Archean Deformation of the Tobacco Root Mountains, Southwestern Montana

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Introduction

The Spuhler Peak Metamorphic Suite (SPMS) lies structurally above the Indian Creek Metamorphic Suite (ICMS) and below the Pony-Middle Mountain Metamorphic Suite (PMMMS). All three units contain gneissic bands, foliation, folds on a range of scales, boudinage, and mineral lineation. These structures have been interpreted in terms of polyphase deformation (Reid 1963, Gilmeister 1971, Cordua 1973, Hansen 1975) or in terms of simple shear (King 1994).

The nature of the contacts between these units has also been the subject of some dispute. Burger (1966) mapped a series of regional scale, tight, slightly overturned antiforms and synforms in the ICMS. The SPMS-ICMS contact appears to crosscut the axial planes of these folds, and Burger interpreted this contact as a fault. Gilmeister (1971) found that the contact between the SPMS and both the ICMS and PMMMS was marked by a continuous quartzite unit, and interpreted the contact as an unconformity. The nature of the relationship between the ICMS and PMMMS has not been well studied.

Analysis of the structures within units and the relationships between units does not settle the question of the origin of the contact, but does indicate that the area was subjected to regional simple shear. Clear evidence exists for only one major phase of ductile deformation. This deformation produced mesoscopic folds and metamorphic fabrics in all three units and may have formed the regional folds in the ICMS. This deformation also folded the continuous, concordant contact between both the ICMS and PMMMS and the SPMS into what may be a regional scale sheath fold. The juxtaposition of the units preceded the formation of this fold.

Purpose and Methods

The purpose of this project is a characterization and correlation of the deformational histories of the SPMS, ICMS, and PMMMS. Observations and structural measurements including fold axes, mineral lineations, and foliation surfaces were taken from sites within all three units in an effort to elucidate the nature of both outcrop and regional scale structures. Analysis of thin sections from all three units relates larger scale structures to microfabrics and puts the deformational history in a petrologic context.

Results and Discussion

Outcrop scale structures throughout the ICMS, PMMMS, and SPMS share a common style and similar pattern of orientation. Compositional banding is present at all locations and in almost all units. The only lithology lacking banding is a set of metamorphosed mafic dikes and sills (MMDs). Bands range in thickness from a few inches to hundreds of meters. One foliation is present throughout all three units and parallels banding at all sites. Mineral lineations are present at many locations; lineations lie within the plane of foliation. At some locations mylonitic rocks with a strong L-fabric dominate; at others lineation is absent or apparent only in thin section.

Banding and foliation are folded in all three units. Outcrop scale cylindrical folds are similar, open to isoclinal, upright to recumbent, and range in amplitude from a few centimeters to tens of meters. Previous interpretations have sought to separate distinct phases of folding on the basis of morphology (Cordua 1973, Hanley 1975). Fold shapes and styles do not separate into distinct sets, however; a continuum exists between open and isoclinal folds, and tightness varies between different bands within some folds. Symmetric and asymmetric folds are both common, and folds with S and Z down plunge vergence are present at most locations. Highly folded areas alternate with larger areas in which folding is almost entirely absent. No pattern to the map scale distribution of these folded and unfolded areas was recognized, and folded zones do not appear to be correlated with any specific lithology. Folded MMDs are present in both the ICMS and PMMMS, as are folds crosscut by MMDs. Sheath folds are far rarer than cylindrical folds, but are present in all three units.

Data collected from sites within the SPMS and adjacent sites within the PMMMS or ICMS indicate that structures within all three units have similar patterns of orientation. Folds that are crosscut by MMDs and folds that deform MMDs also plot in similar orientations. Fold axes plot in girdle or dispersed point maximum distributions, in which folds with S and Z down plunge vergence generally plot on the opposite side of the girdle or point maximum. Mineral lineations plot near point maxima or, if girdle distributions are present, within the angles of separation between folds of opposite vergence (figure 1). This pattern of fold asymmetries is consistent with the rotation of cylindrical fold axes during progressive simple shear (Hansen, 1970).

Regional scale features bear some concordance with outcrop scale structures. A series of slightly overturned folds outlined by marble horizons dominate the map pattern of the ICMS. The axes of these folds plunge shallowly NNW(Burger, 1966) and parallel both the regional average mineral lineation and the point maxima of outcrop scale folds. The axial planes of these folds, however, appear to be crosscut by the SPMS-ICMS contact.

Observation of the ICMS-SPMS and PMMMS-SPMS contacts in Spuhler Gulch, near the hypothesized contact between the ICMS and PMMMS, indicates that a single continuous contact exists between the SPMS and the ICMS and PMMMS gneisses. Foliation and banding in all three units are concordant with this contact. Thus the gneisses of the ICMS and PMMMS are continuous along strike with each other, and are concordant with the SPMS. While largely obscured by the Cretaceous Tobacco Root Batholith, foliations and the map relations of the SPMS, ICMS, and PMMMS also suggest the possibility that the gneisses may wrap around the east side of the SPMS as well, forming a closed map pattern indicative of the presence of a regional scale sheath fold.

