Geothermobarometry of the Indian Creek Metamorphic Suite, Tobacco Root Mountains, Montana

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INTRODUCTION

The Indian Creek Metamorphic Suite (ICMS) is a group of Archean age rocks located in the Tobacco Root Mountains, Montana. The ICMS consists predominately of quartzofeldspathic gneiss with subordinate amounts of hornblende gneiss, pelitic schist, marble, quartzite and iron formation. These rocks are part of northwestern Wyoming Province and are thought to be derived from a sequence of marine sedimentary rocks (Burger and others, 1994.) Overlying the ICMS is the distinctive Spuhler Peak Metamorphic Suite (SPMS) consisting of hornblende-plagioclase gneiss, anthophylite/gedrite-garnet-plagioclase gneiss, sillimanite schist and quartzite.

Radiometric dates for the Tobacco Roots fall into two groups. The oldest dates from the ICMS is a 2.7 Ga Rb-Sr whole rock isochron date this is correlated with an upper amphibolite to granulite event, M1 (James and Hedge, 1988). There is also evidence for another event, M2, at 1.6 to 1.8 Ga recorded by K-Ar biotite and amphibole dates (Giletti, 1966). Immega and Klien (1976) showed that most of the ICMS contains mineral assemblages typical of upper amphibolite to lower granulite facies conditions: 650-750° C and 4-6 kbars. However, some workers have suggested that these rocks may have experienced a previous high pressure granulite facies event, evidenced by the presence of sillimanite pseudomorphs after kyanite and kyanite inclusions in garnets (Burger and others, 1994; Archuleta, 1994)..

There are several possible models for the metamorphic history of the Tobacco Root Mountains. The first proposes a single metamorphic cycle with a high pressure, kyanite producing, event occurring at 2.7 Ga followed by very slow cooling through the amphibole and biotite closure temperatures at about 1.7 Ga. This slow rate of cooling would allow most of the granulite textures and mineral assemblages to re-equilibrate under amphibolite facies conditions (M2) (Dahl, 1979). The second model proposes that there were two events, the initial M1 at 2.7 followed by a separate, lower pressure (4-6 kbar), upper amphibolite to lower granulite grade event at 1.7 Ga (M2) (Dahl, 1979). A third model, suggested by Cheney and others (1994), is that the kyanite is the relict of a high pressure and lower granulite to upper amphibolite grade event that occured at 1.7 Ga (M2) and was followed by near isothermal decompression. This model is based predominately on evidence from the SPMS.

The SPMS is thought to have a very different P-T history than the ICMS (Burger and others, 1994; Brady and others, 1994) Previous workers have shown from garnet zoning patterns and the existance of cordierite replacing garnet that the SPMS followed a nearly isothermal decompression path (Archuleta, 1994). However, Brady and others (1994) suggest that the ICMS followed a counter-clockwise P-T-t path. This study attempts to resolve some of the questions regarding the metamorphic history of the ICMS based on a prograde reaction texture preserved in an amphibole gneiss, new geothermobarometric results and garnet zoning profiles.

METHODS

Ninety-two specimens of the ICMS were collected in the field and forty were thin sectioned. Preference was given to rock types containing a maximum number of mineral phases. Thus hornblende gneiss, pelitic schist, marble and iron formation predominate. Mineral chemistry and x-ray maps of six specimens were obtained using the University of Chicago Cameca-SX50 electron microprobe. This abstract focuses on specimens 36-27 and 36-28, two hornblende gneisses from Millcreek Ridge.

Temperatures and pressures were calculated with the program Thermobarometry 1.9 (Spear and Kohn, 1995) using the Powell (1985) garnet-clinopyroxene thermometer, the Moecher and others (1988) garnet-plagioclase-clinopyroxene-quartz barometer, the Harley (1985) garnet-orthopyroxene thermometer and the Powell and Holland (1987) for garnet-plagioclase-clinopyroxene-quartz barometer.

ASSEMBLAGES AND REACTION TEXTURES

The two amphibole gneiss samples from Millcreek Ridge contain predominately hornblende and plagioclase with orthopyroxene, clinopyroxene, garnet and quartz. The hornblende is fine grained and brown in plain polarized light. The composition of the plagioclase is approximately An_{52}. It is medium to large grained and in many places shows 120° triple grain boundaries. The garnet, a CaMg almandine is usually found as

