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Detrital Garnets in Permian to Cretaceous Sandstones of the Kurosegawa Terrane and its Geological Significance

By

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with 14 Figures

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Abstract: Detrital garnets in Permian to Cretaceous sandstones of the Kurosegawa Terrane in the western part of Kyushu (the Kashinoki−Pass area of Kumamoto Prefecture) have been studied from the sedimentary petrological viewpoint. EPMA analysis of detrital garnets (a total of 1166 grains) have revealed that:

There are significant differences in chemical composition between detrital garnets of the sandstones from the Upper Permian Kuma Formation and the Mesozoic formations.Detrital garnets of the Kuma Formation consist mostly of grandite associated with some almandine garnet and rare spessartine being derived from calcareous metamorphic rocks, probably skarn. On the other hand, detrital garnets of the Upper Triassic formation consist mainly of almandine with minor amount of Mg content, some Mn−Fe garnet, and minor grandite. Those of the Middle to Upper Jurassic formation consist mainly of almandine garnet with minor amount of Mg and Mn content. These Triassic to Jurassic detrital garnets are considered to be derived from high−grade, partly granulite facies, metamorphic rocks. And, detrital garnets of the Lower Cretaceous Yatsushiro Formation consist of almandine with minor amount of Mg and Mn content and grandite derived from calcareous metamorphic rocks (probably skarn) and high−grade metapelites. Based on such mineralogical characters of detrital garnets it can be pointed out that there are significant differences in provenance (namely, rock component in the source area) between the Upper Permian Kuma Formation and the Mesozoic formations in the Kurosegawa Terrane.

Key words: detrital garnet, Permian to Cretaceous, sandstone, provenance, Kurosegawa Terrane.

CONTENTS

I. Introduction

The Yatsushiro−Kuma district of Kumamoto Prefecture, Kyushu, are geotectonically divided into three major belts; namely Ryuhozan, Chichibu and Shimanto Belts from north. Between the former two belts the Usuki−Yatsushiro Tectonic Line(=Median Tectonic Line) is developed, and the Osakama Tectonic Line (=Butsuzo Tectonic Line) is followed on the northside of the lattermost. In the Chichibu Belt, many tectonic lines run nearly parallel with the above−mentioned two tectonic lines, further subdividing into many zones (cf. Matsumoto *et al.*,1962). One of them, the Hinagu−Kawamata Zone is made up of the Upper Permian Kuma Formation, the Upper Triassic formation, the Middle to Uppir Jurassic formation, and the Lower Cretaceous formations, all of which represent clastic sequences. Stratigraphical and paleontological studies on these formations were done by many authors (Kanmera, 1953, 1954; Matsumoto and Kanmera, 1964; Tamura, 1965; Sano, 1977; Yokota and Sano, 1984; Ishiga and Miyamoto, 1986; Ando, 1987 and others). And, petrographical researches were carried out on sandstones of the Permian to Cretaceous formations by Fujii (1956, 1962) and Miyamoto (1980). But, there have been no detailed investigations on the varieties of one mineral species in sandstones, such as garnet, pyroxene, hornblende and so on. Recently Miyamoto *et al.* (1990, 1992) reported on the chemical and mineral composition of detrital garnets in the Permian sandstones of the Kurosegawa Terrane in the western part of Kyushu and the central part of Shikoku. The results are summarized as follows: There are significant diffirences in chemical composition between detrital garnets of sandstones from the Upper Permian Kuma and Middle Permian Kozaki Formations (well−bedded clastic sequences which consist of conglomerate−bearing sediments) and those from the Upper Permian Miyama and Kamoshishigawa Formations (accretionary complex); that is, the formers are characterized by grandite and the latters characterized by almandine. Detrital garnets in sandstones of the Upper Permian Mizukoshi and Upper Permian Ichinose Formations are chemically similar to those of the Kuma and Kozaki Formations.

The study purpose of this paper is to give the further detailed description of detrital garnets in Permian to Cretaceous sandstones of the Kurosegawa Terrane and to interpret their provenance, in addition to the Permian to Cretaceous stratigraphy. 1166 grains of detrital garnets selected in 110 samples were analysed at one point for each grain, because individual grains show scarecely chemical zonation, by EPMA(JCMA−733II) selecting eight elements (Si, Ti, Al, Fe, Mn, Mg, Ca and Cr) for measurement.

Acknowledgment

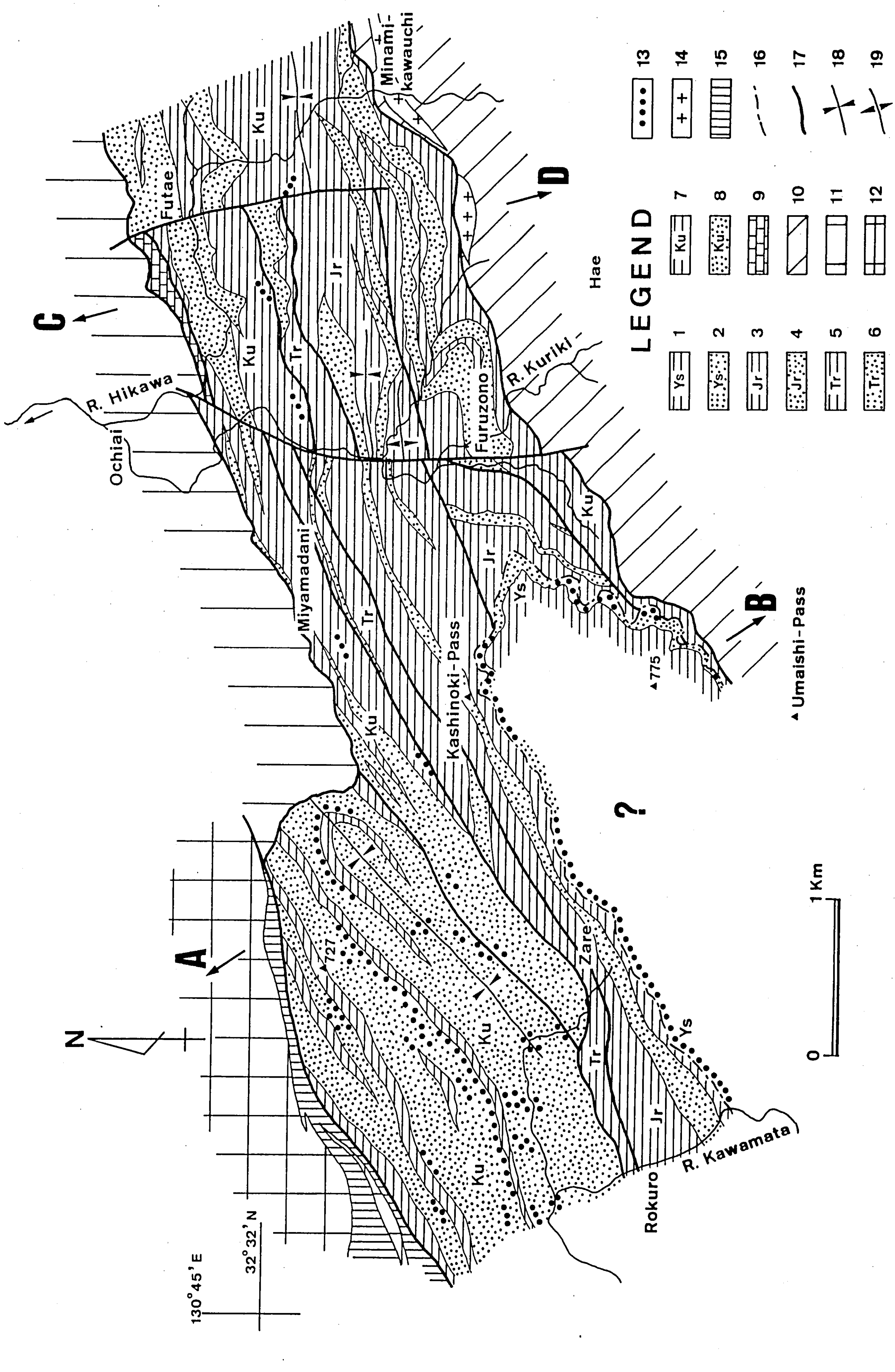
The authors wish to their sincere thanks to Professors Yuji Okimura and Ikuo Hara of Hiroshima University for valuable discussion and fruitful suggestions during this study. The authors gratefully acknowledge Mr. Asao Minami of the same university for EPMA analyses of garnet. We are much indebted to retired Mr. Akito Magai and Mr. Hideo Uemura of Hiroshima University, who helped us in preparing numerous thin sections of sandstones. The field work was in part financially supported by the Grand in Aid for Scientific Researches of the Ministry of Education of Japan.

