Journal of Zhejiang University SCIENCE
ISSN 1009-3095
http://www.zju.edu.cn/jzus
E-mail: jzus@zju.edu.cn

JZUS

Petrological study of the western Iratsu mass from the Sambagawa metamorphic belt, central Shikoku, Japan*

LI Zi-long (厉子龙)†1, TAKASU Akira[2]

([1]Department of Earth Science, Zhejiang University, Hangzhou 310027, China)
([2]Department of Earth Science, Shimane University, Matsue 690, Japan)
†E-mail: zilongli@zju.edu.cn

Received Mar. 16, 2005; revision accepted May 10, 2005

Abstract: The western Iratsu mass, the largest tectonic body in the Sambagawa metamorphic belt, central Shikoku, is mainly composed of epidote amphibolite with minor amounts of eclogite. Systematically, a majority of garnets show bell-shaped chemical zoning of pyrope contents and Mg/(Mg+Fe^{2+}) monotonously increasing outward. The grossular component in zonal garnet increases outwards, maximizes at an intermediate part, and then decreases towards the outermost rim, reflecting a process from increasing to decreasing pressure conditions during the prograde metamorphism. Jadeite contents of omphacite range from 25~20 mole% within the cores to 15~10 mole% at the rims, implying a pressure-decreasing process (from 11×10^5 Pa to 8×10^5 Pa). The peak pressure-temperature (P-T) condition of 630~680 °C and ca. 15×10^5 Pa in the western Iratsu mass is much higher than that of (610±25) °C and $(10\pm1)\times10^5$ Pa of the Sambagawa oligoclase-biotite zone schists. The authors suggest a clockwise P-T-t path for the western Iratsu mass.

Key words: Petrology, P-T-t path, Western Iratsu mass, Sambagawa belt
doi:10.1631/jzus.2005.A0649 **Document code:** A **CLC number:** P58; P59

INTRODUCTION

The Sambagawa metamorphic belt in southwest Japan (Miyashiro, 1973) is a typical high-pressure metamorphic belt that recorded some important information such as tectonometamorphic evolution in subduction and exhumation processes during the late Jurassic to late Cretaceous ages. Some reports of studies on the origin and pressure-temperature (P-T) history of tectonic blocks in central Shikoku are available (Kunugiza *et al*., 1986; Banno *et al*., 1986; Takasu, 1989; Takasu *et al*., 1994; Wallis and Aoya, 2000; Aoya, 2001). The tectonic blocks include Iratsu epidote amphibolite, Tonaru epidote amphibolite, Higashiakaishi peridotite, Nikubuchi peridotite and Sebadani metagabbro masses (Takasu, 1989). The Iratsu epidote amphibolite mass was previously considered to be a single metagabbro mass. However, it can be presently subdivided into the western Iratsu mass and eastern Iratsu mass based on their different protolith and metamorphic history, and no relict structures such as igneous layering or gabbro pegmatite occurring in the western Iratsu mass (Takasu and Kohsaka, 1987).

The purposes of this paper are to present the petrography and mineral chemistry from the S-7 drilling core combined with the surface survey, to calculate P-T conditions, and to suggest a metamorphic P-T-t path of the western Iratsu mass.

GENERAL GEOLOGY OF THE SAMBAGAWA METAMORPHIC BELT

The Sambagawa metamorphic belt, exposed in the Inner Zone of southwest Japan, is bounded to the north by the Cretaceous low-pressure type Ryoke

*Project supported by the National Natural Science Foundation of China (No. 40472040) and Starting Fund of Education Ministry, China

metamorphic belt. These two belts are bounded by a major fault, the Medium Tectonic Line cutting the Sambagawa metamorphic belt and the Ryoke metamorphic belt. The Sambagawa belt southern border occurs along the southern limit of the Mikabu greenstone complex by fault contact. Metamorphic sequences of the Sambagawa belt range from pumpellyite-actinolite facies to epidote amphibolite facies, and locally up to the eclogite facies. Higher-grade tectonic blocks occur locally in the Sambagawa higher-grade metamorphic zones in the central Shikoku. Sambagawa metamorphic belt can be divided into chlorite, garnet and biotite zones of lower to higher metamorphic grade. Geochronological data on the Sambagawa metamorphic belt show that the protolith of the Sambagawa schists accumulated later than the latest Jurassic (130~140 Ma). The age of the metamorphic peak ranges from 90 to 100 Ma (Takasu and Dallmeyer, 1990).

