

Coexisting amphiboles from the Noranda area, Quebec: extension of the actinolite–hornblende miscibility gap to iron-rich bulk compositions

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Abstract

Electron microprobe analyses of apparently equilibrium pairs of coexisting actinolite and hornblende from the metamorphosed Flavrian Pluton near Noranda, Quebec, demonstrate that the actinolite–hornblende miscibility gap extends to extremely iron-rich compositions [$\text{Mg}/(\text{Mg} + \text{Fe}^{2+})$ of 0.1].

Introduction

The presence of a miscibility gap within the calcic amphiboles is indicated by the fairly common occurrence of coexisting actinolite and hornblende in upper greenschist–lower amphibolite facies rocks. Such amphiboles have been described by numerous authors, e.g. Klein (1969), Cooper and Lovering (1970), Brady (1974), Hietanen (1974), and Kuenbaum and Gittins (1974). The purpose of this note is to report chemical analyses of coexisting amphiboles from the Noranda district of Quebec. The compositions of these amphiboles extend the actinolite–hornblende miscibility gap to extremely iron-rich compositions.

Geological setting of samples

All samples in which coexisting amphiboles were analyzed are from the Flavrian Pluton, a 17 km × 8 km intrusion 8 km NE of Noranda, Quebec. We have also observed coexisting actinolite and hornblende in rocks from the Western Lake Dufault Pluton, 8 km east of the Flavrian Pluton, and from a mafic metavolcanic unit (the “Amulet Andesite”) in the area between the two plutons. (The Lake Dufault sample was kindly provided by Dr. G. R. Webber of McGill University, Montreal.)

The Flavrian Pluton, comprising metatrandhjemite and lesser amounts of quartz metagabbro and hybrid metatonalites, has been described in detail by Goldie (1976). Zircons from the Powell Pluton, considered to be a faulted extension of the Flavrian Pluton, and from the metavolcanic rocks which the plutons intrude, have been dated by Krogh and Davis (1971, 1974). They found the intrusion to be 2709

million years old, and the metavolcanic rocks to be “a few million years older.”

Metamorphism

On the basis of textural features, nearly all minerals in the Flavrian Pluton are judged to be of secondary origin. Exceptions, igneous plagioclase and clinopyroxene crystals, are rare. Amphiboles occur as aggregates of randomly-oriented fine-grained crystals, which together with chlorite, stilpnomelane, and ilmenite have replaced igneous pyroxenes.

Goldie (1976) mapped a number of isograds in the Flavrian Pluton, based on model reactions among the observed secondary minerals. From the resulting isograd pattern, Goldie inferred that the distribution of assemblages of secondary minerals throughout the pluton could be related to regular regional-scale variations in temperature and the composition of an $\text{H}_2\text{O}-\text{CO}_2$ gas phase. We believe, therefore, that the secondary minerals are the result of low-grade regional metamorphism during the Kenoran Orogeny (2709–2650 m.y.). Both the Flavrian Pluton and surrounding metavolcanics contain mineral assemblages indicative of greenschist to epidote–amphibolite facies metamorphism.

Mineralogy

Hornblende and actinolite occur not only as independent crystals, but as rims on one another (Fig. 1), as interfingering interlaminated intergrowths, and as irregular patchy intergrowths (Fig. 2). Hornblende is distinguishable by its green, yellow-green, brown-green, or blue-green color and strong pleochroism,

whereas actinolite is colorless to pale green and only weakly pleochroic. In all cases a sharp Becke line separates the two phases. Zoning in the hornblende of some samples (e.g. samples 4, 5) is indicated by color variations as shown in Figure 1.

Chemical analyses

Amphiboles were analyzed with an ARL-AMX electron microprobe, using an energy-dispersive system set up and supervised by P. L. Roeder of Queen's University. Ancillary apparatus consisted of a Princeton Gamma-Tech detector (resolution 160 eV at FWHM), NS-880 multichannel analyzing system, and PDP-11 computer. Nine elements were measured and apparent concentrations corrected for matrix effects by the method of Bence and Albee (1968), using alpha factors from Albee and Ray (1970). Chemical analyses are listed in Table 1.

