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Petrological Study of Sedimentary Rocks in the Itsukaichimachi Group, Kanto Mountains

by

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Abstract The Itsukaichimachi Group is one of the Middle Micoene sedimentary sequences occurring in the Kanto Mountains. The heavy minerals of the Itsukaichimachi Group are characterized by the enrichment of spinel in its lower part. The spinel compositions are different from those in serpentinites and periodotites in the Kanto Province. Furthermore, mineral proportions and compositions throughout the sedimentary sequence are different from those in the surrounding pre-Miocene sedimentary rocks. It suggests that the constituents of the sedimetnary rocks in the Itsukaichimachi Group were not derived from the surronding pre-Miocene rocks.

A shear zone with thickness of about 10 m is present between the Miocene and pre-Miocene sedimentary rocks and is followed upwards by a conglomerate with alternation of reddish and greenish layers. No sedimentary structure is recognisible in the shear zone. Considering the differences of heavy minerals between the Micoene and pre-Miocene rocks, and presence of the shear zone, it is probable that the sedimentary rocks of the Itsukaichimachi Group were not deposited in situ, but they were deposited elsewhere and then tectonically brought to the present position.

Introduction

There are several Early to Middle Micoene sedimentary sequences in the Kanto Mountains, overlying the Chichibu System and Sanbagawa metamorphic rocks. The Itukaichimachi Group is one of the well-studied Tertiary groups (e. g. FUJIMOTO, 1926; KANNO and ARAI, 1964; IBRG, 1981; ITO, 1989). The group is the fill of the Itsukaichi Basin (ca. 4×5 km^2) in the southeastrn margin of the Kanto Mountains. Microfossil age throughout the sequence of the Miocene group correnponds to the Blow's N8 (IRIZUKI *et al.*, 1989).

It has been inferred that the basin was formed by vertical movements of bounding faults by many studies (WATANABE, 1954; ARAI and KANNO, 1961). IBRG (1981) concluded that the basin was a kind of the collapse basin, fundamentally similar to those of the Green Tuff region in the Japan Sea side. Recently ITO (1989) suggested that the Itsukaichi basin has many similarity with the other Miocene basins in the Kanto Mountains and concluded that they were strike-slip basins caused by collision of the Izu-Bonin arc to the southern Kanto Mountains.

In this study, we analysed modal proportions and chemical compositions of heavy and light minerals in sandstones and siltstones in the Itsukaichimachi Group, and discuss the origin of the minerals and the provenance which supplied the sediments.

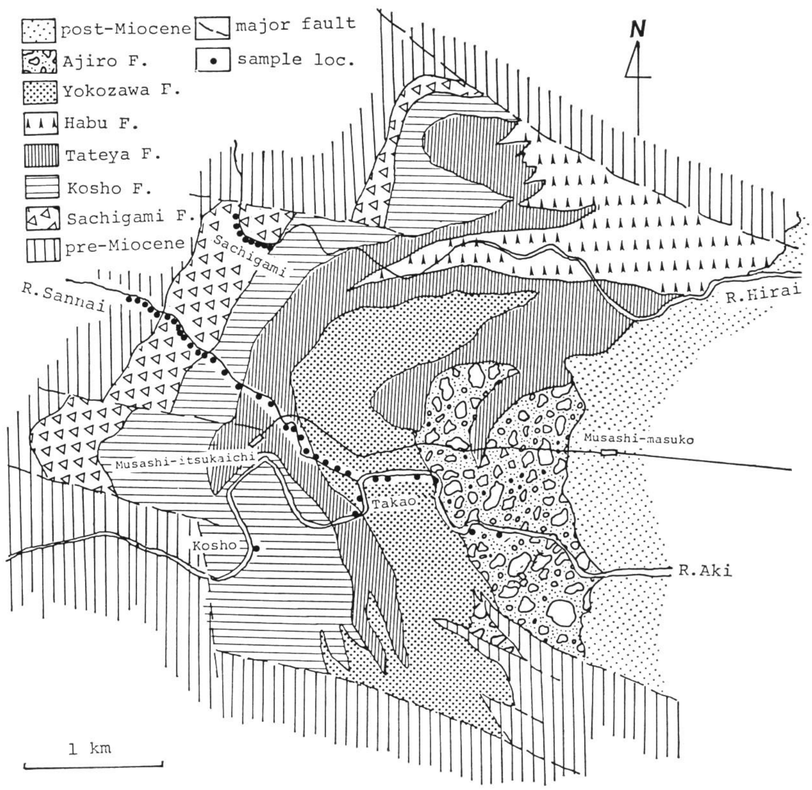

Fig. 1. Geological map of the Itsukaichi Basin (after ITO, 1989) and sample localities.