II. Geological setting

The mapped area(the Kashinoki−Pass area)is located at the drainage of the Kawamata and Kuriki River as tributaries of the Hikawa River, in the vicinity of Rokuro, Toyo−mura, to Komata, Izumi−mura, Yatsushiro−gun, Kumamoto Prefecture, Kyushu (Figs. 1 and 2). Geotectonically it belongs to the Kurosegawa

Fig. 1. Index map of the study area.

Fig. 2. Geological map of the Kashinoki−Pass area, Kumamoto Prefecture.
1−2: Yatsushiro Formation (1: sandstone and shale member, 2: conglomerate and sandstone member), 3−4: Middle to Upper Jurassic formation (3: shale−rich member, 4: sandstone−rich member), 5−6: Upper Triassic formation (5: shale−rich member, 6: sandstone−rich member), 7−8: Kuma Formation (7: shale−rich member, 8: sandstone−rich member), 9: Kakisako Formation, 10: Hashirimizu Formation, 11: Miyama Formation, 12: metamorphic rocks of high−pressure type, 13: conglomerate, 14: mylonitic granite, 15: serpentinite, 16: angular unconformity, 17: fault, 18: axis of syncline, 19: axis of anticline.


N
130°45'E
32°32'N
A
727
B
C
D
Futae
Minami-Kawauchi
R. Hikawa
Ochiai
Miyamadani
Kashinoki-Pass
Furuzono
R. Kuriki
Hae
775
Umaishi-Pass
?
Zare
Rokuro
R. Kawamata
Ku
Jr
Tr
Ys
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1 Km
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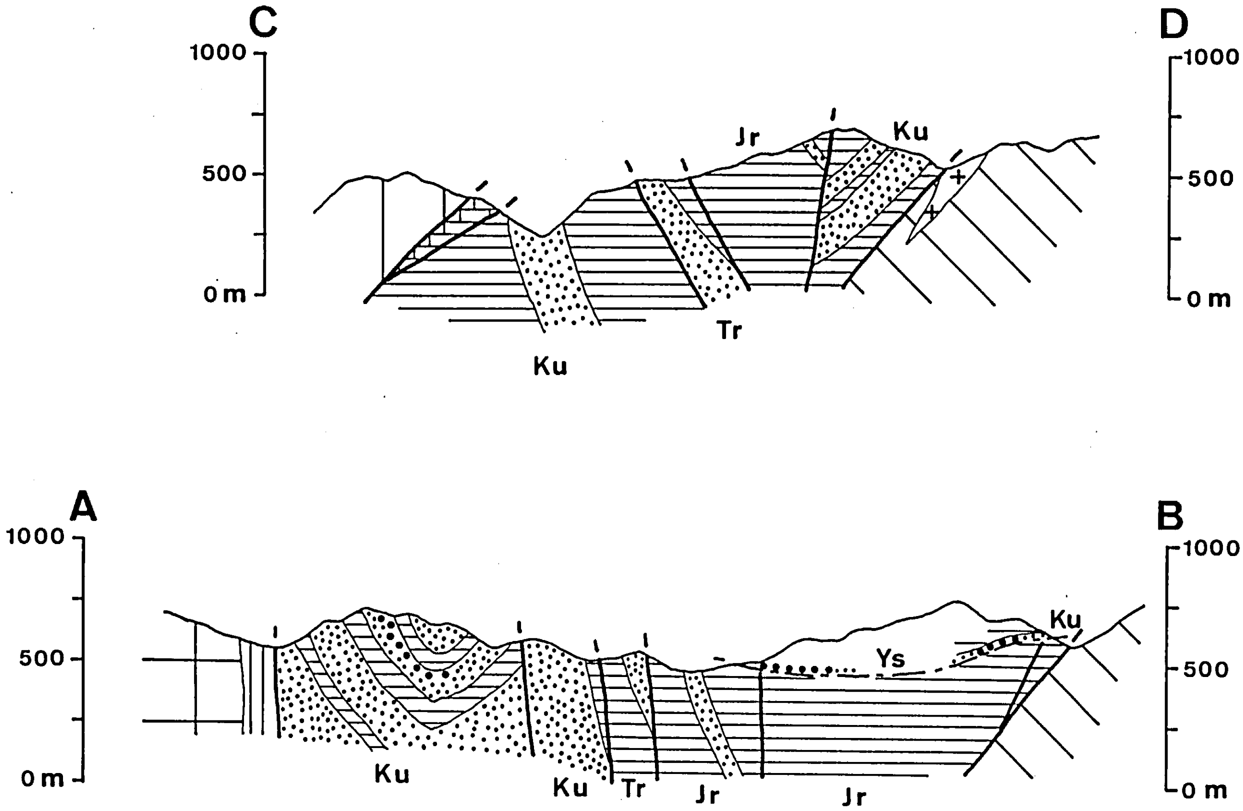

Fig. 3. Geological profiles of the Kashinoki—Pass area. Legend is shown in Fig. 2.

Terrane in the Outer Zone of Southwest Japan. In this area, the metamorphic rocks of high—pressure type, the Miyama Formation, the Kakisako Formation, the Kuma Formation, the Upper Triassic formation, the Middle to Upper Jurassic formation, the Yatsushiro Formation and the Hashirimizu Formation are distributed from north to south (see Figs. 2 and 3). Geological and stratigraphic descriptions of these geological units are briefly given bellow.

