THE KUROSEGAWA MELANGE ZONE IN THE INO DISTRICT TO THE NORTH OF KOCHI CITY, CENTRAL SHIKOKU

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Abstract The Kurosegawa tectonic zone to the north of Kochi City, bounded on both sides by faults from the Shirakidani and the Zohoin groups, respectively, is composed of tectonic units of the Kochigatani Group, the Ino, Takaoka and Yokokurayama Formations and of tectonic blocks of schists of the albite-epidote amphibolite facies, winchite-bearing greenstone, schists of the jadeite-glaucophane type facies series, high-pressure amphibolite, biotite gneiss and the Mitaki igneous rocks. These members are wholly or partly enclosed by serpentinite, suggesting that the Kurosegawa tectonic zone should be regarded as a serpentinite melange zone. The constituent members except serpentinite are classified into three groups, on the basis of their field occurrence, radiometric and paleontological data, and petrologic features; the first group is composed of biotite gneiss, the Mitaki igneous rocks and high-pressure amphibolite, the second group of the schists of the albite-epidote amphibolite facies, the weakly metamorphosed schists of the Ino Formation, winchite-bearing greenstones, the schists of the jadeite-glaucophane type facies series, and the third of the Siluro-Devonian Yokokurayama, the Carboniferous Ino Formations and the Triassic Kochigatani Group. These constituent members are unconformably covered by the Lower Cretaceous Monobegawa Formation, which includes serpentinite gravels in its basal conglomerate. Thus, the fundamental tectonic framework of the Kurosegawa tectonic zone as the serpentinite melange zone was accomplished during the time between Triassic and Lower Cretaceous. Coexistence of the above three groups being remarkably different in lithology and age can be explained not by the vertical lithologic sequence in an island arc or active continental margin, but as the tectonic setting in a suture zone, into which have been brought various kinds of rocks produced in different tectonic environments.

Introduction

The Chichibu terrane of Southwest Japan is underlain by Upper Paleozoic to Lower Mesozoic sedimentary strata including fairly large amounts of limestone and greenstone. In the southern part of the terrane, however, occur various rocks similarly of old ages but not to be correlated with the Paleo-Mesozoic formations. They are Silurian sedimentary and volcanic rocks, acid plutonic rocks and high-grade metamorphic rocks, being in close association with each other in the field. Of

them acid plutonic rocks were described first by ISHIHARA (1931) and SUGIYAMA (1936), and Silurian rocks were subsequently discovered by KOBAYASHI & IWAYA (1940). ICHIKAWA *et al.* (1956) found the last group of rocks in their highly detailed field survey, which showed that all the rocks form lens-shaped complexes which are distributed intermittently along a fault zone running roughly parallel to the elongation of the Chichibu terrane. This fault zone was named the Kurosegawa tectonic zone** by them. The substantial part of this fault zone is

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** Two different designations are currently used for this fault zone in the literatures: Kurosegawa tectonic zone and Kurosegawa structural belt. But the original given by the authors is German: die Kurosegawa zone.

exposed in Shikoku and Kyushu.

Since the study by ICHIKAWA *et al.* (1956), much more kinds of rocks have been found to occur in association with the above three. They are clinopyroxene-garnet-bearing rocks of the granulite facies (HAYAMA, 1959; MIYACHI, 1969; KARAKIDA, 1974), schists of the albite-epidote amphibolite facies (MARUYAMA & UEDA, 1975), schists of the jadeite-glaucophane type of facies series (IWASAKI & SHINOAKI, 1959; MARUYAMA *et al.*, 1978) and rocks to be called semi-schist (UEDA *et al.*, 1980). The last are considered to have been undergone the pumpellyite-actinolite facies to the glaucophane schist facies metamorphism.

Another important rock of the Kurosegawa tectonic zone is serpentinite. Although ICHIKAWA *et al.* (1956) did not list it in the constituting rocks of this fault zone, MATSUMOTO & KANMERA (1949) discussed the importance of serpentinite in the geology of a highly complicated region in west-central Kyushu, which is now considered to be a part of the Kurosegawa tectonic zone. The role of serpentinite as lubricant in the fault zone has been discussed later by MATSUMOTO & KANMERA (1964), BANNO (1964), SUZUKI *et al.* (1976) and HADA *et al.* (1979).

HORIKOSHI (1972) interpreted the Kurosegawa tectonic zone as a fossil subduction zone, from the standpoint of the New Global Tectonics. YAMASHITA (1979) gave a historical review of the studies on this tectonic zone up to now.

The present author has carried on, since 1974, the geologic study of the Kurosegawa tectonic zone in the field to the north of Kochi City in Shikoku. It has become clear that serpentinite is one of the most significant rocks of this fault zone. The detailed field mapping has shown the good continuous distribution of serpentinite, although it has been considered so far to form trains of fragmental masses intermittently cropping out along faults. It is suggested, therefore, that the Kurosegawa tectonic zone is a serpentinite melange zone, as suggested by SUZUKI *et al.* (1976) and HADA *et al.* (1979).

The principal purpose of this paper is to

describe the geology, particularly the mode of occurrence of serpentinite, in a part of the Kurosegawa tectonic zone in some detail and to discuss the significance of the serpentinite melange zone at the southern border of the latest Carboniferous to Early Mesozoic geosyncline in Southwest Japan.

Geology

The Ino district of the Kurosegawa tectonic zone, which is the principal concern of this paper, is located to the north of Kochi City, Shikoku. According to KATTO & KAWASAWA (1958), the old age strata of this district are classified into the following two formations: the Lower Permian Iwami Formation developed in the northern part of the district and the Ino Formation of unidentified age in the southern part. The former has been considered to be a part of the Lower to Middle Permian Shirakidani Group of the Chichibu terrane by SUYARI (1961), SAWAMURA *et al.* (1961) and HIRATA (1974, 1975).