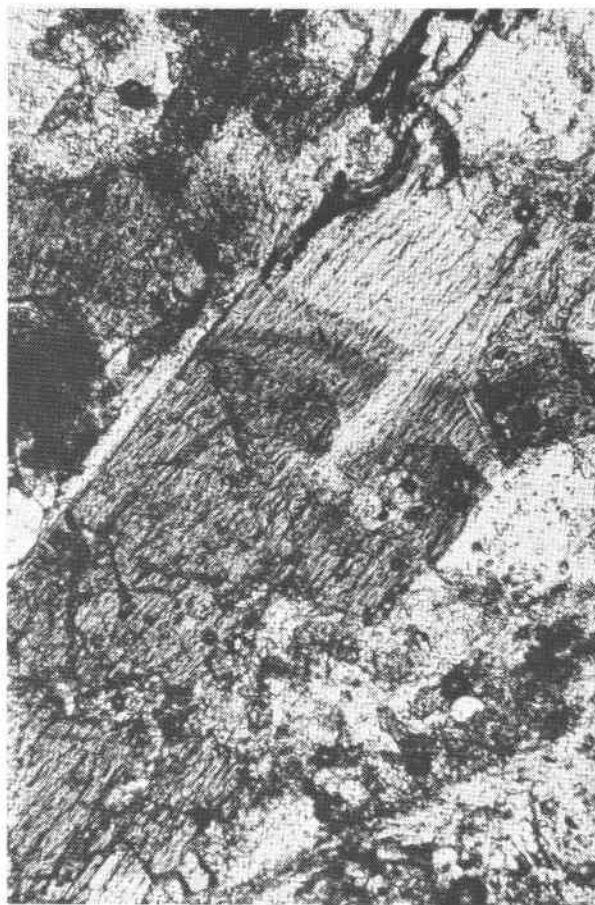


Fig. 1. Actinolite rim (clear) on a zoned hornblende crystal (dark grey) in quartz metagabbro from the Flavrian Pluton. Unanalyzed sample. Plane-polarized light. The field of view is 0.6×0.4 mm.

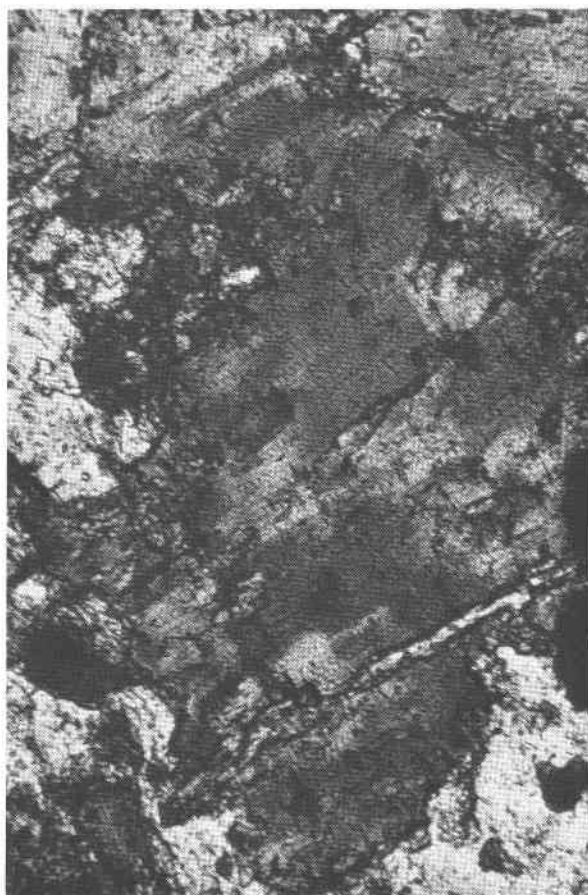


Fig. 2. Patchy intergrowth of actinolite (light grey) and hornblende (dark grey), in metatronohjemite from the Flavrian Pluton (analyzed sample, number 3). Plane polarized light. The field of view is 0.6×0.4 mm.

