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Origins of ophiolites from Maizuru Tectonic Belt, Southwest Japan[1)]

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西南日本舞鶴構造帯に産するオフィオライトの起源

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舞鶴構造帯に産するオフィオライトは，東から西に Eastern，Kamigori および Western の3つの unit に区分できる。各 unit は，280～310Ma頃に形成されたが，それぞれ異なった起源マントルと火成作用から由来したことが明らかになった。Eastern Unit のオフィオライトは MORB 的な性質を示すが，deplete した海洋のマントルより低い ε Nd（<+5）と高い ε Sr（+13.2）をもつ。これらのオフィオライトは中央海嶺か縁海の海嶺上でのホットスポットの火成活動によって形成されたと考えられる。Western Unit のオフィオライトは MORB 的な玄武岩からなり deplete した海洋マントルに似た高い ε Nd（+7.9）と，MORB の起源マントルよりやや高い ε Sr（−8.0）を持つ。このようなオフィオライトは縁海のマントルから形成されたと考えられる。Kamigori Unit のオフィオライトは，アルカリ系列とソレアイト系列の両方の性質を持つ海洋島玄武岩と島孤斑れい岩や角せん岩からなっている。

Abstract The ophiolites of the Maizuru Tectonic Belt are divided into three units; Eastern, Kamigori and Western Units from east to west. They were derived from different source mantles and magmatisms, though they were formed during a similar age (280～310 Ma). The ophiolites of the Eastern Unit show MORB-like nature, but show lower ε Nd (<+5) and higher ε Sr (+13.2) values than those of depleted oceanic mantle. They were probably formed by a hot spot magmatism on a mid-ocean or marginal sea ridge. The ophiolites of the Westem Unit consist mainly of MORB-like basalt, and have a high ε Nd (+7.9) value, which is similar to that of depleted oceanic mantle, and have a slightly higher ε Sr (−8.0) value than MORB source mantle. They must be generated from a marginal sea mantle. The ophiolites of the Kamigori Unit are made up of oceanic island basalt, and island arc metagabbro and amphibolite, which are both of alkaline and tholeiitic natures.

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1) A part of this study was read at 95th an anual meeting of the Geological Society of Japan, in Okinawa, 1988.

I. Introduction

The ophiolites are not always derived from the fragments of typical oceanic crust, but from tectonic slices of various crusts such as an island arc, oceanic island, forearc, and marginal sea floor. For example, the Troodos ophiolite has been considered to be derived from an island arc crust (e. g., Miyashiro, 1973; McCulloch and Cameron, 1983). In this paper, therefore, we use the terminology of "ophiolite" as a rock assemblage name followed after Penrose field conference on ophiolite (Anonymous, 1972).

The pre-Cretaceous formations of Inner Zone of Southwest Japan are divided into Hida, Chugoku Metamorphic, Maizuru Tectonic, Ultra-Tamba, Tamba, and Ryoke Belts from north to south. The Ultra-Tamba Belt was recently defined between Tamba and Maizuru Tectonic Belts (Caridroit *et al*, 1985; Ishiga, 1985a, b).

The Maizuru Tectonic Belt distributes from Maizuru City in Kyoto Prefecture to Hiroshima Prefecture (Igi and Wadatsumi, 1980; Hase, 1964; Mitsuno and Okimura, 1987). The main constituents of the Maizuru Tectonic Belt are Yakuno Complex, Maizuru Group (Middle-Upper Permian) and Lower-Upper Triassic formation. The Yakuno Complex is made up of the dismembered ophiolites with small amounts of felsic igneous rocks. The Yakuno Complex characteristically occurs in Maizuru Tectonic Belt and is a main constituent of the belt. Ishiwatari (1978, 1985a, b) showed that Yakuno Complex and metabasalts of the Maizuru Group had been originally an ophiolite sequence. Here, we consider the rocks of the Yakuno Complex and some of Maizuru Group to the ophiolites of the Maizuru Tectonic Belt (Koide *et al*., 1987a).

The metabasalts in the Maizuru Tectonic Belt had been believed to be similar to mid-ocean ridge basalt (MORB) in chemistry (Igi, 1976; Hase and Nishimura, 1979). Recently, it is reported that some ophiolites in this belt are not typical ocean ridge origins (Ishiwatari, 1985a; Koide 1986, 1990; Koide *et al*., 1987a, b). In this paper, therefore, we compile the geologic and petrologic data of the ophiolites from the Maizuru Tectonic Belt, and discuss their geochemical variation, adding new data. We show that the ophiolites in this belt were originated from the various magmatisms.

II. Outline of Geology

The general structure of the Maizuru Tectonic Belt trends E-W to NE-SW, whereas the ophiolite of the Kamigori area (see Fig. 1) shows structure of WNW-ESE to NW-SE which obliques to the general structure of the Maizuru Tectonic Belt (Shimizu, 1987). Therefore, the Maizuru Tectonic Belt can be divided into three geologic units; Eastern, Kamigori and Western Units. The Kamigori Unit occurs between the Eastern and Western Units. Fig. 2 shows columnar sections of ophiolites in the Maizuru Tectonic Belt, and Table 1 represents rock assem-

