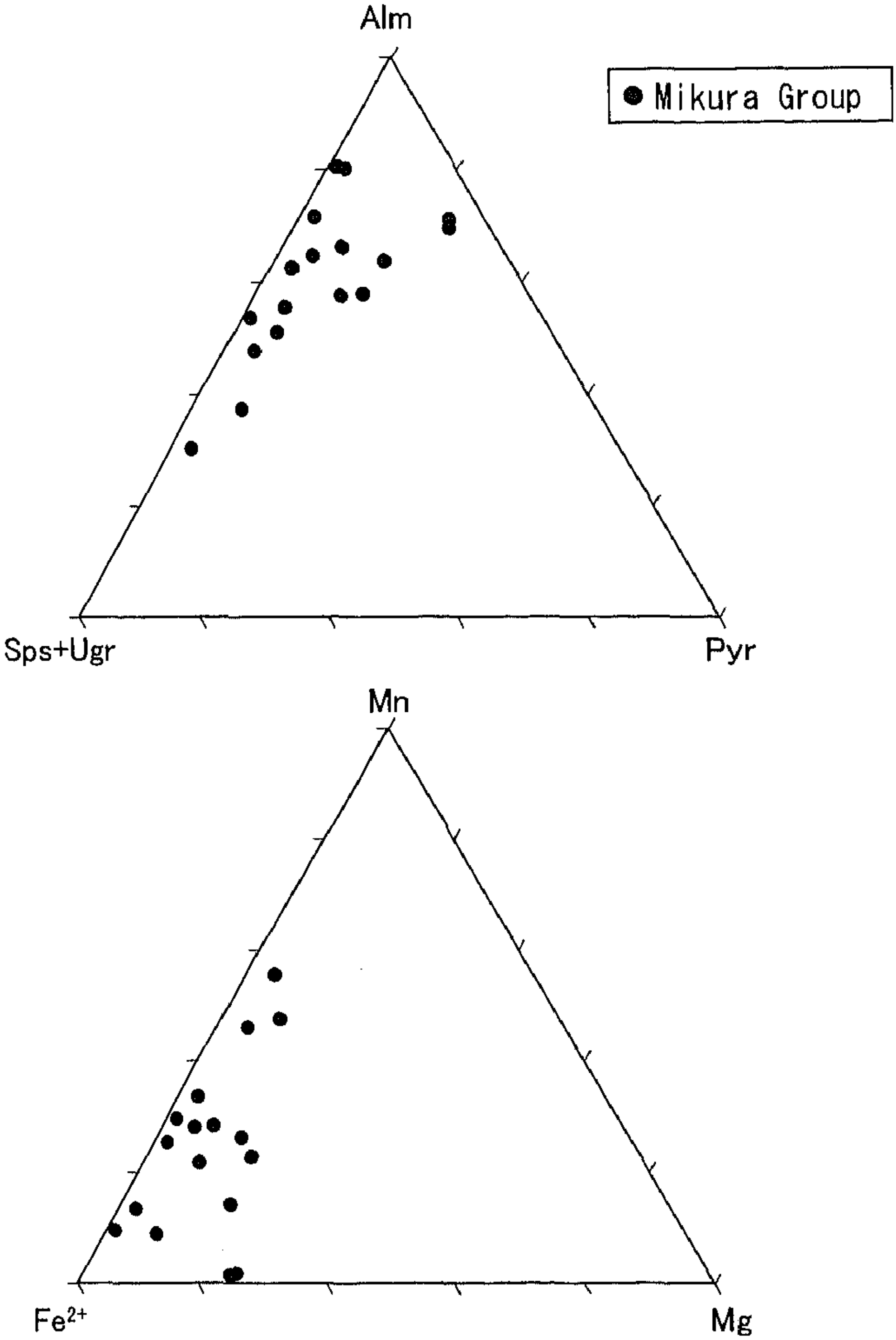


Fig. 39. Chemical compositions of detrital garnets from the Mikura Group.
a) Alm-Sps+Ugr-Pyr diagram, b) Mn-Fe^{2+}-Mg diagram. Alm: almandine, Sps: spessartine, Ugr: Ugrandite, Pyr: pyrope.

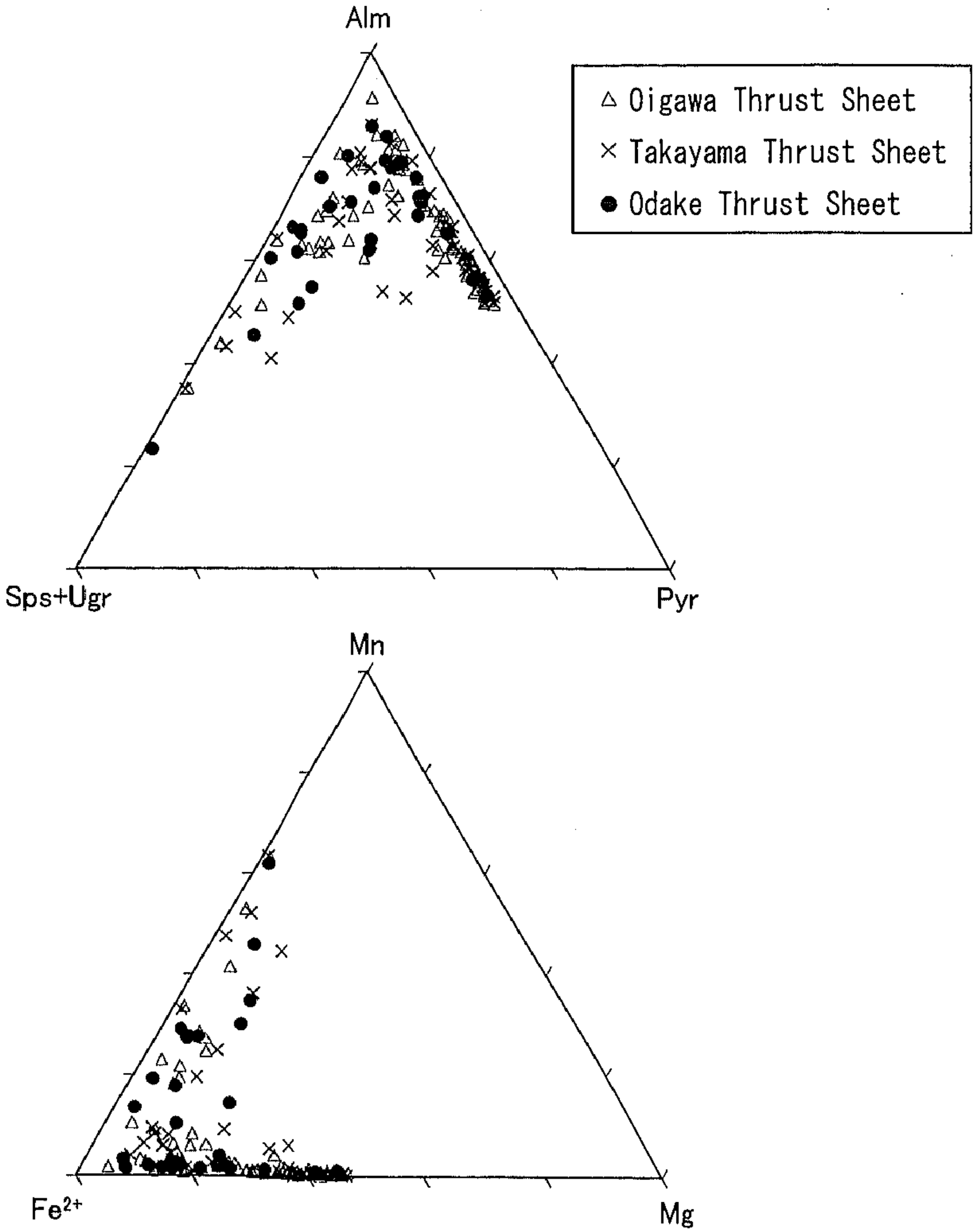


Fig. 40. Chemical compositions of detrital garnets from the Setogawa Group.
a) Alm-Sps+Ugr-Pyr diagram, b) Mn-Fe^{2+}-Mg diagram. Alm: almandine, Sps: spessartine, Ugr: Ugrandite, Pyr: pyrope.

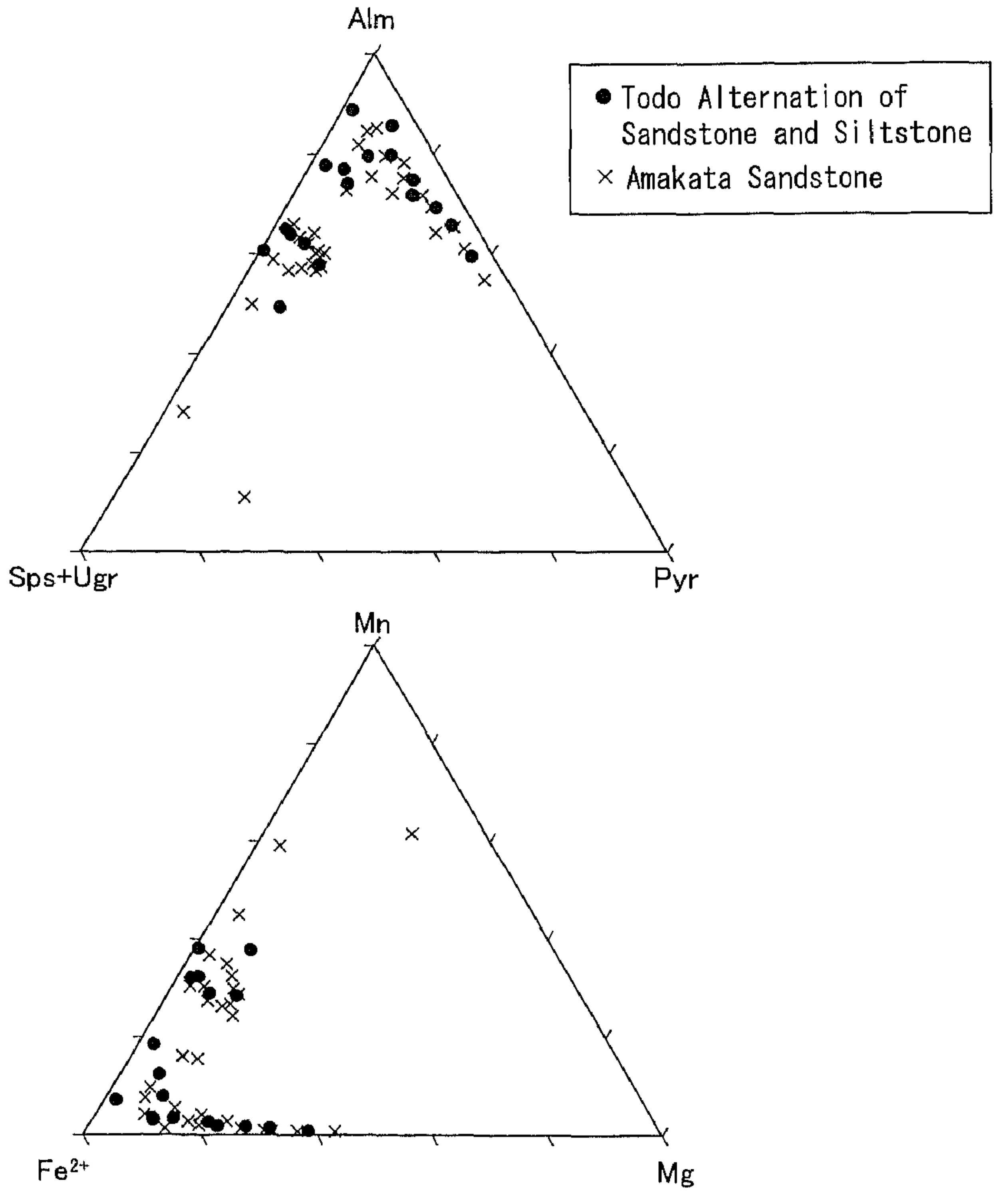


Fig. 41. Chemical compositions of detrital garnets from the Kurami Group.
a) Alm-Sps+Ugr-Pyr diagram, b) Mn-Fe^{2+}-Mg diagram. Alm: almandine, Sps: spessartine, Ugr: Ugrandite, Pyr: pyrope.

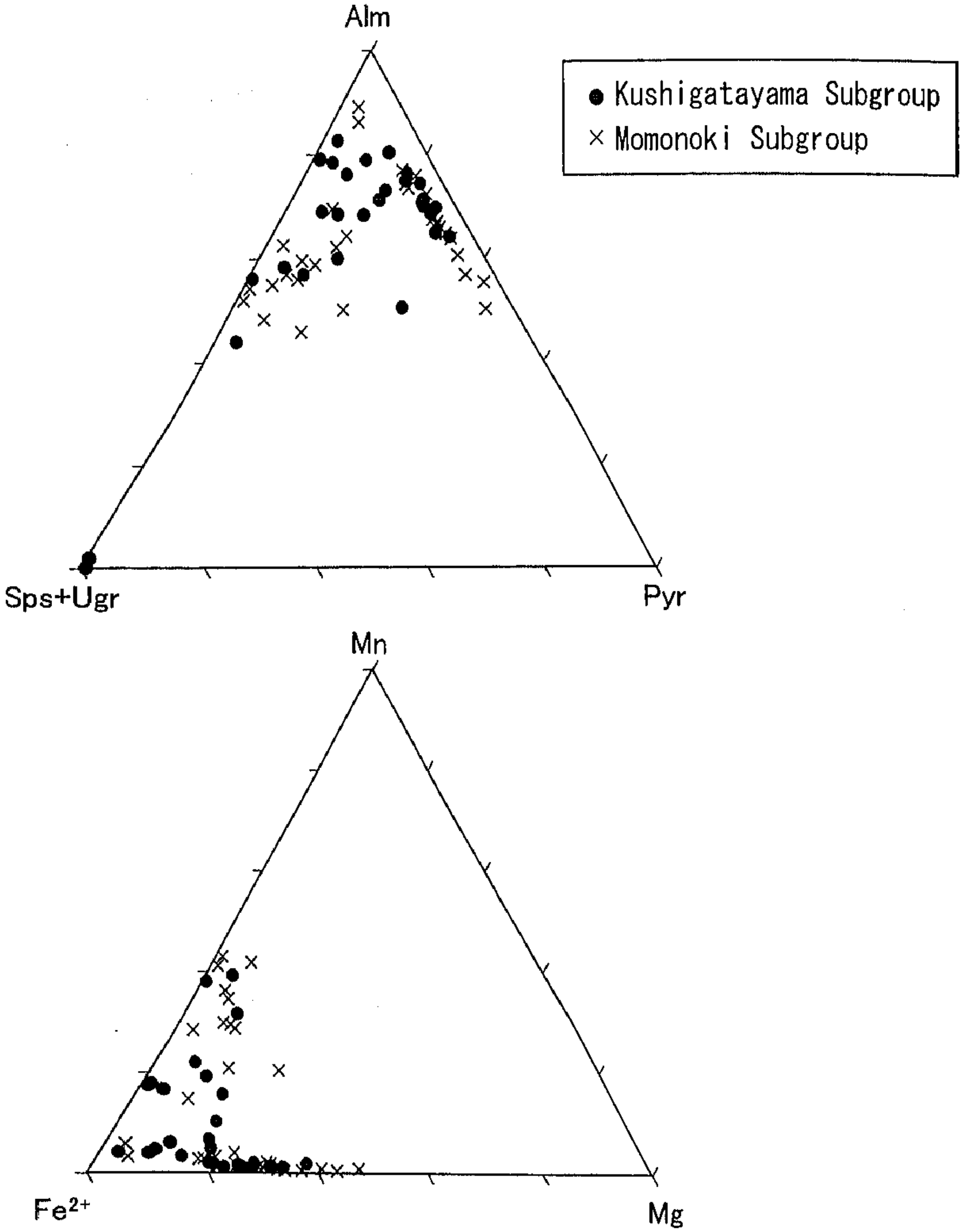


Fig. 42. Chemical compositions of detrital garnets from the Koma Group.
a) Alm-Sps+Ugr-Pyr diagram, b) Mn-Fe^{2+}-Mg diagram. Alm: almandine, Sps: spessartine, Ugr: Ugrandite, Pyr: pyrope.

