

ANATEXITES OF THE LOWER CRUST IN THE SOUTHERNMOST HIDAKA METAMORPHIC BELT, HOKKAIDO, JAPAN

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Abstract: The presence of idiomorphic plagioclase with oscillatory zonal structure serves to identify partially melted portion in high grade metamorphic rocks in the Hidaka Metamorphic Belt, Hokkaido. Pelitic and mafic anatexites are characterized by such a plagioclase accompanied by interstitial quartz-pool of sub-millimeter size. The melt-derived plagioclase develops in both the mesosome and leucosome of pelitic anatexites, and frequently occurs in the quartz-pool of pelitic and mafic anatexites. The quartz-pools sometimes join together to make a veinlet in the anatexites.

The chemistry of pelitic metamorphic rocks change with increasing metamorphic grade. Fe, Mg and Ca contents increase, and K content decreases with increasing metamorphic grade. LREE contents are nearly constant in the greenschist to amphibolite zones, but they are depleted in the granulite facies. Eu content increases with increasing metamorphic grade. Concludingly, pelitic granulites of zone E have a quite different chemistry from that of the lower grade pelitic gneisses.

The bulk chemical compositions of pelitic anatexites with incipiently developed quartz-pools are very similar to those of the greenschist facies rocks. This chemical similarity is consistent with our observations that the anatexites melted *in situ*, but segregation of melts did not take place. A nebularitic pelitic anatexite is enriched in REE, as compared with pelitic gneisses, tonalites, granites and the other types of pelitic anatexites. The bulk partition coefficients between host amphibolites and their veins systematically change with the increasing of metamorphic grade, which suggests that the veins were segregated from their host amphibolites.

Key words: anatexis, mafic anatexite, pelitic anatexite, REE, zoned plagioclase, Hidaka Metamorphic Belt, Japan.

Introduction

Work Setting

Recent experimental petrology clearly indicates that deep-seated crustal rocks melt during high temperature metamorphism. However, many field petrologists are faced with many problems in identifying melt in migmatites, because the rocks have recrystallized completely after its formation. So-called migmatite structures does not guarantee the existence of melt. In this paper, we intend to describe a method of identifying the melting product (e.g. Ashworth, 1976). First, we distinguish the melting product from the other parts of migmatite in the samples by microscopic petrography. Next, the melting product is tested for chemical features.

Outline of geology and metamorphism

The Hidaka Metamorphic Belt consists of the Western Zone of metamorphosed ophiolite and the Main Zone of continental crust thrust over the former (Komatsu et al., 1983). The study area belongs to the Main Zone, which is composed of ultrabasic to acidic intrusives and greenschist to granulite facies metamorphic rocks (see Osanai et al., in this issue). A geological outline of the southernmost Hidaka Mts. area is presented in Fig. 1. Metamorphic rocks comprise pelitic to psammitic rocks and a very small amount of mafic rocks. The lower metamorphic grade portion of this area belongs to the Mesozoic Nakanogawa Group (Kontani, 1978). The rock sequence of the higher metamorphic grade portion are very similar to those of the Nakanogawa Group. Radiometric age of the metamorphic rocks ranges from 40 to 23 Ma, and those of igneous intrusives from 54 to 17 Ma. The maps of metamorphic zones and of the progressive appearance of minerals are shown in Figs. 1 and 2, respectively.

In the eastern part of the study area, the metamorphic grade increases northward, reaching the higher amphibolite facies in

