Structure and oxygen isotope analysis of Precambrian basement in the Cottonwood Creek Area, Black Mountain Quadrangle, Bighorn Mountains, Wyoming

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INTRODUCTION

The Cottonwood Creek study area lies north of Shell Canyon, in the Black Mountain Quadrangle on the western flank of the Bighorn range and the eastern edge of the Bighorn Basin (Fig. 1). Shell Canyon represents a structural boundary between the north-central and south-central Bighorn lineaments, marking the shift in orientation and character of the mountain front (Finley, 1982). Shell Creek and Trapper Creek Monoclines, oriented approximately 45˚ apart (Finley, 1982), represent the two major structural features of this region (Fig.1). Finley (1982) mapped two intersecting faults in the Cottonwood Creek area. The NW-trending Cottonwood fault roughly parallels the fold axis of Shell Creek monocline (N60W), and offsets Precambrian basement by 100 meters. It appears to be an extension of the larger structure. A second, poorly exposed N-S trending fault along Cottonwood creek exhibits relatively minor displacement of Cambrian rocks, and separates two different granites.

This study emphasizes analysis of joints and minor faults associated with the NW-trending basement fault in order to determine fault geometry and regional stresses. Movement along faulted basement blocks is believed to have produced the overlying Shell Creek Monocline (Fig.2) (Finley, 1982), and is evidence of the Precambrian basement control of Laramide-generated folds seen throughout the Wyoming Foreland.

Samples of Precambrian granite were collected from mineralized portions of minor faults in the hanging wall for both optical and oxygen isotope analysis. Oxygen isotope data provides information on the fluid origin and temperature of the granite in the fault zone.

RESULTS/OSERVATIONS

Nature of the granite. Hanging wall rocks on either side of Cottonwood Creek display notable textural and compositional differences. Variations in east and west granite types across the creek, as well as extent of mineralization, suggest the possibility of movement along the N-trending fault proposed by Finley (1982). Rocks east of the fault have a medium grained texture, are somewhat alkalic (45-50% K-spar), and contain relatively little quartz

(8%). They are cut by many minor mineralized and slickensided faults. Oligoclase (25-30%) twins are kinked,
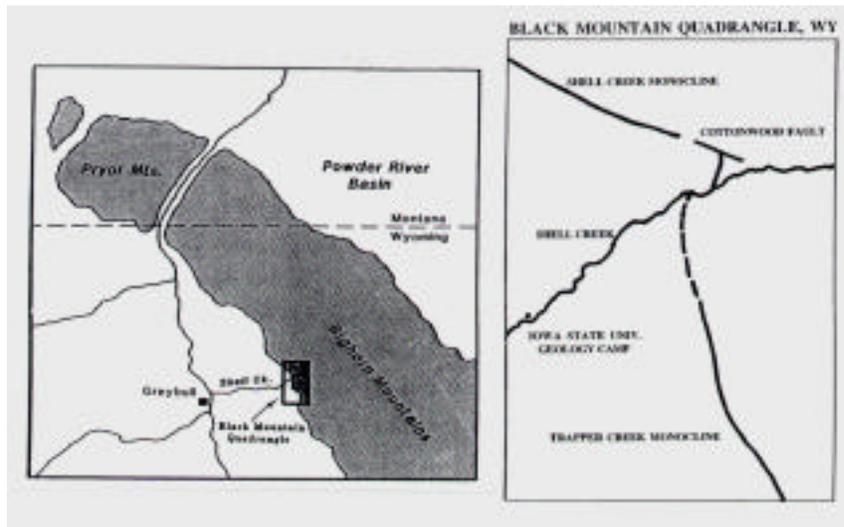

Figure 1: Map of Black Mountain Quadrangle and major structures (modified after Finley, 1982).

Figure 2: Folded Paleozoics of the Shell Creek Monocline are at the top of the photograph. The Precambrian granites of the Cottonwood Creek study area make the low outcrops on the lower right.

showing evidence of shear. Weathered and heavily altered by epidote and chlorite, the granite displays a brecciated nature characteristic of fault zones. In contrast, the area of densely spaced joints west of the fault is less altered by fault mineralization, and is a fine-grained leucocratic granitic porphyry, composed of roughly equal proportions of quartz, K-spar, and oligoclase. The rock here shows more deuteric alteration to secondary minerals of sphene, epidote, magnetite, and chlorite, and more plagioclase cores (85-95%) have been altered to sericite and/or clays.

Minor Faults. The twenty-eight minor faults (Fig. 3a) fall into three relatively distinct populations, each parallel to other observed structures in the quadrangle. The twenty-two faults on the east side of Cottonwood creek included populations parallel to the W-NW trend of Shell Creek monocline and the N-NW trend of the Trapper Creek monocline. The six faults on the west side of the creek show a NE trend evident in many local joints. These faults occur in an area of parallel subvertical joints with spacings of approximately 10 cm, and offset pegmatite dikes less than l cm. Faults display slickensides with steps that indicate the sense of shear, and with the exception of the joint-parallel (NE) set, are heavily mineralized with epidote, chlorite, and in some places, hematite. Nineteen of the twenty-eight fault measurements show reverse motion. N-NW and NE faults show components of left-lateral slip. The composite fault plane solution of minor faults using the P-T

diahedra method of Marrett and Almendinger (1990) shows an E-W trending, subvertical reverse fault, dipping steeply to the north (Fig. 3b).