The geological map of the Ino district is given in Fig. 1. The district is underlain by rocks varied in age and lithology, and the structure is highly complicated by a number of faults. All the rocks except the Cretaceous Monobegawa Formation are regarded as constituents of the Kurosegawa tectonic zone. They are classified, in this paper, into two groups according to the size of the masses bounded by faults or enclosed in serpentinite. Tectonic units are defined to be masses larger in size than 0.3×1.5 km, and the other smaller masses or blocks are called tectonic blocks. The former comprises the masses underlain by the Kochigatani Group, the Ino, Takaoka and Yokokurayama Formations, while rocks such as schists of the albite-epidote amphibolite facies, high-pressure amphibolite, biotite gneiss, the Mitaki granite and schists of the jadeite-glaucophane type facies series are of tectonic blocks. The biotite gneiss and the high-pressure amphibolite have been considered to constitute collectively the Terano metamorphic rocks (ICHIKAWA *et al.*, 1956), but in this paper they are described separately.

Fig. 1. Geologic map of the Ino district.

N.L.: Northern lens, M.L.: Middle lens, S.L.: Southern lens, N.B.: Northern body of the southern lens, S.B.: Southern body of the southern lens.

Fig. 2. The columnar sections of the Shirakidani Group.

1. The Shirakidani Group

The Shirakidani Group consists mainly of sandstone, mudstone, chert and greenstone with a small amount of limestone, the first being predominant. Greenstones include pillow lava, massive lava and sill, all of basaltic composition. They are often intercalated with sandstone or mudstone. The strata show N45°E-EW strike with northward dipping of 45°–90°. The shape of pillow indicates that the southern part of the strata is stratigraphically lower.

Fig. 2 shows the columnar section along Mizuta-Nishitani route. The lower part is composed mainly of greenstone, chert and mudstone, but in the upper, sandstone and mudstone predominate. *Triticites yayamadensis* KANMERA, *Triticites matsumotoi* KANMERA and *fusulinidae* gen. et. sp. indet. are reported from limestone lenses in greenstone by KATTO & KAWASAWA (1958) and HIRATA (1975).

Greenstones of this formation are weakly metamorphosed to form chlorite, pumpellyite, albite, epidote, laumontite, actinolite, calcite and goethite-like opaque mineral. Igneous textures are, generally, well-observed. Relic minerals are partly sericitized plagioclase, cli-

Fig. 3. SiO_2 – $(\text{Na}_2\text{O}+\text{K}_2\text{O})$ and TiO_2 – $(\text{FeO}^*/\text{MgO})$ diagrams. The boundary between tholeiite and alkali basalt is from MACDONALD & KATSURA (1964). H.T.: Hawaiian tholeiite, A.T.: Abyssal tholeiite.

nopyroxene, spinel, apatite and opaque minerals. Olivine is pseudomorphed by chlorite. Clinopyroxene is pinkish under the microscope and is probably titaniferous salite. It is sometimes mantled by aegirine. Chemical analyses of greenstones collected from sills and core of pillows are shown in Table 1. The CIPW norms were calculated presuming the ratio of $\text{Fe}_2\text{O}_3/(\text{FeO}+\text{Fe}_2\text{O}_3)$ is 0.16 of abyssal tholeiite, and in the case of alkaline rocks, 0.11, 0.27 and 0.39, according to SHIDO *et al.* (1971) and LEMAITRE (1962). In the case of mildly alkaline rocks, total alkalis are correlated to $\text{Fe}_2\text{O}_3/(\text{FeO}+\text{Fe}_2\text{O}_3)$ ratio. According to LEMAITRE's data, the average $\text{Fe}_2\text{O}_3/(\text{FeO}+\text{Fe}_2\text{O}_3)$ of basalts to trachyte with total alkalis in the range 0–2.74, 2.75–3.50, and 3.51–8.50 correspond

Table 1. Chemical analyses and their CIPW norms of basic rocks in the Ino district