The glaucophanic metamorphic rocks (cf. Ueta, 1961) of high—pressure type are occurred in fault contact with the Kuma Formation and the Miyama Formation in the northern marginal belt of this area (Nomoto, 1981MS). Original rocks are made up of mudstone, sandstone, green rocks, chert and so on.

The Miyama Formation (Miyamoto *et al.*,1985) is mainly composed of pebbly mudstone including exotic blocks of chert, green rocks, limestone, sandstone and others of various size and shape. The Late Permian radiolarian fossils are obtained from mudstone of this formation formed during the Late Permian as an accretionary complex.

The Kakisako Formation (Kanmera, 1952; Miyamoto *et al.*,1985) mainly consists of limestone and subordinately contains conglomerate and silty shale, which is exposed along a thrust zone between the Miyama Formation on the north and the Kuma Formation on the south(Figs. 2 and 3). The limestone yields abundant fossils of foraminefers and corals, belonging to *Millerella japonica—Kueichophyllum* Zone (Kanmera, 1952). Moreover, brachiopods such as *Prospira* sp. cf. *P. travesi* Thomas and so on are obtained from silty shale (Miyamoto *et al.*, 1985). This formation is assigned to Visean (Early Carboniferous).

As shown in the geological map(Fig. 2), the Kuma Formation (Kanmera, 1953), with the overlying Mesozoic formations, forms a synclinorium with a general trend of ENE—WSW. On the north this formation is demarcated from the metamorphic rocks of high—pressure type by a high—angled fault and from the Miyama and Kakisako Formations by a thrust fault, dipping moderately to the north. On the south it is demarcated from the Hashirimizu Formation, which is an Early Jurassic accretionary complex, by a thrust fault dipping moderately northward, the Fukami Tectonic Line. The Kuma Formation is divided into two belts of north and south, which are separared from each other by a vertical fault running nearly parallel with the general trend of this formation. The fault is placed along the central axis of synclinorium, showing that the geological structure in both belts is characterized by a syncline. According to Kanmera (1953), the Kuma Formation is about 900 m thick, mainly consists of conglomerate, sandstone and shale, and subordinately contains small lenses of limestone, yielding abundantly fusulinids and other fossils. Miyamoto *et al.* (1985) and Ishiga and Miyamoto (1986) reported the occurrence of the Upper Permian radiolarian assemblage characterized by *Follicucullus bipartitus* and *F. charveti* from shale of this formation in the Futae—Kayaba area, Izumi—mura, where is an eastern extension of the present study area. Recently, Permian fusulinids (Sugiyama and Ozawa, 1989) and radiolarians (Sugiyama and Ozawa, 1989; Miyamoto *et al* ., 1991) have been reported from limestone and shale in the mapped area. The details of radiolarian fossils obtained from the Kuma Formation in the present area will be described in another paper.

Upper Triassic formation are developed between the Kuma Formation on the north and the Middle to Upper Jurassic formation on the south, being in fault contact with each other. It is chiefly composed of shale and sandstone, accompanied by acidic tuff and yields *Monotis* sp. The Miyamadani area (see Fig. 2) is one of the best exposures of this *Monotis*−bearing formation, as described by many authors (for example, Yamashita, 1895; Kanmera, 1951;Tamura, 1965; Ando, 1987). Radiolarian fossils such as *Canoptum* sp. A, *Parahsuum* (?) sp., *Canesium* (?) sp., *Betraccium* sp .,*Palaeosaturnalis* sp. A and others are obtained from shale of one locality in this area (Kuwazuru *et al* ., 1990). The beds are right−side−up and steeply dip southward with a general trend of ENE−WSW. The distribution of this formation is restricted within a narrow belt, 200−300 meters wide in N−S direction.

Middle to Upper Jurassic formation is exposed somewhat widely to the south of the Upper Triassic formation, being in fault contact and arranged nearly parallel with that. This formation is demarcated by a fault from the Kuma Formation on the south. The distributing area of the Middle to Upper Jurassic formation is divided into three parts by two faults, which run in ENE−WSW trend and N−S trend respectively (see Fig. 2). In the area along the northern side of ENE−WSW trending fault, the beds of this formation are right−side−up and dip to the south with ca. 70° and a general trend of ENE−WSW. It is composed of shale and sandstone with some thin intercalations of acidic tuff. A sandstone bed of less than 100 meters in thickness is intercalated in the middle part of this formation and can be traced laterally for about 5km. In the southern part of this fault, the beds of this formation dip to the direction of N60°W with ca. 35°, being right−side−up. It consists of shale and sandstone. At the area along the eastern side of N−S trending fault, a couple of syncline and anticline with open form is developed in its western half, while, in its eastern half, the strata with ENE−WSW trend dips in ca. 40° to the south. It is made up of sandstone and shale, being sporadically intercalated with some thin beds of acidic tuff.

The radiolarian fossils indicating the Middle to Upper Jurassic age have been obtained from black shale and acidic tuff of the Middle to Upper Jurassic formation at twenty three localities in total. Bio−stratigraphical studies on these radiolarian fossils will be reported in other paper. Judging from these facts, this formation is the eastern extension of the Middle Jurassic Bisho Formation (Sano, 1977; Hirano and Sano, 1977; Yokota and Sano, 1986) and the Upper Jurassic Ikenohara Formation (Yokota and Sano, 1984), both of which is separately distributed at Bisho−Kobaru, about 2 kilometers west of the present area.

The Yatsushiro Formation overlies the Kuma Formation and the Jurassic formation with a remarkable unconformity (Fig. 2). The beds of the former dip to the south and the north with an angle of ca. 25° in the northern part and the southern part respectively. The basal part of this formation consists of conglomerate and coarse−grained sandstone, and its overlying main part is made up of arkosic, medium−grained sandstone and black shale. The Yatsushiro Formation has been considered to be of Albian (late Early Cretaceous) in terms of international scale (see Matsumoto *et al*., 1980 and others).

The southernmost zone of the mapped area is occupied by the Hashirimizu Formation, being in a fault contact with the Kuma Formation. It is composed mainly of pebbly mudstone and sandstone with intercalated thin layers of monotonous black shale, including exotic blocks of chert, limestone and green rocks. On the basis of the occurrence of fusulinids from limestone, the Hashirimizu Formation had been considered to be of Middle Permian age for a long time. The Early Jurassic radiolarians have, however, been found in black mudstone of this formation, showing an accretionary complex formed during Early Jurassic age (Miyamoto and Kuwazuru, in press).

