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Contact Metamorphism in the Area around the Lower Reaches of the Oze River, Southwest Japan

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In the studied area, through the field and microscopic studies in detail, based upon variations in the mineral assemblage, progressive sequence of mudstone in the studied have been divided into 5 zones, in order of increasing metamorphism; Zone I characterized by chlorite, Zone II by yellow-colored biotite in pleochroism, the Zone III by brown-colored biotite in pleochroism, the Zone IV by cordierite and the Zone V by cordierite replaced into assemblage of chlorite and mica minerals. Distribution of the contact aureole can be regarded to reflect on both the structure of the granite body occurring in a sheet-like body below the land surface, and the movement of actual Otake Fault. The replaced cordierite appear in Zone V can be regarded to formed through hydrothermal reaction in the latest stage of the intrusion process of Hiroshima granite.

Key words : contact metamorphism, Hiroshima granite, cordierite.

I Introduction

Jurassic Kuga Group distributes widely in and around the northeastern part of Yamaguchi Pref. (Hayasaka et al., 1983; Hayasaka, 1987). It is composed mainly of mudstone and sandstone, and it is associated with olistolis of chert and sandstone of various sizes. Greenstone and limestone are few in amount (Toyohara, 1986; Higashimoto et al., 1986; Hayasaka, 1987). The equivalent sedimentary rocks can be roughly traced easterly from this area to the central part of Japan. As a whole, they occur in a terrane, called Tanba-Mino Terrane, extending west-easterly in the Inner Zone of Japan Island (Hayasaka, 1987).

The area around the lower reaches of the Oze River is located in the northeastern margin of Kuga Group (Fig. 1). In the north of the area, the Group is in contact with Late Cretaceous Hiroshima granite. The granite occurring in the studied area is situated in the southern margin of a large-scaled batholith which extends to the