SAMPLES AND PETROGRAPHY OF THE WESTERN IRATSU MASS

Samples

Most samples petrographically studied were from the S-7 drilling core located to the south of Komata, and some 97033001-97033018 samples close to the S-7 drilling site were collected with the eclogite samples being from the central and eastern parts of the western Iratsu mass. The S-7 drilling core samples were composed mainly of amphibolite, clinopyroxenite and peridotite. The amphibolites as main phase consisted mainly of clinopyroxene amphibolite and (garnet) epidote amphibolite with minor biotite amphibolite and hornblendite. Field survey showed that the eclogites usually occur as lens enclosed by the garnet epidote amphibolite in the western Iratsu mass.

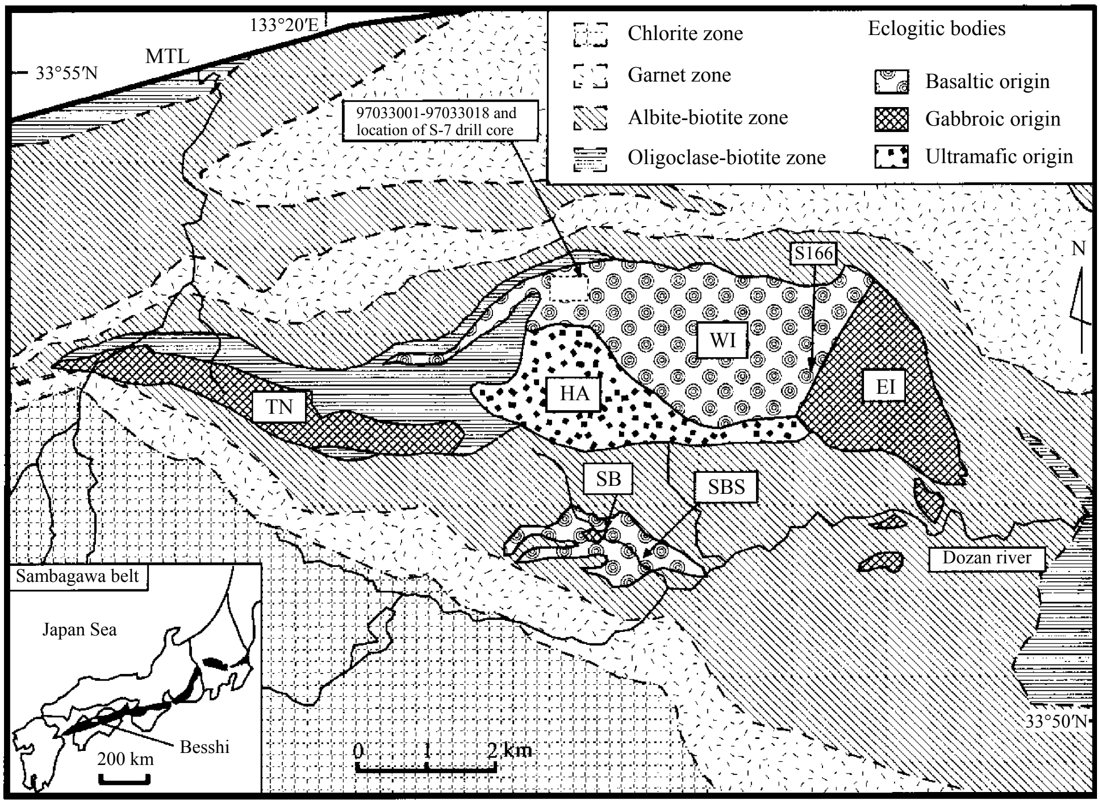


Fig.1 Geological map of tectonic blocks and location of samples in the Central Shikoku, Japan, simply modified from the geological map (Aoya, 2001). Eclogite-bearing bodies: WI=Western Iratsu mass; EI=Eastern Iratsu mass; TN=Tonaru metagabbro mass; HA=Higashi-akaishi peridotite mass; SB=Sebadani metagabbro mass; SBS=Seba basic schist; and MTL=Medium Tectonic Line. 97033001-97033018=sample numbers in order from the field (19 samples) and location of the drilling core=sample location of the S-7 drilling core (total of 227 samples)

Petrographical description

1. Garnet epidote amphibolite

The garnet epidote amphibolite consisted mainly of amphibole, garnet and epidote with small amounts of muscovite, chlorite, rutile, paragonite, albite and Fe-Ti oxides. The pale-green to bluish green amphibole had inclusions of opaque minerals, quartz, epidote and rutile. The garnets