Ionic proportions are given in Table 1 on an H_2O -free basis of 23 oxygens. Ferric iron was not determined, and has been estimated from crystal-chemical constraints according to the method described by Stout (1972) and used by Brady (1974). In accord with this procedure, the ionic proportions are the means of those calculated firstly assuming that cations exclusive of Na and K fill the tetrahedral and $M(1-4)$ sites (giving a minimum estimate of Fe^{3+}), and secondly assuming that cations exclusive of Ca, Na, and K fill the tetrahedral and $M(1-3)$ sites (maximum Fe^{3+}). An APL computer program written by D. M. Carmichael (of Queen's University) and J. M. Allen, facilitated the calculations. $Fe^{3+}/(Fe^{2+} + Fe^{3+})$ values for actinolite are in the range 0.003–0.10, but for hornblende are a little higher, in the range 0.03–0.23.

Table 1. Electron microprobe analyses of coexisting Ca-amphiboles from the Flavrian Pluton, Noranda District, Quebec.

	1-Hb	1-Ac	2-Hb	2-Ac	3-Hb	3-Ac	4-Fhb	4-Fac	5-Fhb	5-Fac
SiO ₂	44.60	52.20	49.08	52.09	48.40	51.81	46.51	50.30	46.47	49.98
TiO ₂	0.07	0.15	0.58	0.08	0.28	0.20	0.47	0.10	0.61	0.06
Al ₂ O ₃	8.40	1.50	2.70	0.13	3.68	0.49	4.01	0.00	3.00	0.39
FeO*	27.27	21.55	28.89	25.90	27.88	25.38	30.73	32.52	32.34	33.50
MnO	0.15	0.33	0.36	0.39	0.29	0.10	0.36	0.57	0.73	0.54
MgO	4.93	9.71	5.82	7.23	5.49	7.66	2.84	2.91	2.34	2.32
CaO	11.73	12.24	10.14	12.13	10.92	11.67	12.57	11.69	11.02	11.06
Na ₂ O	0.99	0.00	0.62	0.01	0.80	0.05	0.69	0.19	0.44	0.00
K ₂ O	0.30	0.02	0.31	0.00	0.11	0.03	0.34	0.01	0.55	0.04
Total	98.44	97.70	98.50	97.96	97.85	97.39	98.52	98.29	97.50	97.89
Cations on Anhydrous Basis of 23 Oxygens										
Si	6.852	7.824	7.515	7.965	7.476	7.920	7.340	7.944	7.433	7.919
Al ^{iv}	1.148	0.176	0.485	0.023	0.524	0.080	0.660	-	0.566	0.073
Al ^{vi}	0.373	0.089	0.002	-	0.146	0.008	0.086	-	-	-
Ti	0.008	0.017	0.067	0.009	0.033	0.023	0.056	0.012	0.074	0.007
Fe ^{3+*}	0.479	0.088	0.495	0.041	0.280	0.117	0.113	0.053	0.295	0.201
Fe ^{2+*}	3.025	2.612	3.204	3.271	3.321	3.127	3.942	4.242	4.030	4.237
Mn	0.020	0.042	0.047	0.051	0.038	0.013	0.048	0.076	0.099	0.073
Mg	1.129	2.169	1.328	1.648	1.264	1.745	0.668	0.685	0.558	0.548
Ca	1.931	1.965	1.663	1.987	1.807	1.911	2.125	1.978	1.888	1.877
Na	0.295	-	0.184	0.003	0.240	0.015	0.212	0.058	0.137	-
K	0.059	0.004	0.061	-	0.022	0.006	0.069	0.002	0.113	0.008

*Total iron expressed as FeO.

** Calculated according to the procedure of Stout (1972), and Brady (1974).

N.B. All samples contain albite, epidote, quartz, and ilmenite, in addition to the minerals listed below.

Sample 1: Hornblende and actinolite from a single intergrowth in hybrid metatonalitic rock containing K-feldspar, sphene and apatite. Location: South end of lot 35, range IX, Beauchastel Township.

Sample 2: Mean composition of three hornblende-actinolite intergrowths in trondhjemite containing stilpnomelane. Location: North end of lot 23, range II, Duprat Twp.

Sample 3: Mean composition of three hornblende-actinolite intergrowths in metatrandhjemite containing chlorite, sphene, apatite, and zircon. Location: Center of lot 39, range V, Duprat Twp.

