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Reply to the comments by Alsop and Holdsworth on "Evidence for non-plane strain flattening along the Moine thrust, Loch Strath nan Aisinnin, North-West Scotland"☆

Matthew Strine[a,*], Steven F. Wojtal[b]

[a]*Department of Earth and Environmental Sciences, University of Rochester, Rochester, NY 14627, USA*
[b]*Department of Geology, Oberlin College, Oberlin, OH 44074-1044, USA*

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We thank Drs Alsop and Holdsworth for their interest in our work and for providing us with an opportunity to clarify our interpretation of these interesting fault rocks. Alsop and Holdsworth suggest that the late folds that affect the mylonitic foliation and lineation from the Loch Strath nan Aisinnin area are a result of large flow perturbation folding. We agree with Alsop and Holdsworth that such perturbations to the regional flow field probably explain the origin and geometry of folds oriented obliquely to transport directions in other fault rocks (Wojtal and Mitra, 1988; Tikoff and Wojtal, 1997) and further agree that this is one possible hypothesis for the origin of these late folds. We do not, however, agree that the process of flow perturbations is responsible for all or even the majority of the minor structures seen in this area.

First, we disagree with Alsop and Holdsworth's contention that there is only limited evidence for sheath folding in the Loch Strath nan Aisinnin area. Fig. 1 shows several examples of folds observed on surfaces roughly normal to the local penetrative lineation. These 'eye' (i.e. elliptical) and 'anvil-shaped' (i.e. adjacent S and Z folds) features are geometrically consistent with sheath folds, and structures like them occur across the Loch Strath nan Aisinnin area. Alsop and Holdsworth selected one of the 'anvil-shaped' structures that we interpret as a sheath fold (Fig. 1A) to include in their discussion (see their fig. 1F). They call this structure a 'mesoscopic culmination', but this structure, be it a sheath fold or a culmination in a flow perturbation-induced fold, does not fall along their mapped culmination crest (see Fig. 2 for the location of this feature). The flow perturbation fold model as outlined in Alsop and Holdsworth's fig. 1D and e, predicts that structures with both S and Z fold senses (like this fold) should occur only along the culmination crest, not to either side of the crest as we have found. Furthermore, we do not see how the flow perturbation model would generate the 'eye' or elliptical sections we observe in this area.

Second, while our data from just north of Loch Strath nan Aisinnin are consistent with that presented by Alsop and Holdsworth, our hitherto unpublished orientation data from farther to the north differ from the orientation data that they present (Fig. 2). North of their culmination crest, we find that hinges of late folds have a mean orientation of 19, 102, subparallel to the regional transport direction. Thus, these data are inconsistent with the flow-perturbation model presented by Alsop and Holdsworth. Therefore, other models need to be considered to explain the orientation of the minor folds in the Loch Strath nan Aisinnin area.

Finally, Alsop and Holdsworth invoke the work of Coward and Potts (1983) in order to explain our non-plane strain flattening quartz c-axis data. Coward and Potts (1983) describe the strain patterns found at tips of shear zones and thrust zones. It is, in our view, unlikely that the deformation patterns observed within this highly strained shear zone,

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* Corresponding author. Tel.: +1-585-275-8816; fax: +1-585-244-5689
E-mail address: matty@earth.rochester.edu (M. Strine).

