Determination of pressure-temperature conditions for Proterozoic metamorphic rocks in the Southern Front Range, Central Colorado

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INTRODUCTION

The Front Range of Colorado is a north-trending segment of the Southern Rocky Mountains that runs approximately 200 miles south through the center of the state from the Wyoming border. It is bounded on the west by a series of high-elevation, intermontaine plateaus called North, Middle, and South Parks, and by the Denver Basin of the Great Plains Province to the east. The southern edge of the Front Range is marked by the Arkansas River, and beyond this boundary lies the Wet Mountains (Larkin et al., 1980). The rocks dealt with in this study are Proterozoic metamorphic rocks from the Wilkerson Pass (9,502 ft.) area of the Southern Front Range, located approximately 45 miles northwest of Colorado Springs. The Southern Front Range and the Wet Mountains are cut off from the Northern Front Range by the Pikes Peak batholith, intruded at about 1.1 Ga. One of the questions this study hopes to address is whether or not the Wet Mountains and Southern Front Range share their geologic history with the rocks further to the north.

The field area consists primarily of a metasedimentary package of sillimanitic and biotitic gneisses, with amphibolites and some ultramafites and calc-silicate deposits (Scott et al., 1978). There are possibly some metabasalts and bimodal metavolcanics, as well, but these are more typical to the south and southwest, and they were not sampled. A model proposed by Tweto (1987) for the Precambrian basement in Colorado shows an eastward-trending sedimentary basin bounded on the north and south by volcanic materials. Although the Southern Front Range has been mapped for decades, and metamorphic conditions have been suggested based on mineral assemblages, no geochemical work has yet been done on the metasedimentary rocks. The main purpose of this study is to establish the P-T conditions of one or more metamorphic events in the Southern Front Range. Doing this will allow a comparison to be made between metamorphic conditions in the north with those in the south. It should also help illustrate more clearly the early tectonic history of Colorado as a part of the orogenic belt south of the Archean Wyoming craton.

METHODS

During the 1996 summer field season, fifty samples were collected from nine localities (see Figure 1). Rocks were sampled with priority given to criteria such as freshness, visible reaction textures, and most importantly, diverse mineral assemblages with a maximum number of phases to constrain P-T conditions. The collected samples very generally fit into one of the following four lithologic categories: calc-silicate gneiss, aluminosilicate gneiss, orthoamphibole gneiss, and cordierite-quartzite. X-ray diffraction was used to determine the composition of some sillimanite porphyroblasts that appeared in hand sample to be pseudomorphs after kyanite or andalusite. Next, twenty-four polished thin sections were made from among the samples. These were all examined, using petrographic microscopy, for reaction textures and mineral assemblages. Several sections were then chosen for closer qualitative analysis on a scanning-electron microscope. Finally, three of the sections with excellent geothermobarometric indicators were selected for further study using the electron microprobe at the University of Massachusetts at Amherst. Detailed mineral chemistry and x-ray maps of samples SMR-F1 (Grt-Ath-Crd-Bt), SMR-H1 (Grt-Sil-Crd-Bt), and SMR-I2 (Spl-Ath-Crd-Bt) were obtained using this process, although the chemical data are not complete at publication (Kretz, 1983). Pressure and temperature conditions will be ascertained through a mixture of fitting assemblages to P-T grids appearing in Spear (1993) and calculating the P-T paths using thermobarometer models.

RESULTS

Assemblages and Reaction Textures. From petrographic study of the thin sections, useful geothermobarometric assemblages and reaction textures were identified and described. The calc-silicates, originally thought to have typical assemblages consisting of calcite, wollastonite, quartz, garnet, diopside, epidote, and vesuvianite, actually varied a good deal from this, so that most have only a few of the expected minerals, and others have anorthite, microcline, and clinozoizite. SEM analysis showed that in at least one case, the diopside present has a 50/50 ratio of Fe to Mg, which may affect the phase relations. Also, the garnet present is a phase of grossularite with no Mg called andradite. Pectolite, an alteration product of wollastonite containing Na, was detected, as well, replacing the centers of many of the wollastonite crystals. One rock type, termed "leopard rock" for its spotted texture, contains calcite, forsterite, quartz, diopside, and tremolite, rutile with ilmenite rims, and an overprint of serpentine and talc.

