

## Electron Microprobe Analyses of Rock-forming Minerals in the Sanbagawa Metamorphic Rocks from the Ayukawa-Sanbagawa Area, Kanto Mountains, Central Japan

Atsushi Miyashita

Seikei High School,  
3–10–13 Kichijoji-kitamachi, Musashino-shi, Tokyo, 180 Japan

**Abstract** Representative chemical compositions of rock-forming minerals in the Sanbagawa metamorphic rocks from the Ayukawa-Sanbagawa area, Kanto Mountains, are tabulated along with their brief descriptions. They include more than 200 electron microprobe analyses of silicate and oxide minerals. In addition to the bulk chemical compositions of metamorphic rocks, mineral assemblages including heavy minerals are presented here. They are basic data for petrological discussions of the metamorphic rocks in the Kanto Mountains.

**Key words:** metamorphic rocks, graphite, garnet, thermometry, mineral assemblage.

### Introduction

The Sanbagawa metamorphic belt is a typical intermediate high-pressure type terrain. It extends about 800 km along the southwestern portion of the Japanese island arc on the Pacific Ocean side. Many workers have been engaged in the petrology of the Sanbagawa metamorphic rocks, especially in central Shikoku, for the last thirty years (*e.g.* Banno, 1964; Banno & Sakai, 1989). They presented the detailed data for chemistry of rock-forming minerals (Higashino *et al.*, 1981, 1984; Aiba *et al.*, 1984).

The Kanto Mountains is located at the eastern end of the Sanbagawa metamorphic belt. Koto (1888) first established the geological framework of this region and named the schists “Sambagawan” after the name of a small valley in the west of Onishi-machi, Gunma Prefecture. Seki (1958) and Toriumi (1975) studied the metamorphic zonation of low grade region with the detailed description of constituent minerals. Recently, Tokuda (1986), Hirajima and Banno (1989), Hashimoto *et al.* (1992) and Makimoto and Takeuchi (1992) presented the tectonic models for the Sanbagawa metamorphic rocks in the Kanto Mountains. However, the petrography of higher grade part has not been published by any authors yet. This paper gives the petrographical basis of the Sanbagawa metamorphic rocks in the Kanto Mountains, especially focused on the data of the

electron microprobe analyses on the rock-forming minerals in the higher grade pelitic schists.

### Outline of Geology and Petrography

The Ayukawa-Sanbagawa area is situated in northern part of the Kanto Mountains (Fig. 1). The localities of the analyzed samples are shown in Fig. 2. The rocks studied here are registered in the rock collection of the petrology division of the National Science Museum.

In the Kanto Mountains, Sanbagawa, Mikabu and Chichibu belts show a zonal arrangement from north to south with ascending stratigraphic order. The Chichibu belt is composed mainly of trench-fill sediments, and is weakly metamorphosed. The Mikabu belt, so-called Mikabu greenrock complex is considered to

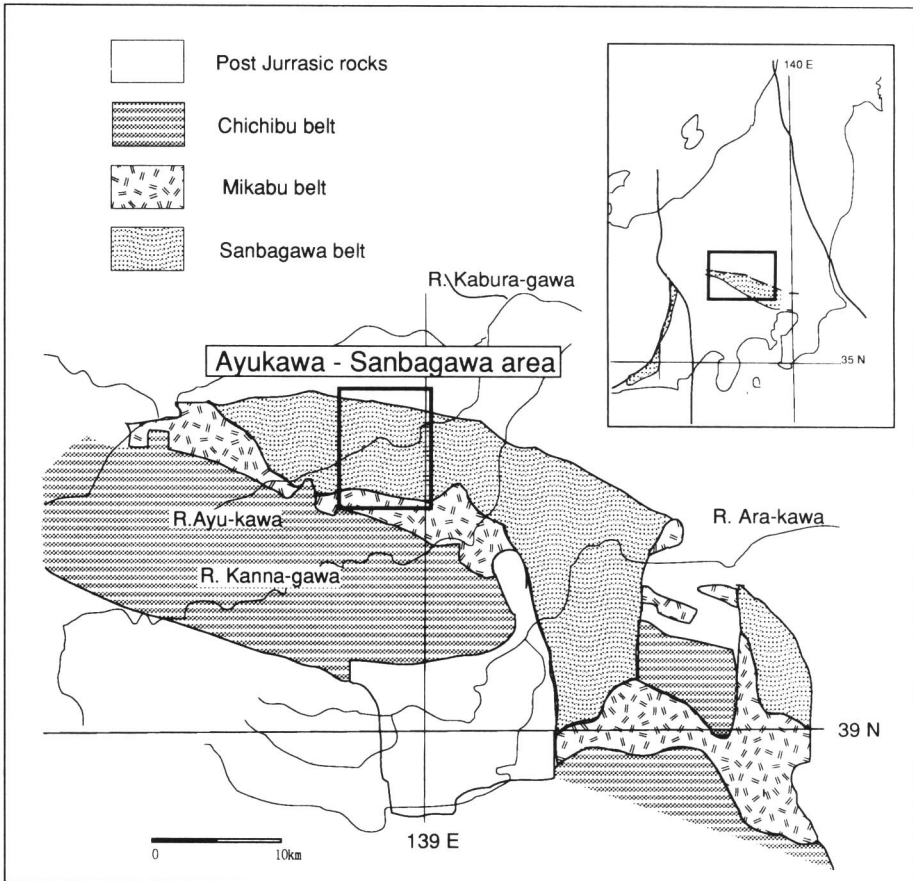


Fig. 1. Geological frameworks of the Kanto Mountains.

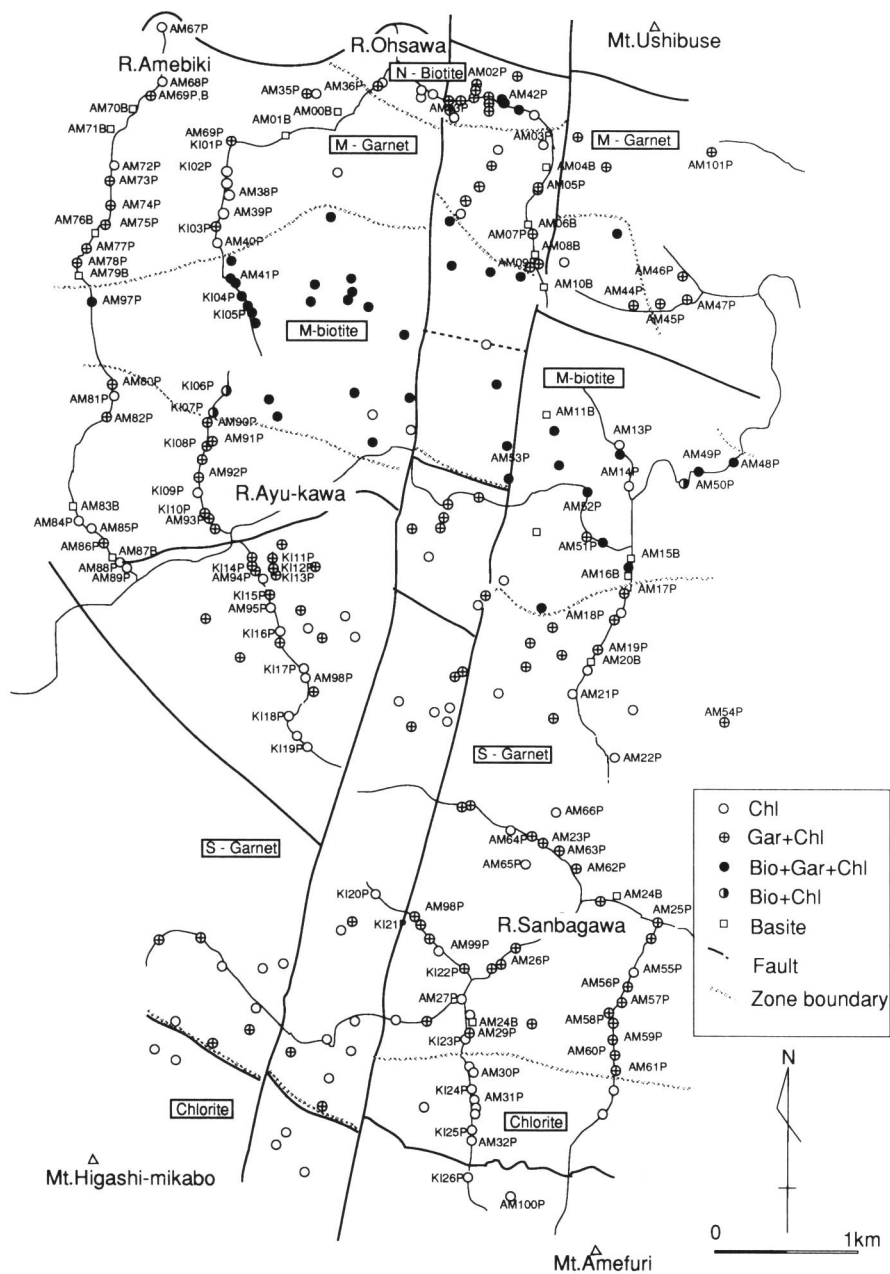


Fig. 2. Locality map in the Ayukawa-Sanbagawa area and division of chlorite, garnet and biotite zones.

be olistostromal melange of blocks and clasts of basic rocks, and is derived parentally from igneous part of the oceanic crust. The petrography and chemistry of the Mikabu belt in this area are summarized by Uchida (1981). The Sanbagawa belt consists dominantly of metapelites, intercalated with metabasites and meta-siliceous rocks, with a small amount of lenticular serpentinite. The Sanbagawa belt in the studied area has an apparent geological structure with a simple monocline trending EWE-WSW and dipping from 30°S to 50°S. Metamorphic grade increases from the Chichibu to the Sanbagawa belt. It is pumpellyite-actinolite facies to sodic-pyroxene chlorite facies in the Chichibu belt and up to albite-epidote amphibolite facies in the Sanbagawa belt (Seki, 1958, Toriumi, 1975; Hirajima & Banno, 1989).