36 grains of detrital garnets were obtained from the Fukawa Formation of the Hota Group. 29 grains correspond to pyrope-rich almandine (Pyr = 16 to 43 mol. %), five grains to spessartine-rich almandine (Sps = 17 to 32 mol. %) and Ca-rich (Ugr = 21 to 24 mol. %) almandine (Fig. 35).

40 grains of detrital garnets were obtained from the Kanigawa Formation of the Hota Group. 26 grains correspond to pyrope-rich almandine (Pyr = 10 to 42 mol. %), seven grains to spessartine-rich almandines (Sps = 9 to 42 mol. %), three grains to grossular (Grs = 41 to 75 mol. %), two grains to Ca-rich almandines (Ugr = 8 and 15 mol. %), two grains two andradites (And = 66 and 73 mol. %), and one grain is almandine-rich spessartine (Sps = 50 mol. %) (Fig. 35).

Four grains were obtained from the Hota Group except for the Fukawa and Kanigawa Formations. Three grains mostly correspond to pyrope-rich almandine (Pyr = 13 to 27 mol. %), while one grain corresponds to Ca-rich almandine (Ugr = 17 mol. %) (Fig. 35).

33 grains of detrital garnets were obtained from the Sakuma Group. 22 grains correspond to pyrope-rich almandine (Pyr = 10 to 47 mol. %), eight grains to Ca-rich (Ugr = 11 to 26 mol. %), two grains to spessartine-rich (Sps = 26 and 31 mol. %) almandine and one grain to almandine-rich spessartine (Sps = 51 mol. %) (Fig. 36).

58 chemical analyses of detrital garnets were obtained from the Futatsuyama Formation. 38 grains are spessartine-rich almandine (Sps = 9 to 43 mol. %), while 12 grains are pyrope-rich almandine (Pyr = 9 to 42 mol. %), four grains are grossular (Grs = 77 to 90 mol. %) and three grains are spessartine (Sps = 50 to 82 mol. %) (Fig. 37).

68 grains of detrital garnets from the sandstones of the leucocratic sandstones, comprising 34 grains from blocks at Yohka Beach, 13 grains from blocks at Hegurinaka and 21 grains at Yohka Beach, were analyzed. The ranges of those garnets from the leucocratic sandstones at Yohka Beach, Hegurinaka and Mineokasengen are similar to each other (Fig. 38). 53 grains belong to pyrope-rich almandine (Pyr = 10 to 43 mol. %), nine grains to Ca-rich almandine (Ugr = 6 to 43

mol. %), three grains to almandine-rich grossular (Grs = 45 to 98 mol. %), and one grain to andradite (And = 98 mol. %).

Setogawa area

18 grains of detrital garnet were obtained from the Mikura Group sandstone. 10 grains correspond to spessartine-rich almandine (Sps = 13 to 45 mol. %), while three grains are assigned to pyrope-rich almandine (Pyr = 17 to 24 mol. %), two grains to Ca-rich almandine (Ugr = 10 and 33 mol. %), and two grains to almandine-rich spessartine (Sps = 41 and 42 mol. %) (Fig. 39).

160 grains of detrital garnets from the sandstones from the Setogawa Group, comprising 30 grains from the sandstones of the Odake Thrust Sheet, 42 grains from the sandstones of the Takayama Thrust Sheet and 88 grains from the sandstones of the Oigawa Thrust Sheet, were analyzed. The ranges of those garnets from the Odake, Takayama and Oigawa Thrust Sheets are similar to each other (Fig. 40). Most of these grains correspond to pyrope-rich almandine (Pyr = 7 to 45 mol. %), while 25 grains are assigned to spessartine-rich almandine (Sps = 9 to 47 mol. %), nine grains to Ca-rich almandine (Ugr = 11 to 27 mol. %), five grains to almandine-rich spessartine (Sps = 43 to 63 mol. %), and one grain to Ca-rich spessartine (Sps = 40 mol. %).

49 detrital garnets, comprising 31 grains from the Amakata Sandstone, and 18 grains from the Todo Alternation of Sandstone and Siltstone, were obtained from the Kurami Group. The ranges of those garnets from the Amakata Sandstone and Todo Alternation of Sandstone and Siltstone are similar to each other (Fig. 41). 24 grains correspond to spessartine-rich almandine (Sps = 7 to 44 mol. %), 20 grains to pyrope-rich almandine (Pyr = 8 to 41 mol. %), three grains to Ca-rich almandine (Ugr = 14 to 17 mol. %), one grain to almandine-rich spessartine (Sps = 45 mol. %), and one grain to Mg-rich spessartine (Sps = 53 mol. %).

61 detrital garnets, comprising 31 grains from the uppermost part of the

Kushigatayama Subgroup and 30 grains from the Momonoki Subgroup, were obtained from the Koma Group. The ranges of those garnets from the Kushigatayama and Momonoki Subgroups are similar to each other (Fig. 42). These grains mostly correspond to pyrope-rich almandine (Pyr = 10 to 45 mol. %) and spessartine-rich almandine (Sps = 6 to 45 mol. %), while seven grains are assigned to Ca-rich almandine (Ugr = 6 to 37 mol. %), and one grain to andradite-rich grossular (Grs = 89 mol. %).

3-7. Detrital clinopyroxene

3-7-1. Occurrence and petrographic description

Mineoka area

The sandstones of the Hota Group except for the Fukawa and Kanigawa Formations and the Sakuma Group, and the Futatsuyama Formation yield detrital clinopyroxenes abundantly. The conglomerate intercalated in the shale of the Haccho Formation, Mineoka Group also contains detrital clinopyroxenes. Moreover, the serpentine sandstones also yield detrital clinopyroxenes abundantly. A lot of detrital clinopyroxenes are obtained from usual thin-sections of those sandstones.

There are little differences of petrographic characteristics of detrital clinopyroxenes, except for those from the tectonic blocks at Hegurinaka or Yohka Beach. Almost all the detrital clinopyroxenes are colorless to light green or brown (Plates 8f to 8j) and angular, rarely subrounded.

Setogawa area

The sandstones of the lower part of the upper Kushigatayama Subgroup yield detrital clinopyroxenes abundantly. Almost all the detrital clinopyroxenes are colorless to light green (Plate 8k), and are angular to subrounded.

3-7-2.Chemical compositions

A total of 194 chemical analyses of detrital clinopyroxenes were obtained from the Mineoka and Setogawa areas in this study. In addition, 55 chemical analyses of detrital clinopyroxenes from the Hota Group obtained by Akabane (1998MS) were recalculated. The tendencies of chemical compositions of detrital chromian spinels vary with each formation or block. Figs. 57 and 58 show the chemical compositions of clinopyroxenes from each formation or tectonic block obtained in this study.

Mineoka area

24 chemical analyses of detrital clinopyroxenes were obtained from the conglomerates intercalated in the shale of the Haccho Formation, Mineoka Group. The conglomerate samples were obtained from the two localities, at Motona and Fusada, and the chemistries of detrital clinopyroxenes are different between those from each sample. The detrital clinopyroxenes obtained from the conglomerate at Motona correspond to diopside and augite (Fig. 43). TiO_2 wt% range is 0.13 to 0.56. Cr wt% range is 0.00 to 1.07. The Cr wt% of four grains are >0.5, that is, chromian diopside. Na wt% range is 0.07 to 0.31, and Al wt% range is 0.36 to 4.06.

All the detrital clinopyroxenes obtained from the conglomerate at Fusada correspond to augite (Fig. 43). TiO_2 wt% range is 0.13 to 0.46. Cr wt% range is 0.67 to 1.28, and all the grains are chromian diopside. Na wt% range is 0.11 to 0.30, and Al wt% range is 1.28 to 4.08.

Four analyses of chemical composition of detrital clinopyroxenes were obtained from the Hota Group sandstone excluding the Fukawa Formation in this study. According to Morimoto (1988), the detrital clinopyroxenes from the Hota Group

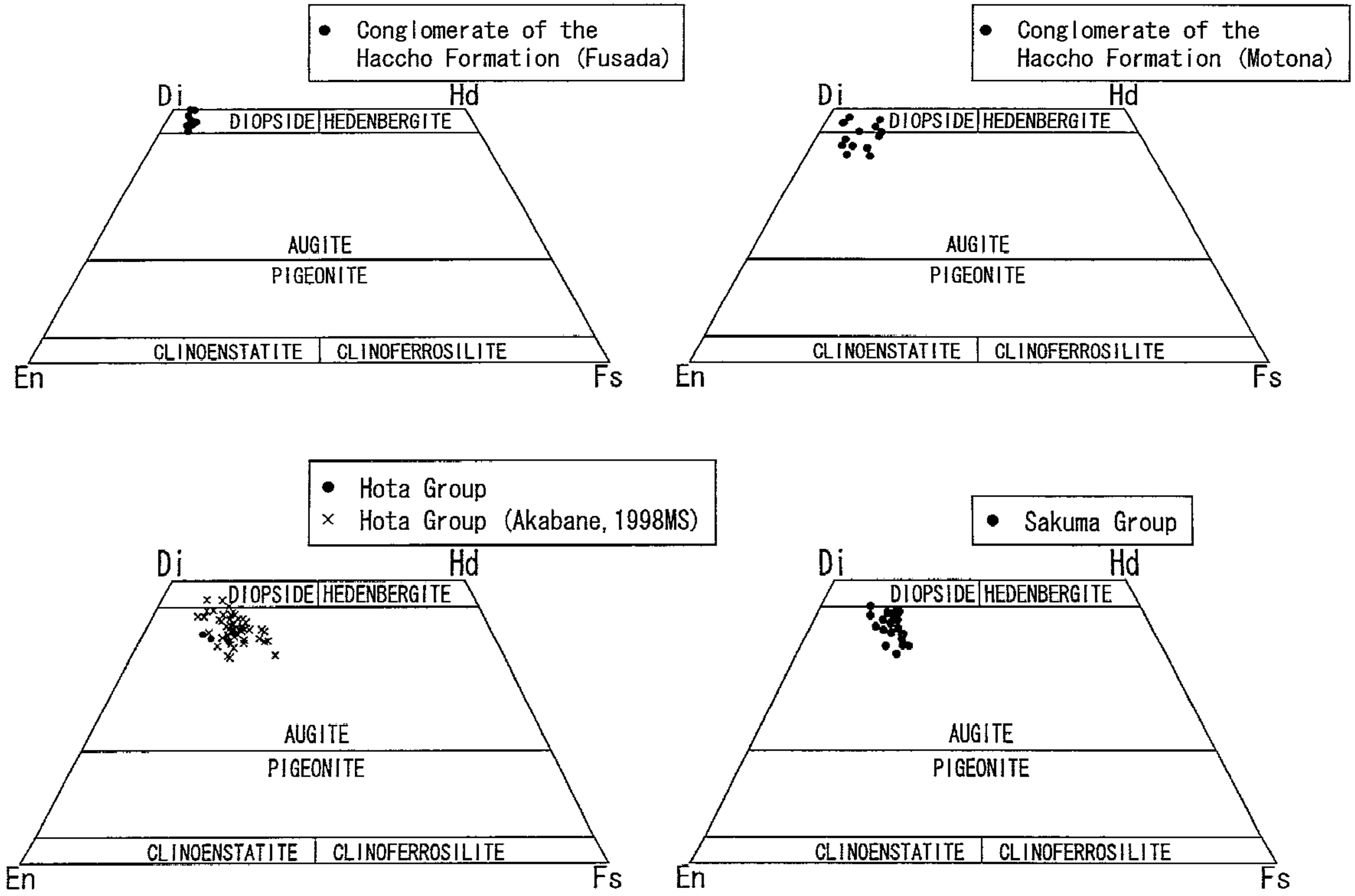


Fig. 43. Di–En–Hd–Fs diagram for detrital clinopyroxenes from the Mineoka area. The subdivision scheme is from Morimoto (1988). Di: diopside, Hd: hedenbergite, En: enstatite, Fs: ferrosilite

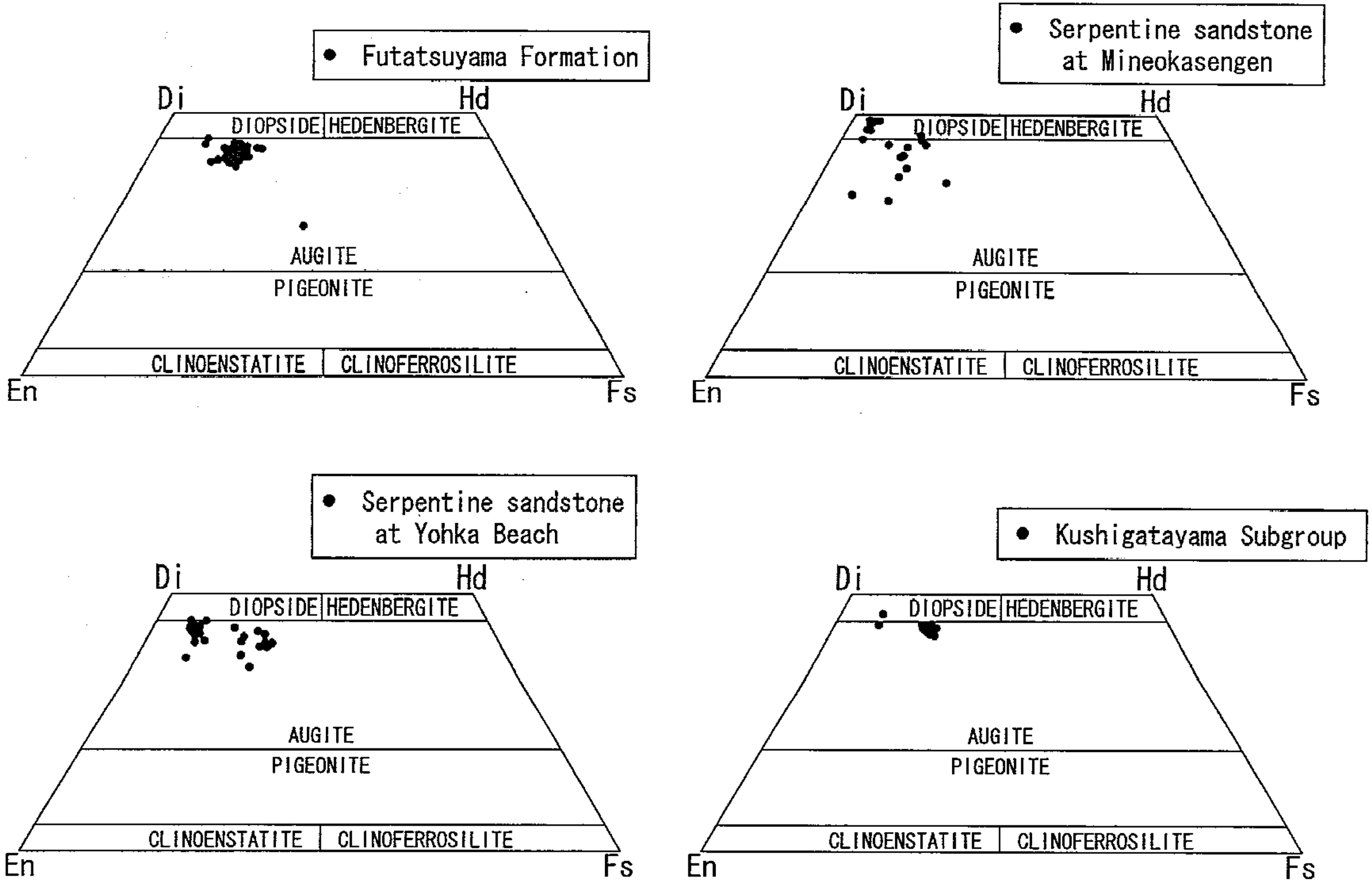


Fig. 44. Di–En–Hd–Fs diagram for detrital clinopyroxenes from the Mineoka and Setogawa areas. The subdivision scheme is from Morimoto (1988). Di: diopside, Hd: hedenbergite, En: enstatite, Fs: ferrosilite.

including those analyzed by Akabane (1998MS) are mainly divided into augite with a small amount of diopside (Fig. 43). All the augites are Ca-rich and Fe-poor. TiO_2 wt% range is 0.00 to 1.10. Cr wt% range is mostly 0.00 to 0.35, and only one grain is Cr wt% > 0.5, that is, chromian diopside. Na wt% range is 0.10 to 0.68, and Al wt% range is 0.89 to 4.83.