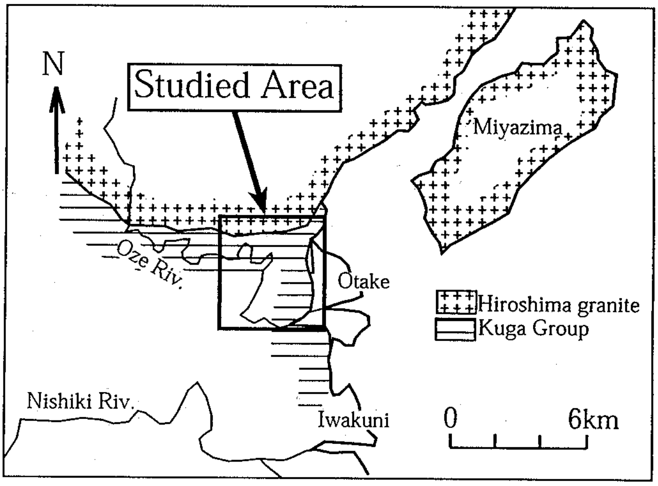

Fig. 1 Location of the studied area

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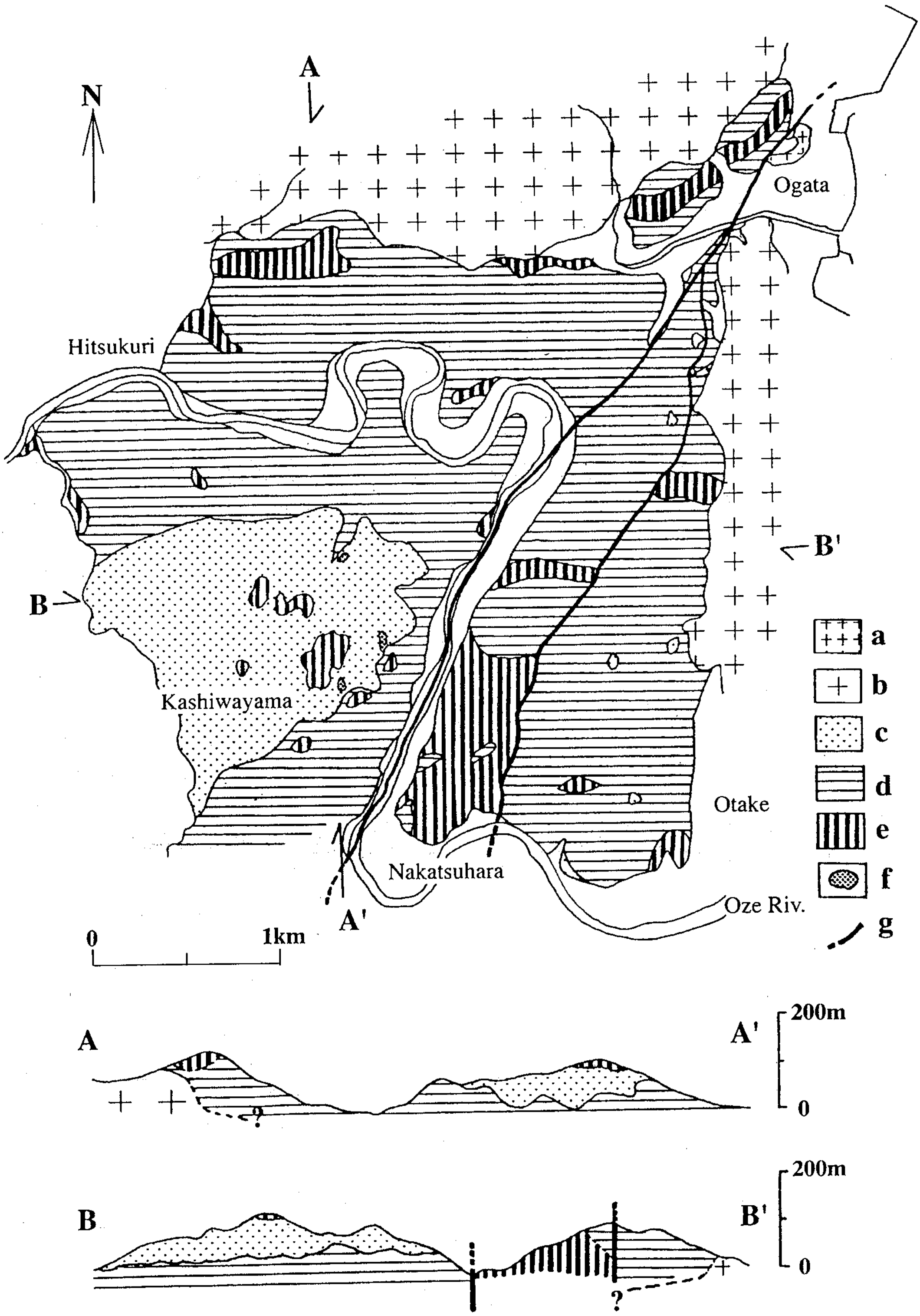

Fig. 2 Geological map and geological profiles in the studied area

a: fine-grained granite, b: medium-coarse grained granite, c: sanstone, d: mudstone, e: chert, f: green rocks, g: faults. Both a and b belong to Hiroshima granite.

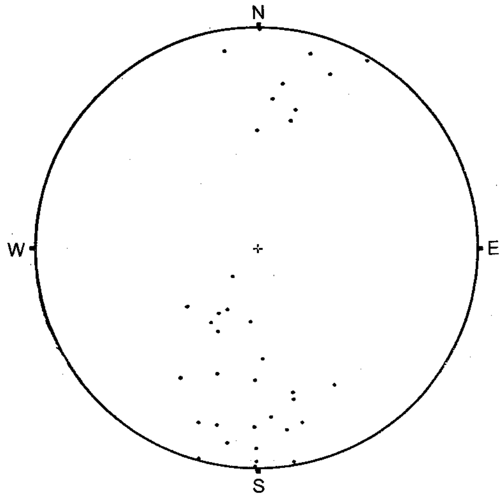

Fig. 3 Point diagram of flaky plane developed in mudstone

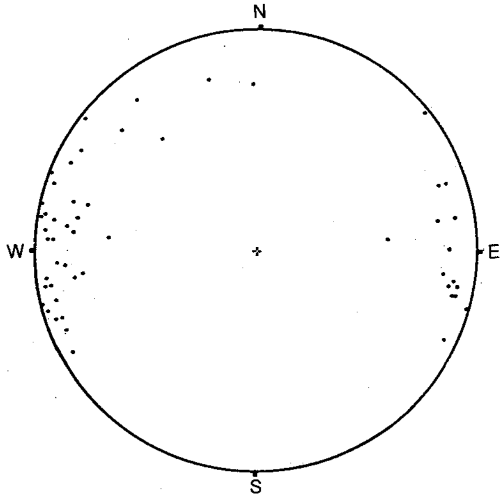

Fig. 4 Point diagram of lineation developed in mudstone

east from the area about 200km long, and has a maximum 100km of width around Hiroshima City (Kojima, 1964). In this area, Kuga Group was weakly metamorphosed by Ryoke Metamorphism (Higashimoto et al, 1986). Additionally, near the granite, the Group has undergone contact metamorphism caused by the granite.

