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# Chemical Composition of Detrital Garnets in Permian to Jurassic Sandstones of the Kurosegawa Terrane in the Kayaba–Nishinoiwa Area, Western Kyushu, Japan

By

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*with 1 Table, 11 Figures and 1 Plate*

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Abstract: In the Kayaba–Nishinoiwa area, Kumamoto Prefecture, the Miyama Formation, the Kakisako Formation, the Kuma Formation, the Upper Triassic formation, the Lower to Middle Jurassic formation and the Hashirimizu Formation are distributed from north to south. The stratigraphy is described in this paper in some detail, and besides detrital garnets in Permian to Jurassic sandstones in the well-organized stratigraphic units of the Kurosegawa Terrane in this area have been studied from the sedimentary petrological viewpoint. EPMA analysis of detrital garnets (a total of 637 grains) have revealed that:

There are significant differences in chemical and mineral composition between detrital garnets of the sandstones from the Upper Permian Kuma Formation and the Triassic to Jurassic formations. Detrital garnets of the Kuma Formation consist mostly of grandite (grossular plus andradite) associated with some almandine and some Mn- and Mg-rich almandine, being chiefly derived from calcareous metamorphic rocks, probably skarn. Detrital garnets of the sandstones of the Upper Triassic formation consist mainly of almandine with some amount of Mg content, some grandite and minor spessartine. And, those of the Jurassic formation consist mainly of Mg-rich almandine, some almandine and minor spessartine without grandite garnets. These Triassic to Jurassic detrital garnets are considered to be chiefly derived from high-grade, partly granulite facies, metamorphic rocks.

Based on such mineralogical characters of detrital garnets, it can be pointed out that there are significant differences in provenance between the Upper Permian Kuma Formation and the Mesozoic formations in the Kurosegawa Terrane.

*Key words*: detrital garnet, EPMA, Permian to Jurassic, sandstone, provenance, Kurosegawa Terrane.

CONTENTS



## I. Introduction

The geology of the Kayaba–Nishinoiwa area (Fig. 1) of Kumamoto Prefecture, Western Kyushu have been not yet studied in detail with a few exceptions (i.e., Kanmera, 1953). By the detailed geologic mapping and radiolarian biostratigraphical study, the authors has resulted in the identification of Early to Middle Jurassic stratigraphic unit hithereto undescribed. Consequently, in this area, the Miyama Formation, the Kakisako Formation, the Kuma Formation, the Upper Triassic formation, the Lower to Middle Jurassic formation and the Hashirimizu Formation are distributed from north to south. With the exception of the Miyama and Hashirimizu Formations (accretionary complex), all the remainder represent clastic sequences. Recently, Miyamoto *et al.* (1992) and Miyamoto and Kuwazuru (1993a) reported on the chemical and mineral composition of detrital garnets in Permian to Cretaceous sandstones cropped out in the Kashinoki-Pass area (the mapped area's neighbor to the west, see Fig. 1). The results are summarized as follows:

There are some significant differences concerning to the chemical and mineral composition between detrital garnets of the sandstones from the Upper Permian Kuma Formation and the Mesozoic (Upper Triassic to Lower Cretaceous) formations. Detrital garnets of the Kuma Formation are composed mostly of grandite garnet, but contain some almandine and rare spessartine garnet. On the other hand, those of the Upper Triassic and the Middle to Upper Jurassic formation consist mainly of almandine with some amount of Mg and Mn content and contain rare grandite. And, detrital garnets of the Lower Cretaceous formation are composed of almandine, pyrope-rich almandine, spessartine-rich almandine and grandite.

The purpose of this article is to descrive the chemical and mineralogical characteristics of detrital garnets from the Permian to Jurassic sandstones exposed in the Kayaba–Nishinoiwa district, in addition to the lithological description of Permian to Jurassic formations. From the 70 sandstone samples collected, 637 grains of detrital garnets were extracted and analysed at one point for each grain by EPMA (JEOL JCMA-733 II) selecting eight elements (Si, Ti, Al, Fe, Mn, Mg, Ca, and Cr) for measurement.

#### Acknowledgment

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## II. Geological setup

The mapped area is located at the upper drainage of two rivers, namely the Hikawa and the Nishinoiwa (upper stream of the Kuma), in the vicinity of Kayaba to Nishinoiwa, Izumi-mura, Yatsushiro-gun, Kumamoto Prefecture, western Kyushu (Fig. 1). The Chichibu Belt of the Western Kyushu, Outer Zone of Southwest Japan, is geotectonically divided into two major zones by the Haki Tectonic Line (Matsumoto and Kanmera, 1952); namely Kurosegawa and Sampozan Zones from north. The studied area belongs to the former zone (Terrane). The stratigraphical subdivision and the geologic structure of the area are shown in the Figures 2 and 3. Geologic descriptions of the stratigraphic units are briefly given bellow.

The Miyama Formation (Miyamoto *et al.*, 1985) is dominated by pebbly mudstones which incorporate many exotic blocks (various size and shape) of chert, green rocks, limestone, sandstone, serpentinite, the Kurosegawa igneous rocks of Mitaki type and metamorphic rocks of Terano type etc. Conodonts and radiolarians, which are rarely found, in-