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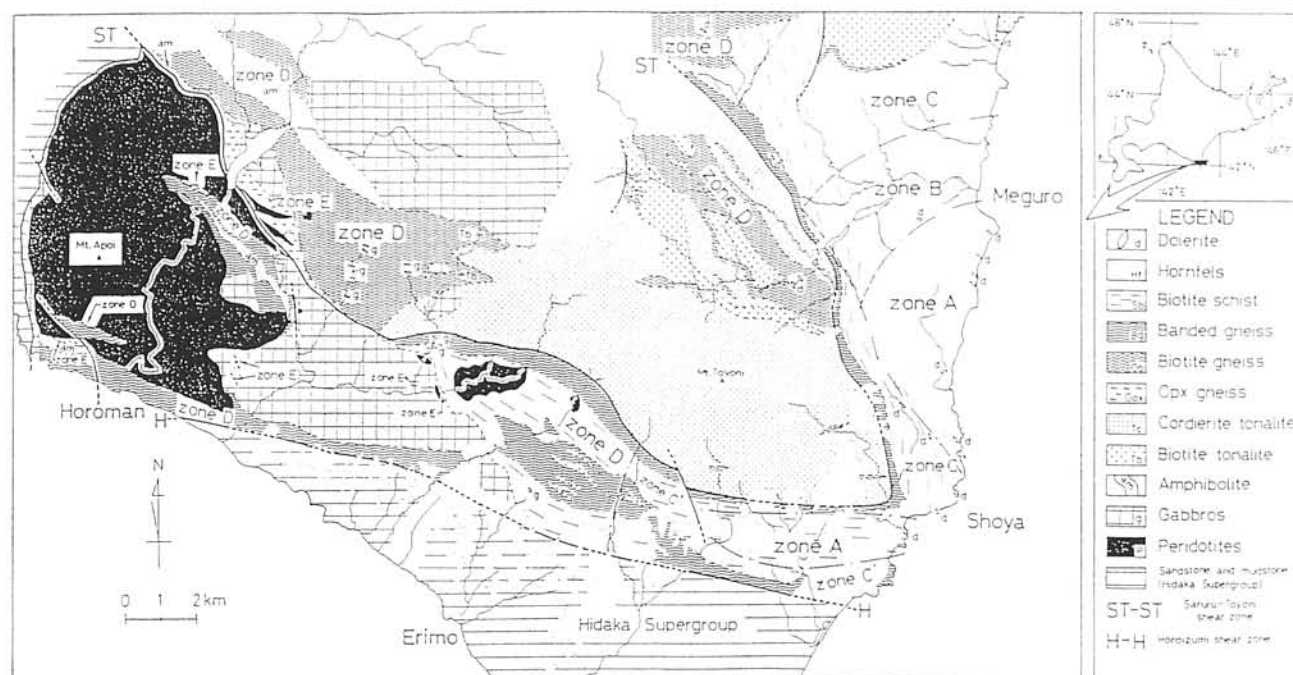


Fig. 1. Generalized geological map and metamorphic zones of the southernmost Hidaka Mts.

Zone	A	B	C	D	E
Chl					
Ms					
Bi					---
Crđ					
Gar					
Opx					
And					
Sil					---
Kfs					---
Pl					
Qz					

Fig. 2. Stability range of each mineral in pelitic metamorphic rocks.

zone D. The metamorphic rocks along the Saruru-Toyoni shear zone are strongly mylonitized by the upthrust of the Central Metamorphic and Igneous Complex (CMIC Mass), which consists of granulites, migmatites, tonalites, gabbros and peridotites, over the Nakanogawa Group. The temperature of the CMIC Mass was high enough to give thermal metamorphism to zones A, B and C at the time of upthrusting (Shiba, 1988). Lower grade metamorphic rocks of the CMIC Mass are mapped as zone D by Shiba (1988), and higher grade rocks as zone E, the granulite facies. Most of the metamorphic

rocks in the CMIC Mass are migmatitic. Metamorphic conditions are as follows: 6–6.5 Kb, 650–750 °C at the high grade part of zone D, and 6.5–7 Kb, 750–800 °C for zone E (Osanaï et al., 1986; Shiba, 1988). These metamorphic conditions are high enough for pelitic gneisses and quartz-bearing amphibolites to melt (e.g. Johannes, 1978; Vielzeuf and Holloway, 1988; Breton and Thompson, 1988).