Petrography also helps constrains the deformational history. Previous work has suggested that rocks from the SPMS were either subjected to multiple metamorphic events or progressive stages of a single event (Burger et al, 1994). These events cannot be separated on the basis of microstructures. Evidence for multiple fabrics in any of the three units is scant; in rare cases biotite forms a vaguely axial planar fabric, but in almost all samples foliation and compositional banding wrap around fold noses. Folded or kinked grains and quartz grains with undulose extinction are absent, and grains form polygonal arcs around folds, indicating that heating outlasted deformation.

Field relationships point to somewhat contradictory interpretations of the regional structural history. The absence of documented MMDs in the SPMS and their pervasive presence in the ICMS and PMMMS could be interpreted as evidence that intrusion took place prior to the juxtaposition of the two units. The concordance of pre- and post-MMD folds with each other, with structures in the SPMS, and with folds in the SPMS contact suggests, however, that MMD intrusion was synchronous with the deformation that folded the ICMS/PMMMS-SPMS contact. Thus all three units share a similar deformational history in relation to MMDs, and some reason must be sought for the failure of the MMDs to intrude the SPMS. The nature of the contact provides further evidence for similar deformational histories. Despite the apparent crosscutting relationship between the SPMS-ICMS contact and axial planes of large folds in the ICMS, the consistent concordance of foliation and banding on either side of the contact and the continuous nature of the contact quartzite indicate that juxtaposition, whether caused by a fault or an unconformity, occurred prior to the major ductile folding in all units.

The consistencies of structural style over a range of scales at all sites, the consistent orientation of regional mineral lineations and fold axis patterns, and the concordance of regional and outcrop scale structures suggest that one regional structural system with one strain ellipse predominated. The pervasive presence of asymmetric folds with rotated axes and the less common presence of sheath folds both indicate that this deformation was dominated by simple shear. The existence of opposite senses of shear at different locations makes the deduction of a regional sense of transport problematic (figure 2). The long axis of this strain ellipse, however, and the regional direction of transport of the deformation responsible for creating regional mesoscopic and microscopic features both plunge shallowly to the north.

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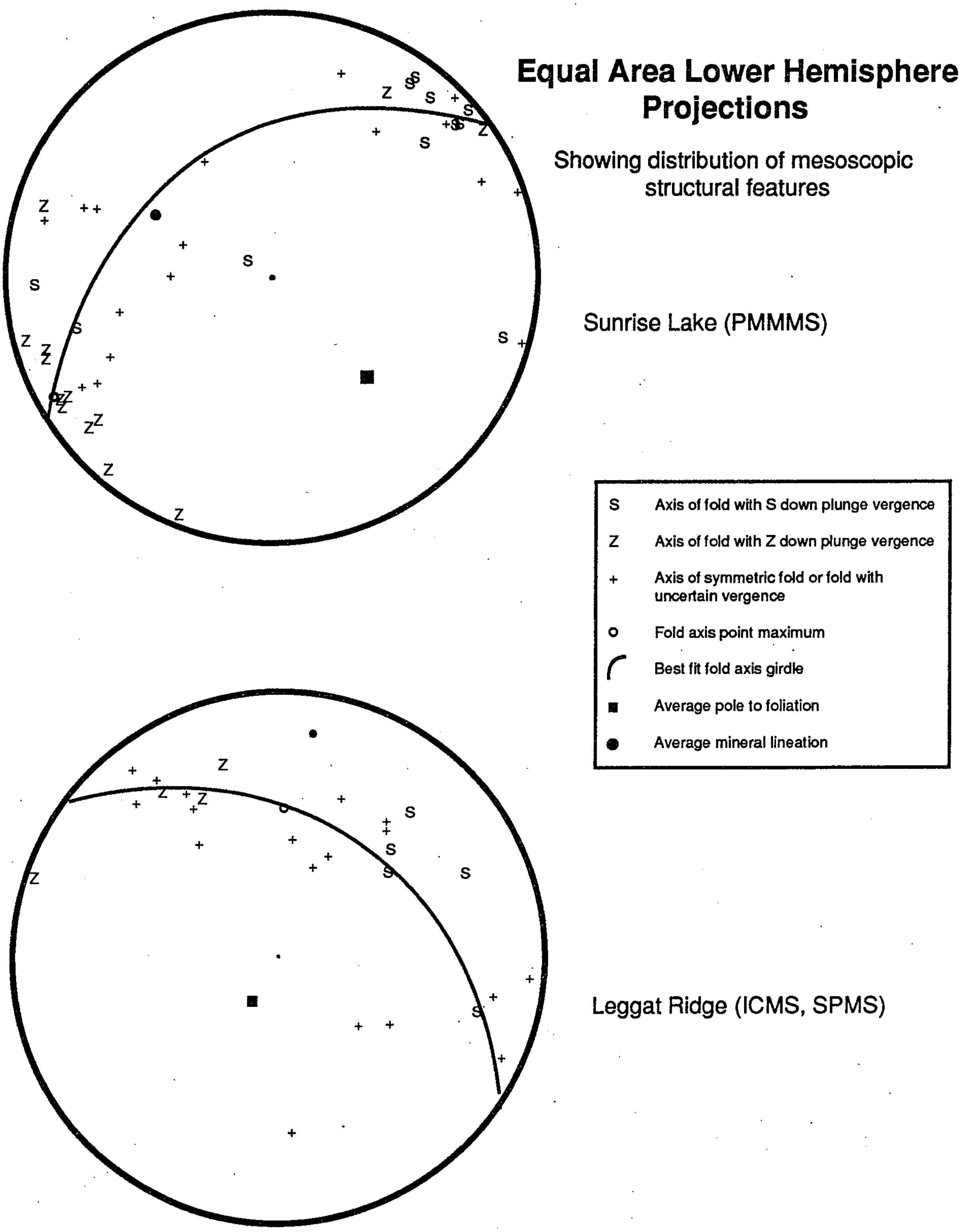

