Geochemistry of metamorphic rocks from Mizoguchi, western Tottori Prefecture, Japan and its geological significance

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The Mizoguchi area, Southwest Japan, has been interpreted as a western continuation of the Hida terrane, based on the similarity of the mineralogy and radiometric age of metamorphic rocks. However, new geochemical data show metapelite and metabasite from the Mizoguchi area differ from those of the Hida terrane in the following points. i) Metapelite is relatively rich in Sc compared to La and Th, and show gently inclined chondrite-normalized REE patterns. ii) In discrimination diagrams for basaltic rocks, metabasite plots in the fields of arc tholeiites or N-MORBs; however, they are relatively depleted in light REEs but much richer in LIL elements than N-MORBs. From these geochemical features the Mizoguchi metamorphic rocks are interpreted to have formed in the fore-arc region of an oceanic island arc. This is in contrast to generally accepted continental setting for the Hida area and suggests the two areas are geologically distinct.

Introduction

Ishiga et al. (1989) report metamorphic rocks from the Mizoguchi area, Tottori Prefecture, Chugoku District, and regard them as exposures of a western continuation of the Hida terrane, central Japan (Fig. 1a). The Hida terrane used to be considered as Precambrian basement underlying the geosynclinal sediments of Southwest Japan, but recently it has been re-interpreted as a nappe that is composed mainly of metamorphosed Paleozoic formations and thrust over younger accretionary complexes (Komatsu et al., 1985; Isozaki and Maruyama, 1991; Sohma and Kunugiza, 1993). The Hida terrane consists dominantly of gneissose rocks, “the Hida gneisses”, accompanied locally by schistose rocks, “the Unazuki schists” along its eastern margin (Fig. 1a). Both the gneisses and schists underwent medium P/T metamorphism at around 230 to 250 Ma, probably associated with the development of orogenic belts in China and/or Korea (Hiroi, 1978; 1981; Suzuki et al., 1989; Sohma and Kunugiza, 1993; Komatsu et al., 1993; Arakawa et al., 2000). To help understand the tectonic evolution of eastern Asia during Paleozoic time, it is

important to clarify the spatial distribution of the Hida terrane. However, this process is hindered by later igneous and tectonic events such as Mesozoic granitic intrusions and the Cenozoic opening of the Sea of Japan.

Whether or not the Hida terrane continues into the Chugoku District is a contentious issue. The long and widely accepted idea that Oki-Dogo, an island in the Sea of Japan (Fig. 1a), is a continuation of the Hida terrane has recently been criticized, mainly based on whole-rock chemical analyses and paleogeographic reconstructions (Sohma et al., 1990; Isozaki and Maruyama, 1991; Sohma and Kunugiza, 1993; Jin and Ishiwatari, 1997; Arakawa et al., 2001). However, geochemical characterization of the Oki metamorphic complex is hampered by migmatization (Kobayashi et al., 1980), which makes it difficult to determine the chemical compositions of the original rocks without very careful consideration to the problem of redistribution of elements. In contrast to the metamorphic rocks of Oki-Dogo, those of Mizoguchi are of lower grade and not migmatized, and accordingly suitable for comparative geochemical studies. The geochemical data we report here are opposed to the generally held view and give new constraints on the tectonic evolution of eastern

Figure 1. Locality map of the Mizoguchi area and the Hida terrane (a) (after Sohma and Kunugiza, 1993; Arakawa, 2000), and geological sketch maps of the Mizoguchi and Unazuki areas (b, c) (after Ohta, 1962; Hiroi, 1978). The Mizoguchi metamorphic rocks are not exposed on a mappable scale. Stars indicate sampling localities.

Asia.

Sample description

The exposures of the Mizoguchi metamorphic rocks are scarce due to the Cenozoic cover of volcanic and pyroclastic materials from the Daisen volcano (Fig. 1b; Ohta, 1962). We collected several specimens of pelitic and basic rocks at Loc. 1 of Ishiga et al. (1989) along the Oye River, where the metamorphic rocks are locally exposed and included in granitic bodies of Cretaceous or Jurassic age (Miyamoto et al., 2000).