General Geology and Analytical Procedures

The Itsukaichimachi Group consists of six stratigraphic units: Sachigami, Kosho, Tateya, Habu, Yokozawa and Ajiro formations, in ascending order (Fig. 1). It has been considered that the group deposited unconformably on the Chichibu System along the western margin and was unconformably overlain by Pliocene alluvial deposit Itsukaichi Gravel) at the western part. Sedimentary sequence in the group changes from talus and fan delta in the Sachigami Formation to submarine talus in the Aziro Formation through slope and submarine fan deposits (ITO, 1989). The lowest unit, Sachigami Formation, is composed mostly of conglomerate with intercalations of sandstone and rarely siltstone and mudstone. It has been considered to deposited as a basal conglomerate (e.g. KANNO and ARAI, 1964; IBRG, 1981; ITO, 1989). The Sachigami Formation is followed by mudstone-rich unit (Kosho Formation), and then tuffaceous unit and sandstone-rich unit. Conglomerate-rich unit (Ajiro Formation) similar to the lowest unit overlies at the top of the Itsukaichimachi Group. Each unit is roughly arranged from west to east, almost conformably overlying. Samples for the petrol-

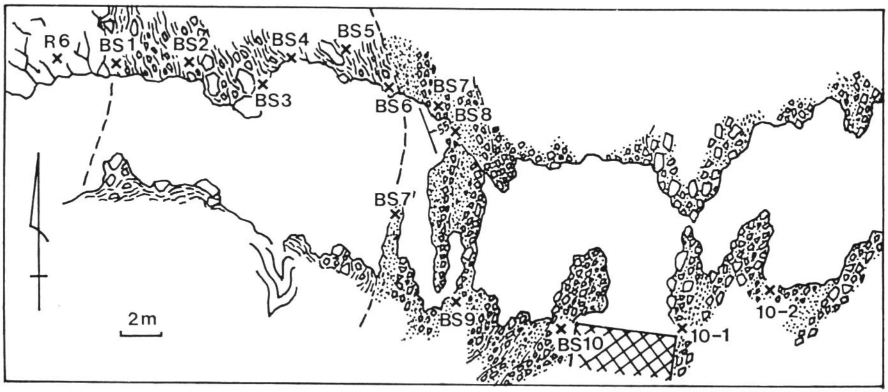

Fig. 2. A sketch map at the contact between the Itsukaichimachi Group and basement rocks at the Sannai River. Numbers show localities of the samples used in Fig. 5. Sample R6 belongs to the Chichibu System. BS1 to BS6; shear zone. BS7 to BS10; pebble zone, 10–1 to 10–2; boulder zone. The broken lines show boundaries between the shear zone and the Chichibu System and/or pebble zone.

ogical study are sandstones and siltstones in most cases or sandy matrices in conglomerates.

Most of the samples were collected at a route cutting all the units mentioned above; along the Sannai and Aki rives (Fig. 1). Condensed sampling was done at the contact between the Itsukaichimachi Group and basement rocks at the Sannai river (Fig. 2). Furthermore, many other samples are collected at the differe nt places as shown in Fig. 1, to compare the heavy mineral proportions with those in the main route.

The samples, highly consolidated, were crushed in the stainless steel mortar. Fine fractions less than 60 mesh were selected and clay minerals and fine-grained particles were removed by washing in running tap water. The specific gravity of methylene iodide was reduced to 2.82 to recover the compositie grains and aggregates consisting of heavy and light minerals. In this procedure, some minerals such as chlorite, biotite and carbonate minerals occur in both the heavy and light fractions. Hence, these minerals were not included in the mineral counts.

The heavy and light fractions were cemented in epoxy resin and prepared for the modal and chemical analyses. All the minerals were identified under profiles of Energy Dispersive Spectrometer (EDS). As a crushed grain is often composed of many minerals, a major constituent is selected in the grain at the counting of the heavy minerals.

More than 10 heavy mineral species were recognized in the sedimentary rocks of the Itsukaichimachi Group. The minerals counted properly are listed in Fig. 3. The most common heavy minerlas are spinel, garnet, epidote, magnetite, ilmenite, sphene, TiO_2 polymolphs and zircon. Accesssary minerals are tourmaline, allanite and apatite.

