ANALYSIS OF DEFORMATIONAL AND METAMORPHIC HISTORY OF CORDIERITE SCHIST, EAST GULCH, COLORADO

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INTRODUCTION

Regional Geology

Precambrian rocks of the Wet Mountains of Colorado, well-exposed along the Arkansas River and its tributaries, record a complex history of deformation and metamorphism in the middle crust. In most of this region, several deformational events at 1.67 Ga and 1.4 Ga have obliterated early fabrics, thereby truncating the deformational and metamorphic history (Siddoway et al., 2000). Sedimentary rocks also underwent metamorphism during deformation of this region. Metasedimentary rocks include aluminous schists that grew large metamorphic porphyroblasts, which overgrew and captured primary textures and information about the prograde metamorphic path (Wilson and Stevens, 1998).

This study focuses on an aluminous, magnesium-rich schist in East Gulch (Fig. 1), a tributary of the Arkansas River that joins the river in Echo Park, CO. Large cordierite porphyroblasts in this schist preserve early deformational fabrics as aligned mineral inclusions. This study utilizes the inclusions within cordierite porphyroblasts to investigate the development of early fabrics and the progression of metamorphic mineral growth.

Cordierite Schist

An east-plunging antiform, exposed in Five Points Gulch, comprises a heterogeneous layered sequence of primarily felsic gneiss, cordierite schist, quartzose schist, calc-silicate gneiss, amphibolite, granitoids (G2 and G3 of Siddoway et al., 2000) and pegmatite (Fig. 1). The cordierite schist unit has been studied in detail by Givot (1998), Stevens and Wilson (1998), and Siddoway et al. (2000). These workers identified two

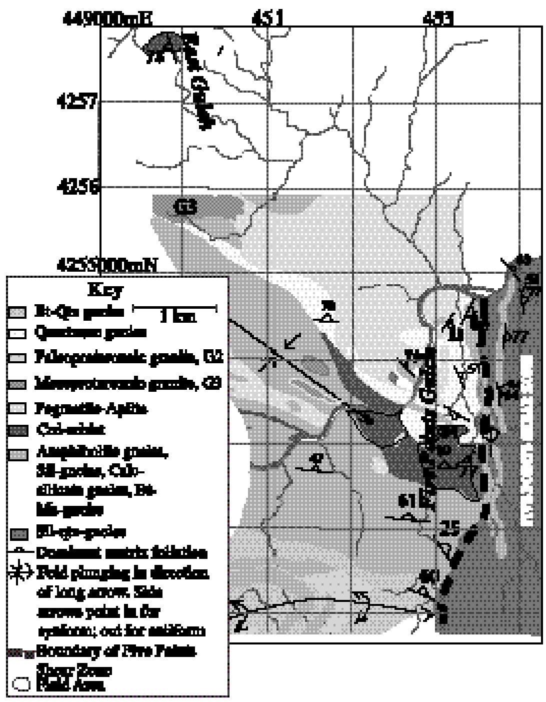

Figure 1. Schematic geologic map of region surrounding field area. Notice the N-S trending Five Points Shear Zone cross-cutting an east-plunging antiform to the south. East Gulch is located to the northwest of map. Adapted from Siddoway et al. (2000).

fabric elements preserved as aligned mineral inclusions within metamorphic cordierite porphyroblasts. The first of these, S_0, is visible as bands of magnetite-rich and quartz-rich inclusions within cordierite porphyroblasts. The second, S_1, is a crenulation cleavage found within most cordierite porphyroblasts; andalusite porphyroblasts do not include S_1 (Siddoway et al., 2000). Siddoway et al. (2000) identified two external foliations. S_2 is the dominant, penetrative foliation and is parallel to compositional layering. The steeply dipping, north-striking foliation of Five Points Shear Zone (S_{SZ}) truncates this fold and S_2. Neither of these foliations is visible within metamorphic porphyroblasts. S_2 wraps around cordierite porphyroblasts and is discordant with internal S_0 and S_1 (Givot, 1998; Stevens and Wilson, 1998).

Large granitic plutons (G3 of Siddoway et al., 2000) between the Five Points Gulch and East Gulch obliterate any prior continuity of folding associated with S_2 and of older fabric elements between them (Fig. 1).

An important question to further the regional investigation of deformational and metamorphic textures begun by workers in Five Points Gulch is: How does the deformational and metamorphic history near East Gulch relate to that near Five Points Gulch?

METHODS

With the assistance of Candice Tellio and other field assistants, I spent three weeks mapping structures at a scale of 1:12000 and collecting oriented and unoriented samples from Five Points Gulch and East Gulch (Fig. 1).

I used a Suunto compass to measure 296 attitudes of internal porphyroblast foliations and of external foliations in each area. I used the measured attitudes for stereonet analysis in the program GEOrient v. 9.0. I focused on measuring internal foliations at both Five Points Gulch and East Gulch in order to pursue the possibility of regional structural continuity among early fabrics.