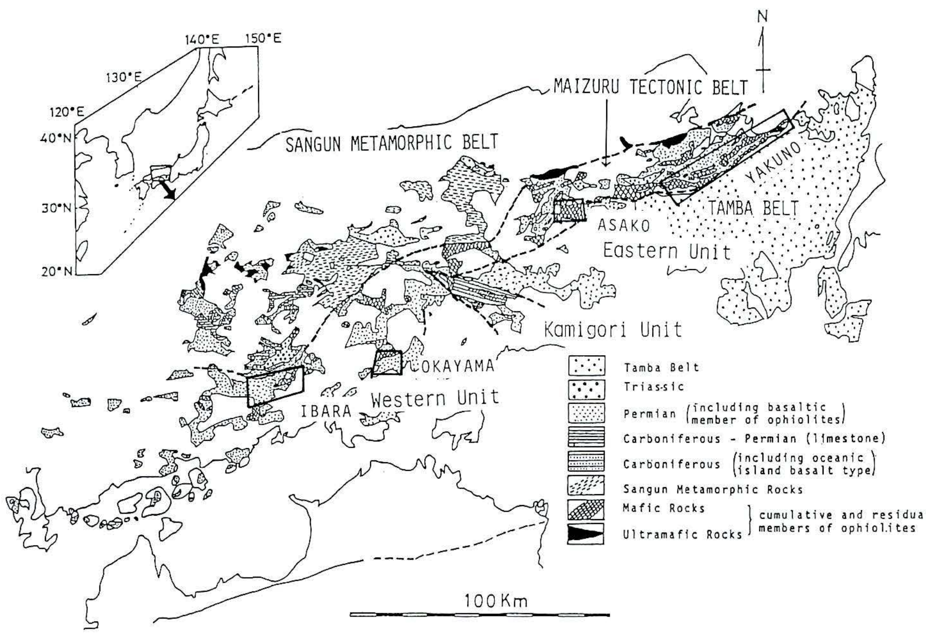


Fig. 1. Geological map of Maizuru Tectonic Belt, modified from Hirokawa (1978). The insert shows its location in Japan. The locations of Eastern, Kamigori and Western Units are shown with bordering broken lines. The areas encircled by solid lines are discussed in the text.

lage of ophiolites and associated rocks, The sedimentary rocks covering and interlayering basaltic rocks included the fossils of the Permian age. Therefore, the ophiolites covered by them are considered the products at the similar age. In the other words, the ophiolites are regarded as the "fossil" of time-space plane.

1. Eastern Unit

The ophiolite succession of the Eastern Unit, especially Yakuno area, is relatively well preserved (Fig. 2), though dyke swarm and pelagic sediments can be rarely observed. Although the ophiolites consist of many tectonic slices, the structure of this ophiolites is originally a stratiform. The ophiolites are covered by the sandstone, chert and slate. The Permian fossil was discovered in the slate. The interlayered limestone with ophiolitic metabasalts was at the Permian time.

We compiled the ophiolites from the Yakuno, Asako, and Akenobe areas as shown Fig. 2. Hayasaka (1987) divided the ophiolite of Asako area into four members. Whereas, Ishiwatari (1985a, b) divided the Yakuno ophiolite into three members; metavolcanics, matacumulates and metaresidua. All members of the ophiolite in the Asako area can correspond to those of the Yakuno ophiolite (Hayasaka, 1987). The ophiolite in the Akenobe area is also compared to the Yakuno ophiolite (Fig. 2).

The volcanic rocks of the Eastern Unit are made up mainly of massive basalt

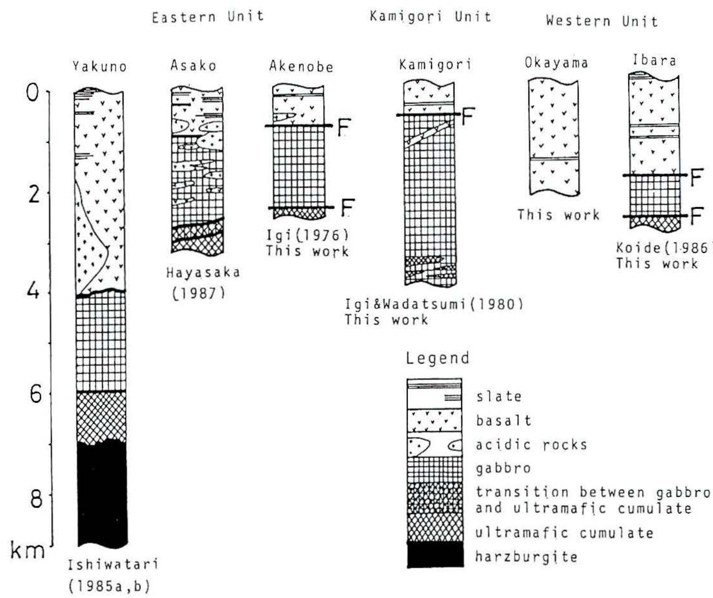


Fig. 2. Columnar sections of ophiolites from Maizuru Tectonic Belt.
Data from Yakuno: Ishiwatari (1985a; b), Asako: Hayasaka (1987), Akenobe: Igi(1976) and this work, Kamigori: Igi and Wadatsumi (1980) and this work,. Ibara: Koide (1986) and this work.

Table 1. Rock assemblage of ophiolites from Maizuru Tectonic Belt .

	Western Unit	Kamigori Unit	Eastern Unit
Sedimentary rocks			
covered	sl, cngl	sl, ss, cngl	sl (Perm), ss, chert
interlayered	sl, sh, chert	ls (Perm), sl	sl, ls (Perm)
Ophiolites			
occurrence	dismembered	dismembered	stratiform
volcanics	bas>dol	bas	dol>>bas
	pil>hy>mass	---	mass>>pil,hy
cumulates	gab, dun, weh	gab, dun, weh	gab, pyxn, weh, dun
residue	none	none	harzburgite
Fractionated Rocks			
frequency	rare	common	abundant
rock type	plgr	di, gr, tnl, q-di, grdi	q-di, tnl>porp, trj

The "Perm" in brackets means Permian fossil age of sedimentary rocks. sl: slate, cngl: conglomerate, ss: sandstone, sh: shale, ls: limestone, bas:basalt, dol: dolerite, pil: pillow lava, hy: hyaloclastite, mass: massive lava, gab: gabbro, dun: dunite, weh: wehrlite, pyxn: pyroxenite, plgr: plagiogranite, di: diorite, tnl: tonalite, q-di:quartz diorite, grdi: granodiorite, porp: porphyrite, trj: trondhjemite.

flows with small amounts of pillow lavas, hyaloclastites and reworked volcaniclastic rocks, which are often intercalated with thin layers of black slate (Igi *et al.*, 1961; Ishiwatari, 1978). Transitional zone exists between the volcanic and the cumulative members, which are composed of fine-grained amphibolite and coarse-grained metagabbro. The cumulative member consists mainly of layered metagabbro, alternating layers of metagabbro, pyroxenite and peridotite, and massive dunite from upper to lower. The residual member is composed wholly of chromian spinel harzburgite.