Sample 4: Ferrohornblende and ferroactinolite from a single intergrowth in hybrid metatonalitic rock containing muscovite, stilpnomelane, sphene, apatite, and augite (a primary, igneous phase). Location: North end of lot 52, range II, Duprat Twp.

Sample 5: Ferrohornblende and ferroactinolite from a single intergrowth in hybrid metatonalitic rock containing chlorite, stilpnomelane, apatite, and augite (a primary, igneous phase). Location: Same as sample 4.

Compositions of coexisting amphiboles

Compositions of actinolite and hornblende are plotted in terms of Na + K *vs.* X_{Mg} [$X_{Mg} = Mg/(Mg + Fe^{2+})$], and tetrahedrally-coordinated aluminum *vs.* X_{Mg} in Figures 3 and 4 respectively.

The compositions of actinolite and hornblende in samples 1-3 vary little from grain to grain. For sam-

ples 2 and 3, the analyses are averages of those from three actinolite-hornblende intergrowths. Samples 1-3 define an actinolite-hornblende miscibility gap in the range $X_{Mg} = 0.28-0.45$. In samples 4 and 5, however, there is a wide range of composition both within composite actinolite-hornblende grains, and from grain to grain. Individual spot analyses are plotted in Figures 3 and 4. On these diagrams, horn-