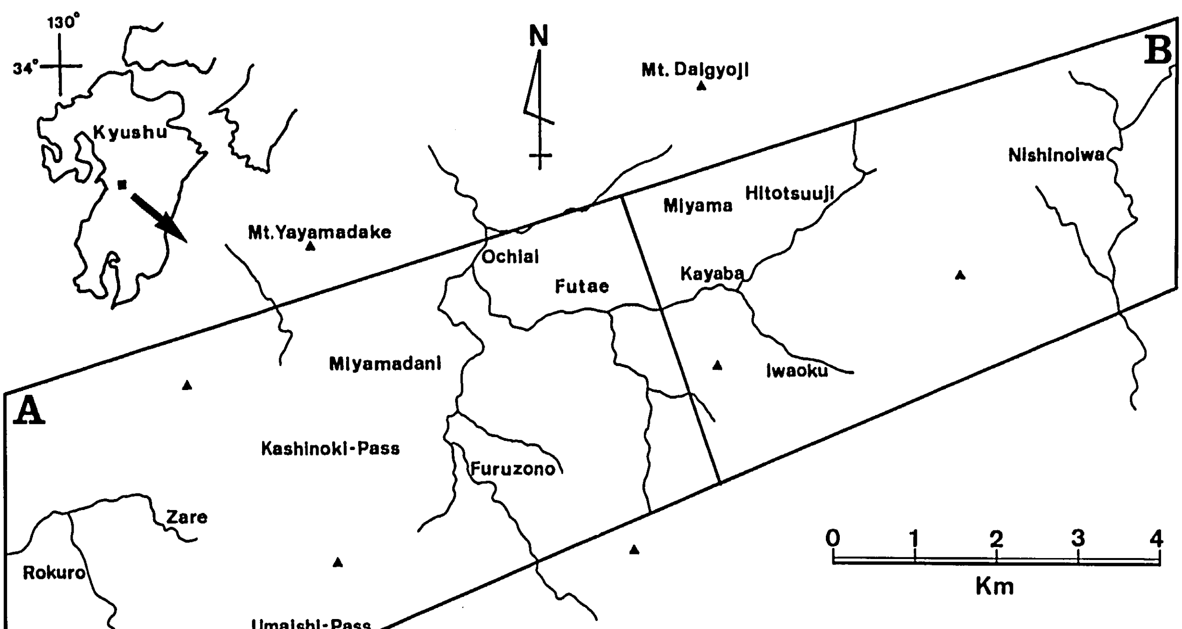
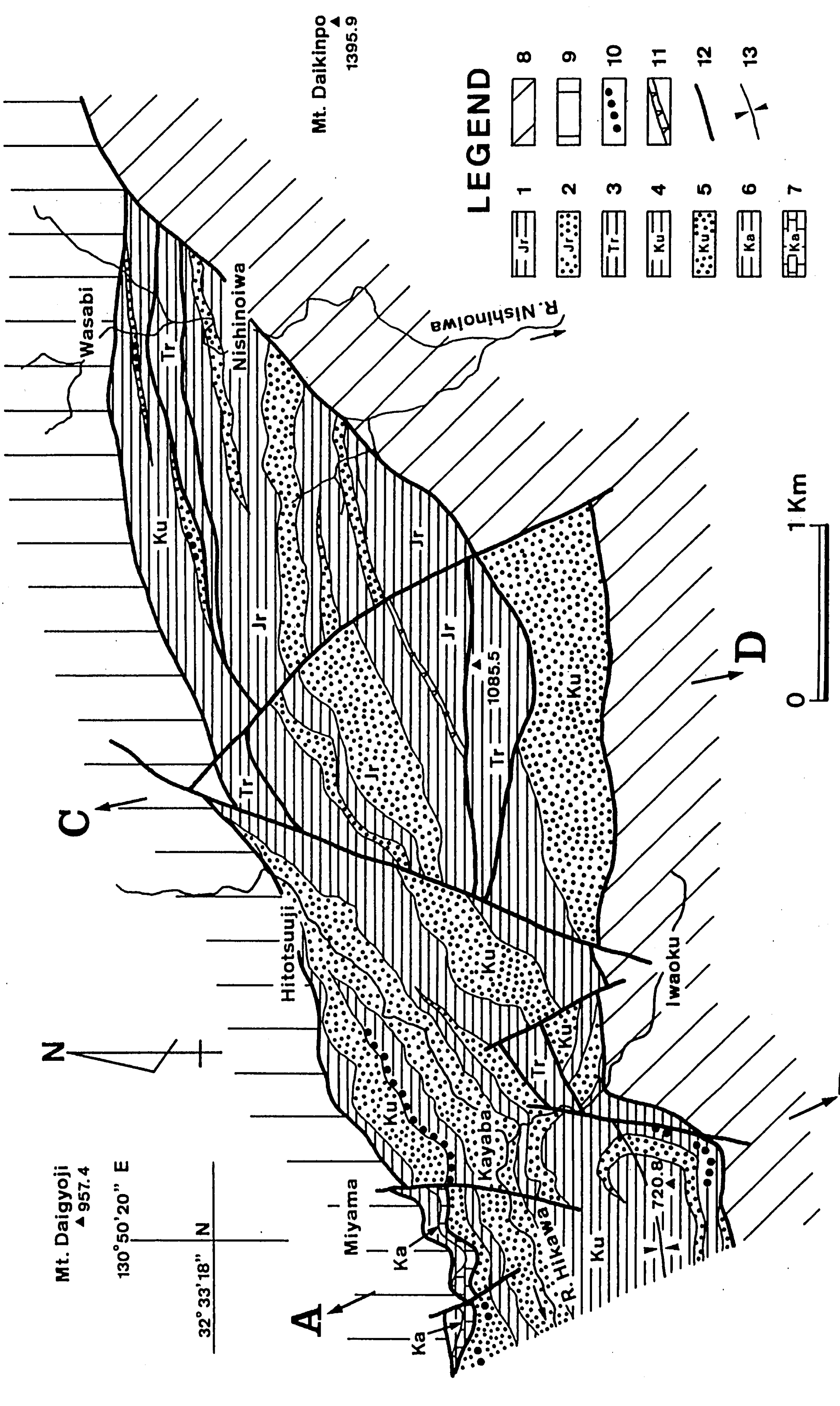



Fig. 1. Index map of the study area.
A: The Kashinoki–Pass area (see Fig. 2 of Miyamoto and Kuwazuru, 1993a)
B: The Kayaba–Nishinoiwa area (see Fig. 2)

Fig. 2. Geological map of the Kayaba–Nishinoiwa area.
1–2: Lower to Middle Jurassic formation(1:shale-rich member, 2: sandstone-rich member), 3: Upper Triassic formation, 4–5: Kuma Formation (4:shale-rich member, 5:sandstone-rich member), 6-7: Kakisako Formation (6: shale, 7: limestone), 8: Hashirimizu Formation, 9: Miyama Formation, 10: conglomerate, 11: acidic tuff, 12: fault, 13: axis of syncline.


