

SHORT COMMUNICATIONS

MINERALOGICAL MAGAZINE, MARCH 1982, VOL. 46, PP. 127-30

A banded iron-formation assemblage containing clinopyroxene, andradite, babingtonite, and cronstedtite

IN the Weld Range, Western Australia, an Archaean banded iron formation (Gole, 1980*a, b*) containing unusual metamorphic assemblages has been intersected by exploratory diamond drilling. The banded iron formation consists of andradite-diopside-magnetite mesobands alternating with quartz-rich mesobands containing augite and magnetite. One sample (UWA Rock Store No. 84774) contains numerous veins, up to 5 mm wide. The veins have margins up to several cm wide in which the vein assemblages and those of the mesoband are intricately intermixed. The minerals in the veins and vein margins in the andradite-diopside mesobands are clinopyroxene, andradite, and minor babingtonite, magnetite, cronstedtite,

stilpnomelane, calcite, epidote, and marcasite. The dominant clinopyroxene is green and in the vein margins commonly contains colourless cores of diopside whereas clinopyroxene within the veins may have thin rims of colourless hedenbergite. Contacts between the diopside core and green clinopyroxene and between the green clinopyroxene and colourless hedenbergite rims are sharp. Andradite coexisting with diopside is slightly pink and is isotropic. In veins and vein margins isotropic andradite grains have colourless, anisotropic rims.

This is the first reported occurrence of babingtonite in any banded iron formation. Babingtonite is found typically associated with zeolites in veins

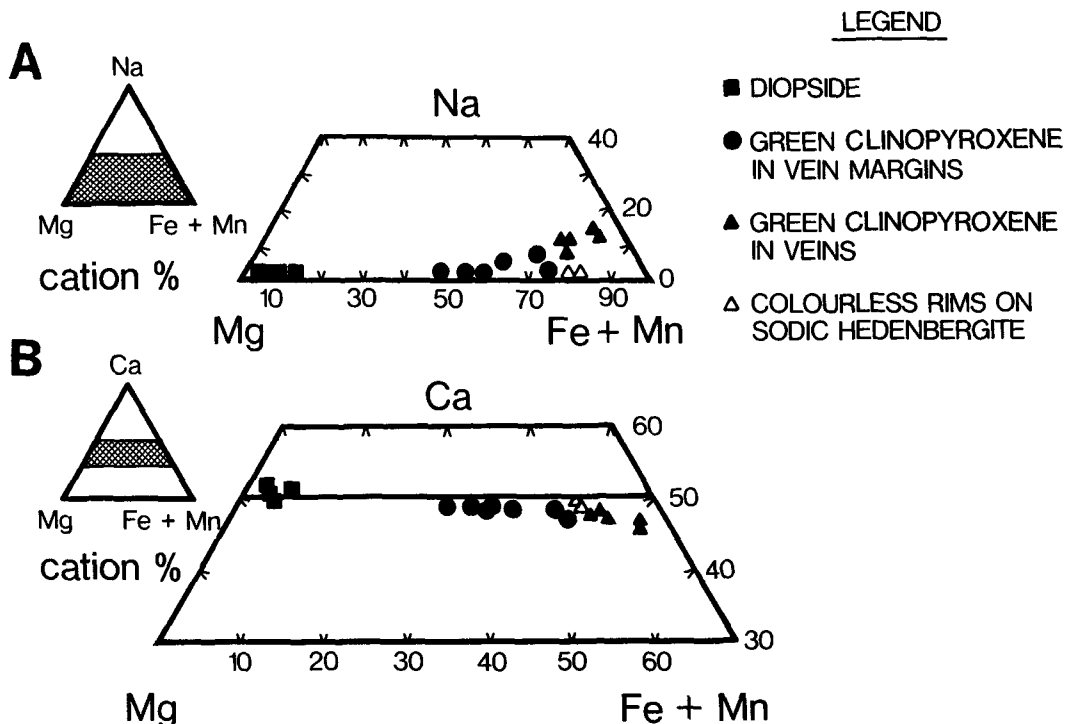


Fig. 1. Compositional variation in clinopyroxenes from sample 84774, plotted (A) within the system Mg-(Fe+Mg)-Na and (B) within the system Mg-(Fe+Mn)-Ca. All Fe as FeO.

and cavities in very low-grade metabasites and it also occurs in Ca-Fe-Si skarns (Burt, 1971).