The fractionated rocks associated with the ophiolites are abundant as compared with other units, and comprise hornblende-quartz diorite, tonalite, porphyrite, granophyre, trondhjemite, dacite and quartz keratophyer. The fractionated rocks intruded into the metavolcanics and metacumulates, and occur as dykes, stocks, sheets and pegmatitic veins. They are frequently mylonitized. The quartz diorite in the Yakuno ophiolite was affected by the same metamorphism as the country metavolcanics. They were, therefore, considered to be the products of the same magmatism of the basic igneous rocks (Ishiwatari, 1985a; Koide *et al.*, 1987b). However, Hayasaka (1987) reportedt that the quartz diorite and tonalite in the Asako area were formed at another magmatic stage of metacumulates because of differences in the mineral fabrics and fractionation trend. Then, he concluded that parts of the fractionated rocks should be fomed by the different magmatism from ophiolitic one.

The ophiolites of the Eastern Unit have been extensively subjected to metamorphism ranging from the prehnite-pumpellyite to granulite facies (Ishiwatari, 1985a; Hayasaka, 1987). The metamorphic facies series, including the prehnite-pumpellyite and epidote amphibolite facies, suggests a low geothermal gradient and a high pressure condition compared with the general ocean floor metamorphism. Ishiwatari (1985a) showed that such a metamorphic condition of the ophiolites requires an unusually thick oceanic crust, about 15-30km thick.

2. Kamigori Unit

The ophiolites of the Kamigori Unit are dismembered. The ophiolites are made up mainly of metagabbro and amphibolite with small amounts of ultramafic and mylonitized granitic rocks, and is lack of the metaresidual member.

Metabasalts occur in fault contact with metagabbro and amphibolite, and are called the Kozuki Formation and the Tatsuno Group. The Kozuki Formation differs from the Tatsuno Group in lithology and fossil fauna. The Kozuki Formation is estimated to be formed at Middle Permian time (Goto and Hiroi, 1985; Pillai and Ishiga, 1987), including Late Carboniferous limestone lenses intercalated with basaltic hyaloclastite (Igi and Goto, 1981). Pillai and Ishiga (1987) reported that the age and biofacies of the Kozuki Formation are similar to those in Ultra-Tamba Belt. On the other hand, the Tatsuno Group is correlated with the Maizuru Group on the basis of lithology and fossil faunas (Igi and Wadatsumi, 1980, Igi and Goto, 1981; Goto, 1986). Therefore, the metabasalts of this group are regarded as the volcanic member of the ophiolite in the Kamigori Unit. The volcanic member is made up mainly of metabasalt with small amounts of hyaloclastite, and is intercalated with black slate.

The cumulative member is composed mainly of metagabbro with small amounts of ultramafic and felsic rocks. The metagabbro frequently shows gneissose texture and is mylonitized, some of which can be called amphibolite. The metagabbro is generally massive and cannot be observed layered structure. The ultramafic rocks which are originally dunitic and wehrlitic cumulates are usually serpentinized. The felsic rocks are generally mylonitized and occur as small bodies, dykes and stocks. The felsic rocks are made up of various rock types, such as diorite, granite, norite, quartz diorite and granodiorite.

3. Western Unit

The ophiolites of the Western Unit are dismembered. The main constituents of the ophiolites are volcanic member with small amounts of cumulative member, and the residual member is lack.

The volcanic member is composed mainly of slightly vesicular pillow basalts with minor amounts of massive basalt lavas, dykes and hyaloclastite. Associated sedimentary rocks are commonly black slate with rarely red shale and chert. The total thickness of the volcanic member is about 2000m. The original structures of pillow lavas, dykes and hyaloclastite are well preserved in the Ibara Ophiolite (Koide, 1986), though they can be not always observed in the ophiolite in the Okayama area because of contact metamorphism by the Cretaceous igneous rocks. The pillow lavas, which are commonly close-packed, are the main constituents of the volcanic member. One tectonic slice, at least, is accompanied with these ophiolites in both the Ibara and Okayama areas. The slice is made up dominantly of black and massive mudstone with a few beds of conglomerate, sandstone, metabasalt, hyaloclastite, acidic tuff and chert.

The cumulative member consists mainly of metagabbro with subordinate amounts of serpentinized ultramafic rocks. The metagabbro shows fine- to coarse-grained gneissose texture. The ultramafic rocks are composed mostly of wehrlite with clinopyroxenite blocks, one to several meters in diameter, where no igneous layering can be observed. The ultramafic rocks are severely altered into serpentinite.

The fractionated rocks are rarely compared with other units. The plagiogranite is scarcely found as mylonitee.

III. Chemistries of Metavolcanics

It is well known that the original bulk chemistry of ophiolites has usually been modified as a result of metamorphism and alteration. To first approximation,

Table 2. Basalt and relict mineral chemistries of from Maizuru Tectonic Belt.

	Western Unit	Kamigori Unit	Eastern Unit
phenocryst assemblage			
	sp+ol±pl, pl±cpx sp+ol+pl+cpx	cpx±pl	sp+ol, pl, cpx
Bulk Rock (n)	33	3	25
FeO*/MgO	1.68 (0.87-3.35)	1.94 (1.30-2.97)	1.68 (0.83-2.64)
TiO_2 (wt%)	1.58 (0.72-2.79)	2.26 (1.63-3.08)	1.41 (0.83-2.12)
Norm #1	ol-hy	Q, ol-hy	ol-hy
rock series	TH	TH&AK	TH
Clinopyroxene			
Si	1.85-1.95	1.80-1.93	1.80-1.95
Ti	0.01-0.03	0.09-0.10	0.01-0.03
Al	0.07-0.15	0.10-0.25	0.08-0.20
Na	< 0.02	0.01-0.03	< 0.02
TiO_2 (wt%)	0.27-1.32	0.59-3.16	0.24-0.92
Wo	33-44	35-46	31-44
rock series	TH	Trans&AK	TH
Spinel			
$Y_{Fe^{3+}}$ #2	0.3 -0.1		0.08-0.12
X_{Cr}	0.4 -0.6		0.4 -0.7
TiO_2 (wt%)	0.2 -0.8		0.2 -0.8
Ti	0.05-0.15		0.05-0.14

The "n" in brackets shows numbers of data. *: total iron as FeO, #1: C.I.P.W. norm calculated using FeO/Fe_2O_3 = 0.1, #2: Fe^{3+} calculated by stoichiometry. sp: spinel, ol: olivine, pl: plagioclase, cpx: clinopyroxene, ol-hy: olivine and hypersthene normative, Q: quartz normative, TH: tholeiitic rock series, AK: alkaline rock series, Trans: transitional between tholeiitic and alkaline rock series, Wo: wollastonite content in clinopyroxene, $Y_{Fe^{3+}}$: $Fe^{3+}/(Fe^{3+}+Cr+Al)$ ratio, X_{Cr}: Cr/(Cr+Al) ratio, element (Si, Ti, Al and Na): atomic value in mineral.

however, it is useful that magmatic properties of ophiolites are estimated by using various discrimination diagram (e. g., Bass *et al.*, 1973; Miyashiro, 1975; Pearce *et al.*, 1975; 1977).