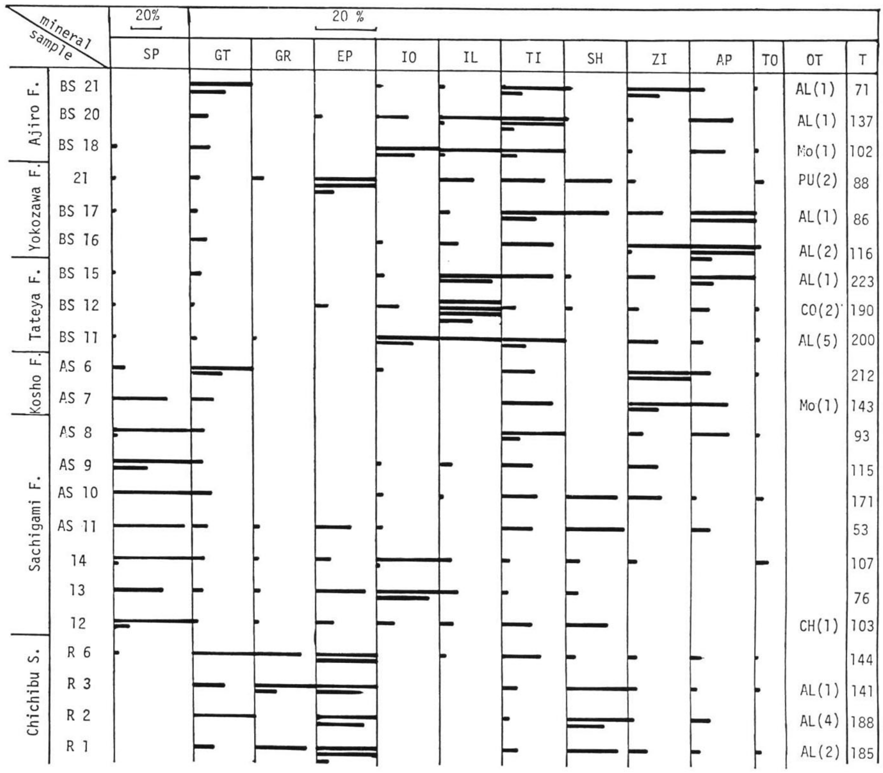

Fig. 3. Modal proportions of heavy minerals in the Miocene and pre-Miocene sedimentary rocks along the Sannai and Aki rivers. Abbreviations: SP-spinel except magnetite, GT-Ca-poor garnet, GR-Ca-rich garnet, EP-epidote, IO-iron ores, IL-ilmenite, TI-TiO_2 polymorphs, SH-sphene, ZI-zircon, AP-apatite, TO-tourmaline, OT-other minerals, AL-allanite, MO-monazite, PU-pumpellyite, CO-corundum, CH-chloritoid, T-total number to counted heavy minerals.

As the EDS profiles do not discriminate among TiO_2 polymorphs, i.e. rutile, anatase and brookite, they are treated together in Fig. 3. Magnetite and hematite are sometimes predominant constituents. They were also treated together as an iron oxide because of uncertainty of their identifications under the EDS profiles.

Except for the minerals listed in Fig. 3, olivine, pyroxenes and amphibole are rarely observed in the heavy fractions. Many thin sections of the sedimentary rocks were made for confirmation of their occurrences. However, we can not find such minerals in most of the thin sections. The present river sands contain abundantly olivine, pyroxenes and amphibole derived from the recent volcanic eruptions in the Kanto Province and the compositions of the minerals at the present river sands are similar to those found in the heavy fractions. Furthermore, olivine and orthopyroxene are minerals altered rapidly. Hence we considered that such rare minerals in the heavy fractions are due to contamination from the river sands as a result of sampling of roose sandstone or filling of the minerals along the cracks. Only amphiboles were rarely found in thin sections. As the proportions of the amphiboles were not affected in the following discussion, they were excluded in Fig. 3.

Light fractions contain quartz, plagioclase, K-feldspar, chlorite, muscovite, serpentine, carbonate minerals, glauconite and so on. Here we only selected quartz, plagioclase and K-feldspar for modal analyses, because proportions of other minerals are highly affected by substraction during soaking in the water or they enter into both the heavy and light fractions.

The minerals were analysed on a EDS (Link Systems), using natural and synthetic materials as standard with corrections by the ZAF method of Statham (1979). The analysed minerals are spinel and garnet in the heavy fractions.

Results and Discussions

Mineral proportions

Proportions of heavy minerals along the Sannai and Aki rivers are shown in Fig. 3, which covers from the basement rocks, i.e. rocks of the Chichibu System, to the top of the Itsukaichimachi Group. Sandstones in the Chichibu System are characterised by persistences of garnet, epidote and sphene, whereas the Miocene sedimentary rocks have variable proportions in heavy minerals.

It is characteristic that the spinel is abundant at the lower part of the group, i.e. Sachigami and Kosho formations. The spinel exceeds often half of the heavy minerals in the Sachigami Formation, which is confirmed in the samples along the Hirai River (Fig. 4). It decreases abruptly within the Kosho Formation and is no more major phases in the heavy fractions above the formation. Whereas, other heavy minerals are highly variable throughout the sedimentary sequence of the Itsukaichimachi Group and proportion of each mineral shows no clear correlation with the sedimentary sequence and lithology. It is due to that drainage basins of the sedimentary rocks were small and major constituents in the basins or drainage pattern have changed during the sedimentation of the Itsukaichimachi Group.

Conglomerates in the Sachigami Formation contain pebbles of calcareous rocks which have been described as limestones (FUJIMOTO, 1926; IBRG, 1981; ITO, 1989). Such calcareous rocks are also present as a pebble in the upper part of the Itsukaichimachi Group (Ajiro Formation). The former rocks are often ophicalcites containing spinel, whereas the latter are limestones. As serpentines are less uncommon in the light fractions of the spinel-rich samples, it is concluded that the spinels in the Sachigami and Kosho formations were derived from ophicalcite or serpentinite. Bulk chemical compositions of spinel-rich and spinel-poor samples are shown in Table 1. The fomer spinel-rich sample is extensively rich in Cr and Ni, compared with the latter one. Both Cr and Ni are rich only in peridotite or its metamorphosed equivalents such as serpentinite and ophicalcite, supporting that such rock-types were present in