Bundles of optically aligned, fibrous cronstedtite, with dark red-brown to emerald green pleochromism, occur in veins and vein margins. X-ray powder patterns show the cronstedtite to have a 7.08 Å basal spacing.

Minerals in the veins show no textural evidence of mutual reaction or replacement except for colourless hedenbergite and marcasite. The colourless rims on green clinopyroxene grains have fine 'saw-tooth'-like projections that disrupt boundaries with neighbouring grains. Marcasite cuts across babingtonite-clinopyroxene grain

boundaries and is later in the paragenetic sequence than these two minerals.

Mineral compositions. Clinopyroxenes show a wide range in Fe, Mg, Na, and estimated Fe³⁺. Diopside, coexisting with andradite or as cores in green clinopyroxene grains, has a nearly pure MgO end-member composition (Table I, no. 1). There is a considerable gap in the Fe/(Fe+Mg) ratio between diopside and the most Mg-rich green clinopyroxene (fig. 1). Electron beam scans across diopside core and green clinopyroxene rim contacts show them to be sharp. Green clinopyroxenes containing diopside cores are zoned with Fe/(Fe+Mg) varying from 0.59 in the centre to 0.77 on the

TABLE I. Probe analyses of clinopyroxene, andradite, and babingtonite in sample 84774

	1	2	3	4	5	6	7
SiO ₂	54.1	51.1	48.5	50.2	35.7	35.3	53.0
TiO ₂	0.03	0.01	0.04	0.00	0.02	0.00	0.00
Al ₂ O ₃	0.30	0.14	0.98	0.03	0.10	6.21	0.45
FeO*	2.36	18.3	25.8	23.3	28.8	21.2	22.6
MnO	0.17	0.20	0.30	0.56	0.12	0.16	1.34
MgO	17.1	7.2	2.33	3.03	0.02	0.00	0.55
CaO	25.8	23.4	20.6	22.8	32.1	34.5	20.0
Na ₂ O	0.01	0.18	1.30	0.10	0.00	0.00	0.03
Total	99.87	100.53	99.85	100.02	96.86	97.37	97.97
Fe ₂ O ₃	0.4†	0.7†	4.8†	0.2†	31.3‡	23.6‡	13.7§
FeO	2.0	17.7	21.5	23.1	0.7	0.0	10.3
Total	99.91	100.63	100.35	100.02	100.06	99.77	99.37
Number of Oxygens							
	6	6	6	6	24	24	14.5
Si	1.98	1.99	1.95	2.01	6.03	5.94	4.98
Al	0.01	0.01	0.05	0.00	0.00	0.06	0.02
	1.99	2.00	2.00	2.01	6.03	6.00	5.00
Al	0.00	0.00	0.00	0.00	0.02	1.17	0.03
Fe ³⁺	0.01	0.02	0.15	0.01	3.98	2.69	0.97
Fe ²⁺	0.06	0.58	0.72	0.78	0.09	0.00	0.81
Mn	0.01	0.01	0.01	0.02	0.02	0.02	0.11
Mg	0.93	0.42	0.14	0.18	0.01	0.00	0.08
Ca	1.01	0.98	0.89	0.98	5.81	6.22	2.01
Na	0.00	0.01	0.10	0.01	0.00	0.00	0.00
	2.02	2.02	2.01	1.98	9.93	10.10	4.01

Correction procedure of Bence and Albee (1968).

* All Fe as FeO. † Fe₂O₃ estimated by the method of Papike *et al.* (1974). ‡ Fe₂O₃ assuming B site = 4.00. § Fe₂O₃ assuming B site = 1.00.