As for the contact metamorphism in and around studied area, in the Yasaka area close to the studied area, Hara et al. (1979) has shown that by the contact metamorphism, the Kuga Group changed to the rocks of cordierite zone in the marginal part, and to those of biotite zone in the other part. Higashimoto et al. (1986) have pointed out that in the Kuga Group in the Otake district which contains the studied area, the isograd for cordierite zone lies at a apparent distance of about 1km from the boundary between the group and the granite, and that for biotite zone at a apparent distance of 2 to 4 km from the boundary.

Because a contact metamorphism occurs around a igneous body, in common a plutonic body such as granite intruded into country rocks, the body is surrounded by a contact aureole. However, in many cases, the aureole has been shown as a mantle surrounding the boundary between the country rocks and exposed granite body, the contact aureole actually represents to some degree the structure of the body below the land surface. Therefore, to clarify the detailed feature and distribution of the contact aureole possibly give important suggestions on *in site* geological structure especially of the igneous body, and to clarify the characteristics of the metamorphic reaction process is also significant for investigating the intrusion process of the igneous body.

It is significant to study the contact metamorphism in this area, being just situated in the marginal part of a large-scaled batholith of Hiroshima granite, especially for investigation of the intrusion process of the granite as a host rock. Thereby, we have carried out field and microscopic studies in detail. As a result, the progressive sequence in the mudstone of the studied area has been divided into 5 zones, and it has been clarified that the distribution of the contact aureole reflect on the structure of the granite body underlying below the land surface in the studied area.

II Geology of the studied area

A. Kuga Group

In the studied area, Kuga Group is composed mainly of mudstone, sandstone and chert.

Mudstone is predominant in the studied area (Fig. 2). In outcrops, it frequently contains a lot of fragment of chert and sandstone, which range from less than 1 centimeter to about half meters in a diameter. Almost all of them are regarded as olistoliths (Toyohara 1976; Higashimoto et al. 1986). Those fragments vary widely in size and shape, even in a outcrop.

Mudstone in the area is commonly gray to dark-gray in color, but in the near part of the granite body, it becomes to reddish gray because of appearance of a lot of recrystallized biotite, and especially in the nearer part of granite body, it contains a lot of spot of porphyroblast. Throughout the area, flaky planes develop along bedding plane in mudstone. Those are complexly folded, ranging from microscopic to megascopic on a scale. Small-sized fragments of chert and/or sandstone occur frequently along the planes. As a whole, those dip toward north or south, and trend west-easterly (Fig. 3). Additionally, the lineation of mudstone, including axes of foldings, tend to trend west-easterly (Fig. 4).

Sandstone is distributed around Kashiwayama where is relatively higher mountain part (Fig. 2). It is dark-gray in color, and well sorted. Its grain size is, on an average, 0.002 millimeters. Though sanstone is massive in common, lamination is occasionally developed.

Chert, as rather large bodies, distributes in the north of Nakatsuhara, in the north of Hitsukuri, and in the west of Ogata. Moreover, small bodies scatter throughout the studies area (Fig. 2). Chert consists of banded chert and massive chert. The former is predominant, and the latter may include silicic mudstone. Those are intensely folded, ranging from microscopic to mezoscopic scales.

B. Hiroshima granite

Hiroshima granite distributes in the northern and eastern parts of the studied area. The granite in the northern part consists mainly of medium-grained biotite granite. Fine-grained granite is sometimes found as small bodies and dikes especially in the marginal part. In the eastern part, fine-grained granite are frequently found as sheet-like bodies.

However it seems that each granite exposes as in the other body, possibility is that those originally occurred as a body.