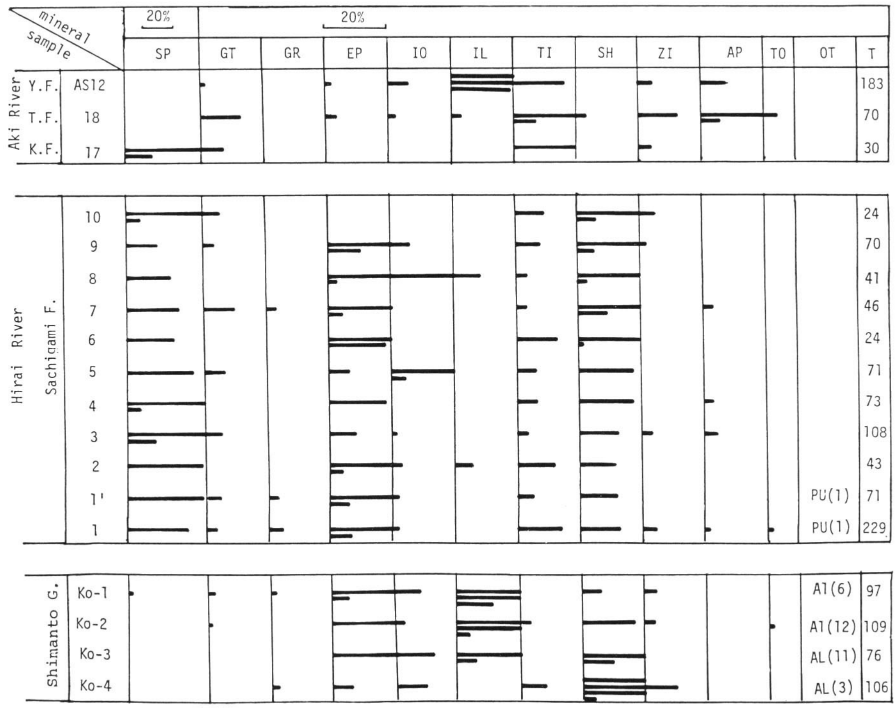

Fig. 4. Modal proportions of heavy minerals in the Miocene sedimentary rocks along the Aki and Hirai rivers, and the Shimanto Group sandstones. Y. F.-Yokozawa Formation, T. F.-Tateya Formation, K. F.-Kosho Formation. Other abbreviations are the same as in Fig. 3.

the provenance of the sedimentary rocks of the Itsukaichimachi Group.

As conglomerates in the Itsukaichimachi Group are composed mainly of sandstone (KANNO and ARAI, 1964; ITO, 1989), it should be assumed at first that the heavy minerals in question were derived from the sandstones in the surrounding pre-Miocene rocks. The sandstones in the Chichibu System (Fig. 3) are different in heavy mineral proportion from those of the Shimanto Group (Fig. 4). The former sandstones are rich in garnet compared with those in the latter ones, but epidote and sphene are abundant in both the pre-Miocene rocks. On the other hand, in the Miocene sandstones, epidote and sphene are only sporadically abundant throughout the sequence as shown in Fig. 3. They are often scarce. Less abundant nature of epidote and sphene in the sandstones in the Itsukaichimachi Group is in contrast with the enrichment of the minerals in both the pre-Miocene rocks. It suggests that the provenance of the heavy minerals in the Miocene sandstones was neither the Chichibu belt nor Shimanto belt.

Fig. 5 shows proportions of heavy minerals at the contact between the Itsukaichimachi Group and basement rocks at the Sannai River. There are four units within

Table 1. Major and trace element abundances of sedimentary rocks. 1: spinel—rich calcareous sample, 2: spinel—rich sample, 3: spinel—poor calcareous sample, 4: representative composition of sedimentary rocks (after HARAMURA, 1962)

	1 AS 9	2 AS 10	3 21	4
wt%				
SiO_2	56.38	63.73	48.98	65.03
TiO_2	0.60	0.90	0.49	0.64
Al_2O_3	10.62	13.77	12.63	15.75
Fe_2O_3	0.66	1.83	1.36	1.99
FeO	3.49	4.41	3.36	3.22
MnO	0.23	0.07	0.47	0.09
MgO	4.03	4.52	1.73	2.09
CaO	17.19	0.74	24.62	0.35
Na_2O	1.81	2.35	1.94	2.07
K_2O	1.55	2.27	1.50	3.76
H_2O ($\pm$)	3.31	5.27	2.81	4.21
P_2O_5	0.13	0.13	0.12	$<$0.05
Total	100.00	99.99	100.01	99.00
ppm				
V	91	138	72	106
Cr	243	467	61	30
Ni	76	227	17	17
Cu	10	21	7	
Zn	62	90	53	
Rb	57	82	48	
Sr	307	100	325	
Y	21	35	16	
Zr	127	186	138	
Nb	11	15	9	
Ba	279	233	278	
Ce	35	47	44	

the 30 m around the contact (Fig. 2 and 5). They are basement rock (Chichibu System), shear zone, fine-pebble zone with alteration of reddish and greenish layers and boulder zone. The shear zone is composed mainly of finely brecciated fragments of slate and chert, sporadically including large angular blocks of chert, sandstone and greenstone. Previous authors (KANNO and ARAI, 1964; IBRG, 1981; ITO, 1989) considered that the Sachigami Formation starts from the boundary between the Chichibu System and the shear zone, i.e. the shear zone considered to belong to the Miocene sequence. There is, however, no sedimentary structure in the shear zone, and the heavy minerals, which should be present in a ordinary sedimentrary rock, are scarce throughout the shear zone (Fig. 5). The sedimentary structure is observed from the pebble zone which consists of alteration of reddish and greenish layers (Fig. 2).