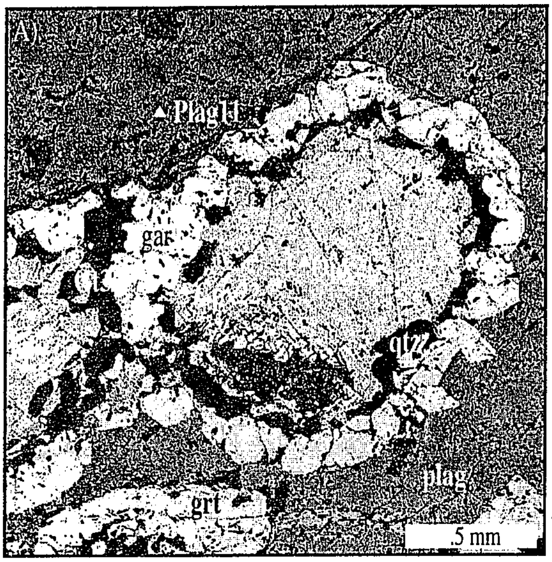
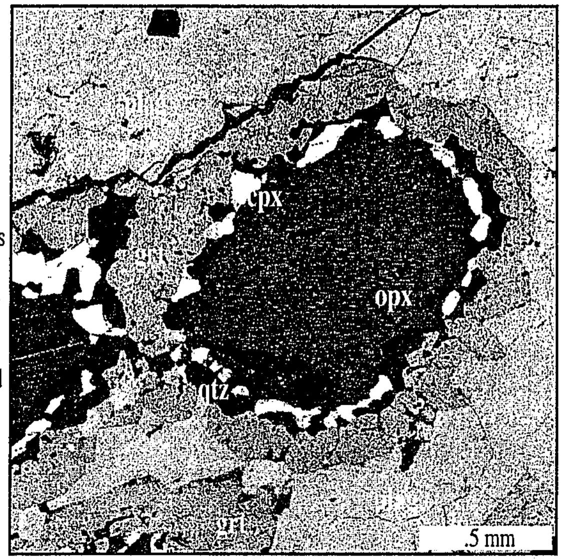
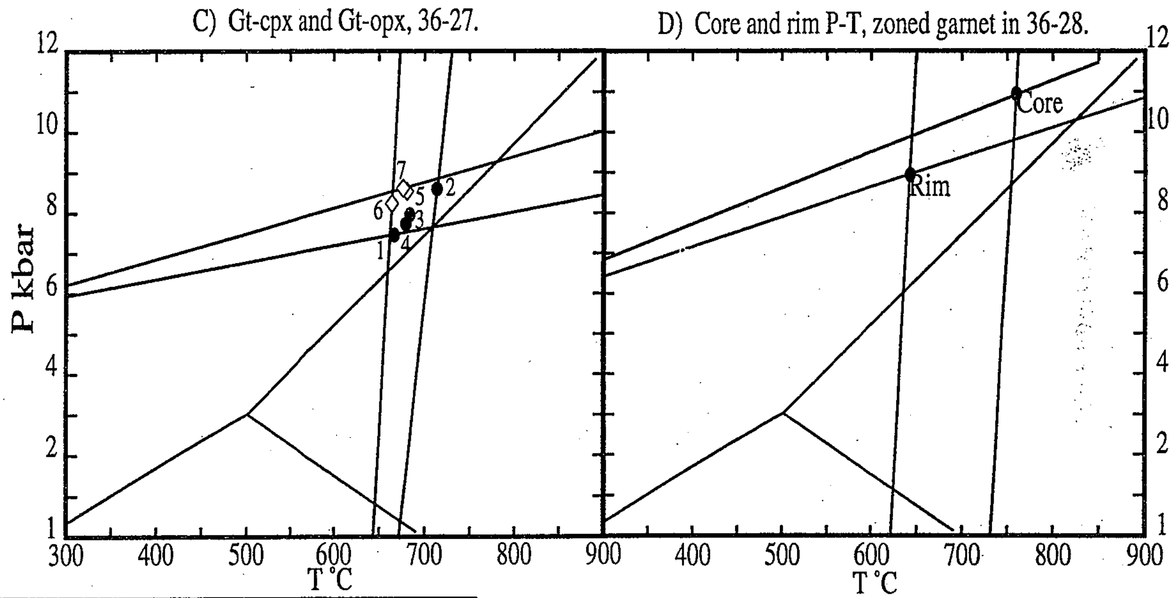
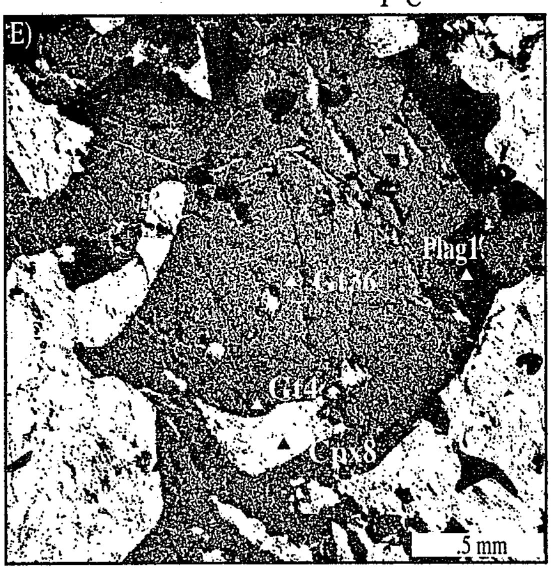