Sp. N.	1****	2*	3*	4*	5*	6*	7*	8*	9****	10****	11****	12*	13*	14*	15*	16*	17*	18*	19*	20*	21****
SiO ₂	52.0	48.7	46.5	42.8	44.2	48.6	49.0	46.5	47.7	48.6	48.3	45.4	42.9	47.4	43.3	43.4	53.2	47.8	48.4	50.1	45.4
TiO ₂	2.60	2.07	1.18	2.78	1.80	1.55	2.31	1.65	1.68	2.56	1.32	4.40	3.39	2.06	2.94	3.19	1.14	1.63	1.81	2.27	1.68
Al ₂ O ₃	19.0	13.7	15.1	13.1	14.8	15.5	12.9	15.2	15.1	15.2	15.2	18.5	19.4	16.3	17.9	15.4	12.5	8.84	14.4	19.3	16.6
Fe ₂ O ₃	4.46	5.68	4.16	2.89	1.87	2.15	2.42	3.64	5.56	4.30	4.87	4.22	7.14	4.43	5.68	1.41	4.83	2.05	2.29	4.87	2.11
FeO	6.98	8.89	11.3	15.2	15.1	11.3	12.7	9.83	8.70	6.73	7.62	11.4	11.2	6.92	8.89	11.4	7.55	10.8	12.0	7.62	11.1
MnO	0.19	0.24	0.25	0.35	0.28	0.29	0.25	0.14	0.21	0.16	0.16	0.52	0.23	0.17	0.02	0.20	0.32	0.19	0.23	0.15	0.27
MgO	2.32	7.40	8.99	7.74	7.78	9.59	6.80	9.88	8.28	8.96	6.82	6.83	1.63	8.31	8.76	11.6	7.27	16.9	6.62	2.96	8.97
CaO	4.15	9.21	8.49	14.2	11.5	6.98	9.68	10.1	7.35	8.05	11.2	5.25	9.09	10.4	8.07	10.0	8.29	9.34	12.7	5.84	12.2
Na ₂ O	4.16	2.87	2.92	0.32	1.97	2.58	2.99	2.64	3.16	4.21	4.20	2.22	2.90	4.02	8.07	2.67	5.66	1.43	1.38	3.73	0.60
K ₂ O	3.69	1.06	0.04	0.03	0.05	0.51	0.09	0.15	1.23	0.79	0.08	0.03	2.55	0.09	3.87	0.07	0.12	0.06	0.06	2.91	0.84
Total	99.54	99.82	99.55	99.41	99.35	99.05	99.14	99.73	98.92	99.56	99.77	99.80	100.43	100.40	100.41	99.34	100.88	99.04	99.89	100.20	99.77
Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C	0.61	-	-	-	-	-	-	-	-	-	-	2.04	-	-	-	-	-	-	-	-	-
or	21.8	6.26	0.26	0.18	0.29	3.01	0.53	0.89	7.27	4.67	0.47	6.09	15.1	0.53	22.3	0.41	0.71	0.36	0.36	17.2	4.96
ab	35.2	24.3	24.7	2.71	15.5	21.8	25.3	22.3	26.7	31.7	21.3	18.8	13.2	27.2	5.17	14.5	44.0	11.1	11.7	3.57	5.08
an	20.6	21.4	28.0	34.2	31.4	29.2	21.5	29.2	23.4	20.2	22.4	26.0	32.4	26.1	33.8	19.8	8.33	17.5	32.9	27.3	40.1
ne	-	-	-	-	0.61	-	-	-	-	-	2.15	4.46	-	6.15	3.68	1.19	4.39	2.10	-	-	-
wo	-	10.2	5.91	15.1	10.7	2.27	11.1	8.75	5.47	8.23	13.9	-	5.32	10.6	2.62	8.27	13.7	12.0	12.6	0.70	8.53
en	3.72	14.7	9.25	13.6	4.80	14.9	13.1	7.76	8.65	6.10	8.79	17.0	1.65	7.53	1.81	5.13	8.70	21.0	16.5	33.6	14.1
fs	3.54	6.92	6.12	15.2	5.82	10.6	13.9	3.97	3.81	1.33	4.19	11.2	3.86	2.17	0.60	2.64	4.12	9.05	17.6	2.62	10.3
fo	1.44	2.59	9.21	4.00	10.2	6.31	2.68	11.8	3.39	11.4	5.84	-	1.69	9.23	14.0	16.6	6.59	12.6	-	2.81	5.80
fa	1.43	1.34	6.71	4.90	13.8	4.94	3.03	6.65	4.07	2.74	3.01	-	4.35	2.93	5.09	9.45	5.21	-	2.42	4.68	
mt	6.46	8.23	6.03	4.19	1.71	3.12	3.51	5.28	8.06	6.23	7.06	6.12	10.4	6.42	8.23	2.04	7.00	2.97	3.32	7.06	3.06
il	4.92	3.93	3.41	5.23	3.42	2.94	4.39	3.13	3.10	4.86	2.51	8.35	6.44	3.91	5.58	6.07	2.64	3.05	3.43	5.16	3.12

Sp. N	22*	23****	24*	25*	26*	27*	28*	29****	30*	31*	32**	33****	34****	35**	36****	37**	38**	39**
SiO ₂	49.5	50.3	50.7	47.6	47.0	50.8	49.8	44.6	47.0	48.2	52.5	51.0	47.2	55.7	50.7	51.3	51.2	49.8
TiO ₂	3.37	4.16	3.12	3.66	2.13	3.82	2.90	2.31	1.74	0.99	0.63	0.99	1.92	0.66	0.78	0.62	0.41	0.89
Al ₂ O ₃	17.2	15.4	15.5	15.7	16.7	15.4	13.9	15.0	13.9	14.3	10.9	16.3	13.1	7.41	18.2	12.8	14.5	15.3
Fe ₂ O ₃	4.91	4.50	5.60	4.99	1.95	6.53	2.08	1.35	2.21	4.50	1.41	1.30	6.17	1.24	3.37	1.32	1.13	1.15
FeO	7.68	7.05	8.76	7.81	10.2	10.2	11.9	10.9	11.6	7.05	7.42	6.84	9.65	6.38	5.27	6.93	5.92	6.02
MnO	0.15	0.36	0.12	0.21	0.02	0.21	0.19	0.28	0.21	0.19	0.19	0.15	0.26	0.17	0.20	0.12	0.11	0.13
MgO	5.31	6.41	4.40	7.86	8.68	1.61	9.86	13.6	7.78	8.06	12.9	7.97	5.07	14.5	4.34	10.2	8.88	13.0
CaO	5.69	5.93	5.84	7.79	11.0	6.18	6.93	8.33	12.5	12.8	8.82	11.1	12.9	11.7	11.8	12.8	10.3	9.36
Na ₂ O	3.56	4.15	4.75	3.14	2.04	4.51	1.77	2.12	2.78	3.28	2.99	3.20	2.41	2.62	2.33	2.85	3.59	0.54
K ₂ O	3.01	0.49	2.01	1.48	0.38	0.81	0.14	0.44	0.08	0.69	0.95	0.88	1.66	0.16	0.66	0.25	0.83	3.14
Total	100.38	98.75	100.80	100.24	100.30	100.07	99.47	98.93	99.80	100.06	98.71	99.73	100.34	100.51	99.65	99.19	96.87	99.33
Q	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
or	17.8	2.90	11.9	8.75	2.25	4.79	0.83	2.60	0.47	4.08	5.61	5.20	9.81	0.94	3.90	1.48	4.90	18.6
ab	30.1	35.1	39.3	26.6	17.3	38.2	15.0	17.9	19.3	18.4	25.3	27.0	15.8	22.2	28.7	24.1	29.4	4.57
an	22.0	22.0	15.0	24.4	35.3	19.4	29.6	30.1	25.2	22.2	13.5	27.5	20.0	7.97	28.3	21.4	21.0	30.0
ne	-	-	0.46	-	-	-	-	-	2.31	5.09	-	0.37	2.48	-	4.27	-	0.53	-
wo	2.58	3.13	5.83	6.00	8.06	4.72	2.02	4.69	15.4	17.2	12.6	11.5	18.4	20.9	12.6	17.6	12.6	6.85
en	3.62	16.0	3.46	9.00	10.3	4.01	24.6	3.65	7.97	11.4	17.8	7.16	9.92	34.6	7.69	13.6	8.20	17.8
fs	1.30	3.03	2.06	2.10	6.70	7.42	15.7	1.68	6.99	4.53	6.53	3.65	7.81	9.52	4.25	5.78	3.50	4.87
fo	6.73	-	5.25	7.41	7.90	-	-	21.2	8.00	6.06	10.0	8.89	1.89	1.06	2.18	8.31	9.75	10.3
fa	2.67	-	3.45	1.91	5.64	-	-	10.8	7.73	2.64	4.05	5.00	1.64	0.32	1.33	3.91	4.60	3.10
mt	7.12	6.52	8.12	7.23	2.83	9.47	3.02	1.96	3.20	6.52	2.04	1.88	8.94	1.74	4.89	1.91	1.68	1.67
il	6.40	7.90	5.92	6.95	4.04	7.25	5.51	4.39	3.30	1.88	1.20	1.88	3.64	1.25	1.48	1.18	0.78	1.69