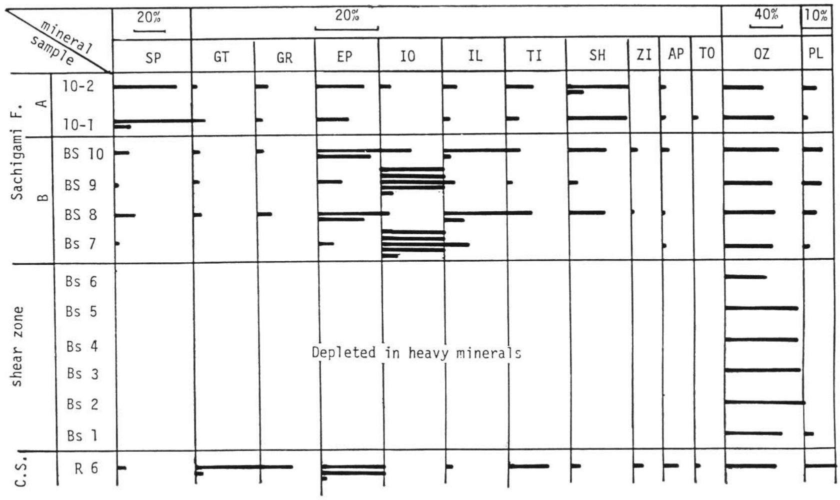

Fig. 5. Modal proportions of heavy and light minerals at the contact between the Itsukaichimachi Group and basement rocks at the Sannai river. Abbreviations: QZ-quartz, PL-plagioclase ($>An_{10}$), C.S.-Chichibu System.

The sandstones in the reddish layers are characterized by presence of abundant iron ores, whereass greenish ones by abundant epidote and ilmenite, and relative enrichment of spinel. The pebble zone is overlain by the boulder zone. As shown in Fig. 5, extreme enrichment of spinel occurs from the boulder zone where spinel proportions are concordant with those in the samples of the Sachigami Formation in Fig. 3 and 4. These characteristics show that the Miocene sequence starts from the pebble zone and the shear zone should be formed by tectonic movements after the sedimentation of the Miocene sequence. Although the pebble zone is tentatively treated here as a part of the Sachigami Formation, it seems that the sedimentary rocks in the zone were not basal conglomerates as well as those in the shear and boulder zones.

In the light fractions, quartz, plagiocladee, and K-feldspar are predominant phases with subordinate amounts of micaceous and carbonate minerals. Proportions of quartz, plagioclase and K-feldspar are shown graphically in Fig. 6. They are divided into four groups: spinel-rich and -poor samples in the Itsukiachimachi Group, shear zone samples and Chichibu System samples. The groups have fairly distinct features in the proportion of the light minerals. Shear zone samples are almost free from plagioclase and K-feldspar (Fig. 5 and 6). Spinel-rich samples are rich in albite and poor in calcic plagioclase, whereas spinel-poor samples are rich in plagioclase. As the porportions of the light minerals treated can not be affected by derivatives from ophicalcite and serpentinite, the light minerals should have been derived from sandstone, chert and volcanics. The spinel-poor sandstones occur in the formation overlying Kosho Formation. Volcanic activity deduced from many tuff layers increases after sedimentation of the Kosho Formation. Hence enrichment of plagioclase in the