Figure 1. Equal area lower hemisphere plots showing orientation of structural features from both sides of the ICMS-SPMS contact at Leggat Ridge and from the PMMMS at Sunrise Lake. SPMS data at Leggat Ridge from King, 1994.

Map of SPMS and surrounding units showing local senses of shear

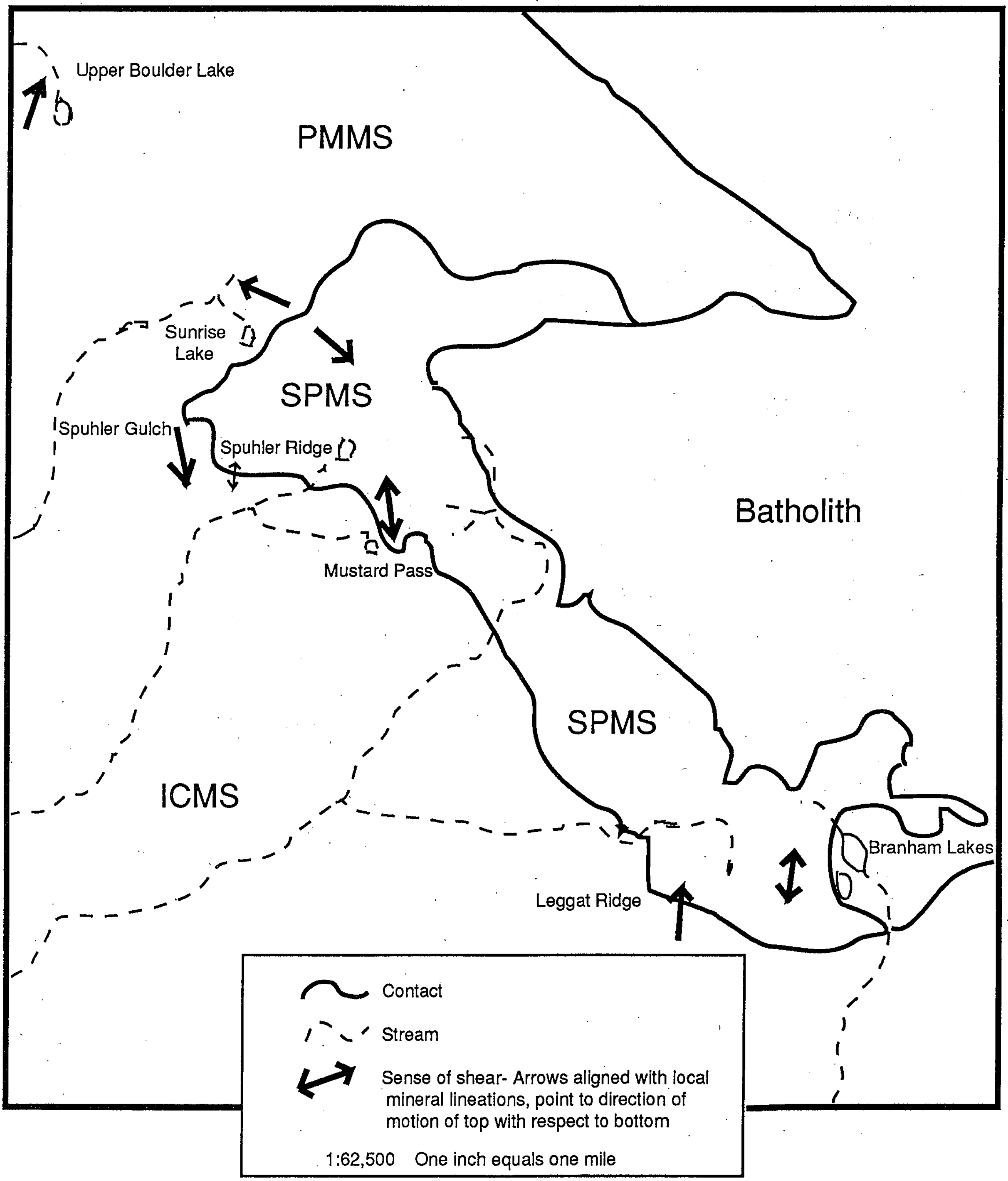

Figure 2. Geologic Map of Spuhler Peak region of southwestern Tobacco Root Mountains showing major lithologic units and local senses of shear. Adapted from Vitaliano et al., 1979