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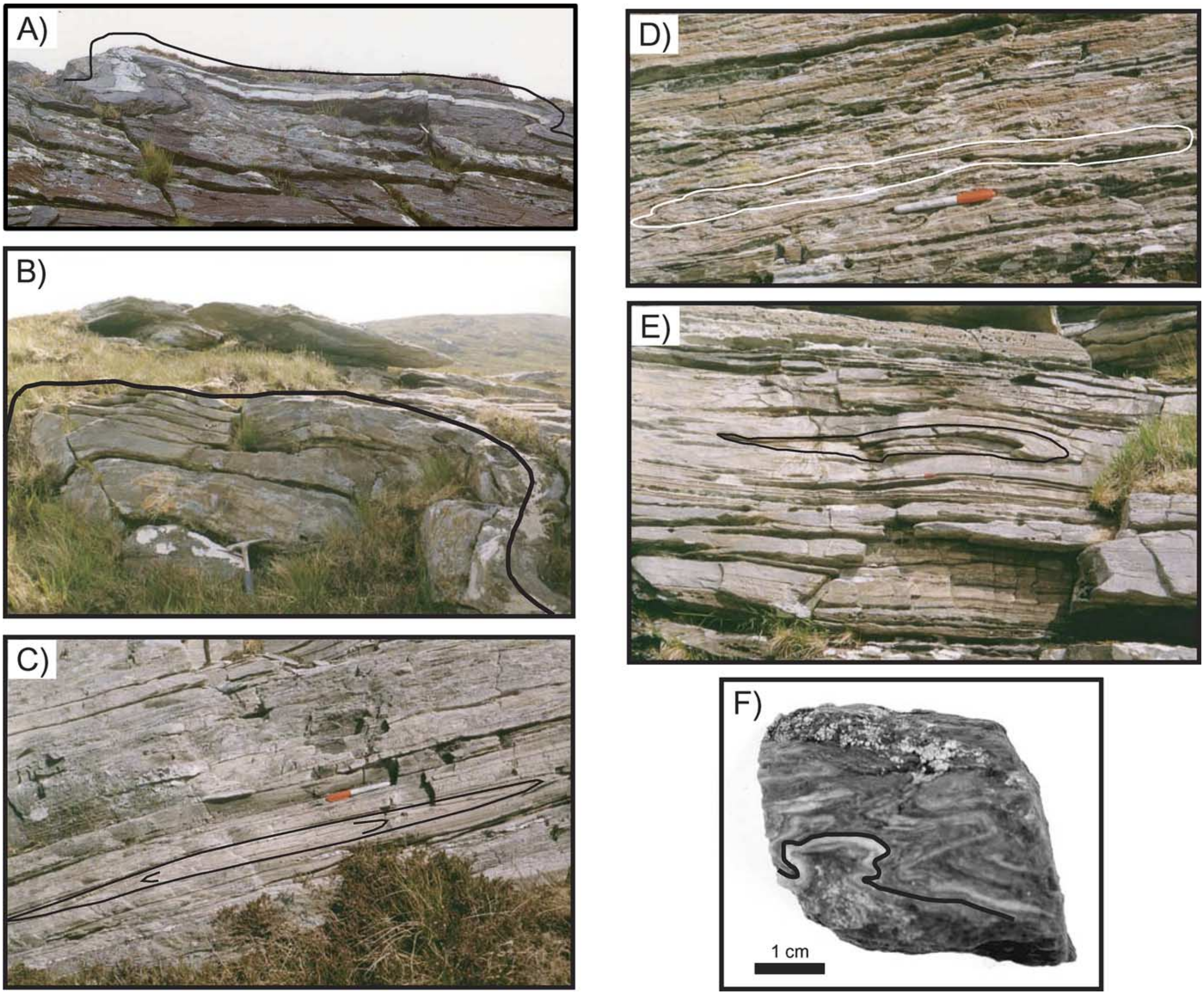

Fig. 1. Sheath folds seen within the hanging wall Moine schists within the Loch Strath nan Aisinnin area (delineated by Fig. 2). All photographs were taken facing approximately east. Scale shown by 28-cm-long rock hammer ((A) and (B)) or 13.9-cm-long marker ((C)–(E)).

which affects rock to at least 140 m beneath the Moine thrust surface at this location, are dominated by the strains associated with the initial propagation of the shear zone. Furthermore, the strain patterns that Coward and Potts (1983) describe are entirely inconsistent with what we observe at the Loch Strath nan Aisinnin location of the Moine thrust zone. In other words, transport perpendicular lineations developed at shear zone tips are kinematically distinct from foliation parallel flattening directions with grain shape lineations oriented parallel to the transport direction. Incidentally, Coward and Potts (1983) state that the quartz c-axis textures from the Moine thrust zone defined by Christie (1960) and Riekels and Baker (1977) record strain increments *later* than those associated with shear zone tip development. Thrust zones have considerable variability along strike (Durney and Ramsay, 1973; Geiser, 1988; Woodward et al., 1988; Mukul and Mitra, 1998; Twiss and Unruh, 1998). The Moine thrust zone demonstrates significant along-strike variation in thrust zone thickness, strain magnitude and strain geometry between the Loch Strath nan Aisinnin area and an area only a few kilometers to the south (Strine and Mitra, 2004). The flow perturbation model proposed by Alsop and Holdsworth cannot explain the evidence for locally elevated strain magnitudes or the increased thrust parallel flattening with the Loch Strath nan Asininn area that we presented in our paper.