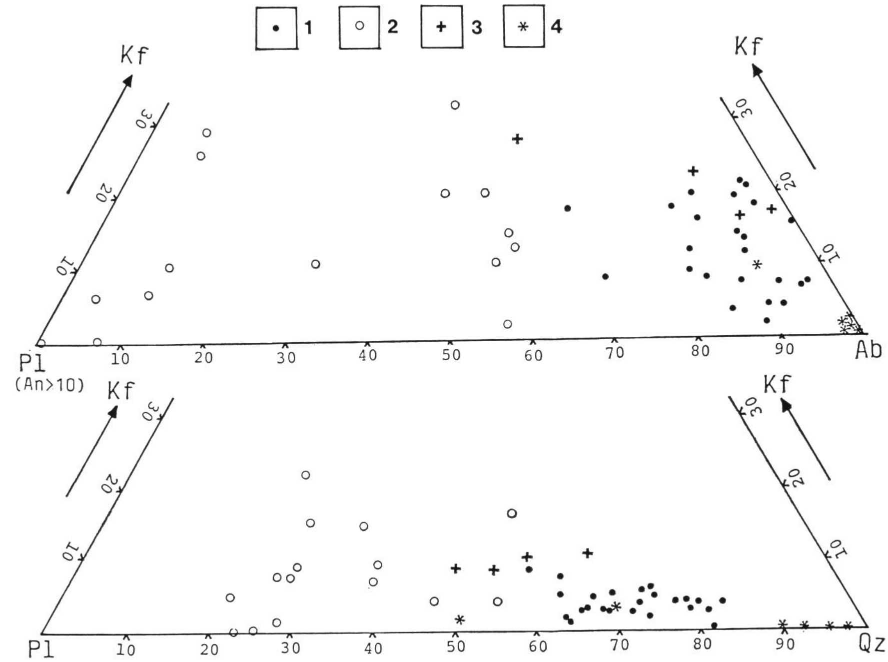

Fig. 6. Modal proportions of light minerals. 1-spinel-rich Miocene samples, 2-spinel-poor Micoene samples, 3-Chichibu System samdstones, 4-samples in the shear zone. QZ-quartz, Kf-K-feldspar, Pl-plagioclase ($>An_{10}$), Ab-albite.

spinel-poor sandstones reflects active volcanism in the Kanto Province after the Kosho Formation and plagioclases are mostly reworked minerals from tuff layers.

Mineral compositions

Spinels in the heavy fractions are associated commonly with carbonate minerals, chlorite and serpentine, supporting that they are derived from ophicalcite or serpentinite. The spinels in the spinel-rich samples are plotted in a ternary diagram of (Mg, Fe)Al_2O_4–(Fe, Mg)Cr_2O_4–(Fe, Mg)Fe_2O_4 (Fig. 7). The spinel compositions vary widely from picotite, chromite, ferritchromite and magnetite. Picotite-chromite series spinel is commonly replaced by ferritchromite and magnetite in a grain. The replacement texture shows that spinels were not derived from peridotite, but from its metamorphosed equivalents such as ophicalcite and serpentinite.

The ophicalcite is one of rare rock-types in Japan. In the Kanto Province, it was described locally in the Sanbagawa metamorphic belt and in the Setogawa belt (Seki and Kuriyagawa, 1962; Wada, 1976). Futheremore, ophicalcite bodies are quite small, usually less than a few hundred meters in length. On the other hand, serpentinite and serpentinized peridotite bodies are quite large and occur in the Chichibu, Shimanto and Sanbagawa belts (e.g. Tazaki, 1966; Yokoyama, 1987; Arai and Ishida, 1987).

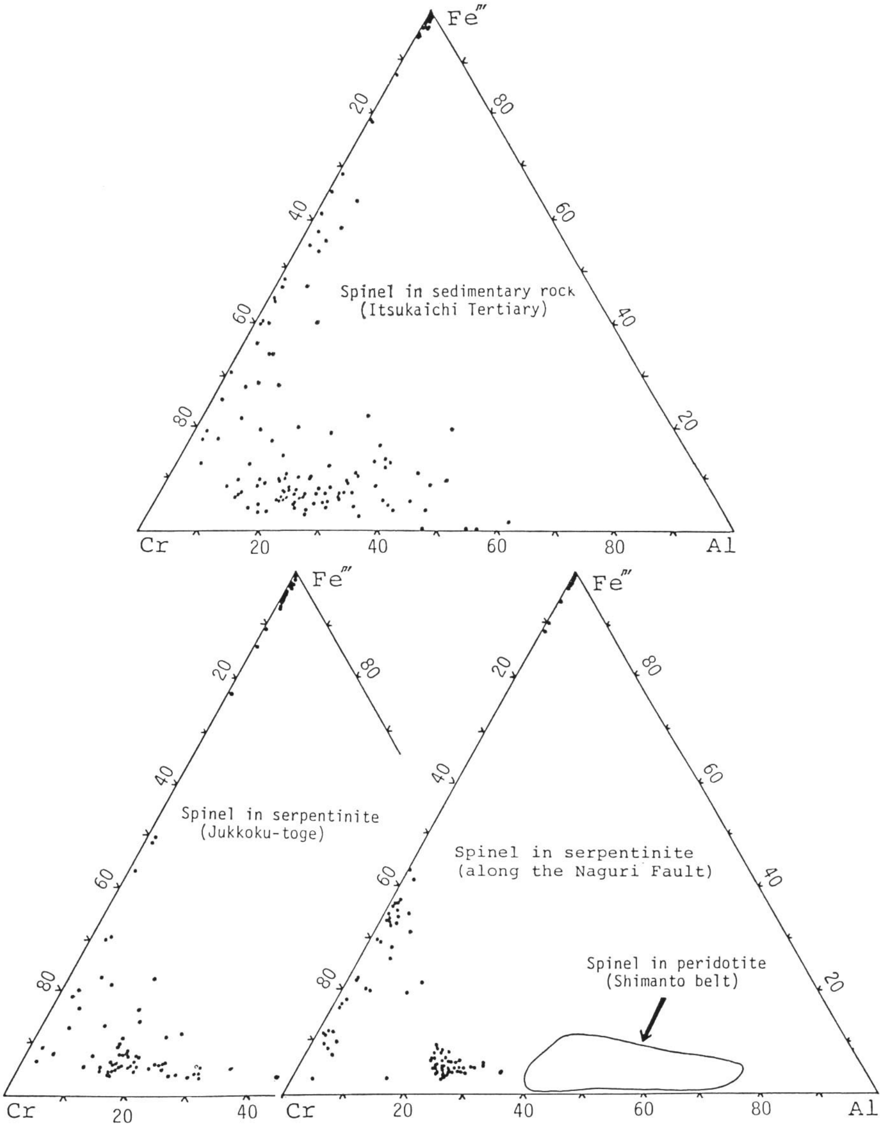

Fig. 7. Chemical compositions of spinels plotted in Al-Cr-Fe diagrams. Data of spinels in the Shimanto belt are from ARAI and ISHIDA (1987).