1. Diopside core in ferrosahlite. 2. Ferrosahlite in vein margin. 3. Green hedenbergite in vein. 4. Colourless rim on green hedenbergite. 5. Isotropic andradite coexisting with diopside. 6. Anisotropic rim on andradite in vein margin. 7. Babingtonite in vein.

edges. Clinopyroxenes in the veins are zoned over a narrower and more Fe-rich range of 0.86 to 0.93 (fig. 1). The most Fe-rich hedenbergites have the highest Na₂O and estimated Fe₂O₃ contents (fig. 1). Colourless rims to sodic hedenbergite are hedenbergite with negligible Na₂O and estimated Fe₂O₃ contents (Table I, no. 4; fig. 1).

Andradite coexisting with diopside is homogeneous and has an almost pure end-member composition (And = 97, Table I, no. 5), whereas a small grossular component is present in andradite occurring as anisotropic rims on isotropic andradite grains (Table I, no. 6).

The babingtonite (Table I, no. 7) is very Fe-rich and contains small amounts of Al₂O₃ and MnO which are common in most babingtonite analyses (Vinogradova and Plyusnina, 1967). From the probe analysis, an estimate of Fe₂O₃ has been made based on the babingtonite formula, Ca₂Fe²⁺Fe³⁺Si₅O₁₄(OH).

Probe analyses of cronstedtite (Table II) show wide variations in composition from points several microns apart, reflecting a variety of layer stacking sequences within very small volumes (Steadman and Nuttall, 1964; Bailey, 1975). The main variations are in SiO₂ and Fe as FeO, which vary antithetically. Recalculation of the analyses on the basis of the 10 cations in the cronstedtite formula, (R_{3-x}R_x³⁺) (Si_{2-x}R_x³⁺) O₅(OH)₄, results in Fe³⁺ substituting for Si in the tetrahedral site in all but two of the compositions in Table II. As SiO₂ decreases, more Fe³⁺ is required to fill both the tetrahedral and octahedral sites. The amount of Fe³⁺ calculated in the octahedral sites approximately equals the total of Al and Fe³⁺ in the tetrahedral sites, as is required for charge balance. Additional Fe³⁺ may, however, also be balanced by vacancies in the structure and as these are not accounted for, the Fe₂O₃ estimated for the cronstedtites in Table II are minimum values.

TABLE II. Probe analyses of cronstedtite in sample 84774

	1	2	3	4	5	6	7
SiO ₂	34.5	33.4	30.9	29.7	27.3	27.1	26.3
TiO ₂	0.04	0.01	0.00	0.02	0.02	0.00	0.00
Al ₂ O ₃	1.10	0.68	0.77	0.76	0.73	0.76	0.74
FeO*	36.6	37.1	44.8	43.5	47.5	47.6	48.2
MnO	2.38	1.96	3.00	2.26	3.10	3.20	3.05
MgO	8.12	7.50	7.60	7.80	6.60	6.86	6.66
CaO	3.68	5.26	1.87	2.53	1.05	0.84	0.76
Na ₂ O	0.10	0.12	0.10	0.15	0.10	0.00	0.05
K ₂ O	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	86.52	86.03	89.04	86.72	86.40	86.36	85.76
Fe ₂ O ₃ †		0.3	7.7	9.0	13.3	13.4	15.2
FeO		36.8	39.9	35.4	35.5	35.5	34.5
Total		86.03	91.84	87.62	87.70	87.48	87.26
Ions per 10 cations							
Si	4.07	3.97	3.62	3.56	3.34	3.33	3.25
Al	0.00	0.03	0.11	0.11	0.10	0.11	0.11
Fe ³⁺	0.00	0.00	0.27	0.33	0.56	0.56	0.64
	4.07	4.00	4.00	4.00	4.00	4.00	4.00
Al	0.15	0.07	0.00	0.00	0.00	0.00	0.00
Fe ³⁺	0.00	0.03	0.41	0.48	0.67	0.68	0.77
Fe ²⁺	3.63	3.67	3.71	3.54	3.64	3.65	3.57
Mn	0.24	0.20	0.30	0.23	0.32	0.31	0.32
Mg	1.43	1.33	1.33	1.39	1.21	1.25	1.23
Ca	0.46	0.67	0.23	0.32	0.14	0.11	0.10
Na	0.02	0.03	0.02	0.04	0.02	0.00	0.01
	5.93	6.00	6.00	6.00	6.00	6.00	6.00

* All Fe as FeO. † Estimated assuming total cations equals 10.00.

