SHORT COMMUNICATIONS

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Goldmanite-rich garnet in skarn veins, Southern Cross greenstone belt, Yilgarn Block, Western Australia

GOLDMANITE, the vanadium analogue of grossular and andradite, has been reported from two principal geological environments: metamorphosed carbonaceous and calcareous shales (Badalov, 1951; Filippovskaya *et al.*, 1972; Benkerrou and Fonteilles, 1989), and skarn deposits (Momoi, 1964; Shepel' and Karpenko, 1970; Benkerrou and Fonteilles, 1989). The type specimen of goldmanite, from a metamorphosed uranium-vanadium deposit in New Mexico (Moench and Meyrowitz, 1964), represents a less common and probably unique occurrence. Goldmanite-rich garnets contain up to 24.9 wt.% V_2O_3, and the goldmanite end-member in individual garnet grains can be as high as 73 mole per cent (e.g. Deer *et al.*, 1982).

Here, we report the occurrence of V-bearing garnet (V_2O_3 = 6.0 to 8.4 wt.%) in skarn veins from the Nevoria gold deposit in the Archaean Yilgarn Block of Western Australia. The Nevoria deposit is located within the broad metamorphic aureole of the Ghooli Dome granodiorite-granite batholith (Fig. 1), and consists of several high-temperature replacement orebodies stratabound to three horizons of grunerite–quartz BIF (Mueller, 1988, 1990).

Mineralogy

The goldmanite-rich garnets occur in scheelite- and sulphide-bearing metasomatic veins, which replace hornblende–plagioclase amphibolites in zones adjacent to the stratabound gold orebodies of the mine. In general, the replacement veins are zoned from grossular–andradite cores to diopside–plagioclase margins (Fig. 2A). Retrograde clinozoisite, epidote, calcite and quartz fill cracks and interstitial spaces in and between the garnets of the vein cores, whereas muscovite and prehnite

Table 1. Microprobe analyses of garnets, Nevoria gold deposit, Western Australia.

	V-poor garnet cores		V-rich rims and late grains	
	1	2	1	2
SiO_2 (wt. %)	38.81	39.07	36.82	37.02
TiO_2	n.d.	0.15	0.38	0.19
Al_2O_3	17.81	17.12	8.14	8.89
Cr_2O_3	0.21	0.18	0.14	0.29
V_2O_3	n.d.	n.d.	8.42	6.03
Fe_2O_3	6.81	7.19	11.53	12.22
FeO	2.23	2.39	4.72	5.03
MnO	0.12	0.14	0.94	0.81
MgO	n.d.	n.d.	0.23	n.d.
CaO	34.08	34.24	30.22	30.09
Total Oxides	100.07	100.48	101.54	100.57
Number of cations on the basis of 12 oxygens				
Si	2.993	3.008	2.958	2.990
Ti	0	0.009	0.023	0.012
Al	1.619	1.553	0.771	0.846
Cr	0.013	0.011	0.009	0.019
V	0	0	0.542	0.390
Fe^{3+}	0.395	0.417	0.697	0.743
Fe^{2+}	0.144	0.154	0.317	0.340
Mn	0.008	0.009	0.064	0.055
Mg	0	0	0.028	0
Ca	2.816	2.824	2.601	2.604
Total Cations	7.988	7.985	8.010	7.999
Garnet end-members (mole %)				
Almandine	5.74	4.85	10.63	11.33
Grossular	75.03	72.39	23.30	28.72
Spessartine	0.23	0.31	2.11	1.80
Uvarovite	0.64	0.55	0.45	0.93
Andradite	18.36	21.46	35.06	37.18
Schorlomite	0	0.44	1.16	0.50
Goldmanite	0	0	27.29	19.54

All garnet analyses from one skarn vein in drill core NUG-5, 17.70 m.
n.d. = not detected.