On the basis of the mineral assemblage in metapelite in central Shikoku, the Sanbagawa schists is divided into three mineral zones, *i.e.* chlorite, garnet and biotite zones in ascending order of metamorphic grade. In the Ayukawa-Sanbagawa area, chlorite zone occurs only at the southern part (Fig. 2). Garnet zone is subdivided into the southern and middle garnet zones. Biotite zone is also subdivided to the middle and northern biotite zones. This complicated arrangement of zone is due to tectonic stacking of four slabs of sub-units (Miyashita, in preparation). They are bordered by thrust.

### Analytical Procedure

The electron microanalyser used for the analyses is JEOL 5400 with fully quantitative Link Systems model 2000 energy-dispersive spectrometer, EDS, of the Natural Science Museum, Tokyo. The analytical conditions are the same as those reported by Yokoyama *et al.* (1993). The X-ray diffractometer used for the analyses of crystallinity of carbonaceous matter is Rigaku Rint 2000 of the Natural Science Museum, Tokyo. The sample preparation and the method of measurement are after Tagiri (1981). X-ray fluorescence analyses of major elements in the meta-pelites are produced by Rigaku model 3040 of the Waseda University.

### Bulk Rock Chemistry

Bulk chemical compositions of 20 metapelites (Appendix 1) are obtained to check compositional effects of partition coefficients among minerals. Although the compositions of metapelites of the Kanto Mountains are lower in FeO and MgO contents than those of average chemical composition of metamorphosed pelitic rocks (Shaw, 1956), they are similar to those from the central Shikoku (Banno, 1964; Goto *et al.*, 1996). Modal proportions of representative minerals of the metapelites mentioned above are shown in Appendix 2. They are identified



under the optical microscope, whereas minor heavy minerals including opaque minerals listed in Appendix 3 are identified under electron microscope with EDS.

### Mineralogy

*Garnet:* Garnet in the metapelite is critical mineral for the zonal mapping of the Sanbagawa metamorphic rocks. It usually shows chemical zoning with regard to MnO, FeO, CaO and MgO. In the southern garnet zone, garnet shows normal zoning where MnO decreases from core to rim. Whereas, in the middle garnet zone, the complex zoned garnets are frequently observed. Detrital garnets (Higashino & Takasu, 1982) are found from some metapelites. They are always MgO-rich and are included in the MgO-poor garnets which were formed by the Sanbagawa metamorphism. There is usually distinct chemical discontinuity at the boundary between them. Chemical composition of the garnet rim is listed in Appendix 4. Each data is average composition of analyses of several points.

*Chlorite:* Chlorite is one of main constituent minerals in the metapelite. The optical character of chlorite is mostly negative in the studied area. The chemical heterogeneity in chlorite is recognized. Chemical composition of the average of several analyses at the most MgO-rich portion is listed in Appendix 5. MgO-rich chlorite is considered to be equilibrated with garnet rim during progressive metamorphism (Higashino, 1975).

*Biotite:* Biotite in the metapelite is also critical mineral for the zonal mapping of the Sanbagawa metamorphic rocks. Biotite is usually brown in color under microscope, and almost homogeneous within an individual grain. In the Kanto Mountains, green biotite is often found in the hematite-bearing siliceous schists and the hematite-bearing metabasite. The green biotite is poor in FeO and rich in MgO compared with brown biotite. Appendix 6 includes analyses of biotites both in the northern and middle biotite zones.

*White mica:* White mica is phengitic. Paragonite has not been found in the Kanto Mountains. Two types of heterogeneity in phengite are recognized. One is a zoning with Na-rich core and Na-poor rim, and another shows Si-rich core and Al-rich rim. Hirajima *et al.* (1992) obtained K-Ar age from white mica. The former type mica shows 67–53 Ma, and the latter shows 87–66 Ma. The FeO + MgO content of phengite is lower in the northern biotite zone than those in the other mineral zones. Chemical compositions of white micas are listed in Appendix 7.

*Amphibole:* Amphibole has not been observed in the metapelites from the Kanto Mountains, different from appearance of amphibole in the highest grade pelites from central Shikoku. In the metabasite of the chlorite zone, amphibole is actinolite and sodic amphibole. In the higher grade zone, amphibole is from actinolite to actinolitic hornblende in the Fe-oxide bearing metabasites (Hashi-

moto & Funakoshi, 1991). In the meta-siliceous rock of the middle biotite zone, Mn-rich amphibole occurs with Mn-rich sodic pyroxene and spessartine garnet. Chemical compositions of amphiboles in the metabasites and meta-siliceous rock are listed in Appendix 8.

*Plagioclase:* Plagioclase is also one of the major phases in the metapelites. Albite porphyroblast occurs in both the metapelite and basite. Such rocks are called “spotted schists”. Although they occur mostly in the higher grade zone of this area, the relationships between the metamorphic grade and the grain size of albite porphyroblast has not been solved yet. Plagioclase is almost pure albite in the garnet zone and shows compositional zoning with a small variation of anorthite content. Both simple and complex types of zonal structure described from the central Sikoku (Otsuki, 1980) are also recognized in this area. In the biotite zone, albite porphyroblast has oligoclase rim. Its maximum An content is from 10 to 13 in the middle biotite zone, and from 17 to 24 in the northern biotite zone. The latter is free from inclusions, different from the porphyroblastic oligoclase of oligoclase-biotite zone in central Shikoku. The chemical compositions of plagioclases both in the northern and middle biotite zones are listed in Appendix 9.

*Epidote:* Epidote group minerals are common in the metabasite. Piedmontite is often found in the meta-siliceous rocks. However, they are minor constituent in the metapelite. Epidote in the metapelite has frequently allanite core where total amount of rare-earth elements such as Ce, La, and Nd exceeds 20 wt%. Analytical results of epidote group minerals in the metapelites are listed in Appendix 10.

*Ilmenite:* Titanite, rutile and ilmenite occur mostly as discrete grains, but composite aggregate composed of the minerals is common. In central Shikoku, ilmenite is only stable phase in the biotite zone and is homogeneous formed at the prograde metamorphism (Itaya & Banno, 1980). On the other hand, ilmenite is rarely found in the metapelite from the Kanto Mountains. Chemical compositions of ilmenites in the metapelites are shown in Appendix 10.

*Carbonaceous matter:* Metapelite contains abundant carbonaceous material. Its crystalline degree changes continuously from amorphous to fully ordered state with increasing metamorphic temperature (Tagiri, 1981). The degree of graphitization is measured by the X-ray diffraction method. Representative data are presented in Appendix 11.

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Appendix 1. Bulk chemical compositions of the pelitic schists from the Kanto Mountains (normalized to 100% and all Fe recalculated as FeO).

No.	32P	100P	19P	23P	25P	29P	60P	41P	48P	49P	97P	05P	09P	73P	74P	75P	02P	42P	43P	120P
Zone	CHL	CHL	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	M-BIO	M-BIO	M-BIO	M-BIO	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	N-BIO	N-BIO	N-BIO	N-BIO
SiO <sub>2</sub>	70.48	63.77	66.27	66.73	68.57	68.01	70.52	69.00	77.47	64.69	71.83	67.83	68.28	71.37	69.37	67.42	66.30	68.45	61.78	65.18
TiO <sub>2</sub>	0.54	0.72	0.65	0.63	0.55	0.55	0.46	0.53	0.26	0.70	0.45	0.65	0.62	0.44	0.52	0.60	0.53	0.55	0.52	0.66
Al <sub>2</sub> O <sub>3</sub>	14.10	16.41	15.84	15.20	12.75	13.63	14.22	14.41	12.47	16.23	14.22	15.20	14.79	13.40	13.10	15.25	14.78	14.62	13.87	15.40
FeO*	4.16	5.91	5.43	6.10	6.00	5.30	4.19	4.87	2.14	5.64	3.85	5.11	4.91	3.91	4.31	4.98	4.45	4.02	4.20	5.39
MnO	0.06	0.13	0.19	0.57	0.77	0.24	0.16	0.23	0.05	0.10	0.06	0.11	0.07	0.12	0.10	0.15	0.14	0.09	0.09	0.30
MgO	1.46	2.80	2.21	1.95	1.98	1.77	1.79	1.86	0.53	2.27	1.25	2.09	1.95	1.35	1.99	1.82	1.65	1.42	2.76	2.22
CaO	1.01	0.53	0.59	0.64	1.62	2.37	0.44	1.13	0.73	1.06	0.45	0.34	0.62	1.48	2.19	0.98	2.00	1.21	2.99	1.20
Na <sub>2</sub> O	3.03	1.79	1.52	1.14	1.67	1.73	1.10	1.41	2.97	2.54	2.02	2.06	1.28	1.90	1.65	1.53	2.08	1.70	1.79	1.90
K <sub>2</sub> O	2.18	3.81	3.68	3.34	2.16	2.58	3.78	3.08	2.03	2.93	3.05	3.42	3.74	2.78	2.79	3.54	3.24	4.51	3.85	3.31
P <sub>2</sub> O <sub>5</sub>	0.09	0.08	0.11	0.08	0.11	0.14	0.08	0.07	0.03	0.12	0.07	0.12	0.13	0.07	0.10	0.09	0.09	0.11	0.08	0.10
lg <sub>10</sub> loss	2.89	4.04	3.52	3.62	3.84	3.69	3.25	3.40	1.33	3.72	2.77	3.08	3.60	3.17	3.87	3.64	4.73	3.31	8.08	4.35