The Mizoguchi metamorphic rocks commonly have grain sizes ranging from 0.1 to 0.5 mm. Although Ishiga et al. (1989) have referred to them as “gneisses”, they do not show typical gneissose structures and are more similar in grain size to the Unazuki schists than the much coarser-grained gneisses of Hida and Oki-Dogo.

Metapelite from the Mizoguchi area commonly shows the mineral association:

biotite + plagioclase + K-feldspar + quartz,

with or without garnet, cummingtonite and hornblende. The biotite and cummingtonite form lepidoblastic and nematoblastic textures, respectively. Actinolite and chlorite also occur partially replacing biotite and cummingtonite.

Metabasite generally shows a granoblastic texture and a weak foliation is only locally developed. Typically the mineral association is:

green hornblende + plagioclase + quartz,

with or without biotite and titanite. The occurrences of secondary minerals such as epidote and calcite forming veinlets and chlorite replacing biotite are also locally common. The fine-grained, massive and homogeneous

Table 1. Petrographic characteristics of metamorphic rocks from Mizoguchi and Unazuki

Locality	M	M	M	M	M	M	M
Specimen No.	840703	840704	840701	852801	852802	990905	990906
Rock Type	pelitic	pelitic	pelitic	pelitic	pelitic	basic	basic
Major silicate minerals							
Qz	+	+	+	+	+	+	+
Pl	+	+	+	+	+	+	+
Kfs	+	+	+	-	-	-	-
Bt	+	+	+	+	+	-	-
Mus	-	-	-	-	-	-	-
Grt	-	+	-	-	-	-	-
Ep	-	+	-	-	-	-	-
Hb	-	-	-	+	-	+	+
Cm	+	-	+	-	-	-	-
Texture	L	P	L, N	L	L	G	G
Grain size (mm)							
Variation	0.1 - 2.0	0.1 - 1.0	0.2 - 0.5	0.2 - 0.8	0.1 - 1.0	0.05 - 0.5	0.05 - 0.5
Most frequent size	0.2	0.2	0.4	0.3	0.3	0.3	0.2
Locality	M	KK	KK	KB	KB	KB	KB
Specimen No.	990914	5	6	11	19	14	24
Rock Type	basic	Bt schist	Bt schist	Bt schist	Bt schist	Hb schist	Hb schist
Major silicate minerals							
Qz	+	+	+	+	+	-	+
Pl	+	+	+	+	+	+	+
Kfs	-	+	+	+	+	-	-
Bt	-	+	+	+	+	+	-
Mus	-	-	+	+	+	-	-
Grt	-	-	-	-	-	-	-
Ep	-	+	-	+	-	+	-
Hb	+	+	-	-	-	+	+
Cm	-	-	-	-	-	-	-
Texture	G	L	L	L	L	L, N	N
Grain size (mm)							
Variation	0.05 - 0.4	0.1 - 0.7	0.1 - 1.0	0.02 - 0.1	0.02 - 0.2	0.03 - 0.3	0.05 - 0.3
Most frequent size	0.2	0.2	0.2	0.03	0.1	0.07	0.1

Localities: M, Mizoguchi; KK, Katakai River basin; KB, Kurobe River basin. Minerals: Qz, quartz; Pl, plagioclase; Kfs, potash feldspar; Bt, biotite; Mus, muscovite; Grt, garnet; Ep, epidote; Hb, hornblende; Cm, cummingtonite; + and - indicates presence and absence, respectively. Textures: L, lepidoblastic, by biotite or muscovite; N, nematoblastic, by amphibole; P, porphyroblastic, by garnet; G, granoblastic.

features of the basic rocks suggest that they originated as basaltic magma.