The pelitic rocks have a less varied composition. The most common minerals occurring are quartz, sillimanite, biotite, and garnet, with retrograde chlorite and muscovite. Large garnets growing over and around sillimanite are common, as in Figure 2. Also evident from these samples is that the sillimanite occurs in two sizes. One is a very coarse-grained crystal that is prominent in the hand samples. (These sillimanites are so big, in fact, that they prompted the XRD testing for original kyanite or andalusite, although the results showed the crystals to be completely sillimanitic.) The second type of sillimanite is fine-grained and needle-like, visible only in thin section. The most unusual thing about these rocks is that there was only one sample, collected in 1995 by R. A. Wobus from locality E, that contained staurolite. No other staurolite was found at all in any other sample. SMR-H1, chosen for microprobe work, has the assemblage garnet + sillimanite + cordierite + biotite + (quartz + chlorite + zircon + magnetite). Cordierite in this sample has beautiful pleochroic zircon haloes contained within it.

The orthoamphibole rocks were collected from two localities hitherto known to have lithologies containing the excellent thermometer anthophyllite. Two samples of this type were found to have rich assemblages that could be used for geothermobarometry. SMR-F1 contains garnet + anthophyllite + cordierite + biotite + (zircon + apatite). SMR-I2 contains spinel + anthophyllite + cordierite + biotite + (zircon + opaques). The cordierite in both of these again shows very nice pleochroic zircon haloes. The spinel in SMR-I2 is a zinc-rich variety called gahnite. The porphyroblasts are relatively large and look like green garnets in plane light. Figure 3 illustrates the pervasive coronas of cordierite around the spinels.

Thermobarometry. Although it is not complete, some geochemical analysis has been carried out on the three samples chosen for probe work. Mineral chemistry data for SMR-I2 came back with low totals, but the stoichiometry is acceptable. One reason for the poor quality of the totals could be that the carbon coating on the slide may have been wearing off or uneven, causing charging of the electrons in the probe. As yet, no quantitative thermobarometric calculations have been successful using these data.

Two x-ray maps were made of garnets from SMR-F1 and SMR-H1, respectively, against the elements silica, magnesium, calcium, and manganese. The garnet in SMR-H1 is, for the most part, relatively flat. There is a slight depletion of Ca at the rim, although the Ca content overall is very low. SMR-F1 showed better garnet zoning. An enrichment of Ca at the rim is barely detectable in the image. More interestingly, though, is that there is significant depletion of Mg (enrichment of Fe) at the rim, clearly shown in Figure 4. This is retrograde diffusion zoning of garnet, discussed in detail by Spear (1993). As a rock cools from its peak metamorphic conditions, garnets react with biotite in an Mg/Fe exchange, and whereas the biotite homogenizes quickly at its new equilibrium composition, the process is much slower for garnets, so that a record is maintained of the change in composition between their cores and rims. The core composition, therefore, is closer to the conditions of highest metamorphism. The difference between the compositions at the core and at the rim can also be used to construct a dynamic history of metamorphism. Working the chemical data to calculate geothermobarometric conditions will be the main focus of this study up until the Keck Symposium.

DISCUSSION

Based on mineral assemblages only, it has been possible to constrain metamorphic conditions rather well by fitting phases into various reactions and P-T grids found in Spear (1993).

$$\text{Sil} + \text{Kfs} = \text{Ms} + \text{Qtz}$$

The pelitic rocks contain sillimanite and microcline, though no muscovite, which indicates that they formed above 610 °C.

$$\text{Grt} + \text{Crd} = \text{As} + \text{Oam}$$
$$\text{Crd} + \text{St} = \text{Sil} + \text{Ged}\ (\text{As} + \text{Oam})$$

The orthoamphibole rocks contain garnet and cordierite but do not have any aluminosilicate minerals occurring with anthophyllite, and this limits the pressures of metamorphism to less than 5 kb. Figure 5 shows a pressure temperature grid for the pelitic and orthoamphibole rocks.

$$\text{Wo} + CO_2 = \text{Qtz} + \text{Cc}$$
$$\text{Tr} + \text{Cc} + \text{Qtz} = \text{Di} + CO_2 + H_2O$$

Wollastonite, although not ubiquitous in the calc-silicate rocks, is abundant. This, however, cannot be used alone as a thermometer because, as seen in Figure 6a, the appearance of wollastonite depends heavily on the CO_2 content of fluids present during metamorphism. Tremolite, calcite, and quartz occurring together puts a maximum temperature of 620 °C on the rocks.