Abbreviations commonly used in Appendixes 1 to 12 are as follows: AM, Atsushi Miyashita; KI, Keiko Imura (Mori); P, pelite and psamite; B, basite; Q, siliceous schist; V, veinlet; CHL, chlorite zone; S-GAR, southern garnet zone; M-BIO, middle biotite zone; M-GAR, middle garnet zone; N-BIO, northern biotite zone.

Appendix 2. Modal proportions of the representative minerals in the Sanbagawa pelitic schists.

No.	32P	100P	19P	23P	25P	29P	60P	41P	48P	49P	97P	05P	09P	73P	74P	75P	02P	43P	120P	
Zone	CHL	CHL	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	M-BIO	M-BIO	M-BIO	M-BIO	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	N-BIO	N-BIO	N-BIO	
Total counts	1963	-	2209	2113	2097	2259	2177	2000	2036	2147	1868	2051	2031	2104	2148	2116	2099	1982	2112	2005
quartz	40.9	-	33.4	40.4	46.3	41.7	41.0	43.6	38.5	35.9	36.6	38.0	40.7	46.5	45.0	38.3	48.2	52.4	37.7	43.2
albite	12.4	-	12.8	7.2	15.6	15.4	12.1	17.9	31.0	15.5	29.7	19.4	1.9	15.2	13.6	17.7	18.1	10.7	12.2	17.7
muscovite	41.2	-	43.0	37.5	24.6	30.2	41.7	25.8	22.1	37.6	25.9	35.2	54.3	30.1	33.7	34.3	24.2	22.3	38.3	33.6
chlorite	3.3	-	8.6	12.8	7.7	6.2	4.6	8.3	2.6	6.3	3.2	6.8	2.3	2.3	3.0	4.3	4.9	4.0	0.2	2.6
garnet	0.0	-	0.3	1.2	0.5	0.4	0.0	0.7	0.5	0.6	0.1	0.1	0.0	1.9	0.1	1.7	0.9	0.8	0.0	1.5
biotite	0.0	-	0.0	0.0	0.0	0.0	0.0	0.5	0.7	0.9	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
epidote	0.5	-	0.0	0.0	0.0	2.1	0.0	0.2	2.4	0.6	1.1	0.0	0.0	0.2	0.2	0.2	0.0	0.0	0.0	0.0
titanite	1.2	-	1.4	0.2	0.4	1.9	0.3	0.9	1.5	1.5	0.9	0.0	0.3	1.3	0.7	0.8	0.0	0.0	0.0	0.0
tourmaline	0.1	-	0.0	0.2	0.5	0.1	0.1	0.1	0.0	0.4	0.0	0.0	0.0	0.2	0.3	0.0	0.2	0.6	0.0	0.0
apatite	0.2	-	0.4	0.1	0.3	0.1	0.0	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.3	0.0	0.0	0.3	0.0	0.0
carbonate	0.0	-	0.0	0.0	3.5	1.7	0.0	1.9	0.0	0.0	0.0	0.0	0.1	1.5	2.2	1.9	2.2	6.8	10.4	0.0
opaque	0.4	-	0.2	0.2	0.6	0.3	0.0	0.4	0.4	0.5	1.3	0.2	0.1	0.6	1.0	0.7	1.3	1.2	1.1	1.3
others	0.0	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
gar/chl ratio	-	-	0.04	0.10	0.07	0.06	0.01	0.08	0.21	0.10	0.03	0.02	0.02	0.82	0.03	0.40	0.19	0.19	-	0.57

Appendix 3. Number of grains of heavy minerals observed in thin sections of the Sanbagawa pelitic schists.

No.	32P	100P	19P	23P	25P	29P	60P	41P	48P	49P	97P	05P	09P	73P	74P	75P	02P	43P	120P	
Zone	CHL	CHL	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	M-BIO	M-BIO	M-BIO	M-BIO	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	N-BIO	N-BIO	N-BIO	
Total counts	105	92	116	137	73	96	138	84	98	93	81	73	87	50	100	41	46	37	26	
zircon																				
rutile					1		1	14	13		21	54	3	24	1	41	59	115	68	52
ilmenite	1		5	82				25		1		9		2		6	5	1	2	
Fe-sulfide	26		4	18	4	43	8	10	34	61	33	4	29	33	37	18	7	40	10	11
Cu-Fe-S			1	2		3	2	4	6	7		1	1	7	5	10	8	4	5	25
sphalerite			2	2		4	1	5	6	5	1	4	1	5	7	5	5	6	4	13
galena	2		3	2		9	7	3	4	1	9	1		2	10	5				4
Fe-oxide	3	15	18	3	5	2	7	12	12	10	49	3	9	1	38	10	30	5	13	1
allanite	51	22	31	27	54	17	28	19	24	29	7	39	19	12	4	6	7			1
monazite		1	1			1		1	1			1	6					12	5	
thorite	2		7	3	4	10	15	9	2	1	2	20	15	9	2	4	2	2	2	
REE-carbonate								21			1	3		13		17	37	18	1	35
others	AP		Co,Ba				Co	Ni-Co	Cu-S	Cu-S	AP		Cu-S			Ni-Co				
TOTAL	190	130	180	200	223	185	208	207	200	208	204	208	173	154	202	165	206	240	146	204

Abbreviations: AP, arsenopyrite; Ba, barite; Co, cobaltite; Cu-S, Cu sulfide; Ni-Co, Ni-Co sulfide.

Appendix 4. Average chemical compositions and atomic ratios of the rims of garnets.

No.	KI11	KI14	KI12	KI13	KI16	KI17	AM98P	AM26P	KI22	AM29P	AM19P	AM21P	AM64P	AM23P	AM62P
Zone	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR
Point	6*	3*	5*	3*	2*	6*	3*	5*	2*	3*	3*	4*	5*	6*	3*
SiO <sub>2</sub>	37.89	37.44	38.04	37.41	37.30	36.95	36.76	36.53	36.40	37.37	37.44	36.43	37.39	36.65	37.67
TiO <sub>2</sub>	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.06	0.00	0.36	0.29
Al <sub>2</sub> O <sub>3</sub>	21.34	20.68	21.06	20.94	20.62	20.43	20.64	20.23	20.54	20.69	20.69	19.90	20.95	20.80	21.19
FeO	20.38	20.88	24.13	23.00	22.20	20.36	18.18	17.50	17.33	16.84	23.64	22.56	21.74	18.84	23.22
MnO	10.91	11.25	5.39	6.87	7.26	14.09	17.15	18.67	15.46	13.58	7.57	12.89	13.20	15.63	6.26
MgO	0.66	0.51	0.56	0.60	0.56	0.41	0.42	0.44	0.39	0.38	0.69	0.56	0.54	0.37	0.54
CaO	9.71	9.27	11.63	11.56	11.56	7.71	6.67	6.69	7.98	10.98	10.11	7.06	6.79	6.95	11.21
TOTAL	100.89	100.03	100.81	100.47	99.50	99.95	99.82	100.06	98.10	99.79	100.23	99.46	100.61	99.60	100.38
Si	3.007	3.013	3.016	2.987	3.004	2.999	2.990	2.980	2.995	3.007	3.002	2.988	3.006	2.979	2.998
Ti	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.022	0.017
Al	1.997	1.961	1.968	1.970	1.958	1.954	1.979	1.945	1.992	1.957	1.956	1.924	1.985	1.993	1.988
Fe	1.353	1.405	1.600	1.536	1.495	1.382	1.237	1.194	1.193	1.133	1.585	1.547	1.462	1.281	1.546
Mn	0.734	0.767	0.362	0.465	0.495	0.969	1.182	1.290	1.078	0.925	0.514	0.895	0.899	1.076	0.422
Mg	0.078	0.061	0.066	0.071	0.067	0.050	0.051	0.054	0.048	0.046	0.082	0.068	0.065	0.045	0.064
Ca	0.826	0.799	0.988	0.989	0.998	0.670	0.581	0.585	0.704	0.947	0.869	0.620	0.585	0.605	0.956
TOTAL	7.995	8.006	8.000	8.023	8.017	8.024	8.020	8.048	8.010	8.015	8.013	8.046	8.002	8.001	7.991
(O=12)															
No.	AM25P	AM55P	AM57P	AM58P	AM60P	AM61P	AM50P	AM91P	KI08	AM92P	KI10	AM17P	AM18P	AM80P	AM82P
Zone	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR
Point	2*	5*	4*	4*	7*	5*	3*	4*	2*	3*	4*	4*	4*	5*	6*
SiO <sub>2</sub>	36.40	37.40	37.29	37.19	37.79	37.48	36.75	37.26	37.97	36.82	37.40	36.44	37.43	37.69	37.13
TiO <sub>2</sub>	0.00	0.00	0.00	0.07	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00
Al <sub>2</sub> O <sub>3</sub>	19.91	21.17	21.09	21.04	21.30	21.00	20.77	20.90	20.96	20.71	20.65	20.17	20.76	21.12	20.77
FeO	26.46	19.30	18.25	16.66	15.51	16.27	17.41	15.75	15.93	14.91	18.91	20.36	15.05	16.24	21.13
MnO	8.49	16.20	16.34	18.27	16.43	13.67	15.71	16.03	12.42	19.38	14.91	14.17	16.61	13.32	12.19
MgO	0.73	0.48	0.44	0.42	0.38	0.41	0.44	0.44	0.27	0.30	0.55	0.59	0.46	0.47	0.46
CaO	7.01	6.41	6.49	6.44	9.39	11.01	8.21	9.62	12.64	6.66	7.20	7.98	9.83	11.85	7.57
TOTAL	99.00	100.96	99.90	100.09	100.83	99.89	99.29	100.00	100.19	98.78	99.62	99.93	100.14	100.69	99.25
Si	2.993	2.998	3.012	3.003	3.007	3.003	2.989	2.997	3.022	3.011	3.027	2.968	3.006	2.996	3.015
Ti	0.000	0.000	0.000	0.004	0.002	0.003	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000
Al	1.930	2.001	2.008	2.002	1.998	1.983	1.991	1.982	1.966	1.996	1.970	1.936	1.965	1.979	1.988
Fe	1.820	1.294	1.233	1.125	1.032	1.090	1.184	1.060	1.060	1.020	1.280	1.387	1.011	1.079	1.435
Mn	0.591	1.100	1.118	1.250	1.107	0.928	1.082	1.092	0.837	1.343	1.022	0.978	1.130	0.897	0.838
Mg	0.089	0.057	0.053	0.051	0.045	0.049	0.053	0.053	0.032	0.037	0.066	0.072	0.055	0.056	0.059
Ca	0.618	0.551	0.562	0.557	0.801	0.945	0.715	0.829	1.078	0.624	0.624	0.696	0.846	1.009	0.656
TOTAL	8.041	8.001	7.986	7.992	7.992	8.001	8.014	8.013	7.995	7.991	7.989	8.050	8.013	8.016	7.991
(O=12)															