The magmatic parentage of ophiolites can be identified in terms of relict minerals chemistries. Cliopyroxene and spinel are commonly preserved in the metabasalt and metadolerite of the ophiolites from the Maizuru Tectonic Belt. The compositions of these minerals would provide important information on the magmatic character.

The Al-Si and Ti-Al diagrams of clinopyroxene proposed by Kushiro (1960) have been widely used for discrimination of the magmatic parentage (e. g., LeBas, 1962; Aoki, 1964). Maruyama (1976) advocated the boundaries between the clinopyroxenes of the tholeiitic and alkaline rock series.

Spinel from MORB has characteristically a low Fe^{3+} content (Bryan, 1972; Ridley *et al.*, 1974; Sigursson and Schilling, 1976), ranging from 0.4 to 0.6 in Cr/(Cr+Al) ratio (Dick and Bullen, 1984). These characteristics are useful to determine magmatic affinity between MORB and ophiolitic basalts.

Published and newly obtained data of metabasalts and metadolerites are listed in Table 2.

1. Eastern Unit

Concerning the Eastern Unit, chemical descriptions of the ophiolites in the Yakuno area (Ishiwatari, 1978, 1985a, b; Koide *et al.*, 1987b). Asako area (Hayasaka, 1987) and Akenobe area (Igi, 1976) have already reported. We add some chemical analyses of metabasalts in the Asako area.

The metabasalts and metadolerites are usually non-porphyritic. Some of them have spinel, olivine, plagioclase and clinopyroxene phenocrysts. The metabasalts and metadolerites of the Eastern Unit belong to the tholeiitic rock series and their chemical features show the similarity to MORB and marginal sea basalts, judging from various discrimination diagrams (Koide *et al.*, 1987b).

The relict clinopyroxenes of metabasalts and metadolerites have the high Si (1.80–1.95) and low Al (0.08–0.20), Ti (<0.03), Na (<0.02) and Wo (0.31–0.44) contents. The data show a tholeiitic nature of the host basalts (Igi, 1976; Ishiwatari, 1985b; Hayasaka, 1987). The relict spinel has low $Fe^{3+}/(Cr+Al+Fe^{3+})$ ratio (0.08–0.12), and its Cr/(Cr+Al) ratio ranges from 0.4 to 0.7 (Ishiwatari, 1985b). These characteristics are also similar to those of MORB and marginal sea basalts.

2. Kamigori Unit

The chemical natures of the Kamigori Unit are already reported by Igi and Wadatsumi (1980). We carried out field survey and petrographic description of this ophiolite.

The metabasalts of this Unit are classified into non-porphyritic and porphyritic varieties. The non-porphyritic metabasalts consist of clinopyroxene, plagioclase, glass and opaque minerals, and their textures are glassy, variolitic, intersertal, intergranular, subophitic and ophitic. The porphyritic metabasalts have the phenocryst assemblages of clinopyroxene$\pm$plagioclase. Their groundmass shows the similar texture to that of non-porphyritic metabasalt, and is composed of clinopyroxene, plagioclase, glass and opaque minerals.

The metabasalts in the Tatsuno Group have FeO*/MgO ratio (1.30–2.97) higher than those of MORB and TiO_2 content (1.63–3.08 wt%) higher than those of island arc basalts. They have normative quartz. The relict clinopyroxenes show both tholeiitic and alkaline natures. The alkaline clinopyroxenes have high Al (>0.2) and Ti (>0.05), and low Si (<1.85), Na (<0.02), Wo (<0.4) contents. On the other hand, the pyroxenes of tholeiitic basalt have low Al (<0.2) and Ti (<0.05)

and high Si (<1.85), Na (>0.02), Wo (>0.4) contents. The metabasalts in the Tatsuno Group show both tholeiitic and alkaline natures. Furthermore, those high TiO_2 contents are never observed in island arc basalts.

3. Western Unit

The metabasalts of the Western Unit are classified into three, i.e., SO, PC and TR types (Koide 1986, 1990; Koide *et al.*, 1987a). The SO type has olivine phenocrysts with spinel inclusions. The PC type is non-porphyritic, or has plagioclase or clinopyroxen phenocrysts or both. The TR type is characterized by olivine+plagioclase+clinopyroxene±spinel assemblage.

Koide (1986) discussed that the metabasalts belong to the tholeiitic rock series. The evidence is as follows; 1) olivine tholeiite in C.I.P.W. norm (Yoder and Tilley, 1962), 2) plotted in the non-alkaline rock series field on $Na_2O+K_2O-SiO_2$ diagram (MacDonald and Katsura, 1964), 3) showing tholeiitic variation trends in the SiO_2-, TiO_2- and FeO* (total iron as FeO) -FeO*/MgO diagrams (Miyashiro, 1975), and 4) tholeiitic clinopyroxenes in terms of the Al-Si, Ti-Al (Maruyama, 1976) and Al_2O_3-FeO (Takasawa and Hirano, 1977) relations.