Petrographic characteristics of individual specimens from the Mizoguchi area and the Unazuki schists (described later) are given in Table 1.

Mineral chemistry and equilibration temperature

The formation conditions of the Mizoguchi metamorphic rocks were estimated by analyzing chemical compositions of coexisting biotite and garnet in metapelite, and hornblende and plagioclase in metabasite using an electron probe micro-analyzer, JEOL JXA-733, at Okayama University, with an accelerating voltage of 15

kV and a sample current of $1.0\text{--}2.0 \times 10^{-8}$ A. Standards used were natural or synthetic oxides and silicates. Matrix corrections followed the procedures of Bence and Albee (1968) with alpha factors of Nakamura and Kushiro (1970). Representative analyses are listed in Table 2.

Garnet has a pyrope component of approximately 15 mol% in the core and 12 mol% at the rim. Biotite adjacent to the garnet has Mg/(Mg+Fe) ratios of 0.37–0.40. Hornblende belongs to the magnesio-hornblende group, according to the Leake's (1978) classification. The rims tend to be richer in Si and poorer in Ti and Al than the cores (Table 2). Plagioclase coexisting with the hornblende has a Na/(Na+Ca) ratio of 0.43–0.64.

Table 2. Representative microprobe analyses of metamorphic minerals from Mizoguchi

Specimen No.	840704	840704	840704	852805	852805	852805	840708	840708	852806	852806
Phase	Grt core	Grt rim	Bt	Grt core	Grt rim	Bt	Am core	Am rim	Am core	Am rim
SiO ₂	37.15	36.84	32.39	37.42	37.07	34.84	47.95	48.27	49.62	51.00
TiO ₂	0.06	0.04	1.85	0.04	0.01	1.51	1.07	0.96	1.10	0.88
Al ₂ O ₃	20.99	20.53	18.34	20.97	20.80	19.31	6.56	6.20	6.50	5.67
FeO*	34.19	34.46	24.80	33.69	34.70	21.99	14.32	14.11	11.33	10.81
MnO	2.23	2.83	0.26	2.76	3.15	0.12	0.38	0.36	0.33	0.34
MgO	3.78	2.97	8.85	3.71	2.92	7.67	13.62	13.61	15.72	16.10
CaO	1.25	1.54	0.20	1.46	1.41	0.05	12.15	12.31	11.92	11.85
Na ₂ O	nd	nd	0.08	nd	nd	0.09	0.97	0.94	0.75	0.61
K ₂ O	nd	nd	7.45	nd	nd	8.91	0.40	0.38	0.34	0.23
Total	99.65	99.21	94.22	100.05	100.06	94.49	97.42	97.14	97.61	97.49
Cations/O=	12.000	12.000	22.000	12.000	12.000	22.000	23.000	23.000	23.000	23.000
Si	2.993	3.001	5.120	3.002	2.996	5.404	7.073	7.131	7.165	7.326
Ti	0.004	0.002	0.220	0.002	0.001	0.176	0.119	0.107	0.119	0.095
Al	1.993	1.971	3.417	1.983	1.981	3.530	1.140	1.080	1.106	0.960
Fe	2.303	2.347	3.278	2.260	2.345	2.852	1.767	1.743	1.368	1.299
Mn	0.152	0.195	0.035	0.188	0.216	0.016	0.047	0.045	0.040	0.041
Mg	0.454	0.361	2.085	0.444	0.352	1.773	2.995	2.997	3.384	3.448
Ca	0.108	0.134	0.034	0.125	0.122	0.008	1.920	1.949	1.844	1.824
Na	nd	nd	0.025	nd	nd	0.027	0.277	0.269	0.210	0.170
K	nd	nd	1.502	nd	nd	1.763	0.075	0.072	0.063	0.042
Total	8.007	8.011	15.715	8.004	8.013	15.550	15.414	15.393	15.299	15.205
Ab	nd	nd	nd	0.58	0.58	0.58	0.60	0.60	0.60	0.60

*total iron as FeO; nd, not determined; Grt, garnet; Bt, biotite; Am, amphibole; Ab, Na/(Na+Ca) of coexisting plagioclase.

