SMALL SCALE FOLD AND FOLIATION ORIENTATIONS RELATED TO MULTIPLE STAGES OF DUCTILE DEFORMATION, QUETICO-WAWA BELT JUNCTION, NEAR REID LAKE, QUETICO PROVINCIAL PARK, ONTARIO, CANADA.

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INTRODUCTION

The 1993 Quetico Keck project focused on understanding metamorphic terranes of the Canadian Shield, as they appear just north of the Minnesota-Ontario border within Quetico Provincial Park. The study area was located around Reid Lake. Sections of two subprovinces of the Superior Province of the Canadian Shield, the Quetico and the Wawa, and the junction between them, lie within the area. The Quetico subprovince has been interpreted as an accretionary wedge, consisting primarily of metagreywackes (Percival and Williams, 1989). It has undergone Amphibolite facies metamorphism which was overprinted by later Greenschist facies metamorphism (Oxboel, 1990; Percival, 1989). Related to this metamorphism, the Quetico subprovince has an axial zone of extreme anatexic migmatization and S-type plutonism (Card, 1990; Percival and Williams, 1989). The Wawa subprovince is a Granite-Greenstone belt, interpreted as a metamorphosed volcano-plutonic arc (Percival and Williams, 1989; Sylvester et al, 1987). Oceanic crust, north of the passive margin of the Wawa subprovince, was subducted beneath the Wabigoon volcano-plutonic arc. The Quetico subprovince was the fore-arc wedge of this system. When subduction ended, the Quetico collided with and sutured to the Wawa. This shifted the Quetico to a back-arc setting related to subduction on the southern margin of the Wawa (Williams, 1990; Card, 1990; Percival and Williams, 1989).

The rocks of the study area represent the suture boundary. Since these rocks were ductile and partially melted during the collision, the rocks of the two subprovinces are highly mixed together in the area. Thus no distinct boundary between the subprovinces exists. But in the zone of mixing, the suturing event created folds and foliations. This specific project was conducted to investigate the generations of these folds and foliations. Heavy anatexis of some units caused the study to be limited to the schist-dominated units of the area. In those units, thin leucosomes highlighted folding and schistosity was clear. The small size of the study area allows for the assumption that orientations, of axial surfaces and foliations, remained constant from outcrop to outcrop. Thus, orientations could be used to help distinguish between fabrics.

FOLDS

The orientations of 85 axial surfaces and hinge lines were measured in the field. Variations in strike, dip, and plunge are not isolated to individual localities, but are widely distributed. Axial surface orientations differ within the same outcrop. This was due to the presence of three generations of folds in the Reid Lake area. Although these have different orientations, all were observed to have disharmonic, noncylindrical properties.

When the axial surfaces were plotted as poles on stereonets, the three distinct orientations appeared. The fold hinge lines, which correspond with these axial surface categories, were then plotted on the stereonets. A great circle was fit to the hinge lines to represent the local orientation of the axial surface. The poles to these great circles always fell within the tight cluster of measured axial surface poles. The orientation of the F_1 axial surface was N30E;60W. The F_2 great circle showed an axial surface orientation of N75E;75W. The F_3 axial surface orientation was N05W;55W.

Each of the three generations of folds has distinctive characteristics. F_1 was usually isoclinal folding of an S_0 compositional banding. The limbs of these folds are parallel with the F_1 axial surface, which runs subparallel to the Quetico-Wawa boundary. F_1 folds usually showed S-symmetry, although some Z and M folds were seen. F_2 was ptygmatic and limited isoclinal folding of the F_1 axial surface and S_0 around the F_2 axial surface. These F_2 folds showed only S-symmetry. F_3 appeared as ptygmatic and isoclinal folding of the limbs of F_1 and F_2 isoclinal folds around the F_3 axial surface. These folds also have S-symmetry. Often, though, F_3 folding appeared only as ductile elongation of the older foliations, such as the S_0 leucosomes. In horizontal outcrop surfaces, this appeared as normal separation of leucosome boundaries. The paradox of these folds is that F_2 ptygmatic folding appears on the limbs of F_3 folds. Some F_4 ptygmatic folds were also observed.

