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Microprobe analyses of zoned amphiboles from quartz diorites in the Daito-Yokota granitic complex, San-in belt, southwest Japan

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Introduction

Compositional variation of amphibole formed under progressively oxidizing condition have been documented from the Finnmarka complex, Norway (Czamanske and Wones, 1973), and from mineralized plutons of many porphyry copper-bearing granitoids (Mason, 1978 : Chivas, 1981 : Hendry et al., 1985). Amphiboles in Cretaceous-Paleogene granitoids in the San-in belt, southwest Japan, which typically contain magnetite (magnetite series granitoids : Ishihara, 1977), are considered to have formed under progressively oxidizing conditions at shallow depths (Murakami, 1977 : Tainosho et al, 1979 : Czamanske et al., 1981 : Kanisawa, 1983 : Sakiyama, 1983).

Kawakatsu and Yamaguchi (1987) described successive zoning of amphiboles with a progressively oxidizing trend from shallow intrusive mass of quartz diorite in the Cretaceous-Paleogene granitoids in Daito-Yokota area, and demonstrated mineralogic data and textural evidence indicating that the zoned amphibole has formed under subsolidus condition in the presence of fluid phase separated during secondary boiling.

We will present here all of the analytical data of the zoned amphiboles. All of the analytical data were plotted in Fig. 3 of the previous paper (Kawakatsu and Yamaguchi, 1987). Geological setting, textural relations of amphibole and the accompanying minerals, and texture of the successive zoning of amphibole were described in the previous paper.

Analytical methods and chemical compositions of amphibole

Typically zoned amphiboles from equigranular quartz diorite (032517, 032517-HB, 050307, 032505, 032505-HB, 032517-HB-R) consists of five distinct zones : 1) a pale brown core (C) of magnesio-hornblende, magnesian hestingsitic hornblende, and edenitic hornblende : 2) a pale green zone (PG) of magnesio-hornblende : 3) a green oscillatory zone (O) of magnesio-hornblende through actinolitic hornblende to actinolite : 4) a green uniform zone (U) of actinolite : and 5) a dark green zone (DG) of magnesio-hornblende to actinolitic hornblende, in the sequence from core to rim. Amphiboles of porphyritic quartz diorite (032518) consists of only the pale brown core (c) and pale green rim (g). The amphibole is devoid of the other outer zones of the amphibole in the equigranular quartz diorite.

Microprobe analyses of amphiboles were made using a JXA-733 microanalyser, monitoring the analytical points by scanning back-scattered electron image, with an accelerating potential of 15 Kv and a sample current of 0.02 μA. Natural and synthetic oxides, silicates and glasses were used as reference standards. The data were corrected by the method of Bence and Albee (1968). Structural formulae were calculated on the anhydrous basis of 23 oxygen. All of the analyses are listed in Table 1 and plotted in Fig. 1. Values of $Fe^{3+}/(Fe^{3+}+Fe^{2+})$ were determined for amphibole separates of the two rock specimens by wet chemical analyses. The amphibole separates of from the equigranular quartz diorite contains 11.72 FeO we % and 3.55 Fe_2O_3 we %, and that from the porphyritic quartz diorite contains 11.97 FeO we % and 2.90 Fe_2O_3 we %. The values of $Fe^{3+}/(Fe^{3+}+Fe^{2+})$ is 0.21 and 0.18, respectively, for these amphibole separates. Czamanske et al. (1981) described amphiboles with values of $Fe^{3+}/(Fe^{3+}+Fe^{2+})=0.18-0.24$ from quartz diorite-granodiorites in the Daito-Yokota area.

Values of $Fe^{3+}/(Fe^{3+}+Fe^{2+})$ of each microprobe analysis analyses were estimated using the crystal chemical constraints according to the method described by Stout (1972) and Robinson et al. (1982). The structural formulae are the means of those calculated first, by assuming total cations to be 13 exclusive of K, Na, and Ca, and then, by assuming total cations to be 15 exclusive of K and Na. The resultant structural formulae yield a range of 0.10–0.26 for $Fe^{3+}/(Fe^{3+}+Fe^{2+})$, with most analyses falling within 0.4–0.22. The average for all the 89 analyses is 0.18, and is similar to the values for the amphibole separates determined by the wet chemical analyses.

Amphibole separates were analysed using YANACO CHN-corder (Model MT-3) to determine H_2O content, by J. Yamamoto, department of geology, Shimane university. The amphibole separates contain 2.18 and 1.99 wt % of H_2O, respectively. H_2O contents calculated for the amphibole analyses, on the assumption of ideal hydroxy-amphibole, are 2.01–2.07 wt %. Microprobe analyses of F content were made using a synthetic fluorphlogopite as standard. All the analyses show relatively low F content of 0.03–0.20 wt %. There is no evidence of substitution of OH by O, coupled with that of cations. The zoned amphiboles are concluded to be essentially hydroxy-amphibole.