I collected 55 samples, focusing analysis on those: a) displaying interesting textural features with potential for providing a metamorphic mineral growth history and kinematic indicators; b) containing mineral assemblages useful in the estimation of P-T conditions; and c) representative of specific units within the regional metamorphic sequence.

Fifteen of these samples were selected, based on the above criteria and on their potential to provide information about matrix-porphyroblast relationships, for textural analysis in thin section. Eleven of these sections came from the Five Points Gulch area to provide regional context and textures for comparison with those at East Gulch. Four sections were prepared perpendicular to the dominant external foliation (176/77W) and parallel to the mineral stretching lineation (~72/287) from two unoriented and two oriented samples from East Gulch. Textural and metamorphic mineral relationships seen in thin section were correlated with field observations of deformational fabrics and mineral relationships.

RESULTS FROM EAST GULCH

Structural Data

An interesting pattern of foliation development is found at East Gulch (Figure 2). The dominant external foliation (S_{EG}) in East Gulch dips steeply and strikes nearly N-S. The mean orientation, calculated by Georient, is 176/77W. This orientation raises the question of whether S_{EG} is related to the same deformational event as S_2 of Five Points Gulch or to the deformational event responsible for the formation of Five Points Shear Zone. S_{EG} is similar in orientation to that of the Five Points Shear Zone fabrics. S_{EG} contains many rootless intrafolial isoclinal folds of an earlier foliation. At East Gulch, cordierite porphyroblasts are elongated within S_{EG}, which wraps around the porphyroblasts, and parallel to the mineral stretching lineation. S_{EG} is younger than S_0 and S_1.

S_0 measured from inclusion trails within 21 cordierite porphyroblasts from East Gulch generally strikes northeast-southwest and dips northwest. When plotted on a stereonet,

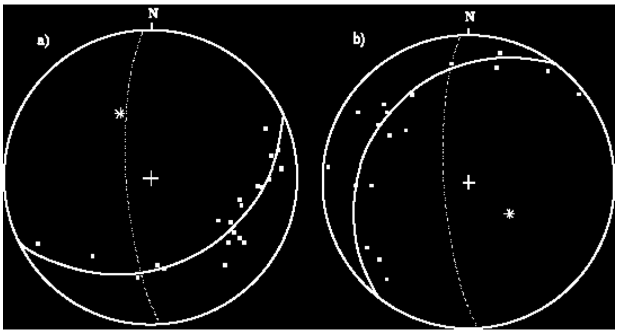

Figure 2. Equal area stereonet projections from East Gulch. Great circle is best fit to poles. Asterixes represent fold axes. Dashed line is mean plane to S_{EG} at 176/77W. a) Plot of poles to relict bedding (S0) measured from compositional variations within cordierite porphyroblasts (n=21). Fold axis = 50/334. b) Plot of poles to crenulation cleavage (S1) measured within cordierite porphyroblasts (n=18). Fold axis = 61/127.

poles to S_0 align with a pi-pole at 50/334 (Fig. 2a). Cordierite porphyroblasts at East Gulch

preserve a crenulation cleavage (S_1) at a high angle (approximately 120°) to S_0. S_1 measured from inclusion trails within cordierite porphyroblasts generally strikes northeast-southwest and dips southeast. The poles to S_1 plot on a stereonet with a pi-pole at 61/127 (Fig. 2b). In outcrop, S_0 changes orientation within the area of a meter, revealing small windows into mesoscopic folding.

Petrography of Cordierite Schists

In all sections, sillimanite is fibrolitic and is found primarily in the form of felted masses, or pods, often included within large muscovite crystals. Whereas the general outline of sillimanite pods is like that of a sheared porphyroblast, the associated muscovite crystals are large, tabular and do not share the deformed form of the sillimanite pods. Sillimanite and smaller muscovite crystals align throughout all sections in two primary directions, at approximately 30 degrees, resembling a S-C fabric, in which the “S” fabric corresponds to an overprinted $S_{EG'}$ and the “C” fabric corresponds to S_{EG}. In two of the sections, sillimanite pods trace out intrafolial microfolds. In thin sections from Five Points Gulch, sillimanite is weakly aligned in only one orientation.

Muscovite inclusions within biotite are present and optically continuous with large, tabular muscovite at the biotite grain boundary. A similar texture is visible in one section with muscovite included in quartz.

In the four thin sections from East Gulch, inclusion trails within cordierite and plagioclase porphyroblasts were defined by preferentially oriented opaque minerals (either magnetite or ilmenite), quartz, and muscovite. Opaques align with neither $S_{EG'}$ nor S_{EG}. Muscovite inclusions are aligned in two orientations. The first is parallel to the alignment of opaque minerals, the other is oblique to the alignment of opaque minerals. In one section, the parallel set of muscovite needles and opaques aligns with S_{EG}. In another section, a set is oriented parallel to the aligned sillimanite of $S_{EG'}$.