FOLIATIONS

Up to six foliations have been observed in the outcrops of the Reid Lake area. Characteristics such as cross-cutting relationships and amount of post-formation deformation were used to assign numbers S_0 to S_4. S_0, as stated would propagate from the southwest and the resulting duplex structure, once eroded, would account for the tonalite-amphibolite-tonalite sequence. In the SLF type section, brecciation dips more gently (25-35°NW) than the local S_1 foliation. This brecciated, shallowly dipping plane is suggestive of a thrust fault. However, applying present-day plate tectonics to Archean docking events may be problematic. The Archean continental crust was almost certainly substantially thinner, hotter, and therefore less dense than modern-day continental crust. Accretion and even obduction may not have taken place in the same manner as in the more recent geologic past. Convergence at subduction boundaries may not have been necessary. However, having found neither an isoclinal fold nose, nor evidence of an irregular tonalite-amphibolite contact, thrusting must be viewed as an acceptable hypothesis.

CONCLUSIONS: Despite the problems intrinsic in each of the three models, the repetition of tonalite at the south end of the SLF could be explained by any of them. The double layer model seems the most problematic. The thinness of the amphibolite and the conjectured regular contact do not accommodate the double layer model. The single layer model is more probable because of the isoclinal folding present within the amphibolite. These could be parasitic to larger regional isoclinal folds. No major fold noses were discovered within the study area, but this does not eliminate the possibility of the existence of one. Preliminary observations most strongly support a model based on thrust faulting. The shallowly-dipping brecciated zone could result from thrust faulting produced by compressional stresses. Regardless of which model is selected, field observations suggest that the SLL has undergone multiple deformational events; both ductile followed by brittle including the faulting along the Silence Lake Lineament.

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above, is compositional banding. Usually these bands include leucosomes of plagioclase and quartz, in places with K-feldspar, biotite, and amphibole. There are also mesosomes of amphibole, with homogeneously incorporated feldspar, quartz, and biotite. Except in fold noses, isoclinal folding has transposed S_0 banding into the F_1 axial surface. Thus, the F_1 axial surface is highlighted by this migmatite banding as S_1. S_1 also appears as the primary schistosity in the mesosomes, as well as in the local tonalite sills.

The other four foliations appear similar to each other. Generally, they are observed as parallel alignment of individual crystals of amphibole, biotite, quartz, and plagioclase. They are not however, segregated bands of these minerals. These foliations also appear in intrusive dikes with graphic texture as parallel quartz grains. In other dikes and sills, including the tonalites, they occur as oriented amphiboles. However, in units which have experienced high levels of in situ melting, the occurrence of these foliations, and any folding, is very limited.

Three of these four foliations appear to run parallel to subparallel with the axial surfaces of folds. S_2 runs about N70E, 80N - N70W, 80S, parallel with the F_2 axial surface. The mineral alignments of S_2 crosscut S_1 in F_1 folds. Measurements of S_2 show that its orientation from place to place is more consistent than S_1. This suggests that S_1, more than S_2, has been rotated by later deformation. S_3 runs about N15E, 70W - N15W, 70E, parallel with the F_3 axial surface. It commonly cross-cuts S_2 in F_2 folds, and generally is shown to offset S_2. Also, the elongation of S_0/S_1 leucosomes in the limbs of F_2 folds is parallel with S_3. Measurements of S_3 show that it has a more consistent orientation than S_1 and S_2. This suggests that S_3 has been rotated less than either S_1 or S_2. S_4 has been observed to offset S_3. S_4 crosscuts F_2 and F_3 folds, running subparallel to S_1 (N30E, 70W). S_1 is folded by F_2 and F_3. Therefore, S_4 cannot be the same as S_1, but must be a younger foliation. Some F_1 folds may actually be F_4 folds since the F_1 axial surface and S_4 are parallel. The fourth of these foliations was only rarely observed preventing any determination of its age relationships.