C. Geological Structure

Sandsone occurs as a large sheet-like body lying apparently on mudstone in the southwestern part of the area. The boundary between sandtone and mudstone is not flat surface, but composed of folded surface with combination of syncline and anticline whose axes are trend west-easterly. Those trends are in consistent with lineation of mudstone (Fig. 2 *geological profiles*). However, it seems to lay on mudstone apparently, it can be regarded as a large-scaled olistolith. On the other hand, chert is occur as a rather irregular shaped body. Roughly speaking, many of them are ellipsoidal form (Fig. 2). As same as in sandstone, those chert masses are also regarded as olistoliths.

Hiroshima granite intrude into Kuga Group. In the northern part, the contact surface between them are steeply inclined. In the north of Ogata, the surface trend northeasterly, and in the north of Hitsukuri, it trends west-easterly. In the eastern part, the surface is near horizontal (Fig. 2 *geological profile*). In the eastern part, as a whole, the contact surface is near horizontal or gently inclined to the west or southwest.

After Yoshino and Hayashi (1979), each surface can be regraded as a part of the steps-like boundary surface which is characterized by the combination of steeply and gently inclined contact surfaces. Steeply inclined contact surfaces in this area, possibly, meet another gently inclined surfaces under the land surface.

III Main recrystallized minerals in mudstone

As mentioned above, Kuga Group in the near part of granite bodies have been distinctively metamorphosed by contact metamorphism. So that, every rock in there contains recrystallized minerals. In this chapter, we make a petrographical description of mudstone through microscopic studies, focusing mainly on recrystallized minerals. Their recrystallization reaction process based on the chemical aspect in detail are in considering, and those will be reported at some other time.

Several kinds of recrystallized minerals through the contact metamorphic reaction appear in mudstone. Though the same minerals are also found in thin layers in sandstone and chert, In here, we describe those only in mudstone.

Among these minerals, chlorite and muscovite are commonly found throughout the studied area. Higashimoto et al. (1986) reported that chlorite and celicite have been recrystallized by Ryoke Metamorphism preceded the contact metamorphism by the granite. Accordingly, it is hard to distinguish chlorite and some mica minerals recrystallized by Ryoke metamorphism from those by the contact metamorphism.

Quartz and plagioclase appear in a mosaic. The coarser their grain become, the nearer to the granite bodies.

Biotite commonly appears in mudstone occurring relatively near the granite bodies. Through microscopic study of it, biotite has been grouped into two different types, each of which is different to the other in their pleochroism. The one is a yellow-colored (hereafter, type I biotite) and the other a brown-colored (hereafter, type II biotite). As the type I is found in mudstone distributing farther away from the boundary between the granite and Kuga Group, comparing with mudstone containing the type II, the difference in pleochroism can be regarded to reflects on the difference in progressive grade in the contact metamorphism.

Cordierite commonly appear as a porphyroblast of rounded black-colored spots, ranging from 0.5 to 3 millimeters in a diameter, in mudstone occurring nearer the granite bodies. Sometimes a lot of it scatters in a specimen. Microscopic study have revealed that cordierite occurs in two different forms. The one is a common cordierite, (hereafter, type I cordierite) (platel, upper). On the other hand, the latter is the one which was wholly replaced by an assemblage of crowded minerals such as chlorite and mica, so to speak it seems to be a pseudomorph (hereafter, type II cordierite) (platel, lower). The grain size of the type II is similar to it of the type II. It appears in specimens from localities nearest the granite bodies. Up to now, it is not certain whether the type II was formed through alternation by the other thermal effect than the contact metamorphism which recrystallized biotite and the type I cordierite, or through the retrogressive metamorphism. Anyway, because locations of mudstone containing type II tend to be nearest bodies of the granite, the mudstone containing the type II