21 chemical analyses of the detrital clinopyroxenes were obtained from the Sakuma Group. The detrital clinopyroxenes from the Sakuma Group are mainly divided into augite with a small amount of diopside (Fig. 43). All the augites are Ca-rich and Fe-poor. TiO_2 wt% range is 0.37 to 0.98. Cr wt% range is 0.00 to 0.31. Na wt% range is 0.20 to 0.50, and Al wt% range is 1.46 to 5.17.

69 chemical analyses were obtained from the Futatsuyama Formation. The detrital clinopyroxenes obtained from the Futatsuyama Formation correspond to augite (Fig. 44). All the augites are Ca-rich and Fe-poor, though one grain has rather higher Fe content. TiO_2 wt% range is 0.31 to 1.06. Cr wt% range is 0.0 to 0.38. Na wt% range is 0.17 to 0.46, and Al wt% range is 0.54 to 4.09.

24 chemical analyses of detrital clinopyroxenes were obtained from the serpentine sandstone at Yohka Beach. The plots on the scheme of Morimoto (1988) show the bimodal distribution (Fig. 44), though most of them correspond to Ca-rich and Fe-poor augite. TiO_2 wt% range is 0.10 to 0.49. Cr wt% range is 0.0 to 1.1. Seven grains are Cr wt% > 0.5, that is, chromian diopside. Na wt% range is 0.04 to 0.27, and Al wt% range is 0.47 to 3.55.

22 chemical analyses of detrital clinopyroxenes were obtained from the serpentine sandstones at Mineokasengen. They are divided mainly into augite and diopside (Fig. 44). The plots on the scheme of Morimoto (1988) show the bimodal distribution. The one group is composed of diopside, and the other group is composed mainly of augite with a minor amount of diopside. The diopsides are Fe-poor, and the augites are Ca-rich and Fe-poor. TiO_2 wt% range is 0.03 to 2.06, and some of the augites are included in titanaugite. Cr wt% range is 0.01 to 1.19. The detrital clinopyroxenes which belong to the first group are all chromian diopside. Na wt%

range is 0.00 to 0.01, and Al wt% range is 0.71 to 5.89.

Setogawa area

30 chemical analyses of detrital clinopyroxenes were obtained from the sandstones of the lower part of the upper Kushigatayama Subgroup. The detrital clinopyroxenes obtained from the Kushigatayama Subgroup can be divided into two groups on the scheme of Morimoto (1988), though these detrital clinopyroxenes belong to augite (Fig. 44). The one group is composed of 28 grains of augite, and the other group is composed of augite and diopside. The augite of the first group are Ca-rich and Fe-poor. TiO_2 wt% range is 0.13 to 0.38. Cr wt% range is 0.00 to 0.04. Na wt% range is 0.20 to 0.36, and Al wt% range is 0.62 to 1.45. The second group clinopyroxene are characterized by high Cr content and thier Cr wt% are > 0.5.

3-8. Discussion

3-8-1. Modal compositions of sandstone

Mineoka area

According to the diagram of Dickinson et al. (1983), the Mineoka Group sandstones are plotted in the field of Recycled Orogen or Mixed (Fig. 20). The sandstones of the Fukawa Formation of the Hota Group are more quartz-feldspathic than those of the Mineoka Group, and they are plotted in the field of Continental Block. The sandstones of the rest of the Hota Group and the Futatsuyama Formation are more lithic than those of the Mineoka Group and are plotted in the field of Dissected to Transitional Magmatic Arc. The sandstones of the rest of the Hota Group and the Futatsuyama Formation contain intermediate to mafic volcanic rock fragments abundantly, and seem to have a different provenance from those of the Mineoka Group and the Fukawa Formation. The Sakuma Group sandstones are further lithic and are plotted in the field of Transitional to Undissected Magmatic Arc. However, the sandstones of this group contain not only volcanic fragments but also abundant fragments of mudstone. Most of the detritus of the Sakuma Group seem to have been supplied from the adjacent area. In fact, conglomerates of the Sakuma Group contain many clasts of sedimentary and volcanic rocks of the Mineoka and Hota Groups (Saito, 1991).

As mentioned above, there is a possibility that the alternation of sandstone and shale of the Mineoka Group is Paleogene. However, if the Mineoka Group sandstone is lower Miocene as reported by Saito (1992), the variety of the framework mode observed in the Mineoka and Hota Group sandstones suggest that there were three sedimentary basins which have different provenances in the Early Miocene around the Mineoka area.

As for the sandstones from tectonic blocks, two leucocratic sandstones at Hegurinaka and Yohka Beach show a similar distribution of the plots with those of the Fukawa Formation sandstone (Fig. 20). The serpentine sandstones at Mineokasengen and Yohka Beach are plotted extremely near to the vertex of L and Lt in the Q-F-L and Qm-F-Lt diagrams of Dickinson et al. (1983); in the field of Magmatic Arc of the Q-F-L diagram and in the field of Recycled Orogen of the Qm-F-Lt diagram. However, an assemblage of rock fragments of the serpentine sandstone at Yohka Beach is different from that of the other serpentine sandstones. The serpentine sandstone at Yohka Beach contains not only mafic and ultramafic rock fragments but also fragments of mudstone and a minor amount of felsic volcanic rock fragment. The provenance of the serpentine sandstone at Yohka Beach seems to be different from that of the serpentine sandstones at Mineokasengen.

Setogawa area

According to the diagram of Dickinson et al. (1983), the Mikura Group sandstones are plotted in the field of Dissected to Transitional Magmatic Arc (Fig. 23). The sandstones of the Setogawa Group show a similar distribution of the plots to the Mikura Group sandstones (Fig. 23), though their distributional area of the plots is slightly wider than that of Mikura Group sandstones. The sandstones of the Takayama Thrust Sheet of the Setogawa Group are plotted in the field of Dissected to Transitional Magmatic Arc, while the sandstones of the Oigawa Thrust Sheet are plotted in the field of Recycled Orogen or Mixed to Dissected Arc. The sandstones of the Kurami Group are more lithic than those of the Setogawa Group, and are plotted in the field of Transitional Magmatic Arc (Fig. 23). The modal compositions of the Koma Group sandstones are different among the sandstones from the each horizon (Fig. 23). The sandstones of the lower part of the upper Kushigatayama Subgroup are very lithic and are plotted in the field of Undissected Magmatic Arc. The sandstones from the upper horizon of the Kushigatayama Subgroup are more quartz-feldspathic and are plotted in the field of Transitional Magmatic Arc. The sandstones from the uppermost part of the Kushigatayama Subgroup show a similar distribution of the plots to those of the Setogawa Group. The sandstones from the lower part of the Momonoki Subgroup also show a similar distribution of the plots to those of the Setogawa and Mikura Groups, and are plotted in the field of Recycled Orogen or Mixed to Dissected Arc. The sandstones from the upper part of the Momonoki Subgroup are more lithic and are plotted in the field of Transitional Magmatic Arc. These sandstones show a similar distribution of the plots to those of the Kurami Group.

The modal compositions of the sandstones from the Mikura and Setogawa Groups, the uppermost part of the Kushigatayama Subgroup and the lower part of the Momonoki Subgroup are similar to each other (Fig. 23). This means that the composition of detritus supplied to the Setogawa area had not changed from the Eocene to the early Middle Miocene. The sandstones of these groups contain fragments of mudstone, chert, granite and felsic volcanic rock. As possible source rocks for these rock fragments near the Setogawa area, there are shale and chert in the Shimanto, Chichibu and Mino Belts, granites in the Ryoke Belt and volcanic rock of the Nohi Rhyolites. The sandstones of the Kurami Group and the upper part of the Kushigatayama Subgroup are more lithic than sandstones of the Mikura and Setogawa Groups, though an assemblage of rock fragments is same as ones of the Mikura and Setogawa Groups. The sandstones of the lower part of the upper Kushigatayama Subgroup contain intermediate to mafic volcanic rock fragments abundantly, and they seem to have a different provenance.

Comparison of modal compositions of sandstones from the Mineoka and Setogawa areas

The modal compositions of sandstones in the Mineoka and Setogawa areas were compared with each other and those of the sandstones in the adjacent area. As mentioned by Watanabe and Iijima (1990), the modal compositions of the sandstones of the Mineoka and Setogawa Groups are similar to each other and also similar to those of the Sagamiko Group in the Kobotoke Belt (Sakai, 1987). Furthermore, the sandstones of the Mikura Group are also similar to those of the Mineoka, Sagamiko and Setogawa Groups. However, the modal compositions of sandstones of the Hota Group which was deposited in the same age as the Setogawa Group and perhaps Mineoka Group are remarkably different from those of the Mineoka, Sagamiko and Setogawa Groups. Although the sandstones of the Hota Group can be divided into two types in terms of the modal composition, both types of sandstones are different from those of the Mineoka and Setogawa Groups; one is more quartz-feldspathic, and the other is more lithic than those of the Mineoka and Setogawa Groups. It is probable that there were at least three sedimentary basins which have a different provenance in the Early Miocene time, respectively.

3-8-2. Clast composition of conglomerate

The conglomerate intercalated in the shale of the Haccho Formation at Fusada is composed mainly of the constituents of the Kamogawa Ophiolitic Complex exposed in the Mineoka Mountains, such as basalt, dolerite, gabbro, serpentinite, metamorphic rock and limestone (Fig. 21). Andesite also occurs in the distributional area of the Hota Group on a small scale, only tens of meters in size (Sakagami et al., 1997). The clasts compositional ratio of this conglomerate, however, differs from that of the tectonic blocks observed in the Mineoka Mountains at present. Concerning their exposure areas (Ogawa, 1981) in the Mineoka Mountains, serpentinites are the most dominant rock and basaltic rocks are subordinate. Gabbro, metamorphic rocks or other rocks occur rarely. The most important difference between this conglomerate and the Kamogawa Ophiolitic Complex is that this conglomerate contains clasts of rhyolite and no clasts of sedimentary rocks except for tuff and limestone. The rhyolite is not distributed in the Mineoka Mountains at present. It is inferred that the source rocks of these clasts were sited near each other and near the depositional site of this conglomerate, because almost all the clasts are angular to sub-angular, and there are little difference in size of the clasts of each rock species. Although it is ambiguous whether the source rocks of these clasts correspond to the precursor rocks in the Mineoka Mountains or not, there is a possibility that the ophiolitic complex had contained rhyolite and andesite at that time and rhyolite and andesite had been dissected and lost at present.

The characteristics of the Fusada conglomerate are also observed similarly in the Motona conglomerates, but not in any other conglomerates in the Mineoka area. The Ishihata conglomerate member of the Takazuru Formation of the Hota Group (Saito, 1992), the Okuzure Formation of the Sakuma Group (Saito, 1991) and the tectonic block of conglomerate at Yohka Beach (serpentine sandstone) contain abundant clasts of the sedimentary rocks such as sandstone and mudstone, but neither rhyolite nor andesite clasts. On the other hand, conglomerates which contain clasts of gabbro, basalt, diorite and rhyolite with small fragments of serpentinite and metamorphic rocks are found in the Odake Thrust Sheet of the Setogawa Group and the upper Kushigatayama Subgroup. As mentioned above, these conglomerates contain many detrital chromian spinels. The conglomerates in the Haccho Formation and the Odake Thrust Sheet are similar to each other in terms of following three points: (1) The clasts of conglomerates are composed mainly of intermediate to mafic plutonic rock and felsic to mafic volcanic rocks with a minor amount of serpentinites and metamorphic rocks. (2) These conglomerates are distributed in near the serpentinite body, and intercalated in the alternation of shale and tuff. (3) As shown later, the chemistry of detrital chromian spinels is different from the chromian spinels in the Mineoka type serpentinites. The conglomerates found in the Kushigatayama Subgroup also satisfy the points of (1) and (3), though they occur as blocks in muddy matrix.

3-8-3. Detrital chromian spinel

Mineoka area

A large amount of detrital chromian spinels occur in the conglomerates of the Haccho Formation at Fusada and Motona and the serpentine sandstone at Mineokasengen and Yohka Beach. Detrital chromian spinels are also obtained from the sandstone of the Mineoka, Hota and Sakuma Groups and the leucocratic sandstone at Hegurinaka, Mineokasengen and Yohka Beach using the heavy liquid separation. These chromian spinels were analyzed, and those chemical data were plotted on three diagrams, namely Mg# vs. Cr# diagram, Cr# vs. TiO_2 wt% diagram and ternary diagram of Cr-Al-Fe^{3+}. There are some differences in their trends of chemical compositions of detrital chromian spinels from each formation or tectonic block (Figs. 24 to 29).

Cr# range of nearly all grains is 0.35 to 0.85, though the serpentine sandstones at Mineokasengen yield spinels whose Cr# is around 0.2 (Fig. 28). Almost all the spinel suites have a negative trend in the Mg# vs. Cr#, while the negative trend of the Hota Group spinel suites, except for those of the Fukawa and Kanigawa Formations, is ambiguous because of a small number of analyses. The negative trend of spinel suites of the conglomerates at Fusada and Motona differs from that of the other spinel suites, and the negative trend slope of spinel suites of those conglomerates are more gentle compared with that of other spinel suites (Fig. 25). The plot areas of the Fusada and Motona conglomerates in the Mg#-Cr# diagram are shifted to the lower Mg# side than those of the other formations or tectonic blocks. According to Arai (1980) and Arai et al. (1990), this shift suggests that the source rocks for these detrital chromian spinels were formed under the lower equilibrium temperature than those of the others.

The Cr# vs. TiO_2 wt% diagrams indicate that there are also some differences among spinel suites. Although almost all the detrital chromian spinels are TiO_2 wt% <0.5, the Mineoka and Sakuma Groups spinel suites have TiO_2 wt% peaks at about 0.5 to 0.7 of Cr# (Figs. 24 and 27). The spinel suites of serpentine sandstones are characterized by an extreme low-Ti in comparison with that of other spinel suites (Fig. 28).

There is somewhat difference in the Fe^{3+}3# range of each formation or tectonic block. The spinel suites of the Mineoka and Sakuma Groups and the Kanigawa Formation of the Hota Group contain many spinels having Fe^{3+}3# more than 0.1 (Figs. 24 to 27).

The chemical analyses of chromian spinels from the Mineoka type serpentinites are given by Arai et al. (1990). Most of the detrital chromian spinels are plotted in the field of the Mineoka type serpentinites in the Mg#-Cr# diagram (Figs. 24, 26 to 29), though the detrital chromian spinels from the conglomerates at Fusada and Motona are plotted in the area between the spinels from the Mineoka type and Hayama type serpentinites (Fig. 25). All the spinel suites, however, contain higher Cr# spinels compared with those from Mineoka type serpentinites (Figs. 24 to 29). In short, the characteristics of source rocks of detrital chromian spinels obtained the

Mineoka area, except for those from the conglomerates at Fusada and Motona, correspond to those of the Mineoka type serpentinites (Arai et al., 1990). The origin of the most of the detrital chromian spinels from the Mineoka area seems to be the same as those of the Mineoka type serpentinites.

Setogawa area

Numerous detrital chromian spinels occur in the conglomerates of the Odake Thrust Sheet of the Setogawa Group and conglomerate blocks in the upper Kushigatayama Subgroup. Detrital chromian spinels are also obtained from the sandstone of the Mikura, Setogawa and Kurami Groups and the Koma Group except for the lower part of the Kushigatayama Subgroup using the heavy liquid separation. These chromian spinels were also analyzed, and those chemical data were plotted on three diagrams, namely Mg# vs. Cr# diagram, Cr# vs. TiO_2 wt% diagram and ternary diagram of Cr-Al-Fe^{3+}. There are also some differences in their trends of chemical compositions of detrital chromian spinels (Figs. 30 to 33).

Cr# range of nearly all grains is 0.25 to 0.90, though most of the chromian spinels from the Mikura Group sandstones have Cr# > 0.55 (Fig. 30). Cr# range of the conglomerates in the Odake Thrust Sheet and the conglomerate blocks of the upper Kushigatayama Subgroup is 0.30 to 0.70 (Figs. 31 and 33). All the spinel suites have a negative trend in the Mg# vs. Cr#, though their negative trends are more ambiguous than those of the spinel suites of the Mineoka area. The negative trends of spinel suites of the conglomerates in the Odake Thrust Sheet and the conglomerate blocks of the upper Kushigatayama Subgroup differ from the other spinel suites, and the negative trend slopes of spinel suites of these conglomerates are gentler in comparison with those of the other spinel suites (Figs. 31 and 33). The plot areas of these conglomerates in the Mg#-Cr# diagram are shifted to the lower Mg# side than those of the others. As mentioned above, this shift suggests that the source rocks for these detrital chromian spinels were formed under the lower equilibrium temperature than those of the others (Arai, 1980; Arai et al., 1990). The spinel suites of the sandstones of the Setogawa and Koma Groups contain chromian spinels with high Mg# and high Cr# (Figs. 31 and 33).