CONCLUSIONS

This information about the folds and foliations has allowed for a history of local deformation to be reconstructed. First, since S_0 banding is mainly related to migmatites, migmatization must have occurred before D_1. D_1 then followed producing F_1 isoclinal folds and S_1 foliation. Following this, D_2 created F_2 ptygmatic and isoclinal folds, and S_2 foliation. Next, D_3 took place creating ductile extension of S_0/S_1. At this time, S_3 foliation and F_3 ptygmatic and isoclinal folds were formed. Finally, D_4 created at least S_4 foliation and possibly F_4 folds. Due to rotation, little can be said about the strain associated with the D_1 and D_2. However, limited rotation of D_3 structures suggests that its direction of greatest shortening, Z, was trending at N85E and plunging 35 degrees. The direction of greatest lengthening, X, was then in the plane of the axial surface trending at N05W and horizontal. However, it is not certain whether or not deformation was coaxial. The same is true for D_4 deformation. There appears to have been no latter rotation of D_4 structures. Thus for D_4, Z trended at S60E and plunged 20 degrees.

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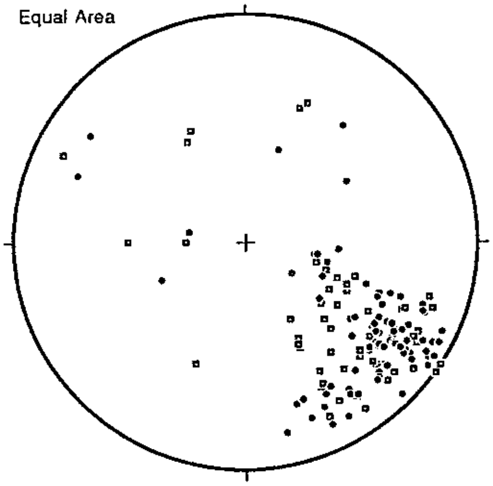

Figure 1. Poles of S1 (dots) and F1 fold axial surfaces (boxes)

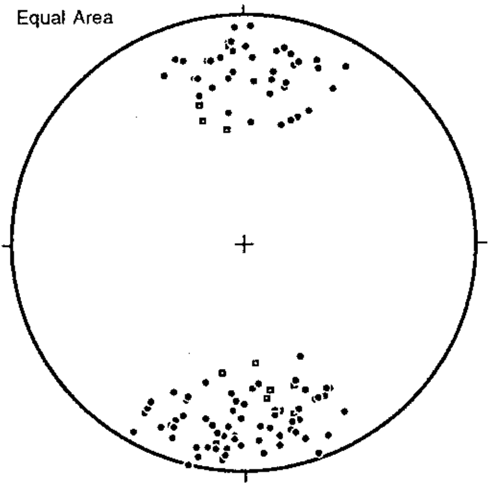

Figure 2. Poles of S2 (dots) and F2 fold axial surfaces (boxes)

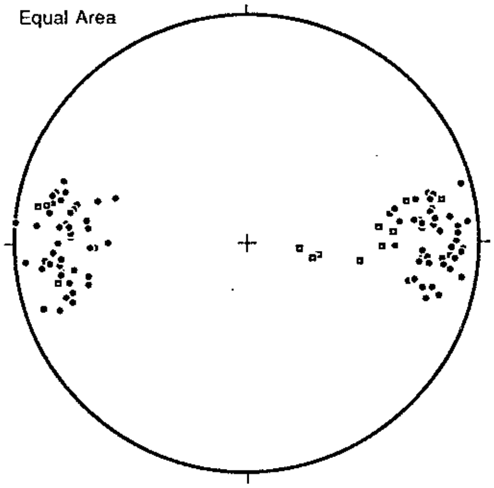

Figure 3. Poles of S3 (dots) and F3 fold axial surfaces (boxes)