Equilibration temperatures of minerals were estimated using the geothermometers of Dasgupta et al. (1991) and Holland and Blundy (1994), for pressures ranging from 0.4 to 0.7 GPa, the possible values of pressure during the Hida and Oki metamorphism (Suzuki et al., 1989; Sawada et al., 2000). The results give temperatures of 550–660°C (ca. 610°C on average) between garnet (rim) and biotite, and 570–750°C (ca. 680°C on average) between hornblende (rim) and plagioclase. The faint compositional zoning of garnet and hornblende makes the estimated temperatures higher to some extent at the cores than the rims, suggesting the peak conditions of metamorphism correspond to the amphibolite or granulite facies as seen in the Hida terrane (Hiroi, 1983; Suzuki et al., 1989).

Whole-rock chemistry

Chemical compositions of eight metamorphic rocks from the Mizoguchi area were analyzed at Activation Laboratories Ltd., Canada, using ICP-OES for major elements and Sc, and ICP-MS for other elements. Results are listed in Table 3 and compared with the published data of equivalent rocks from the Hida terrane in Figures 2, 3 and 4. Chemical analyses of biotite

gneisses and intercalated hornblende gneisses from the Hida gneiss region are available from the literature (Naito, 1993; Jin and Ishiwatari, 1997; Arakawa et al., 2000). In contrast very few chemical data of Unazuki schists have been published. Although Hiroi (1984) has analyzed a number of ferruginous pelitic rocks of laterite origin, they are unsuitable for comparison in this study because of their unusual compositions. A comparison between rocks of similar lithology is more meaningful, and we, therefore, collected several specimens of biotite- and hornblende-schists from the Kurobe and Katakai River basins where alternating basic, pelitic, psammitic and quartzo-feldspathic schists are exposed (Fig. 1c; Hiroi, 1978; Suwa, 1979). The geochemical data of the Unazuki schists we collected are listed in Table 4. Their petrographic characteristics (Table 1) are consistent with the descriptions by Hiroi (1978) and Suwa (1979). Besides the specimens in Tables 1 and 4 there are also schists composed of alternating basic and pelitic laminae 1–2 mm thick, but we do not consider them here because of their inhomogeneity.

Figure 2 shows that metapelite and metabasite from the Mizoguchi area are similar in major element compositions to biotite-schist or -gneiss and hornblende-schist