appeared to be porphyroblastic with locally developed asymmetric shadow. Phengite zoning by the sample 769 was observed by an electron probe microanalyzer, with this zonal phengite coexisting with bluish green amphibole, garnet, quartz and plagioclase.

2. Eclogite

The eclogite consisted mainly of garnet, omphacite, amphibole and epidote with minor amount of quartz, albite, white mica and showing porphyroblastic or grano-lepidoblastic texture. Most garnet grains were euhedral to subhedral porphyroblasts with inclusions of omphacite, amphiboles, epidote, quartz, rutile and opaque minerals. Omphacite coexisted with garnet, rarely as inclusions in garnet (Fig.2a). The symplectite aggregate of amphibole, albite and epidote is regarded as retrograde products of reaction between omphacite and garnet.

3. Eclogitic amphibolite

The eclogitic amphibolite consisted mainly of amphibole, epidote, garnet, quartz and plagioclase with minor amounts of muscovite (containing phengite), opaque minerals, rutile, titanite (Fig.2b) showing schistosity and porphyroblastic texture. Garnet, containing inclusion of omphacite, directly contacts symplectite aggregates of clinopyroxene, albite, epidote and amphibole. Amphibole occurs in matrix or as symplectite aggregate with albite between garnet and omphacite crystals.

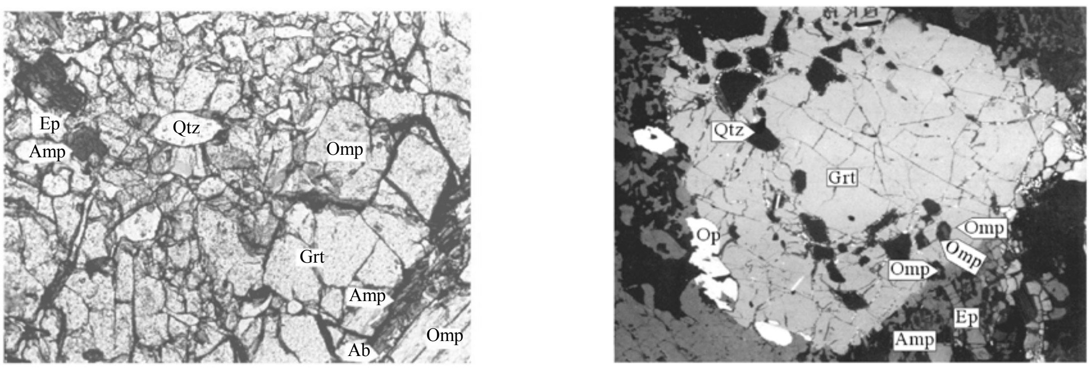
4. Clinopyroxene amphibolite

The clinopyroxene amphibolite is mainly composed of clinopyroxene and amphibole with minor amounts of epidote, chlorite, white mica, plagioclase and quartz with granoblastic texture. Plagioclase grains contain some inclusions of clinopyroxene, amphibole and apatite.