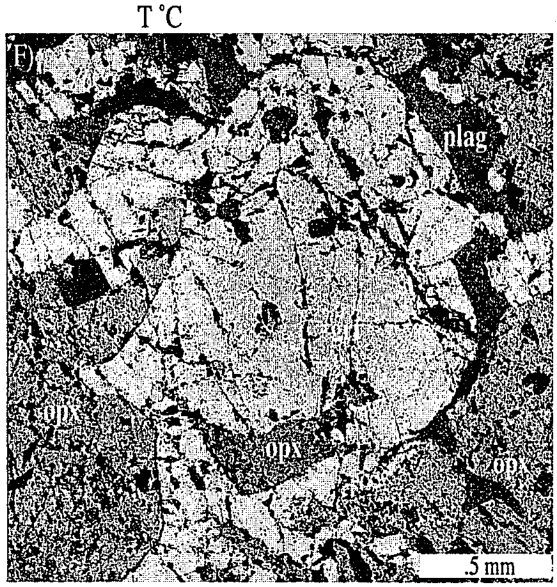
Figure 1. A) Backscattered electron image of opx ringed by cpx and qtx and then grt in a matrix of plag in specimen 36-27. Texture illustrates reaction (1) Electron microprobe analyses for labled points given in Table 1. B) Ca x-ray map of same location as in (A) highlightd the cpx. C) Calculated P-T for grt-cpx pairs (white diamond) and grt-opx pairs (black circles) from sample 36-27.







D) Calculate P-T for core and rim compositions found in a zoned garnet in 36-28. E) Mg x-ray of the garnet highlights the zoning. Sample locations are shown (white triangles). Point analses of those areas are given in table 1. F) Back-scattered electron images of the zoned garnet shows the other phases present.



small grains associated with the pyroxenes (Figure 1.A-B.) Quartz occurs as simplectitic intergrowths with the garnet and as grains separating garnet from the pyroxenes. In specimen 36-27, there are large grains of orthopyroxene rimmed by small grains of clinopyroxene. Specimen 36-28 shows large grains of both orthopyroxene and clinopyroxene.

A beautiful reaction texture is found in specimen 36-27 (Figure 1.A-B.) In this sample, orthopyroxene is ringed by a corona of quartz and clinopyroxene that is in turn ringed by garnet and resides in a plagioclase matrix. This texture suggests the following reaction took place in this rock:

$$2\ (Fe,Mg)_2Si_2O_6 + CaAl_2Si_2O_8 = (Fe,Mg)_3Al_2Si_3O_{12} + Ca(Fe,Mg)Si_2O_6 + SiO_2 \quad (1)$$

Orthopyroxene Anorthite Garnet Clinopyroxe Quartz

GEOTHERMOBAROMETRY

The temperature and pressure of metamorphism for specimen 36-27 was calculated for three garnet-clinopyroxene pairs and four garnet-orthopyroxene pairs from analyses taken in the area shown in Figure 1.A-B(see Table 1 for analyses.) The results are plotted in Figure 1.C. They were found to fall between 650-725° C and 7.5-9 kilobars.

X-ray maps of Ca, Mg, Mn and Fe for a garnet from specimen 36-28 show zoning in Fe, Mg and Mn. (See Figure 1.A-B.) Garnet-clinopyroxene temperatures and pressures were computed for core and rim garnet compositions yielding 750° C and 11 kbar and 650° C and 9 kbars, respectively (Fig. 1.D). The rim temperature falls within the range of temperatures calculated for specimen 36-27.

DISCUSSION AND CONCLUSIONS

The two pyroxene mineral assemblage found in these rocks is indicative of granulite conditions. This is supported by the beautiful reaction texture found in 36-27 (Fig. 1.A-B). Reaction (1) produces garnet, a high density mineral and therefore is a prograde (increasing pressure) reaction. In the SPMS, researchers see simplectites of orthopyroxene and anorthite replacing garnet. This seems to be the retrograde companion to the prograde texture seen in the ICMS rocks and supports different P-T paths for the formations. The metamorphic conditions calculated for these rocks, 650-750° C and 7.5-11 kbars, also supports granulite conditions. These specimens appear to record the high pressure event and do show any overprinting by lower pressure amphibolite grade event that effected the rest of the ICMS.