Table 3. Chemical compositions of metamorphic rocks from Mizoguchi

Specimen No.	840703	840704	840701	852801	852802	990905	990906	990914
Rock Type	pelitic	pelitic	pelitic	pelitic	pelitic	basic	basic	basic
SiO ₂ (wt.%)	58.87	57.80	60.06	59.36	62.99	51.36	51.71	50.65
TiO ₂	1.13	1.09	1.16	1.15	0.93	1.26	1.06	1.08
Al ₂ O ₃	16.86	18.25	15.74	16.86	16.30	16.90	16.91	16.88
FeO*	8.72	7.53	9.09	8.05	5.77	9.11	9.92	10.93
MnO	0.17	0.24	0.20	0.15	0.08	0.22	0.24	0.26
MgO	2.48	1.91	3.29	2.44	2.06	5.65	4.98	5.10
CaO	4.32	4.49	4.75	4.52	4.14	7.98	7.36	7.27
Na ₂ O	3.73	3.61	3.61	3.56	3.46	3.80	3.55	3.69
K ₂ O	2.05	2.91	0.51	1.90	1.88	0.69	0.64	0.85
P ₂ O ₅	0.20	0.69	0.22	0.20	0.18	0.16	0.11	0.11
LOI	0.95	1.27	0.96	1.08	1.90	1.02	0.94	0.90
Total	99.48	99.79	99.59	100.16	100.32	99.14	98.52	98.94
Sc (ppm)	32	25	29	27	23	35	44	44
V	135	90	217	141	117	287	342	320
Cr	19	10	19	90	48	87	28	43
Co	16	8.4	17	15	12	25	18	18
Ni	11	<15	<15	76	<15	<15	<15	<15
Cu	27	<10	17	20	21	15	<10	<10
Zn	141	113	127	104	94	75	59	57
Rb	54	93	15	44	50	25	24	29
Sr	211	250	268	219	186	255	238	233
Y	46	60	33	39	48	30	25	24
Zr	210	182	143	193	218	92	30	26
Nb	13	10	3	4	5	2	1	<1
Ba	280	564	230	318	230	105	86	87
La	16.0	16.0	9.6	13.1	15.1	3.9	2.3	1.9
Ce	36.0	40.0	23.0	30.6	36.0	11.4	6.6	5.5
Pr	4.59	5.06	3.28	4.52	5.39	1.94	1.15	1.01
Nd	22.0	24.0	15.0	20.3	24.4	9.8	6.1	5.6
Sm	5.8	7.1	4.5	5.2	6.4	3.2	2.3	2.1
Eu	1.66	1.31	1.50	1.77	1.51	1.37	1.00	0.96
Gd	5.7	7.7	5.1	6.4	7.7	4.4	3.4	3.2
Tb	1.2	1.6	1.0	1.1	1.3	0.8	0.7	0.6
Dy	7.8	9.5	5.9	6.7	7.9	5.1	4.2	4.1
Ho	1.6	1.9	1.3	1.4	1.7	1.1	0.9	0.9
Er	5.1	5.8	3.6	4.3	5.0	3.4	2.7	2.7
Tm	0.86	0.90	0.56	0.61	0.70	0.47	0.40	0.39
Yb	5.7	5.7	3.6	4.0	4.5	3.2	2.7	2.6
Lu	0.84	0.83	0.54	0.60	0.67	0.46	0.39	0.38
Hf	5.8	4.9	3.4	5.3	6.0	2.6	1.1	1.0
Ta	0.6	0.5	0.1	0.3	0.3	0.1	<0.1	<0.1
Pb	14	16	15	13	<5	<5	15	8
Th	2.9	1.9	1.2	2.6	3.8	0.3	0.2	0.2
U	0.8	0.7	0.3	0.6	1.1	0.1	0.2	0.1
A/CNK	1.04	1.06	1.04	1.05	1.07	0.79	0.85	0.84
K/NK	0.27	0.35	0.09	0.26	0.26	0.11	0.11	0.13

*total iron as FeO; A/CNK, Al₂O₃/(CaO+Na₂O+K₂O) mole ratio; K/NK, K₂O/(Na₂O+K₂O) mole ratio.

or -gneiss from the Hida terrane, respectively. Both the metapelite from the Mizoguchi area and biotite schist from Unazuki have Al₂O₃/(CaO+Na₂O+K₂O) mole ratios of ca. 1.0 and K₂O/(Na₂O+K₂O) mol ratios of

0.1– 0.4, which correspond to the Low-K group of Hida gneisses of Jin and Ishiwatari (1997).

Despite the similarity in major elements, trace element analyses reveal some clear differences between

Figure 2. Variations of major oxides vs. SiO_2 in metamorphic rocks from Mizoguchi and the Unazuki schist zone. Hatched fields represent the compositions of hornblende- and biotite-gneisses from the Hida gneiss region (after Naito, 1993; Jin and Ishiwatari, 1997; Arakawa, 2000).