*** From the Shikrakidant group

*** From the Bngyol schist derived from lava

** From the Bngyol schist derived from amphibolite

* From the Ino formation

*** From the Shikakidant group
 ** From the Bngyol schist derived from lava
 * From the Bngyol schist derived from amphibolite

to 0.11, 0.27 and 0.39, respectively. The norms and the alkali-silica plots of Fig. 3 suggest that the original rocks of the greenstones are of the alkali rock series, being harmonious with the inference from microscopic observation of relic clinopyroxene.

2. The Zohoin Group

The Zohoin Group develops in the southern-most part of the studied area, and the strata strike EW-60°E with about 50°N dip. It is made up mainly of alternating sandstone and mudstone with a small amount of chert. The rocks yields *Daonella Natica*, *Pentalium*, *Ammonoidae* and *Gastropoda* showing Middle Triassic age (HIRATA, 1974).

3. Tectonic units and tectonic blocks of the Kurosegawa tectonic zone

Most of the member rocks of the Kurosegawa tectonic zone are found in this area, excluding the following: welded tuff described from Yokokurayama (YOSHIKURA & SATO, 1976) and staurolite-bearing gneiss at Kinseki, eastern Shikoku (KARAKIDA, 1977).

A. Tectonic unit

a. The Ino Formation

KATTO & KAWASAWA (1958) defined the Ino Formation as the schistose strata rich in greenstone, being typically exposed along the route Ino-ohashi to Kashiki. Although they considered, from the lithological similarity of this formation and the Permian-Carboniferous formations in Shikoku, that the Ino Formation is Permian, no fossils have been found therefrom. On the other hand, the conodont study by MATSUDA & SATO (1979) and the radiometric dating by UEDA *et al.* (1980) have given conflicting results. The former indicates that some parts of the Ino Formation are Upper Carboniferous to Lower Permian in age, whereas from the latter a 352–394 m.y. glaucophanitic metamorphism is inferred to have affected the major part. The term Ino Formation is used here to denote a complex of schistose rocks delineated by SAWAMURA *et al.* (1961).

The Ino Formation occupies the largest area among the tectonic units, and is frequently intruded by serpentinite. Three major tectonic units of this formation separated by serpentinite are called here the northern,

middle and southern lenses.

1) The southern lens (10×4 km)

This is composed of two bodies being in contact by fault. The fault between them strikes EW and dips 70–90°S and is accompanied by serpentinite intrusions in the eastern and western parts. The northern body consists mainly of mudstone with lesser amounts of chert. Small amounts of greenstone occur in lenticular shapes several meters across. Chert forms lenses generally less than scores of meters in long diameter, but in some cases, short and long diameters reach 200 m and several hundred meters, respectively. The beds of the northern body, generally, strike N60°E-EW and dip 40–90°S.

The southern body consists mainly of greenstone and chert with small amounts of mudstone and limestone. Greenstone is derived from pillow lavas, massive lava, sill and dike. The strata strike nearly EW and dip 30–50°S in the western part, but both dip and strike are not uniform in the eastern part, where the body is further subdivided into four parts by faults accompanying serpentinite. The internal structural trends of each part are different from part to part (Fig. 2).

2) The middle lens (6×1 km)

This lens consists mainly of greenstone, mudstone and chert with a small amount of limestone. Greenstone and mudstone seldom intercalate with each other. The beds show isoclinic structure of N45°E-EW strike and 40–90°N dip. The downwards concentration of vesicles in pillows indicates the upturned stratigraphic relation between the underlying greenstone mass and the overlying mudstone layers. In the western part of the lens appears a narrow and long serpentinite mass, while in the northern part occurs a small tectonic block (400×100 m) of schist with embryonal albite porphyroblasts.

3) the northern lens (2.5×10 km)

This lens is formed mainly of greenstone, mudstone and chert with a small amount of limestone. Judging from the shapes of pillows, the northern side of the greenstone mass is stratigraphically lower. The strata of this mass generally, trend EW and dip nearly vertical, but the structure becomes

Fig. 4. The columnar sections of the Takaoka Formation.

different suddenly near the Engyoji area.