Petrography of anatexites

Textures showing melting

Ashworth (1976), Dougan (1979) and McLellan (1983) stated that plagioclase with idiomorphic zoning would have crystallized from a melt. Plagioclases included in high grade gneisses of the study area sometimes show a rhythmic oscillatory zoning, forming into idiomorphic zonal structure and euhedral crystal, and usually have a normal zoning (core = calcic, rim = sodic). It is unlikely that these plagioclases crystallized in highly packed solid circumstances in metamorphism. A space filled by an interstitial melt is required for the crystallization of the idiomorphic plagioclase. It is not likely that a large space would be filled by a large amount of fluid under high grade metamorphic conditions, because fluids have a great compressibility. If a large amount of hydrosolution was equilibrated with the high grade metamorphic rocks, the rocks would dissolve easily, and a melt would be produced. It is most possible that an idiomorphic plagioclase with a rhythmic oscillatory zoning crystallized from a melt. Accordingly, metamorphic rocks which contain such a kind plagioclase have experienced anatexis, and the rocks be referred to as anatexites as defined by Mehnert (1968).

After anatexis, the melt crystallizes during the cooling stage, and results in a new migmatitic texture. If the melt separates from the anatexites, segregation veins develop as seen in the rocks. If the melt segregates to form a tiny melt-pool, and remains *in situ*, a recrystallized melt is observed in place of the tiny melt-pool. The metamorphic rocks of the study area contain rarely K-feldspar. In this case,

a crystallized melt-pool may be mainly composed of quartz and plagioclase. Concludingly, it is the texture of a crystallized melt that a pool composed of single crystal quartz includes oscillatory zoned idiomorphic plagioclases. This texture resembles the melting products reported by Takahashi (1986), and Vielzeuf & Holloway (1988).

Table 1. Mineral assemblages of pelitic and mafic anatexites

Rock	Mineral	Bi	Pl	Qz	Kfs	Crd	Sil	And	Gr	Hb	Cpx	Cum	Qz-pool
81621		+++	+++	+++	+	++	+	++	++				+
81622 pelitic		+++	+++	+++	+	++	+	++	++				++
81107		+++	+++	+++	+	+++	+		++				
86872		++	+++	++	+		++		++				
80802			++	+						+++	+		
81622 mafic		+	+++	++						++	+++	++	+++
81622 vein		+	++	+++						+	+	+	
86891		+	+++	++						+++		++	++
86891 vein			+++	+++						++		+	

+++; abundant, ++; common, +; rare



Fig. 3. Thin section photographs of anatexites (crossed nicols). Scale bars indicate 1 mm.

Textures indicating *in situ* melting

Pelitic anatexites

Anatexites develop on the higher-grade part of the muscovite breakdown reaction in zone D, as Breton & Thompson (1988) discuss. Pelitic anatexites are widely distributed in zone D in the CMIC Mass. Mineral assemblages of pelitic anatexites are presented in Tab. 1. Many pelitic anatexites show typical migmatite structures, but some are free from any migmatite structures and veins. However, coarse to fine-grained idiomorphic plagioclases commonly appear in all anatexites, and usually show an oscillatory zonal structure (Fig. 3). The zoning range is An = 20–40, but is differing from grain to grain in the sample. Typical zonal patterns of plagioclases are shown in Fig. 4. Such plagioclases frequently occur in quartz-pools of sub-millimeter size (Fig. 3a) and in both the mesosome and the leucosome, and sometimes have a dusty mantle which resembles the remelting texture of plagioclase reported by Tsuchiyama (1985). In the anatexites of the samples # 81621 and # 81622 (Fig. 5a), the melanosome and the veins develop poorly, and the modal amount of quartz-pools is less than 20%. These textures suggest that the pelitic anatexites melted *in situ*, but its melt was not separated from the host rock. On the other hand, the anatexites # 81107 and # 86872 which show a schlieren structure and a nebulitic structure include idiomorphic plagioclases but not any quartz-pool. In these anatexites, much melt might be produced, and segregated from the anatexite. Many gneiss ghosts still remain in the anatexites # 81107 and # 86872. There are intermediate type between the samples # 81621 and # 86872.

Mafic anatexites

Migmatized amphibolites, which are very rare in zone D, but common in zone E, also contain coarse to fine-grained idiomorphic plagioclases with oscillatory zoning, and are called mafic anatexites herein. In zone D anatexites, idiomorphic plagioclases appear only in quartz-pools and veins. In contrast to zone D anatexites, most plagioclases in zone E anatexites show oscillatory idiomorphic zoning in the host portion of the rock as well as in the veins. Typical zonal structures of plagioclases are shown in Fig. 4. Mineral assemblages of mafic anatexites are presented in Tab. 1.