LEGEND
1 Jr
2 Jr
3 Tr
4 Ku
5 Ku
6 Ka
7 Ka
8
9
10
11
12
13
Mt. Daikinpo
1395.9
Mt. Daigyoji
957.4
130°50'20" E
32°33'18" N
N
A
B
C
D
Wasabi
Nishinoiwa
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1085.5
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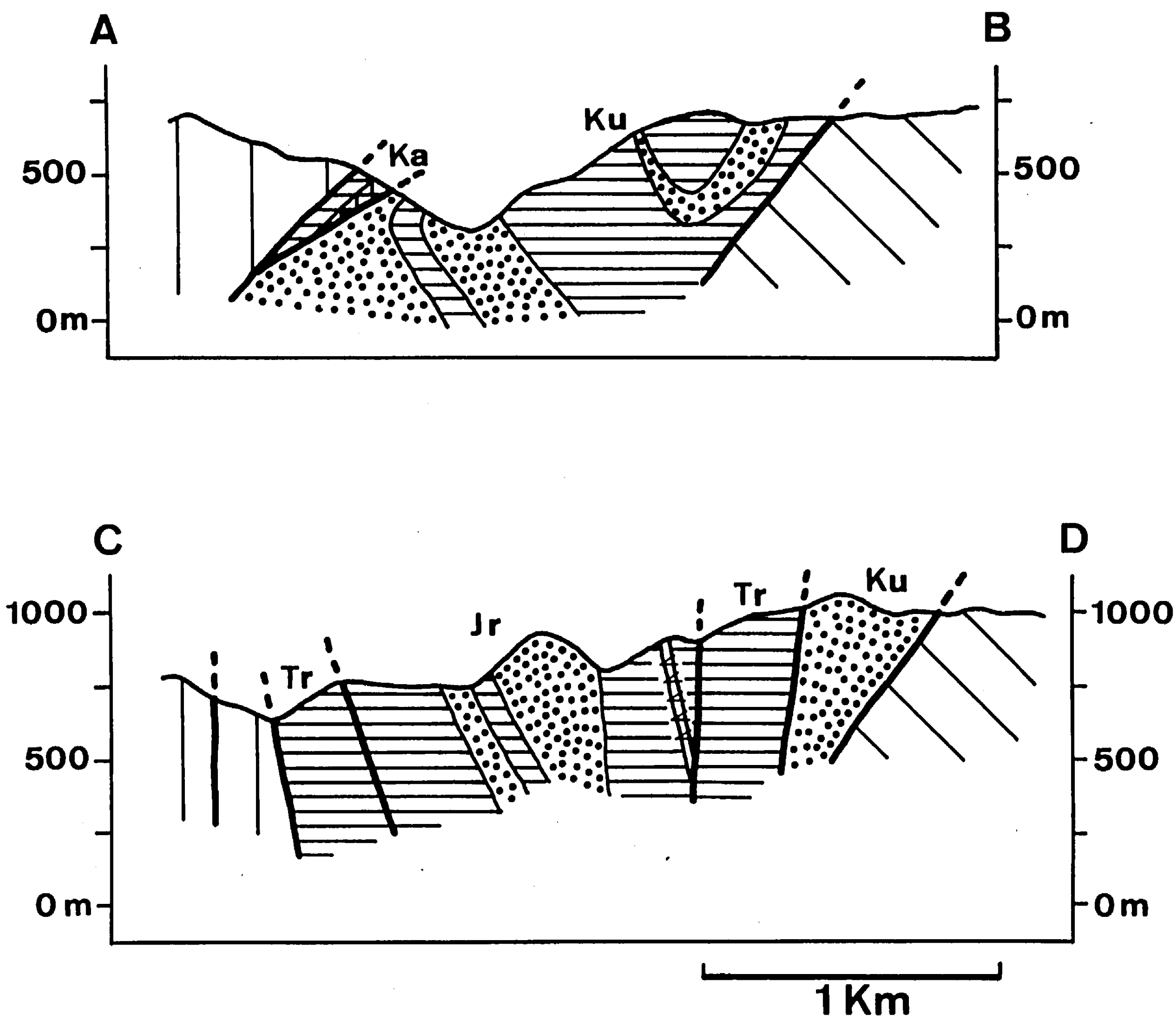


Fig. 3. Geological profiles of the Kayaba–Nishinoiwa area. Legend and profiling lines are shown in Fig. 2.

dicate Early to Middle Permian ages for chert blocks. Howeover, the Late Permian radiolarian fossils are obtained from mudstone, being matrix of pebbly mudstone. This formation is considered to be an accretionary complex formed during the Late Permian.

The Kakisako Formation mainly consists of limestone and subordinate conglomerate and silty shale (Kanmera, 1952; Miyamoto *et al.*, 1985). It is exposed along a thrust zone between the Miyama and the Kuma Formations as shown by Figs. 2 and 3. The distribution of this formation is continued to the west direction (see Fig. 2 of Miyamoto and Kuwazuru, 1993a). The limestone yields the Early Carboniferous (Visean) foraminifers and corals; *Millerella japonica – Kueichouphyllum* fauna (Kanmera, 1952). And also, brachiopods such as *Prospira* sp. cf. *P. travesi* Thomas are obtained from silty shale (Miyamoto *et al.*, 1985).

The Kuma Formation (Kanmera, 1953), with the overlying Triassic and Jurassic formations, is exposed widely in the western part of the study area, forming a syncline with a general trend of ENE-WSW (Fig. 2). However, in eastern part of this area the Kuma Formation is divided into two belts of north and south, which are corresponding to the northern and southern wings of the syncline, respectively. The maximum thickness is estimated to about 1,200m. This formation mainly consists of sandstone, shale and conglomerate, and subordinate small lenses of limestone, yielding abundantly fusulinids and foraminifers. Miyamoto *et al.* (1985) and Ishiga and Miyamoto (1986) reported the occurrence of the Upper Permian radiolarian fossils characterized by *Follicucullus bipartitus* and *Fo. charveti* from shale of this formation in the Rokuro – Futae area where is an western extension of this area, and they are also obtained from shale of two localities in the vicinity of Kayaba.

The Upper Triassic formation is exposed sporadically with four narrow lenticular bodies, which are mainly composed of shale and subordinate sandstone. Each of four bodies is characterized by the occurrence of Upper Triassic pelecypods; *Monotis* sp. and others (Kanmera, 1953; Ando, 1987 and so on).

The Lower to Middle Jurassic formation is exposed widely to the east of the NNE-SSW trending fault which is developed in the middle part of this area (see Fig. 2). On the north this formation is demarcated from the Upper Triassic foramtion and partly the Kuma Formation by a high-angled fault dipping to the south. On the south it is demarcated from the Triassic formation by a high-angled fault and the Hashirimizu Formation by a thrust fault, dipping moderately northward. Although locally overturned, the strata are typi-