Table 1－1 Microprobe analyses of amphiboles.

	032517 O－1	O－2	O－3	U－4	U－5	O－6	O－7	O－8	O－9	DG－10	DG－11	PG－12	PG－13	O－14	O－15	O－16	U－17	U－18	O－19
SiO_2	49.10	49.01	50.76	52.87	52.93	50.81	50.75	50.68	50.54	49.17	49.37	48.48	48.56	49.53	50.77	51.79	52.90	53.41	51.26
TiO_2	0.97	0.87	0.56	0.16	0.12	0.17	0.14	0.15	0.13	0.01	0.03	0.96	0.95	0.76	0.50	0.32	0.10	0.06	0.15
Al_2O_3	5.17	4.95	3.60	2.33	2.17	4.10	3.85	4.09	4.33	4.56	4.36	5.70	5.55	4.67	3.81	3.22	1.99	1.73	4.01
Fe_2O_3	2.02	2.46	2.12	2.01	1.60	2.83	2.89	2.62	2.47	2.43	2.19	3.17	2.72	2.35	2.49	2.06	2.09	1.82	2.42
FeO	11.40	11.21	10.36	9.67	10.07	10.50	10.09	10.40	10.92	15.79	16.19	10.88	11.30	11.11	10.36	10.43	9.55	9.59	10.71
MnO	0.47	0.50	0.48	0.47	0.49	0.50	0.46	0.51	0.51	0.43	0.43	0.52	0.53	0.50	0.47	0.49	0.47	0.49	0.53
MgO	14.39	14.38	15.34	16.37	16.20	14.96	15.15	14.94	14.55	11.36	11.22	14.24	14.11	14.55	15.24	15.61	16.40	16.54	15.01
CaO	11.99	12.06	12.23	12.48	12.60	12.48	12.54	12.41	12.57	12.36	12.38	11.80	12.00	12.01	12.19	12.53	12.61	12.68	12.47
Na_2O	0.96	0.93	0.63	0.41	0.36	0.58	0.51	0.57	0.52	0.59	0.54	1.11	1.04	0.85	0.63	0.52	0.31	0.22	0.57
K_2O	0.45	0.42	0.26	0.11	0.10	0.20	0.17	0.17	0.16	0.23	0.21	0.36	0.40	0.40	0.26	0.21	0.08	0.07	0.16
Total	96.92	96.79	96.34	96.88	96.64	97.13	96.55	96.54	96.70	96.93	96.92	97.22	97.16	96.73	96.72	97.18	96.50	96.61	97.29
	Structural formulae based on O=23																		
Si	7.215	7.218	7.440	7.643	7.677	7.402	7.424	7.419	7.402	7.361	7.397	7.113	7.137	7.281	7.416	7.513	7.675	7.728	7.445
Al^{IV}	0.785	0.782	0.560	0.357	0.323	0.598	0.576	0.581	0.598	0.639	0.603	0.887	0.863	0.719	0.584	0.487	0.325	0.272	0.555
Σ(Tet.)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	0.110	0.077	0.061	0.040	0.048	0.105	0.088	0.124	0.149	0.166	0.167	0.098	0.099	0.090	0.072	0.064	0.016	0.023	0.132
Ti	0.107	0.096	0.062	0.017	0.013	0.019	0.015	0.017	0.014	0.001	0.003	0.106	0.105	0.084	0.055	0.035	0.011	0.007	0.016
Fe^{3+}	0.223	0.272	0.233	0.218	0.175	0.311	0.319	0.288	0.272	0.274	0.247	0.349	0.300	0.259	0.274	0.224	0.228	0.198	0.264
Fe^{2+}	1.402	1.381	1.270	1.170	1.221	1.279	1.234	1.273	1.337	1.977	2.029	1.336	1.390	1.366	1.266	1.265	1.159	1.161	1.301
Mn	0.058	0.062	0.060	0.058	0.060	0.062	0.057	0.063	0.063	0.055	0.055	0.065	0.066	0.062	0.058	0.060	0.058	0.060	0.065
Mg	3.152	3.157	3.352	3.528	3.503	3.249	3.304	3.260	3.177	2.535	2.506	3.114	3.092	3.189	3.319	3.376	3.547	3.568	3.250
Σ(Al^{VI} to Mg)	5.052	5.045	5.038	5.031	5.020	5.025	5.017	5.025	5.012	5.008	5.007	5.068	5.052	5.050	5.044	5.024	5.019	5.017	5.028
R^{2+}* in M4	0.052	0.045	0.037	0.031	0.020	0.024	0.016	0.025	0.013	0.008	0.006	0.068	0.051	0.051	0.043	0.024	0.018	0.016	0.028
Ca	1.888	1.903	1.920	1.933	1.958	1.948	1.965	1.946	1.972	1.983	1.987	1.855	1.890	1.892	1.908	1.948	1.960	1.966	1.941
Na(M4)	0.060	0.052	0.042	0.036	0.023	0.028	0.019	0.029	0.015	0.009	0.007	0.077	0.059	0.058	0.049	0.028	0.021	0.018	0.032
Σ(M4)	2.000	2.000	1.999	2.000	2.001	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.001	2.000	2.000	1.999	2.000	2.001
Na(A)	0.213	0.214	0.137	0.079	0.078	0.136	0.126	0.133	0.133	0.162	0.150	0.239	0.237	0.184	0.129	0.118	0.066	0.044	0.129
K	0.084	0.079	0.049	0.020	0.019	0.037	0.032	0.032	0.030	0.044	0.040	0.067	0.075	0.075	0.048	0.039	0.015	0.013	0.030
Σ(A)	0.297	0.293	0.186	0.099	0.097	0.173	0.158	0.165	0.163	0.206	0.190	0.306	0.312	0.259	0.177	0.157	0.081	0.057	0.159