The anatexites # 81622 (Fig. 3b, c) of zone D contains a quartz-pool of sub-millimeter size. The modal amount of the quartz-pool is about 20%. Some quartz-pools link together to make a veinlet, but some are still separated from each other (Fig. 5b). These petrographic textures suggest the following: Amphibolite melted *in situ*, and produced a small amount of melt, but the melt still stayed near its place of birth. The anatexites # 86891 (Fig. 3d) collected in zone E contains a few quartz-pools, and many veins. As stated before, plagioclases in either part of the host amphibolite and the leucocratic vein clearly show idiomorphic oscillatory zoning. These textures may be attributed to the segregation of the bulk melt. These petrographical observation shows that the degree of partial melting of # 86891 was larger than that of # 81622.

Chemical transformation of pelitic metamorphic rocks

The average major element composition and REE composition of metamorphics and intrusives are presented in Tab. 2. Zones A, B and C are occupied by hornfels, and zone D by pelitic gneisses. Pelitic granulites occur in zone E. These metamorphic rocks do not contain plagioclase that shows idiomorphic oscillatory zonal structure. Furthermore, based on the studies of rock type and initial ratio of Sr isotopes (Osanaï et al., this book), the original rocks of zones A, B, C, D, and E are believed to have been chemically similar to each other. REE normalized patterns are shown in Fig. 6. Figure 7 illustrates the compositional patterns normalized with the average composition of zone A & B metasediments.

The major bulk chemical compositions of pelitic metamorphic rocks change during progressive metamorphism: that is, Fe, Mg and Ca contents increase, and K content decreases with increasing metamorphic grade. Tonalites have a major element composition similar to zone D pelitic metamorphics. REE compositions of pelitic metamorphics also change systematically during the metamorphism (Fig. 6). LREE contents of metamorphics are nearly constant in zones A, B, C and D, in contrasting to their depletion in zone E pelitic granulites. Eu content increases with increasing metamorphic grade. The enrichment of Eu correlates with the plagioclase modal percent in the rocks. The REE composition of zone

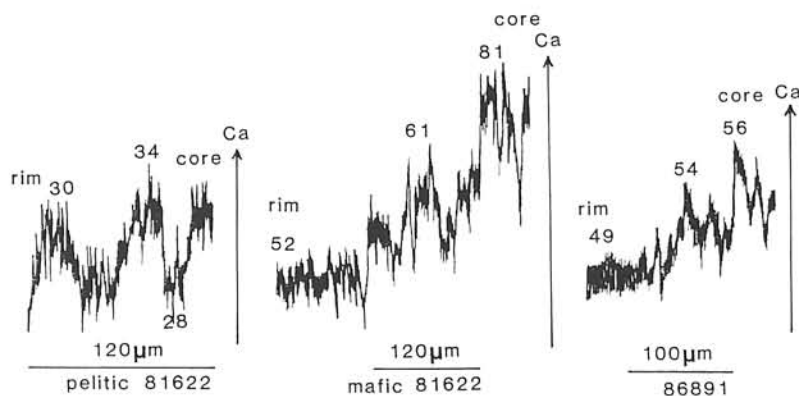


Fig. 4. Zoning profiles of plagioclases in anatexites.

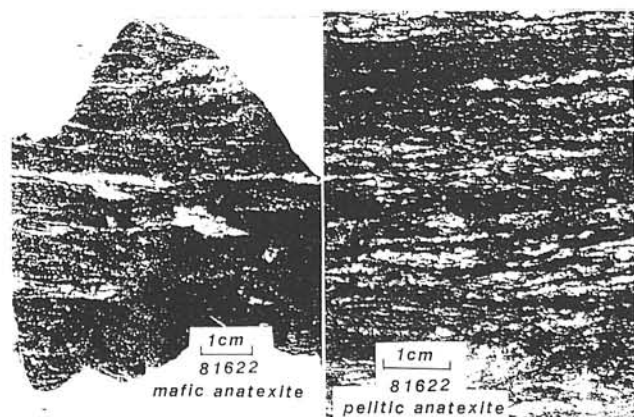


Fig. 5. Polished surface photographs of anatexites.