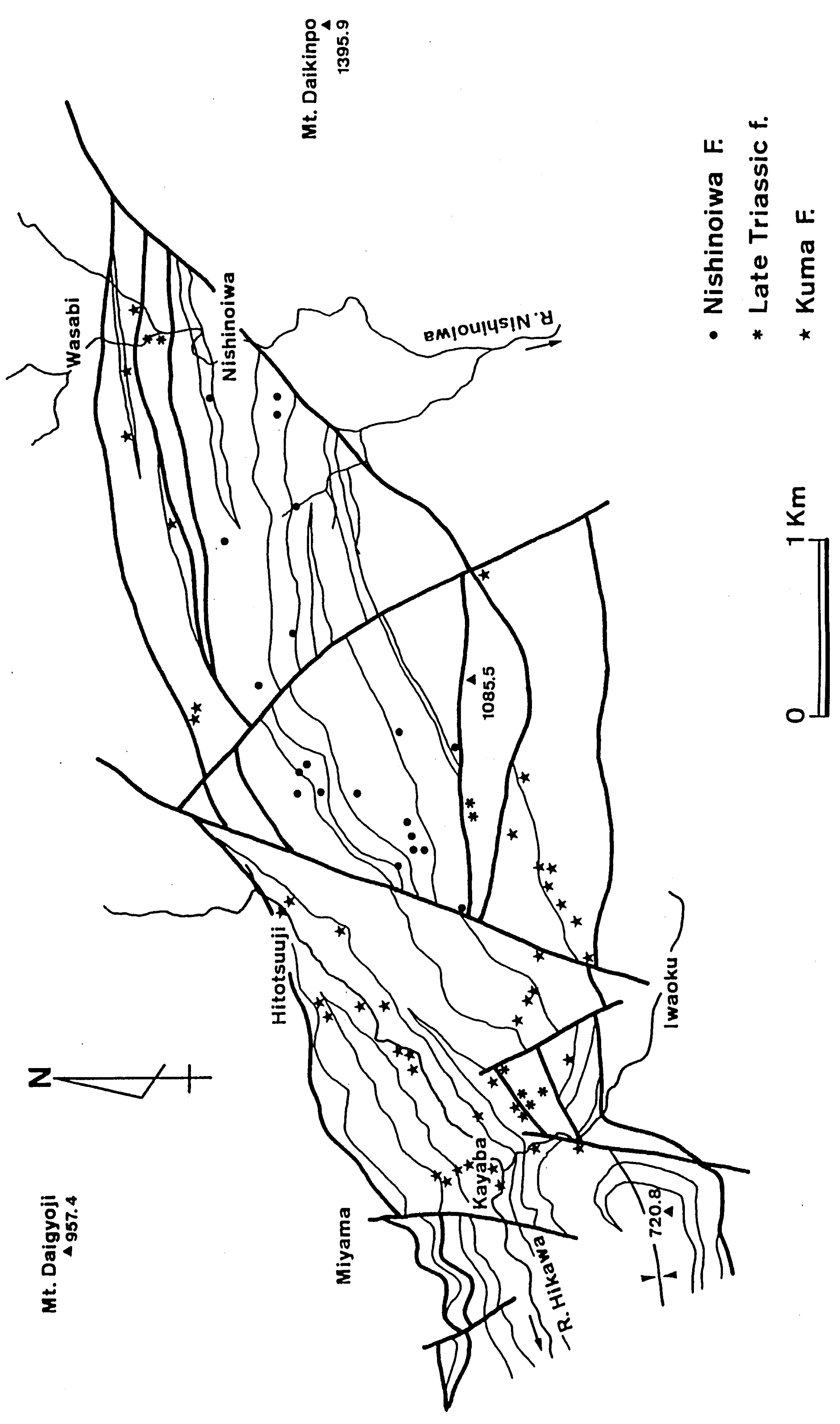


Fig. 4. Map showing localities of the examined sandstones from the Kayaba–Nishinoiwa area.

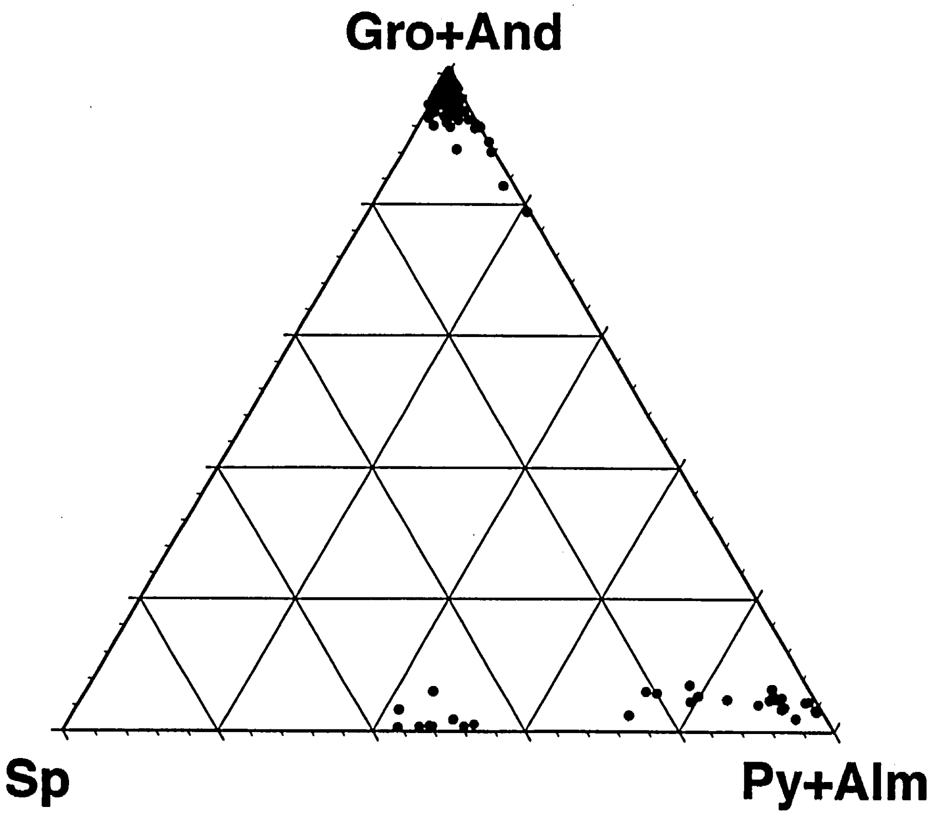


Fig. 5. (Gro+And)–Sp–(Py+Alm) diagram for detrital garnets in sandstones from the Kuma Formation. Analysed grain number=310. Py: pyrope, Alm: almandine, Sp: spessartine, Gro: grossular, And: andradite.