* $R^{2+}=Fe^{2+}+Mg+Mn$.

C, pale brown core : PG, pale green zone : O, green oscillatory zone : U, green uniform zone : DG, dark green zone, in equigranular quartz diorite.

Table 1 − 2 Microprobe analyses of amphiboles (continued).

	032517			032517−HB					050307								
	O−20	O−21	DG−22	PG−1	C−2	PG−3	C−4	PG−5	O−1	DG−2	DG−3	DG−4	O−5	O−6	O−7	PG−8	PG−9
SiO_2	50.94	50.33	49.17	47.05	44.78	48.67	44.59	49.09	49.98	48.07	47.45	48.32	51.64	49.16	48.71	48.31	47.33
TiO_2	0.15	0.11	0.03	1.12	1.74	1.11	1.91	0.88	0.05	0.06	0.06	0.16	0.14	0.81	0.90	1.14	1.57
Al_2O_3	4.00	4.52	4.68	6.18	8.91	6.21	9.62	5.82	3.98	5.33	5.59	6.16	3.67	4.80	5.34	5.91	7.37
Fe_2O_3	2.58	2.74	2.45	4.02	2.79	3.15	2.99	2.89	3.89	4.97	4.55	4.07	2.32	3.52	3.23	3.51	3.59
FeO	10.50	10.69	16.21	10.32	12.69	10.32	12.92	10.87	12.75	13.71	14.39	13.34	11.03	9.74	10.44	9.54	9.29
MnO	0.51	0.53	0.44	0.54	0.51	0.51	0.50	0.49	0.35	0.38	0.38	0.41	0.45	0.41	0.48	0.44	0.43
MgO	14.97	14.53	11.13	13.86	12.00	14.40	11.91	14.26	13.13	11.69	11.20	11.98	14.86	15.04	14.54	14.93	14.84
CaO	12.56	12.51	12.34	11.84	11.73	11.89	11.72	11.97	12.58	12.50	12.41	12.45	12.63	12.08	11.95	11.84	11.91
Na_2O	0.51	0.55	0.61	1.11	1.42	0.96	1.59	0.85	0.36	0.52	0.59	0.54	0.34	0.79	0.97	1.12	1.35
K_2O	0.16	0.16	0.25	0.31	0.58	0.29	0.64	0.37	0.16	0.21	0.31	0.25	0.11	0.39	0.37	0.31	0.35
Total	96.88	96.67	97.31	96.35	97.15	97.51	98.39	97.49	97.23	97.44	96.93	97.68	97.19	96.74	96.93	97.05	98.03
	Structural formulae based on O=23																
Si	7.431	7.373	7.348	6.983	6.674	7.088	6.577	7.160	7.372	7.156	7.127	7.135	7.503	7.208	7.152	7.063	6.862
Al^{IV}	0.569	0.627	0.652	1.017	1.326	0.912	1.423	0.840	0.628	0.844	0.873	0.865	0.497	0.792	0.848	0.937	1.138
Σ(Tet.)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	0.118	0.154	0.172	0.065	0.239	0.154	0.250	0.160	0.064	0.091	0.117	0.207	0.132	0.037	0.076	0.081	0.121
Ti	0.016	0.012	0.003	0.125	0.195	0.122	0.212	0.097	0.006	0.007	0.007	0.018	0.015	0.089	0.099	0.125	0.171
Fe^{3+}	0.284	0.302	0.275	0.449	0.312	0.344	0.331	0.316	0.432	0.557	0.514	0.453	0.254	0.388	0.356	0.385	0.391
Fe^{2+}	1.280	1.310	2.026	1.282	1.583	1.259	1.595	1.327	1.573	1.706	1.807	1.648	1.340	1.195	1.282	1.168	1.127
Mn	0.063	0.066	0.056	0.068	0.064	0.063	0.062	0.061	0.044	0.048	0.048	0.051	0.055	0.051	0.060	0.054	0.053
Mg	3.255	3.173	2.479	3.067	2.666	3.126	2.619	3.100	2.887	2.594	2.508	2.637	3.219	3.287	3.183	3.254	3.207
Σ(Al^{VI} to Mg)	5.016	5.017	5.011	5.056	5.059	5.068	5.069	5.061	5.006	5.003	5.001	5.014	5.015	5.047	5.056	5.067	5.070
R^{2+}* in M4	0.017	0.017	0.011	0.055	0.059	0.068	0.069	0.060	0.005	0.003	0.001	0.014	0.016	0.048	0.056	0.068	0.070
Ca	1.963	1.964	1.976	1.883	1.873	1.855	1.852	1.870	1.988	1.994	1.997	1.970	1.966	1.898	1.880	1.855	1.850
Na(M4)	0.020	0.020	0.013	0.063	0.068	0.077	0.079	0.069	0.006	0.003	0.002	0.016	0.018	0.055	0.064	0.078	0.080
Σ(M4)	2.000	2.001	2.000	2.001	2.000	2.000	2.000	1.999	1.999	2.000	2.000	2.000	2.000	2.001	2.000	2.001	2.000
Na(A)	0.124	0.136	0.164	0.256	0.342	0.194	0.376	0.171	0.097	0.147	0.170	0.139	0.078	0.170	0.212	0.239	0.299
K	0.030	0.030	0.048	0.059	0.110	0.054	0.120	0.069	0.030	0.040	0.059	0.047	0.020	0.073	0.069	0.058	0.065
Σ(A)	0.154	0.166	0.212	0.315	0.452	0.248	0.496	0.240	0.127	0.187	0.229	0.186	0.098	0.243	0.281	0.297	0.364