As shown in the Cr# vs. TiO_2 wt% diagrams (Figs. 30 to 33), all the spinel suites in the Setogawa area contains spinels with a relatively higher TiO_2 wt% content, though most of the chromian spinels are TiO_2 wt% < 0.5. Most of the chromian spinels with high TiO_2 wt% are 0.5 to 0.7 in Cr#.

There are few differences in the Fe^{3+}3# range of each formation. All the spinel suites in the Setogawa area contain many spinels having Fe^{3+}3# more than 0.1 (Figs. 30 to 33).

In comparison with the chromian spinels in the Circum-Izu Massif serpentinites, only the chromian spinels from the conglomerates in the Odake Thrust Sheet and the conglomerate blocks of the upper Kushigatayama Subgroup are plotted in the field of the Hayama type serpentinites which are distributed in the Setogawa Belt, in the Mg#-Cr# diagram (Figs. 31 and 33). Most of the detrital chromian spinels from the sandstones of the Setogawa, Kurami and Koma Groups are plotted in the field of the Mineoka type serpentinites in the Mg#-Cr# diagram (Figs. 31 to 33). The detrital chromian spinels from the Mikura Group are not plotted in both the Mineoka and Hayama type serpentinites, and most of them have high Cr# > 0.55. All the spinel suites contain higher Cr# spinels compared with the spinels from Mineoka and Hayama type serpentinites (Figs. 30 to 33). In short, the origin of most of the detrital chromian spinels from the sandstones of the Setogawa, Kurami and Koma Groups seems to be the same as those of the Mineoka type serpentinites, while the origin of the detrital chromian spinels from the conglomerates in the Odake Thrust Sheet and conglomerate blocks in the upper Kushigatayama Group seems to be the same as those of the Hayama type serpentinites.

Emplacement of the Circum-Izu Massif serpentinites

As discussed above, the spinel suits except for those of the spinels from the Mikura Group and the conglomerates in the Haccho Formation are composed of the spinels which correspond to those in the Circum-Izu Massif serpentinites. The emplacement process of the Circum-Izu Massif serpentinites has been discussed by some authors (e.g. Ogawa and Taniguchi, 1987; Arai, 1991, 1994a; Fujioka et al., 1995). According to Arai (1991, 1994a), the Circum-Izu Massif peridotite is a backarc basin peridotite origin, and the high Cr# detrital chromian spinels observed in the serpentine sandstone are of the fore-arc peridotites origin. Recently, Ohara (2003) compiled the data of backarc basin peridotites in the Philippine Sea, and showed that the chemical characteristics of chromian spinel in backarc basin peridotite in the Philippine Sea were similar to those of the abyssal peridotite which had been reported by Dick and Bullen (1984). According to Ohara (2003), the Cr# range of chromian spinels in backarc basin peridotites is about 0.2 to 0.6, and the range of TiO_2 wt% is 0.0 to 1.0. The spinels with a relatively higher TiO_2 content have Cr# from 0.4 to 0.6. A peak of TiO_2 wt% is observable nearly at 0.5 of Cr# in the spinel suits of the sandstones of the Mineoka and Sakuma Groups and the conglomerate blocks of the upper Kushigatayama Subgroup (Figs. 24, 27 and 33). It is known that the spinels with a relatively higher TiO_2 content and Cr# at about 0.5 are contained in plagioclase bearing abyssal peridotite and backarc basin peridotite (Dick and Bullen, 1984; Ohara, 2003), and the serpentinites in the Mineoka Mountains contain plagioclase characteristically (Arai and Takahashi, 1988). Although serpentinites bearing such high Ti spinels have not been confirmed in the Mineoka Mountains so far, those serpentinites seem to have been exposed in the Early to early Middle Miocene. It is supposed that most of the low Ti spinels (TiO_2 wt% < 1.0) with Cr# 0.2 to 0.6 had been supplied from the abyssal or backarc basin peridotites.

The sandstones and conglomerates in the Mineoka and Setogawa areas, contain not only the spinels with Cr# 0.2 to 0.6 but also those with Cr# > 0.6 (Figs. 24 to 33). The high Cr#s are often contained in forearc peridotite (e.g. Ishii et al., 1992) but also in boninite (e.g. Barnes and Roeder, 2001). The ranges of Cr# and Mg# of the detrital chromian spinels from the Mikura Group are mostly 0.55 to 0.85, and 0.3 to 0.65, respectively (Fig. 30). These characteristics are similar to those of the forearc peridotite, but are not similar to those of the boninite. The source rocks of the detrital chromian spinels in the Mikura Group seem to have had a forearc peridotite as its origin. The chromian spinels with high Cr# in the other groups or tectonic blocks in the Mineoka and Setogawa areas also seem to have been supplied from the forearc peridotites, though there is a possibility still that these are boninite in origin. In fact, occurrences of a small amount of boninite like high-magnesian and high-silica volcanic rock have been reported from the Odake Thrust Sheet of the Setogawa Group (Ohashi and Shiraki, 1981). According to Ohashi and Shiraki (1981) and Barnes and Roeder (2001), the range of Cr# and Mg# of the chromian spinel in boninites are 0.5 to 0.7 and 0.6 to 0.9, respectively. Some grains of each spinel suite in the Mineoka and Setogawa areas are plotted in this area, and there is a possibility that these detrital chromian spinels were supplied from boninites.

The high-Ti spinels ($TiO2$ wt% > 1.0%) are also contained in the spinel suites of the Mineoka and Setogawa areas except for the spinel suits of the conglomerates in the Odake Thrust Sheet and the Haccho Formation, and blocks of the upper Kushigatayama Subgroup. The plot distributions of the high-Ti spinels of the Mineoka and Sakuma Groups spinel suites at 0.5 to 0.8 of Cr# correspond to the spinels in a basaltic clast from the Sakuma Group (Figs. 24 and 27) and to the spinels in alkaline and picrite basalts accompanied with the Circum-Izu Massif serpentinites (Tazaki, 1975; Tazaki and Inomata, 1980; Ishida et al., 1988, 1990; Taniguchi and Ogawa, 1990).

The detrital chromian spinels from the conglomerates in the Haccho Formation at Fusada and Motona are plotted in an intermediate field between the fields of spinels in the Mineoka and Hayama type serpentinites yielding high Cr# spinels (Fig. 25). It is inferred that the discrepancy between the source rocks of the detrital chromian spinels from the conglomerates in the Haccho Formation and the Circum-Izu Massif peridotites is caused by difference of an equilibrium temperature of the peridotites-genesis (e.g. Arai et al., 1990). Taking into account that the clast compositions of these conglomerates are similar to those in the Odake Thrust Sheet of the Setogawa Group, it is presumed that there was serpentinites characterized by intermediate characteristics between the Mineoka and Hayama type serpentinites in the Early Miocene time. The plot distributions of these conglomerates spinel suites in the Mg#-Cr# diagram are similar to those of diapiric serpentinites seamounts in the forearc region in the Izu-Ogasawara-Mariana arc (Ishii et al., 1992).

To summarize the above-mentioned discussion of the detrital chromian spinels, the forearc peridotites had supplied detrital chromian spinels to the Setogawa area until the Oligocene, and the Circum-Izu Massif serpentinites was emplaced in the early Early Miocene. The alkaline and picrite basalts accompanied with the Circum-Izu Massif serpentinites also seem to have been emplaced in the early Early Miocene. However, the high Ti chromian spinels are barren in the spinel suites of the conglomerates in the Odake Thrust Sheet and the Haccho Formation and blocks of the upper Kushigatayama Subgroup, even though these conglomerates contains a large amount of basalt clasts. It is probable that those alkaline and picrite basalts had not been emplaced yet when these conglomerates were deposited. The spinel suites of these conglomerates have common characteristics, that is, their negative trend slopes in the Mg#-Cr# diagram are more gentle than that of the Mineoka type serpentinites. This characteristic is similar to that of the Hayama type serpentinites. On the other hand, the spinel suites of the early Early Miocene Takayama Thrust Sheet are plotted in the field of the Mineoka type serpentinites, and they contain many high Ti chromian spinels. It is presumed that the Hayama type serpentinites were firstly emplaced in the earliest early Miocene, and after that, the Mineoka type serpentinites were emplaced with alkaline and picrite basalts. Although the Mineoka type serpentinites are not distributed in the Setogawa area at present, it is presumed that they were also distributed in the Setogawa area at least in the Early Miocene. This is because the spinel suit of the Kurami Group which was deposited in forearc basin near the serpentinites in the Setogawa Group are plotted in the field of the Mineoka type serpentinites.

3-8-4. Detrital garnet

Mineoka area

The detrital garnets from the sandstones of the Mineoka Group, the Fukawa and Kanigawa Formations of the Hota Group, the Sakuma Group, the Futatsuyama Formation, and the leucocratic sandstone at Hegurinaka, Mineokasengen and Yohka Beach were analyzed. Those chemical data were plotted on the ternary diagrams of almandine—spessartine + ugrandite—pyrope and Mn—Fe—Mg (Figs. 34 to 38). There are differences in the chemical composition of the detrital garnets from each formation or tectonic block. As shown in these diagrams, the plots of the garnets from the Mineoka Group, the Fukawa Formation and the leucocratic sandstones show similar distributions (Fig. 34, 35 and 38). Those garnets are composed of pyrope-rich almandine. The Sakuma Group sandstones also contain such pyrope-rich almandines (Fig. 36). According to Teraoka et al. (1998) and Tanaka and Adachi (1999), those garnets are contained in high-grade intermediate P/T metamorphic rocks (granulite facies) which have a muddy to sandy rocks in origin. They also mentioned that granulite which contains extremely pyrope-rich almandines had not been found from the Honshu arc, and such garnets were contained in gneisses comprising the continental basement. The pyrope-rich detrital garnets obtained from the Mineoka area seem to suggest such gneiss as their origin. However, the occurrence of such pyrope-rich almandines have been reported from the Jurassic to Cretaceous sandstones in the Mino, Chichibu and Shimanto Belts (e.g. Adachi and Kojima, 1983; Takeuchi, 1986; Teraoka et al., 1997). There is a possibility that the pyrope-rich detrital garnets from the Mineoka area have been reworked from such sandstones. Taking into account the modal compositions of sandstones and frequencies of the occurrence of detrital garnets, most of the pyrope-rich detrital garnets except for those from the Fukawa Formation and the leucocratic sandstones seem to be recycled garnets. However, there is still a possibility that the detrital garnets in the Fukawa Formation and the leucocratic sandstones were directly supplied from the continental basement of the Asian Continent. This is because of the following three points: 1) the modal compositions of those sandstones are plotted in the field of Continental Block (Fig. 20) in the diagrams of Dickinson et al. (1983), 2) those sandstone contain a large amount of detrital garnet (more than 20 grains per one thin-section), 3) it is known that the Japan Sea had not opened when the early Miocene Fukawa Formation was deposited (e.g. Otofuji et al., 1985). Because the modal compositions of sandstone and chemistries of the detrital garnets from the Kanigawa Formation which overlies the Fukawa Formation are different from those of the Fukawa Formation sandstones, the sediments from the continental basement seem to have been supplied temporarily.

The detrital garnets from the sandstones of the Futatsuyama Formation consist mostly of spessartine-rich almandine, and the sandstones of the Mineoka Group, the Kanigawa Formation of the Hota Group, and the Sakuma Group also contain spessartine-rich almandine. Such spessartine-rich almandines are contained in granitic rocks and low P/T metamorphic rocks (e.g. Teraoka et al., 1998). There are some blocks of metamorphic rocks containing garnets in the Mineoka Belt (Kanehira et al., 1968; Ogo and Hiroi, 1991). According to Ogo and Hiroi (1991), the garnets in the metamorphic rocks of the Mineoka Belt are spessartine-rich almandine, however, those chemistries are different from the detrital garnets from the Mineoka area (Figs. 34 to 38). The detrital garnets of the spessartine-rich almandine in the Mineoka area seem to have been supplied from granitic rocks or low P/T metamorphic rocks such as those in the Ryoke Belt. It is known that metamorphic rocks in the Ryoke Belt contain spessartine-rich almandine (e.g. Asami and Hoshino, 1980; Ono, 1981).

Setogawa area

Except for the detrital garnets from the Mikura Group sandstones, the detrital garnets obtained from the Setogawa area show similar tendencies one another. The detrital garnets from the Mikura Group sandstones consist mostly of spessartine-rich almandine, while those from the sandstones of the other groups are composed of pyrope-rich almandine and spessartine-rich almandine (Figs. 39 to 42). As discussed above, detrital garnets of the spessartine-rich almandine in the Mineoka area seem to have been supplied from granitic rocks or low P/T metamorphic rocks in the Ryoke Belts, and those of the spessartine-rich almandine seem to have been supplied from high-grade intermediate P/T metamorphic rocks such as granulite facies. Taking into account that the modal compositions of sandstones in the Setogawa area are plotted in the field of Recycled Orogen to Magmatic Arc and that the frequency of the detrital garnets is conspicuous, most of the pyrope-rich detrital garnets seem to be reworked garnets from the Chichibu, Mino and Shimanto Belts.

3-8-5. Detrital clinopyroxene

Mineoka area

The detrital clinopyroxenes from sandstones of the Hota and Sakuma Groups and the Futatsuyama Formation, conglomerates in the Haccho Formation of the Mineoka Group and the serpentine sandstones were analyzed, and those chemical analyses were plotted on the three diagrams proposed by Leterrier et al. (1982). Their diagrams are useful for the clinopyroxenes in the basaltic rocks, and they are not applicable to the detrital chromian diopsides which originate from ultramafic rocks. Because all the detrital clinopyroxenes from the conglomerates in the Haccho Formation at Fusada were chromian diopsides, these discrimination diagrams proposed by Leterrier et al. (1982) were not appropriate to them.

According to their diagrams, the detrital clinopyroxenes obtained in this study are discriminated into three categories. The detrital clinopyroxenes from the Hota and Sakuma Groups and the Futatsuyama Formation are plotted in the field of orogenic calcalkali basalts (Figs. 46 to 48), while the clinopyroxenes from the conglomerates of the Haccho Formation at Motona and the serpentine sandstone at Yohka Beach are plotted in the field of orogenic tholeiitic basalts (Figs. 45 and 49). Only the clinopyroxenes from the serpentine sandstone at Mineokasengen are plotted in the field of non-orogenic basalts such as MORB, though the plots are rather scattered (Fig. 50).

These detrital clinopyroxenes are compared with those in the igneous rocks in and around the Boso Peninsula based on the three categories discriminated by the diagrams of Leterrier et al. (1982). In the Mineoka Mountains, serpentinites and basaltic rocks bearing clinopyroxenes are distributed. Chemical analyses of the clinopyroxenes in these rocks are reported by Uchida and Arai (1978) and Tazaki and Inomata (1980), respectively. According to Uchida and Arai (1978), the clinopyroxenes in the serpentinites are all chromian diopside. The chemical analyses of clinopyroxenes in the basaltic rocks shown by Tazaki and Inomata (1980) are also plotted in the field of non-orogenic basalt in the diagram of Leterrier et al. (1982). This assemblage of chromian diopsides and non-orogenic basalts origin clinopyroxenes is similar to that of detrital clinopyroxenes from the serpentine sandstones at Mineokasengen. Furthermore, it is known that a small amount of tholeiitic basalts which are considered as an arc origin occur in the Mineoka Mountains (Sato et al. 1999), though the chemical analyses of clinopyroxenes in those basalts has not obtained. There is a possibility that the source rocks of detrital clinopyroxenes from the conglomerates of the Haccho Formation at Motona and the serpentine sandstone at Yohka Beach correspond to this arc-type tholeiitic basalt. As for the source rocks of detrital clinopyroxenes from the Hota and Sakuma Groups and the Futatsuyama Formation, there is no exposure of igneous rocks which can be the source rocks for these detrital clinopyroxenes in the Boso Peninsula.