Figure 3. La-Th-Sc ratios in pelitic rocks (a) and trace element discrimination diagrams for basaltic rocks (b-d) after Pearce and Cann (1973) and Meschede (1986). UC, upper continental crust; OC, average oceanic crust; WPB, within-plate basalt; LKT, low-potassium tholeiite; CAB, calc-alkali basalt; OFB, ocean-floor basalt; WPA, within-plate alkali basalt; WPT, within-plate tholeiite; MORB, mid-ocean ridge basalt; VAB, volcanic arc basalt. Hatched fields and symbols are as in Figure 2.

the rocks of the Hida terrane and the Mizoguchi area. The trace element analyses also emphasize similarities between the Hida gneisses and Unazuki schists. In the

La-Th-Sc diagram (Fig. 3a), the Hida gneisses and Unazuki schists show correspondence to the average composition of upper continental crust, whereas the

Figure 4. Concentration patterns of REE in pelitic rocks (a) and basic rocks (b) normalized with the values of C1 chondrite (Sun and McDonough, 1989). Hatched fields and symbols are as in Figure 2.

Mizoguchi metapelites are relatively rich in Sc, suggesting the addition of oceanic crustal components to upper continental materials (Taylor and McLennan, 1985). In ternary discrimination diagrams for basaltic rocks (Figs. 3b–d), metabasites from the Mizoguchi area plot in the fields of arc tholeiites or mid ocean ridge basalts (MORBs), unlike the Hida schists and gneisses which plot in the fields of calc-alkaline basalts.

The concentration patterns of REE make the distinction more clear between the Mizoguchi and Hida metamorphic rocks. Compared to the Hida biotite-schist or -gneiss, the Mizoguchi metapelite is enriched in heavy REEs and depleted in light REEs, showing gently inclined patterns (Fig. 4a), similar to those of fore-arc turbidites (McLennan, 1989). However, two specimens of the Unazuki biotite schist (nos. 5 and 6), which were collected at outcrops of Kitamatadani, a mountain stream in the Katakai River basin, are not so rich in light REEs as the other Hida biotite-schists and -gneisses. Because the outcrops are in the area of alternating biotite- and hornblende-schist (see the route map by Suwa, 1979), it is possible that the chemical compositions of the biotite schists show the effect of mechanical mixing of basic rocks during sedimentation.

The Mizoguchi metabasites are relatively depleted in light REEs contrary to the Hida hornblende-schists and -gneisses exhibiting light REE enrichment patterns (Fig. 4b). The type of REE pattern shown by the

Mizoguchi metabasites is typical for N-MORBs or fore-arc tholeiites (Sun and McDonough, 1989; Hickey and Frey, 1982; Tatsumi, 1995). Furthermore, because the Mizoguchi metabasites are much richer in LIL elements than N-MORBs (Fig. 5), it is suggested that they originated in an island arc environment (Pearce, 1983).

Based on the above geochemical characterization, we consider the Mizoguchi metamorphic rocks originally formed in the fore-arc region of an immature, oceanic island arc.

Discussion

The Unazuki biotite schists and hornblende schists analyzed in this study have almost the same compositions as the Hida biotite gneisses and hornblende gneisses, respectively. They are much more widely distributed in the Unazuki schist zone than the lateritic schists (Hiroi, 1978; Suwa, 1979); in other words, the extremely aluminous rocks appear to be unusual even in this zone, though they are important as hosts to minerals that can be used to characterize the P-T conditions of regional metamorphism. It follows that the Unazuki schist zone and Hida gneiss region are essentially identical in their principal chemical characteristics. These data are in accord with the idea proposed by several workers that the tectonic setting was the same throughout the Hida terrane. The general consensus is that the Hida terrane formed in a rift zone at a continental margin, marginal sea or continental island arc on the basis of the predominance of calcareous sediments and the bimodal compositions of volcanic rocks (Sohma et al., 1990; Naito, 1993; Komatsu et al., 1993; Arakawa et al., 2000).

In contrast, the rocks of the Mizoguchi area are clearly distinct from the Hida terrane both in the chemical characteristics of pelitic and basic rocks as well as the absence of metamorphosed laterite, limestone and acid volcanic rock. As mentioned above, the Mizoguchi metamorphic rocks exhibit geochemical characteristics suggesting they formed in the fore-arc region of an oceanic island arc. This tectonic setting is clearly different from that of the Hida terrane, and therefore, we consider that the Mizoguchi area and Hida terrane are geologically discontinuous.