* $R^{2+} = Fe^{2+} + Mg + Mn$.

C, pale brown core : PG, pale green zone : O, green oscillatory zone : U, green uniform zone : DG, dark green zone, in equigranular quartz diorite.

Table 1－3 Microprobe analyses of amphiboles (continued).

	050307							032505										
	C－10	C－11	C－12	C－13	C－14	PG－15	PG－16	PG－1	O－2	U－3	U－4	U－5	O－6	O－7	O－8	O－9	O－10	O－11
SiO_2	43.46	42.73	43.31	43.39	43.39	48.44	48.10	48.56	49.53	53.56	54.19	54.29	51.41	51.11	51.82	51.87	47.91	48.23
TiO_2	2.16	2.33	2.29	2.25	2.25	1.10	1.12	1.14	0.80	0.24	0.13	0.10	0.16	0.18	0.13	0.12	0.26	0.25
Al_2O_3	9.53	9.83	9.35	9.13	9.15	6.05	5.99	6.19	5.72	2.51	2.15	1.82	4.03	4.13	3.45	3.85	7.23	6.44
Fe_2O_3	3.72	3.75	3.10	3.45	3.03	3.37	3.44	2.03	1.53	1.87	1.28	1.23	2.50	1.89	3.16	2.79	2.77	2.22
FeO	11.22	11.36	12.16	11.51	11.60	8.90	9.13	12.25	12.02	9.61	9.58	9.30	10.01	10.40	8.59	9.01	11.37	11.82
MnO	0.42	0.40	0.40	0.40	0.38	0.44	0.44	0.35	0.31	0.36	0.32	0.33	0.33	0.34	0.30	0.32	0.35	0.33
MgO	12.66	12.29	12.02	12.26	12.52	15.35	15.14	13.77	14.09	16.80	17.08	17.20	15.53	15.35	16.44	16.09	13.40	13.37
CaO	12.02	11.72	12.02	12.03	12.09	12.03	11.88	12.37	12.52	12.91	13.06	12.88	12.62	12.81	12.96	12.67	12.49	12.53
Na_2O	1.78	1.78	1.50	1.32	1.52	1.10	1.18	0.93	0.73	0.39	0.28	0.21	0.49	0.53	0.40	0.39	0.98	0.86
K_2O	0.48	0.55	0.58	0.64	0.69	0.32	0.30	0.54	0.43	0.09	0.06	0.05	0.18	0.19	0.08	0.07	0.24	0.24
Total	97.45	96.74	96.73	96.38	96.62	97.10	96.72	98.13	97.68	98.34	98.13	97.41	97.26	96.93	97.33	97.18	97.00	96.29
	Structural formulae based on O＝23																	
Si	6.460	6.408	6.501	6.522	6.510	7.056	7.047	7.085	7.218	7.619	7.700	7.752	7.440	7.433	7.459	7.472	7.046	7.146
Al^{IV}	1.540	1.592	1.499	1.478	1.490	0.944	0.953	0.915	0.782	0.381	0.300	0.248	0.560	0.567	0.541	0.528	0.954	0.854
Σ(Tet.)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	0.129	0.146	0.155	0.139	0.127	0.095	0.081	0.149	0.201	0.040	0.060	0.059	0.128	0.141	0.045	0.126	0.300	0.270
Ti	0.241	0.263	0.259	0.254	0.254	0.121	0.123	0.125	0.088	0.026	0.014	0.011	0.017	0.020	0.014	0.013	0.029	0.028
Fe^{3+}	0.416	0.422	0.350	0.390	0.342	0.369	0.378	0.223	0.168	0.200	0.137	0.132	0.273	0.207	0.343	0.302	0.306	0.247
Fe^{2+}	1.395	1.425	1.526	1.448	1.455	1.085	1.119	1.495	1.465	1.143	1.138	1.111	1.211	1.265	1.035	1.086	1.399	1.465
Mn	0.053	0.051	0.051	0.051	0.048	0.054	0.055	0.043	0.038	0.043	0.039	0.040	0.040	0.042	0.037	0.039	0.044	0.041
Mg	2.805	2.748	2.690	2.747	2.800	3.333	3.307	2.995	3.061	3.563	3.618	3.661	3.351	3.328	3.528	3.455	2.938	2.953
Σ(Al^{VI} to Mg)	5.039	5.055	5.031	5.029	5.026	5.057	5.063	5.030	5.021	5.015	5.006	5.014	5.020	5.003	5.002	5.021	5.016	5.004
R^{2+}* in M4	0.040	0.054	0.031	0.029	0.026	0.057	0.063	0.031	0.021	0.015	0.005	0.014	0.020	0.002	0.001	0.021	0.015	0.005
Ca	1.914	1.883	1.933	1.937	1.943	1.877	1.865	1.934	1.955	1.968	1.988	1.971	1.957	1.996	1.999	1.955	1.968	1.989
Na(M4)	0.046	0.062	0.036	0.034	0.030	0.065	0.072	0.035	0.024	0.017	0.006	0.016	0.023	0.002	0.001	0.024	0.017	0.006
Σ(M4)	2.000	1.999	2.000	2.000	1.999	1.999	2.000	2.000	2.000	2.000	1.999	2.001	2.000	2.000	2.001	2.000	2.000	2.000
Na(A)	0.467	0.456	0.401	0.351	0.412	0.246	0.263	0.228	0.182	0.091	0.071	0.042	0.114	0.147	0.111	0.085	0.262	0.241
K	0.091	0.105	0.111	0.123	0.132	0.059	0.056	0.101	0.080	0.016	0.011	0.009	0.033	0.035	0.015	0.013	0.045	0.045
Σ(A)	0.558	0.561	0.512	0.474	0.544	0.305	0.319	0.329	0.262	0.107	0.082	0.051	0.147	0.182	0.126	0.098	0.307	0.286

* $R^{2+} = Fe^{2+} + Mg + Mn$.

C, pale brown core : PG, pale green zone : O, green oscillatory zone : Ugreen uniform zone : DG, dark green zone, in equigranular quartz diorite.

Table 1 − 4 Microprobe analyses of amphiboles (continued).

