PROTEROZOIC METAMORPHIC CONDITIONS OF CENTRAL COLORADO
Pressure and temperature constraints from thermometry and pelitic mineral assemblages

Kimberly A. Hannula
Carleton College

The amphibolite facies metamorphism of the Proterozoic Colorado Province took place about 1670 million years ago. Past work suggests that the event was a relatively high temperature/low pressure event, based on the lack of kyanite throughout the region. Although geothermal gradients have been estimated for areas within the Front Range, little work has dealt specifically with the metamorphism of the rest of the province. This study focuses on the metamorphic conditions of several areas in which Proterozoic rocks are exposed in the Salida area of central Colorado, including the east side of the Arkansas graben (the Salida area), Cottonwood Pass and Mirror Lake in the central Sawatch Range, Mt. Ouray, and Hunt's Lake in the northern Sangre de Christo Range. I used two methods of determining the temperature to provide a check on my estimates: the stability of various pelitic mineral assemblages and Fe-Mg cation exchange geothermometry.

Pelitic Mineral Assemblages

The regions fell into three general metamorphic grades. The lowest grade rocks contained andalusite as the only aluminosilicate, as well as biotite and muscovite. Only the southern part of the Salida area falls into this category. Sillimanite appears in the middle grade, coexisting with biotite, muscovite, and andalusite (which appears to be continuing metastably). Cottonwood Pass, Mt. Ouray, and the northernmost part of the Salida area contain this assemblage. The third and highest grade, sillimanite + biotite + k-spar, is present only at Hunt's Lake. Garnets are occasionally present in all areas except Cottonwood Pass.

Geothermometry

The garnet-biotite cation exchange thermometer, based on the reaction:

Fe-garnet + Mg-biotite = Mg-garnet + Fe-biotite,

is used extensively for pelitic rocks in the amphibolite facies. There is a great deal of uncertainty, however, about the effects of calcium and manganese substitution for iron and magnesium in the garnet on the calculated temperature. Several solid solution models correcting for Ca^{2+} substitution gave been proposed. I compared the results of two calcium corrections, those of Hodges and Spear (1982) and Hoinkes (1986), and the Ferry and Spear (1978) ideal solution calibration with temperature estimates based on pelitic mineral assemblages. the Ferry and Spear calibration yielded temperatures that agreed most closely with those predicted by the mineral assemblages. In addition, the Ferry and Spear calibration gave temperatures that agreed most closely with those calculated using the garnet-hornblende thermomcter of Graham and Powell (1984) from rocks from the Mirror Lake area. The effect of calcium on this thermometer may not be as great as currently thought.

The garnets from several samples, including those from Mt. Ouray and Hunt's Lake, had high manganese contents. Although the Hunt's Lake sample yielded realistic temperatures, the temperatures calculated from the Mt. Ouray samples were not at all consistent with the observed mineral assemblages. The effect of manganese on garnet solid solution remains a mystery.

Geothermal gradients

The geothermal gradient that best fits the temperature and pressure estimates for this area is 55-60° C/km (Fig. 2). This is consistent with gradients calculated for the northern and central Front Range (60° C/km (Nesse, 1984) and 50° C/km (Swayze and Holden, 1985) respectively). The high temperature/low pressure character of this metamorphism, along with the young age of the metamorphism (about 1670 Ma) compared to the suspected suturing of Colorado to the Archean Wyoming craton (before 1763 Ma) and the occasional noted increase in grade towards plutons (Jones, 1981), led Reed et al. (in press) to believe that the regional metamorphism and deformation were largely due to the intrusion of syn-orogenic Boulder Creek-age plutons. My results support their conclusion.