Appendix 4. (continued).

No.	AM86P	AM41P	KI04	KI05	KI07	AM48P	AM49P	AM53P	AM97P	AM35P	KI03	AM05P	AM07P	AM09P	AM46P
Zone	S-GAR	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR
Point	4*	5*	3*	6*	2*	5*	7*	3*	5*	3*	8*	2*	4*	3*	7*
SiO2	37.82	37.58	37.85	37.59	37.45	37.50	37.51	38.00	37.53	36.95	37.41	38.03	37.66	37.07	37.32
TiO2	0.00	0.00	0.00	0.07	0.22	0.06	0.00	0.00	0.25	0.00	0.10	0.00	0.00	0.09	0.00
Al2O3	21.19	20.79	20.35	20.74	21.31	20.66	20.74	20.83	21.11	20.25	20.70	20.82	20.30	20.61	20.51
FeO	16.72	24.87	24.44	28.66	15.10	29.74	20.15	29.90	21.59	20.56	25.27	24.84	23.47	20.34	22.81
MnO	12.25	7.58	5.67	3.02	12.37	1.28	11.82	1.45	9.84	8.86	6.55	5.85	6.61	11.24	5.76
MgO	0.34	0.72	0.71	0.90	0.44	0.72	0.67	0.64	0.67	0.57	0.64	0.57	0.66	0.58	0.56
CaO	12.11	9.47	10.16	8.95	13.48	10.63	9.66	10.42	9.58	11.92	9.52	10.71	10.72	9.75	12.37
TOTAL	100.43	101.01	99.18	99.93	100.37	100.59	100.55	101.24	100.57	99.11	100.19	100.82	99.42	99.68	99.33
Si	3.007	2.999	3.051	3.019	2.974	2.999	3.003	3.016	2.994	2.995	3.005	3.024	3.035	2.994	3.007
Ti	0.000	0.000	0.000	0.004	0.013	0.004	0.000	0.000	0.015	0.000	0.006	0.000	0.000	0.005	0.000
Al	1.986	1.956	1.934	1.963	1.995	1.948	1.957	1.949	1.985	1.935	1.960	1.951	1.928	1.962	1.948
Fe	1.112	1.660	1.648	1.925	1.003	1.989	1.349	1.985	1.441	1.394	1.697	1.652	1.582	1.374	1.537
Mn	0.825	0.512	0.387	0.205	0.832	0.087	0.801	0.097	0.665	0.608	0.446	0.394	0.451	0.769	0.393
Mg	0.040	0.086	0.085	0.108	0.052	0.086	0.080	0.076	0.080	0.069	0.077	0.068	0.079	0.070	0.067
Ca	1.032	0.810	0.878	0.770	1.147	0.911	0.829	0.886	0.819	1.035	0.819	0.912	0.926	0.844	1.068
TOTAL	8.002	8.023	7.983	7.994	8.016	8.024	8.019	8.009	7.999	8.036	8.010	8.001	8.001	8.018	8.020

(O=12)

No.	AM47P	AM45P	AM44P	AM69P	AM73P	AM74P	AM75P	AM77P	AM78P	AM42P	AM02P	AM120P	AM106P
Zone	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	N-BIO	N-BIO	N-BIO	N-BIO
Point	4*	6*	3*	6*	7*	4*	9*	4*	4*	10*	3*	3*	3*
SiO2	37.32	37.28	37.41	37.27	37.22	37.37	37.77	37.47	37.52	37.22	36.87	37.07	37.86
TiO2	0.00	0.05	0.00	0.00	0.28	0.27	0.24	0.25	0.00	0.00	0.02	0.00	0.00
Al2O3	20.78	20.53	20.74	21.03	20.87	21.07	21.38	21.03	21.04	21.18	21.16	20.71	21.41
FeO	21.70	25.64	22.78	27.76	28.05	22.31	29.09	26.57	26.70	28.04	29.42	24.69	25.38
MnO	9.73	3.03	6.05	3.97	1.41	7.81	0.63	3.89	5.90	2.61	2.36	6.25	5.26
MgO	0.67	0.71	0.71	0.95	1.68	0.84	2.10	0.62	0.62	1.10	1.28	0.99	0.96
CaO	10.17	12.40	12.33	9.06	10.24	10.29	9.25	10.68	9.06	9.30	8.61	9.38	10.17
TOTAL	100.37	99.64	100.02	100.04	99.75	99.96	100.46	100.51	100.84	99.45	99.72	99.09	101.04
Si	2.992	2.997	2.994	2.993	2.980	2.991	2.990	2.990	2.998	2.995	2.971	3.001	2.997
Ti	0.000	0.003	0.000	0.000	0.017	0.016	0.014	0.015	0.000	0.000	0.001	0.000	0.000
Al	1.964	1.945	1.957	1.991	1.969	1.987	1.995	1.978	1.981	2.009	2.010	1.976	1.998
Fe	1.455	1.724	1.525	1.864	1.878	1.493	1.926	1.773	1.784	1.887	1.983	1.672	1.680
Mn	0.661	0.206	0.410	0.270	0.096	0.529	0.042	0.263	0.399	0.178	0.161	0.429	0.353
Mg	0.080	0.085	0.085	0.114	0.200	0.100	0.248	0.074	0.074	0.132	0.154	0.119	0.113
Ca	0.874	1.068	1.057	0.780	0.878	0.882	0.785	0.913	0.776	0.802	0.743	0.814	0.863
TOTAL	8.026	8.028	8.028	8.012	8.018	7.998	8.000	8.006	8.012	8.003	8.023	8.011	8.004

(O=12)



Appendix 5. Average chemical compositions and atomic ratios of the MgO-rich parts of chlorites.