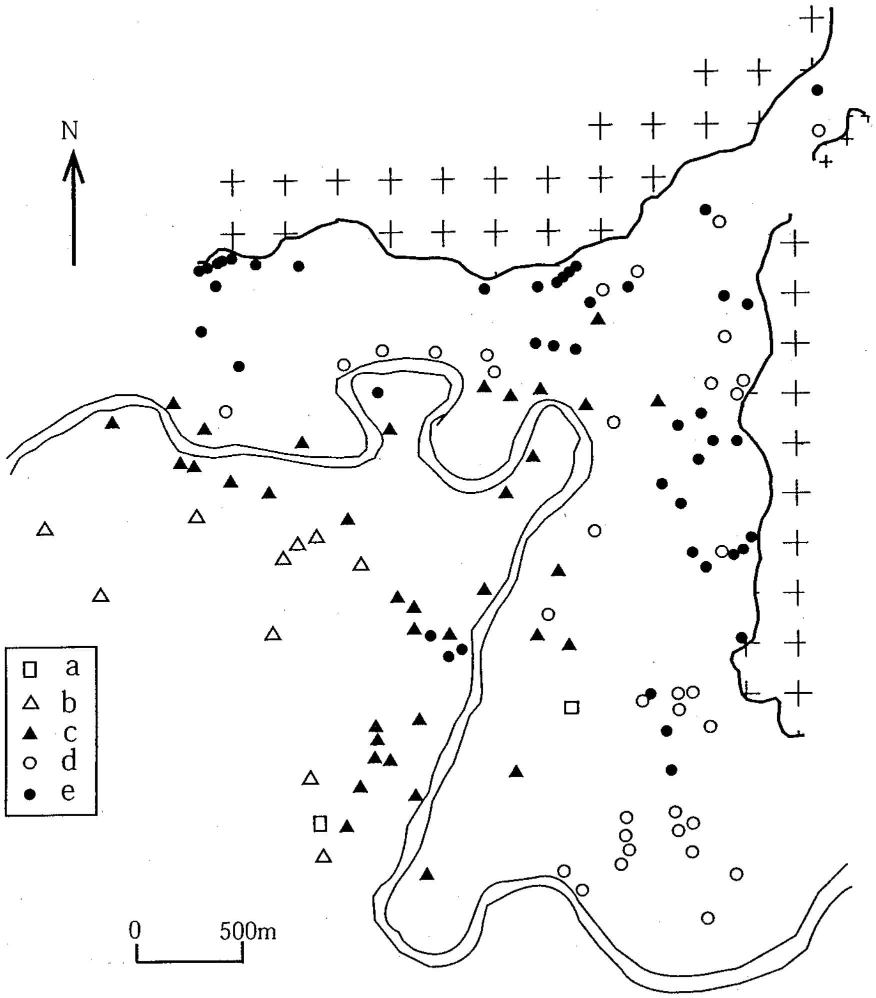

Fig. 5 Spatial variation of mineral assembleges in mudstone
a to e in the legend show mineral assemblage a to e respectively (see Text).

have possibly undergone the other thermal, possibly hydrothermal, effect caused by the granite, added to the contact metamorphism recrystallizing biotite and/or the type I cordierite in this area.

From the viewpoint of mineralogy and petrology, the replacement reaction to form such different types of cordierite in this area, is now in studying.

Garnet is found in few specimens from the specimen located relatively near the granite body, and it does not exist together with the type I cordierite mentioned above. K-feldspar also rarely appears only in mudstone occurring nearest the granite bodies.

After that, we have distinguished following 8 mineral assemblages in the progressive order of metamorphic grade.

a. muscovite+chlorite+quartz+plagioclase
b. muscovite+chlorite+quartz+plagioclase+biotite (type I)