E metamorphics is quite different from those of lower grade metamorphics. The REE patterns of some pelitic granulites are similar to that of restite. Tonalites have a REE pattern similar to those of zone D and E' (= the lower grade part of zone E) metamorphics. Major elements and REE compositions of granites are clearly different from those of metamorphics and anatexites. In conclusion, metamorphosed sediments of the zones A, B, C, D and E' gradually change their chemical compositions during progressive metamorphism. Furthermore, the chemistry of gneisses varies drastically from zone D to zone E, which may be attributed to intense dehydration.

Chemical characteristics of anatexites

Pelitic anatexites

Tab. 3 indicates chemical compositions of pelitic anatexites. The REE patterns normalized with Leedy chondrite are

Table 2. Average major element and REE compositions of pelitic metamorphic and granitic intrusives

Zone	A&B	C	D	E'	E	Tonalite	Granite
SiO ₂	62.03	63.91±0.69	62.74±0.85	62.31±1.94	62.06±2.12	64.02±2.19	72.43
Al ₂ O ₃	17.33	16.87±0.33	16.93±1.00	16.98±0.80	16.76±0.93	16.66±0.66	14.56
Σ FeO	5.93	6.10±0.88	6.31±0.59	6.93±0.93	6.91±1.02	4.88±0.69	0.88
MgO	2.73	2.99±0.24	2.88±0.19	3.06±0.21	3.41±0.52	2.56±0.47	0.54
CaO	2.29	1.66±0.52	2.52±0.40	2.29±0.50	3.21±1.17	3.03±0.18	1.73
Na ₂ O	3.52	2.45±0.48	3.57±0.24	3.66±1.00	3.74±0.53	3.58±0.38	4.28
K ₂ O	3.21	3.44±0.54	2.69±0.25	1.93±0.68	1.15±0.79	2.37±0.29	2.89
Total (ppm)	97.04	97.42	97.64	97.16	97.24	97.10	97.31
	(1)	(3)	(5)	(10)	(5)	(4)	(1)
La	18.6±0.7	20.8	20.3±0.2	20.3±1.8	15.1±1.3	20.1	16.8
Ce	45±3	49	48±1	48±3	34±5	44	39
Nd	19.9±0.9	22.8	21.6±0.35	21.3±1.3	14.1±2.4	19.8	16.7
Sm	4.41±0.18	5.22	4.98±0.01	5.01±0.34	3.22±0.78	4.71	4.19
Eu	0.89±0.08	0.97	1.08±0.10	1.16±0.09	1.31±0.25	1.16	0.48
Gd	3.4±0.2	4.0	3.5±0.15	3.4±0.4	2.2±1.3	3.1	2.9
Dy	2.89±0.15	3.27	2.46±0.09	2.33±0.31	1.90±1.72	1.95	1.92
Er	1.52±0.18	1.59	1.12±0.05	1.06±0.04	1.39±1.08	0.95	0.76
Yb	1.06±0.20	1.09	0.65±0.05	0.52±0.07	1.35±1.44	0.46	0.46
Lu	0.07±0.03	0.09	0.05±0.01	0.03±0.01	0.18±0.22	0.00	0.02
Y	13.6±1.4	15.6	9.3±0.5	8.4±0.3	9.3±5.8	7.5	7.4
	(3)	(1)	(3)	(3)	(4)	(1)	(1)