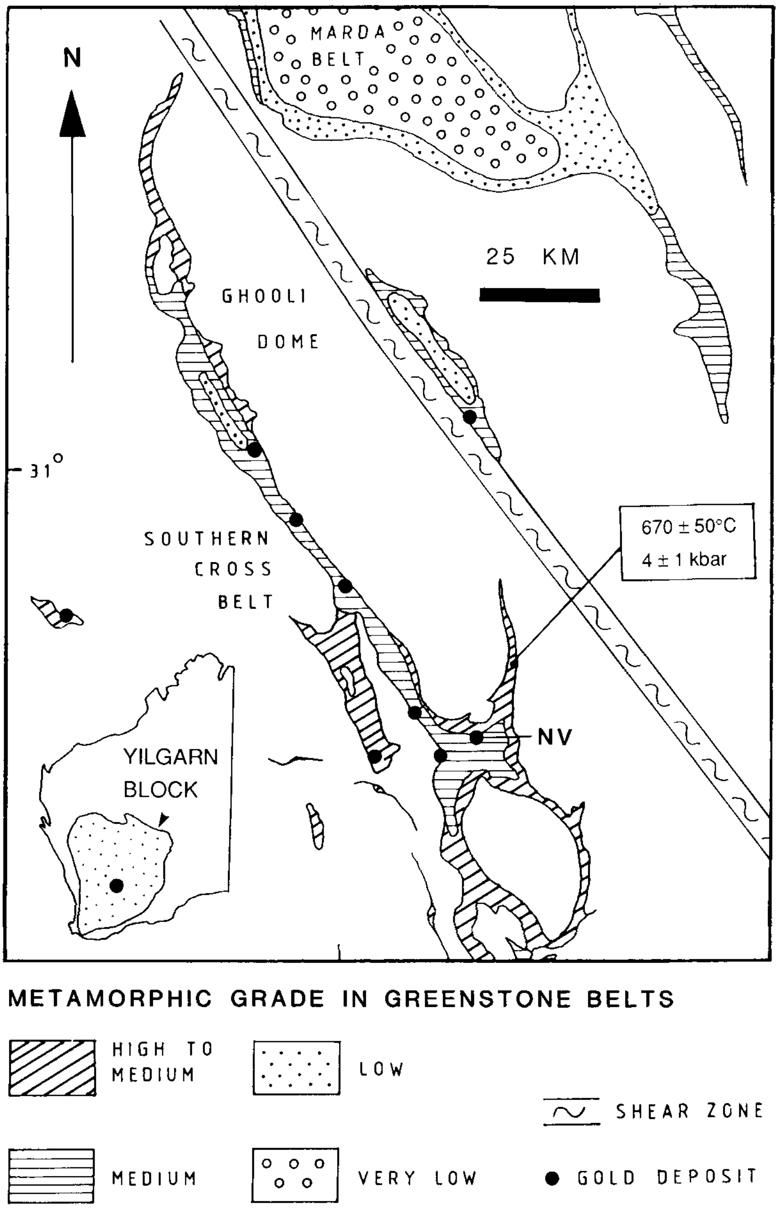

FIG. 1. Map of the Southern cross area showing the distribution of metamorphic grade in the greenstone belts (after Ahmat, 1986), and the location of the Nevoria (NV) and other gold skarn deposits. Metamorphic nomenclature is after Winkler (1979). The quantitative metamorphic *P–T* data are from Gole and Klein (1981). The inset map of Western Australia shows the outcrop area of the Archaean Yilgarn Block, and the position of the Southern Cross map.

partly replace plagioclase in the vein margins. The mafic amphibolites of the mine sequence contain between 220 and 381 ppm vanadium (Wang, 1988).

Goldmanite-rich garnet with dark orange-red colour forms the 50–75-μm wide outer rims of zoned grossular–andradite grains (Fig. 2B), and rare isolated crystals enclosed in clinozoisite. Microprobe analyses show that vanadium is highly enriched in garnet rims and in texturally late grains relative to garnet cores, the maximum recorded goldmanite content being 27.3 mole