Furthermore, Koide (1986) and Koide *et al.* (1987a) reported that the metabasalts are similar to mid-ocean ridge and marginal sea basalts in the following chemical features; 1) unfractionated nature (high Cr_2O_3 contents and low FeO*/MgO ratios), 2) higher TiO_2 contents than island arc tholeiites, 3) lower TiO_2 contents than oceanic island tholeiites (Bass *et al.*, 1973), 4) plotted in the MORB field in the AFM diagram (Kawabe *et al.*, 1979), 5) plotted in the ocean ridge and floor basalt field in the FeO*-MgO-Al_2O_3 diagram (Pearce *et al.*, 1977), 6) low Rb and Sr contents, and 7) low Fe^{3+} content of spinel (Bryan, 1972; Ridley *et al.*, 1974; Sigurdsson and Shilling, 1976).

However, there are some differences in the rock chemistry between the metabasalts and MORB. The average SiO_2 content of the metabasalts of the Western Unit is about 51 wt%, and is slightly higher than that of MORB which is around 48-50 wt%. Most of marginal sea basalts are similar in SiO_2 contents to MORB with an exception of East Scotia sea basalt (Saunders and Tarney, 1979; Muenow *et al.*, 1980), having high SiO_2 contents (52 wt%) similar to the metabasalts of the Western Unit (Koide, 1986). On the C.I.P.W. norm diagram, the metabasalts characteristically have higher normative plagioclase than MORB, and are similar to Shikoku Basin basalt (Marsh *et al.*, 1980).

IV. Isotope Geochemistry

Rubidium and Strontium are easy to move during metamorphism and alteration. We should pay attention to Sr isotope data applied to the ophiolites. The ophiolites are generally affected by metamorphism and alteration.

Samarium and Neodymium are believed to be immobile elements during low

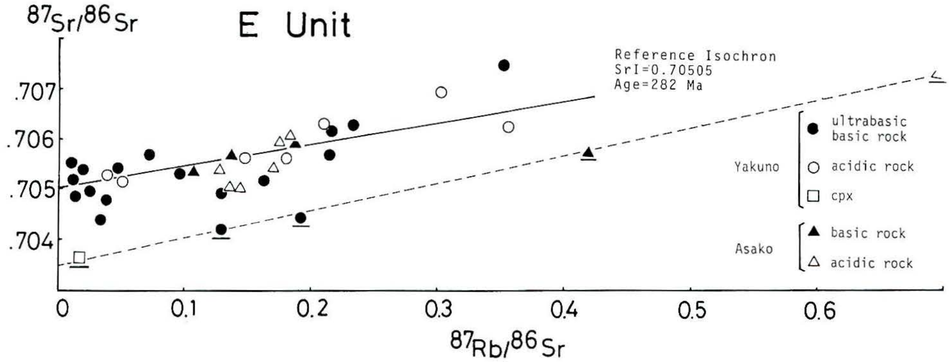


Fig. 3. $^{87}Sr/^{86}Sr$–$^{87}Rb/^{86}Sr$ diagram of ophiolites from Eastern Unit.
The reference isochron shown by a solid line is for the SrI of 0.70505 and age of 282 Ma. The five data with underlined symbols combined by a broken line show another correlation (age: 388±14 Ma, SrI: 0.70353±8).

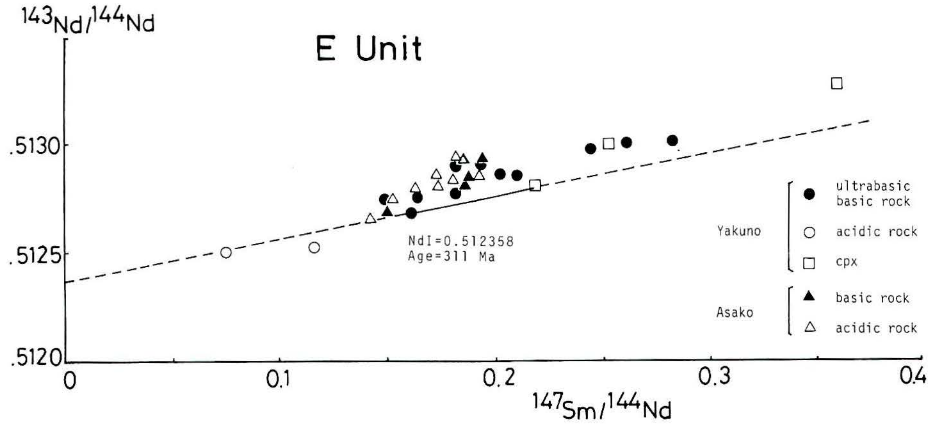
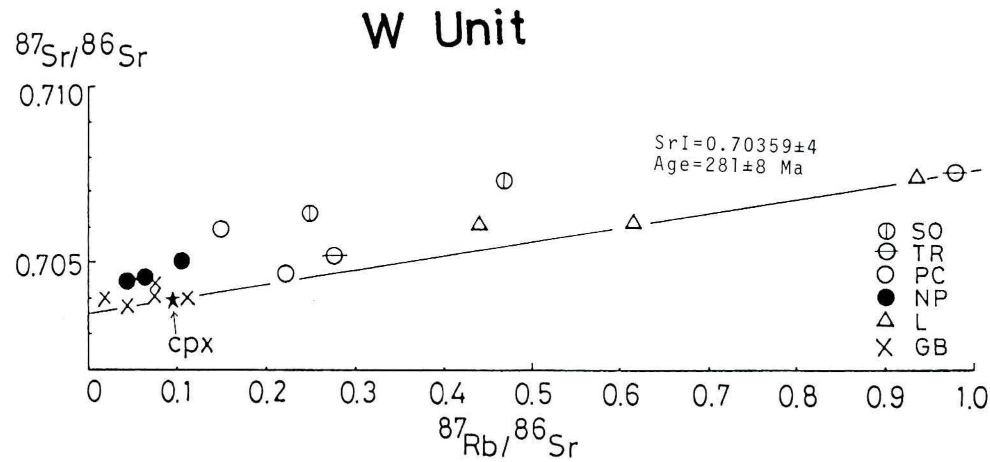


Fig. 4. $^{143}Nd/^{144}Nd$–$^{147}Sm/^{144}Nd$ diagram of ophiolites from Eastern Unit.
The reference isochron calculated by one whole rock of metadolerite and its relict clinopyroxene, shown by a solid and broken lines, indicates the NdI of 0.512358 and age of 311 Ma. Isochron obtained from metagabbros and the associated rocks shows the NdI of 0.512 265 with the age of 426 Ma (Sano, in press).

grade metamorphism. Accordingly, the Nd isotope ratios are useful to estimate the source material of ophiolites. For example, the metamorphic rocks of the eclogite facies preserve their isotope compositions at the magmatic stage (Bernard-Griffiths *et al.*, 1985).