	032505						032505−HB				032517−HB−R				032518	
	O−12	O−13	O−14	O−15	O−16	O−17	C−1	C−2	C−3	C−4	C−1	PG−2	C−3	C−4	g-1-1	g-1-2
SiO_2	50.75	50.85	51.01	51.95	50.09	52.67	45.98	46.32	46.34	46.43	42.82	48.91	44.18	44.55	48.76	49.38
TiO_2	0.17	0.28	0.33	0.26	0.44	0.24	1.72	1.69	1.51	1.53	2.22	1.00	2.52	2.35	0.95	0.96
Al_2O_3	4.74	4.73	5.03	3.87	5.26	3.99	9.43	9.32	8.91	8.47	10.20	6.92	10.02	9.69	5.83	5.78
Fe_2O_3	3.11	1.48	2.30	2.40	3.04	1.74	2.17	2.66	4.01	3.21	3.30	3.29	2.32	2.42	2.79	1.95
FeO	9.08	10.44	10.23	9.22	9.81	9.63	12.47	10.85	11.08	11.34	12.11	9.41	12.62	12.58	11.59	12.11
MnO	0.36	0.33	0.32	0.34	0.35	0.31	0.30	0.30	0.37	0.35	0.41	0.35	0.41	0.40	0.50	0.48
MgO	15.61	15.23	15.25	16.27	15.20	16.21	12.57	13.50	13.12	13.25	11.93	15.24	12.39	12.55	13.78	13.79
CaO	12.73	12.77	12.50	12.72	12.53	12.54	12.13	11.97	11.28	11.85	11.51	11.98	11.50	11.55	11.97	12.35
Na_2O	0.54	0.61	0.65	0.57	0.76	0.43	1.33	1.39	1.54	1.41	1.94	1.21	2.02	1.97	0.91	0.74
K_2O	0.08	0.12	0.13	0.08	0.20	0.13	0.44	0.33	0.24	0.29	0.51	0.37	0.44	0.52	0.31	0.35
Total	97.17	96.84	97.75	97.68	97.68	97.89	98.54	98.33	98.40	98.13	96.95	98.68	98.42	98.68	97.39	97.89
	Structural formulae based on=23															
Si	7.340	7.392	7.348	7.452	7.245	7.518	6.708	6.722	6.742	6.779	6.415	7.013	6.497	6.533	7.145	7.194
Al^{IV}	0.660	0.608	0.652	0.548	0.755	0.482	1.292	1.278	1.258	1.221	1.585	0.987	1.503	1.467	0.855	0.806
Σ(Tet.)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	0.148	0.202	0.202	0.107	0.141	0.189	0.329	0.316	0.270	0.237	0.216	0.183	0.233	0.224	0.152	0.186
Ti	0.018	0.031	0.036	0.028	0.048	0.026	0.189	0.184	0.165	0.168	0.250	0.108	0.279	0.259	0.105	0.105
Fe^{3+}	0.339	0.162	0.249	0.259	0.331	0.187	0.238	0.289	0.436	0.351	0.371	0.354	0.255	0.265	0.307	0.213
Fe^{2+}	1.098	1.269	1.232	1.106	1.187	1.150	1.521	1.318	1.351	1.385	1.518	1.130	1.554	1.545	1.421	1.475
Mn	0.044	0.041	0.039	0.041	0.043	0.037	0.037	0.037	0.046	0.043	0.052	0.043	0.051	0.050	0.062	0.059
Mg	3.366	3.301	3.275	3.479	3.277	3.449	2.734	2.921	2.846	2.884	2.664	3.258	2.716	2.743	3.010	2.995
Σ(Al^{VI} to Mg)	5.013	5.006	5.033	5.020	5.027	5.038	5.048	5.065	5.114	5.068	5.071	5.076	5.088	5.056	5.057	5.033
R^{2+}* in M4	0.013	0.005	0.033	0.021	0.027	0.038	0.048	0.065	0.113	0.068	0.071	0.074	0.088	0.087	0.056	0.034
Ca	1.973	1.989	1.929	1.955	1.942	1.918	1.896	1.861	1.758	1.854	1.847	1.841	1.812	1.815	1.879	1.928
Na(M4)	0.015	0.006	0.038	0.024	0.031	0.044	0.056	0.074	0.128	0.078	0.081	0.085	0.100	0.099	0.064	0.039
Σ(M4)	2.001	2.000	2.000	2.000	2.000	2.000	2.000	2.000	1.999	2.000	1.999	2.000	2.000	2.001	1.999	2.001
Na(A)	0.136	0.166	0.144	0.135	0.182	0.075	0.320	0.317	0.306	0.321	0.482	0.251	0.476	0.461	0.195	0.170
K	0.015	0.022	0.024	0.015	0.037	0.024	0.082	0.061	0.045	0.054	0.097	0.068	0.083	0.097	0.058	0.065
Σ(A)	0.151	0.188	0.168	0.150	0.219	0.099	0.402	0.378	0.351	0.375	0.579	0.319	0.559	0.558	0.253	0.235

* $R^{2+}=Fe^{2+}+Mg+Mn$.