Joints. Thirty-five joints were measured in the Precambrian rock (Fig.3c). A steeply dipping, ENE trending set was the most strongly developed, with strikes ranging between N55-85E. Three minor populations are present: a steeply dipping N-S set, a steeply dipping NW (N50-85W) set, and a shallowly dipping NW-striking, SW-dipping set. The N-S and ENE set are roughly orthogonal and have been previously noted by Finley (1982).

3(a)   3(b)   3(c)
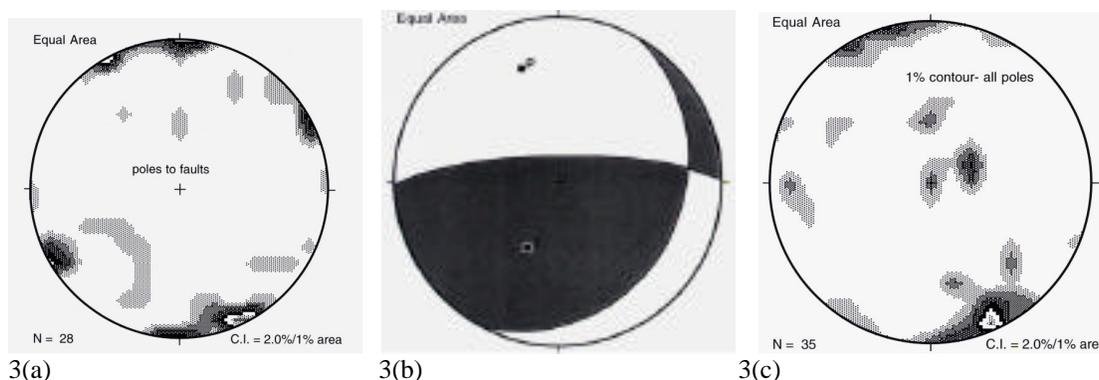
Figure 3: (a) Contoured poles to 28 minor faults in the hanging wall of Cottonwood Fault (b) Composite fault plane solution of minor faults (c) Contoured poles to 35 joints on hanging wall and footwall of Cottonwood Fault.

DISCUSSION

The field work along Cottonwood Creek was concentrated in the hanging wall area of the Cottonwood Fault, at the projected intersection of the Shell Creek and Trapper Creek Monoclines (Fig.1). The fault forms part of the inside corner of these W-NW and N-NW trending structures. The 100 meter displacement of Precambrian granitic basement along the Cottonwood fault represents approximately 10% of the 1090 meters of structural relief exhibited by the Shell Creek Monocline. If the location of the corner lies near the Cottonwood fault, and the total displacement of the corner is comparable to the two major monclines, then additional local basement faults with significant displacement are hidden by cover rocks. Thus, the basement in the Cottonwood area may represent one of several fault-bounded blocks.

This study postulates high angle reverse movement of the basement, in which a series of subhorizontal, untilted fault-bounded blocks have been uplifted in response to NE-SW Laramide compression. Shallow dips and consistent strikes of the overlying Flathead Sandstone suggests that there has been little or no rotation of fault blocks. Finley (1982) shows vertical motion along high angle faults to have displaced the Precambrian basement in the Cottonwood Creek area. Given the sub-vertical nature of minor structures in the field area (Fig. 3a-3c), it is not surprising that the near-surface expression of reverse movement along the Cottonwood Fault is vertical.

Although one mechanism of basement uplift generally cannot account for the intense structural complexity of the region (Palmquist, 1978), most researchers propose differential vertical uplift as the dominant model of basement tectonics in the Bighorns (Prucha, et al., 1965; Palmquist, 1978;

Matthews and Work, 1978; Stearns and Stearns, 1978). This model leaves the folded sedimentary section and the uplifted basement block structurally out of balance. Brown (1993) suggests that this imbalance is accommodated by bed-lengthening or bed-thinning within the layered rocks. Stearns and Stearns (1978) show that the nature of the folded cover can be used to place constraints on basement fault geometry. Field and related laboratory experiments have shown that low-angle basement faulting produces a faulted sedimentary section (Stearns and Stearns, 1978). The unfaulted Shell Creek Monocline is believed to be a forced fold formed by a high angle reverse fault. Vertical uplift of the basement in the field area is partially accomodated by detachment, and possible thinning of the ductile Cambrian Gros Ventre shales within the monocline (Finley, 1982). Detachment between this lower sedimentary layer and the forcing block allows for minimal faulting within the section (Brown, 1993). No thinning has been noted to occur within post-Cambrian rocks of the Shell Creek Monocline (Finley, 1982), and it is possible that the remaining displacement is accommodated by slip within the layered rocks (Stearns and Stearns, 1978).