III. Chemical composition of detrital garnets in sandstones

Garnet is a characteristic constituent of high grade metamorphic rocks and is also found in some igneous rocks and as detrital grains in sedimentary rocks. The chemical end−members of garnet are pyrope, almandine, spessartine, uvarovite, grossular and andradite. The study of detrital garnet in sediments is reliable for provenance purposes, because the compositional range of a garnet is closely related to the physical condition under which the garnet formed. Electron microprobe analyses of detrital garnet are considered to provide valuable information on the sources of sedimentary rocks, as exemplified by Suzuki (1977), Adachi and Kojima (1983), Hearn and McGee (1983), Adachi (1985), Morton (1985), Musashino and Kasahara (1986), Torikai (1990) and Takeuchi (1986, 1989, 1992 a and b).

The detrital garnets in Permian to Cretaceous sandstones of the Kurosegawa Terrane in the western part of Kyushu, Southwest Japan have been studied from the sedimentary petrological viewpoint. The specimens of sandstone from the Upper Permian to the Early Cretaceous formations in the Kashinoki−Pass area have been collected according to a predetermined plan to secure adequate stratigraphical coverage as effectively as possible throughout this area. The localities for the collected specimens are shown in Fig. 4.

A: The Kuma Formation

52 samples of sandstone from the Kuma Formation have been collected (see Fig. 4) and 561 grains of detrital garnets from them have been analyzed by EPMA. The chemical compositions of garnet are plotted on two types of ternary diagrams (Fig. 5). As shown on the (grossular plus andradite) − (spessartine) − (pyrope plus almandine) diagram (Fig. 5−1), about nine−tenths garnets (502/561) in the samples of the Kuma belong to Ca−rich type (containing more than about 90 mol. % in

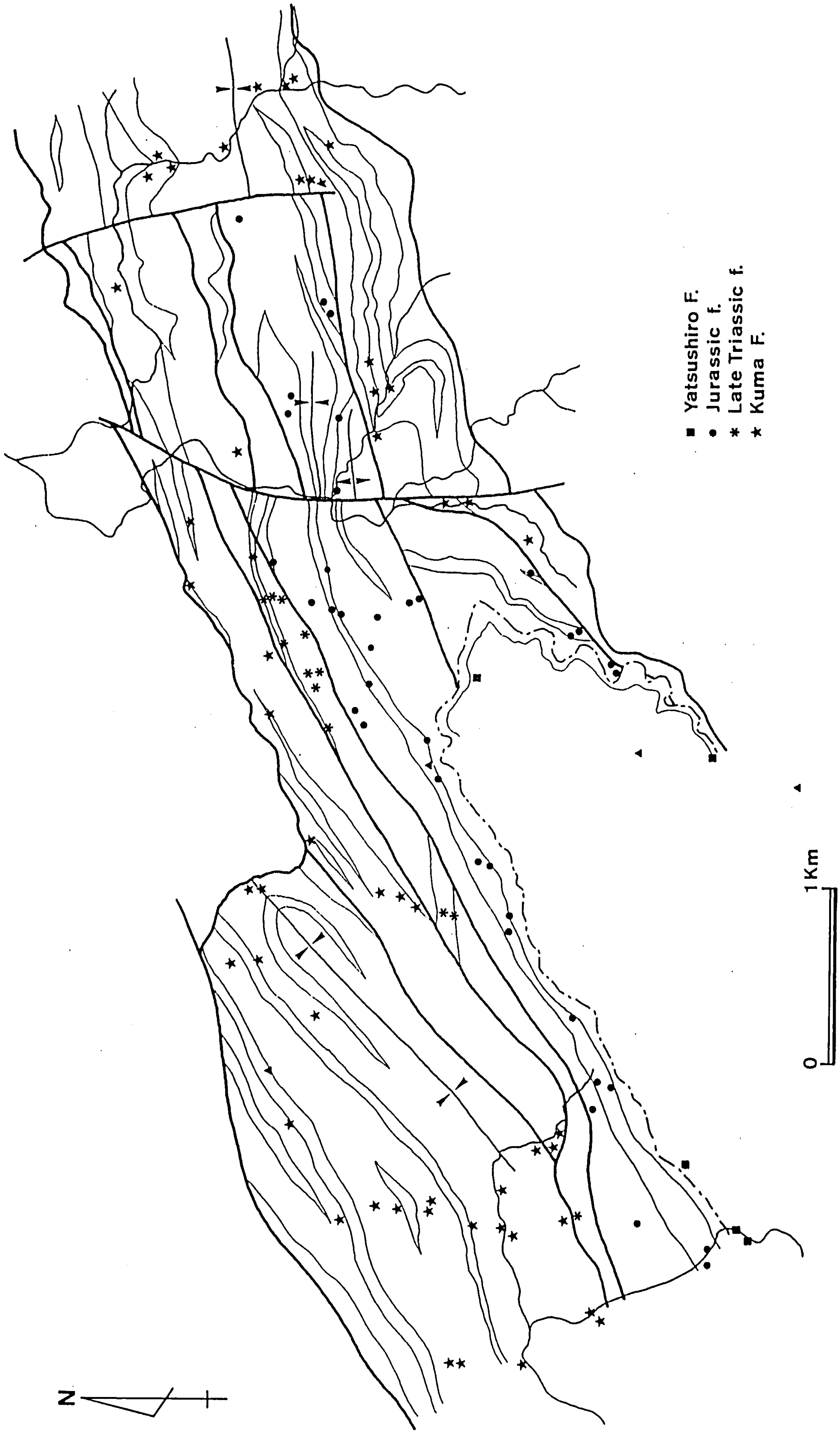

Fig. 4. Map showing localities of the examined specimens from the Kashinoki – Pass area.