Greenstones of the Ino Formation are weakly metamorphosed to form chlorite, actinolite, epidote, ferroglaucophane, pumpellyite, muscovite, albite and quartz with rare occurrence of lawsonite, aegirine, stilpnomelane and calcite. Metamorphic facies is the glaucophane schist to pumpellyite-actinolite facies and practically uniform in the whole area. But small tectonic blocks (400×100 , 700×120 m) of greenstone near Yashiro and Naruyama, have embryonal albite porphyroblasts. The epidote coexisting with chlorite and actinolite in the greenstones is richer in Al than those of the Ino Formation proper, suggesting that they were formed at higher temperature than the surrounding rocks of the Ino Formation (NAKAJIMA & MARUYAMA, 1978). Thus, even though the greenstone and schistose greenstone of the Ino Formation belong to the same mineral facies, there seems to be slight difference in metamorphic grade between them.

Greenstones retain their igneous textures and minerals, clinopyroxene (colorless to pale brown) and spinel. Plagioclase is sericitized and partly becomes albite. Opaque minerals have the original shapes, though their margins are altered into sphene. Greenstones derived from dike or pillow's core and con-

taining small amounts of metamorphic minerals, were chemically analysed (Table 1). Normative mineral compositions and alkali-silica relations (Fig. 3) show that the greenstone analyses fall in both alkali basalt and tholeiite fields. The tholeiites have higher TiO_2 contents at a given total FeO/MgO ratio than island arc tholeiites, and are similar in composition to oceanic tholeiites.

b. The unit of the Takaoka Formation (1.5×0.7 km)

This unit is situated to the west of the southern lens of the Ino Formation and is completely surrounded by serpentinite. It is composed mainly of sandstone, mudstone and conglomerate. The gravels in the conglomerate are largely of sandstone, granite, gneiss and rhyolite. The strike and dip of the strata vary markedly, but the northern part of the mass is considered to be stratigraphically lower as judged from cross-lamination and graded bedding in the clastic rocks. The schematic columnar section is shown in Fig. 4. In the middle part, we see a thin layer of non-fossiliferous limestone being 1 m thick. In the lower portion of the eastern part of this unit occur a conglomerate layer, which becomes thick up to 130 m to the west. Blocks to be designated as "gravels" in the conglomerate become sometimes as large as $100 \times$

250 m. They should rather be called olistoliths. The predominant rocks of the olistoliths are granite and gneiss. They are cemented by sandstone which contains rhyolite gravels several millimeters across.

c. The unit of the Kochigatani Group (2×0.6 km)

The Kochigatani Group develops in the southeastern part of the investigated area. It consists mainly of alternating sandstone and mudstone and is strongly folded, making it difficult to estimate the exact thickness of the strata. This formation yields *Monotis*, *Halobia*, *Pecten*, *Myophoria* and *Podozamites* from four localities (HIRATA, 1974). They indicate the Upper Triassic age.

d. The unit of the Yokokurayama Formation (2×0.4 km)

This is exposed in the northeastern part of the studied area. SAWAMURA *et al.* (1961) regarded it as the Silurian from the lithology, but HIRATA (1975) found Devonian plant fossils in mudstone. This formation is composed mainly of alternating sandstone, mudstone and rhyolite tuff with a small amount of limestone lenses which contains *Favosites* sp. (HIRATA, 1975).

B. Tectonic blocks

a. Tectonic blocks of metamorphic rocks

1) Blocks of the albite-epidote amphibolite facies rocks (several meters across to 40×250 m, NAKAJIMA & MARUYAMA, 1978)

They are found at Yashiro, Kitayama and Naruyama. In the Kitayama area, a block of schists appears enclosed thoroughly by serpentinite, while at the other two localities, blocks are bounded by faults being accompanied serpentinite in places. These blocks are composed of basic, pelitic and psammitic schists. Muscovites from pelitic schists gave K-Ar ages of 317 and 327 m.y. (UEDA *et al.*, 1980).

2) Winchite-bearing greenstone blocks (less than 100×500 m, NAKAJIMA & MARUYAMA, 1978)

Blocks of greenstone bounded by faults with or without serpentinite in the Ino Formation or in the tectonic blocks of albite-epidote amphibolite facies grade, occur at Kitayama and Yashiro. Characteristic mineral assem-

blage of the greenstones is epidote-chlorite-albite-quartz. Ferroglaucophane sometimes coexists with actinolite and winchite.

3. Blocks of schists of the jadeite-glaucophane type facies series (MARUYAMA *et al.*, 1978)

These are all xenoliths as large as or less than 100 m^3 in serpentinite, mostly found in the Engyoji area. Some of them are derived from greenschist and amphibolite, but others are from chert, pillow lavas, massive lava and hyaloclastite. Eleven specimens were chemically analysed by means of the electron-probe microanalyzer, the result being given in Table 1. Metabasites derived from amphibolite have narrow range of FeO^*/MgO ratio, 0.50—1.0, suggesting that they are cumulates in origin. The other metabasites show the two types of chemistry of alkali basalt and tholeiite (Fig. 3). Chemical analyses of the relic clinopyroxene are in good harmony with the bulk chemistry of the host rocks (Fig. 5).

Three episodes of metamorphism can be distinguished on the basis of textural evidences given by petrographic observations. At first, a middle- to high-grade low-pressure type metamorphism took place and then that of the jadeite-glaucophane type facies, and finally a low T and high P metamorphism leading the reaction of jadeite and quartz producing less jadeitic pyroxene. Not all the high-pressure type metamorphic rocks underwent the first stage metamorphism of low-P/T type. Some schists derived from basaltic lava preserve their original igneous textures well, and no trace of the low-pressure metamorphism is recognized in them. Muscovites inferred to be equilibrated with high-pressure minerals gave the K-Ar ages of 208—240 m.y.