No.	AM30P	AM31P	KI25P	KI26P	AM32P	AM100P	KI12	KI13	KI14	KI16	KI17	KI21	KI22	AM58P	AM26P
Zone	CHL	CHL	CHL	CHL	CHL	CHL	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR
Point	3*	12*	2*	3*	2*	10*	2*	3*	4*	4*	4*	3*	3*	4*	3*
SiO <sub>2</sub>	24.42	24.13	24.60	25.57	24.03	25.23	24.90	24.99	24.74	24.72	24.66	25.39	24.17	24.11	24.03
Al <sub>2</sub> O <sub>3</sub>	20.56	19.41	20.59	19.42	20.40	20.63	20.15	20.06	19.89	19.89	20.61	20.06	21.17	20.79	20.20
FeO	31.49	27.85	29.17	29.22	29.99	26.64	31.06	31.07	29.57	29.51	29.84	29.30	28.73	27.73	28.01
MnO	0.52	0.49	0.63	0.42	0.54	0.78	0.87	0.88	0.68	0.94	1.33	0.80	0.83	1.36	1.71
MgO	10.39	11.80	11.52	11.95	10.61	13.21	10.67	10.10	11.34	10.97	10.62	11.62	10.88	11.13	10.13
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00
TOTAL	87.38	83.68	86.51	86.58	85.57	86.49	87.65	87.10	86.22	86.03	87.06	87.17	85.78	85.25	84.08
Si	5.365	5.454	5.394	5.590	5.362	5.452	5.445	5.500	5.461	5.474	5.408	5.522	5.341	5.356	5.437
Al	5.324	5.171	5.321	5.004	5.365	5.255	5.194	5.203	5.175	5.192	5.328	5.142	5.514	5.443	5.387
Fe	5.786	5.265	5.349	5.342	5.597	4.815	5.680	5.718	5.458	5.466	5.473	5.329	5.309	5.152	5.300
Mn	0.097	0.094	0.117	0.078	0.102	0.143	0.161	0.164	0.127	0.176	0.247	0.147	0.155	0.256	0.328
Mg	3.403	3.976	3.765	3.894	3.529	4.256	3.478	3.313	3.731	3.621	3.472	3.767	3.584	3.685	3.417
Ca	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.000
TOTAL	19.975	19.960	19.946	19.908	19.955	19.921	19.958	19.898	19.952	19.929	19.928	19.907	19.903	19.923	19.869

(O=28)

No.	AM29P	AM19P	AM21P	AM64P	AM23P	AM62P	AM25P	AM55P	AM61P	AM90P	AM91P	AM92P	KI08	KI10	AM17P
Zone	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR	S-GAR
Point	3*	3*	3*	4*	5*	4*	2*	4*	3*	6*	5*	3*	3*	3*	5*
SiO <sub>2</sub>	25.11	25.02	23.81	24.39	24.14	24.51	23.32	24.69	24.89	24.16	24.64	24.41	23.97	24.66	24.65
Al <sub>2</sub> O <sub>3</sub>	20.44	20.10	20.41	22.31	21.23	20.44	19.51	21.34	20.18	20.41	20.52	20.53	19.07	20.54	20.27
FeO	28.83	27.99	27.38	28.63	28.84	30.20	28.33	29.54	30.27	29.31	28.38	29.29	29.72	28.00	28.78
MnO	0.86	1.05	1.21	1.25	1.38	0.89	1.66	1.38	0.54	0.93	0.90	1.08	0.52	1.26	0.99
MgO	11.41	11.69	11.28	11.42	11.01	10.51	10.72	11.29	11.01	10.96	11.76	11.08	10.63	11.53	11.54
CaO	0.05	0.07	0.07	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	86.70	85.92	84.16	88.22	87.03	86.55	83.54	88.24	86.89	85.77	86.20	86.39	83.91	85.99	86.23
Si	5.482	5.500	5.354	5.230	5.276	5.411	5.343	5.325	5.460	5.367	5.407	5.380	5.466	5.424	5.424
Al	5.260	5.208	5.410	5.639	5.470	5.319	5.269	5.425	5.218	5.344	5.308	5.333	5.125	5.325	5.257
Fe	5.264	5.146	5.149	5.134	5.272	5.576	5.428	5.329	5.553	5.445	5.209	5.399	5.667	5.150	5.296
Mn	0.159	0.196	0.230	0.227	0.255	0.166	0.322	0.252	0.100	0.175	0.167	0.202	0.100	0.235	0.185
Mg	3.713	3.831	3.781	3.650	3.587	3.459	3.661	3.630	3.600	3.629	3.847	3.640	3.613	3.780	3.785
Ca	0.012	0.016	0.017	0.000	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL	19.890	19.897	19.941	19.915	19.941	19.931	20.023	19.961	19.931	19.960	19.938	19.954	19.971	19.914	19.947

(O=28)

Appendix 5. (continued).

No.	AM18P	AM80P	AM82P	AM86P	AM41P	KI04	KI05	KI07	AM48P	AM49P	AM53P	AM14P	AM97P	AM35P	KI03
Zone	S-GAR	S-GAR	S-GAR	S-GAR	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-GAR	M-GAR
Point	4*	4*	5*	5*	3*	3*	3*	3*	4*	2*	3*	5*	3*	3*	5*
SiO <sub>2</sub>	24.84	24.79	24.57	24.58	24.19	24.53	25.60	26.65	25.10	25.05	25.22	24.65	24.60	24.07	23.85
Al <sub>2</sub> O <sub>3</sub>	20.55	20.91	21.34	20.52	20.62	19.84	21.71	19.69	19.85	20.28	20.09	19.79	20.92	19.44	20.05
FeO	29.05	29.41	29.58	29.23	28.51	26.23	27.31	29.68	30.30	26.83	30.32	29.57	28.48	29.65	29.58
MnO	1.08	0.95	1.08	1.01	0.77	0.58	0.61	0.58	0.65	0.69	0.61	0.66	0.54	0.54	0.76
MgO	11.40	11.43	11.49	11.26	12.03	12.46	13.32	11.72	11.34	13.49	11.62	11.31	11.72	10.24	10.09
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.03
TOTAL	86.98	87.49	88.06	86.60	86.12	83.64	88.55	88.37	87.24	86.34	87.86	85.98	86.50	83.94	84.36
Si	5.421	5.381	5.306	5.397	5.322	5.489	5.398	5.698	5.487	5.433	5.467	5.459	5.369	5.478	5.403
Al	5.286	5.350	5.432	5.311	5.347	5.232	5.395	4.962	5.114	5.185	5.134	5.166	5.382	5.215	5.354
Fe	5.302	5.339	5.343	5.367	5.246	4.908	4.816	5.307	5.539	4.867	5.497	5.477	5.198	5.643	5.604
Mn	0.200	0.175	0.198	0.188	0.143	0.110	0.109	0.105	0.120	0.127	0.112	0.124	0.100	0.104	0.146
Mg	3.709	3.699	3.699	3.685	3.945	4.156	4.187	3.736	3.695	4.362	3.755	3.734	3.813	3.474	3.407
Ca	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.007
TOTAL	19.928	19.944	19.978	19.948	20.003	19.895	19.905	19.819	19.955	19.974	19.965	19.960	19.901	19.914	19.921

(O=28)

No.	AM05P	AM07P	AM09P	AM46P	AM47P	AM45P	AM44P	AM69P	AM73P	AM74P	AM77P	AM78P	AM42P	AM02P	AM120P
Zone	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	N-BIO	N-BIO	N-BIO
Point	4*	6*	3*	4*	4*	5*	3*	6*	4*	4*	4*	2*	7*	4*	3*
SiO <sub>2</sub>	24.92	25.80	25.16	24.74	24.20	25.04	24.96	24.37	24.66	25.10	24.92	24.19	23.49	24.73	25.04
Al <sub>2</sub> O <sub>3</sub>	19.52	19.72	19.73	20.38	20.23	19.57	19.81	20.95	20.46	20.54	20.38	20.65	20.81	21.23	20.02
FeO	29.15	23.81	28.63	29.56	30.83	26.42	29.45	29.00	27.82	27.26	30.62	29.78	28.35	25.29	25.85
MnO	0.56	0.80	0.58	0.75	0.92	0.85	0.62	0.74	0.43	0.49	0.69	0.85	0.34	0.15	0.76
MgO	11.74	15.30	12.06	11.54	10.30	13.19	11.61	11.80	12.68	13.72	11.17	10.93	11.57	14.19	12.98
CaO	0.00	0.08	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	85.89	85.51	86.21	86.97	86.48	85.07	86.45	86.86	86.05	87.11	87.78	86.40	84.56	85.59	84.65
Si	5.507	5.559	5.518	5.409	5.374	5.514	5.485	5.321	5.393	5.399	5.421	5.341	5.261	5.350	5.517
Al	5.084	5.008	5.100	5.252	5.295	5.079	5.132	5.391	5.274	5.207	5.226	5.374	5.494	5.414	5.199
Fe	5.387	4.291	5.251	5.405	5.726	4.865	5.413	5.295	5.088	4.904	5.571	5.499	5.310	4.576	4.763
Mn	0.105	0.146	0.108	0.139	0.173	0.159	0.115	0.137	0.080	0.089	0.127	0.159	0.065	0.027	0.142
Mg	3.867	4.914	3.943	3.761	3.410	4.330	3.804	3.840	4.134	4.399	3.622	3.598	3.863	4.576	4.263
Ca	0.000	0.018	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL	19.950	19.936	19.932	19.966	19.978	19.947	19.949	19.984	19.969	19.998	19.967	19.971	19.993	19.943	19.884

(O=28)

Appendix 6. Average chemical compositions and atomic ratios of biotites.

