Veins as stress indicators, Mazatzal Mountains, AZ

Martin Wong
Department of Geosciences, Williams College, 947 Main St. Williamstown, MA 01267
Faculty sponsor: Paul M. Karabinos, Williams College

INTRODUCTION

Precambrian rocks in the northern Mazatzal Mountains underwent the Mazatzal Orogeny at 1.65 Ga (Karlstrom and Bowring, 1991) which resulted in extensive folding and thrusting. The purpose of this study is to examine the spatial distribution and geometry of veins within two quartzite units in the mountains; the Deadman Quartzite and the Mazatzal Peak Quartzite, and to understand their relation to deformation. Veins may fill tension or shear fractures which form with different orientations to a stress field. Identifying and mapping these different types of veins will provide a detailed picture of the stress field in the northern Mazatzal Mountains during orogeny.

RESULTS

In the field, the most common type of vein in the study area is 10-100 cm in length, relatively thick (1-3 cm), and tapered rapidly at either end. These veins commonly have visible quartz fibers which are perpendicular to the vein walls and crack-seal textures. A second type of vein is typically thin (usually several mm in thickness), long, and planar. Most of these veins have no visible fibers, but some have fibers which are parallel to the vein walls. A third common type of vein is bedding parallel and typically several mm thick. Bedding parallel veins frequently have quartz fibers parallel to the beds.

In thin section, the most common vein texture is fibrous perpendicular to vein walls (Figure 1). This texture is most commonly, but not exclusively, associated with the thick, tapering vein type. Another less common texture is fibrous nearly parallel to the vein walls (Figure 2). A third texture is blocky rather than fibrous crystals (Figure 3). Both the blocky texture and the vein parallel fibrous texture are commonly associated with thin, planar veins.

Thin section analysis indicated that most veins are composed entirely of quartz. However, some veins are composed entirely of hematite, or of hematite and quartz or chlorite and quartz. Figure 4 shows a photomicrograph of a composite vein of chlorite and quartz.

The thick and tapering vein type has a fairly consistent orientation throughout the study area. The mean pole of the most prominent set of such veins has a trend of 56° and a plunge of 10° (Figure 5). This set is orthogonal to most measured fold axes, which have a mean trend of 220° and a plunge of 18°. Another, less prevalent set of tapering veins has a mean pole trending 136° and plunging 16°. This set is parallel to most measured fold axes.

Veins with fibers parallel to the vein wall have a less consistent regional orientation than tapering veins. However, there appear to be 6 main sets of these veins, four of which are steeply dipping, and two of which are shallowly dipping. Two of the steeply dipping vein sets have mean poles trending 253° and plunging 24° and trending 200° and plunging 17°. The other two sets of steeply dipping shear veins have orientations similar to the thick, tapering vein sets, with mean poles trending 300° and plunging 20° and trending 223° and plunging 5° (Figure 6). The two shallowly dipping sets of shear veins have mean poles trending 348° and plunging 80° and trending 136° and plunging 60° (Figure 7).

Quartz fiber lineations are present on both shear veins and bedding parallel veins. Quartz fiber lineations have a fairly wide range of orientations, but can generally be grouped into three sets, two shallowly plunging and one steeply plunging. The most common set of shallowly plunging fibers has a mean trend of 312° and a plunge of 25°. A second common set of shallowly plunging fibers has a mean trend of 262° and a plunge of 20°. The more steeply plunging set has a mean trend of 51° and a plunge of 70° (Figure 8). Some surfaces have multiple orientations of fibers, especially bedding parallel veins.

DISCUSSION

Vein textures with fibers perpendicular to the vein wall suggest that these veins initially opened by tension fracture since quartz fibers track the dilation direction of the fracture as it opens. Tension fractures form parallel to σ_1 and perpendicular to σ_3. Because the thick, tapering vein set only displayed fibers perpendicular to the vein wall, I interpret the tapering veins as tension veins and use their orientation to track changes in σ_1 throughout the study area. As indicated by figure 4, the most prevalent set of tapering veins has a mean pole trending 56° and plunging 10°. In tension veins, this pole represents the σ_3 direction. σ_1 is perpendicular to σ_3, suggesting that if σ_1 was approximately horizontal, it had a trend of 326° during tension vein formation. This estimated σ_1 value is very similar to estimates of thrusting direction in the northern Mazatzal Mountains. Puls (1989) estimated that the thrusting direction was 310° based on a geometric and kinematic study of folding and thrusting. Doe and Karlstrom (1991) suggest that the thrust direction was 289° based on a regional average of quartz fiber orientations. Assuming that the transport direction is parallel to σ_1 during thrusting, the stress fields during thrusting and tension vein formation were very similar. This suggests that thrusting and tension vein formation were contemporaneous.