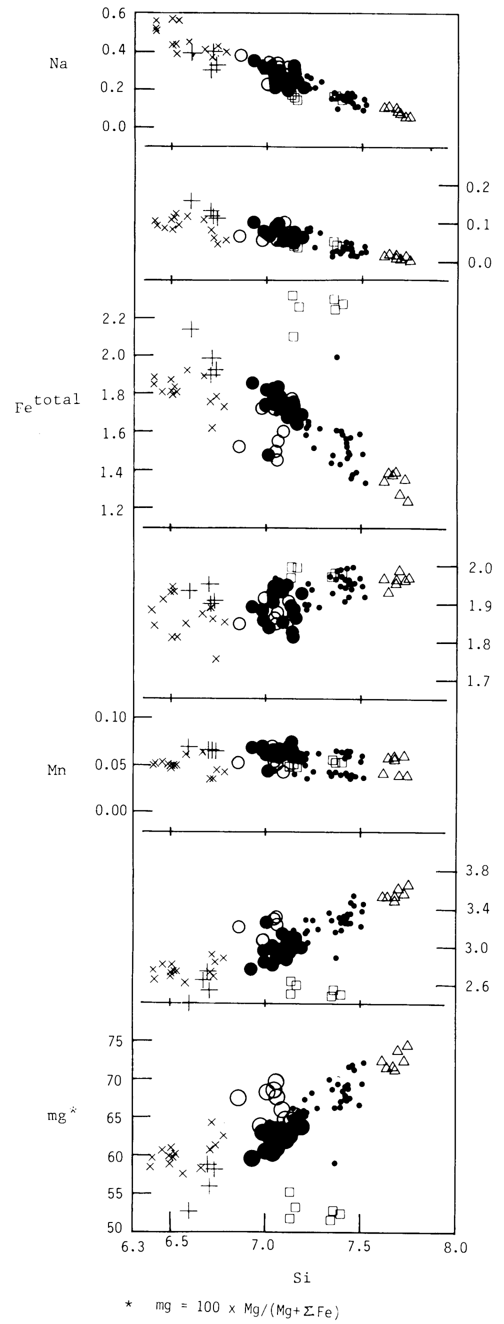
C, pale brown core : PG, pale green zone : O, green oscillatory zone : U, green uniform zone : DG, dark green zone, in equigranular quartz diorite.
g, pale green rim, in porphyritic quartz diorite.

Table 1 — 5 Microprobe analyses of amphiboles (continued).