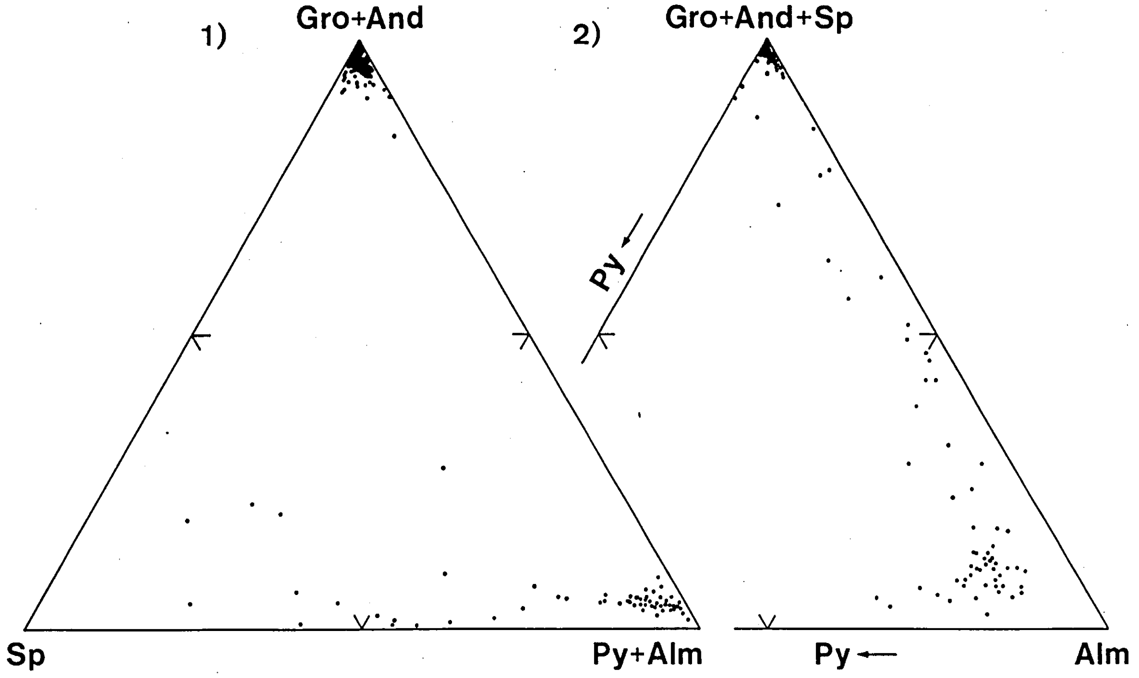

Fig. 5. Plots of chemical compositions of detrital garnets in sandstones from the Kuma Formation in the Kashinoki−Pass area. Analysed grain number=561. Py: Pyrope, Alm: Almandine, Sp: Spessartine, Gro: Grossular, And: Andradite.

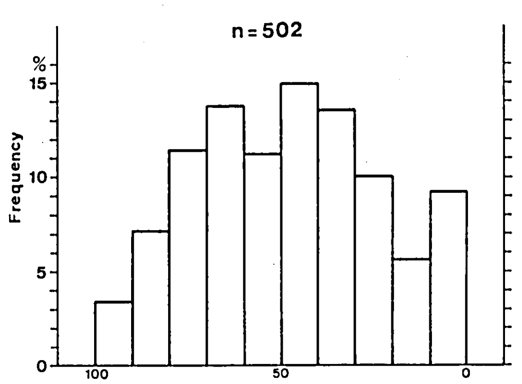

Fig. 6. Frequency (%) distributions with respect to grossular content (mol%) in Ca−rich garnets in sandstones from the Kuma Formation.

grandite content), namely, grandite (grossular plus andradite). Fig. 6 represents the frequency distribution of grossular content for these Ca−rich garnets and remaining 59 grains of garnet are of pyralspite type, showing wide range of chemical composition.

B: The Upper Triassic formation

13 samples of sandstone from this formation have been collected and 125 grains of detrital garnets from them have been analysed by EPMA. The chemical compositions of detrital garnets are plotted in Fig. 7−1 and −2. In the samples of the Upper Triassic formation, only three grains of grandite garnet have been found. Most of garnet grains are of pyralspite type (almandine) with spessartine content of less than 60 percent and pyrope content of less than 35 percent.

C: The Middle to Upper Jurassic formation

36 samples of sandstone from this formation have been collected (Fig. 4) and 434 grains of detrital garnets from them have been analysed by EPMA. Fig. 8−1 and −2 shows the chemical compositions of these garnet. In the samples of the Jurassic formation, most of detrital garnets are of almandine type with pyrope content of less than 43.6 percent and spessartine content of less than 70.5 percent. There are rarely of grandite type (3/434).

D: The Yatsushiro Formation

9 samples (Fig. 4) of sandstone from the Lower Cretaceous Yatsushiro Formation have been collected and 92 grains of detrital garnets have been analysed by EPMA. Fig. 9 illustrates their compositions. Detrital granets consist of almandine, pyrope−rich almandine (the highest py. mol.% = 45.2), spessartine−rich almandine and grandite (28/92). As shown in Fig. 10, most of grandite garnets have less than 10 mol. % in grossular content. As far as grandite garnets are concerned, there are significant differences in chemical composition between garnets in the Kuma Formation and those in the Yatsushiro Formation (cf. Figs. 6 and 10).

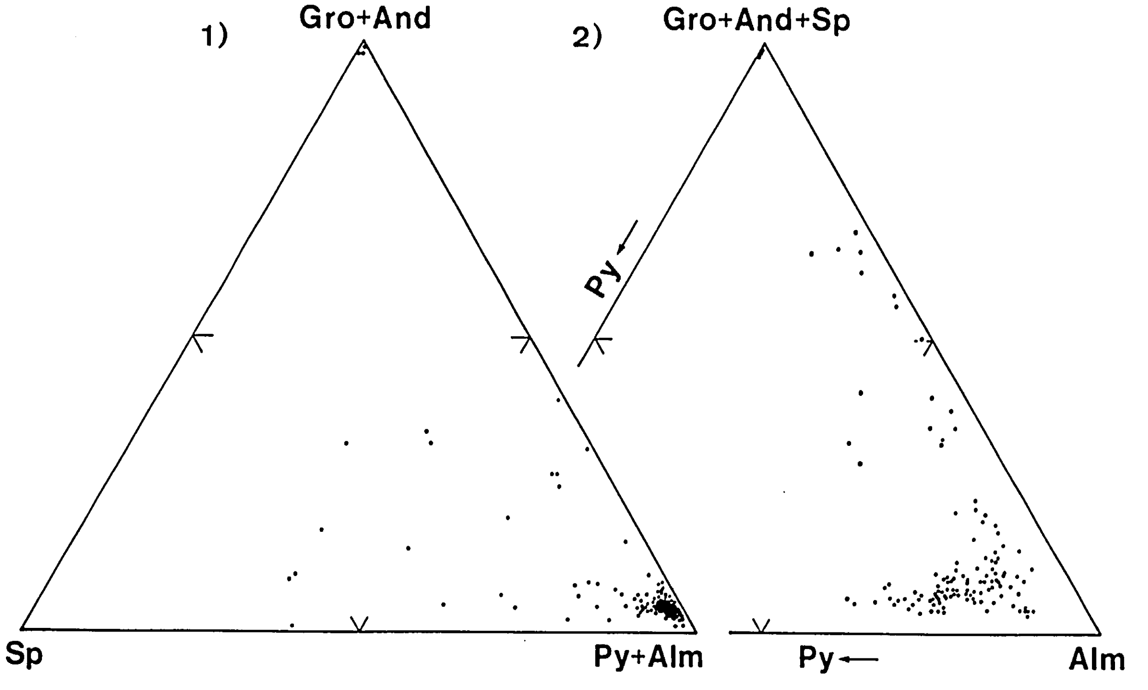

Fig. 7. Plots of chemical compositions of detrital garnets in sandstones from the Upper Triassic formation in the Kashinoki–Pass area. Analysed grain number=125. Symbols are identical with those of Fig. 5.