MINERAL CHEMISTRY

Mineral compositions of major elements were analyzed using an electron probe microanalyzer (JEOL 8800M) at the Research Center for Coastal Lagoon Environments, Shimane University, Japan. Analytical conditions include accelerating voltage of 15 kV, beam current of 2.5×10^{-8} A, and beam diameter of 5 μm.

Garnets in the garnet epidote amphibolite, eclogitic amphibolite and eclogite from the western Iratsu mass have much higher Mg and lower Mn in Mn-Mg-Fe triangles than those from the Sambagawa schists. These garnets belong to that of a C-type eclogite (Coleman *et al.*, 1965), a blueshist facies type eclogite. Most garnet grains from the western Iratsu mass have normal zoning and show bell-shaped patern



(a) (b)

Fig.2 Photomicrography of the western Iratsu metamorphic rocks. (a) Garnet having inclusions of barroisite, epidote, quartz and omphacite with symplectite aggregate of amphibole and albite surrounding garnet and omphacite in the lower right. Eclogite. Sample No. S166. Ordinary polars; and (b) symplectite composite of amphibole and albite enclosed omphacite and garnet in the eclogitic amphibolite. Sample No. 778. Ordinary polars. Length of field of view=2 mm in (a), and =1 mm in (b)

of Mn content and increasing Mg contents from core to rim. Pyrope, grossular and spessartine components in the zonal garnet from the eclogite samples varied from 12 to 22, 24 to 27 and 11 to 2 mole% from the cores to the rims, respectively. These values were similar to those of 11 to 18, 80 to 81, 8 to 1.4 mole% from the eclogitic amphibolite and 9 to 33 mole%, 69 to 78 mole% and 17 to 1 mole% from the garnet epidote amphibolite, respectively (Table 1). Elemental mapping of zonal garnet as inclusion in amphibole crystal shows existence of Ca content increasing from the core, reaching peak in the transitional zone, and then decreasing towards the rim.

Lots of clinopyroxenes are diopside and some

Table 1 Representative compositions of garnet, clinopyroxene, amphibole and phengite in the western Iratsu mass metamorphic rocks