	032518																		
	g-2-1	g-2-2	g-2-3	g-2-4	g-2-5	g-2-6	g-2-7	c-3-1	c-3-2	g-3-3	g-4-1	g-4-2	c-4-3	g-4-4	g-5-1	g-5-2	g-5-3	g-5-4	c-5-5
SiO_2	47.81	47.74	48.39	48.05	46.93	47.90	48.48	44.70	43.71	47.23	49.02	48.99	45.56	48.97	47.81	47.67	47.91	47.91	45.43
TiO_2	1.27	1.16	1.04	1.15	1.50	1.50	0.91	1.59	1.70	1.00	1.09	1.09	1.52	1.03	0.96	1.02	1.05	1.01	1.49
Al_2O_3	6.77	6.61	6.34	6.15	7.20	6.63	5.45	8.10	9.09	5.98	5.74	5.68	8.79	6.11	6.02	5.96	6.24	6.02	8.38
Fe_2O_3	3.09	2.10	2.35	3.08	1.98	2.94	3.54	3.77	2.76	2.81	3.04	3.00	2.68	2.38	3.18	3.63	3.39	2.89	3.55
FeO	12.14	12.98	12.13	11.32	13.27	11.60	11.16	11.82	14.50	12.20	11.61	11.65	13.83	12.25	11.58	10.88	11.41	11.74	12.40
MnO	0.52	0.50	0.54	0.58	0.55	0.56	0.54	0.52	0.54	0.51	0.61	0.54	0.54	0.56	0.49	0.54	0.50	0.52	0.52
MgO	13.02	12.79	13.17	13.82	12.60	13.65	13.91	12.27	10.73	12.92	13.92	13.97	11.70	13.54	13.43	13.78	13.49	13.49	12.18
CaO	12.24	12.24	12.40	12.16	11.97	11.91	12.14	12.18	11.97	12.21	11.70	11.65	12.04	12.12	12.22	12.13	12.39	12.23	12.04
Na_2O	0.79	0.89	0.66	0.99	1.22	1.09	0.85	1.05	1.38	0.77	1.08	1.11	1.40	0.90	0.83	0.89	0.74	0.89	1.17
K_2O	0.42	0.48	0.32	0.46	0.53	0.42	0.40	0.70	0.83	0.51	0.30	0.32	0.64	0.37	0.42	0.46	0.45	0.45	0.61
Total	98.07	97.49	97.34	97.76	97.75	98.20	97.38	96.70	97.21	96.14	98.11	98.00	98.70	98.23	96.94	96.96	97.57	97.15	97.77
	Structural formulae based on O=23																		
Si	6.998	7.043	7.108	7.038	6.929	6.986	7.121	6.697	6.595	7.065	7.136	7.139	6.713	7.130	7.068	7.039	7.036	7.070	6.727
Al^{IV}	1.002	0.957	0.892	0.962	1.071	1.014	0.879	1.303	1.405	0.935	0.864	0.861	1.287	0.870	0.932	0.961	0.964	0.930	1.273
Σ(Tet.)	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	0.166	0.192	0.206	0.100	0.182	0.125	0.065	0.128	0.212	0.119	0.121	0.115	0.239	0.178	0.117	0.076	0.116	0.117	0.190
Ti	0.140	0.129	0.115	0.127	0.167	0.165	0.101	0.179	0.193	0.113	0.119	0.119	0.168	0.113	0.107	0.113	0.116	0.112	0.166