(n): data numbers

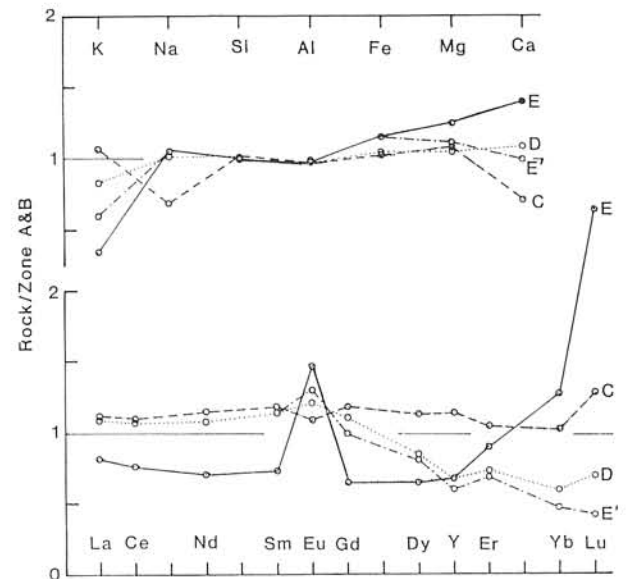
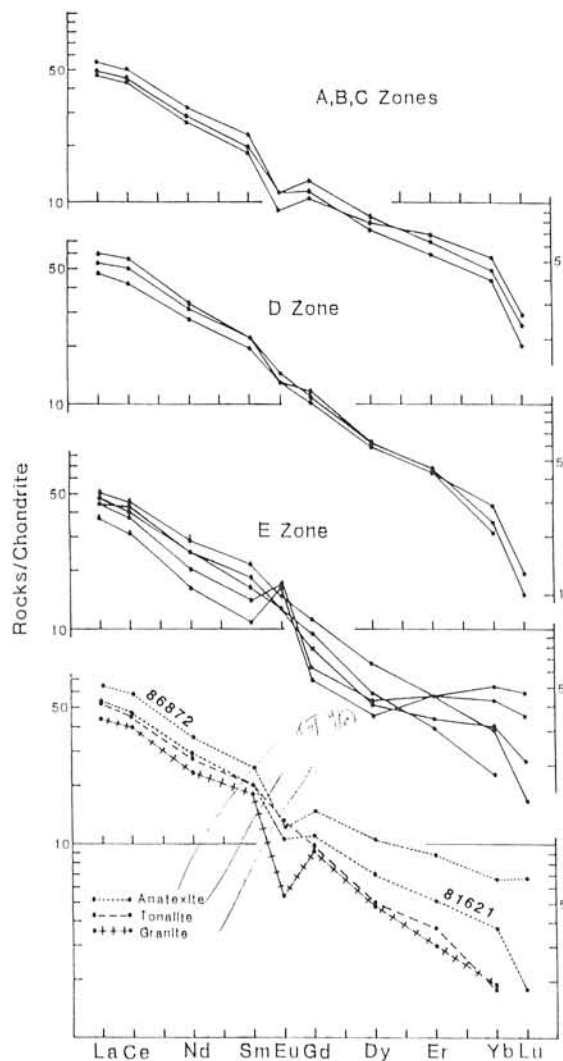
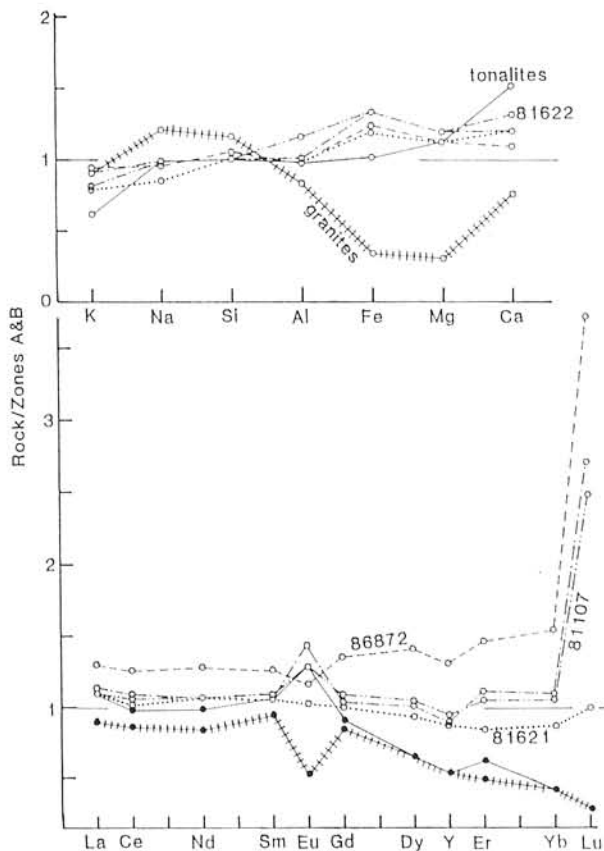
**Fig. 7.** Chemical transformation of pelitic metamorphics during progressive metamorphism.**Fig. 6.** REE normalized patterns of pelitic metamorphics, pelitic anateixites and intrusives.

