# Geothermobarometric Examination of the Wet Mountains Fremont and Custer Counties, South-Central Colorado

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## INTRODUCTION

This project focuses on determining the pressure-temperature conditions for the Wet Mountains of central Colorado. This mountain range is fault bounded by Laramide structures that underwent continued movement into the late Cenozoic (Condie and Lanzirotti, 1988). By determining the pressure and temperature of the area, we can then compare the results to other areas in the region and establish whether or not the laramide faults influenced the mineral crystallization conditions or reset the temperature and pressure values for the area.

## PROCEDURE

Samples were collected from several locations for examination of mineral composition, textural relationships and to determine pressure and temperature ranges for the area. While still at Colorado College, thin section chips were cut and sent to a commercial lab to have polished thin sections made. Once back at Smith, the thin sections were examined for mineral content, using a standard petrographic microscope. Thin sections were then chosen to be examined by the Scanning Electron Microscope (SEM), located at Smith, on the basis of mineral assemblages thought to be present after examination under the petrographic microscope. The thin sections that were chosen contained possible garnet-pyroxene, garnet- biotite, and garnet- cordierite mineral assemblages that would reveal possible temperature and pressure ranges. Using the mineral assemblages, a rough estimate of the temperature and pressure range was determined using the P-T grids for Pelites from Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths by Frank Spear. Three thin sections were then analyzed for chemical composition by the microprobe at the University of Massachusetts, Amherst, the results of which were then used in Hodges and Spear's garnet-biotite geothermometry program (Hodge and Spear, 1982) to determine temperature ranges for the samples, and the area in general.

## PETROGRAPHY

Most samples were pelite shists and gneisses, with significant amounts of magnetite, and a few were amphibolites. The biotites in most cases have very intense, brown pleochroism, which may indicate a relatively high iron content. Only two samples contained cordierite, CP-4 and RV-D5, and of those two, only CP-4 contained sillimanite, and neither contained any garnet. What was thought to be cordierite in CP-5A was actually plagioclase containing numerous small inclusions. In the hand sample, the cordierites seem to be only on the uppermost surfaces of the rock and are not found throughout. In CP-4 however, the cordierites are prevalent in the rock, and seemed to contain only two small fibrous mats of sillimanite bunched at one end among the cordierite and biotite. However, when examined under the SEM, more sillimanite was located between other mineral grains in a more crystalline, cement form. Six thin sections were chosen to be examined by the SEM, GR-1, GR-2, GR-M, CP-3, CP-4, and CP-5A, based on mineral assemblages observed. They came from two sites; Boneyard Gulch, a granulite locality, and along Rt. 50 in Cotopaxi, a cordierite locality. The Boneyard Gulch samples were believed to have come from an area of Charnockites which appear to have been transported from the lower crust during the intrusion of the granite plutons (Condie and Elms, 1986). They are described by T. Lanzirotti and K. Condie to have plagioclase (An 28), quartz, potassium feldspar, amphibole, biotite, and orthopyroxene. The samples from this area that were examined, however, do not contain any amphibole, biotite or, potassium feldspar, and thus are not from a charnockite deposit. Three contain unusual assemblages of garnet-clinopyroxene-plagioclase with a granular texture. The samples that contained garnet also contained either biotite or pyroxene, but not both. The samples from Boneyard Gulch, GR-1, GR-2 and GR-M, show a reaction between plagioclase and clinopyroxene to produce garnet (see Figure 3). These sections are broken down into three areas; one side contains plagioclase and pyroxene only, while the other side contains plagioclase and garnet only, with a transition zone in the middle. The transition zone contains hedenbergite pyroxenes which are surrounded by calcium rich grossular-andradite garnet halos. The other two samples from Boneyard Gulch, GR-D and GR-3, do not have any garnets, and contain both clinopyroxene and othropyroxene, which are more indicative of a granulite facies rock, although they still do not contain any potassium feldspar or biotite.

## RESULTS/DISCUSSION

The differences between the two sets of mineral assemblages for Boneyard Gulch perhaps shows the beginning of a regression to a lower metamorphic facies, from granulite to amphibolite. These mineral assemblages place the samples in the upper amphibolite to lower granulite facies, which gives a temperature range of approximately 600°C to 900°C and a pressure range from approximately 2 to 12 kbars (Spear, 1993). Due to the high iron content of these samples, demonstrated by the large quantity of magnetite and the dark pleochroism of the biotite, I believe though that the pressure is lower, between 2 and 6 kbars, since, in granulite and amphibolite facies, the pressure goes down with increasing iron content.

The garnet analyzed by the microprobe showed a zonation with both iron and magnesium decreasing from core to rim and calcium increasing slightly in the same direction (see Figure 4). This may be due to either a decrease in temperature or an increase in pressure as the garnet was crystallizing. Using the microprobe analyses, the temperature of crystallization for the garnet was more defined. Comparing the garnet core composition with the homogeneous biotite yeilded a temperature of 525°C, while comparing the garnet rim with the biotite yeilded a permerature of 450°C. These temperatures are lower than expected. However, ther is a large spessartine component in these garnets that may effect the thermometer results. The other sample from the same area contains sillimanite-biotite-cordierite assemblages which, according to Spear, indicates a temperature above 575° C and a pressure between 2 and 6 kbars. This temperature is higher than the one given by the garnet-biotite thermobarometry but is within the pressures estimated using mineral assemblages.