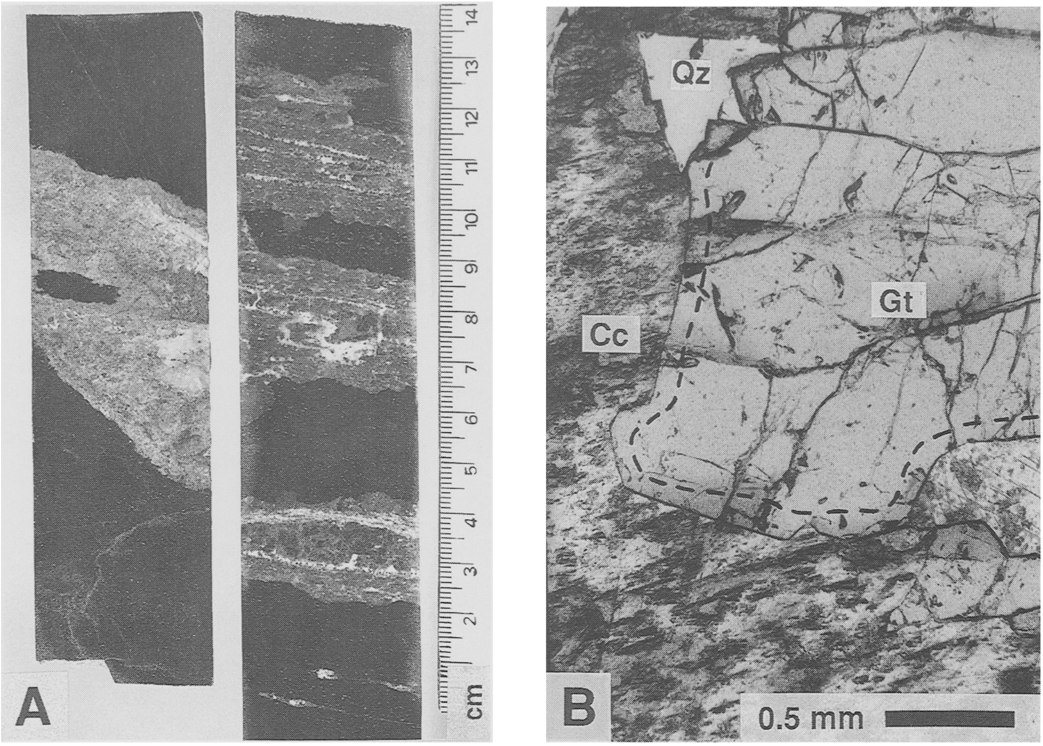

FIG. 2. Garnet in skarn veins from the Nevoria gold deposit, Southern Cross greenstone belt, Western Australia. (A) Photograph of polished drill-core specimens. The skarn veins (grey to white) are zoned from grossular-andradite cores to diopside–plagioclase margins. The irregular margins against fine-grained hornblende–plagioclase amphibolites (black) indicate replacement. (B) Photomicrograph in plane polarized light. Subhedral grossular-andradite garnet (Gt), intergrown with calcite (Cc) and quartz (Qz). The outermost zone of vanadium-enriched garnet, distinguished from the core by its deeper orange colour, is indicated by the dashed line.

per cent (Table 1). The enrichment of vanadium from core to rim is accompanied by significant enrichments in iron and manganese, and minor increases in titanium. Vanadium substitutes mainly for aluminium in the garnet lattice, leading to much lower grossular mole fractions in rims relative to cores. Schorlomite and uvarovite remain below 2 mole per cent in goldmanite-rich garnet (Table 1).

Discussion

Peak metamorphic temperatures in the Nevoria mine area are estimated at 570–610 °C (Wang, 1988), at a regional lithostatic pressure of 4 ± 1 kbar (Fig. 1). The mineralogically zoned skarn veins in the mine formed after the metamorphism of their mafic host rocks to hornblende–plagioclase amphibolites. The peak fluid temperature during skarn formation is constrained by the reaction clinozoisite + quartz + calcite = grossular to between 550 and 580 °C, assuming a pressure of 4 kbars and a low mole fraction CO_2 (0.03–0.05) in the hydrothermal fluid (Mueller, 1990).

As goldmanite-rich garnet is restricted to the rims of zoned grains and to isolated crystals enclosed in clinozoisite, we conclude that vanadium was incorporated into the grossular-andradite lattice during late growth at about 550 °C. The minimum temperature for the formation of goldmanite is considered to be about 450 °C (Deer *et al.*, 1982). The source of the vanadium in skarn at Nevoria is probably the host amphibolite. Apparently, vanadium released during the replacement process was concentrated in the fluid phase until the late stage of garnet crystallization.

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Key Centre for Teaching and Research in Strategic Mineral Deposits, Department of Geology, University of Western Australia, Nedlands W. A. 6009, Australia

A. G. MUELLER

Department of Geology, University of Western Australia, Nedlands W.A. 6009, Australia
Present address:
Département Cartes et Synthèses Géologiques, B.R.G.M., Avenue de Concyr, BP 6009, 45060 Orléans Cédex, France

C. P. DELOR