Generally NW-trending Laramide structures, resulting from NE-SW directed stress, have been cut into blocks by the reactivation of NE, E-W, and N-S striking zones of Precambrian weakness (Brown, 1993). The E-W and N-S structural patterns noted to characterize the Wyoming Foreland (Prucha, et. al., 1965) are clearly expressed in the minor structures of the Cottonwood Creek area (Fig.3). The roughly subvertical, perpendicular N-NW and NE trending minor faults may represent Precambrian joint sets reactivated by regional Laramide stress. Field observations show that the NE trending minor faults are almost certainly reactivated, due to their location within closely spaced and parallel joints. Joints show the same roughly orthagonal N-S (NNW) and ENE sets seen in minor faults. Rohr and others (1964) observed the same trends in 400 fractures measured in Shell Canyon. Minor faults striking WNW are sub-parallel to the fold axis of the Shell Creek Monocline. NW-oriented minor faults and joints (N50-85W) are consistent with typical Laramide-age structures. Steeply-dipping NW Laramide sets sharing similar trends (N70-88W), are also present in the Piney Creek Area on the eastern flank of the central segment of the range (Hudson, 1969). General joint trends in the study area were consistent with those of Osterwald (1959), who noted prominent steeply dipping NW and NE sets in the Bighorns. The S and SW-dipping, low angle, sheeting(?) joints are relatively common in the field area, but the subhorizontal NE (N10-17E) set reported by other workers in the Bighorns were not observed.

Two possible fault planes are shown in the composite fault plane solution (Fig. 3b). The E-W trending, steeply dipping plane is preferred, based on the N60W strike and vertical dip of the surface exposure, and is compatible with the postulated high angle reverse mechanism. This subvertical plane does not exhibit the pure dip-slip motion of Finley (1982), but rather displays the minor oblique movement proposed by Brown (1993) for reverse faults not perpendicular to the maximum principal stress. Corresponding to a N-plunging principal stress, the plane does not follow the NE-directed stress cited by most workers, including Wise and Obi (1992) for the Five Springs Area, but is more in conjunction with the late Eocene stress cited by Brown (1993). The second plane is not preferred because of its NE strike, as well as its low dip angle that would cause faulting of the cover rocks.

OXYGEN ISOTOPES

   Quartz, feldspar, and epidote from six samples in the hanging wall of the Cottonwood fault were analyzed for oxygen isotopes at laboratory facilities at the California Institute of Technology, using laser-based microanalytical techniques. Samples showed generally low values of ^{18}O for quartz (7.194-8.529‰), feldspar (5.006-6.173‰), and epidote (<0‰). Fractionation (= $^{18}O_{qtz}$- $^{18}O_{fsp}$) values were large, ranging from 1.443-2.918, most being over 2.1‰. Temperatures based upon this fractionation ranged between roughly 250°-450°C, and were calculated on the basis of Faure (1977), using an An content of 12%. If oxygen exchange reactions attained equilibrium, then the fractionation factor is a function of temperature, and can be used to ascertain a temperature of equilibration (Faure, 1977). If equilbrium has not been reached, this method no longer provides an accurate geothermometer. Anomalously high temperatures may reflect disequilibrium by partial exchange with a low ^{18}O fluid, presumably light meteoric water. It is probable that feldspar exchanged oxygen more rapidly with the fluid than did quartz (Hoefs, 1997). Epidote is always heavier than fluid with which it reacts; therefore, negative ^{18}O values for epidote cannot occur except by reaction with light fluid, and together with low ^{18}O values for
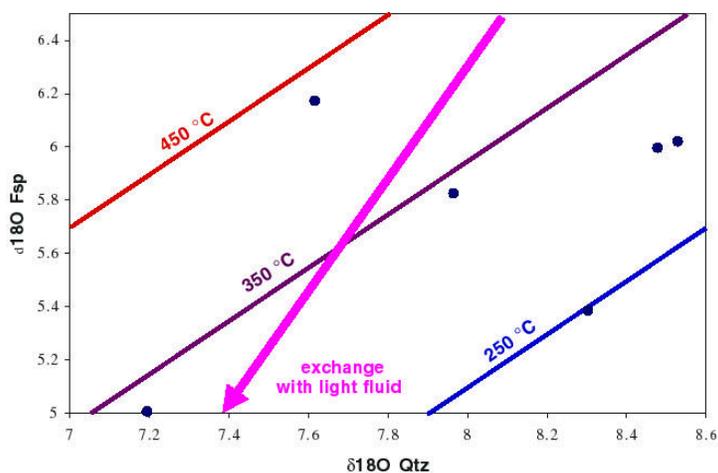

Figure 4: Quartz ^{18}O values versus Feldspar ^{18}O values for coexisting mineral pairs from hanging wall samples. Lines of constant $_{atz-fsp}$ show temperatures between 250°-450°C.

both quartz and feldspar, suggest that lower temperature fluids (250°C), percolating down through existing fractures, have interacted with the granite in this area. It can be inferred then, that these meteoric fluids have moved along the Cottonwood fault producing the low temperature mineralization (epidote and chlorite) that characterizes the zone.

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