In conclusion, we agree with Alsop and Holdsworth's argument that late folds oblique to fault zone fabrics may result from perturbations to the flow field. However, we are certainly not convinced that their flow perturbation fold model should be the preferred hypothesis for the origin of

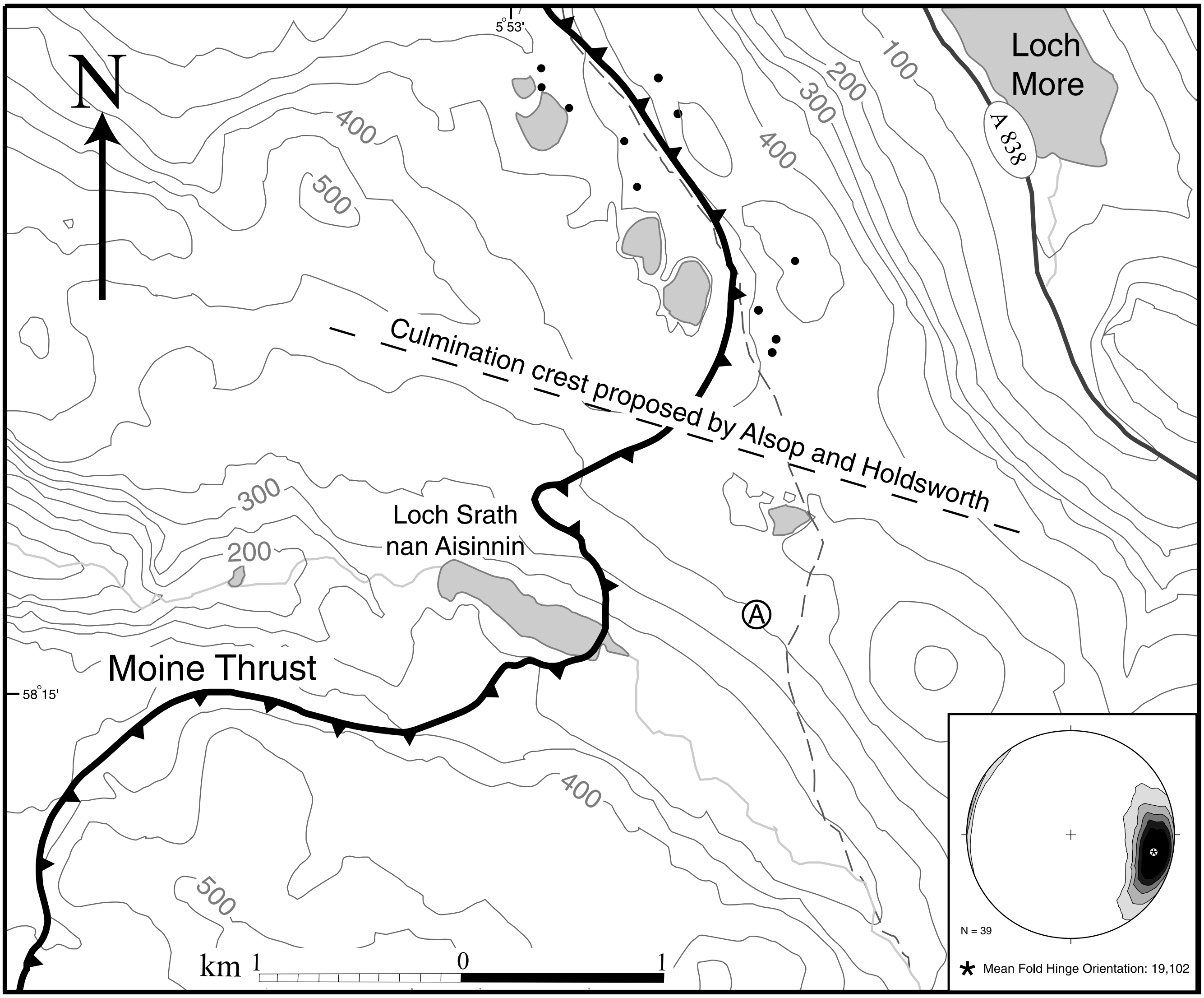

Fig. 2. Generalized topographic map of the Loch Strath nan Aisinnin area. Fold hinge orientation data shown on inset (lower hemisphere equal area projection with a 5% contour interval) are from sample sites (marked by small filled circles) north of the culmination crest proposed by Alsop and Holdsworth. 'A' marks the location of the sheath fold seen in Fig. 1A as well as in Alsop and Holdsworth's fig. 1F.

the oblique minor folds in Loch Strath nan Aisinnin area. Regardless of the origin of the minor folds, our primary conclusions remain unchanged. Natural thrust zones have complex histories; here the formation of a penetrative lineation that was later folded (whether by sheath folds or flow perturbation folds).

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