4). Blocks of amphibolite, garnet amphibolite, and garnet-clinopyroxene amphibolite (several tens centimeters across to 3×1 km, MARUYAMA, 1976; YOSHIKURA *et al.*, 1981)

The size of the blocks varies from place to place. The largest is situated at the southern part of the studied area. Generally, layered structure develops well. Rhythmical alternation of plagioclase-rich and hornblende-

Fig. 5. SiO_2 - Al_2O_3 , TiO_2 - Al_2O_3 diagrams (wt. %) of relic phenocryst or microphenocryst clinopyroxenes in the Engyoji schists. Left-hand side diagrams were made from the chemical compositions of Ca-rich clinopyroxenes of phenocrysts or microphenocrysts from basalts compiled by MARUYAMA (1976) and those from FODOR & KEIL (1975), AYUSO & BENCE (1976), and MAZZULLO & BENCE (1976). The dotted and open circles are from tholeiite and alkali basalt, respectively. The right-hand side diagrams show the compositional variations of relic Ca-rich pyroxenes from the Engyoji schists. The area enclosed by the dotted line corresponds the compositional range in one sample. A dot means an average composition for a phenocryst or microphenocryst, for each about 5 points were measured. Most of them are plotted in the tholeiite field, but some in the alkali basalt field. A: alkali basalt, TH: tholeiite.

rich layers several millimeters to one centimeter each is conspicuous, thereby suggesting that some of the rocks at least were layered-gabbro in origin. The banded structure cross-cuts the extending direction of serpentinite belt (*e.g.*, the Yashiro mass, see Fig. 3 from NAKAJIMA & MARUYAMA, 1978).

Mineral assemblages of the amphibolites are, hornblende + plagioclase, hornblende + plagioclase + garnet, hornblende + plagioclase

clase + garnet + clinopyroxene, all of which can be observed even in one block (*e.g.*, the Tsukanohara and Imose blocks). A xenolith several meters across in serpentinite near Imose was described by MARUYAMA (1976), who showed that the partition coefficient between garnet and clinopyroxene cores $K_D^{\text{garnet-clinopyroxene}} = \frac{(\text{Fe}''/\text{Mg})_{\text{gar}}}{(\text{Fe}''/\text{Mg})_{\text{cpx}}}$ is 4.2, indicating the granulite facies conditions.

Fig. 6. The route map showing the distribution trend of serpentinite in the southeastern part of the studied area. Open triangle means boulders in the case of no exposures.

This type of rocks clearly underwent two episodes of metamorphism: early the high-pressure amphibolite facies metamorphism and later the greenschist facies metamorphism. The latter gave rise to the formation of veins composed of any of Al-epidote, chlorite, prehnite, quartz and albite.

The K-Ar age of the pargasitic hornblende in the Tsukanohara block was determined as 409 m.y. (YOSHIKURA *et al.*, in preparation). 5). Blocks of biotite gneiss (several meters across)

This kind of blocks occur along small valleys to the west of Soanji and of Ejiri. Primary mineral assemblages are, garnet+muscovite+plagioclase+quartz, and biotite (Y, Z=brown)+plagioclase+K-feldspar+quartz. The rocks are usually strongly deformed and retrograded to form sericite, epidote, sphene, quartz and chlorite.

b. Tectonic blocks of igneous rocks (50×300 m to 800×130 m)

This group of tectonic blocks comprises intermediate to acidic plutonic rocks which have been called the Mitaki igneous rocks (ICHIKAWA *et al.*, 1956). Generally, they are holocrystalline and equigranular, but porphyritic in some cases. They are made up mainly of plagioclase and quartz with subordinate amounts of K-feldspar, hornblende and biotite. All the minerals are deformed strongly. Quartz shows wavy extinction and mafic minerals are partly or wholly chloritized. In addition, epidote, sphene, sericite, albite, quartz and prehnite have been formed as secondary minerals.

Some ellipsoidal to circular stocks (about 10 m across) of porphyrite are set in the Tsukanohara amphibolite block. The time of formation of the stocks is considered to be after the formation of the amphibolite block. This type of rocks is similar in composition to the so-called Mitaki igneous rocks.

4. Ultramafic and related rocks

Ultramafic rocks are completely serpentinized for the most part, but in some parts diopside, olivine and chromian spinel occur as relic minerals. The representative mineral paragenesis of the serpentinite is serpentine+magnetite+brucite.

Along the east side of the Kagami-gawa river near Hiji, wehlite, clinopyroxenite, metagabbro and plagiogranite are exposed being accompanied with serpentinite. The mineral assemblage of the metagabbro is pargasitic hornblende + plagioclase + aluminous clinopyroxene+quartz. Plagiogranite is mainly composed of albite and quartz with a small amount of augite (less than 1 modal %). It is cut by network veins of pectolite. On the basis of Fe-Mg partitioning among ferromagnesian minerals, YOKOYAMA (1977) concluded that ultramafic rocks have suffered the granulite facies metamorphism prior to the serpentinization.

Rodingite often occurs in the serpentinites. The original rocks of some rodingites can be identified as gabbro or dolerite by their relic textures.

Modes of occurrence of serpentinites will be given in later pages.

5. The Monobegawa Formation

A layer of conglomerate covers the Siluro-Devonian Yokokurayama Formation unconformably at a locality 1 km east of Hiji. The unconformity is overturned. Gravels in the conglomerate are largely of chert, mudstone and sandstone, but some of serpentinite. This formation is composed mostly of alternation of sandstone and mudstone. Towards the south, mudstone becomes predominant. In the northern part of the Tsukanohara area, the general trend of the beds is 70—80°E with 40—50°N dip. Near Tsukanohara, the rocks are strongly deformed. HIRATA (1975) found many animal and plant fossils of Lower Cretaceous age from this formation. At some horizons clastic serpentinite layers have been reported (KATTO *et al.*, 1976).