The volcanic rocks in the Izu arc and Miura Peninsula are possible for source rocks of detrital clinopyroxenes from the Hota and Sakuma Groups and the Futatsuyama Formation. Fujioka and Saito (1992) reported the chemical analyses of

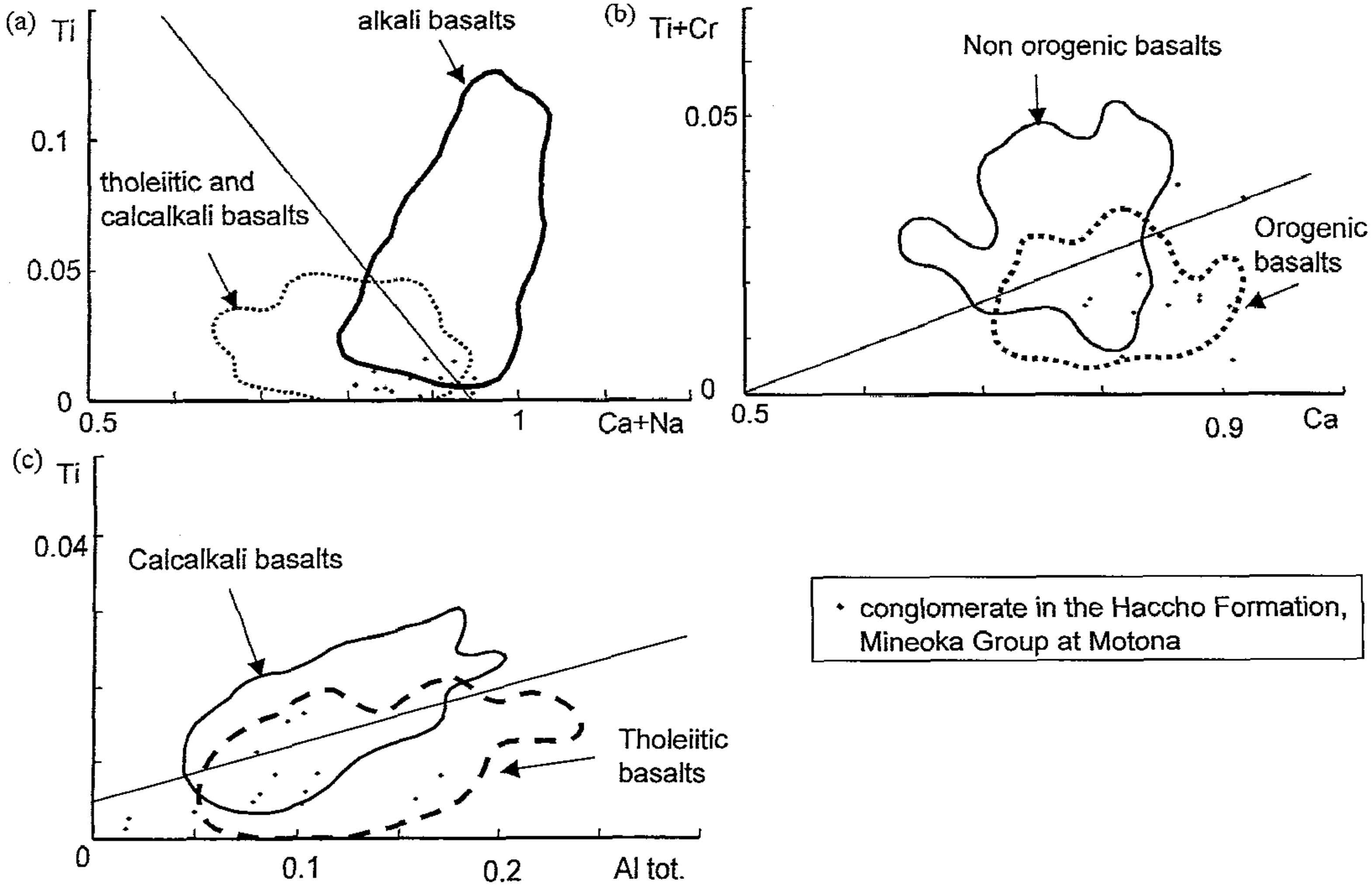


Fig. 45. Discrimination diagrams for detrital clinopyroxenes from conglomerate of the Haccho Formation, Mineoka Group. After Leterrier et al. (1982). (a) Ti vs. Ca+Na diagram, (b) Ti+Cr vs. Ca diagram, (c) Ti vs. total Al diagram. All values are in formula units based on 6 oxygens

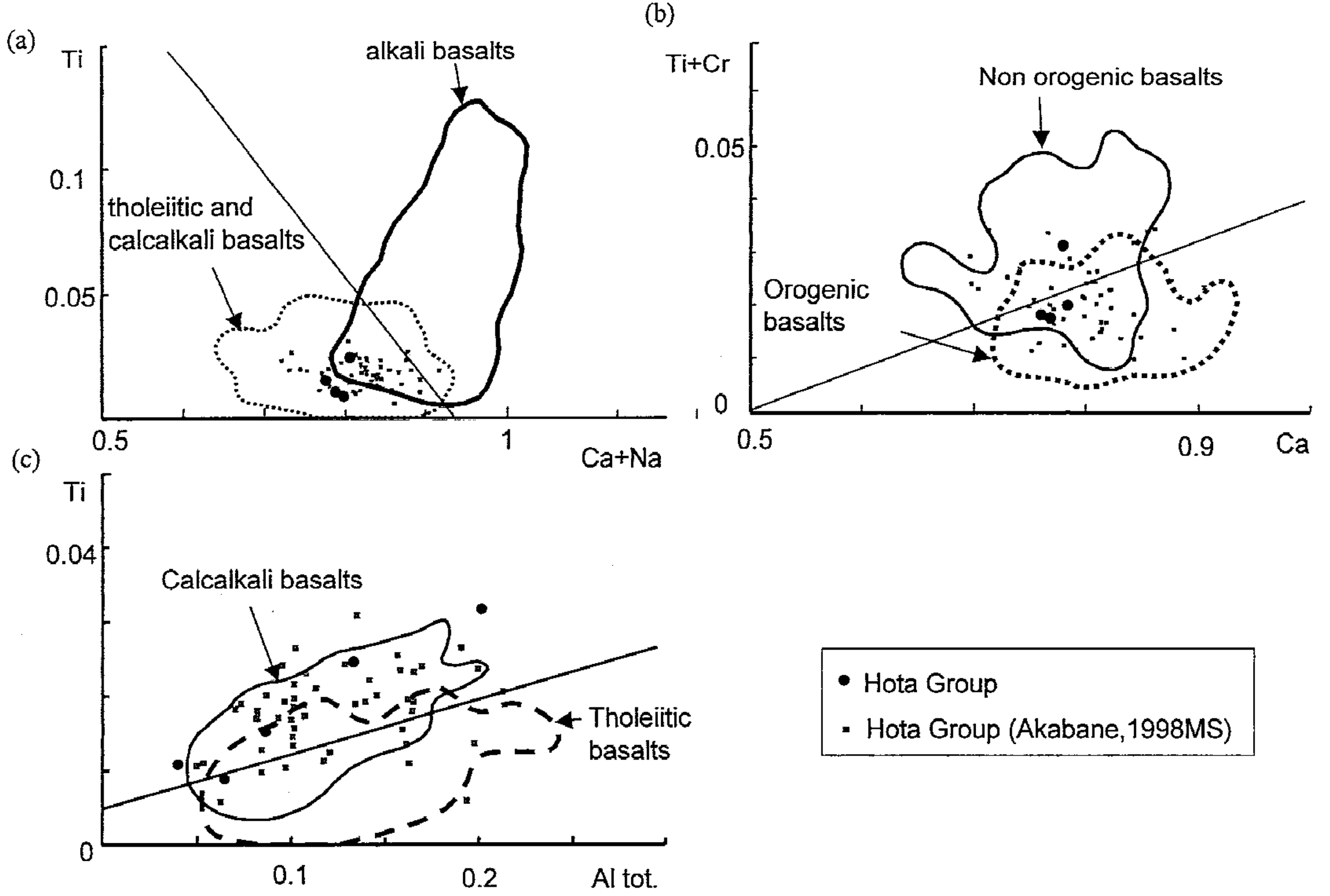


Fig. 46. Discrimination diagrams for detrital clinopyroxenes from the Hota Group. After Leterrier et al. (1982). (a) Ti vs. Ca+Na diagram, (b) Ti+Cr vs. Ca diagram, (c) Ti vs. total Al diagram. All values are in formula units based on 6 oxygens

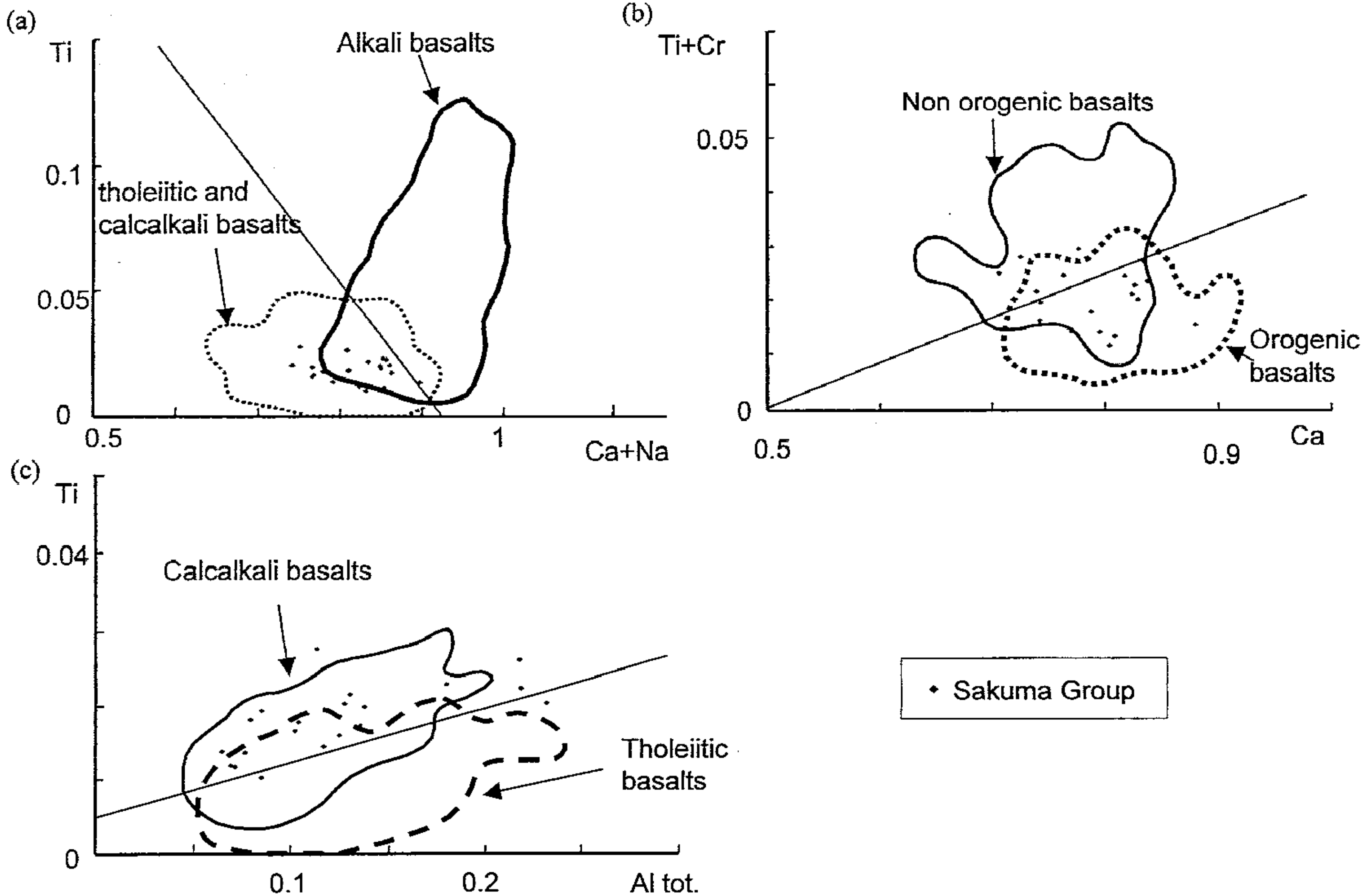


Fig. 47. Discrimination diagrams for detrital clinopyroxenes from the Sakuma Group. After Leterrier et al. (1982). (a) Ti vs. Ca+Na diagram, (b) Ti+Cr vs. Ca diagram, (c) Ti vs. total Al diagram. All values are in formula units based on 6 oxygens

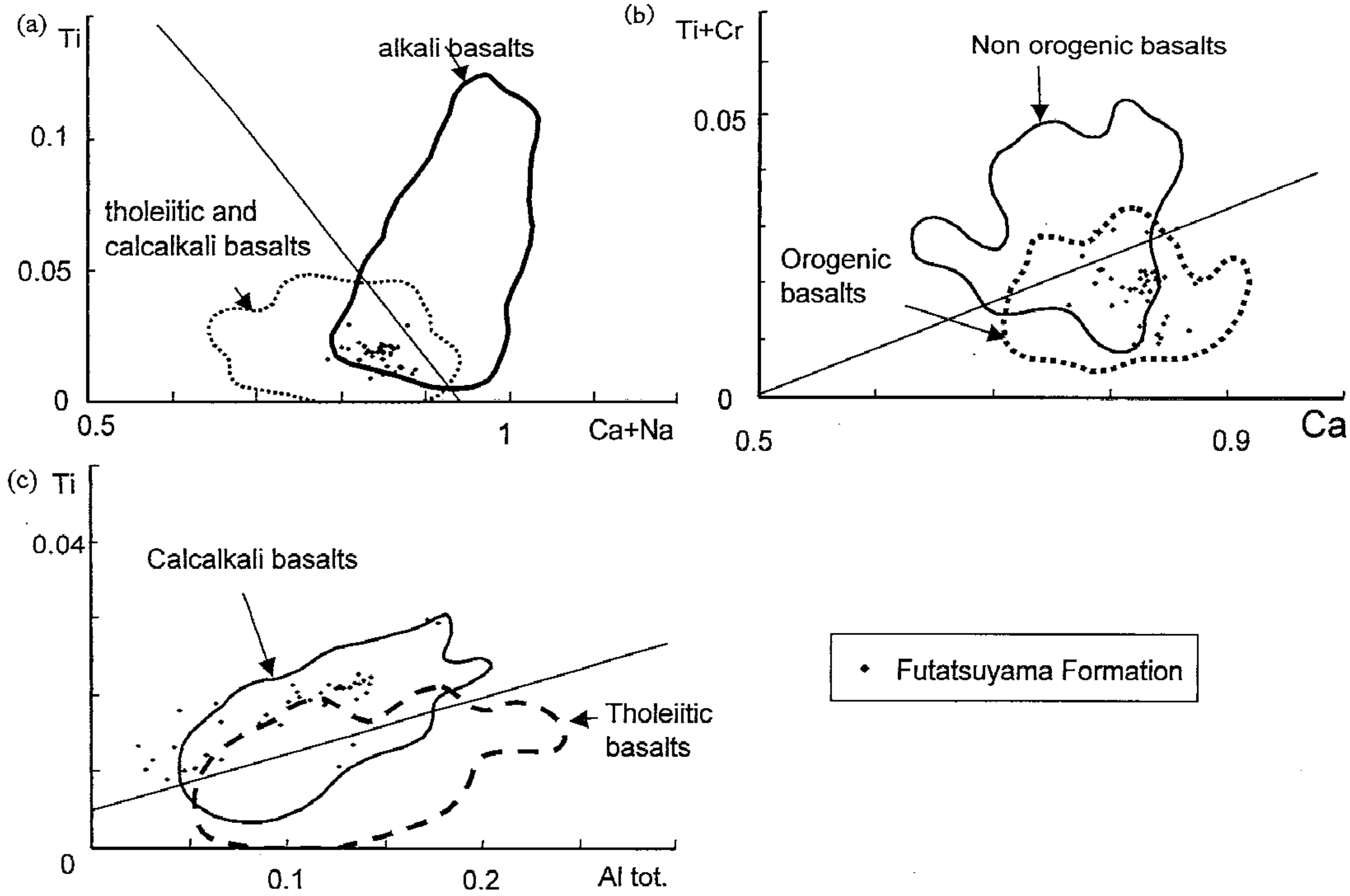


Fig. 48. Discrimination diagrams for detrital clinopyroxenes from the Futatsuyama Formation. After Leterrier et al. (1982). (a) Ti vs. Ca+Na diagram, (b)Ti+Cr vs. Ca diagram, (c) Ti vs. total Al diagram. All values are in formula units based on 6 oxygens