The less prevalent set of tension veins forms nearly parallel to the axial planes of most folds. This suggests that the formation of these veins is related to folding. I interpret these veins to represent tension fractures which form near the hinge line of folds.

Veins with fibers parallel to the vein walls are interpreted as shear veins. The orientation of these shear veins suggests that they formed under a similar stress field as the tension veins. Shear fractures tend to form at approximately 30° from the σ_1 orientation. The two steeply dipping shear vein sets have mean poles trending 252° and plunging 15° and trending 195° and plunging 15°. Assuming that these are conjugate vein sets, the intersection of the two planes is parallel to σ_2 and the acute bisector of the planes is parallel to σ_1. This suggests that σ_1 during shear vein formation was nearly horizontal with a trend of 314°. Shallowly dipping shear veins also indicate a similar σ_1 direction, having formed dipping at 10-30° from the estimated σ_1 orientation. The estimated σ_1 direction during shear vein formation is very similar to the estimated values of σ_1 for both thrusting and tension vein formation. This suggests that, like tension veins, shear veins were formed contemporaneously with thrusting.

Shear veins that have similar orientations to tension veins may have initially formed as tension fractures. Multiple fiber orientations on bedding parallel and shear veins suggests that polydirectional movement has occurred. This polydirectional movement may be in response to shifting principle stress directions during orogeny. Such changes in the stress field may have induced shear motion in veins with a tensile origin. An alternate possibility is that these shear veins originally formed at 30°to σ_1 and were subsequently reoriented during folding. There is some scatter in the interpreted sets of veins which may be due to reorientation during folding. However, this scatter seems fairly minimal, suggesting that both tension and shear veins formed late during folding. Most sets of tension and shear veins have a relatively consistent orientation despite a wide range of bedding orientations. Had vein formation occurred prior to or early on with respect to folding, veins should have a much wider range of orientations.

Quartz fibers record a range of movement on a variety of surfaces. The set with a mean trend of 312° and a plunge of 25° most likely represents movement in the thrust direction on both horizontal shear veins and on bedding parallel veins where bedding is close to horizontal. The second nearly horizontal set most likely indicates movement on steeply dipping shear veins. The more steeply plunging set of fibers probably represents bedding parallel slip in areas with steep bedding, possibly in response to folding.

Analysis of tension and shear veins in the northern Mazatzal Mountains provides insights into the deformation of thrust sheets during orogeny. Tension veins suggest that during transport, thrust sheets expand outwards perpendicular to the transport direction. . Steeply dipping shear veins also accommodate this expansion at approximately 30° to the transport direction. When moving over obstructions such as ramps, thrust sheets may expand parallel to the transport direction near the crests of folds. Shallowly dipping shear faults contribute to crustal shortening in the direction of thrusting.

REFERENCES

Doe, M. F. and Karlstrom, K. E., 1991, Structural Geology of an Early Proterozoic Foreland Thrust Belt, Mazatzal Mountains, Arizona: in Karlstrom, K. E., Proterozoic Geology and Ore Deposits of Arizona, Arizona Geologic Society Digest 19, p. 181-192.

Engelder, T., 1987, Joints and shear fractures in rock, in Atkinson, B.K. (ed.), Fracture mechanics of rock: Academic Press, London, p. 27-69.

Karlstrom, K. E. and Bowring, S. A., 1991, Styles and timing of Early Proterozoic deformation in Arizona: Constraints on tectonic models: Proterozoic Geology and Ore Deposits of Arizona, Arizona Geologic Society Digest 19, p. 1-10.

Puls, D.D., 1986, Geometric and kinematic analysis of a Proterozoic foreland thrust belt, northern Mazatzal Mountains, central Arizona [Masters Thesis]: Flagstaff, Arizona, Northern Arizona University, p.102

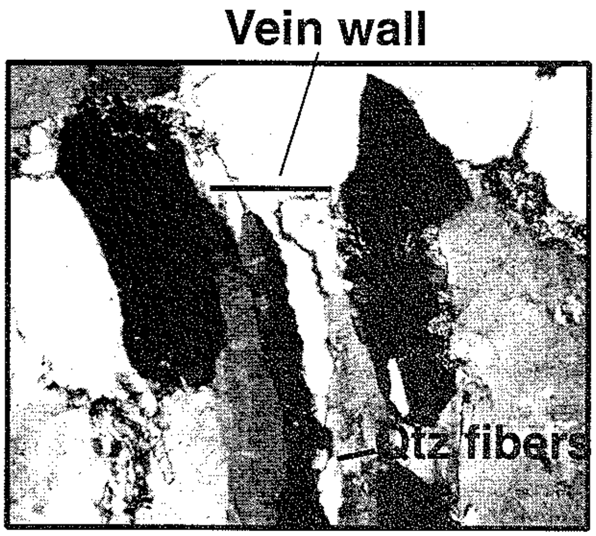

Figure 1 - Photomicrograph showing quartz fibers in a vein. Vein wall is nearly horizontal in this image (shown by black line). Quartz fibers are elongated vertically in this image, perpendicular to the vein wall. Field of view is 2.4 by 4 mm. Sample 8A-1.