Some interesting problems arise from the reactions discussed above. The absence of K-feldspar + muscovite often implies that the rocks have undergone partial melting. However, the temperatures for these rocks, constrained to about 600 °C, are not really high enough for partial melting to have occurred. Another puzzle from the Tr-Cc-Qtz assemblage is that rocks from the same locality contain diopside, forsterite, and calcite. This is theoretically impossible because at equilibrium the bulk composition of these rocks cannot support all of these phases. Figure 6b is a ternary phase diagram showing the crossing tie lines of these two assemblages.

CONCLUSIONS

As far as can be determined at this time, the conditions of metamorphism in the Southern Front Range involved temperatures between 610 °C and 620 °C and pressures at or below 5 kilobars. The window of metamorphic temperature conditions is very narrow. Hopefully, further work will decrease the range of pressures, as well. Both the temperatures and the pressures are at the lower end, although still in range, of the thermal and barometric conditions predicted in the literature.

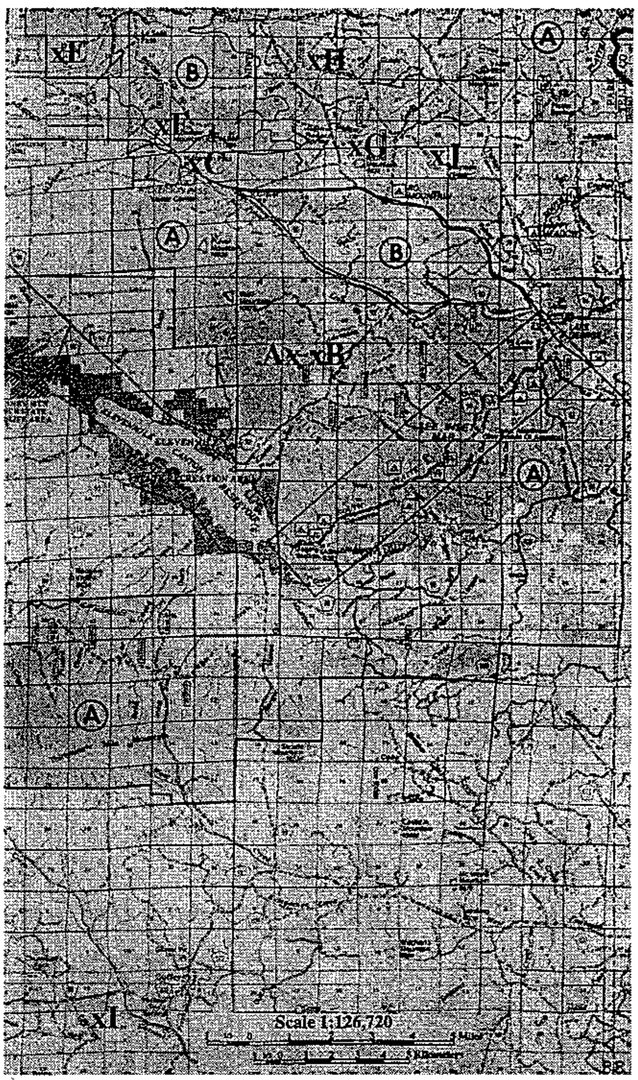

Figure 1. Location map of field area and sample sites

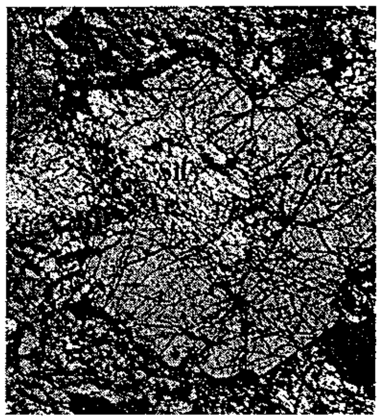

Figure 2. SMR-E10: Photograph showing garnet growing around coarse-grained sillimanite

Figure 3. SMR-I2: Photograph showing cordierite coronas around gahnite (spinel)

