Fracture Analysis of the Pipestone Trace
Boundary Waters Canoe Wilderness Area, Minnesota

Lora Stevens
Pomona College
Claremont, CA 91711

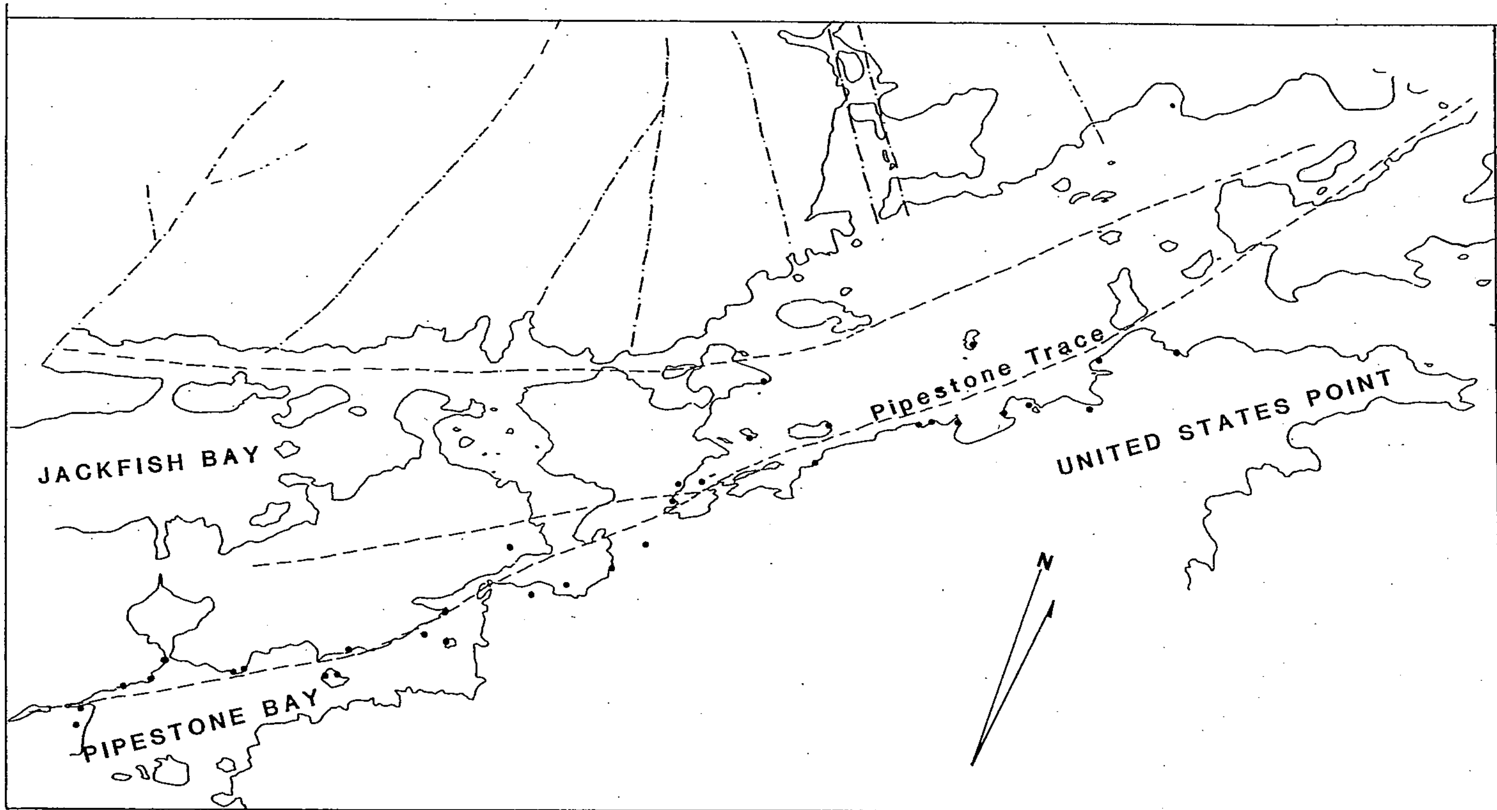
The Pipestone Trace of the Burntside Lake Fault Zone, northern Minnesota, is a steeply dipping fault of undetermined net slip.(Figure 1) R. Bauer (pers. commun.) believes the fault to be predominantly dip-slip near its southwestern end, based upon a pattern of juxtaposed metamorphic facies. To the northeast, where the strike of the fault is more northerly, a strike-slip component of displacement may be prominent. Sims (1971) and H. Woodard (pers. commun.) believe the Pipestone Trace to be a splay of the Vermilion fault, which also has undetermined slip. It would, therefore, be beneficial to our understanding of the regional geology if the slip vector on this trace could be resolved. The purpose of this study is to characterize the fracture patterns along the fault and to use their geometric relationships, if possible, to determine its sense of movement.

Forty-seven sites along approximately 11km of fault were examined (Figure 1). At each site a study plot was measured on the outcrop. The size of the plot was arbitrarily set to a value of $1.2m^2$ ($4ft^2$), which I consider a representative scale for fracture analysis. The fracture sets in each plot were oriented using the right-hand rule and counted. General comments such as spacing, noticeable shear, length, termination, regularity, hydrothermal mineralization, and host rock lithology were noted. Most of the bedrock is crystalline intrusives and migmatitic gneiss. An exception is a thin, non-continuous bed of extremely altered felsic metavolcanics which could be easily mistaken in hand sample for mylonite found in cataclastized zones of the crystallines.