The clinopyroxenes in ophiolitic basalts and dolerites are usually preserved. The chemistries of relict clinopyroxenes are generally used for the determination of the magmatic nature. The isotope data of them are also effective for the discussion on the origin of an ophiolite (e. g., Koide *et al.*, 1985). We determined



Fig, 5. $^{87}Sr/^{86}Sr$-$^{87}Rb/^{86}Sr$ diagram of ophiolites from Western Unit.
The isochron shown by a solid line indicates theSrI of 0.70359±4 and age of 281±8 Ma. SO: spinel and olivine porphyritic basalt, TR: transitional type basalt, PC: plagioclase and clinopyroxene porphyritic basalt, NP: non-porphyritic basalt, L: basalt from Lower member, GB: metagabbro (Koide, 1986).

the isotope compositions of bulk rocks, relict clinopyroxene and mafic fraction. Because the accuracy of isochron can be checked by them and they can expand the range of $^{147}Sm/^{144}Nd$ ratio.

The Nd and Sr isotopes of ophiolites in the Kamigori Unit have not yet been obtained. These isotopes of the Yakuno and Asako ophiolites in the Eastern Unit and the Ibara ophiolite in the Western Unit have been analyzed and some of the isotope data are already published (Koide *et al.*, 1987a, b; Koide, 1990; Sano, in press).

The Sr and Nd isotopes and Rb, Sr, Sm and Nd concentrations were analyzed after the methods of Kagami *et al.*, (1982; 1987). The isochrons of Rb-Sr and Sm-Nd systematics were calculated by York (1966) using decay constants of ^{87}Rb: $1.42\times10^{-11}y^{-1}$ and ^{147}Sm: $6.54\times10^{-12}y^{-1}$, respectively.

1. Eastern Unit

For the ophiolite in Yakuno area, 26 Sr isotope ratios were analyzed on 18 basic to ultrabasic rocks, 7 fractionated rocks and 1 clinopyroxene of metagabbro. 16 Nd isotope ratios were measured on 11 basic to ultrabasic rocks, 2 fractionated rocks, 2 clinopyroxenes of metagabbro and 1 clinopyroxene of metadolerite. For the ophiolite in the Asako area, 11 Sr and Nd isotope ratios were analyzed on 4 basic rocks and 7 fractionated rocks.

The $^{87}Sr/^{86}Sr$-$^{87}Rb/^{86}Sr$ diagram for the ophiolites of the Eastern Unit is shown in Fig. 3. The reference isochron, which has an initial Sr isotope ratio (SrI) of 0.7051 and an isochron age of 282 Ma (Ishiwatari *et al.*, 1990), is also shown in this isochron diagram. The Yakuno ophiolite does not form a clear isochron. However,

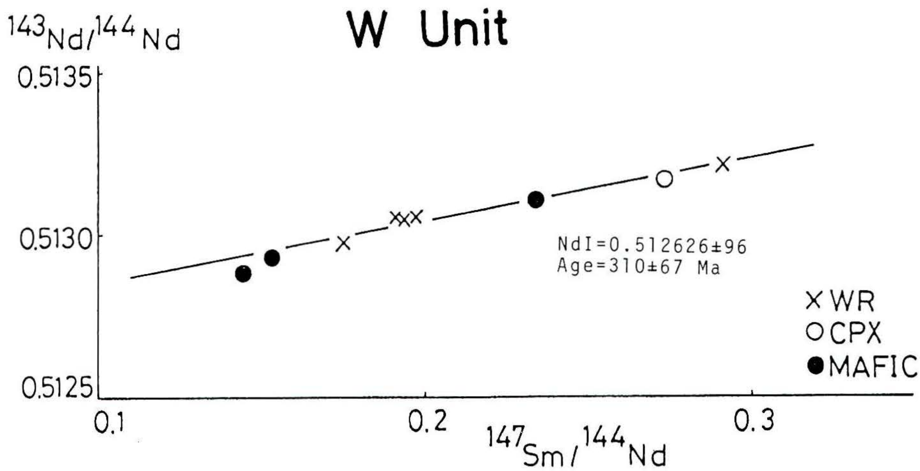


Fig. 6. $^{143}Nd/^{144}Nd$–$^{147}Sm/^{144}Nd$ diagram of ophiolite from Western Unit.
The isochron shows the NdI of 0.51263±1 and age of 310±69 Ma. WR: whole rock, CPX: relict clinopyroxene, MAFIC: mafic fraction.

most of data represent a positive correlation and plot around this isochron. Five data with the underlined symbols plot below the reference isochron, and show a linear correlation (age: 388±14 Ma, SrI: 0.70353±8).

Fig. 4 is the Nd isochron diagram. The plotted data does not also form an isochron. The reference isochron, indicating initial Nd isotope ratio (NdI) of 0.5 12358 and age of 311 Ma, is determined by two data of metadolerite and its relict clinopyroxene (Sano, in press). This age is similar to those of other ophiolites from the Maizuru Tectonic Belt (280–310 Ma; Koide *et al.*, 1987a, b; Koide, 1990). On the other hand, it has been reported that the isochron age obtained from metagabbro in the member of the Yakuno ophiolite is about 430 Ma on Sm-Nd systemitc (Sano, in press). The NdI is 0.512265.

2. **Western Unit**

The ophiolites of the Western Unit has suffered a metamorphism of the prehnite-pumpellyite to amphibolite facies. Five samples were less recrystallized and preserved their primary Sr isotopic natures. The isochron of these samples shows an age of 281±8 Ma and the SrI of 0.70359±4 (Fig. 5). A relict clinopyroxene of the metabasalt also plots just on the isochron. This supports that the isochron age (281 Ma) and the SrI represent the original values of magma (Koide *et al.*, 1987a).