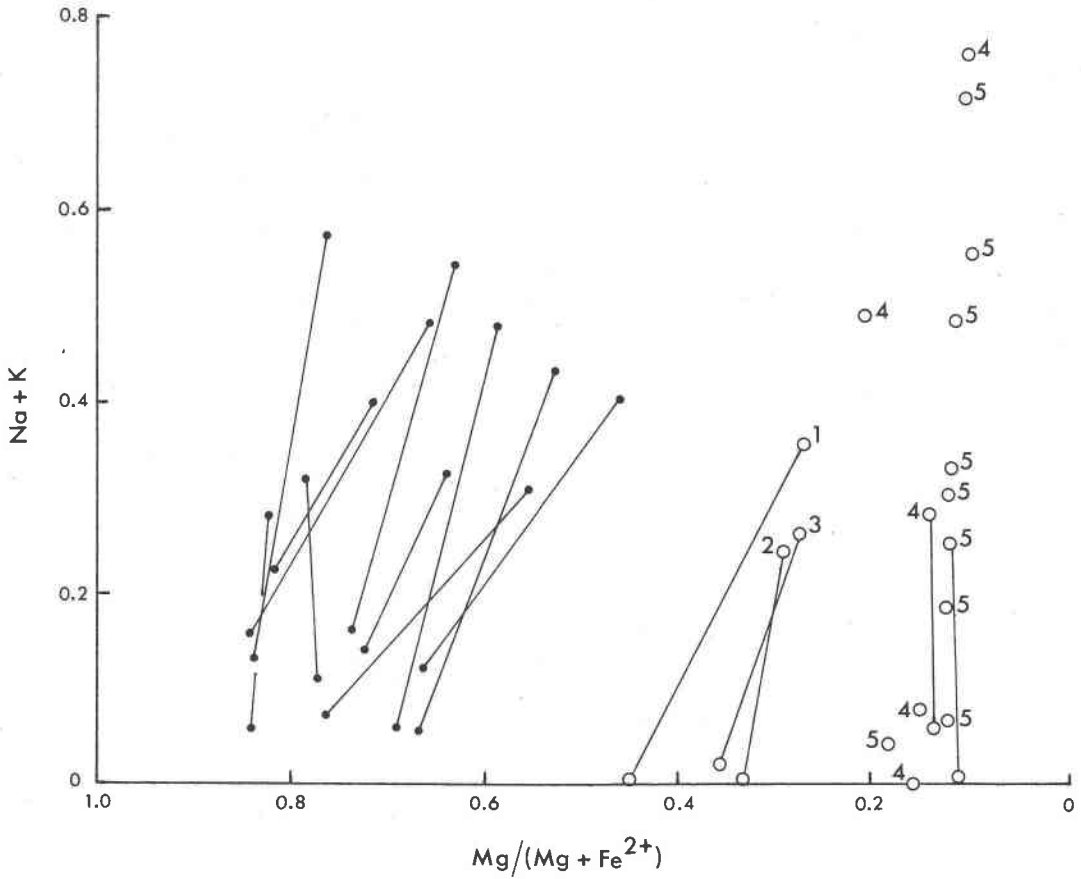


Fig. 3. Amphibole compositions plotted in terms of Na + K versus Mg/(Mg + Fe²⁺). Circles = amphiboles from the Flavrian Pluton. Dots = actinolite and hornblende analyses from Klein (1969), Cooper and Lovering (1970), and Brady (1974). Tie lines join coexisting amphiboles in the same sample.

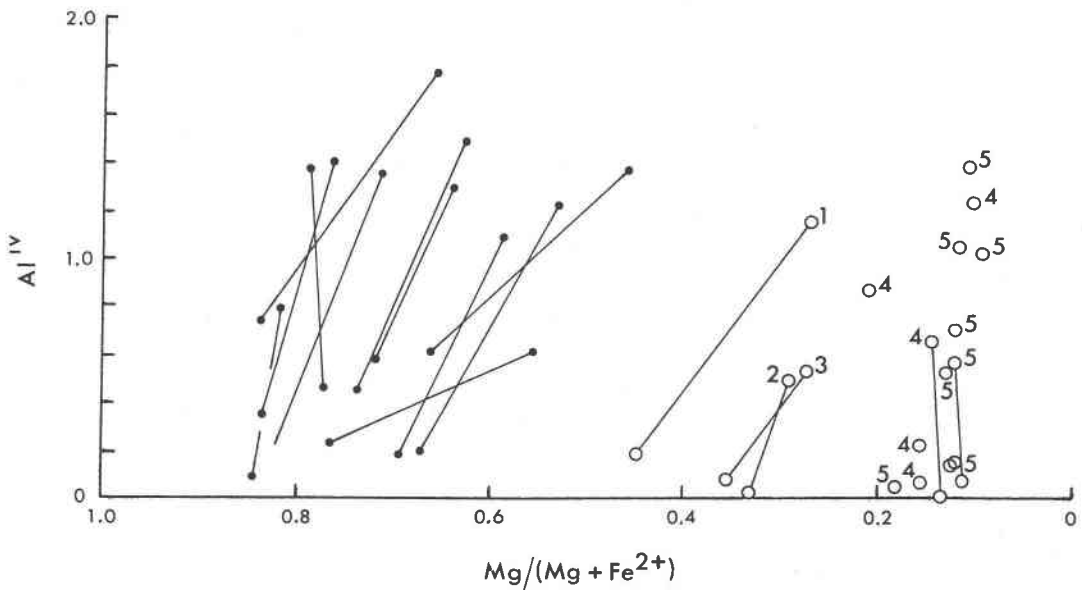


Fig. 4. Amphibole compositions plotted in terms of tetrahedral aluminum versus Mg/(Mg + Fe²⁺). Symbols as for Fig. 1.

blende shows the greatest variation in composition, with Na + K up to 0.7 and Al^{iv} up to 1.4 in sample 5. Tie lines have only been drawn between analyses of immediately adjacent actinolite and hornblende in the same intergrowth. Note that few analyses plot inside the area defined by the tie lines. In spite of the wide variation in amphibole composition indicative of disequilibrium in samples 4 and 5, analyses of immediately adjacent actinolite and hornblende appear to give a consistent miscibility gap at very high iron to magnesium ratios. Equilibrium may therefore have been closely approached, but only over distances of the order of a few tens of microns.

For comparison, previously published analyses of coexisting actinolite and hornblende from Klein (1969), Cooper and Lovering (1970), and Brady (1974) are shown as dots in Figures 3 and 4. These analyses, plus others reported in the literature (e.g. Hietanen, 1974) lie at lower iron contents ($X_{Mg} > 0.5$) than those described here. Assuming a close approach to chemical equilibrium in our samples, the data suggest that the actinolite-hornblende miscibility gap extends to very high iron contents (X_{Mg} as low as 0.1 in sample 5), and therefore covers most of the possible range of iron to magnesium ratios.

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