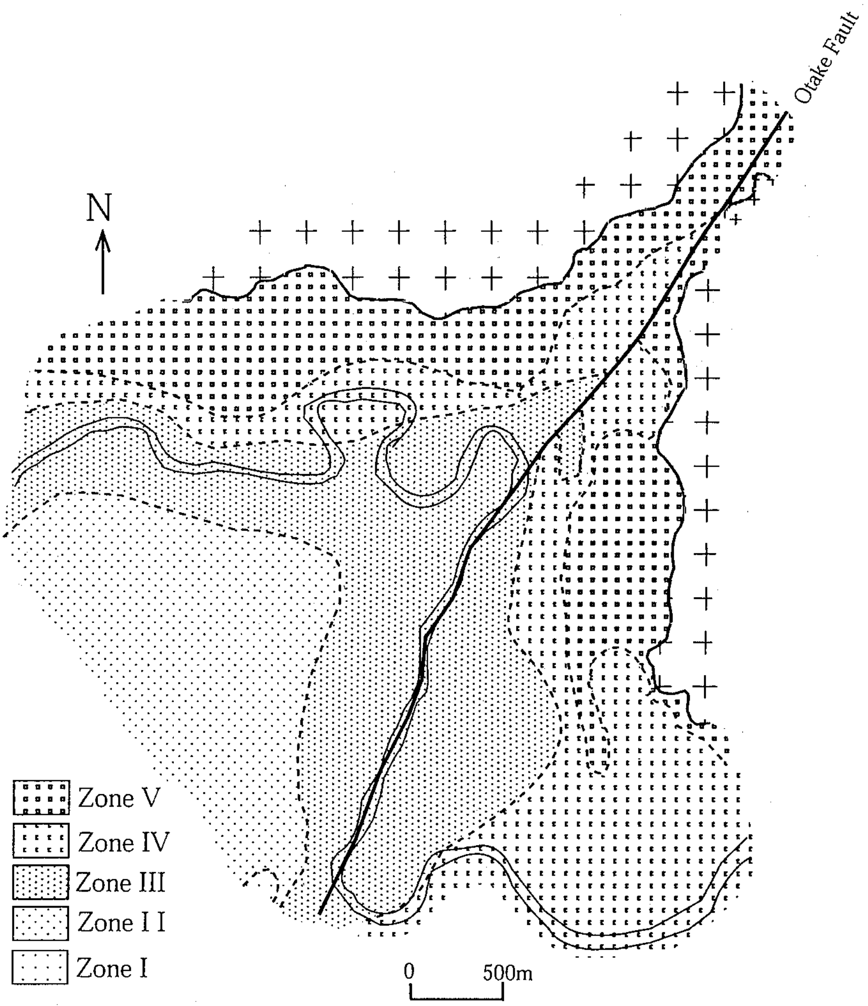

Fig. 6 Zonation of mudstone characerized by each mineral assemblage
Zone I: mineral assemblage a, Zone II: b, Zone III: c, Zone IV: d, Zone V: e (see Text)

c1. muscovite+chlorite+quartz+plagioclase+biotite (type II)
c2. muscovite+chlorite+quartz+plagioclase+biotite (type II)+garnet
d1. muscovite+chlorite+quartz+plagioclase+biotite (type II)+cordierite (type I)
d2. quartz+plagioclase+biotite (type II)+cordierite (type I)
e1. quartz+plagioclase+biotite (type II)+cordierite (type II)
e2. muscovite+chlorite+quartz+plagioclase+biotite (type II)+cordierite (type II)
+K-feldspar

Fig.5 shows the spatial variation of above-mentioned mineral assemblages in mudstone. In here. we call the zone in which mudstone characterized by "a" assemblage distributes Zone I, "b" Zone II, "c1" and "c2" Zone III, "d1" and "d2" Zone IV and "e1" and "e2" the Zone V, in the progressive order of the metamorphic grade.

As for the zoning, Zone I is probably correspond to the chlorite zone, Zone II and III to the biotite zone and the others to the cordierite zone reported by Hara et al. (1979) and Higashimoto et al. (1986).

Fig. 6 shows the distribution of those zones, showing contact aureole. It is clarified that the effect of the contact metamorphism extended widely. Additionally, distributions of these zones are not simple. Zone III and IV tend to distribute smoothly in a mantle-like fashion surrounding the granite body in the northern part. On the other hand, in the eastern part, Zone III distribute more widely than that in the northern, and Zone V occurs in a irregular fashion.

Zone II, in particular, of lower metamorphic grade occupies in rather topographically higher places, in the north of Kashiwayama, and Zone III lies below the Zone II. Furthermore, the boundary between them inclines gently to the southwest.

The extension of each Zone III, IV and V is cut by the active Otake Fault (Higashimoto et al., 1983). However the apparent gaps in distribution of Zones at the fault seem to reflect the right lateral movement in the faulting, up to now it has not yet been clarified that what kind of faulting have produced the gaps, because of shortage of data.

Ⅳ Conclusion

As for the contact aureole in this area, in particular, boundary between Type I and type II, suggests Hiroshima granite is widespread like as a sheet gently inclined to the west or southwest, under shallow part of the land surface. It can be supported by the opinion that Hiroshima granite occurs in a large-scaled sheet-like batholith (Hayashi, 1995). And, the fact that near the boundary between Kuga Group and the granite body in the northern part, distribution of Zone IV and Zone V are characterized by the alternation of wider and narrower ones supposes that gently inclined contact surface occurs below the land surface on which distribution of Zone III become wider, and steeply inclined contact surfaces occur below the narrower distribution of it. It can be supported by the report that the boundary between Hiroshima granite and Kuga Group shows a steps-like structure composed of combination of gently inclined contact surface and steeply inclined one (Yoshino and Hayashi, 1979). Finally, it is important that study of the contact metamorphism will give significant information concerning not only to intrusion process of plutonic intrusives, but also for *in site* geological structure, including the movement of active faults.