Table 3. Chemical compositions of pelitic and mafic anatexites

Sample	Pelitic					Mafic				
	81621	81622	81107	81107G	86872	80802	81622	81622V	86891	86891V
SiO ₂	62.86	62.88	60.67	65.49	65.48	50.78	49.88	54.23	53.28	56.94
Al ₂ O ₃	17.26	17.51	20.22	16.49	16.73	15.06	12.73	20.53	15.98	19.77
FeO total	7.15	7.91	7.79	6.80	7.29	11.05	12.77	6.11	8.75	5.52
MgO	3.08	3.25	3.18	2.81	3.05	9.29	7.22	3.42	8.52	5.13
CaO	2.77	2.99	2.75	2.97	2.48	10.06	12.34	12.07	9.64	8.79
Na ₂ O	3.03	3.46	3.47	3.49	3.39	2.30	0.82	1.25	3.01	4.20
K ₂ O	2.53	2.89	2.62	2.82	3.01	0.33	0.93	1.05	0.30	0.32
(ppm)										
La	20.4	21.1	20.4	22.0	24.3	2.1	5.3	6.1	4.3	3.8
Ce	46	49	48	49	57	7	15	14	14	10
Nd	21.2	21.1	21.4	21.7	25.5	6.5	13.3	8.9	10.0	4.8
Sm	4.63	4.67	4.77	4.82	5.59	2.96	4.45	2.56	3.76	1.80
Eu	0.92	1.28	1.14	1.07	1.04	0.95	1.23	1.66	0.86	0.90
Gd	3.4	3.5	3.7	3.9	4.6	3.9	5.5	3.0	4.4	1.9
Dy	2.73	2.89	2.98	3.98	4.10	4.52	7.28	3.48	5.42	2.25
Er	1.29	1.69	1.59	2.14	2.23	4.10	6.08	2.34	3.69	1.98
Yb	0.92	1.15	1.11	1.64	1.63	2.74	4.30	1.84	3.14	1.36
Lu	0.07	0.19	0.17	0.23	0.26	0.37	0.67	0.31	0.43	0.20
Y	11.9	12.0	12.7	17.8	17.9	24.4	38.9	17.7	28.7	11.6

81107G: ghost in 81107; V = vein; 80802: amphibolite

**Fig. 8.** Chemical characteristics of pelitic anatexites.

presented in Fig. 6. The chemical compositions of pelitic anatexites were normalized with the average composition of zones A & B metasediments, because zones A & B metamorphics is considered to be the original rocks of the anatexites (Fig. 8).

The chemical compositions of anatexites # 81621, # 81622 and # 81107 are nearly the same as those of zones A & B metasediments. This chemical similarity between the anatexites and the metasediments is consistent with the view that the anatexites melted *in situ*, but did not much segregate melt. On the other hand, a nebulitic anatexite # 86872 is enriched in REE, especially in HREE, as compared to pelitic gneisses, tonalites, granites and the other types of anatexites of this area (Fig. 8). A gneiss ghost remaining in the anatexite # 81107 is richer in HREE than the host anatexite, though its LREE content is similar to that of the host. The gneiss ghost is considered to be a restite portion in the anatexite. Based on the chemical difference between the gneiss ghost and the host anatexite, the REE composition of segregated melt is estimated as follows: LREE content of the melt is similar to that of the bulk anatexites, and the melt is poorer in HREE than the bulk anatexite. The REE composition of the estimated melt is similar to that of tonalite.

Mafic anatexites

Tab. 3 gives chemical compositions of mafic anatexites together with the compositions of their veins. The REE patterns are presented in Fig. 9. The chemical composition of a vein in a mafic anatexite was normalized with the composition of its host amphibolite (Fig. 10).