Interpretation. The primary assemblage in the Fe-Mg silicate-rich mesoband is andradite-diopside-magnetite. This assemblage must have formed under very oxidizing conditions as nearly all Fe is in the Fe^{3+} state. A later fluid phase was introduced into the iron formation by way of a network of veins and, on a microscopic scale, by diffusion along grain boundaries. Reaction with the fluid phase resulted in replacement of andradite and diopside by mineral assemblages that progressively contain more and more Fe^{2+} . The interpreted sequence of minerals is: (andradite-diopside-magnetite) \rightarrow (andradite-ferrosahlite) \rightarrow (Sodic hedenbergite-babingtonite-Al andradite \pm cronstedtite \pm stilpnomelane \pm epidote) \rightarrow (hedenbergite and marcasite). The minerals that are last in the paragenetic sequence represent the most reduced state. These mineralogical changes indicate that the fluid was reducing and that its f_{O_2} was controlled by an external reservoir. Na, Al, and minor amounts of S were introduced into the iron formation by the fluid.

Acknowledgements. I am grateful to Amax for allowing access to their diamond drill core. J. Hillyer of the

University of Western Australia Electron Microscopy Center is thanked for his assistance. Discussions with W. Schreyer on textures were most helpful. Support from a Commonwealth Postgraduate Research Award is acknowledged.

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[Manuscript received 20 November 1980]

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CSIRO, Division of Mineralogy, Private Bag, P.O. Wembley, W.A. 6014, Australia

M. J. GOLE

MINERALOGICAL MAGAZINE, MARCH 1982, VOL. 46, PP. 130-2

Barian wölsendorfite from East Greenland

WITHIN the Devonian acid volcanic rocks of Randbøldal, northern East Greenland (Bütler, 1954), uranium has been found in concentrations of up to 1500 ppm (Secher *et al.*, 1975), two orders of magnitude above the average encountered in rhyolitic rock types (cf. Rogers and Adams 1969). Secher *et al.* (1975) have shown that the uranium is mainly concentrated in globular grains and veinlets of hydrocarbon, which are associated with sulphides, most commonly pyrite. The carburan (uraniferous hydrocarbon) mineralization is thought to be epigenetic whereby magmatic uranium was fixed by the hydrocarbons (Steenfelt, in press). Primary uranium minerals such as uraninite have not been observed, but oxidation during weathering has led to the development of limonite and yellowish secondary uranium minerals of which wölsendorfite appears to be the most prolific (Secher *et al.*, 1975). Wölsendorfite commonly forms coatings or dense aggregates in cavities

of the weathered rock but can also be associated with carburan. Optical data are impossible to obtain from the present material due to the fine-grained and turbid nature of the wölsendorfite (samples: GGU nos. 132627 and 202851).

Electron microprobe analyses have been made of an area of wölsendorfite associated with a 1×2 mm bleb of carburan in a quartz-phyric rhyolite. The wölsendorfite is yellow-orange in colour and forms a fine, platy aggregate. It is also partly intergrown with micaceous alteration products of the silicic rhyolite groundmass. The analyses show the wölsendorfite to be homogeneous with an average composition as given in Table I. The detection of Si, Al, Fe, and K may be due to impurities, such as micas, included in the probe beam, which was defocused to prevent volatile loss and specimen damage. Atomic proportions in Table I have been calculated using the basic formula $PbU_2O_7 \cdot 2H_2O$. Compared with the few