KINEMATIC ANALYSIS OF A PROPOSED GNEISS DOME
AND POSSIBLE BIG SKY OROGENY STRUCTURE,
HIGHLAND MOUNTAINS, SOUTHWEST MONTANA

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INTRODUCTION

The Precambrian rocks of the Highland Mountains in southwest Montana have been interpreted as a gneiss dome with a leucocratic core that mobilized during the early Proterozoic (O’Neill et al., 1988). While gneiss domes and core complexes have been described in the Cordillera (Yin, 2004), no Proterozoic domes in the area surrounding the Highland Mountains have been identified. To further characterize the kinematics of the dome first documented by O’Neill et al., (1988) and document evidence for possible late Proterozoic deformation described as the Big Sky orogeny (Harms et al., 2004), this study analyzed kinematic indicators in 19 samples for evidence of sense of shear in the formation of the Highland dome.

Dome formation during orogenesis is usually attributed to one of two end members: core complexes (extensional) and gneiss domes (compressional) (Yin, 2004). Many structural mechanisms are proposed for dome growth depending on stress fields and fault orientations (Yin, 2004). The Highland dome is thought to have formed from density differences, a mechanism for dome growth that creates down-dip movement and a radial pattern of lineation in addition to augen gneiss (O’Neill et al., 1988). A radial pattern of lineation and normal-sense displacement can be indicative of gneiss domes. Core complexes in the Cordillera described by Davis and Coney (1979) also include a core of augen gneiss and mylonites, but the direction of the upper plate relative to the core is unidirectional, producing a non-radial pattern of lineation. While the end-members represent different tectonic settings, evidence for distinction based on field data is difficult (Yin, 2004).

Indicators for sense of shear are formed from both brittle and ductile processes which cause certain minerals to deform differently depending on pressure and temperature conditions. In this study, rotated porphyroclasts and S/C fabrics were used as kinematic indicators to determine sense of shear. Elevated temperature conditions can create a ductile quartz-rich matrix in which feldspars deform brittle and rotate rigidly; if the deformation is non-coaxial, the feldspars can display asymmetry with dynamically recrystallized tails; the direction the tails step up indicates the direction of shear (Simpson and Schmid, 1983). Many of the Highlands Mountains Proterozoic rocks are leucocratic and were collected for this study for sense of shear determination because the common feldspars acted as porphyroclasts during shear. In addition to rotated porphyroclasts, non-coaxial deformation can also create a mylonitic texture with ‘S’ and ‘C’ surfaces—another kinematic indicator (Lister and Snoke, 1984). The ‘S’ fabric, or schistosity, occurs along the maximum finite strain orientation (often the dominant foliation) and the ‘C’ fabric represents areas of discrete shear (shear bands) at a small angle to the ‘S’ fabric (Lister and Snoke, 1984). The ‘S’ orientation forms in
the direction finite elongation, and when both fabrics are ascertained, indicate a movement direction. Spatial analysis of the sense of shear at locations around the Highland Mountains dome documents the finite strain associated with proposed dome formation.

**METHODS**

To identify sense of shear, 43 oriented hand samples were collected with foliation and lineation measured in the field. From these hand samples, 30 were cut perpendicular to foliation, parallel to lineation, and oriented thin sections created.

Hand samples were photographed with a Nikon D70 digital camera; thin sections were scanned with a Nikon Super Coolscan 5000 slide scanner with both plane and cross polarized light. Images were compiled in Deneba Canvas with fabrics and rotated porphyroclasts digitally recorded as separate layers (Fig. 1). Based on up to three independent observers, clear sense of shear was determined in 19 samples (the other 11 samples did not show definitive sense of shear). For each of these unambiguous 19 samples, stereoplots were created with StereoWin ver.1.2 (Almendinger, 2003) and plotted on the Highland Mountains geologic map (Fig. 2).

**RESULTS**

Although an overall determination for the entire structure remains ambiguous, certain trends of sense of shear emerge along transects of the Highland Mountains gneisses (Fig. 2).
The northeast portion (Fig. 3A) of this study is the least consistent in terms of sense of shear. The point farthest to the northwest shows reverse movement directed to the southeast, yet the point farthest southeast in the area indicates normal movement towards the southeast.

The central transects (Fig. 3B) are consistent with a westerly dip and reverse movement to the east. The point furthest northeast in the central area is part of a mesoscopic fold documented in the field. Foliation of these samples is consistent with mapped structural data from O’Neill et al. (1996), generally with north-south strikes and dips <40° to the west.

The southernmost portion (Fig. 3C) is more complicated. Samples west of the dome axis, mapped by O’Neill et al. (1996), show normal movement to the west, while those of the eastern limb indicate a reverse sense of shear to the northwest.
movement to the east along the eastern limb of the fold and reverse movement to the northwest along the western limb. Inset is enlargement of Figure 2 which describes units and stereoplot diagrams.

The easternmost sample (Fig. 3C) from the informally-named “O’Neill’s Gulch area” (see Matthews and Labadie, this volume) also indicates normal movement to the southeast.

DISCUSSION
This study can neither reinforce nor contradict the claim of a gneiss dome being the dominant map-scale structure of Proterozoic rocks of the Highland Mountains. Due to inconsistent data at a macroscopic scale, and knowing that mesoscopic folds occur in the area, without further study, a kinematic construction of the Highland Mountains dome is ambiguous. Additionally, samples for this study do not adequately represent the eastern, and more obscure, limb of the “dome”. Sampling of the eastern limb is difficult because it is not as well exposed and developed roads are limited nevertheless, more data from this area should be obtained.

Rock types sampled for this study do not appear to accommodate strain differently; yet more study of innermost core rocks is necessary to determine the influence of mylonitization on rock types. Given this lack of samples, structural features in the inner core are not compared for this study.

Interestingly, leucocratic intrusions, which are presumed contemporaneous with the dome development (O’Neill et al., 1988), are sheared in most locations. However, some leucocratic intrusions are sheared and unsheared in the same location (not affected by cross-cutting relationships) possibly showing different timing in deformation.

Many mesoscopic folds that parallel the axis of the dome, as defined by O’Neill et al. (1988), occur in the area. Although not quantitatively studied for this research, these folds possibly result in reorientation of the mylonites used for this study. As a consequence, the normal movement of the supracrustal cover rocks proposed by O’Neill et al. (1988) is not definitively indicated in the data. The mesoscopic folds appear synchronous with the overall deformation that generated the dome based on map relationships (O’Neill et al., 1988 and O’Neill et al., 1996), and parallelism of axes to observed foliation. The western limb, while not wholly consistent, does show reverse moment along many transects; and as a counter to the interpreted Highland Mountains dome, the dominant map-scale structure might be a fold.

Regardless if the Highland Mountains structure is a dome or an anticline, it could represent a collisional area; if so, the structure has an axis parallel with the proposed orogenic zone called the Big Sky orogen (Harms et al., 2004). Future work determining if the structure is a gneiss dome or doubly-plunging anticline could provide evidence for the orientation of stresses and evolution of the North American craton; but extensive Mesozoic and Cenozoic intrusions and Laramide structures obscure the majority of the exposed Proterozoic rocks. Dating of leucocratic sills, both sheared and unsheared, and collecting data along more transects, particularly the east and core would be the most effective methods to determine the timing and kinematic formation of the Highland Mountains structure during what appears to be the Big Sky orogeny.

REFERENCES