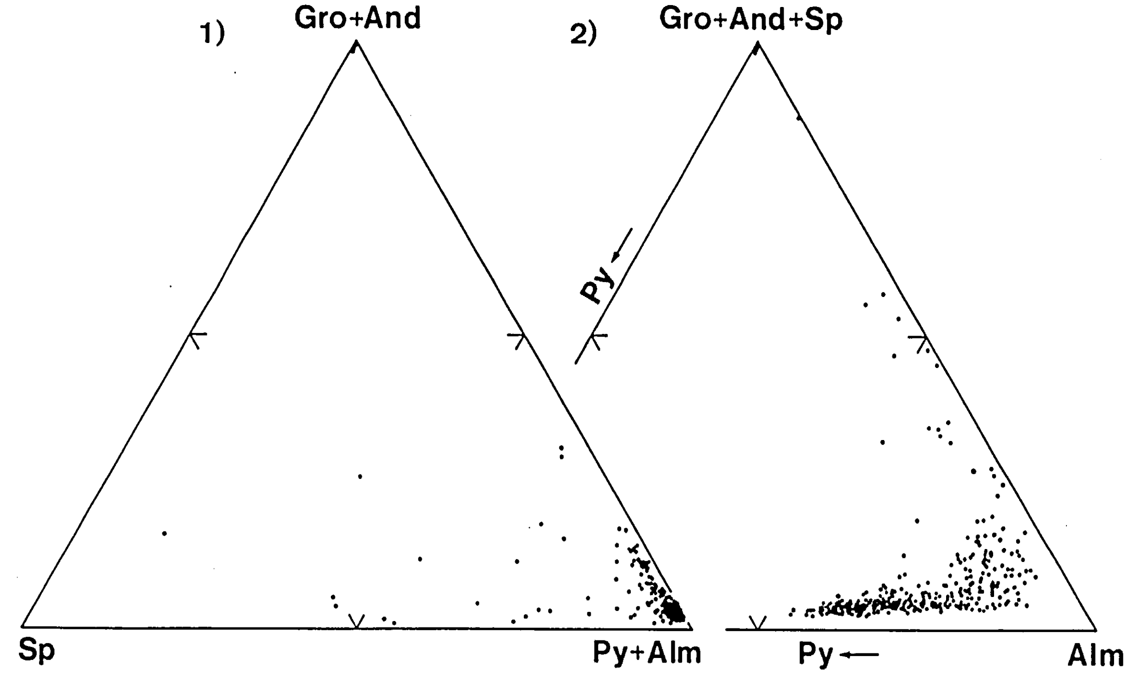

Fig. 8. Plots of chemical compositions of detrital garnets in sandstones from the Middle to Upper Jurassic formation in the Kashinoki–Pass area. Analysed grain number=434. Symbols are identical with those of Fig. 5.

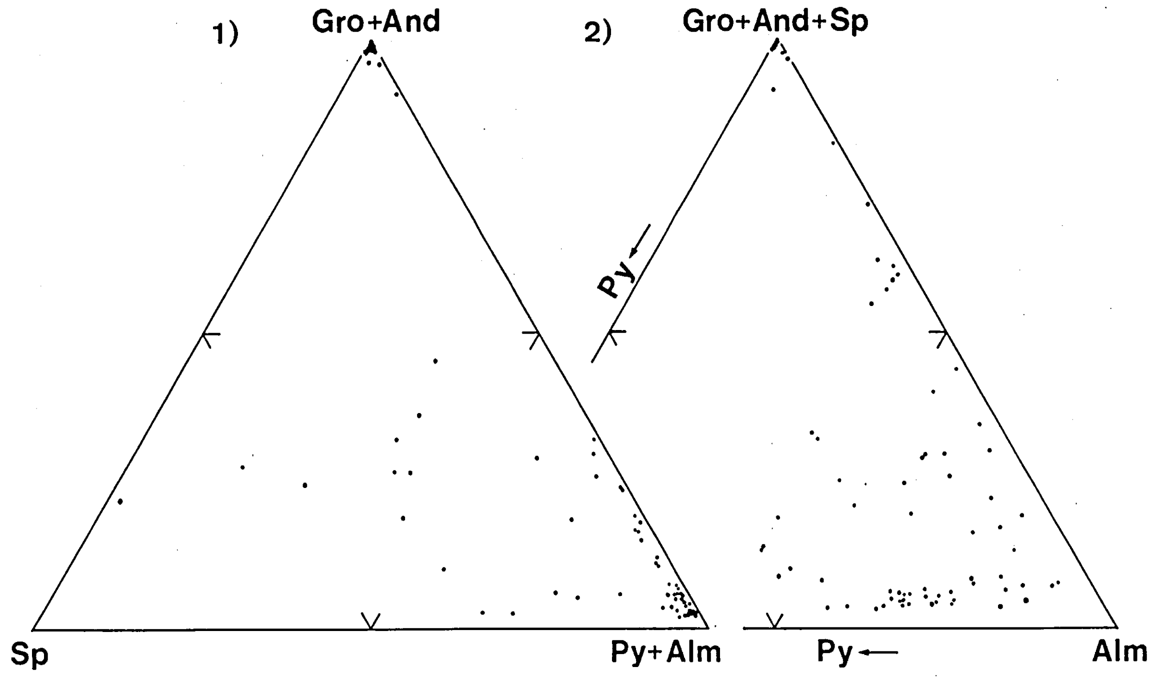

Fig. 9. Plots of chemical compositions of detrital garnets in sandstones from the Yatsushiro Formation in the Kashinoki−Pass area. Analysed grain number=92. Symbols are identical with those of Fig. 5.

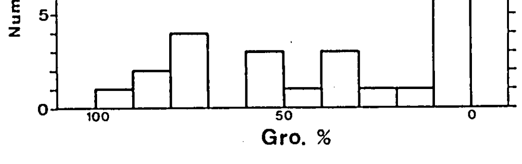

Fig. 10. Number frequency distribution with respect to grossular content (mol%) in Ca−rich garnets in sandstones from the Yatsushiro Formation.

IV. Discussion

The Kuma Formation is distributed within the Kurosegawa Terrane of the Chichibu Belt in Kumamoto Prefecture, Kyushu. It is a conglomerate−bearing well−bedded clastic sequence, which consist largely of coarse−grained sandstone and shale with small lenses of the Late Permian limestone yielding the fusulinaceans characterized by the occurrence of *Lepidolina kumaensis* (Kanmera, 1953, 1954). Moreover, Miyamoto *et al.* (1985) and Ishiga and Miyamoto (1986) reported the occurrence of the Late Permian radiolarian assemblage characterized by *Follicucullus bipartitus* and *F.charveti* from mudstone of this formation. As mentioned in the preceding chapter, the majority of detrital garnets in sandstones from the Kuma Formation distributed in the Kashinoki−Pass area, Kyushu, consist of Ca−rich garnet (grossular−andradite series).