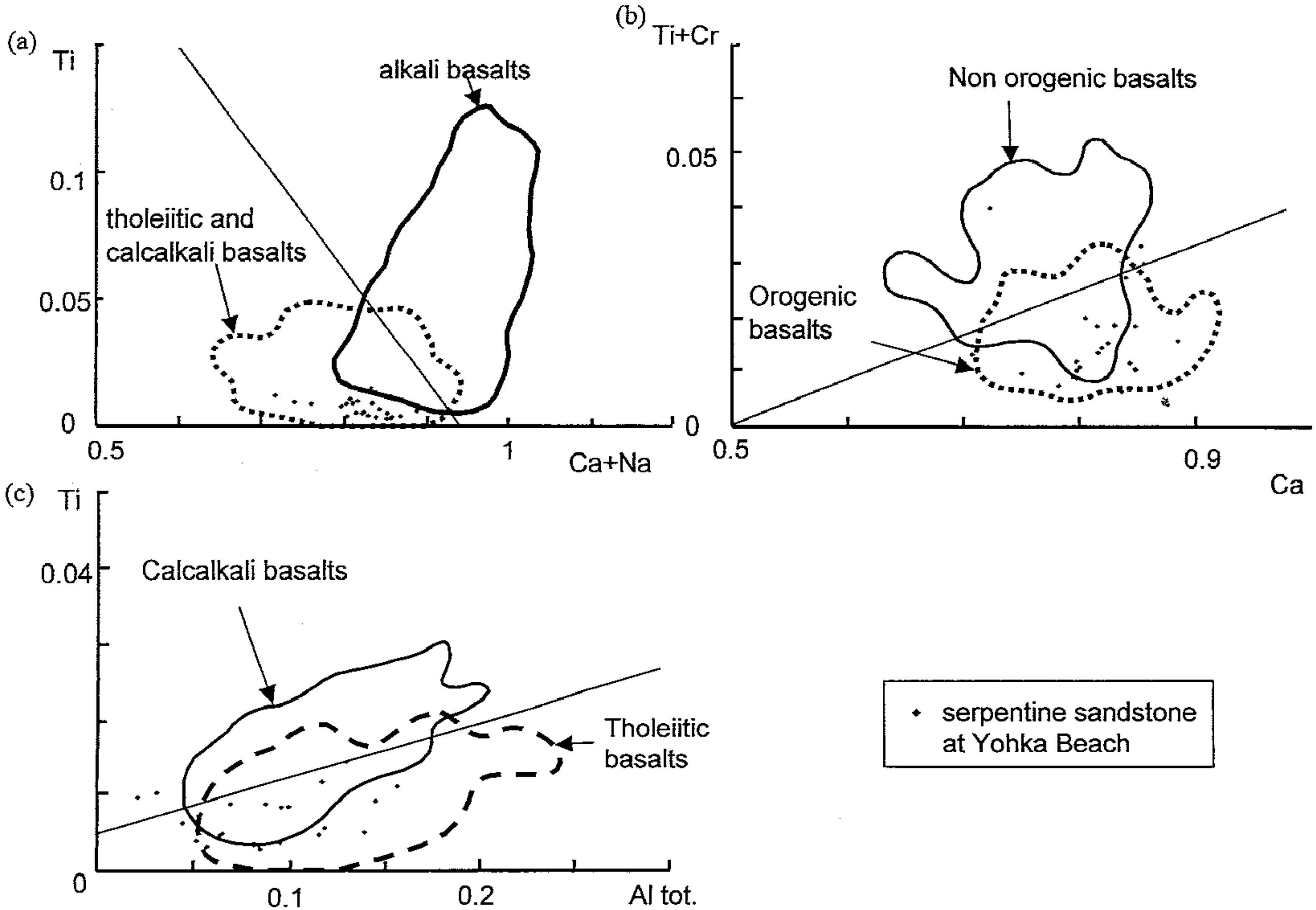


Fig. 49. Discrimination diagrams for detrital clinopyroxenes from the serpentine sandstone at Yohka Beach. After Leterrier et al. (1982). (a) Ti vs. Ca+Na diagram, (b) Ti+Cr vs. Ca diagram, (c) Ti vs. total Al diagram. All values are in formula units based on 6 oxygens

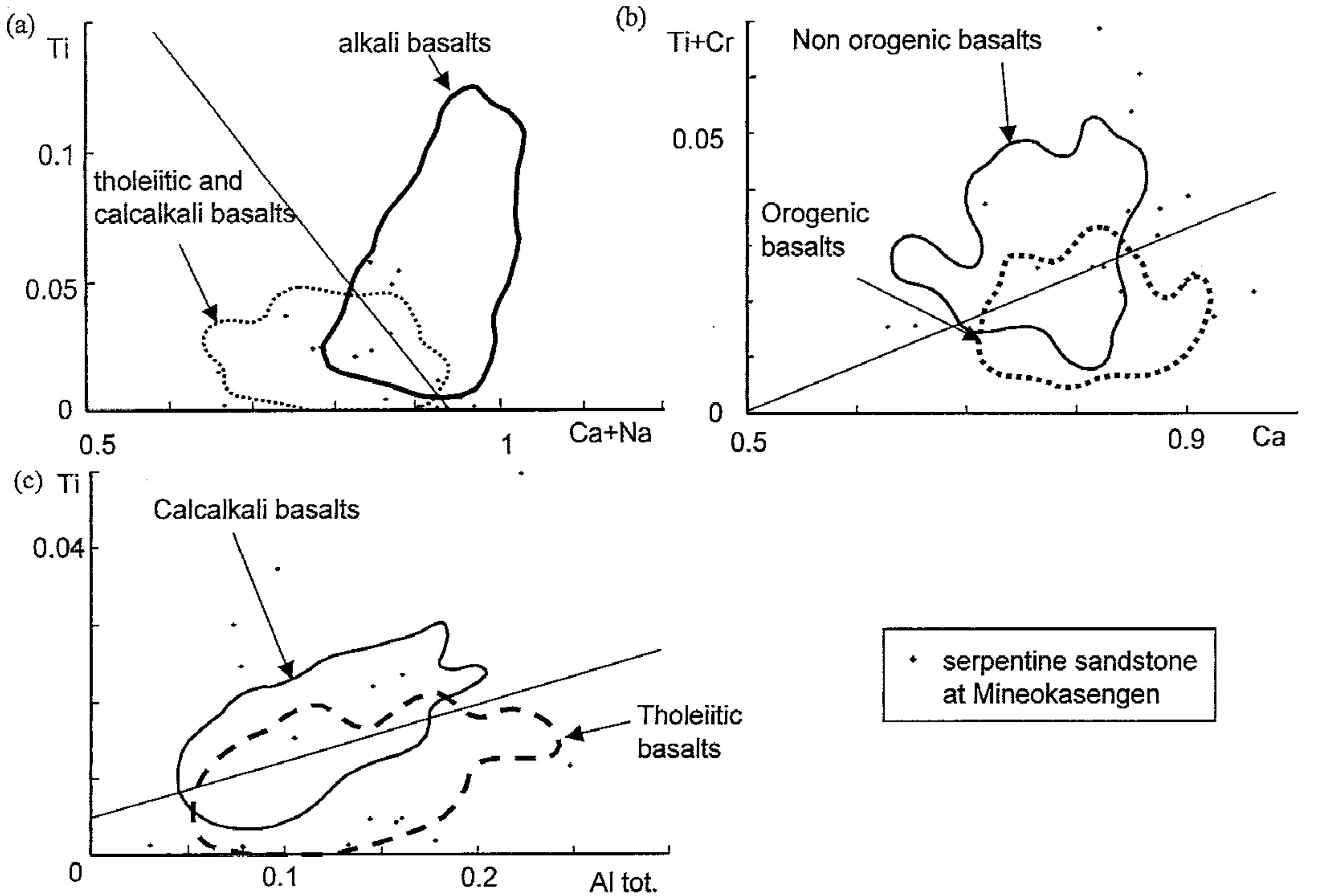


Fig. 50. Discrimination diagrams for detrital clinopyroxenes from the serpentine sandstone at Mineokasengen. After Leterrier et al. (1982). (a) Ti vs. Ca+Na diagram, (b) Ti+Cr vs. Ca diagram, (c) Ti vs. total Al diagram. All values are in formula units based on 6 oxygens.

detrital clinopyroxenes in the volcaniclastic rocks derived from the boring cores around the Izu Islands. According to them, all the detrital clinopyroxenes are Ti-poor, and their cation of Ti (6 oxygenes) is concentrated in the range of 0.0 to 0.1. Those characteristics differ from those of the detrital clinopyroxenes from the Hota and Sakuma Groups and the Futatsuyama Formation. Taniguchi et al. (1988) described the occurrence of the intrusive andesite from the Miura Peninsula, and reported its age as 23.4±0.8 Ma. According to them, this andesite intruded into the mudstone of the Hayama Group, which is correlated to the Hota Group (e.g. Ogawa, 1980), and this andesite belongs to the calcalkali rock series. Taniguchi et al. (1988) also reported the chemical analyses of clinopyroxenes in this andesite. The chemical analyses of these clinopyroxenes are plotted in the field of calcalkali basalts the same as detrital clinopyroxenes from the Hota and Sakuma Groups and the Futatsuyama Formation. Taniguchi et al. (1988) considered that this andesite was generated by magmatism in the Izu arc or the Northeast Honshu arc. There is a possibility that the source rocks of detrital clinopyroxenes from the Hota and Sakuma Groups and the Futatsuyama Formation were a product by the same magmatism which generated the andesite in the Miura Peninsula.

Setogawa area

The detrital clinopyroxenes from the sandstones of the lower part of the upper Kushigatayama Subgroup of the Koma Group were analyzed, and those chemical analyses are plotted on the three diagrams proposed by Leterrier et al. (1982). Two detrital clinopyroxenes which have Cr_2O_3 wt.% > 0.5 are excluded from the discrimination diagrams. The detrital clinopyroxenes from the lower part of the upper Kushigatayama Subgroup are plotted in the field of orogenic tholeiitic basalts (Fig. 51).

The lower part of the Kushigatayama Subgroup is composed of lavas and volcaniclastic rocks (e.g. Koyama, 1993). The chemical composition of lava and

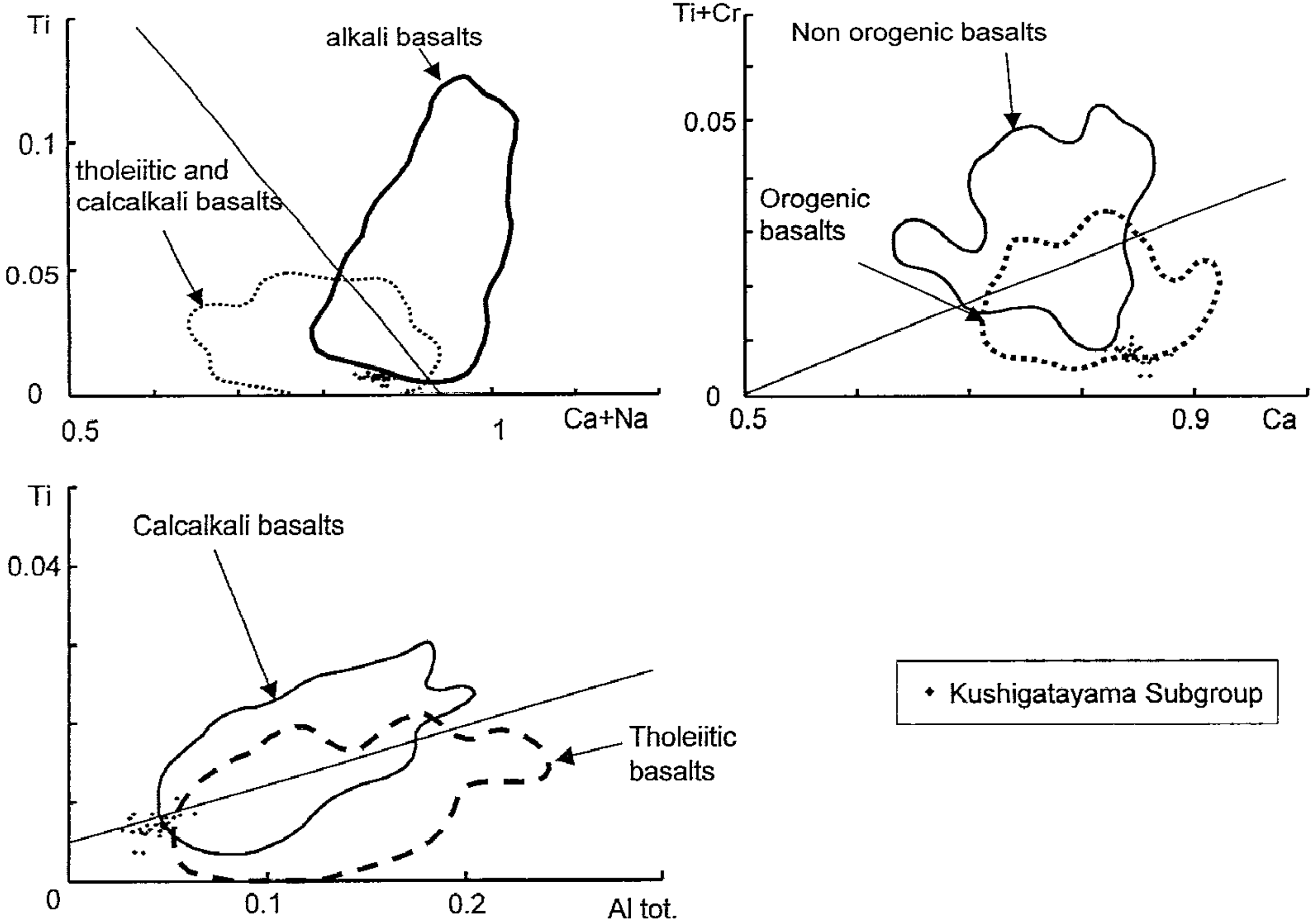


Fig. 51. Discrimination diagrams for detrital clinopyroxenes from the Kushigatayama Subgroup of the Koma Group. After Leterrier et al. (1982). (a) Ti vs. Ca+Na diagram, (b) Ti+Cr vs. Ca diagram, (c) Ti vs. total Al diagram. All values are in formula units based on 6 oxygens

clinopyroxene of the Kushigatayama Subgroup has been reported by Shimazu and Ishimaru (1987). According to them, the volcanic rocks of the Kushigatayama Subgroup belong to island arc tholeiite, and the clinopyroxenes comprise diopside, augite and chrome diopside. The chrome diopside occurs as a megacryst. The chemistry of the detrital clinopyroxenes from the upper Kushigatayama Subgroup is similar to those in the lava and volcaniclastic rocks in the lower Kushigatayama Subgroup in terms of that detrital clinopyroxenes are plotted in the field of orogenic tholeiitic basalt and that they contains a small amount of chrome diopside.

As mentioned above, Fujioka and Saito (1992) reported the chemical analyses of detrital clinopyroxenes in the volcaniclastic rocks derived from the boring cores around the Izu Islands. The chemical characteristics of those clinopyroxenes are also similar to those of the detrital clinopyroxenes from the Kushigatayama Subgroup.

3-8-6. Belongings of the Futatsuyama Formation and tectonic blocks in the Mineoka Belt

The sandstones of the Futatsuyama Formation and the Hota Group except for the Fukawa and Kanigawa Formations are similar to each other in terms of modal compositions of sandstones and chemistry of detrital clinopyroxenes. Thus, there is a possibility that the Futatsuyama Formation belongs to the Hota Group. However, the Futatsuyama Formation sandstones contain a larger amount of the detrital garnets than the Hota Group except for the Fukawa and Kanigawa Formations, and the chemistries of those detrital garnets are different from those of the Fukawa and Kanigawa Formations. The difference of the chemical compositions of detrital garnets seems to be explained by the abrupt change such as the feeding route of the sediments.

The belongings of tectonic blocks of clastic rocks are considered based on the above-mentioned results. It is presumed that the tectonic blocks of leucocratic sandstone at Hegurinaka, Mineokasengen and Yohka Beach belong to the Fukawa

Formation of the Hota Group, because the framework composition of the sandstone and the chemical compositions of detrital chromian spinel and garnet are similar to each other.