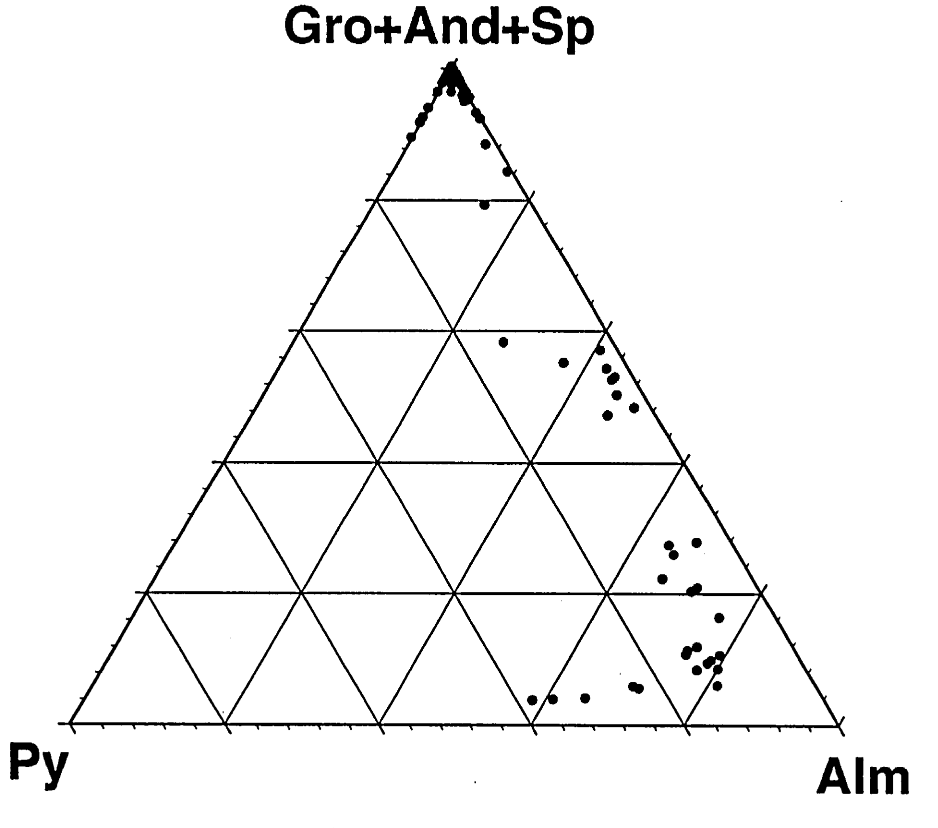


Fig. 6. (Gro+And+Sp)–Py–Alm diagram for detrital garnets in sandstones from the Kuma Formation. Symbols are identical with those of Fig. 5.

cally southward-younging. This formation is made up of sandstone and shale, being sporadically intercalated with some thin beds of acidic tuff. The total thickness exceeds 1,200 meters. The Lower to Middle Jurassic well-reserved radiolarian fossils are obtained from the shale and acidic tuff at six localities of the study area. This formation is tentatively named the Nishinoiwa Formation.

The Hashirimizu Formation occupies the southernmost part widely in this area, being a thrust fault contact with the Kuma Formation and the Lower to Middle Jurassic formation. It is composed mainly of pebbly mudstone and sandstone, including exotic blocks of chert, limestone, green rocks and others. From black mudstone of this formation, being matrix of pebbly mudstone, the Lower Jurassic radiolarians have been obtained in the Hae and Minamikawauchi areas to the west of the mapped area. Judging from the lithofacies and geological age, this formation is considered to be an accretionary complex formed during the Early Jurassic (Miyamoto and Kuwazuru, 1993b).

The details of litho- and bio-stratigraphy and geological structure will be given in another paper.

## III. Chemical composition of detrital garnets in sandstone

Garnet group is especially characteristic in metamorphic rocks of a wide variety of types, as well as being in some granites and pegmatites and acidic volcanic rocks. Because of being fairly resistant to abrasion and to chemical action, it is generally found in detrital sediments. The chemical end-members of garnet are pyrope, almandine, spessartine, uvarovite, grossular and andradite. The chemical compositions of detrital garnet in sediments are guides to know the nature of source rocks in the provenance terrane, because its range of a garnet is closely related to the physical condition under which the garnet formed, as exemplified by Suzuki (1977), Adachi and Kojima (1983), Hearn and McGee (1983), Adachi (1985, 1991), Morton (1985), Musashino and Kasahara (1986), Torikai (1990), Takeuchi (1986, 1989, 1992a, b, 1994), Miyamoto *et al.*, (1992, 1993), Miyamoto and Kuwazuru (1993a) and so on.

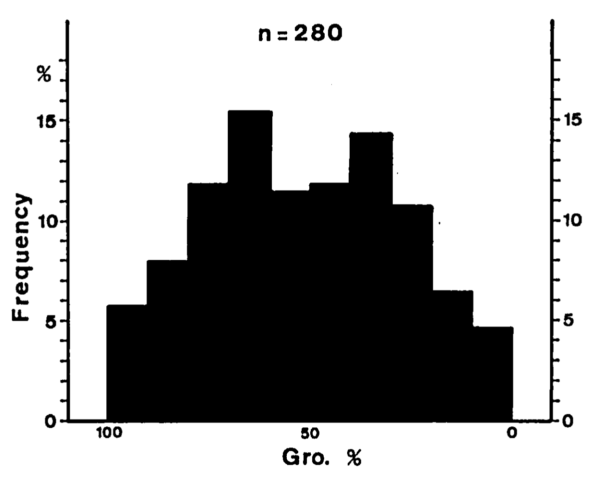


Fig. 7. Frequency distribution with respect to grossular content (mol. %) in Ca-rich garnets in sandstones from the Kuma Formation.

The detrital garnets in Permian to Jurassic sandstones of the Kurosegawa Terrane in the Kayaba–Nishinoiwa area have been studied from the sedimentary petrological viewpoint. The specimens of sandstone 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. Plate 1 shows the microphotograph of detrital garnets in the Kuma Formation and the Jurassic formation. Detrital grains of analysed garnets are 0.05-0.5 mm in size averaging about 0.2 mm; some retain the original shape and some are highly cracked.

### A. The Kuma Formation

310 grains of detrital garents, 42 samples of sandstone collected from the Kuma Formation have been analysed by EPMA (see Fig. 4). The chemical compositions of garnet are plotted on two types of ternary diagrams (Figs. 5 and 6). As shown on the (grossular plus andradite)-(spessartine)-(pyrope plus almandine) diagram (Fig. 5), about nine-tenths garnets (280/310) in the samples of the Kuma Formation belong to Ca-rich type (containing more than 80 mol. % in grandite content). Fig. 7 represents the frequency distribution of grossular content for these Ca-rich garnets. And, remaining 30 grains of garnet are of pyralspite type, namely, some Mn-rich (40 to 60 mol%) almandine garnets and some almandine garnets with minor amount of Mg and Mn content. The representative data of the chemical composition of garnets of the Kuma Formation are tabulated in Table 1.

### B. The Upper Triassic formation

8 samples of sandstone from the Upper Triassic formation have been collected (see Fig. 4) and 127 grains of detrital garnets from them have been analysed by EPMA. The chemical compositions of garnets are plotted on two types of ternary diagrams (Figs. 8 and 9). In the samples of the Upper Triassic formation, 33 grains of grandite garnet have been found. Most of garnets grains are pyralspite type (almandine) with pyrope content of less than 36 percent. There are rarely of spessartine garnet (Fig. 8).

### C. The Lower to Middle Jurassic formation

200 grains of detrital garnets, 20 samples of sandstone collected from the Lower to Middle Jurassic formation (see Fig. 4) have been analysed by EPMA. Figs. 10 and 11 illustrate their compositions. In the samples of the Jurassic formation, grandite garnet have never been found, but all of detrital garnets are pyralspite type (almandine) with spessartine content of less than 52 percent and with pyrope content of less than 42 percent.