Our conclusion is in contrast to the earlier work of Ishiga et al. (1989) who regarded the Mizoguchi metamorphic rocks as the exposures of a western continuation of the Hida terrane based on similarities in mineralogy, metamorphic temperature conditions and radiometric ages. In fact, however, even these features are not entirely compatible between the two regions. The Mizoguchi metamorphics are comparable to the

Table 4. Chemical compositions of biotite- and hornblende-schists from the Unazuki schist zone

Specimen No.	5	6	11	19	14	24
Rock Type	Bt schist	Bt schist	Bt schist	Bt schist	Hb schist	Hb schist
SiO ₂ (wt.%)	56.86	65.16	68.82	59.44	46.97	55.47
TiO ₂	1.00	0.70	0.58	0.93	1.37	0.87
Al ₂ O ₃	17.50	16.73	14.9	16.41	18.93	17.91
FeO*	7.65	3.85	2.83	5.70	9.85	6.06
MnO	0.25	0.07	0.07	0.13	0.15	0.14
MgO	2.89	1.58	1.13	1.75	6.05	3.96
CaO	5.16	3.73	2.65	3.82	5.34	6.87
Na ₂ O	3.77	4.12	3.34	3.61	3.65	3.77
K ₂ O	2.18	1.82	2.84	4.03	3.29	1.37
P ₂ O ₅	0.35	0.15	0.15	0.22	0.40	0.25
LOI	1.82	1.26	1.25	2.07	1.56	1.43
Total	99.43	99.17	98.56	98.11	97.55	98.10
Sc (ppm)	17	13	8	14	26	19
V	193	86	44	130	259	193
Cr	41	57	73	91	53	46
Co	19	9	3	15	30	17
Ni	22	<15	<15	<15	29	15
Cu	18	19	<10	33	31	12
Zn	143	32	<30	98	101	39
Rb	76	66	68	113	93	34
Sr	641	394	542	366	846	809
Y	21	27	35	29	31	17
Zr	120	163	350	235	146	94
Nb	6	6	14	11	6	5
Ba	950	509	471	500	465	487
La	17.5	18.8	38.3	27.9	20.3	20.2
Ce	37.0	39.0	79.3	59.4	45.7	37.6
Pr	4.93	5.03	9.81	7.26	6.21	4.83
Nd	20.2	20.0	36.3	28.1	26.6	18.9
Sm	4.4	4.3	6.9	5.7	5.8	3.8
Eu	1.46	1.37	1.66	1.57	1.98	1.30
Gd	4.4	4.5	6.7	5.6	6.2	3.8
Tb	0.7	0.7	1.0	0.9	0.9	0.5
Dy	3.7	4.4	5.7	4.8	5.3	3.0
Ho	0.7	0.9	1.2	1.0	1.1	0.6
Er	2.0	2.9	3.6	3.0	3.0	1.7
Tm	0.28	0.42	0.55	0.42	0.42	0.24
Yb	1.8	2.8	3.7	2.9	2.9	1.6
Lu	0.28	0.44	0.58	0.43	0.42	0.24
Hf	3.1	4.4	8.7	6.0	3.8	2.5
Ta	0.3	0.4	0.9	0.6	0.3	0.3
Pb	52	29	5	27	15	<5
Th	2.8	4.5	11.1	7.1	2.7	3.9
U	0.9	1.7	4.3	2.5	0.8	1.3
A/CNK	0.98	1.08	1.11	0.95	0.98	0.89
K/NK	0.28	0.23	0.36	0.42	0.37	0.19

*total iron as FeO; A/CNK, Al₂O₃/(CaO+Na₂O+K₂O) mole ratio; K/NK, K₂O/(Na₂O+K₂O) mole ratio.