The tectonic blocks of serpentine sandstones seem to have two origins. The serpentine sandstone at Yohka Beach seems to belong to the Sakuma Group, because the clast assemblage of the conglomerate is similar to each other and both the sandstone of the Sakuma Group and the serpentine sandstone characteristically contain abundant fragments of mudstone. The framework compositions of the sandstone and the chemical compositions of detrital chromian spinel and clinopyroxene seem to reflect the local difference of the lithology of the provenance.

However, it is impossible to infer the belonging of the serpentine sandstones at Mineokasengen, because the chemistries of detrital chromian spinel and clinopyroxene differ undoubtedly from those from the other sandstones in the Mineoka area.

The timing when the tectonic blocks of clastic rocks were caught in the sheared basalts or serpentinites as tectonic blocks seems to be in the period of sedimentation of the Sakuma Group. This is owing to the following two points; 1) There is no tectonic block of clastic rocks which belong to the Miura Group which conformably overlies the Sakuma Group. 2) There was a right lateral faulting in the Mineoka Belt in the early Middle Miocene (Saito, 1991). The serpentine sandstone at Yohka Beach seems to be caught in the fault zone just after its sedimentation.

3-8-7. Reconstruction of paleogeography around the Mineoka-Setogawa area

The paleogeography around the Mineoka-Setogawa area from the Eocene to early Middle Miocene was reconstructed based on the modal composition of sandstones and the chemistries of the detrital heavy minerals obtained in this study (Figs. 52 to 56).

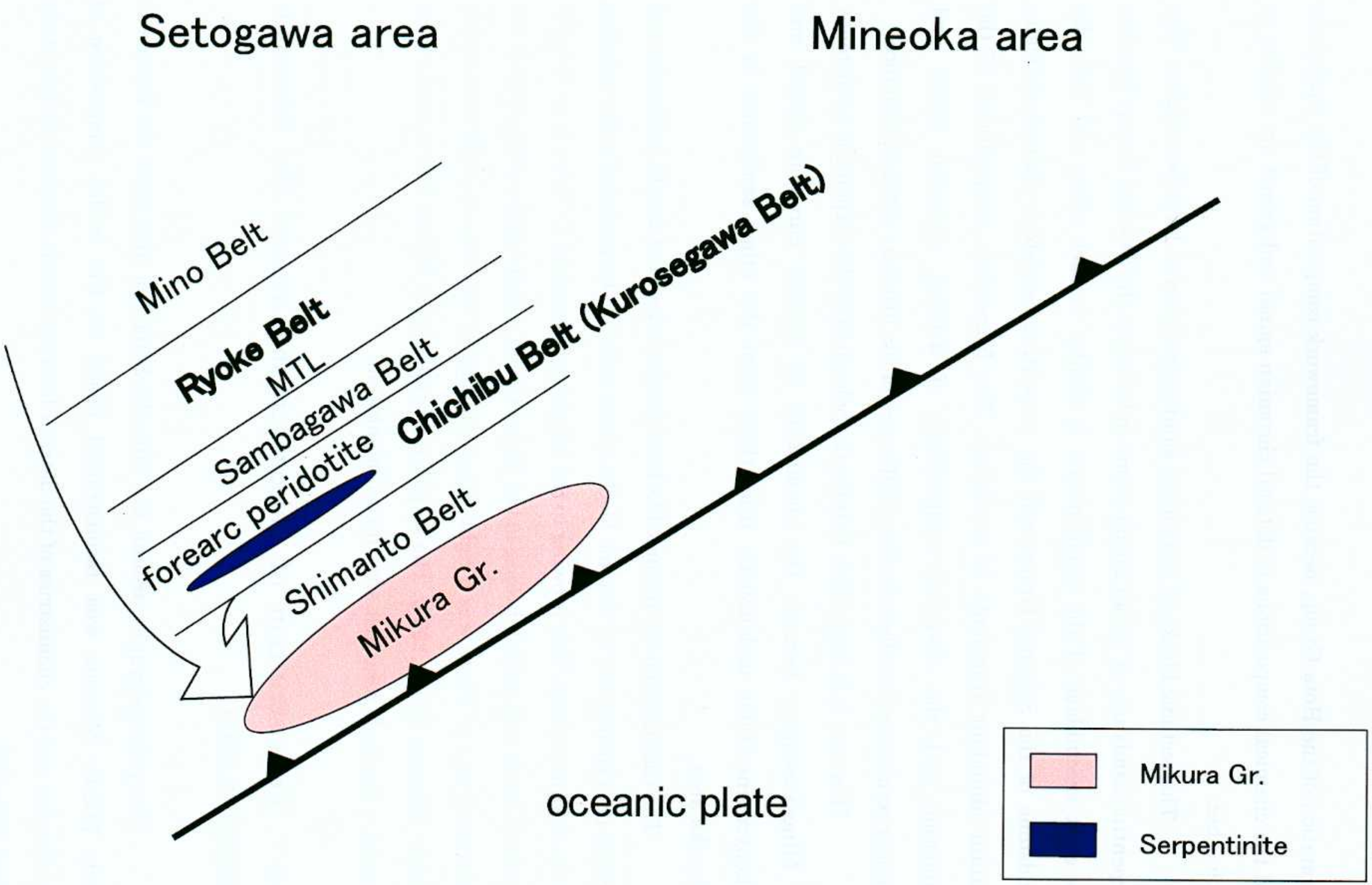


Fig. 52. Reconstructed paleogeography in the late Eocene to early Oligocene time for the Mineoka-Setogawa area.

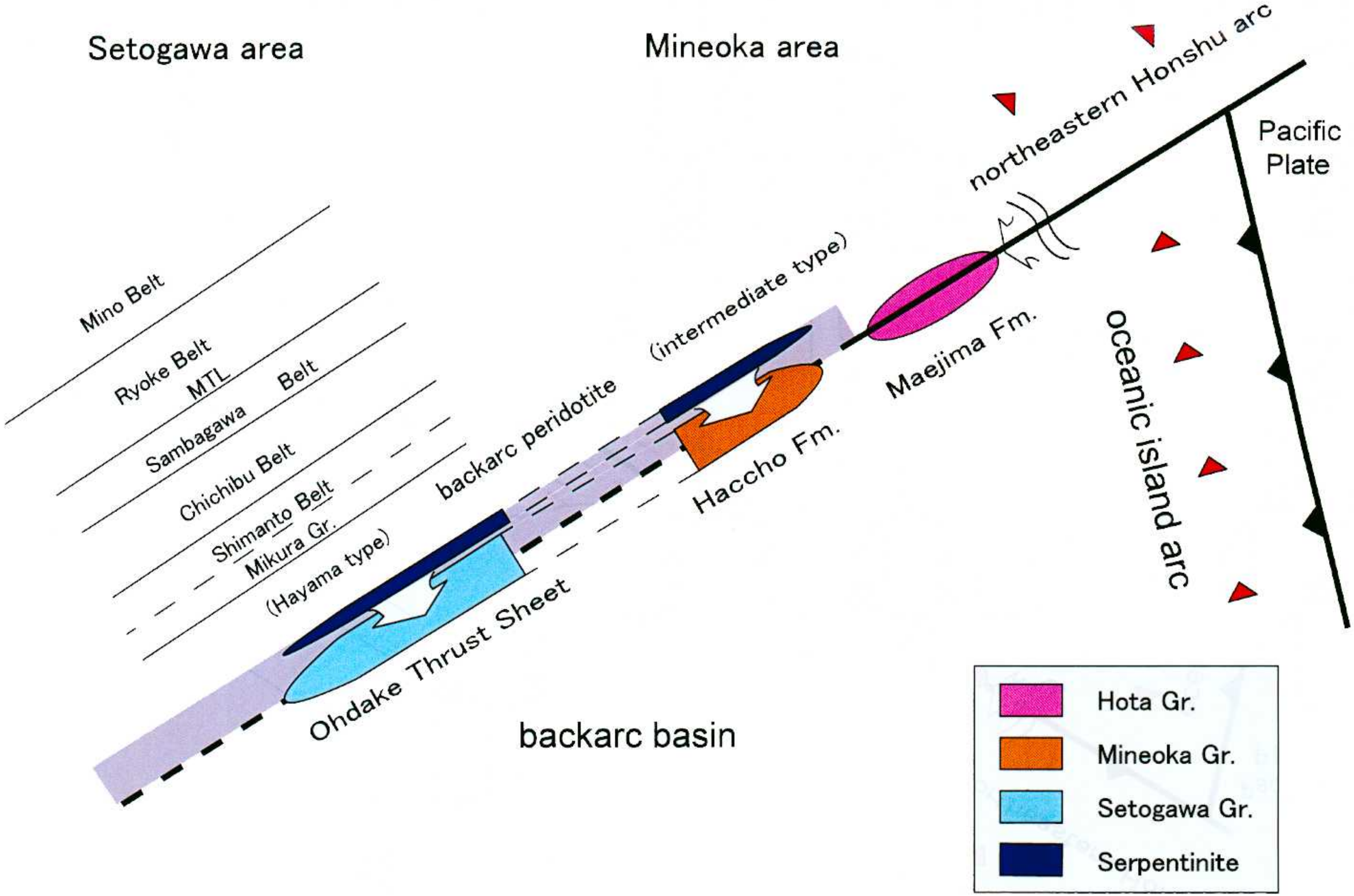


Fig. 53. Reconstructed paleogeography in the earliest early Miocene time for the Mineoka-Setogawa area.

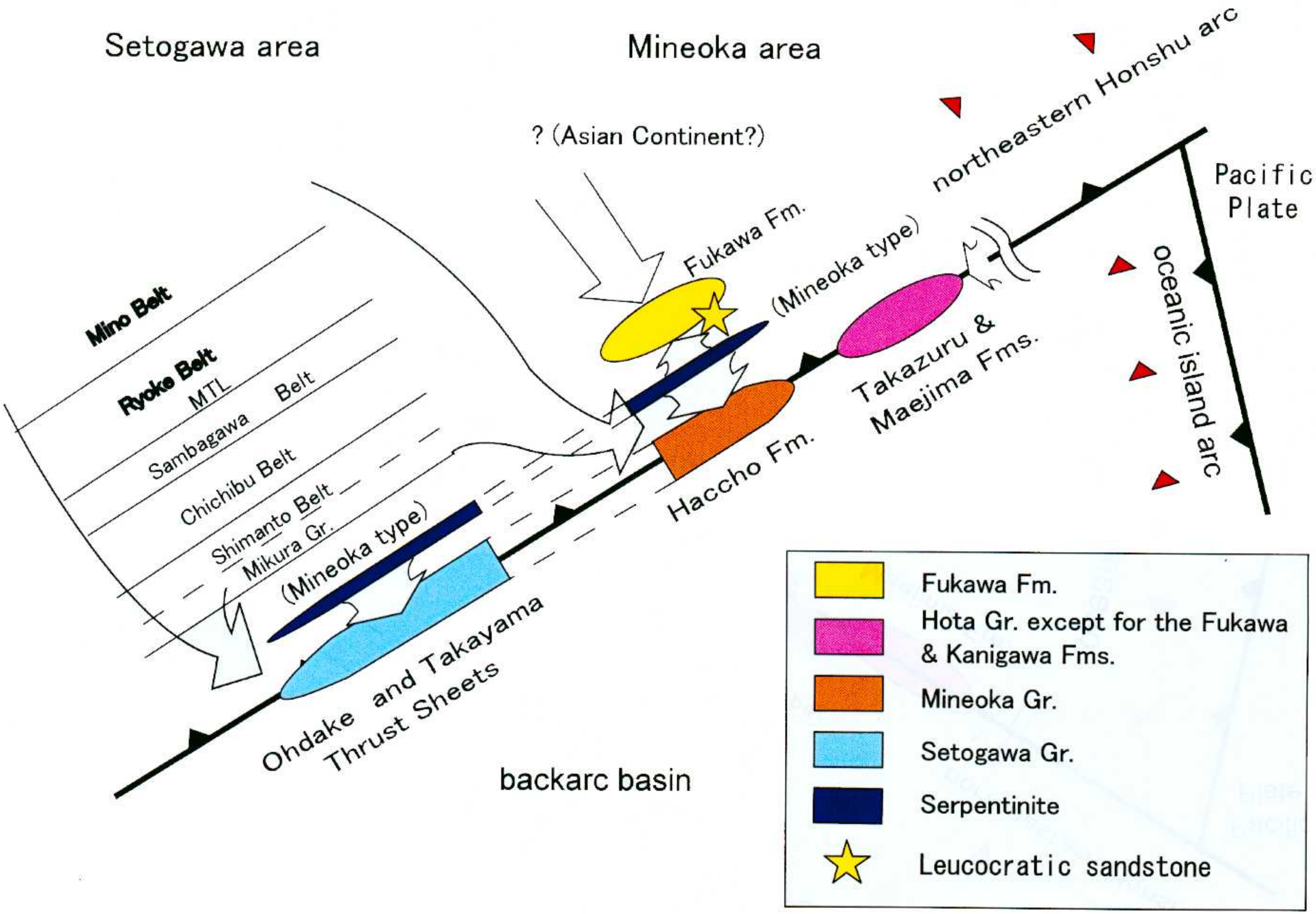


Fig. 54. Reconstructed paleogeography in the early Early Miocene time for the Mineoka-Setogawa area.

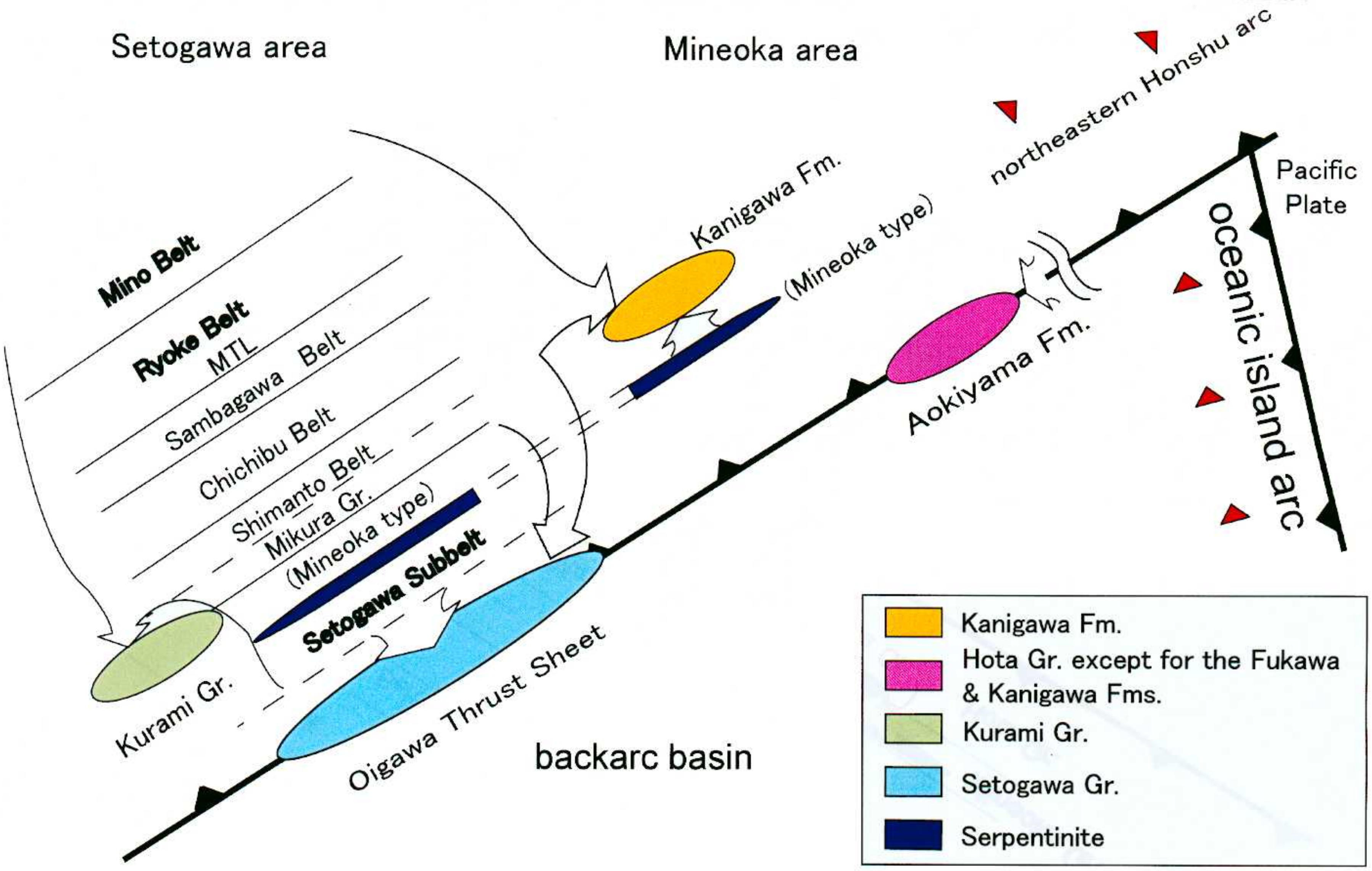


Fig. 55. Reconstructed paleogeography in the late Early Miocene time for the Mineoka-Setogawa area.