No.	AM41P	AM48P	AM49P	AM53P	KI04	KI5P	KI07	AM97P	AM51P*	AM52P*	AM42P	AM102P	AM106P
Zone	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	N-BIO	N-BIO	N-BIO
SiO2	37.34	35.74	40.78	35.45	36.17	36.05	35.31	36.29	41.89	38.49	34.68	35.66	36.17
TiO2	1.46	0.97	0.84	1.04	1.42	1.34	0.87	1.23	0.67	0.93	1.70	1.71	1.44
Al2O3	16.75	17.12	15.68	17.15	16.77	16.79	17.08	17.18	16.85	14.09	16.79	16.92	17.12
FeO	21.77	24.24	19.98	24.49	20.70	20.90	23.53	22.20	8.84	13.50	22.50	19.49	20.71
MnO	0.65	0.35	0.22	0.43	0.46	0.38	0.35	0.39	0.62	0.75	0.00	0.00	0.39
MgO	8.22	7.97	9.43	8.53	9.12	9.09	8.74	8.32	15.10	15.06	7.88	9.65	9.28
CaO	0.07	0.03	0.06	0.05	0.00	0.29	0.09	0.19	0.11	0.03	0.00	0.00	0.00
Na2O	0.00	0.03	0.00	0.00	0.33	0.00	0.07	0.38	0.06	0.04	0.00	0.00	0.00
K2O	8.46	8.30	8.38	7.92	9.07	8.49	7.81	8.50	10.20	10.08	8.59	9.59	9.39
TOTAL	94.72	94.75	95.37	95.06	94.04	93.33	93.85	94.68	94.34	92.97	92.14	93.02	94.50
Si	2.873	2.788	3.053	2.757	2.873	2.870	2.769	2.809	3.038	2.937	2.771	2.790	2.797
Ti	0.084	0.057	0.047	0.061	0.085	0.080	0.051	0.072	0.037	0.053	0.102	0.101	0.084
Al	1.519	1.574	1.384	1.572	1.570	1.576	1.579	1.568	1.440	1.267	1.582	1.560	1.560
Fe	1.401	1.581	1.251	1.593	1.375	1.392	1.543	1.437	0.536	0.861	1.504	1.275	1.339
Mn	0.042	0.023	0.014	0.028	0.031	0.026	0.023	0.026	0.038	0.048	0.000	0.000	0.026
Mg	0.943	0.927	1.053	0.989	1.080	1.079	1.022	0.960	1.632	1.713	0.939	1.125	1.070
Ca	0.006	0.003	0.005	0.004	0.000	0.025	0.008	0.016	0.009	0.002	0.000	0.000	0.000
Na	0.000	0.005	0.000	0.000	0.051	0.000	0.011	0.057	0.008	0.006	0.000	0.000	0.000
K	0.830	0.826	0.801	0.786	0.919	0.862	0.781	0.839	0.944	0.981	0.876	0.957	0.926
TOTAL	7.698	7.784	7.608	7.790	7.984	7.910	7.787	7.784	7.682	7.868	7.774	7.808	7.802

\*green biotite

(O=11)



Appendix 7. (continued).

No.	AM05P	AM09P	AM35P	AM47P	AM67P	AM68P	AM69P	AM73P	AM73P	AM75P	AM44P	AM47P	AM02P	AM42P	AM42P
Zone	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	N-BIO	N-BIO
SiO <sub>2</sub>	49.11	49.19	48.74	48.38	49.57	46.38	47.95	48.09	49.25	47.75	48.05	48.38	47.44	46.53	47.43
TiO <sub>2</sub>	0.32	0.43	0.39	0.00	0.31	0.46	0.27	0.80	0.00	0.77	0.33	0.00	0.75	0.64	0.49
Al <sub>2</sub> O <sub>3</sub>	27.97	27.81	28.66	29.52	27.12	31.79	29.83	30.33	28.01	30.37	27.90	29.52	32.63	33.12	30.91
FeO	4.11	3.99	3.66	3.73	3.38	2.27	2.77	2.00	3.33	2.38	4.24	3.73	2.04	1.94	2.41
MgO	2.40	2.65	2.20	2.20	2.67	1.59	2.27	2.44	2.76	2.36	2.50	2.20	1.37	1.29	2.00
CaO	0.00	0.17	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na <sub>2</sub> O	0.00	0.00	0.29	0.00	0.44	0.71	0.00	1.09	0.40	1.16	0.00	0.00	0.84	0.88	0.00
K <sub>2</sub> O	10.75	10.93	10.66	10.77	10.48	10.16	10.97	9.71	10.43	9.54	10.52	10.77	10.31	10.28	11.07
TOTAL	94.66	95.17	94.60	94.60	93.97	93.53	94.06	94.46	94.18	94.33	93.54	94.60	95.38	94.68	94.31
Si	3.334	3.327	3.306	3.281	3.377	3.163	3.261	3.234	3.345	3.221	3.305	3.281	3.166	3.130	3.214
Ti	0.016	0.022	0.020	0.000	0.016	0.024	0.014	0.040	0.000	0.039	0.017	0.000	0.038	0.032	0.025
Al	2.238	2.217	2.292	2.359	2.178	2.556	2.391	2.404	2.242	2.415	2.262	2.359	2.567	2.626	2.469
Fe	0.233	0.226	0.208	0.212	0.193	0.129	0.158	0.112	0.189	0.134	0.244	0.212	0.114	0.109	0.137
Mg	0.243	0.267	0.222	0.222	0.271	0.162	0.230	0.245	0.279	0.237	0.256	0.222	0.136	0.129	0.202
Ca	0.000	0.012	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na	0.000	0.000	0.038	0.000	0.058	0.094	0.000	0.142	0.053	0.152	0.000	0.000	0.109	0.115	0.000
K	0.931	0.943	0.923	0.932	0.911	0.884	0.952	0.833	0.904	0.821	0.923	0.932	0.878	0.882	0.957
TOTAL	6.996	7.014	7.008	7.006	7.003	7.024	7.005	7.011	7.012	7.019	7.008	7.006	7.007	7.023	7.005

(O = 11)

No.	AM42P	AM43P	AM43P	AM43P	AM43P	AM43P	AM43P	AM43P	AM43P	AM43P	AM43P	AM43P	AM43P	AM43P	AM43P
Zone	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO
SiO <sub>2</sub>	47.11	46.10	47.29	46.67	46.77	49.05	46.16	46.87	46.43	46.87	46.43	46.87	46.43	46.87	46.43
TiO <sub>2</sub>	0.00	0.47	0.33	0.00	0.51	0.31	0.69	0.40	0.43	0.40	0.43	0.40	0.43	0.40	0.43
Al <sub>2</sub> O <sub>3</sub>	36.59	32.68	30.81	32.57	33.11	28.34	32.20	32.67	32.25	32.67	32.25	32.67	32.25	32.67	32.25
FeO	0.00	1.83	2.34	2.27	2.21	2.99	1.61	1.81	1.95	1.81	1.95	1.81	1.95	1.81	1.95
MgO	0.22	1.40	1.95	1.26	1.43	2.73	1.63	1.29	1.59	1.63	1.29	1.63	1.29	1.59	1.63
CaO	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na <sub>2</sub> O	0.33	0.79	0.46	0.39	0.45	0.53	0.66	0.67	0.65	0.66	0.67	0.66	0.67	0.65	0.66
K <sub>2</sub> O	10.22	10.33	10.72	10.85	10.90	10.38	10.58	10.43	10.62	10.58	10.43	10.62	10.58	10.43	10.62
TOTAL	94.66	93.60	93.90	94.01	95.38	94.33	93.53	94.14	93.92	94.33	93.53	94.14	93.92	94.33	93.92
Si	3.116	3.137	3.217	3.169	3.133	3.323	3.145	3.166	3.154	3.166	3.154	3.166	3.154	3.166	3.154
Ti	0.000	0.024	0.017	0.000	0.026	0.016	0.035	0.020	0.022	0.020	0.022	0.020	0.022	0.020	0.022
Al	2.853	2.621	2.470	2.607	2.614	2.263	2.586	2.601	2.582	2.601	2.582	2.601	2.582	2.601	2.582
Fe	0.000	0.104	0.133	0.129	0.124	0.169	0.092	0.102	0.111	0.102	0.111	0.102	0.111	0.102	0.111
Mg	0.022	0.142	0.198	0.128	0.143	0.276	0.166	0.166	0.161	0.166	0.161	0.166	0.161	0.166	0.161
Ca	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na	0.042	0.104	0.061	0.051	0.058	0.070	0.087	0.088	0.086	0.087	0.088	0.087	0.088	0.086	0.087
K	0.863	0.897	0.930	0.940	0.932	0.897	0.920	0.899	0.920	0.899	0.920	0.899	0.920	0.899	0.920
TOTAL	6.909	7.029	7.026	7.023	7.029	7.013	7.030	7.006	7.036	7.006	7.036	7.006	7.036	7.006	7.036

(O = 11)

Appendix 8. Representative chemical compositions and atomic ratios of amphiboles in basites and siliceous schists.