## IV. Concluding remarks

The Upper Permian Kuma Formation, the Upper Triassic

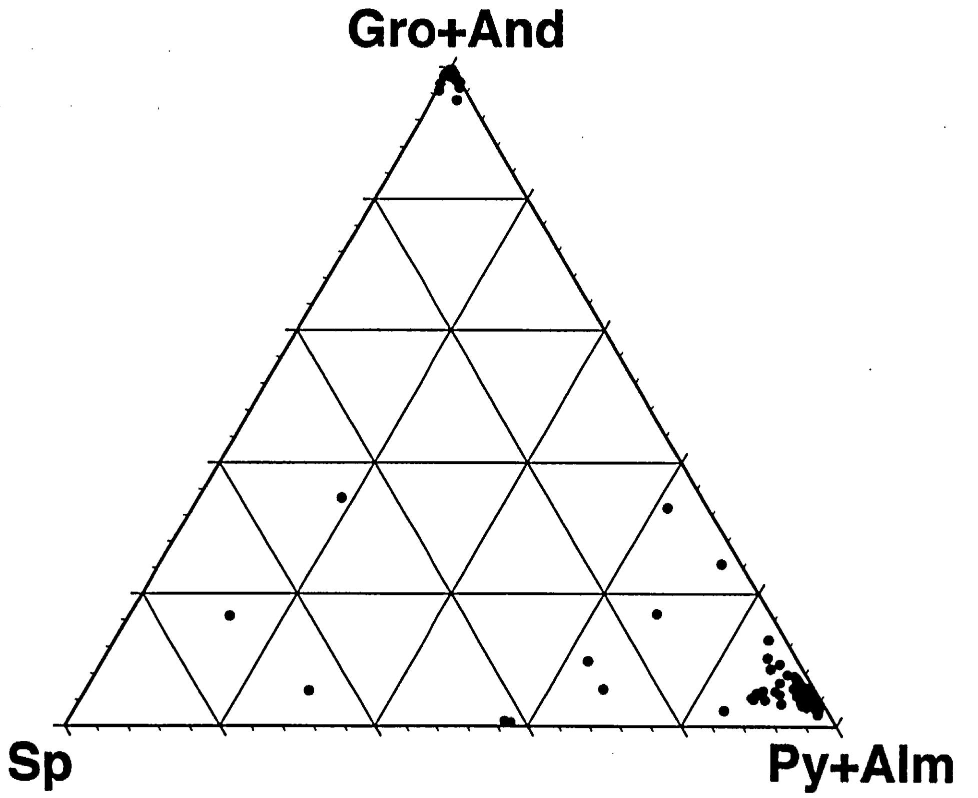


Fig. 8. (Gro+And)–Sp–(Py+Alm) diagram for detrital garnets in sandstones from the Upper Triassic formation. Analysed grain number=127. Symbols are identical with those of Fig. 5.

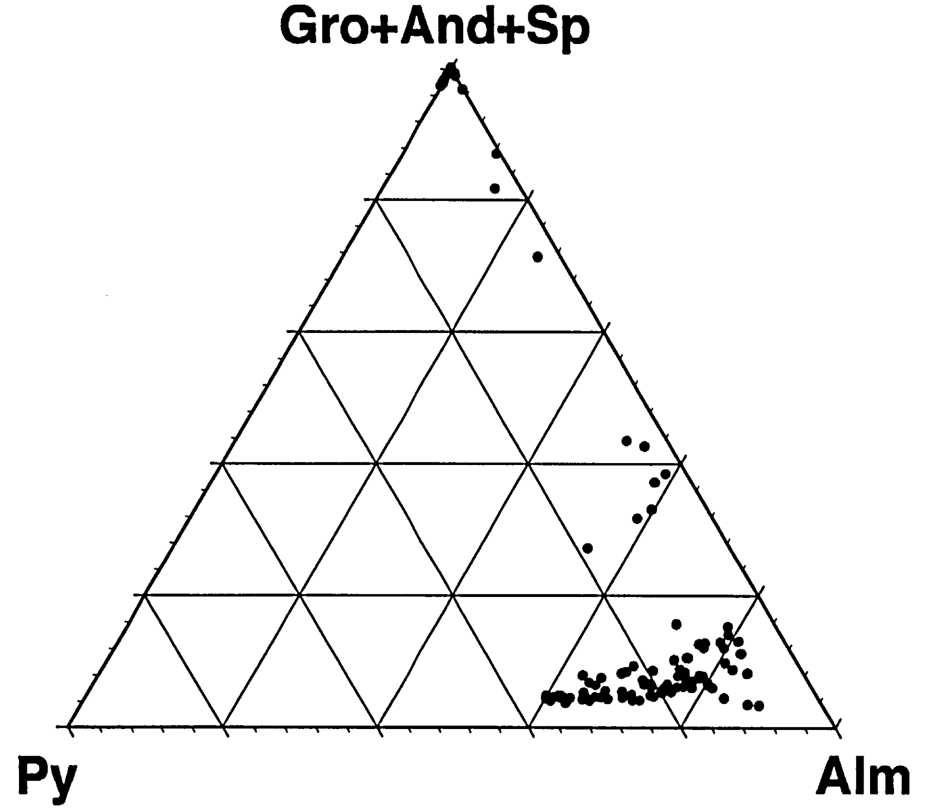


Fig. 9. (Gro+And+Sp)–Py–Alm diagram for detrital garnets in sandstones from the Upper Triassic formation. Symbols are identical with those of Fig. 5.