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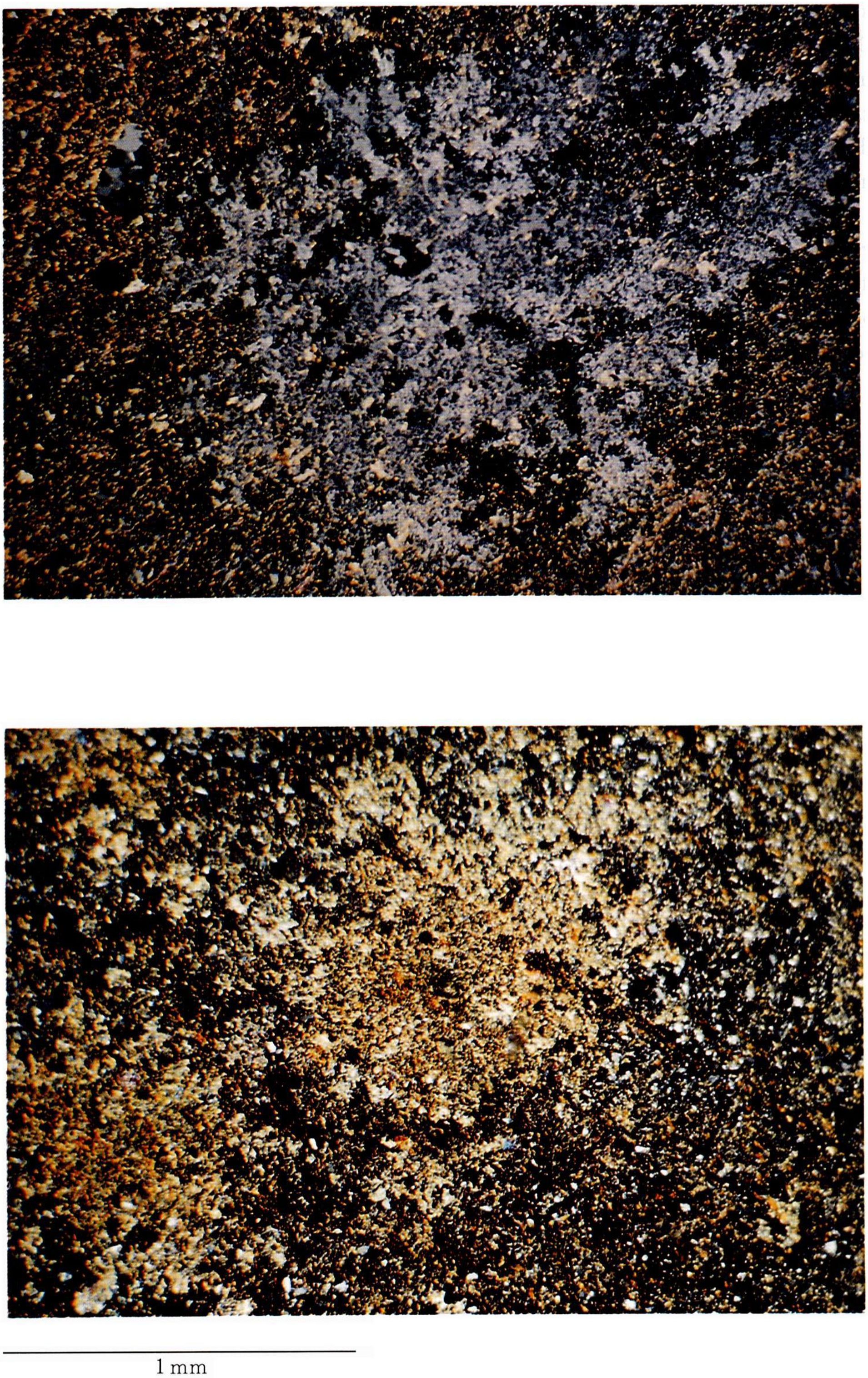

Plate1 Photomicrographs of two kinds of cordierite appeared in mudstone in the studied area.
upper: normal cordierite, lower: cordierite replaced into crowd of chlorite and mica minerals. (See text)