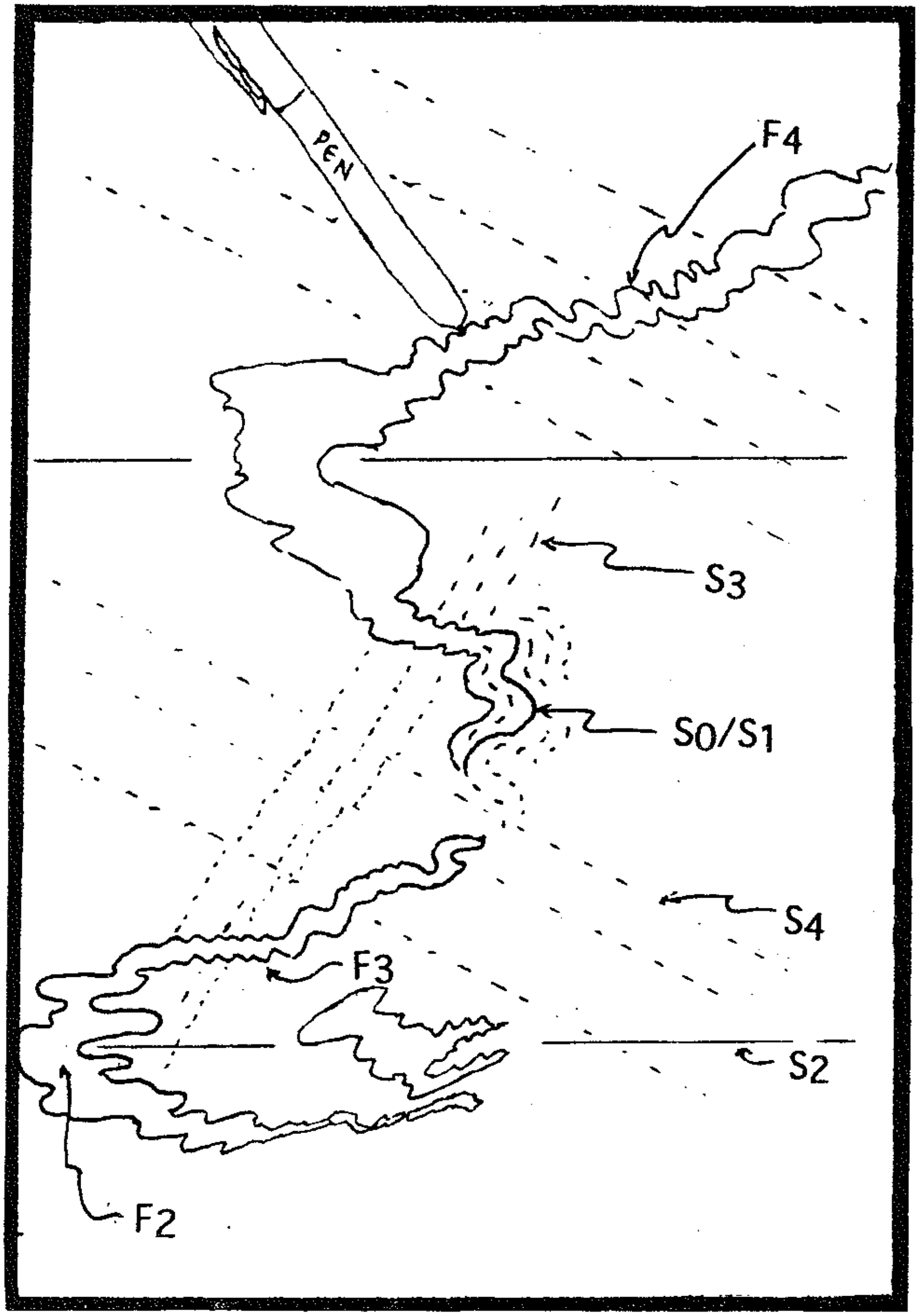

Figure 4. A photograph-based sketch of a trondhjemite leucosome in amphibole-schist, on the west shore of Reid Lake, showing F_2 folding. The fold limbs are offset by S_3 and show F_4 ptygmatic folding. In the schist, S_3 mineral alignments are offset by S_4. S_2 mineral alignments run parallel to the F_2 axial surfaces. Pen for scale.

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