No.	AM33B	AM33B	AM28B	AM28B	AM76B	AM12Q	AM12Q	AM12Q	AM12Q	AM15B	AM15B	AM15B	AM16B	AM16B	AM00B	AM00B
Zone	CHL	CHL	S-GAR	S-GAR	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-GAR	M-GAR
Position	core	—	core	rim	core	core	core	rim	core	rim	core	rim	core	—	core	rim
SiO <sub>2</sub>	55.83	53.96	54.51	55.71	44.25	55.57	55.45	51.04	55.50	51.35	53.94	53.20	54.46	50.67	53.82	53.82
TiO <sub>2</sub>	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al <sub>2</sub> O <sub>3</sub>	8.59	1.13	2.20	0.54	9.12	1.21	0.35	3.92	1.44	4.07	0.98	2.25	0.91	6.61	0.00	0.00
FeO	13.84	13.25	9.21	6.96	19.33	8.93	6.22	14.93	9.51	13.31	10.41	10.11	9.32	14.00	14.69	14.69
MnO	0.00	0.00	0.30	0.00	0.45	5.41	12.35	1.36	5.01	0.00	0.38	0.35	0.51	0.00	0.41	0.41
MgO	9.55	14.77	17.14	19.39	8.81	16.43	19.81	13.19	16.03	14.00	17.05	17.14	17.37	12.29	14.18	14.18
CaO	1.42	10.47	10.02	12.39	8.97	3.37	1.34	7.73	3.41	11.36	12.51	11.77	11.99	9.13	12.12	12.12
Na <sub>2</sub> O	6.42	1.39	1.59	0.44	2.92	5.39	0.43	2.93	4.78	1.07	0.50	0.63	0.61	2.47	0.46	0.46
K <sub>2</sub> O	0.00	0.00	0.00	0.00	0.52	0.33	0.00	0.20	0.20	0.12	0.00	0.20	0.00	0.00	0.00	0.00
TOTAL	95.65	94.97	94.97	95.43	94.60	96.64	95.95	95.30	95.88	95.28	95.77	95.65	95.17	95.17	95.68	95.68
Si	7.895	7.930	7.813	7.951	6.750	7.695	7.084	7.428	7.702	7.568	7.829	7.664	7.894	7.434	7.987	7.987
Ti	0.000	0.000	0.000	0.000	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Al(IV)	0.105	0.070	0.187	0.049	1.250	0.197	0.053	0.572	0.236	0.432	0.168	0.336	0.106	0.566	0.000	0.000
Al(VI)	1.327	0.126	0.185	0.042	0.390	0.000	0.000	0.101	0.000	0.275	0.000	0.046	0.050	0.577	0.000	0.000
Fe <sub>3+</sub>	0.587	0.250	0.482	0.095	0.910	0.000	0.000	1.196	0.000	0.242	0.143	0.444	0.160	0.415	0.040	0.040
Fe <sub>2+</sub>	1.073	1.388	0.634	0.737	1.612	1.081	0.755	0.674	1.157	1.408	1.125	0.787	0.974	1.320	1.785	1.785
Mn	0.000	0.000	0.036	0.000	0.058	0.635	1.336	0.168	0.589	0.000	0.047	0.043	0.063	0.000	0.052	0.052
Mg	2.013	3.236	3.662	4.125	2.003	3.392	3.773	2.862	3.316	3.076	3.689	3.681	3.753	2.688	3.137	3.137
Ca	0.215	1.649	1.539	1.895	1.466	0.500	0.183	1.205	0.507	1.794	1.946	1.817	1.862	1.435	1.927	1.927
Na(B)	1.785	0.351	0.425	0.105	0.476	0.865	0.107	0.627	0.904	0.206	0.008	0.140	0.075	0.565	0.021	0.021
Na(A)	0.000	0.045	0.017	0.017	0.388	0.582	0.000	0.200	0.382	0.100	0.133	0.035	0.096	0.138	0.111	0.111
K	0.000	0.000	0.000	0.000	0.101	0.058	0.000	0.037	0.035	0.023	0.000	0.037	0.000	0.000	0.000	0.000

(O = 23)

Appendix 8. (continued).

No.	AM01B	AM01B	AM06B	AM06B	AM69B	AM69B	AM70B	AM70B	AM71B	AM71B	AM71B	AM08B	AM08B
Zone	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR	M-GAR
Position	core	rim	core	rim	core	rim	core	rim	core	rim	core	rim	core
SiO <sub>2</sub>	49.16	53.24	49.87	53.24	53.15	54.37	48.81	54.25	50.67	54.19	47.39	53.53	
TiO <sub>2</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Al <sub>2</sub> O <sub>3</sub>	5.82	1.40	4.97	1.49	3.02	1.02	5.74	0.85	4.33	1.20	6.94	1.30	
FeO	16.77	11.87	16.61	11.82	10.96	10.70	15.68	11.18	15.66	11.27	19.42	13.08	
MnO	0.00	0.41	0.30	0.31	0.53	0.91	0.49	0.40	0.34	0.38	0.30	0.00	
MgO	11.43	16.00	11.84	15.97	16.04	16.23	12.42	16.15	12.62	16.05	9.54	15.00	
CaO	8.37	11.71	8.13	11.67	9.56	11.89	9.93	11.97	8.63	12.21	8.15	12.01	
Na <sub>2</sub> O	3.29	0.59	3.22	0.79	2.12	0.68	2.03	0.88	2.68	0.63	3.20	0.71	
K <sub>2</sub> O	0.20	0.00	0.20	0.00	0.00	0.00	0.33	0.00	0.12	0.00	0.30	0.00	
TOTAL	95.04	95.22	95.14	95.29	95.38	95.80	95.43	95.68	95.05	95.93	95.24	95.63	
Si	7.319	7.767	7.384	7.775	7.645	7.896	7.222	7.923	7.466	7.890	7.108	7.874	
Ti	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Al(IV)	0.681	0.233	0.616	0.225	0.355	0.104	0.778	0.077	0.534	0.110	0.892	0.126	
Al(VI)	0.340	0.008	0.251	0.031	0.157	0.071	0.223	0.069	0.218	0.096	0.334	0.100	
Fe <sub>3+</sub>	0.682	0.397	0.823	0.319	0.659	0.141	0.762	0.013	0.802	0.026	0.950	0.037	
Fe <sub>2+</sub>	1.441	1.065	1.275	1.135	0.679	1.162	1.214	1.353	1.165	1.348	1.544	1.574	
Mn	0.000	0.051	0.038	0.038	0.065	0.112	0.061	0.049	0.042	0.047	0.038	0.000	
Mg	2.537	3.480	2.613	3.476	3.439	3.514	2.739	3.516	2.772	3.484	2.133	3.289	
Ca	1.335	1.831	1.290	1.826	1.473	1.850	1.574	1.873	1.363	1.905	1.310	1.893	
Na(B)	0.665	0.119	0.673	0.136	0.462	0.038	0.364	0.077	0.595	0.048	0.652	0.107	
Na(A)	0.285	0.048	0.252	0.088	0.129	0.154	0.218	0.172	0.171	0.130	0.279	0.096	
K	0.038	0.000	0.038	0.000	0.000	0.000	0.062	0.000	0.023	0.000	0.058	0.000	

(O = 23)

Appendix 9. Representative chemical compositions and atomic ratios of plagioclases in the biotite zones.

No.	AM41P	K105	K106	AM48P	AM49P	AM53P	AM97P	AM02P	AM42P	AM43P	AM106P	AM118P
Zone	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	N-BIO	N-BIO	N-BIO	N-BIO	N-BIO
SiO <sub>2</sub>	65.18	65.55	65.72	65.61	66.54	66.56	65.32	62.34	62.92	65.34	63.75	63.75
Al <sub>2</sub> O <sub>3</sub>	21.52	21.32	20.93	21.34	21.48	19.99	21.23	22.79	23.37	21.55	23.07	22.92
CaO	2.69	2.43	1.70	2.28	2.28	0.96	2.36	4.20	4.60	2.34	4.39	4.12
Na <sub>2</sub> O	9.94	10.57	10.64	10.52	10.69	11.16	10.37	9.44	9.27	10.32	9.51	9.15
K <sub>2</sub> O	0.00	0.20	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	99.33	100.07	98.99	99.75	100.99	98.78	99.28	98.77	100.16	99.55	100.72	99.94
Si	2.882	2.885	2.911	2.890	2.895	2.952	2.891	2.792	2.780	2.883	2.799	2.813
Al	1.122	1.106	1.093	1.108	1.102	1.045	1.108	1.203	1.217	1.121	1.194	1.192
Ca	0.127	0.115	0.081	0.108	0.106	0.046	0.112	0.202	0.218	0.111	0.207	0.195
Na	0.852	0.902	0.914	0.899	0.902	0.960	0.890	0.820	0.794	0.883	0.810	0.783
K	0.000	0.011	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL	4.983	5.019	4.999	5.005	5.005	5.009	5.000	5.016	5.009	4.998	5.009	4.983
Ca/(Ca+Na)	0.13	0.11	0.08	0.11	0.11	0.05	0.11	0.20	0.22	0.11	0.20	0.20

(O=8)

Appendix 10. Representative chemical compositions and atomic ratios of epidotes and ilmenites in pelites.