At the north-east margin of the Itsukaichi Basin, small serpentinite bodies occur along the Naguri Fault (OZAWA and KOBAYASHI, 1986). To decipher the origin of the spinels in the Itsukaichimachi Group, spinels in the serpentinite and peridotites mentioned above were analysed. They were plotted in Fig. 7. As metamorphic rocks has not been observed in the conglomerate of the Itsukaichimachi Group, ophicalcite and serpenitite in the Sanbagawa metamorphic belts were excluded from candidates of provenace of the spinels. The Sanbagawa metamorphic rocks contain aboundant epidote and sphene. Exclusion of the belt from the candidates is supported by poor proportions of epidote and sphene in the sedimentary rocks of the Itsukaichimachi Group.

Fig. 7 shows that spinels in the Itsukaichimachi Group are quite different from those in the the serpentinized peridotite in the Shimanto belt. Whereas, they are somewhat similar to those in the serpentinites in the Jukkoku-toge and along the Naguri Fault. Such similarity is due to that both the serpentinite bodies have been suffered from low temperature metamorphism as well as the spinels in the Miocene sedimentary rocks. However, there is difference between the spinels. Itsukaichimachi Group contains commonly picotites rich in Fe^{3+} and Al, compared with those in the serpentinite bodies, and spinel around $Fe(Fe_{40}Cr_{60})_2 0_4$, common in the Itsukaichimachi Group, is absent in both the serpentinite bodies. In addition, there are critical differences in other heavy minerals. Both the serpentinite bodies include clinopyroxenite and rodingite, but ophicalcite has not been described in the bodies. Even if we admitted that such serpentinites were carbonatized after the sedimentation, it is hard to explain the differences of the spinel compositions and paucity of Ca-rich garnet in the Miocene sedimentary rocks. Ca-rich garnet is a major phase of the rodingite (metagabbro) in the serpentinite bodies at the Jukkoku-toge and along the Naguri Fault. There is no correlation in modal proportion between spinel and Ca-rich garnet in the Miocene rocks. As there are some differences of proportions of the heavy minerals and spinel compositions between the Itsukaichimachi Group and the serpentinite bodies, it is probable that spinels in the Itsukaichimachi Group were not derived from the serpentinite and peridotite bodies described so far from the Kanto Province.

As metamorphic rock is not included in the conglomerates, garnets in the heavy fractions are reworked grains from sandstone. Hence chemical compositions of the Ca-poor garnets in the Itsukaichimachi Group are compared with those in sandstones of the Chichibu System in Fig. 8. There is no clear differences between the garnets in the spinel-rich and spinel-poor sedimentary rocks, suggesting that the garnets in both the rock-types were derived from the same source throughout the sedimentation of the Itsukaichimachi Group. Garnet with pyrope content more than 30 is common in the Itsukaichimachi Group. Such a garnet is rare in the Chichibu System. Roughly speaking, the pyrope content is dependent on temperature of the metamorphic conditions. Hence, the garnets in the pre-Miocence sandstones were derived originally from the rocks metamorphosed at the lower temperature than those in the Itsukaichimachi Group. The difference of the garnet compositions supports that the provenance of the sedimentray rocks in the Itsukaichimachi Group was not the Chichibu belt.