The garnet zoning in sample 36-28 (Figure 1.E-F, 2) is typical of granulite facies rocks that homogenized at high temperature and experienced diffusion on the rims as the rock cooled (see Figure 2). The zoning has a flat center with slight increases in Fe and Mn and decreases in Mg at the rim. The core does not appear to have been effected by diffusion and so can be assumed to record the peak metamorphic conditions. This zoning profile, a flat core that preserves the peak temperatures and pressures and slight diffusion at the rims, is indicative of relatively rapid cooling (e.g.. Lasaga, 1977; Tracy, 1982). This evidence for rapid cooling after a high pressure event (M1) supports the necessity of a separate and distinct M2 event. (This assumes that the high pressure event recorded by sample 36-27 and 36-28 is M1 at 2.7 Ga.) A single event at 2.7 Ga with a long slow cooling path could not have occurred without resetting the temperatures and pressures recorded by the mineral compositions. This supports the existence of two events, M1 and M2, with different peak pressures.

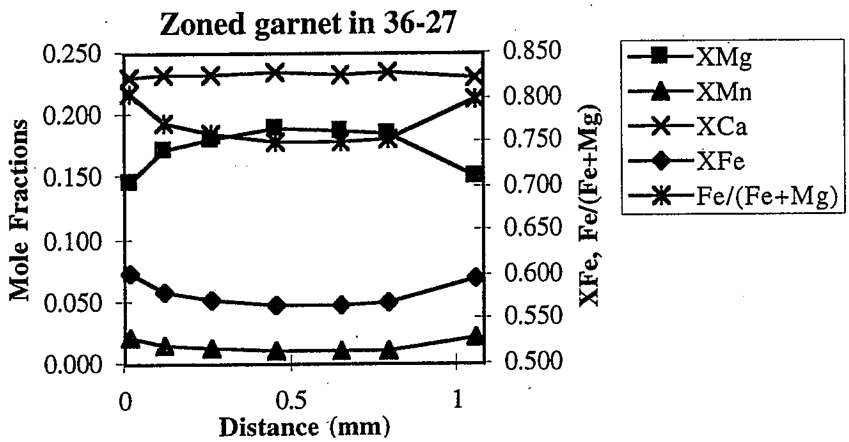


Figure 2. Zoning in the major cations rim to rim across a garnet in 36-28

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Table 1. Electron microprobe analyses

Sample	36-27				36-28			
Mineral*	**Gt 36**	**Opx 21**	**Cpx 22**	**Plag 11**	**Gt 1 (core)**	**Gt 4 (rim)**	**Plag 1**	**Cpx 8**
				wt.% Oxides				
SiO2	39.134	54.449	54.141	57.044	38.642	38.514	60.929	53.048
Al2O3	22.481	0.956	1.563	28.454	22.092	21.886	26.485	1.948
TiO2	0.045	0.062	0.123	0.000	0.147	0.088	0.000	0.155
FeO	23.500	21.464	6.925	0.000	26.054	26.942	0.000	11.150
MgO	6.996	22.002	14.603	0.000	4.880	3.874	0.000	12.049
MnO	0.695	0.195	0.111	0.000	0.445	0.896	0.000	0.155
CaO	7.163	0.537	22.622	0.332	8.415	8.181	0.117	21.872
K2O	0.002	0.005	0.004	10.227	0.006	0.001	7.325	0.006
Na2O	0.000	0.000	0.388	5.381	0.000	0.000	6.239	0.470
total wt. %	100.017	99.671	100.481	101.438	100.682	100.382	101.095	100.854
				*Cations***				
Si	3.002	2.015	1.987	2.524	2.991	3.007	2.668	1.976
Al	2.033	0.042	0.068	1.484	2.016	2.015	1.367	0.086
Ti	0.003	0.002	0.003	0.000	0.009	0.005	0.000	0.004
Fe	1.508	0.664	0.213	0.000	1.687	1.759	0.000	0.347
Mg	0.800	1.213	0.799	0.000	0.563	0.451	0.000	0.669
Mn	0.045	0.006	0.003	0.000	0.029	0.059	0.000	0.005
Ca	0.589	0.021	0.890	0.485	0.698	0.684	0.344	0.873
K	0.000	0.000	0.000	0.462	0.001	0.000	0.530	0.000
Na	0.000	0.000	0.028	0.019	0.000	0.000	0.007	0.034
total cations	7.979	3.963	3.990	4.974	7.993	7.981	4.916	3.994

*Numbers correspond to sample locations, see Figure 1. Mineral abbreviations: Gt-garnet, Opx-orthopyroxene, Cpx-clinopyroxene, Plag-plagioclase

**Number of cations based on: garnet (12 oxygens); clinopyroxene and orthopyroxene (6 oxygens); plagioclase (8 oxygens)