	Metamorphic minerals													
	Garnet						Pyroxene				Amphibole		Phengite	
Rock types*	1		2		3		4		2	3	1	2	1	
Sample No.	775	775	S166	S166	778	778	566	566	S166	778	758	S166	769	769
Point No.	6′	8′	44	48	4′	5′	3′	4′	34	1′	15″	50	22	23
Position	Core	Rim	Core	Rim	Core	Rim	Core	Rim					Core	Rim
SiO_2 (wt%)	37.04	38.07	38.06	38.15	37.81	38.38	54.09	53.82	55.82	56.23	52.09	46.56	47.90	45.36
TiO_2	0.14	0.06	0.22	0.02	0.14	0.05	0.01	0.04	0.05	0.03	0.11	0.47	0.46	0.24
Al_2O_3	19.91	20.75	20.80	21.28	19.87	20.55	5.10	2.48	9.93	9.87	4.38	13.89	27.75	29.86
FeO_T	26.54	27.79	24.50	27.48	29.20	29.23	5.66	6.16	6.15	7.38	10.24	13.18	3.43	3.63
MnO	5.69	0.29	4.31	0.77	2.82	0.48	0.14	0.15	0.03	0.00	0.11	0.12	0.00	0.00
MgO	1.64	4.89	3.23	4.37	2.13	3.58	11.86	13.20	7.91	6.95	16.16	11.01	2.65	2.07
CaO	8.75	7.89	9.60	8.75	7.20	7.92	19.72	22.16	13.26	12.11	12.04	8.39	0.01	0.01
Na_2O							3.61	2.17	6.96	7.46	1.21	4.48	0.79	0.86
K_2O							0.03	0.03	0.05	0.04	0.11	0.35	10.97	10.75
Total	99.71	99.74	100.72	100.82	99.17	100.19	100.49	100.18	100.16	100.07	96.45	98.45	93.96	92.78
	$O=12$						$O=6$				$O=23$		$O=22$	
Si	3.00	3.00	3.00	2.98	3.05	3.03	1.97	1.98	2.00	2.02	7.52	6.67	6.58	6.33
Al^{IV}	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.02	0.00	0.00	0.48	1.33	1.42	1.67
Al^{VI}	1.90	1.93	1.93	1.96	1.89	1.91	0.19	0.09	0.42	0.42	0.26	1.00	3.07	3.24
Ti	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.05	0.03
Fe^{3+}	1.80	1.83	1.61	1.80	1.97	1.93	0.05	0.06	0.06	0.06	0.12	0.35	0.00	0.00
Fe^{2+}	1.71	1.78	1.56	1.73	1.97	1.92	0.13	0.12	0.13	0.17	1.12	1.23	0.35	0.38
Mn	0.39	0.02	0.29	0.05	0.19	0.03	0.00	0.01	0.00	0.00	0.01	0.02	0.00	0.00
Mg	0.20	0.58	0.38	0.51	0.26	0.42	0.64	0.73	0.42	0.37	3.48	2.35	0.54	0.43
Ca	0.76	0.67	0.81	0.73	0.62	0.67	0.77	0.87	0.51	0.47	1.86	1.29	0.00	0.00
Na							0.26	0.16	0.48	0.52	0.34	1.24	0.21	0.23
K							0.00	0.00	0.00	0.00	0.02	0.06	1.92	1.91
Total	9.76	9.81	9.59	9.76	9.97	9.93	4.04	4.03	4.03	4.03	15.22	15.59	14.15	14.22
Sps	24.90	22.00	26.70	24.30	20.50	22.00								
Prp	12.80	0.60	9.50	1.70	6.30	1.10								
Gross	6.50	18.90	12.50	16.90	8.40	13.90								
Alm	55.90	58.50	51.40	57.20	64.80	63.00								
Jd							17.00	7.00	43.00	47.00				
Acm							8.00	8.00	6.00	5.00				
Aug							75.00	85.00	52.00	48.00				
(Si/2)−3													0.29	0.16
Na/(Na+K)													0.10	0.11

*Rock types: 1: garnet epidote amphibolite; 2: eclogite; 3: eclogitic amphibolite; 4: Clinopyroxene amphibolite. FeO_T as total of FeO. Fe^{3+} estimation of garnet and amphibole is used the method (Droop, 1987). The equation F=46(1−13/$Ø$) is obtained for amphibole, where F is Fe^{3+} value, $Ø$ is the total cation number and the ideal total cation number=13 was adopted, exclusive Na, K and Ca (O=23) pale-green clinopyroxenes in the clinopyroxene amphibolite are augite with jadeite content changing from 25~20 mole% within the cores to 15~10 mole% at the rims and decreasing Al and Na components from core to rim. Omphacites in the eclogitic amphibolite and eclogite have jadeite contents ranging from 42~50 mole%.

Phengite in the garnet epidote amphibolite is enriched in FeO (up to 3.6 wt%) and MgO (2.7~3.6 wt%), being much higher than those of muscovite in the Sambagawa pelitic schists (Enami, 1983). The zonal phengite in the garnet epidote amphibolite shows that Si^{4+}, Mg^{2+} and Na^{+} contents decrease from 6.7 to 6.3, 0.58 to 0.43 and 0.17 to 0.02, and that Al (total) and Fe^{2+} contents increase from 4.4 to 4.9 and 0.35 to 0.39 from core to rim, respectively.

ESTIMATE OF P-T CONDITIONS IN THE WESTERN IRATSU MASS

Pre-peak pressure condition

The prograde P-T conditions were obtained from the mineral assemblage, which had omphacite, amphibole, epidote, quartz and albite enclosed within the cores of garnet porphyroblasts in the eclogite and eclogitic amphibolite. Pairs of amphiboles (as inclusion within the core portion of garnet) and core-portion garnet (sample S166) yielded ca. (560±30) °C by the garnet-amphibole pair thermometer (Ravna, 2000). The temperature values obtained from the method of Graham and Powell (1984) were 20~50 °C higher than the above data. Normal zonal pattern of garnets also significantly indicated that garnet grains were subjected to prograde process from the epidote amphibolite facies to the eclogite facies.