INTERPRETATIONS

Three deformational events have been recorded in the cordierite schists of East Gulch. The first deformational event was responsible for the formation of a crenulation cleavage (S_1) oblique to S_0. The angular contact between internal S_1 and S_0 for all pairs averages ~119° with a standard deviation of 20º, so any potential folding associated with the formation of S_1 must be at a scale larger than the East Gulch area.

During the second deformational event, compositional layering (S_0) folded about a moderately plunging, N26W-trending fold axis, and S_1 folded about a more steeply plunging, N127E-trending fold axis. $S_{EG'}$ could be axial planar to this folding but has been so strongly overprinted by S_{EG} that its orientation at East Gulch is unknown. Because the fold axis of internal S_0 lies upon the mean plane of S_{EG}, S_{EG} could have formed during this event, in which case the ordering of sillimanite growth at East Gulch differs from that at Five Points Gulch. The second deformation occurred either after or during cordierite and plagioclase growth, as evidenced by the alignment of muscovite within some cordierite and plagioclase porphyroblasts similar to that of $S_{EG'}$. Sillimanite grew during or prior to this deformation because relic $S_{EG'}$ is defined in thin section by the preferred orientation of sillimanite fibers and bundles.

The third deformational event overprinted $S_{EG'}$ with S_{EG}. Based on microtextural analysis, I propose that the same deformational event that created the Five Points Shear Zone is responsible for S_{EG}. S_{EG} is similar in orientation to S_{SZ} (as defined by Siddoway et al., 2000). Assuming that the general sequencing of regional events at East Gulch mirror those presented by Siddoway et al. (2000), the relative timing of the formation of S_{EG} places it with that of S_{SZ}. Like S_{SZ} (described in Acevedo, this volume), S_{EG} is defined by the deformation of abundant sillimanite pods and bundles. Sillimanite had grown prior to this deformation but remained stable because sillimanite, rather than a later phase, defines S_{3EG}. This deformation is followed by a second generation of muscovite overgrowing sillimanite.

Based on thin section analysis, biotite, muscovite, cordierite, sillimanite, quartz and plagioclase are in equilibrium at peak temperature assemblage. Using this information, I interpreted the peak pressure and temperature of the cordierite schists at East Gulch based on reactions in the KFMASH chemical system, as presented by Spear (1995) for metapelites (Fig. 3). This analysis indicates that the final fabric developed at low pressures (2.3 to 7 kbars) and high temperatures (575-725°C).

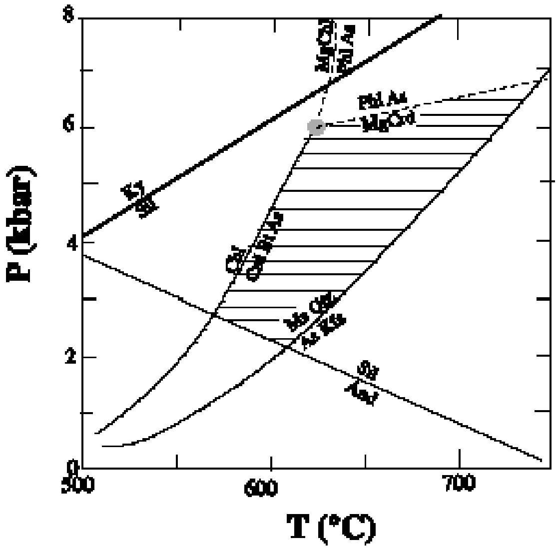

Figure 3. P-T grid for pelites based on KFMASH chemical system. Mineral symbols: Ky=kyanite, Sil=sillimanite, MgChl=Mg-chloride, Phl=phlogopite, As=aluminosilicate, Chl=chlorite, MgCrd=Mg-cordierite, Crd=cordierite, Bt=biotite, Ms=muscovite, Kfs=K-feldspar, Qtz=quartz. Metamorphic domain of East Gulch denoted by horizontal stripes. This is constrained by the absence of K-feldspar and Chlorite. Maximum temperatures for East Gulch are approximately 575 to 725 °C at pressures of approximately 2.3 to 7 kbars. Adapted from Spear (1995).

CONCLUSIONS

Early fabrics preserved within porphyroblasts in the cordierite schists of East Gulch record a complex polyphase metamorphic and deformational history. Not only do cordierite and plagioclase porphyroblasts preserve S_0 and S_1, but in thin section, they also preserve relics of S_2 as inclusions. Through the interpretation of these internal foliations the presence of larger scale deformation responsible for the folding of S_0 and S_1 is recognizable. This study also suggests that the deformation of the Five Points Shear Zone extends farther north than previously interpreted.

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