## CONCLUSION

From these results, the Wet Mountains appear to be in an upper amphibolite facies to possibly a lower granulite of metamorphic grade. I am estimating that the temperature ranges from 500°C to 700°C and that the pressure ranges from 2 to 6 kbars. This was determined by the mineral assemblages observed in thin section, and thermobarometric results from chemical data collected from a microprobe.

## FUTURE RESEARCH

Further chemical analyses will be performed on the plagioclase-garnet-pyroxene samples to determine the conditions necessary for the reaction to occur in this instance. Also, the clinopyroxene-orthopyroxene samples will be analyzed for temperature-pressure values, as well as two other samples collected on the east side of the Ilse fault, a major fault that runs through the middle of the Wet mountains and experienced Laramide movement. The fault divides the Wet mountains into a higher eastern half and a lower western half, though it is not known if the area was once one terrain which has been faulted or if the fault joins two different terrains (Noblett, Cullers and Bickford, 1987). These last samples will help determine if the Laramide movement on the Ilse was significant enough to alter the thermobarometric conditions in the area.

## REFERENCES


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| Sample | Bio | Quartz | Hnbld | Plag | Musco | Garnet | Crd | Sil | Mag | Ill | Perth | Micro | Tit | Pyx | Apt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CP-3 | | | Tremolite | | Talc, Chlt | | | | | | | | | | |
| CP-4 | X | X | | X | X | | X | X | X | | | | X | | |
| CP-5a | X | | | X | X | X | | | X | X | | | X | | X |
| GR-1 | | | | X | | X | | | X | | | | | Fe | |
| GR-2 | | X | | X | | X | | | X | | | | | Fe | |
| GR-3 | X | X | X | X | | | | | X | | | | | Opx/Cpx | |
| GR-D | | X | X | X | | | | | X | | | | | Opx/Cpx | |
| GR-M | | X | | X | | X | | | X | X | | | | Fe (Cpx) | |
| M-1 | | | X | X | | | | | X | | X | | | | |
| RV-D5 | | X | | | X | | X | | | | X | X | | | |
| HC-1a | X | X | X | X | | | | | X | | | | X | | X |
| HC-2a | X | X | | X | X | | | | X | | | X | | | |
| RV-1 | X | X | | X | | X | | | | | | X | | | |
| RV-10 | X | X | | X | | X | | | X | | | | | | |
| RV-11 | X | X | | X | | X | | | X | | | | | | |
| RV-12 | X | X | | X | X | X | | | X | | | X | | | |
| RV-13a | X | X | | X | X | | | | X | | | X | | X | |
| RV-D1 | X | X | | X | | X | | | X | | | | | | |
| RV-D2 | X | X | | X | | | | | | | X | | | | |
| RV-D3 | X | X | | X | | X | | | X | | X | | | | |
| RV-D4 | X | X | | X | | X | | | X | | X | | | | |
| RV-M | X | X | | X | | X | | | X | | X | | | | |