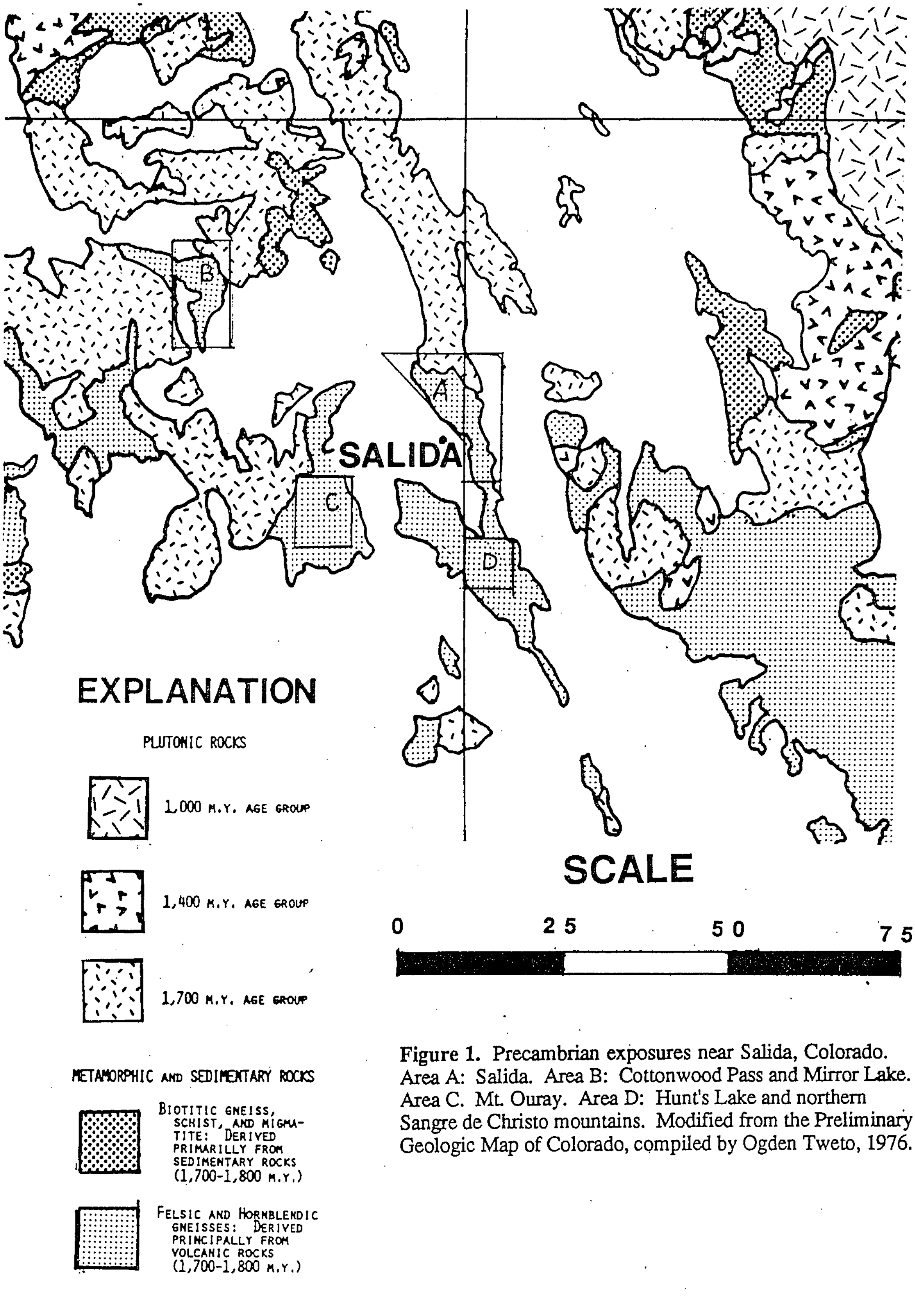

Figure 1. Precambrian exposures near Salida, Colorado. Area A: Salida. Area B: Cottonwood Pass and Mirror Lake. Area C. Mt. Ouray. Area D: Hunt's Lake and northern Sangre de Christo mountains. Modified from the Preliminary Geologic Map of Colorado, compiled by Ogden Tweto, 1976.