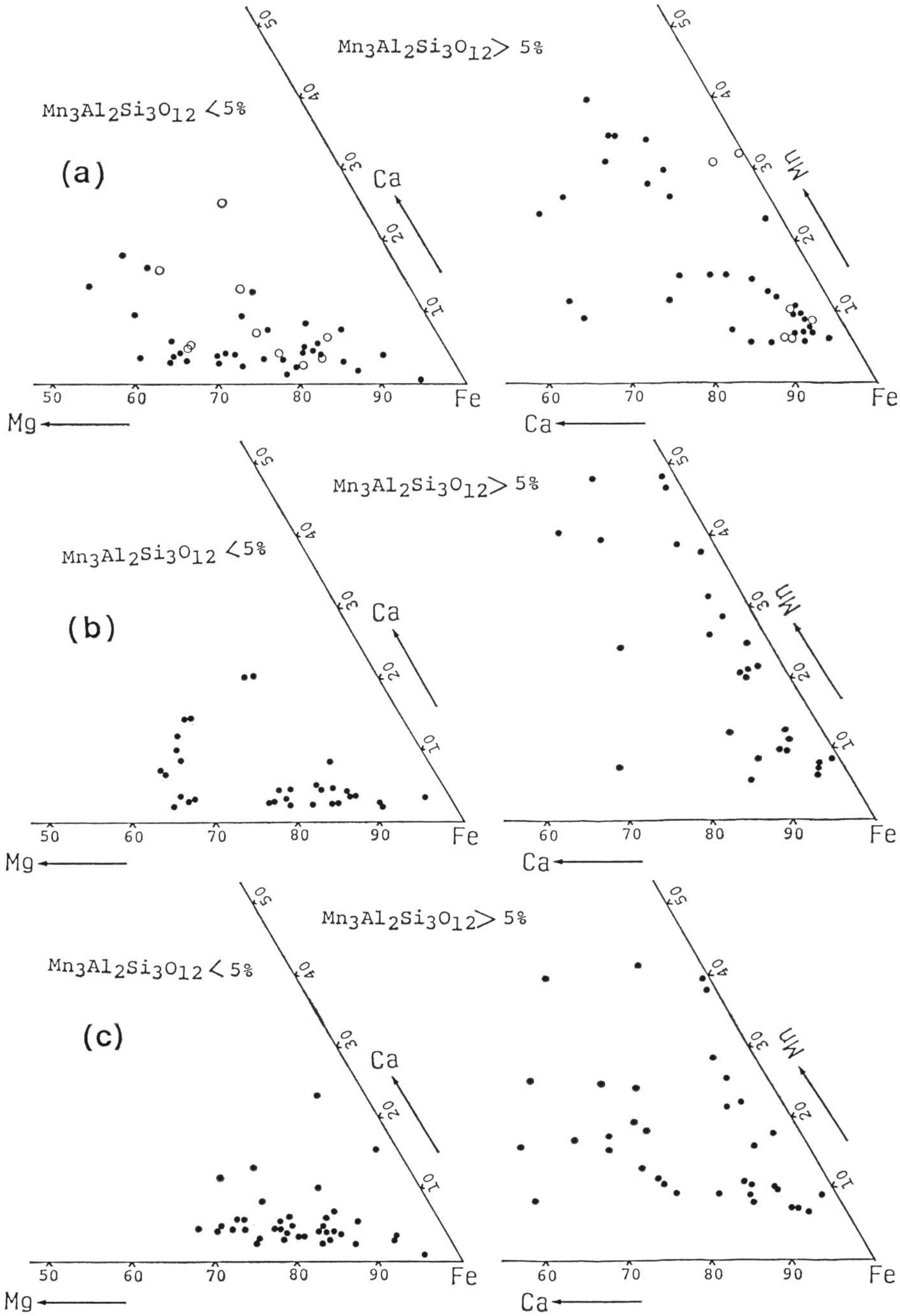

Fig. 8. Chemical compositions of Ca-poor garnets in the Miocene and pre-Miocene sedimentary rocks. (a); garnet in the spinel-rich samples. Open circles show garnet in epidote-rich samples. Closed ones shows garnet in epidote-free samples. (b); garnet in the spinel-poor samples. (c); garnet in the Chichibu System sandstones.

Summary

The sedimentary rocks in the Itsukaichimachi Group are characterized by the abundant spinel in its lower part. Spinel compositions are different from those in the serpentinites and peridotites in the Kanto Province. Garnet compositions and proportions of epidote and sphene are also different from those in the surrounding pre-Miocene sandstones. They suggest that the provenance of the sedimentary rocks were not the Chichibu and Shimanto belts, and spinels were not derived from the serpentinite bodies at the Jukkoku-toge and along the Naguri Fault. Although we could not designate the real provenance of the sedimentary rocks, it is reasonable from the presences of shear zone between the Itsukaichimachi Group and basement rocks that the Middle Miocene sedimentary rocks were deposited far from the present position and was brought there tectonically after the sedimentation.

As an alternative explanation of the provenance, it is possible that the spinel-bearing ophicalcite and serpentinite were present in the Chichibu and Shimanto belts and they have been completely eroded together with the surrounding sandstones which were different in heavy minerals from the present Chichibu System sandstones studied here.

Other Middle Miocene sedimentary rocks in the Kanto Mountains are also enigmatic in origin. In the Middle Miocene sequence in Chichibu City, conglomerate occur in its lower part. It does not contain pebbles belonging to the Sanbagawa metamorphic rocks, but contain granite and metamorphic rocks of the Ryoke belt (IJIRI, 1950; WATANABE, *et al.* 1950a). The Middle Miocene conglomerate in Ogawa-machi also does not contain the Sanbagawa metamorphic rock but contains abundantly Ryoke-type granite and metamorphic rocks in spite of its overlying on the Sanbagawa metamorphic rocks (WATANABE, *et al.*, 1950b). Furthermore the Miocene sequence at the northern end of the Kanto Mountains thrusted over the Sanbagawa metamorphic belt (KRG, 1985). As all the Miocene sequences mentioned above were deposited within a narrow duration (e.g. IRIZUKI *et al.*, 1989), provenance of the Miocene seimentary rocks in the Itsukaichi Basin should be explained by a similar process to those of the other Middle Miocene basins in the Kanto Mountains. In this sense, we favor an idea that the sedimentary rocks of the Itsukaichimachi Group were deposited at the other place and then tectonically brought there after the sedimentation, rather than an alternative idea of complete erosion of the provenance.

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