**Figure 1.** Mineral table showing mode analysis for each thin section examined

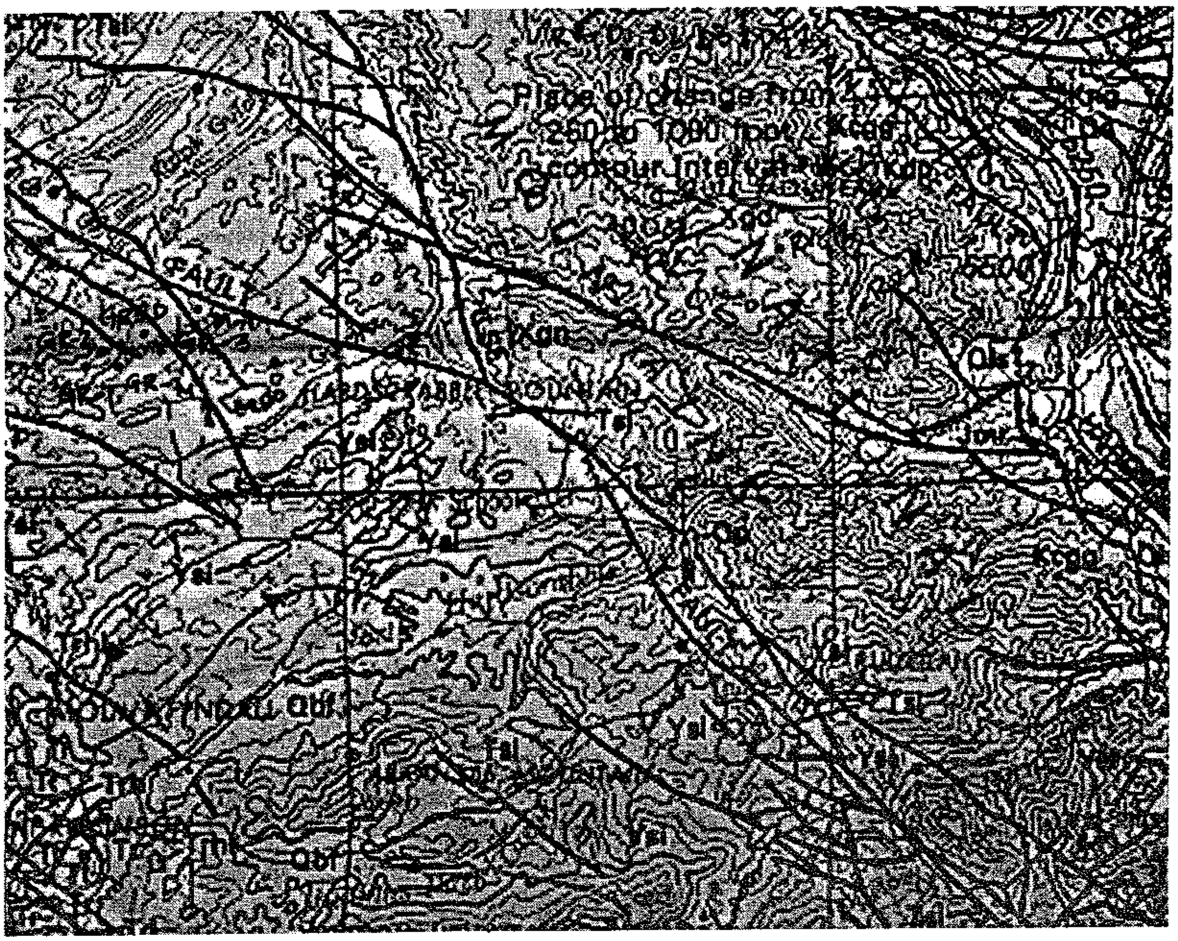

**Figure 2.** Map showing locations where samples were collected. (Cotopaxi samples not shown)

**Figure 3.** Microprobe image of plagoiclase+ pyroxene = garnet reaction. Black mineral is magnetite, gray mineral in center is pyroxene, surrounded by garnet, surrounded by plagioclase

**Figure 4.** Garnet showing zonation with $Fe^{2+}$ increasing to the rim and Mg decreasing to the rim

| Mineral | SiO2 | TiO2 | Al2O3 | MgO | CaO | MnO | FeO | Fe2O3 | Na2O | K2O |
|---|---|---|---|---|---|---|---|---|---|---|
| CP-5A sample | | | | | | | | | | |
| biotite take#1 | 2.7604 | 0.0514 | 1.5371 | 2.1514 | 0.0016 | 0.0359 | 0.4572 | 0 | 0.0294 | 0.8196 |
| take#2 | 2.7509 | 0.0464 | 1.5761 | 2.1293 | 0.003 | 0.0311 | 0.4469 | 0 | 0.0373 | 0.8245 |
| take#3 | 2.8228 | 0.0537 | 1.5126 | 2.0878 | 0.001 | 0.0306 | 0.4418 | 0 | 0.0296 | 0.8041 |
| | | | | | | | | | | |
| Garnet : rim | 2.989 | 0.003 | 1.998 | 0.281 | 0.152 | 2.034 | 0.549 | 0.001 | 0 | 0 |
| core | 2.963 | 0.001 | 1.98 | 0.348 | 0.119 | 2.092 | 0.504 | 0.027 | 0 | 0 |
| | | | | | | | | | | |
| GR-M sample | | | | | | | | | | |
| garnet #1 | 2.995 | 0.008 | 1.4722 | 0 | 1.9232 | 0.0804 | 1.0021 | 0.52 | 0 | 0 |
| garnet #2 | 2.9832 | 0.0054 | 1.502 | 0 | 1.9188 | 0.0751 | 1.0324 | 0.4958 | 0 | 0 |
| | | | | | | | | | | |
| pyroxene #1 | 1.8912 | 0.0062 | 0.1091 | 0.018 | 0.9313 | 0.0089 | 0.8749 | 0.1282 | 0.0322 | 0 |
| pyroxene #2 | 1.8985 | 0.0065 | 0.1214 | 0.0186 | 0.9349 | 0.0094 | 0.8794 | 0.1 | 0.0314 | 0 |
| | | | | | | | | | | |
| feldspar #1 | 2.2029 | 0 | 1.7841 | 0 | 0.8044 | 0 | 0.0149 | 0 | 0.1941 | 0.0035 |
| feldspar #2 | 2.2217 | 0 | 1.7669 | 0 | 0.7907 | 0 | 0.0078 | 0 | 0.2099 | 0.0053 |
| feldspar #3 | 2.4529 | 0 | 1.5308 | 0 | 0.5514 | 0 | 0.0206 | 0 | 0.4425 | 0.0095 |
| feldspar #4 | 2.4648 | 0 | 1.518 | 0 | 0.5416 | 0 | 0.0132 | 0 | 0.468 | 0.009 |

**Figure 5.** Chemical data taken from Umass microprobe. These values were used in the thermobarometric program to calculate temperature of the samples