No.	AM31P	AM29P	AM62P	AM48P	AM49P	AM50P	K106	K107	AM73P	No.	AM25P	AM41P
Zone	CHL	S-GAR	S-GAR	M-BIO	M-BIO	M-BIO	M-BIO	M-BIO	M-GAR	Zone	S-GAR	M-BIO
SiO <sub>2</sub>	37.26	37.13	37.44	37.17	37.11	37.47	38.03	37.16	37.84	SiO <sub>2</sub>	-	-
TiO <sub>2</sub>	-	-	-	-	-	-	-	-	-	TiO <sub>2</sub>	53.50	53.51
Al <sub>2</sub> O <sub>3</sub>	27.69	26.04	26.28	25.87	26.62	26.44	27.22	25.16	26.67	Al <sub>2</sub> O <sub>3</sub>	-	0.26
Fe <sub>2</sub> O <sub>3</sub>	6.30	8.54	8.60	8.86	7.58	8.42	7.91	10.08	8.35	FeO	30.48	31.32
MnO	0.00	0.00	0.00	0.00	0.33	0.33	0.35	0.00	0.00	MnO	16.10	14.48
CaO	22.67	22.48	22.30	22.79	21.84	22.78	22.99	22.54	22.78	CaO	-	-
TOTAL	93.92	94.19	94.62	94.69	93.48	95.44	96.50	94.94	95.64	TOTAL	100.08	99.57
Si	6.014	6.027	6.041	6.015	6.043	6.009	6.016	6.019	6.038	Si	-	-
Ti	-	-	-	-	-	-	-	-	-	Ti	1.005	1.006
Al	5.268	4.982	4.998	4.934	5.109	4.998	5.075	4.804	5.016	Al	0.000	0.008
Fe <sub>3+</sub>	0.765	1.043	1.044	1.079	0.929	1.016	0.942	1.229	1.003	Fe	0.636	0.655
Mn	0.000	0.000	0.000	0.000	0.046	0.045	0.047	0.000	0.000	Mn	0.340	0.307
Ca	3.921	3.910	3.855	3.951	3.811	3.915	3.897	3.912	3.895	Ca	-	-
TOTAL	15.969	15.938	15.938	15.979	15.938	15.964	15.976	15.964	15.952	TOTAL	1.981	1.975
Fe/Fe+Al	0.13	0.17	0.17	0.18	0.15	0.17	0.16	0.20	0.17	-	-	-

(O=25)



Appendix 11. XRD analyses of graphites in pelites.

No.	Zone	d(002)g	HHW deg	Lc(002)	Others
AM30P	CHL	3.410	1.38		59 Zr, Tou
AM31P	CHL	3.380	0.64		127 Zr
AM32P	CHL	3.414	1.21		67 Zr
AM100P	CHL	3.409	2.19		37 Zr, Ral
AM17P	S-GAR	3.361	0.69		118 Zr, Ana
AM18P	S-GAR	3.396	1.15		71 Zr
AM21P	S-GAR	3.381	0.94		87 Zr, Rut, Det-g
AM23P	S-GAR	3.375	0.68		120 Zr
AM24P	S-GAR	3.371	0.70		117 Zr, Rut, Tou
AM25P	S-GAR	3.394	1.10		74 Zr, Rut, Det-g
AM27P	S-GAR	3.390	0.99		82 Tou
AM29P	S-GAR	3.399	1.19		69 Zr, Tou
AM55P	S-GAR	3.394	1.23		66 Zr, Rut, Ana
AM56P	S-GAR	3.386	1.15		71 Zr, Rut, Tou
AM57P	S-GAR	3.386	1.17		70 Zr, Det-g
AM58P	S-GAR	3.396	1.10		74 Zr, Rut
AM59P	S-GAR	3.413	1.11		73 Zr
AM60P	S-GAR	3.400	1.10		74 Zr
AM64P	S-GAR	3.376	0.64		127 Zr, Rut, Ana
AM80P	S-GAR	3.396	1.11		73 Zr
AM82P	S-GAR	3.394	1.07		76 Zr, Ana
AM84P	S-GAR	3.382	0.89		92 Zr
AM85P	S-GAR	3.389	0.87		94 Zr
AM86P	S-GAR	3.403	1.39		59 Zr, Tou
AM88P	S-GAR	3.387	0.88		93 Zr
AM89P	S-GAR	3.379	0.77		106 Zr, Det-g
AM90P	S-GAR	3.374	0.70		117 Zr, Ral
AM91P	S-GAR	3.382	0.97		84 Zr
AM92P	S-GAR	3.400	1.45		56 Zr, Ral
AM94P	S-GAR	3.369	0.64		128 Zr, Ral
AM95P	S-GAR	3.386	0.81		101 Zr, Ral
AM96P	S-GAR	3.367	0.71		115 Zr, Tou, Ral
AM98P	S-GAR	3.377	1.00		82 Zr, Rut
AM99P	S-GAR	3.386	1.03		79 Zr, Det-g

No.	Zone	d(002)g	HHW deg	Lc(002)	Others
AM13P	M-BIO	3.375	0.63		130 Zr, Tou
AM14P	M-BIO	3.398	1.17		70 Zr, Det-g
AM41P	M-BIO	3.370	0.55		148 Zr
AM48P	M-BIO	3.359	0.32		255 Zr
AM49P	M-BIO	3.379	0.68		120 Zr
AM50P	M-BIO	3.379	0.70		117 Zr
AM53P	M-BIO	3.399	1.11		73 Zr
AM97P	M-BIO	3.371	0.65		126 Zr
AM03P	M-GAR	3.367	0.49		167 Zr
AM05P	M-GAR	3.371	0.53		154 Zr, Ana
AM07P	M-GAR	3.370	0.63		130 Zr, Tou
AM09P	M-GAR	3.379	0.79		103 Zr, Tou
AM35P	M-GAR	3.377	0.81		101 Zr
AM36P	M-GAR	3.376	0.69		118 Zr
AM38P	M-GAR	3.380	0.79		103 Zr
AM39P	M-GAR	3.389	1.01		81 Zr, Tou, Ana
AM40P	M-GAR	3.370	0.56		146 Zr, Tou
AM44P	M-GAR	3.375	0.84		97 Zr
AM46P	M-GAR	3.367	0.66		124 Zr
AM67P	M-GAR	3.372	0.62		132 Zr, Ana
AM68P	M-GAR	3.374	0.48		170 Zr
AM69P	M-GAR	3.367	0.73		112 Zr, Tou
AM72P	M-GAR	3.364	0.53		154 Zr
AM73P	M-GAR	3.361	0.22		371
AM74P	M-GAR	3.371	0.46		177 Zr
AM75P	M-GAR	3.364	0.24		340 Zr
AM78P	M-GAR	3.384	0.86		95 Zr
AM02P	N-BIO	3.361	0.32		255 Zr
AM42P	N-BIO	3.364	0.36		227 Zr
AM43P	N-BIO	3.376	0.56		146

Abbreviations: Zr, zircon; Tou, Tourmaline; Ana, anatase; Rut, rutile; Det-g, detrital graphite; Ral, ralstonite.





Appendix 12. (continued).

No.	Type	Zone	Nap	hb	act	Nam	bio	gar	chl	mus	stl	qtz	pl	adu	epi	all	apa	tou	tit	nut	car	gph	OPQ
AM70B	basite	M-GAR			+				+	+		+	+			+					+		+
AM71B	basite	M-GAR		+					+	+		+	+										+
AM72P	pelite	M-GAR							+	+		+	+						+		+		+
AM73P	pelite	M-GAR							+	+		+	+						+		+		+
AM74P	pelite	M-GAR							+	+		+	+						+		+		+
AM75P	pelite	M-GAR							+	+		+	+						+		+		+
AM76B	basite	M-GAR		+					+	+		+	+						+		+		+
AM77P	pelite	M-GAR							+	+		+	+						+		+		+
AM78P	pelite	M-GAR							+	+		+	+						+		+		+
AM79B	basite	M-GAR							+	+		+	+						+		+		+
AM80P	pelite	S-GAR							+	+		+	+						+		+		+
AM81P	pelite	S-GAR							+	+		+	+						+		+		+
AM82P	pelite	S-GAR							+	+		+	+						+		+		+
AM83B	basite	S-GAR		+					+	+		+	+						+		+		+
AM84P	pelite	S-GAR							+	+		+	+						+		+		+
AM85P	pelite	S-GAR							+	+		+	+						+		+		+
AM86P	pelite	S-GAR							+	+		+	+						+		+		+
AM87B	basite	S-GAR		+					+	+		+	+						+		+		+
AM88P	pelite	S-GAR							+	+		+	+						+		+		+
AM89P	pelite	S-GAR							+	+		+	+						+		+		+
AM90P	pelite	S-GAR							+	+		+	+						+		+		+
AM91P	pelite	S-GAR							+	+		+	+						+		+		+
AM92P	pelite	S-GAR							+	+		+	+						+		+		+
AM93P	psamite	S-GAR							+	+		+	+						+		+		+
AM94P	pelite	S-GAR							+	+		+	+						+		+		+
AM95P	pelite	S-GAR							+	+		+	+						+		+		+
AM96P	pelite	S-GAR							+	+		+	+						+		+		+
AM97P	pelite	M-BIO							+	+		+	+						+		+		+
AM98P	pelite	S-GAR							+	+		+	+						+		+		+
AM99P	pelite	S-GAR							+	+		+	+						+		+		+
AM100P	phillite	CHL							+	+		+	+						+		+		+
AM101P	pelite	M-GAR							+	+		+	+						+		+		+
AM102P	pelite	N-BIO							+	+		+	+						+		+		+
AM103P	psamite	N-BIO							+	+		+	+						+		+		+
AM104P	pelite	N-BIO							+	+		+	+						+		+		+
AM104B	basite	N-BIO							+	+		+	+						+		+		+