Modes of occurrence of serpentinite

Three major serpentinite belts run through the studied district from east to west (Fig. 1). The northern serpentinite belt extends from Engyoji to Naruyama through Karaiwa. The middle belt, the largest, is a belt from Engyoji to Imose through Naruyama. The southern belt is that from Engyoji to Imose through Yashiro. Further, these serpentinite

belts extend, converging into one belt, at least 28 km outside the studied area, and hence they are in total more than 36 km long. In addition to these major belts, numerous small serpentinite belts are there all over the studied area. They are mostly small lenses but some are thin and long belts, which extend for a remarkably long distance. The modes of occurrence of the serpentinite are illustrated in Fig. 6, which is a traverse map of an area 4 km northwest of the Ino station. A small serpentinite belt, denoted as A in the figure, is 20 to 200 m wide and can be traced for 2.2 km, being detected at seventy-one outcrops in the area. In another area 1 km west of the Ino station, a quite narrow serpentinite belt 0.5 to 3 m wide can also be traced for 1.2 km being detected at nineteen exposures. The lithologies on both sides of the serpentinite belt are sometimes different from each other, demonstrating that the serpentinites were intruded into faulted sites. The faults which border the tectonic units or blocks are either intruded by serpentinite, or at least part of them are intruded. The internal structure of tectonic units, as defined by layering of amphibolite or bedding planes of weakly metamorphosed rocks of the Ino Formation, are sometimes discordant with the elongation of the serpentinite belts (Fig. 1 and 6).

MATSUDA & SATO (1979) discovered conodonts of the Upper Carboniferous to Lower Permian type from the Ino Formation at five localities shown in Fig. 1. At three localities, serpentinite is exposed within 10 m from the conodont localities. It was not confirmed, however, that the conodont-bearing strata were surrounded by serpentinite or not owing to the poor exposure. On the other hand, at the remaining two localities, serpentinite does not crop out within 500 m from the conodont localities. One of the conodont localities is nothing but 300 m far from one of the localities of semi-schists which gave K-Ar ages of 352-394 m.y. (Fig. 1). Therefore, there should be remarkable stratigraphic discontinuities even in the tectonic units of the Ino Formation itself, even if serpentinite is not discerned in the field.

Discussion

Summarizing the descriptions given above, the followings can be pointed out about the geologic characteristics of the Ino district of the Kurosegawa tectonic zone: 1) Serpentinite shows remarkable horizontal continuity of distribution. 2) The distribution trend of serpentinite is sometimes discordant with the internal structures of the tectonic units or blocks. 3) Serpentinite always encloses wholly or partly the units and blocks of the Kurosegawa tectonic zone. 4) The remarkable diversity is there in lithology and age of the rocks of the units and blocks. These characteristics indicate that the Kurosegawa tectonic zone is a typical serpentinite melange zone. The areal extent of this zone is also comparable with those of the other melange belts exemplified by the Polar Urals (EFIMOV *et al.*, 1978), Taurus suture zone in the Tethyan belt (HALL, 1976), an ophiolite melange zone near the southern boundary of the high-pressure schist belt in the northern New Caledonia (BLACK & BROTHERS, 1977) and the Kamuikotan belt (GOUCHI, 1976). The schematic profile of the Kurosegawa melange zone is delineated in Fig. 7.

The Kurosegawa tectonic zone was defined by ICHIKAWA *et al.* (1956) as a fault zone characterized by the presence of any of the three members: the Mitaki igneous rocks, the Silurian rocks and the high-grade metamorphic rocks. The semi-schists were not included in the constituent members, because it had been thought to be rocks of the Upper Carboniferous to Permian formations metamorphosed by the tectonic movements to have formed the Kurosegawa zone. UEDA *et al.* (1980), however, demonstrated that the K-Ar ages of the semi-schists are 352-394 m.y., thus, they are not metamorphosed Permian-Carboniferous rocks. If the Kurosegawa zone is defined as a melange zone containing older sedimentary and metamorphic rocks, there is no reasons to exclude the semi-schists, schists of the albite-epidote amphibolite facies and schists of jadeite-glaucophane type facies series. These are always surrounded by serpentinite completely or partly. If we define

Fig. 7. Schematic N-S profile of the Kurosegawa tectonic zone in the Ino district.

the members of the Kurosegawa tectonic zone as those enclosed by serpentinite, we must list up the Permian Takaoka Formation, the Triassic Kōchigatani Group and the Ino Formation (the semi-schists and Carboniferous), too.

The area occupied by the semi-schists in the Kurosegawa zone of this area, is the largest, about 50%, as compared with those of serpentinite (30%), the sum of the high-grade metamorphic rocks, the Mitaki igneous rocks and the Siluro-Devonian (5%) and the others (10%). The similarly high proportion of semi-schists is recognized throughout the whole Kurosegawa zone from Kii Peninsula to Kyushu; at Babebana (MAEJIMA & YOSHIKURA, 1976; MAEJIMA, 1978), in the eastern part of Shikoku (SUYARI, 1954, 1958; YAMASHITA *et al.*, 1958; IWASAKI & SHINOAKI, 1959; OGAWA, 1971), in the central part of Shikoku (SAWAMURA *et al.*, 1961; SUYARI, 1961, this paper), in the western part of Shikoku (ICHIKAWA *et al.*, 1956) and in the Hinagu area in Kyushu (UETA, 1961; MATSUMOTO & KANMERA, 1964). Therefore, the Kurosegawa zone can rather be defined

as the zone characterized by the association of serpentinite and semi-schists. The Cretaceous Monobegawa Formation covers unconformably the rocks of the Kurosegawa zone and contains serpentinite gravels in its basal layer. Therefore, the Monobegawa Formation should not be added to the members of the Kurosegawa zone, because the fundamental framework of the zone as the serpentinite melange belt had been accomplished by the Cretaceous time. The same stratigraphic relationship between the overlying molasse-type Cretaceous formation and the members of the Kurosegawa zone has been described in the Katsuuragawa area (KASENO, 1945) and the Hinagu area (MATSUMOTO & KANMERA, 1964).