The $^{143}Nd/^{144}Nd$–$^{147}Sm/^{144}Nd$ diagram for the ophiolite of Western Unit is shown in Fig. 6. The isochron age determined by 5 whole rocks, 2 mafic fractions and 1 relict clinopyroxene is 310±69 Ma, and NdI is 0.512626±96.

The SrIs of teh Western Unit recalculated using the isochron age of 281 Ma range from 0.7035 to 0.7055. The NdIs of the Western Unit recalculated using

Table 3. Characteristics in ophiolites of Maizuru Tectonic Belt.

	Western Unit	Kamigori Unit	Eastern Unit
Structure	E-W~NE-SW	NW-SE	E-W~NE-SW
Age			
fossil	---	Permian	Permian
magmatic	280~310 Ma	---	280~310 Ma
			430 Ma
metamorphic	270~290 Ma	---	270~280 Ma
Ophiolite	dismembered	dismembered	stratified
volcanics	pillow lava	lava	massive lava
	MORB-like basalt	ocean island basalt	MORB-like dolerite
		(AK&TH)	
fractionated rocks	rare	common	abundant
Isotope			
ε_{Nd}	+ 7.9	---	< +5
ε_{Sr}	- 8.0	---	+ 13.2 (-8~+25)
Tectonic Setting	marginal sea ridge	arc or ocean island	ocean island?

the isochron age 310 Ma range from 0.512590 to 0.512671.

V. Origin of Ophiolites in Maizuru Tectonic Belt

We summarize the characteristic of the ophiolites from each unit in terms of their differences in Table 3.

1. Eastern Unit

Sano (in press) reported the Yakuno ophiolite has two difftrent consituents of yunger basaltis (300 Ma) and older gabbro (430 Ma). There is possibility that the ophiolites in the Eastern Unit are divided into two part, that is, the older metagabbros and younger metabasalts.

The younger ophiolitic basalts of the Eastern Unit were regarded as the fragments of an ancient oceanic crust on the basis of their rock assemblage and stratiform occurrence (Ishiwatari, 1978, 1985a, 1985b). The chemical features of the basalts and relict minerals indicate that the rocks belong to the tholeiitic rock series and show a similarity to MORBs.

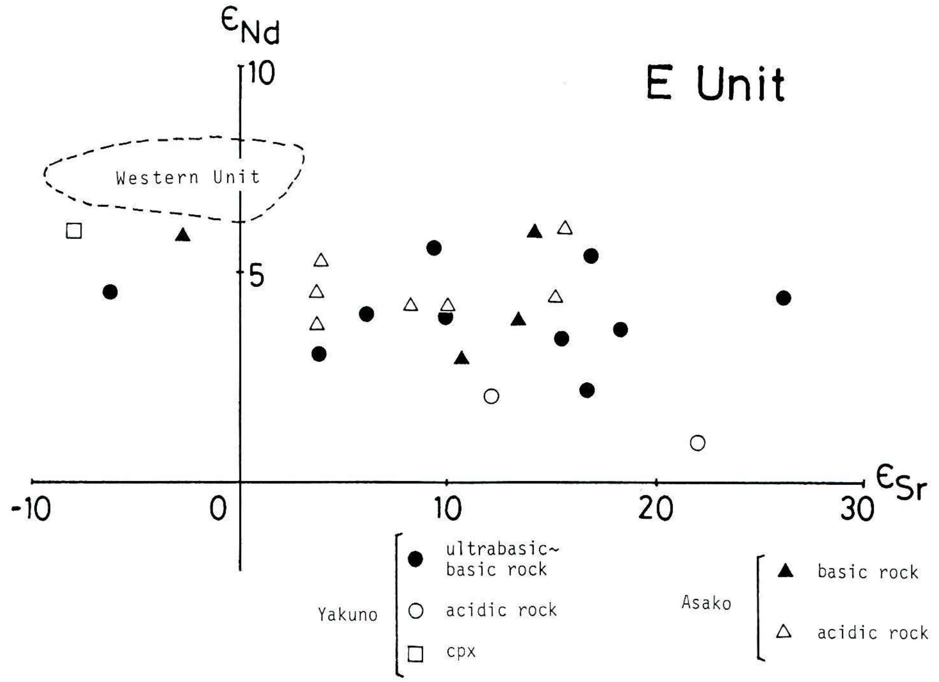


Fig. 7. ε Nd—ε Sr diagram of ophiolite from Eastern Unit.
The ε values are calculated from the initial isotopic ratios. The field encircled with a broken line show that of ophiolites from Western Unit. Cpx (star) represents a relict clinopyroxene. The extend of variation in each Nd isotope ratio is very small. Therefore, ε value can be calculated as follows:

$$\varepsilon\,Nd=\left(\frac{R\ sample}{R\ CHUR}-1\right)\times 10^4$$

where Rsample is the initial isotope ratio of the sample and RCHUR is the initial ratio of CHUR (chondoritic uniform reservoir) whose present value is $^{143}Nd/^{144}Nd=0.51264$, $^{147}Sm/^{144}Nd=0.1967$, $^{87}Sr/^{86}Sr=0.7045$, and $^{87}Rb/^{86}Sr=0.0839$ (Jacobsen and Wasserburg, 1980, 1984).

The source mantle of modern N-type MORB has the highest ε Nd and lowest ε Sr values as compared with ocean island and continental basalts (Zindler *et al.*, 1984). The ε Nd and ε Sr values for source mantle of MORB range from +13 to +3 and from +10 to −34, respectively. In ε Nd- ε Sr diagram (Fig. 7), the mantle array extends from the origin (zero) to upper left.