Eclogite facies conditions

Eclogite facies conditions were evaluated from matrix omphacite coexisting with the rim of garnets in the eclogite and eclogitic amphibolite. Temperature values of ca. 630~680 °C and pressure values of 13×10^5~15×10^5 Pa were obtained based on the omphacite (enclosed in the intermediate part of the garnet) and garnet pair thermometers (Krogh, 1988; Pattison and Newton, 1989; Ravna, 2000) and jadeite content of $Jd_{42\text{-}50}$ in omphacite. Therefore, the temperature condition ranging from 650±30 °C is suggested for the peak temperature condition of the western Iratsu mass.

Breakdown conditions

Temperature values of 540~590 °C from the garnet epidote amphibolite, eclogite and eclogitic amphibolite were obtained using amphibole-garnet pair thermometers of Krogh (1988) and Ravna (2000) based on the contact relationship between amphibole and garnet crystals in the matrix or between amphiboles and some garnets with the outermost rim part, which underwent retrograde metamorphism.

Experimental studies showed that the Si content of phengite is an indicator of the pressure-temperature conditions under which they formed (Massonne and Schreyer, 1987; McCarthy and Patinon, 1998). The chemical compositions of the zonal phengite from the garnet epidote amphibolite showed that maximum Si values ranging from 6.6 to 6.7 represent higher-pressure conditions (Velde, 1967), and that variation in Si values from 6.6 to 6.7 within the core to 6.3~6.5 at the rim reflects that phengitic crystal underwent a process of decreasing pressure.

RECONSTRUCTION OF METAMORPHIC P-T-t TRAJECTORY OF THE WESTERN IRATSU MASS

Metamorphic P-T path of the western Iratsu mass can be constructed from the data discussed above. (1) A record of lower temperature equilibrium as discerned by some amphiboles (bearing barroisite) as inclusions and epidote within core, and omphacite (stage I) as inclusion at intermediate to rim positions in zonal garnet from the eclogite and eclogitic amphibolite. (2) Most zonal patterns of garnet show normal zoning with higher $Mg/(Mg+Fe^{2+}+Mn)$ ratios, indicating prograde metamorphism at much higher P-T conditions than those of the Sambagawa prograde metamorphism (Fig.3). Grossular component increases from the core through the transitional zone, then decreases towards the rim of the garnet as inclusion in the amphibole crystal from the garnet epidote amphibolite, reflecting that garnet crystal growth underwent two sub-stages, increasing pressure to peak pressure condition earlier and then decreasing pressure to climax temperature condition later during the prograde metamorphic process. Due to similarity in mineral assemblages, mineral chemistry and P-T conditions between eclogitic amphibolite and eclogite, we suggest that both of the eclogitic amphibolite and eclogite took the prograde P-T path, although the eclogite preserves high-pressure metamorphism at ca. 15×10^5 Pa. (3) Evidence of retrograde metamorphism in the eclogitic amphibolite and eclogite can be deduced by the symplectite aggregate of amphibole and albite between garnet and omphacite, and rutile enclosed by titanite as well as retrograde mineral assemblage of amphibole+epidote+albite remained after the peak temperature metamorphism. Some garnet crystals have a thin zonal part in the outermost rim part, which reflected the effect of retrograde metamorphism underwent. Furthermore, change of jadeite content in clinopyroxene and zonal phengite can be considered as indicators of near peak metamorphic P-T field in the P-T diagram. Decreasing jadeite content from the core to the rim of omphacite in the eclogitic amphibolite reflects decreasing pressure process after the peak of pressure condition. The changes of jadeite contents of omphacite in clinopyroxene amphibolite, imply a pressure-decreasing process from 11×10^5 to 8×10^5 Pa, probably corresponding to the reaction process of jadeite+quartz→albite. Furthermore, existence of clinopyroxene with 10~25 mole% of jadeite contents might be products after the peak metamorphism due to increasing Na and decreasing Al. Zoning phengite in the garnet epidote amphibolites may undergo metamorphic process of decreasing pressure after the peak-pressure metamorphism judging from the variation of Si content in the zoning of phengite.