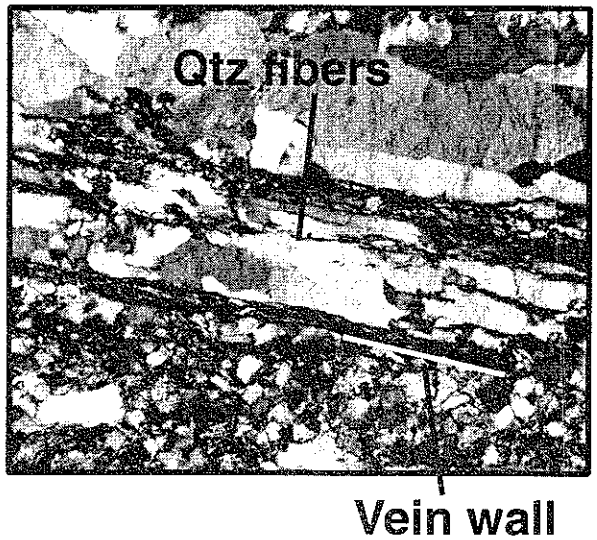

Figure 2 - Photomicrograph of fibrous vein texture parallel to the vein wall. Vein wall (shown by white line) and quartz fibers are nearly horizontal in this image. Field of view is 2.4 by 4 mm. Sample 10A-1.

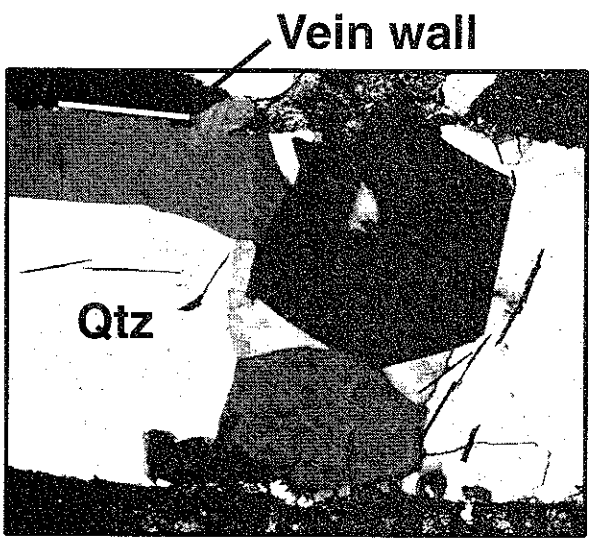

Figure 3 - Photomicrograph showing blocky quartz crystals in a vein. Vein wall is nearly horizontal in this figure (shown by white line). Field of view is 2.4 by 4 mm. Sample 2F-1.

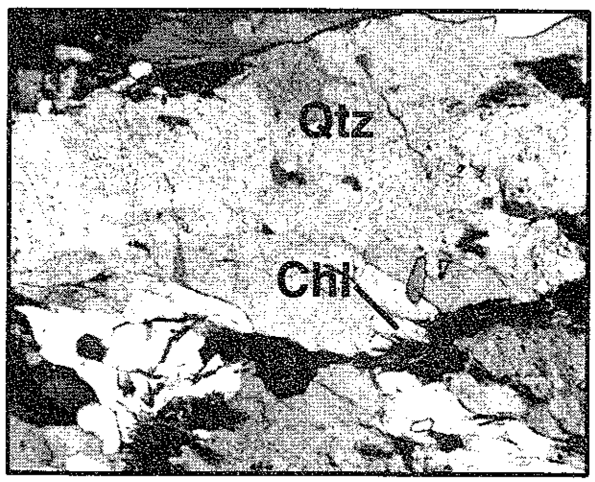

Figure 4 - Photomicrograph showing a fibrous texture in a vein. The vein is composed of both quartz and chlorite. Field of view is 2.4 by 4 mm. Sample 6A-3.