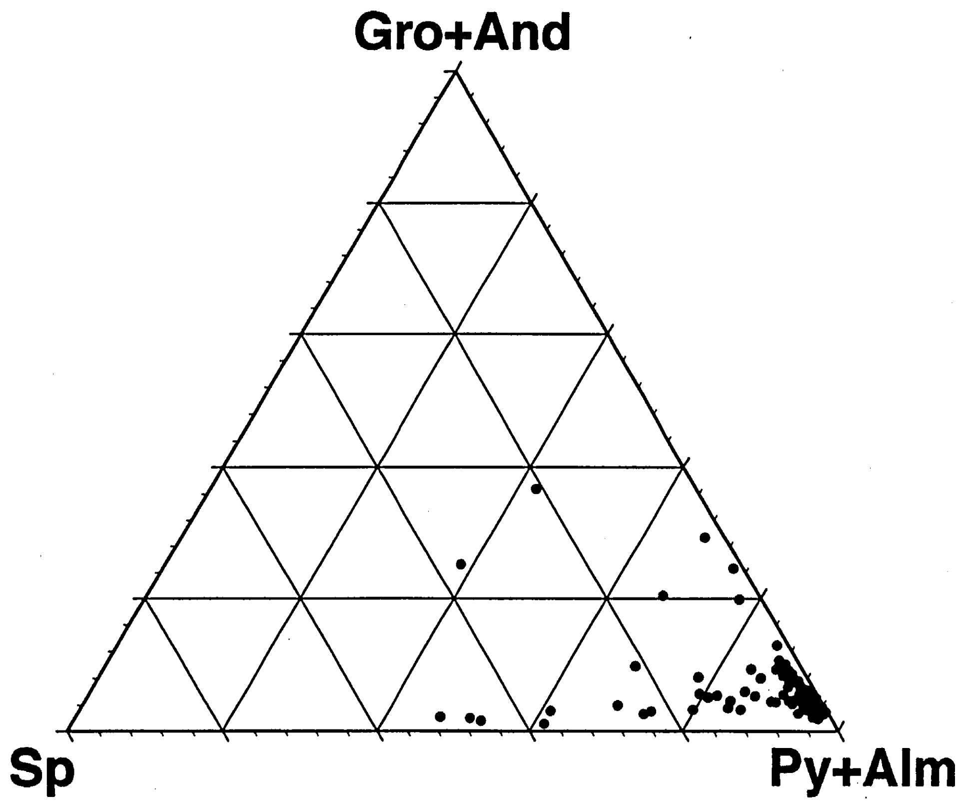


Fig. 10. (Gro+And)–Sp–(Py+Alm) diagram for detrital garnets in sandstones from the Lower to Middle Jurassic formation. Analysed grain number=200. Symbols are identical with those of Fig. 5.

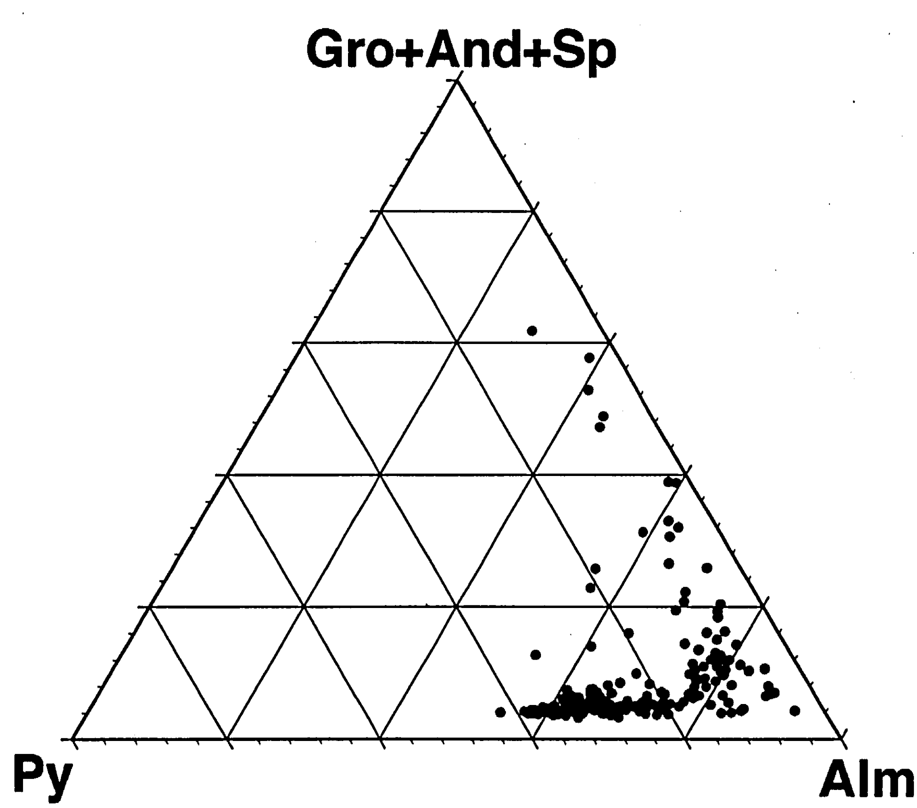


Fig. 11. (Gro+And+Sp)–Py–Alm diagram for detrital garnets in sandstones from the Lower to Middle Jurassic formation. Symbols are identical with those of Fig. 5.

Table1. Representative chemical compositionof detrital garnets in sandstones of the Kuma Formation.

| Grain No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ (wt %) | 39.5 | 38.8 | 38.5 | 35.9 | 35.5 | 37.4 | 37.7 | 36.7 | 39.7 | 39.5 |
| $TiO_2$ | 0.0 | 0.3 | 0.5 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $Al_2O_3$ | 21.0 | 16.5 | 13.5 | 5.9 | 0.5 | 21.3 | 21.5 | 20.6 | 22.4 | 22.3 |
| $Cr_2O_3$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| FeO* | 3.1 | 9.0 | 12.7 | 22.6 | 30.2 | 36.5 | 34.8 | 17.5 | 27.2 | 28.3 |
| MnO | 0.1 | 0.9 | 0.3 | 0.2 | 0.3 | 1.8 | 2.3 | 24.0 | 0.3 | 0.4 |
| MgO | 0.1 | 0.1 | 0.1 | 0.2 | 0.0 | 3.2 | 2.5 | 0.6 | 9.9 | 9.2 |
| CaO | 37.0 | 35.3 | 35.6 | 34.5 | 34.0 | 0.6 | 1.8 | 0.1 | 1.0 | 1.0 |
| Total | 100.9 | 101.0 | 101.3 | 100.1 | 100.6 | 100.8 | 100.5 | 99.4 | 100.6 | 100.7 |
| Almandine | 0.0 | 0.5 | 0.6 | 0.0 | 0.0 | 81.3 | 79.4 | 40.8 | 58.4 | 61.1 |
| Spessartine | 0.3 | 2.0 | 0.7 | 0.5 | 0.6 | 4.1 | 5.3 | 56.6 | 0.7 | 0.9 |
| Pyrope | 0.5 | 0.5 | 0.4 | 0.6 | 0.1 | 12.9 | 10.2 | 2.4 | 38.1 | 35.3 |
| Ugrandite | 99.3 | 97.0 | 98.3 | 98.9 | 99.3 | 1.7 | 5.1 | 0.2 | 2.8 | 2.8 |
| Gro. | 91.4 | 74.0 | 62.0 | 28.4 | 2.3 | - | - | - | - | - |
| And. | 8.6 | 26.0 | 38.0 | 71.6 | 97.7 | - | - | - | - | - |
| Uva. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | - | - | - | - | - |

* Total Fe as FeO

formation and the Jurassic formation are distributed within the Kurosegawa Terrane of the Chichibu Belt in the Kayaba-Nishinoiwa area, Kumamoto Prefecture, Kyushu. In this article, the present writers are described the chemical and mineral composition of detrital garnets from Permian to Jurassic sandstones. We have already the descriptionon the chemical and mineral composition of detrital garnets from Permian to Cretaceous sandstones distributed in the Kashinoki-Pass area of the west adjacency (Miyamoto *et al.*, 1992; Miyamoto and Kuwazuru, 1993a). From those data, the followings are concluded:

(1) The majority of detrital garnets in Permian sandstones developed within the Kurosegawa Terrane consists of Ca-rich garnets (see Fig. 5 of Miyamoto and Kuwazuru, 1993a and Figs. 5 and 6). The rocks, in which Ca-rich garnets occur as a main constituent, are generally contact or thermally metamorphosed impure calcareous sediments, particularly metasomatioc skarn deposits. Judging from the conglomerate-sandstone petrolographical characters (cf. Kanmera, 1953; Fujii, 1962; Kano, 1967 and others) and the chemical composition of detrital garnets, it would be assumed that the provenance of the Permian strata of the Kurosegawa Terrne 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.