Table 1. TEMPERATURE AND PRESSURE ESTIMATES BY REGION

Region	Temperature	Pressure
Northern Salida	about 580^{o} C (garnet-biotite thermometry from Jones, 1981)	2.6 - 5.1 kbars (temperature estimate, pressence of sillimanite)
Southern Salida	about 450^{o} C (garnet-biotite thermometry, this study)	1.7 - 3 kbars (temperature estimate, presence of andalusite, lower pressure limit of amphibolite facies)
Cottonwood Pass	500 - 650^{o} C (coexistence of andalusite, sillimanite, and muscovite)	2.5 - 3.8 kbars (coexistence of andalusite, sillimanite, and muscovite)
Mirror Lake	about 570^{o} C (garnet-biotite and garnet-hornblende thermometry, this study)	no constraints
Mt. Ouray	about 650^{o} C (high Mn^{2+} garnet-biotite thermometry), 550 - 600^{o} C (coexisting muscovite and sillimanite, metastable (?) andalusite)	2.5 - 3.8 kbars (second temperature estimate, coexisting muscovite and sillimanite)
Hunt's Lake	about 610^{o} C (high Mn^{2+} garnet-biotite thermometry) 575 - 700^{o} C (coexisting sillimanite and k-spar)	2.3 - 5 kbars (temperature of 610^{o} C, coexisting k-spar and sillimanite), 2 - 7 kbars (coexisting k-spar and sillimanite)

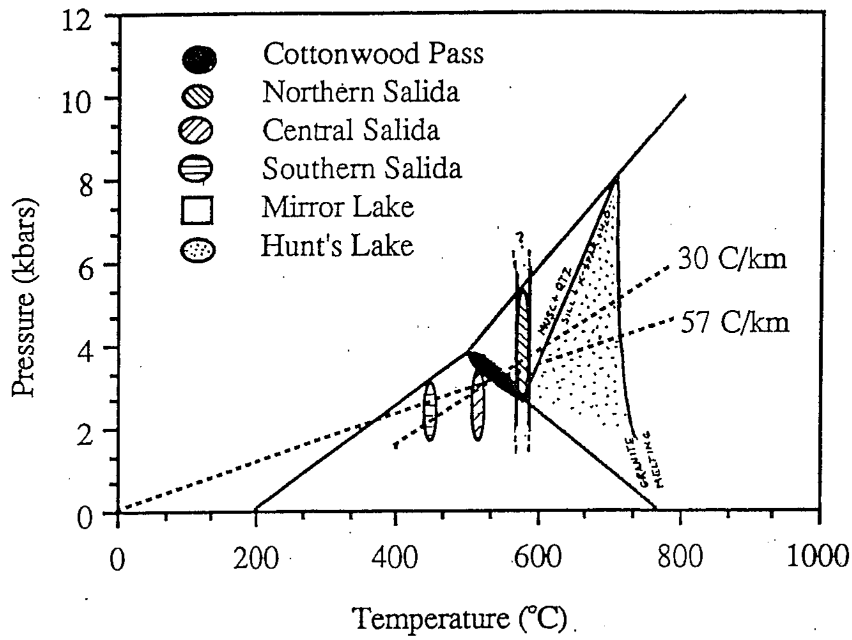

Figure 2. Temperatures and pressures for each area and possible geothermal gradients. See Table 1. for basis for choice of each T-p region.

References

Ferry, J.M., and Spear, F.S., 1978, Experimental calbriation of the partitioning of Fe and Mg between biotite and garnet: Contributions to Mineralogy and Petrology, v. 66, p. 113-117.

Graham, C.M., and Powell, R., 1984, A garnet-hornblende geothermometer: Calibration, testing, and application to the Pelona Schist, Southern California: Journal of Metamorphic Geology, v. 2, p. 13-31.

Hodges, K.V., and Spear, F.S., 1982, Geothermometry, geobarometry, and the Al_2SiO_5 triple point at Mt. Moosilauke, New Hampshire: American Mineralogist, v. 67, p. 1118-1134.

Hoinkes, G., 1986, Effect of grossular-content in garnet on the partitioning of Fe and Mg between garnet and biotite: Contributions to Mineralogy and Petrology, v. 92, p. 393-399.

Jones, K., 1981, Garnet-biotite geothermometry applied to metapelitic rocks near Salida, Colorado, (unpublished senior thesis) Northfield, Minnesota: Carleton College.

Nesse, W.D., 1984, Metamorphic petrology of the northeast Front Range, Colorado: the Pingree Park area: Geological Society of America Bulletin, v. 95, p. 1158-1167.

Reed, J.C., Bickford, M.E., Premo, W.R., Aleinikoff, J.N., and Pallister, J.S., 1989, Deformation and metamorphism related to arc magmatism in the accretionary terrane of the Early Proterozoic Colorado Province: in press.

Swayze, G.A., and Holden, G.S., 1985, Middle Proterozoic metamorphism, central Front Range, Colorado: Geological Society of America Abstracts with Programs, v. 17, n. 4, p. 266.