Fe^{3+}	0.340	0.233	0.260	0.339	0.220	0.322	0.391	0.425	0.313	0.316	0.331	0.327	0.297	0.260	0.353	0.403	0.375	0.321	0.395
Fe^{2+}	1.486	1.602	1.491	1.387	1.639	1.416	1.372	1.482	1.830	1.526	1.415	1.422	1.705	1.492	1.432	1.344	1.401	1.449	1.536
Mn	0.064	0.062	0.067	0.072	0.069	0.069	0.067	0.066	0.069	0.065	0.075	0.067	0.067	0.069	0.061	0.068	0.062	0.065	0.065
Mg	2.841	2.813	2.884	3.018	2.773	2.968	3.046	2.741	2.414	2.881	3.021	3.035	2.570	2.939	2.960	3.033	2.953	2.968	2.689
Σ(Al^{VI} to Mg)	5.037	5.031	5.023	5.043	5.050	5.065	5.042	5.021	5.031	5.020	5.082	5.085	5.046	5.051	5.030	5.037	5.023	5.032	5.041
R^{2+}* in M4	0.037	0.030	0.023	0.043	0.050	0.065	0.042	0.021	0.030	0.020	0.082	0.085	0.046	0.051	0.030	0.038	0.023	0.031	0.042
Ca	1.920	1.935	1.952	1.908	1.894	1.861	1.911	1.955	1.935	1.957	1.825	1.819	1.901	1.891	1.936	1.919	1.950	1.934	1.910
Na(M4)	0.043	0.035	0.026	0.049	0.057	0.074	0.048	0.024	0.035	0.023	0.093	0.096	0.053	0.058	0.034	0.043	0.027	0.036	0.048
Σ(M4)	2.000	2.000	2.001	2.000	2.001	2.000	2.001	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.001	2.000
Na(A)	0.181	0.220	0.162	0.232	0.292	0.234	0.194	0.281	0.369	0.200	0.212	0.218	0.347	0.196	0.204	0.212	0.184	0.219	0.288
K	0.078	0.090	0.060	0.086	0.100	0.078	0.075	0.134	0.169	0.097	0.056	0.059	0.120	0.069	0.079	0.087	0.084	0.085	0.115
Σ(A)	0.259	0.310	0.222	0.318	0.392	0.312	0.269	0.415	0.529	0.297	0.268	0.277	0.467	0.265	0.283	0.299	0.268	0.304	0.403

* $R^{2+}=Fe^{2+}+Mg+Mn$.

c, pale brown core : g, pale green rim, in porphyritic quartz diorite.



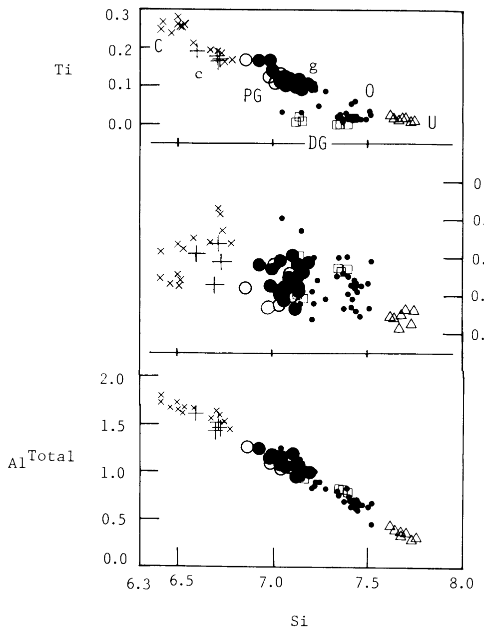


Fig. 1 Compositional variations of amphiboles. ×, pale brown core (C) : large open circle, pale green zone (PG) : small solid circle, green oscillatory zone (O) : triangle, green uniform zone (U) : square, dark green zone (DG), in equigranular quartz diorite. Cross, pale brown core (c) : large solid circle, pale green rim (g), in porphyritic quartz diorite.

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