We could not obtain the clear isochron of the yunger ophiolites from Eastern Unit. As a purely separated relict clinopyroxene has a low $^{87}Rb/^{86}Sr$ ratio (0.016), its SrI is not so variable even if the age estimation is mistaken. Therefore, the Sr isotope ratio of the clinopyroxene (0.70365±5) may be close to the value of its magma. The $^{87}Sr/^{86}Sr$ ratio of the relict clinopyroxene, which is the lowest estimation, is higher than those of typical MORBs, most of which are lower than 0.7035 (Koide *et al.*, 1987a). The isotope compositions of the younger ophiolites from the Eastern Unit plot on the high ε Sr side of the mantle array. The lowest

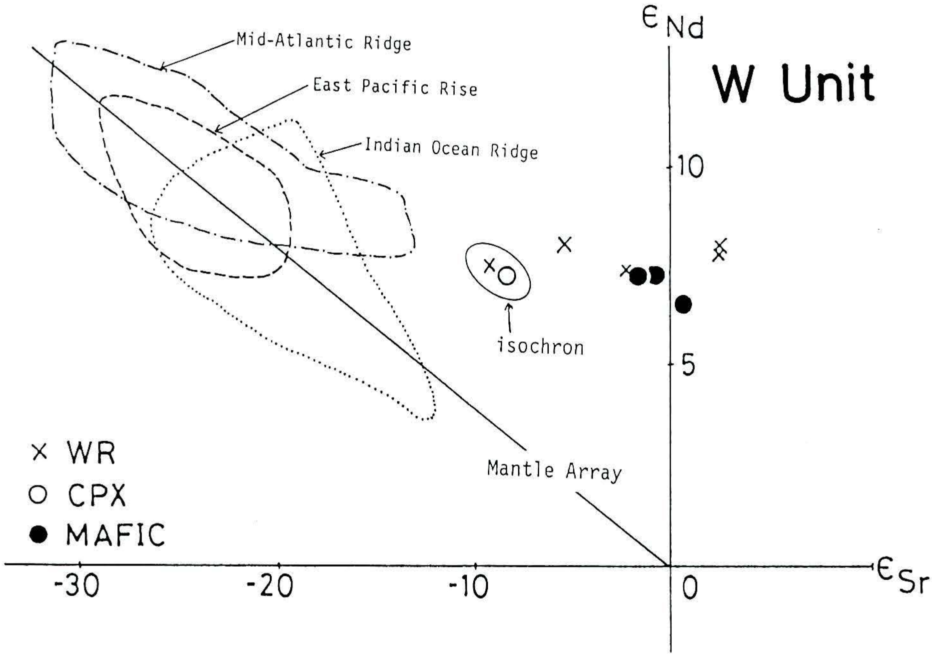


Fig. 8. ε Nd−ε Sr diagram of ophiolites of Western Unit.
MORBs from Indian ocean ridge, East Pacific Rise and Mid-Atlantic Ridge plot in the fields encircled with a dotted line, a broken line and a chain line, respectively. Symbols are the same as in Fig. 7.

value should indicate a source mantle having a high Sr isotope ratio. The five data with underlined symbols show the linear correlation (Fig. 3). The age is 388 Ma and SrI is 0.70353. The corrlation may indicate another magatic activity. The ε Nd values (less than +5) of the yunger ophiolite are also clearly lower than those of depleted oceanic mantle. These results evidently show that the younger ophiolites were not derived from a typical depleted oceanic mantle but from an enriched oceanic mantle such as a hot spot magmatism on an ocean island.

The older metagabbro (ε Nd=3.4) shows also the enriched nature compared to the typical N-type MORBs. This age agrees with the older correlation of the Rb-Sr systematic within error. Sano (in press) concluded the the older metagabbro is not drived form the oceanic crust, but from an undepleted lower crust.

2. **Kamigori Unit**

Ishiwatari (1986) and Ishiwatari *et al.* (1990) showed that the chemistries of the metagabbro and amphibolite are similar to island arc magmatic rocks. His conclusion was obtained by the chemistry of the plutonic rock. However, the metabasalts of the Kamigori Unit show the chemical affinity to tholeiite and alkaline basalts occurred in ocean island on the basis of their high TiO_2 contents. The high TiO_2 content of the metabasalt is never observed in the island arc magmatism. The chemistry of the volcanic rock directly reflects its magmatic nature. The available chemical data are not so much. Furthermore, the specimen of Ishiwatari's analyses and ours are different. The two different results may be derived from the chemistries of the different samples. If the both results are correct, it suggests that the ophiolites of this unit may be made up of tectonic slces of various origins, at least two origins of ocean island and island arc.

3.· Western Unit

The metabasalts of the Western Unit are MORB-like tholeiite. Being compared with MORB, however, the metabasalts are slightly rich in SiO_2 and in normative plagioclase. These features are observed in marginal sea basalt, In ε Nd- ε Sr diagram (Fig. 8), the ophiolites from the Western Unit plot on the high ε Sr side of the mantle array. The source mantles may have a slightly higher ε Sr value than that of a typical depleted ocean mantle, whereas the ε Nd values are similar to those of the oceanic mantle. Koide and his coresearchers determined the clear isochron used by the purely separated relict clinopyroxene. The high ε Sr should be a magmatic nature. The result suggests the mantle source enriched in Sr isotope, which originally has depleted mantle nature. They considered that these characteristics suggest the origin of the marginal sea mantle.

Summary

1) The structure of the Kamigori Unit trends NW-SE, whereas the Eastern and Western Units show E-W to NE-SW. The magmatic, metamorphic and fossil ages of the all ophiolites are similar to each other, except older metagabbro of the Eastern Unit.

2) The ophiolite sequences of the Maizuru Tectonic Belt are recognized. Especially, those of the Eastern Unit are relatively well preserved. In the Maizuru Tectonic Belt, the ophiolites are rarely accompanied with pelagic sediments and are lack in sheeted complex. The magmatic activities of the fracionated rocks associated with the ophiolites increase from west to east.

3) The metavolcanics of the Eastern Unit are massive, though those of the Western Unit show pillow-structure. The whole rock major element chemistries of both Units represent the MORB-like tholeiitic basalts, but that of the Kamigori Unit is similar to oceanic island basalts which may include both tholeiitic and alkaline rock series. The source mantle of the Western Unit is similar to that of depleted oceanic mantle based upon the depleted Nd isotopic composition and slightly higher Sr isotopic ratio than that of oceanic mantle. On the other hand, the source mantle of the basalts in the Eastern Unit is isotopically much undepleted than that of the Western Unit. Moreover, origin of the metagabbros in this Unit is probably different from the metavolcanics, because the Sm-Nd age of the former is evidetly older tha latter.

Conclusively, though the ophiolites from each unit show the different geologic, petrochemical and geochemical characteristics, having been resulted from differences in their source mantle, magmatism and mode of emplacement.

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