Lithological correlatives of the Upper Permian Kuma Formation developed in other areas within the Kurosegawa Terrane include the Middle Permian Kozaki Formation (Kanmera, 1961) and the Late Permian Mizukoshi Formation (Matsumoto and Fujimoto, 1939; Yanagida, 1958, 1963) in Kyushu and the Late Permian Ichinose (Katto *et al.*, 1956; Hada and Yoshikura, 1991) in Shikoku and others. From the EPMA analytical study it has been clarified that most of detrital garnets in these formations are made up of Ca−rich garnets as well as those in the Kuma Formation (Miyamoto *et al* ., 1992 and this study). Description of the sampling localities of sandstones in these formations is given by Miyamoto *et al.* (1992). In the samples of the Kozaki (cf. Fig. 11), Ichinose (cf. Fig. 13) and Mizukoshi (cf. Fig. 14) Formations, grandites occupy about 92 percent (118/129), about 96 percent (43/45) and about 86 percent (92/107) of the total detrital garnets examined, respectively. Moreover, the detailed investigation of the chemical composition indicates that Ca−rich garnets from the Kozaki Formation (cf. Fig. 12) are similar to those in sandstones of the Kuma Formation (Fig. 6). From these fact it has been concluded that the majority of detriral garnets in Permian sandstones developed within the Kurosegawa Terrane consist of Ca−rich garnets. The rocks, in which Ca−rich garnets occur as a main constituent, are generally contact or thermally metamorphosed impure calcareous sedimints, particularly metasomatic skarn deposits. Thus, it may be assumed that the detrital garnets in the Kuma,

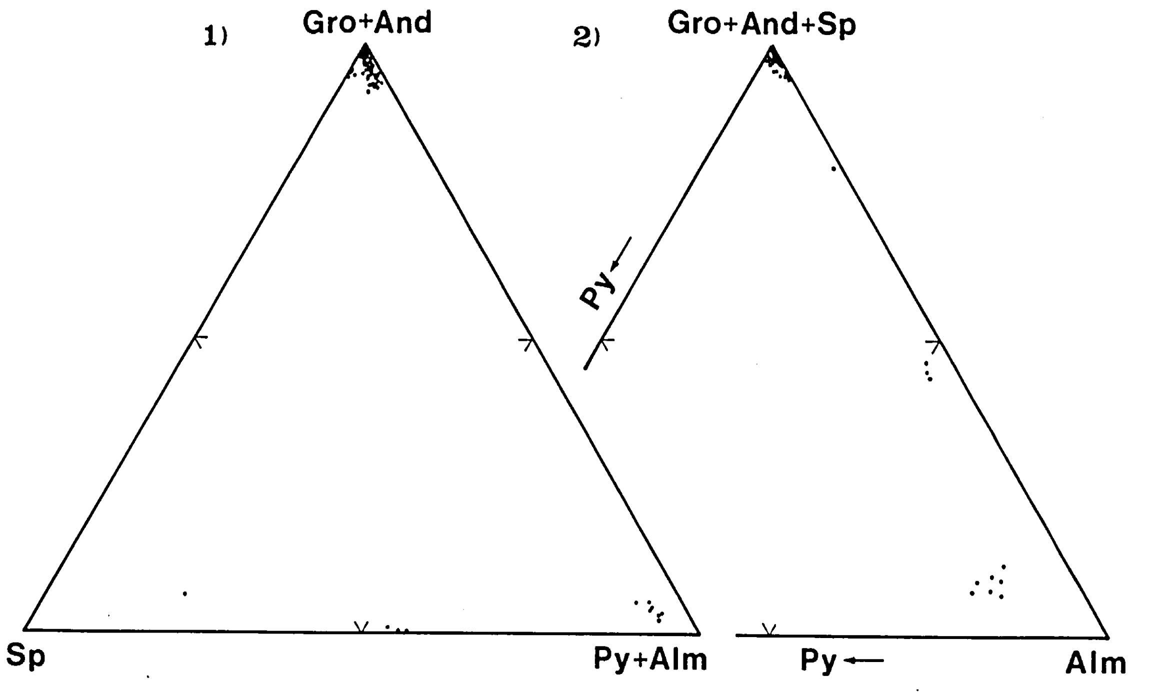

Fig. 11. Plots of chemical compositions of detrital garnets in sandstones from the Kozaki Formation. Analysed grain number=129. Symbols are identical with those of Fig. 5.

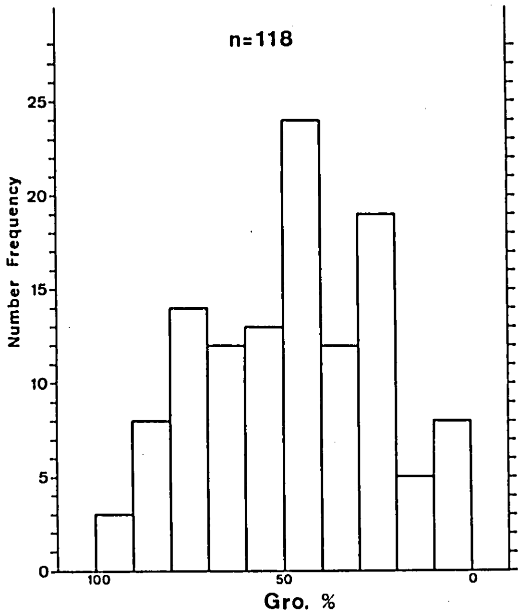

Fig. 12. Number frequency distribution with respect to grossular content (mol%) in Ca−rich garnets in sandstones from the Kozaki Formation.

Kozaki, Ichnose and Mizukoshi Formations were derived from the high−temperature type metamorphic rocks.

Conglomerates of the Kuma, Kozaki, Ichinose and Mizukoshi Formations mentioned above have been referred to the Usuginu−type ones (Kano, 1967a and b, 1971). As described by Kanmera (1953, 1961), Miyachi (1966), Yanagida (1958), Yanagi and Hamamoto (1977) and others, the conglomerate are made up mainly of well−rounded gravels of acidic to basic plutonic (granitic rocks, granodiorite, gabbro and others) and acid to intermediate volcanic and dike rocks, such as rhyolite, andesite, quartz−porphyry, porphyrite, subordinately of sedimentary rocks (acidic tuff, chert, limestone, sandstone and shale). Kano (1967) described the chemical compositions of granitic pebbles from the conglomerate in the Kuma, Kozaki and Mizukoshi Formations, and he insisted that the Permian granitic materials may have been transported from somewhere within the Higo gneiss zone and the Yatsushiro tectonic zone (=Kurosegawa Tectonic Zone). According to Fujii's petrographical study (1962), the source rocks for the sandstones of the Kuma and Kozaki Formations are granitic rocks, volcanic rocks, basic plutonic and green rocks, and volcanic rocks (including dike rocks) and sedimentary rocks respectively. Judging from the conglomerate−sandstone petrographical characters and chemical composition of detrital garnets, therefore, it would be assumed that the provenance of the Permian strata of the Kurosegawa Terrane was composed chiefly of acidic to basic plutonic rocks, acidic to intermediate volcanic rocks, and contact or thermally metamorphosed impure calcareous sediments and particularly metasomatic skarn deposits.