The major element compositions of the veins are andesitic (or tonalitic), but the REE contents are very different from those of tonalites (Figs. 6, 9). In comparing the non-migmatic amphibolite # 80802 with mafic anatexites (Fig. 9), the mafic anatexites are found to be richer in REE, especially in LREE. Furthermore, the veins are richer in LREE and poorer in HREE than non-migmatic amphibolite.

Fig. 10 shows the normalized REE patterns of veins in # 81622 (zone D) and # 86891 (zone E). The smooth curves of the normalized patterns, except for Eu, suggest that the veins (= melt) were segregated from their host amphibolites.

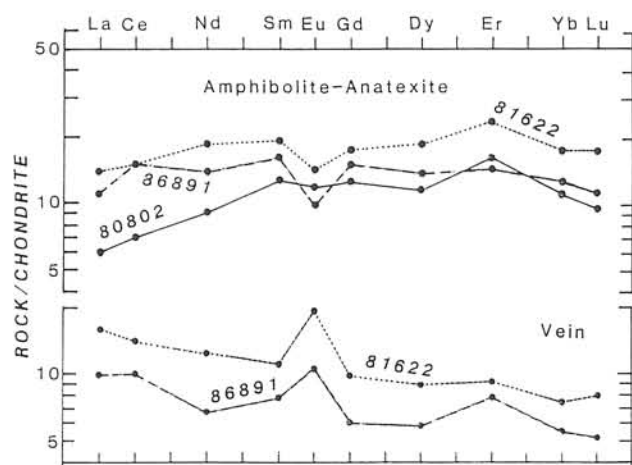


Fig. 9. REE normalized patterns of mafic anateixites and veins.

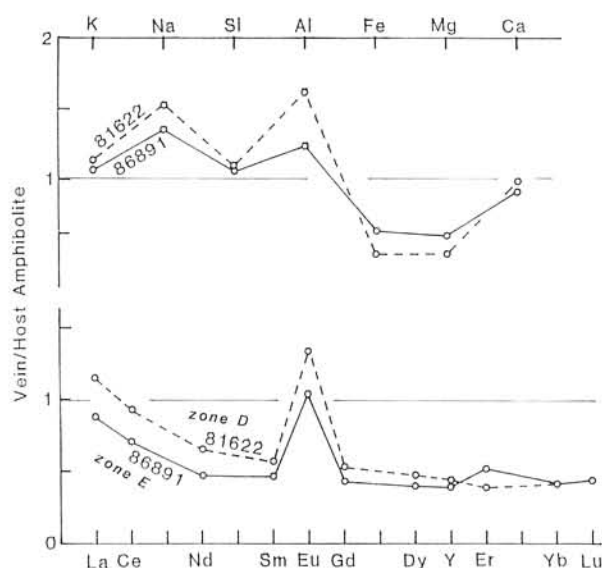


Fig. 10. Bulk partition coefficients between mafic anateixites and their veins.

An apparent partition coefficient of REE between the host amphibolite and the vein are much alike in the two samples. Furthermore, the coefficient of LREE is smaller in zone E anateixite than in zone D anateixite, which may be related to the magnitude of partial melting. In these amphibolite-systems, the increase of partial melting degree means that hornblende begins to dissolve into a melt (Naney, 1983), and it results in decreasing the LREE content of the melt (Henderson, 1984). The Eu positive anomaly of veins is related to a modal percent of plagioclase, and indicates selective melting of plagioclase and quartz in the amphibolite. The difference of Eu positive anomaly between the two anateixites corresponds to the difference in modal ratio of plagioclase and hornblende in the vein (Tab. 1), and may be due to the magnitude of partial melting. The partition

coefficients of major elements come near 1 in zone E anateixite, which is consistent with the high degree of partial melting of zone E anateixite.

Conclusion

We have presented a petrographical criterion to distinguish anateixites from the other migmatites: that is, anateixites preserve idiomorphic plagioclase with oscillatory zoning and a quartz-pool as a recrystallized melting product. By this criterion, many pelitic and mafic anateixites were confirmed in the high grade zones of the Hidaka metamorphic belt. The petrographical observations are consistent with the chemical tests.

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