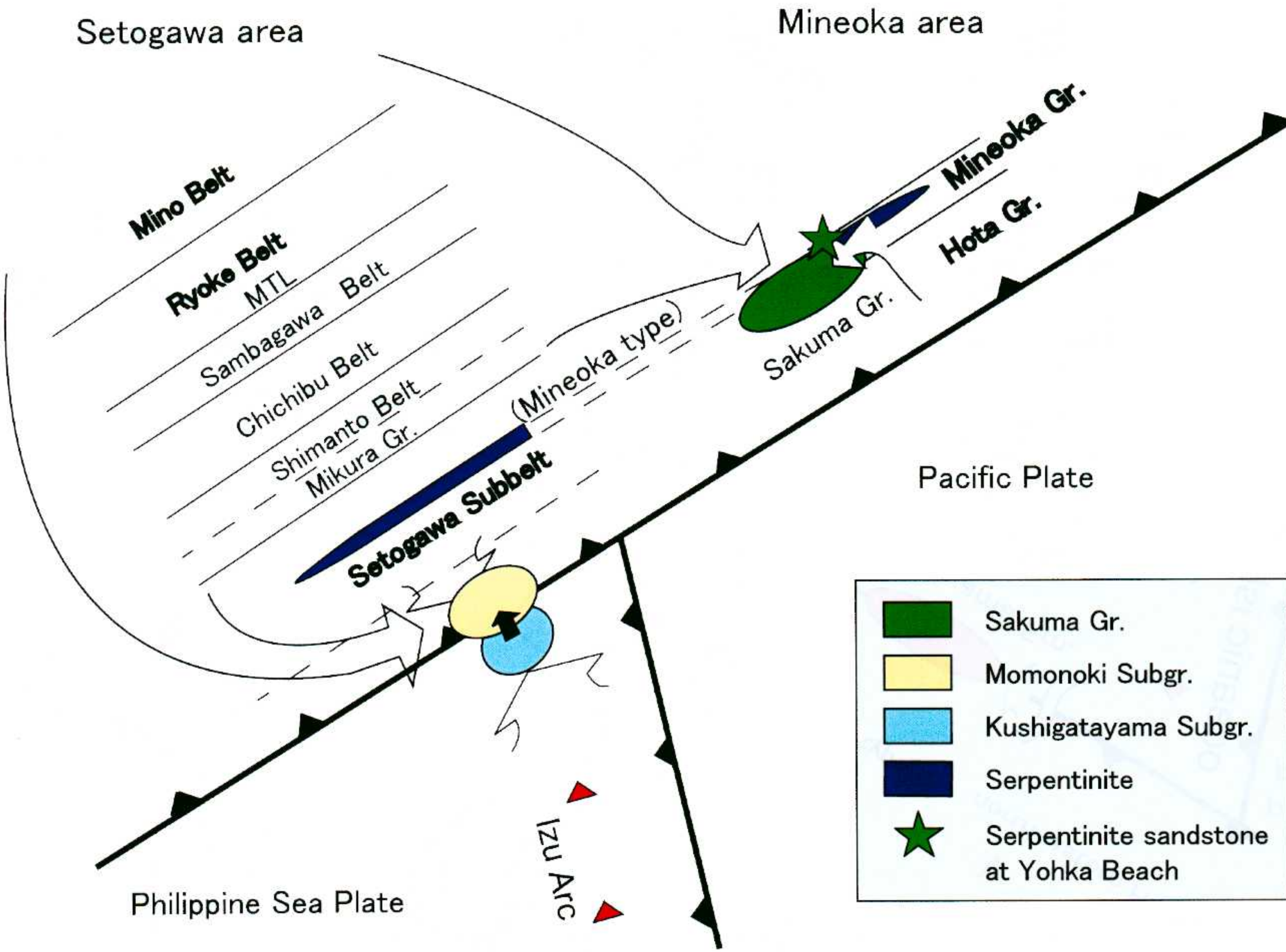


Fig. 56. Reconstructed paleogeography in the early Middle Miocene time for the Mineoka-Setogawa area.

Late Eocene to Oligocene

In the late Eocene to Oligocene, the Mikura Group was deposited in the Setogawa area (Fig. 52; Sugiyama and Shimokawa, 1990). The Mikura Group sandstones contain chromian spinels with high Cr#, detrital garnets composed mainly of spessartine-rich almandine, and rock fragments of felsic volcanic rock and granites. It is probable that the detrital chromian spinels from the Mikura Group originated from forearc peridotites. The serpentinites in the Kurosegawa Belt seem to be a source rock for the detrital chromian spinels from the Mikura Group, because the serpentinites in the Kurosegawa Belt are the nearest one to the Mikura Group "basin" among the serpentinites which contain chromian spinels with high Cr# (e.g. Hisada and Arai, 1989). The source rock for the detrital garnets and fragments of granite seems to be the granite and metamorphic rocks in the Ryoke Belt. The metamorphic rocks in the Ryoke Belt contain spessartine-rich almandine (e.g. Asami and Hoshino, 1980; Ono, 1981). It is difficult to conclude that the detrital garnets from the Mikura Group have been reworked from the clastic rocks in the Mino, Chichibu and Shimanto Belts, because the sandstones in these belts contain a large amount of pyrope-rich almandine (e.g. Adachi and Kojima, 1983; Teraoka et al., 1997, 1999).

Early Early Miocene

In the earliest Early Miocene, the clastic rocks of the Mineoka Group and the Hota Group were deposited in the Mineoka area (e.g. Saito, 1992), and the clastic rocks of the Setogawa Group was deposited in the Setogawa area (e.g. Sugiyama and Shimokawa, 1990) (Figs. 53 and 54). The clastic rocks of the Mineoka and Setogawa Groups are anticipated to have the same provenance on the basis of the similarities of modal compositions of the sandstone and the chemistries of detrital chromian spinel and garnet. However, it is presumed that the provenance of the Hota Group was completely separated from those of the Mineoka and Setogawa Groups. This is because the modal composition of the sandstone and assemblage of detrital heavy minerals of the Hota Group are different from those of the Mineoka and Setogawa Groups sandstones.

The modal compositions of Mineoka and Setogawa Groups sandstones are similar to those of the sandstones of the Mikura Group. Most of the detritus of the Mineoka and Setogawa Groups have the same provenance as that of the Mikura Group. However, the chemistries of detrital chromian spinels and garnets of the Mineoka and Setogawa Groups are different from those of the Mikura Group. Most of the detrital chromian spinels from the Mineoka and Setogawa Groups are similar to spinels in the Circum-Izu massif serpentinites in terms of chemistry. Also the detrital garnets from the Mineoka and Setogawa Groups are inferred to be derived from high grade metamorphic rocks such as granulite comprising a continental basement, and granite or low grade metamorphic rocks. As mentioned above, granite and metamorphic rocks in the Ryoke Belt could be source rocks of the spessartine-rich almandine. However, there is a possibility that detrital garnets from the Mineoka and Setogawa Groups are reworked grains, since the frequency of the detrital garnets of these groups is very low and the sandstones in the Mino, Chichibu and Shimanto Belts contain such garnets (e.g. Adachi and Kojima, 1983; Teraoka et al., 1997, 1999).

The Hota Group is divided into two groups based on the modal compositions of sandstone and the composition of the assemblage of detrital heavy minerals. One group is composed of the Maejima, Takazuru and Aokiyama Formations, and the other group consists of the Fukawa and Kanigawa Formations. The Fukawa and Kanigawa Formations are distributed to the north of the Mineoka Mountains, while the others are distributed to the south. It is known that the Fukawa and Kanigawa Formations were deposited in shallow marine environment (Nakajima et al., 1980), while the other formations were deposited in deep sea (Saito, 1992) and are regarded as components of an accretionary complex (Saito et al., 1992). Especially the Fukawa Formation sandstones are extremely quartz-feldspathic and contain a large amount of detrital garnets composed of pyrope-rich almandine. Some of the detrital garnets of the Fukawa Formation originated from the high grade metamorphic rocks such as granulite comprising a continental basement (e.g. Takeuchi, 1986). There is a possibility that the detritus of the Fukawa Formation was directly supplied from the continental basement as suggested by the following three points; 1) Modal composition of sandstone is extremely quartz-feldspathic and is plotted in the field of Continental Block on the diagrams of Dickinson et al. (1983). 2) Frequency of occurrence of detrital garnets is extremely higher than those of the other formations in the Mineoka and Setogawa areas. 3) Chemistry of the detrital garnets shows that they are derived from high grade metamorphic rocks which lacks in the Honshu arc at present. The Fukawa Formation sandstones also contain detrital chromian spinels whose chemistries are similar to those in the Mineoka type serpentinites. In summary, the Fukawa Formation was deposited in forearc area near the Mineoka type serpentinites and most of its detritus was derived from the continental basement (Fig. 54). The leucocratic sandstones, which comprise tectonic blocks in the Mineoka Mountains, also seem to have been deposited with the Fukawa Formation sandstone judging from the similarities of modal composition of sandstone and chemistries of detrital chromian spinel and garnet (Fig. 54).

The sandstones of the Maejima, Takazuru and Aokiyama Formations of the Hota Group contain a larger amount of felsic to mafic volcanic rock fragments and detrital clinopyroxenes. The chemistries of detrital clinopyroxenes show that they originated from orogenic calcalkali basalt, and that they are different from those of the detrital clinopyroxenes from the same age strata on the Izu arc as indicated by Saito and Fujioka (1992). It is inferred that the detritus of the Maejima, Takazuru and Aokiyama Formations were supplied from the Northeastern Honshu arc, and it is also presumed that they were supplied from the arc on the Mineoka Plate. Although it is difficult to determine which volcanic activity is the origin of the detritus of the Hota Group, the detritus of the Hota Group seems to be supplied along the trench from the northeast. This is because quartz-feldspathic Fukawa Formation sandstones were deposited in shallow marine environment in the forearc area.

As mentioned above, an emplacement of the Circum-Izu massif serpentinites occurred in this period (Fig. 53). Both conglomerates and sandstones in the Mineoka and Setogawa Groups contain detrital chromian spinels which originated probably from the Circum-Izu massif serpentinites. However, the chemistries of detrital chromian spinels in conglomerates of both groups are different from those of the detrital chromian spinels in sandstones of both groups. In other words, the conglomerates of the both groups contain detrital chromian spinels whose chemistries are similar to spinels in the Hayama type serpentinites, while sandstones of the both groups contain spinels whose chemistries are similar to those in the Mineoka type serpentinites. It is inferred that the Hayama type serpentinites was emplaced at first, since all the detrital chromian spinels obtained from the late Early Miocene to Middle Miocene strata in the Mineoka and Setogawa area have similar chemistries to the spinels in the Mineoka type serpentinites.

Furthermore, the detrital chromian spinels are composed of spinels which have abyssal or backarc basin peridotite, forearc peridotite and intra-plate basalt as their origin. However, it is difficult to conclude that the detrital chromian spinels have abyssal peridotite as their origin, because the Pacific Plate, which is the unique oceanic plate having abyssal peridotite around the Mineoka and Setogawa areas, has an old and cold oceanic crust, and it is unlikely that the Pacific Plate had obuducted on the Honshu arc. Therefore, the origin of the detrital chromian spinels can be regarded as a backarc basin peridotite. If it is inferred that the origin of the detrital chromian spinels is backarc basin peridotite, the presence of island arc which made a pair with the backarc basin should be required. However, it is difficult to conclude that the Izu arc was located to the east of the Mineoka area as mentioned by some authors (e.g. Seno and Maruyama, 1984; Hall et al., 1995). Instead of the Izu arc, an island arc on the Mineoka Plate, which is supposed to exist from Eocene to Middle Miocene to the east of the Izu arc (Ogawa and Taniguchi, 1987; Sato et al., 1999), can be regarded as the arc which made a pair with the backarc basin, though the timing of the obduction of oceanic plate as shown in the models of Ogawa and Taniguchi (1987) and Sato et al. (1999) should be modified.

Late Early Miocene

In the late Early Miocene, the Hota Group was deposited in the Mineoka area (Fig. 55). The detritus of volcaniclastics had been continuously supplied along trench. At the forearc side of the Mineoka area, the Kanigawa Formation was deposited. The sandstones of the Kanigawa Formation contain a small amount of detrital chromian spinels and garnets. Chemistry of detrital garnets shows that they originate to the high grade metamorphic rocks such as granulite and granite or low grade metamorphic rocks. However, there is a possibility that detrital garnets of the Kanigawa Formation are reworked origin, since frequency of occurrence of detrital garnets is very low, and the Kanigawa Formation sandstone contains a large amount of sedimentary rock fragments (Plates 1e and f). The detrital chromian spinels from the Kanigawa Formation were derived from the Mineoka type serpentinites.

In the Setogawa area, clastic rocks of the Oigawa Thrust Sheet of the Setogawa Group and the Kurami Group were deposited in the late Early Miocene (Fig. 55). The Oigawa Thrust Sheet contains olistolith from the thrust sheets of the Setogawa Subbelt (Sugiyama, 1980). On the other hand, the Kurami Group overlies the Mikura Group and the strata in the Setogawa Subbelt unconformably (Watanabe, 1988). Both groups contain detrital chromian spinels whose chemistries are similar to the spinels in the Mineoka type serpentinites. It is supposed that most of the detritus of the Oigawa Thrust Sheet and the Kurami Group had been derived from the adjacent area. The detrital garnets from these strata seem to be reworked from the older sedimentary rocks judging from the low frequency of detrital garnets and similarity of chemistry of detrital garnets.

Early Middle Miocene

In the early Middle Miocene, the Sakuma Group was deposited in the Mineoka area and the Koma Group was deposited in the Setogawa area (Fig. 56). The Sakuma Group unconformably overlies the Hota Group (Suzuki et al., 1991) and contains a large amount of clasts of the Mineoka and Hota Groups (Saito, 1991). This means that the Mineoka and Hota Groups had become to be contacted each other until the early Middle Miocene. The Mineoka and Hota Groups prbably have been arranged in the early Middle Miocene by a lateral movement. Saito (1991) concluded that the Sakuma Group was deposited in a pull-apart basin formed by a right lateral movement. In this period, the serpentine sandstone at Yohka Beach was also deposited (Fig. 56), and the tectonic blocks of serpentine sandstone and leucocratic sandstone were caught into the sheared serpentinites and basalts.

The provenance of the Koma Group had changed one time. Until the lower part of the upper Kushigatayama Subgroup was deposited, the detritus had been derived from only the volcaniclastic rocks. The chemistry of detrital clinopyroxenes from the lower part of the upper Kushigatayama Subgroup is similar to that of detrital clinopyroxenes from the contemporaneous deep-sea sediments on the Izu arc (Saito and Fujioka, 1992). The provenance of the uppermost part of the Kushigatayama Subgroup and the Momonoki Subgroup is inferred to be identical. Their sandstones contain a large amount of quartz and feldspar, and they also contain detrital chromian spinels and garnets. The chemistries of detrital chromian spinels and garnets from them are similar to those from the Setogawa and Kurami Groups sandstones. The detritus of the uppermost part of the Kushigatayama Subgroup and the Momonoki Subgroup seems to have been derived from the Honshu arc. This suggests that initial contact of the Honshu and Izu arcs occurred at the timing between the sedimentation of the lower part of the upper Kushigatayama Subgroup and uppermost part of the Kushigatayama Subgroup, that is, 16 to 15 Ma (Aoike, 1999).