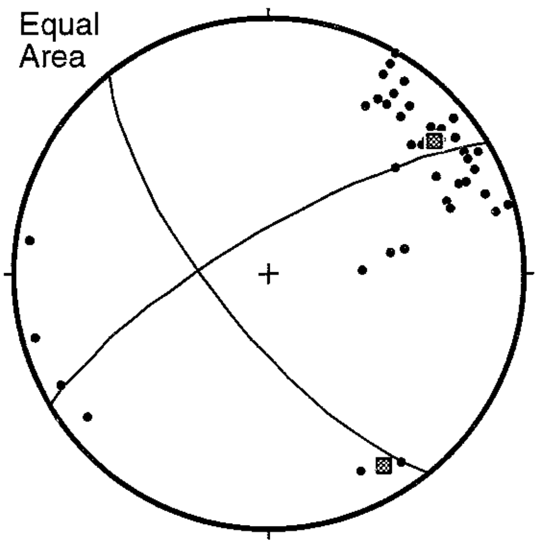

Figure 5 - Equal area projection of poles to tapering veins (dots). Also shown is the mean pole (box) and plane to this pole. Note the two sets at nearly right angles.

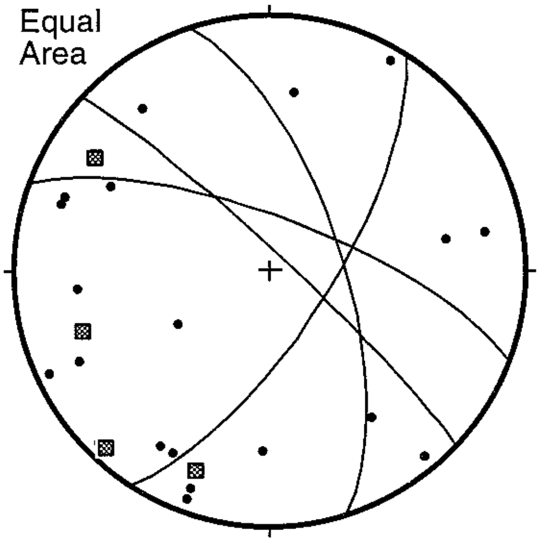

Figure 6 - Equal area projection of poles to steeply dipping veins with fibers parallel to vein walls (dots). Also shown are the mean poles (boxes) and planes to these poles. Note that 2 sets have similar orientations as tapering veins.

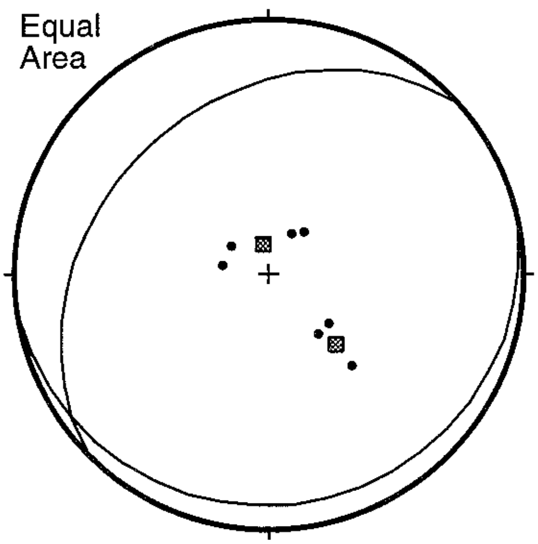

Figure 7 - Equal area projection of shallowly dipping veins with fibers parallel to vein walls (dots). Mean poles (boxes) and planes to these poles for two sets are also shown.

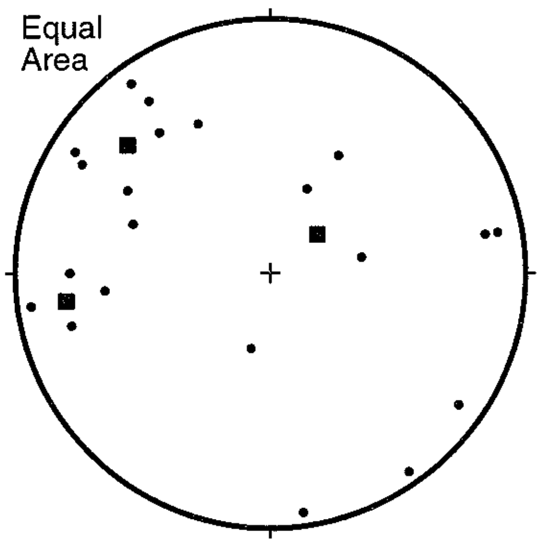

Figure 8 - Equal area projection of quartz fiber lineations. Boxes indicate mean vectors for three general sets of fibers.