We suggest a P-T-t path for the western Iratsu mass (Fig.3) that shows prograde metamorphism evolved from epidote amphibolite facies to eclogite facies in early stage and underwent rapidly increasing pressure during the subduction process of the protolith of the western Iratsu mass in 100~140 Ma (Takasu *et al*., 1994). The P-T-t path arrived at the peak of the pressure metamorphism, and then underwent a decreasing pressure process to peak temperature metamorphism in ≥100 Ma. Subsequently, late stage retrograde metamorphism preceded passed ca. 11×10^5~8×10^5 Pa to epidote amphibolite facies together with the Sambagawa metamorphic schists in 85~100 Ma with the rapidly decreasing pressure process under nearly isothermal condition during the obduction process.

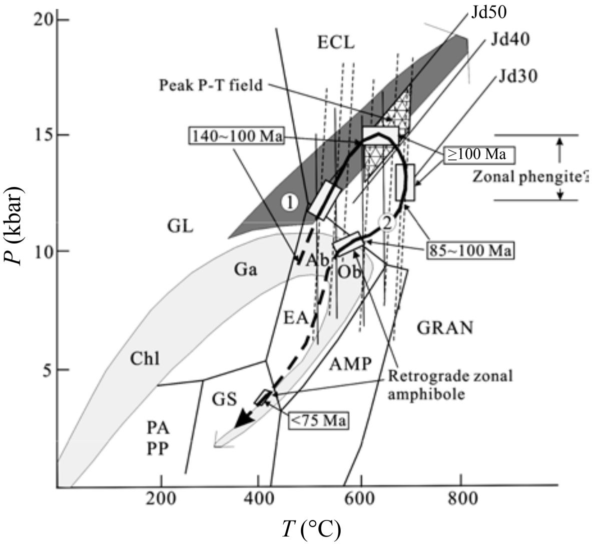


Fig.3 P-T-t path of the western Iratsu mass. The P-T path of the Sambagawa metamorphism (a lightly grayed curve from Chl, Ga, Ab to Ob) was drawn for comparison and the P-T paths of other tectonic blocks could be seen in Takasu *et al.*(1994). ①=a general proposed prograde P-T path for tectonic blocks of the Sambagawa metamorphic belt (Takasu *et al.*, 1994); and ②=a proposed P-T-t path of the western Iratsu mass. Rectangle field shows P-T condition estimated based on geothermobarometers during peak metamorphism. The solid and dashed lines represent temperature values using garnet-amphibole pairs and garnet-clinopyroxene pairs thermometers, respectively. ECL=eclogite facies; GL=glaucophane schist facies; EA=epidote amphibolite facies; AMP=amphibolite facies; GRAN=granulite facies; GS=green-schist facies; PA=pumpellyite-actinolite facies; PP=prehnite-pumpellyite facies; Chl=chlorite zone; Ga=garnet zone; Ab=albite-biotite zone; Ob=oligoclase-biotite zone; JD=jadeite contents in omphacite

ACKNOWLEDGEMENTS

We express our sincere thanks to Prof. K. Yokoyama (National Science Museum, Japan) for his kind permission to use the S-7 drilling core samples and to T. Sakurai for his provision of the eclogite samples. Li is very grateful to Dr. Roser (Shimane University) and Dr. Tunogae (University of Tsukuba) for useful comments.

References

Aoya, M., 2001. P-T-D path of eclogite from the Sambagawa belt deduced from combination of petrological and microstructural analyses. *J. Petrol.*, **42**:1225-1248.