Unazuki schists rather than Hida gneisses with respect to grain size, but show higher equilibration temperatures and lack mineral associations indicative of medium P/T type metamorphism (see Hiroi, 1978, 1983). Ishiga et

al. (1989) obtained a radiometric age of ca. 185 Ma for a sample of Mizoguchi metabasite using the Rb-Sr whole rock-mineral isochron method, whereas the regional metamorphism of the Hida terrane took place

Figure 5. Concentration patterns of trace elements in metamorphic rocks from Mizoguchi and the Unazuki schist zone normalized with the values of N-type MORB (Sun and McDonough, 1989). Symbols are as in Figure 2.

at 230–250 Ma or earlier (e.g., Hiroi, 1978; Suzuki et al., 1989). The age of the Mizoguchi metabasite corresponds to the timing of intrusion of Funatsu granites, which caused the contact metamorphism of surrounding rocks in the Hida terrane (Shibata et al., 1970; Suzuki et al., 1989; Ota and Itaya, 1989; Sohma et al., 1990). Because the Mizoguchi metamorphic rocks occur in close association with Jurassic granitoids (Ishiga et al., 1989; Miyamoto et al., 2000), it is possible that the age of 185 Ma indicates the timing of contact metamorphism by the granitoids. Unlike the Unazuki schists adjacent to the Funatsu granites, however, the Mizoguchi metamorphic rocks do not show evidence for polymetamorphism. Retrograde products formed after the peak amphibolite facies metamorphism are observed in the Mizoguchi metamorphic rocks; however, they are only of local importance and the secondary overprint was low-grade. We, therefore, consider this event to have had no significant effect on the age determination using the Rb–Sr internal isochron method. It is debatable whether the age indicates the timing of regional metamorphism or contact metamorphism, but in any case there is no evidence for regional, medium- or high-P/T metamorphism before the Jurassic in the Mizoguchi area.

Oki-Dogo has long been widely accepted as the western continuation of the Hida terrane because of the similarities in the grade and age of metamorphic rocks (Ohta, 1963; Shibata and Nozawa, 1966; Hayase and Ishizaka, 1967; Hoshino, 1979; Kobayashi et al., 1980; Suzuki and Adachi, 1994; Yamashita and Yanagi, 1994; Dallmeyer and Takasu, 1998; Sawada et al., 2000). On the other hand, since Komatsu et al. (1985) suggested the Hida terrane is a nappe thrust over the Paleozoic accretionary complexes of Southwest Japan, several workers have distinguished the Oki metamorphic complex from the Hida terrane, based on paleogeographical

considerations and differences in whole-rock compositions between the Oki and Hida gneisses (Sohma et al., 1990; Isozaki and Maruyama, 1991; Sohma and Kunugiza, 1993; Jin and Ishiwatari, 1997; Arakawa et al., 2001). Indeed, the rarity of calcareous rocks in Oki-Dogo suggests a provenance distinct from the Hida terrane, but we should examine the degree of redistribution of elements when we compare the compositions of common types of rocks, because migmatization has significantly affected the Oki metamorphic complex (Kobayashi et al., 1980). In addition, according to Arakawa et al. (2001), the metabasites of the Oki-Dogo area appear to have different geochemical characteristics from those of the Mizoguchi area, but their considerable variation in chemical composition and mode of occurrence do not yet allow us to obtain conclusive evidence regarding the possible differences in their tectonic settings. Further investigation of the geochemical characteristics of the Oki-Dogo and Mizoguchi areas would help clarify their geological relationship.

Conclusions

The metamorphic rocks of the Mizoguchi area were originally formed in the fore-arc region of an oceanic island arc, in contrast to those of the Hida terrane, which show affinities with rocks from continental margins or continental island arcs. The difference in the tectonic setting of rock formation suggests the geological discontinuity between the Mizoguchi area and the Hida terrane.

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