(2) On the other hand, the detrital garnets from the Mesozoic formations consist mainly of almandine, Mg-rich almandine, Mn-rich almandine, spessartine and grandite (see Figs. 7–9 of Miyamoto and Kuwazuru, 1993a and Figs. 8–11). 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.

(3) It should be noted that stratigraphical variation of the chemical composition of detrital garnets in Permian to Jurassic sandstones in the Southern Kitakami Belt (Takeuchi, 1992a) shows a close resemblance to that of the Kurosegawa Terrane in Kyushu, except for minor differences.

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**[Place-name]**

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|---|---|
| Furuzono | 古園 |
| Futae | 二重 |
| Hitotsuuji | 一つ氏 |
| Iwaoku | 岩奥 |
| Izumi-mura | 泉村 |
| Kashinoki-Pass | 樫の木峠 |
| Kayaba | 河合場 |
| Kumamoto | 熊本 |
| Miyama | 深山 |
| Miyamadani | 深山谷 |
| Mt. Daigyoji | 大行寺山 |
| Mt. Daikinpo | 大金峰 |
| Mt. Yayamadake | 矢山岳 |
| Nishinoiwa | 西の岩 |
| Ochiai | 落合 |
| R. Hikawa | 氷川 |
| Rokuro | 鹿路 |
| Umaishi-Pass | 馬石峠 |
| Wasabi | 朝日 |
| Yatsushiro-gun | 八代郡 |
| Zare | 座連 |

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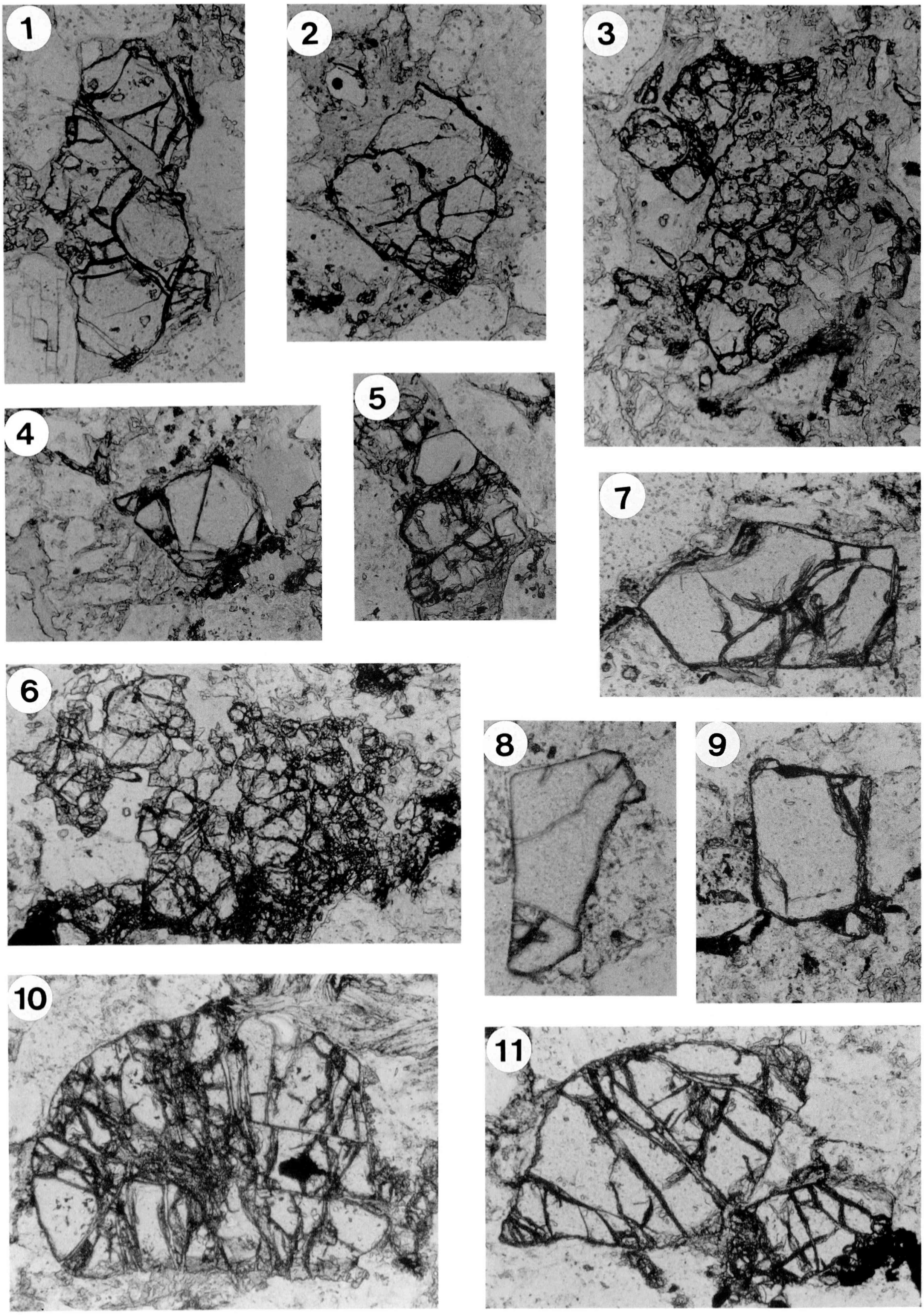
**Explanation of Plate 1**

Photomicrographs showing the detrital garnets in sandstones of the Kuma Formation and the Jurassic formation.
Fig. 1. Almandine garnet (Alm.%=65.9, Sp.%=20.1)
Fig. 2. Grandite garnet
Fig. 3. Grandite garnet
Fig. 4. Grandite garnet
Fig. 5. Grandite garnet
Fig. 6. Grandite garnet
Fig. 7. Almandine garnet (Alm.%=58.2, Py.%=37.7)
Fig. 8. Almandine garnet (Alm.%=62.3, Py.%=33.3)
Fig. 9. Almandine garnet (Alm.%=60.4, Py.%=35.9)
Fig. 10. Almandine garnet (Alm.%=75.8)
Fig. 11. Almandine garnet (Alm.%=75.1)
Figs. 1–6: from the Kuma Formation
Figs. 7–11: from the Jurassic formation
Magnification of all figures: $\times 180$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