Banno, S., Sakai, C., Higashino, T., 1986. Pressure-temperature trajectory of the Sambagawa metamorphism deduced from garnet zoning. *Lithos*, **19**:51-63.

Coleman, R.G., Lee, D.E., Beatty, L.B., 1965. Eclogites and eclogites: their differences and similarities. *Geol. Soc. Am. Bull.*, **76**:483-508.

Droop, G.T.R., 1987. A general equation for estimating Fe^{3+} concentration in ferromagnesium silicates and oxides from microprobe analysis using stoichiometric criteria. *Mineralogical Magazine*, **51**:431-435.

Enami, M., 1983. Petrology of pelitic schists in the oligoclase-biotite zone of the Sambagawa metamorphic terrain, Japan: phase equilibria in the highest-grade zone of a high-pressure intermediate type of metamorphic belt, Japan. *J. Metamor. Geol.*, **1**:141-161.

Graham, C.M., Powell, R., 1984. A garnet-hornblende geothermometer: calibration, testing, and application to the Pelona schist, Southern California. *J. Metamor. Geol.*, **2**:13-31.

Krogh, E.J., 1988. The garnet-clinopyroxene Fe-Mg geothermomter—a reinterpretation of existing experimental data. *Contrib. Mineral. Petrol.*, **99**:44-48.

Kunugiza, K., Takasu, A., Banno, S., 1986. The origin and metamorphic history of the ultramafic and metagabbro bodies in the Sambagawa metamorphic belt. *Geological Society of America, Memoir*, **164**:375-385.

Massonne, H.J., Schreyer, W., 1987. Phengite geobarometry based on the limited assemblage with K-feldspar, phlogopite, and quartz. *Contributions to Mineralogy and Petrology*, **96**:212-224.

McCarthy, T.C., Patinon, D.A.E., 1998. Empirical calibration of the silica-Ca-tschermarks-anorthite (SCAn) geobarometer. *J. Metamor. Geol.*, **16**:675-686.

Miyashiro, A., 1973. Metamorphism and Metamorphic Belts. George Allen and Unwin, London.

Pattison, D.R.M., Newton, R.C., 1989. Reversed experimental calibration of the garnet-clinopyroxene Fe-Mg exchange geothermometer. *Contrib. Mineral. Petrol.*, **101**:87-103.

Ravna, E.K., 2000. Distribution of Fe^{2+} and Mg between coexisting garnet and hornblende in synthetic and natural systems: an empirical calibration of the garnet-hornblende Fe-Mg geothermometer. *Lithos*, **53** (3-4):265-277.

Takasu, A., 1989. P-T Histories of Peridotite and Amphibolite Tectonic Blocks in the Sambagawa Metamorphic Belt, Japan. *In*: Daly, J.S., Cliff, R.A., Yardley, B.W.D.(Eds.), Evolution of Metamorphic Belt. Geological Society, London, p.533-538.

Takasu, A., Dallmeyer, R.D., 1990. $^{40}Ar/^{39}Ar$ mineral age constraints for the tectonothermal evolution of the Sambagawa metamorphic belt, Central Shikoku, Japan: A cretaceous accretionary prism. *Tectonophysics*, **185**:111-139.

Takasu, A., Kohsaka, Y., 1987. Eclogites from the Iratsu epidote amphibolite mass in the Sambagawa metamorphic belt, Besshi district, Japan. *Journal of Geological Society of Japan*, **93**:517-520 (in Japanese).

Takasu A., Wallis, S.R., Banno, S., Dallmeyer, R.D., 1994. Evolution of the Sambagawa metamorphic belt, Japan. *Lithos*, **33**:119-133.

Velde, B., 1967. Si^{4+} content of natural phengites. *Contrib. Mineral. Petrol.*, **14**:250-258.

Wallis, S.R., Aoya, M., 2000. A reevaluation of eclogite facies metamorphism in SW Japan: proposal for an eclogite nappe. *Journal of Metamorphic Geology*, **18**:653-664.