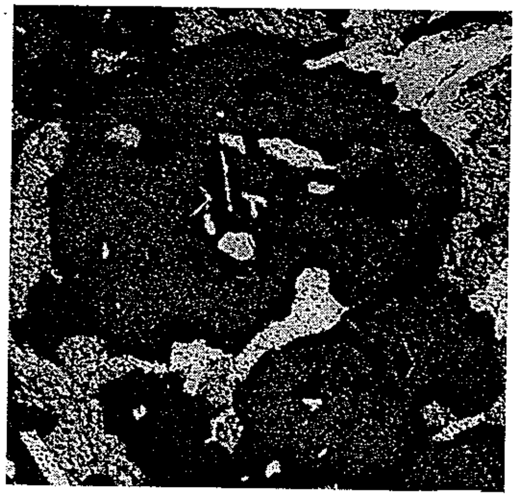

Figure 4. SMR-F1: X-ray map of garnet showing depletion of Mg toward rim

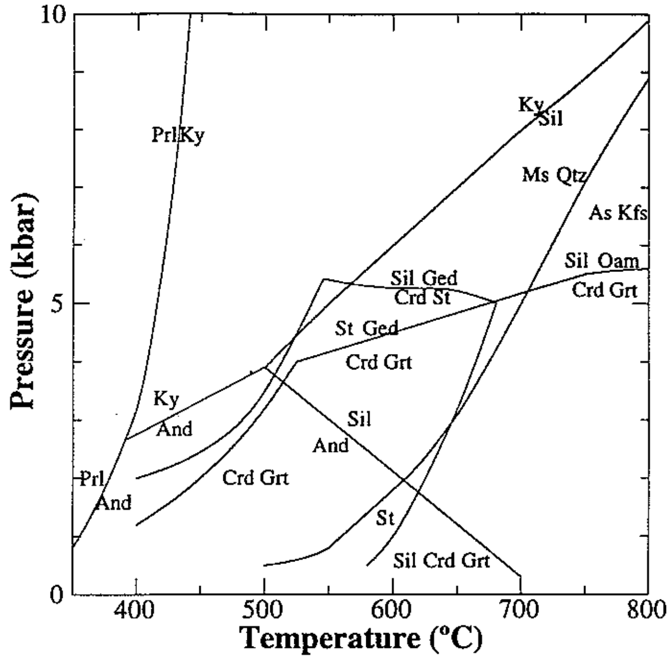

Figure 5. P-T Grid for pelitic and orthoamphibole rocks. Adapted from Spear, 1993

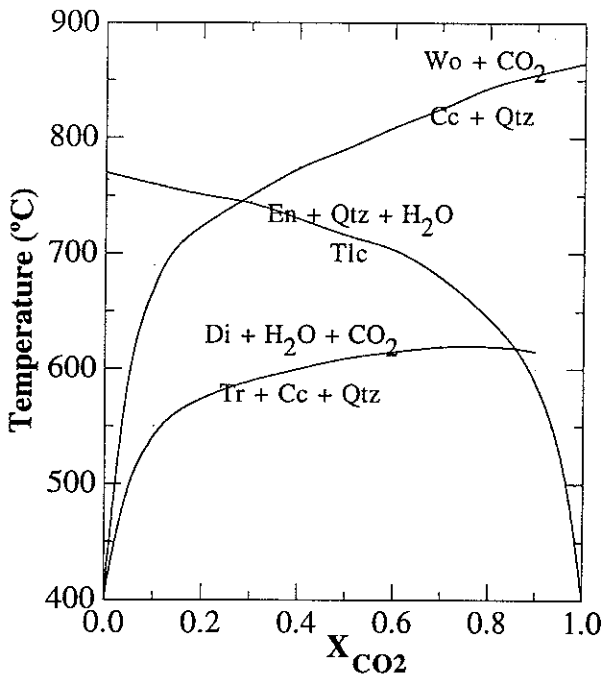

Figure 6a. T - X_{CO2} Grid for calc-silicate rocks. Adapted from Spear, 1993

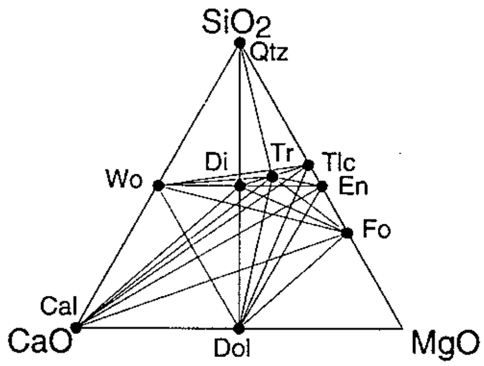

Figure 6b. Ternary composition diagram for system SiO_2-CaO-MgO-H_2O-CO_2. From Spear, 1993

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