On the other hand, the detrital garnets from the Mesozoic formations distributed in the Kashinoki−Pass area, consist mainly of almandine with some grandite (Figs.7−9), and they are regarded as being derived from high− and low−grade, partly granulite facies, metamorphic rocks, granitic rocks, thermally metamorphosed impure calcareous sediments and others. There are significant differences in chemical composition between

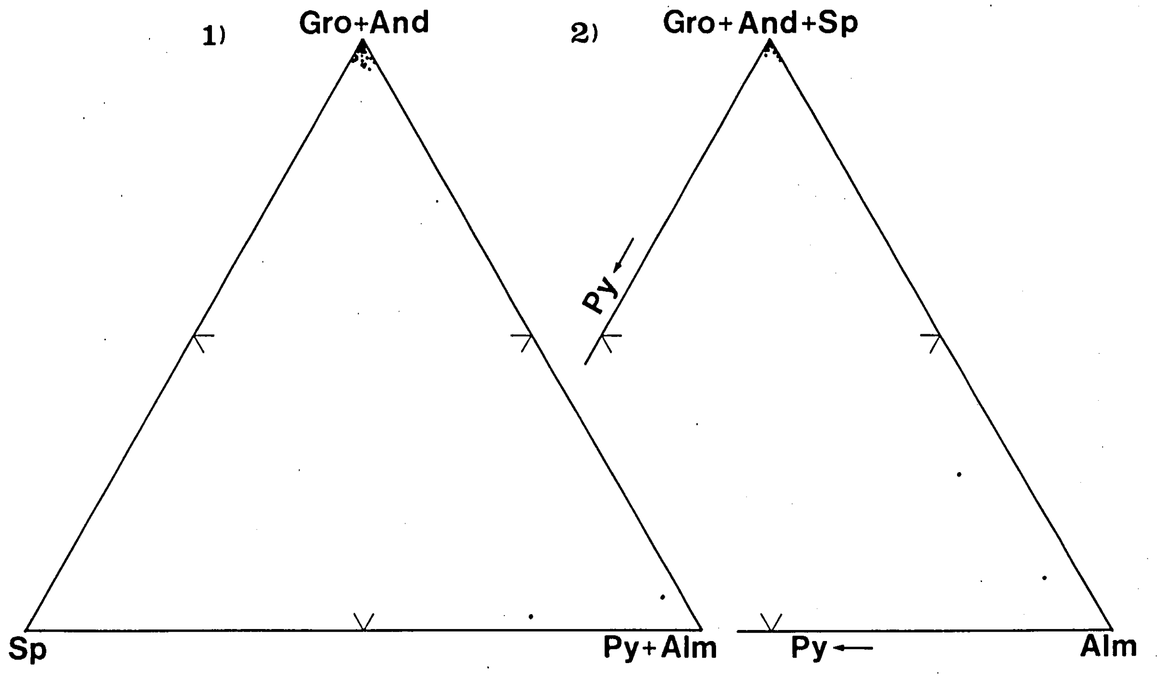

Fig. 13. Plots of chemical compositions of detrital garnets in sandstones from the Ichinose Formation. Analysed grain number=45. Symbols are identical with those of Fig. 5.

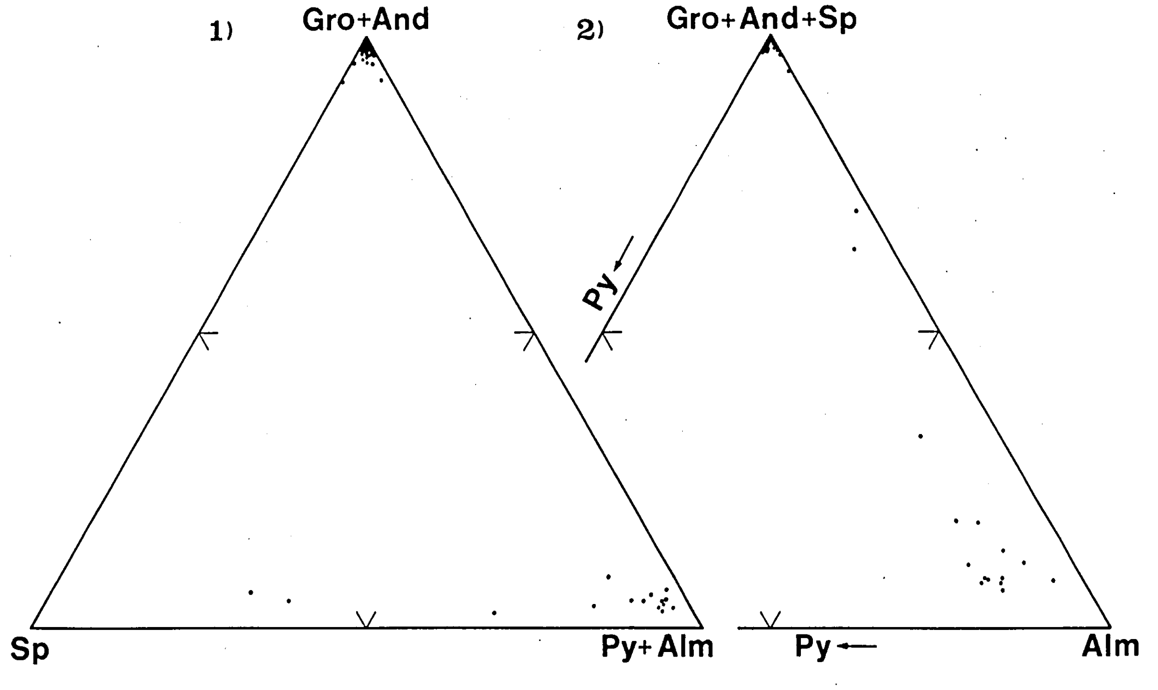

Fig. 14. Plots of chemical compositions of detrital garnets in sandstones from the Mizukoshi Formation. Analysed grain number=107. Symbols are identical with those of Fig. 5.

the detrital garnets of the sandstones from the Kuma Formation and those from the Mesozoic formatioms.

Takeuchi (1992b) has described the chemical composition of detrital garnet in Permian to Jurassic sandstones in the Southern Kitakami Belt, Northeast Japan: The majority of the detrital garnets from the Middle Permian and the Lower to Middle Triassic formations are composed of Ca−rich garnets of grossular and andradite series, while those of the Upper Triassic strata consist mainly of Ca−rich garnets, almandine and Mn−Fe garnets, and those of the Lower Jurassic formation are also made up of Mn garnets with some almandine and Fe−Mg garnets. Moreover, most of detriral garnets of the Middle to Upper Jurassic formation are composed of Mg−Fe garnets containing 30−40 mol.% in pyrope content. It should be noted that stratigraphical variation of the chemical composition of detriatl garnets in Permian to Jurassic sandstones of the Southern Kitakami Belt show a close resemblance to that of the Kurosegawa Terrane in Kyushu, except for minor differences, though there are significant differences in chemical composition between detrital garnets of sandstones from the Permian formations in the Chichibu Terrane and those from the Middle to Upper Permian Maizuru Group in the Inner Zone of the Southwest Japan (cf. Torikai, 1990).

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* : in Japanese with English abstract
** : in Japanese
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