As to the relationships between the other groups of rocks, gneiss is intruded by granite at Babebana, Kii Peninsula (MAEJIMA & YOSHIKURA, 1976; YOSHIKURA & YOSHIDA, 1979), gneiss and amphibolite are interlayered conformably at Imose area (YOSHIKURA, 1977), and amphibolite is intruded by porphyrite (in this paper). Therefore, gneiss, granite and amphibolite had formed a com-

plex before it was split into the present-day tectonic units. These members all have radiometric ages about 400 m.y. (KAWANO & UEDA, 1966; HAYASE & ISHIZAKA, 1967; HAYASE *et al.*, 1968; UEDA & ONUKI, 1969; HAYASE & NOHDA, 1969; ISHIZUKA, 1972; NOHDA, 1973; YOSHIKURA *et al.*, 1981). Semi-schists (352—394 m.y.), jadeite-glaucophane schists (208—240 m.y.) and the schists of albite-epidote amphibolite facies (317—327 m.y.) never constitute one tectonic unit with any of the gneiss, granite and amphibolite. Furthermore, some porphyritic dikes younger than amphibolite occur.

Consequently, the member rocks of the Kurosegawa zone are divided into at least three groups; the first is that of gneiss, granite and amphibolite, the second of the semi-schists, jadeite-glaucophane schists and the schists of the albite-epidote amphibolite facies, and the last of the weakly or unmetamorphosed rocks, the Siluro-Devonian, Carboniferous, Permian and Triassic. Each of three groups may further be divided into subgroups, as the jadeite-glaucophane schists and semi-schists have different ages, and the unmetamorphosed Siluro-Devonian and Triassic never constitute the same tectonic unit or block.

ICHIKAWA *et al.* (1956) considered that the Kurosegawa tectonic zone was a fracture zone reaching to the depth of the presumed basement complex in the Late Paleozoic to Early Mesozoic geosyncline in Southwest Japan. HAYAMA (1959) insisted that the Pre-Cambrian basement must have existed beneath the geosyncline in those days on the basis of his study on the garnet-clinopyroxene rock. HORIKOSHI (1972) discussed that the Kurosegawa zone was a fossil subduction zone, because it is a zone characterized by long and narrow serpentinite belts along the southern extremity of the geosyncline.

The Kurosegawa tectonic zone is characterized by three groups of rocks mentioned above which are remarkably different from each other in lithology and age. The metamorphic facies of the first and the second groups are clearly different, suggesting the different tectonic histories of the two. The

relevant tectonic settings to the Kurosegawa serpentinite melange zone would be expected to those of the suture zone, which is the only place where various kinds of rocks different in lithology and age can be gathered to form a complex intruded presumably by serpentinite.

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* in Japanese with English abstract

** in Japanese

*** in Japanese with German abstract

四国中央部高知市北方の黒瀬川メランジ帯

丸 山 茂 徳

(要 旨)

高知市北方の黒瀬川帯は①非変成堆積岩類(シルル・デボン系横倉山層, 三層系川内ヶ谷層群, 二層系高岡層, 伊野層の一部(二層・石炭系)), ②低温高圧型変成岩類(伊野層の一部(352—394 Ma), ヒスイ輝石—藍閃石型結晶片岩類(208—240 Ma), 曹長石—緑簾石角閃岩相の結晶片岩(317—327 Ma), ウィンチャイトを含む緑色岩), ③黒雲母片麻岩, ④高圧角閃岩相に属する変塩基性岩(409 Ma), ⑤三滝かこう岩類によって構成され, 北方と南方は断層関係で各々, 白木谷層群, 蔵法院層群に接している。黒瀬川帯構成メンバー間には常に断層が存在し, さらに断層内に蛇紋岩が貫入している場合が一般的である。この産状は蛇紋岩メランジ帯のそれである。

当地域の黒瀬川メランジ帯では蛇紋岩と低温高圧型変成岩類の占める面積の割合は各々, 30%, 50%である。このことは黒瀬川帯が蛇紋岩を一般的に伴う, 先三波川低温高圧型広域変成帯であることを示している。

産状・年代および岩石学的性質に基づいて, 黒瀬川帯構成メンバーは①, ②, ③④⑤の三グループに区分できる。これら三者の岩相の差は, 島弧や活動的大陸縁の深度の差では説明できなく, 水平方向の著しい短縮による

ものと思われる。

黒瀬川帯構成メンバーは下部白亜系物部川層に不整合関係で被れているので水平方向の著しい短縮と蛇紋岩メランジ帯としての基本的骨格の形成は下部白亜紀には完了していたと思われる。

(地 名)

Babebana	バベ鼻	Naruyama	成山
Ejiri	江尻	Nishitani	西谷
Engyoji	円行寺	Niyodogawa	仁淀川
Hiji	尾立	Shogase	勝ヶ瀬
Hinagu	日奈久	Shirakidani	白木谷
Imose	妹背	Takaoka	高岡
Ino-ohashi	伊野大橋	Tsukanohara	塚ノ原
Iwami	石見	Yashiro	八代
Kashiki	鹿敷	Yokokurayama	横倉山
Kitayama	北山	Zohoin	蔵法院
Kochigatani	川内ヶ谷	Ino	伊野
Mizuta	水田	Rendai	蓮台
Monobegawa	物部川

Plate I. Downwards concentration of vesicles in pillows in the middle lens of the Ino Formation, indicating the upturned stratigraphy. The bottom is upper stratigraphically, and the arrow means an apparent way of bedding plane.