The crystalline rock suite exhibits little variation in the intensity of fracturing, except within mylonite zones. These were excluded from this study. The metavolcanics, however, demonstrate a much greater intensity of fracturing--on average about four times that of the crystalline rocks. Because of their sparsity and differing lithology, the metavolcanics are not represented in the rose diagrams shown on the next page (Figure 2); and fracture data may be assumed to have been collected in a single general bedrock lithology.

Each rose diagram is based on the percentage of a particular variable with the rim of the half circle corresponding to 5%. The dashed line in each figure is the approximate strike of the Pipestone Trace. Rose 1 represents the different orientation of joints measured at all sites along the fault, excluding the number of individual fractures striking at any given orientation. This illustrates the probability of occurrence of an orientation along the fault. Rose 2 represents the orientation of all 1407 individual fractures counted along the fault. Rose 3 "filters" the information in rose 2 by only representing orientations of those fractures qualitatively chosen as well-defined.

Figure 1



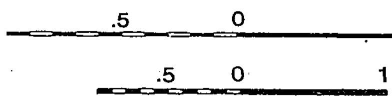
LEGEND

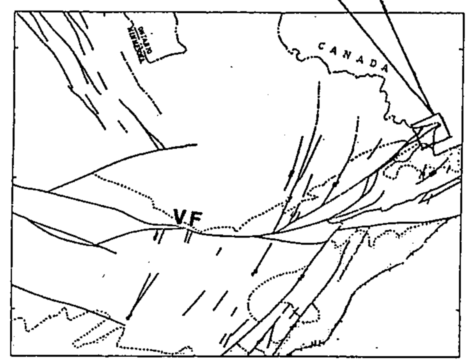
- - - - Burntside Lake faults (includes Pipestone Trace)

— · — · presumed faults (mapped by Beloit)

• fracture orientation sites

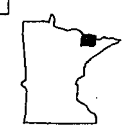
SCALE





After Sims (1971)

VF–Vermilion Fault



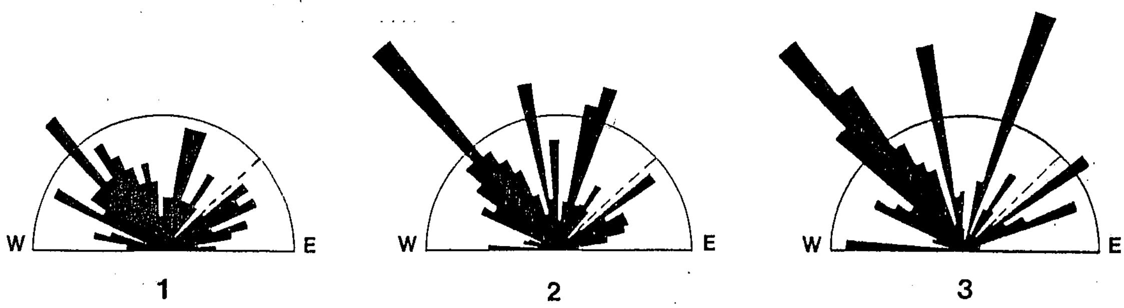


Figure 2

The geometric pattern that emerges in the rose diagrams cannot be used to support any single model for fracture origin and faulting. Indeed, most of the fracturing is probably unrelated to the Pipestone fault. This region has undergone several episodes of intense deformation. The following is a list of other possible origins of these fractures:

1) the nearby intrusion of the Vermilion batholith
2) isostatic adjustments due to the stripping of cover from the batholith and/or later glaciation
3) earlier and/or later episodes of faulting in the area

Assuming that certain fracture sets to be related to faulting, models relating portions of the fracture pattern to faulting are described below:

<u>Model #1--Simple shear</u>
The simple shear model is the most current theoretical fracture model applied to faults (Sylvester, 1988). However, the resulting fractures--R, R', P, etc. are related only to the shearing of loose overburden and not to bedrock. It is no surprise then that most of the measured fracture sets along the trace cannot be identified as resulting from simple shear. However, one major set of fractures that strikes 50°-55°, approximately parallel to the trace of the fault, could be interpreted to be a result of laminar simple shear during the Pipestone Trace faulting. Some fractures within this set display left-lateral displacement, suggesting similar movement occurred along the Pipestone Trace.
The dominant 315°-330°-striking fracture set could be related in like manner to faults of similar orientation mapped by Beloit College students in the northwest of the region (Figure 1) These faults appear to truncated by the Pipestone Trace and related splays.

<u>Model #2--Pure shear</u>
Fracture sets striking at 20° and 315° could be a conjugate pair related by pure shear. The apparent strike of the maximum principle stress is then oriented at 345°-360°. If this stress orientation influenced motion of the Pipestone Trace, then the conjugate fractures could be interpreted as "secondary faults" related to left-lateral strike-slip along the Pipestone. (Anderson, 1951; Ramsay, 1967) Furthermore, the large set of fractures striking 345°-350° could then be interpreted as extensional fractures striking parallel to the maximum principle stress. (Sylvester, 1988)

The evidence for left-lateral strike-slip along the Pipestone Trace is consistent and suggestive, but inconclusive. I consider the data to be inadequate, given the complexity of the structure and geological history of this region, as well as our incomplete and controversial state of knowledge concerning the use of fractures as kinematic indicators of faulting (e.g.--Pollard and Aydin, 1988). Nevertheless, the description and organization of possible models might create insight for further and more conclusive research.

References

Anderson, E.M., 1951, *The Dynamics of Faulting*, Oliver and Boyd, Edinburgh and London.

Pollard, D.D., and Aydin, A., 1988, Progress in understanding jointing over the past century, GSA Bulletin, V. 100, pp. 1181-1204.

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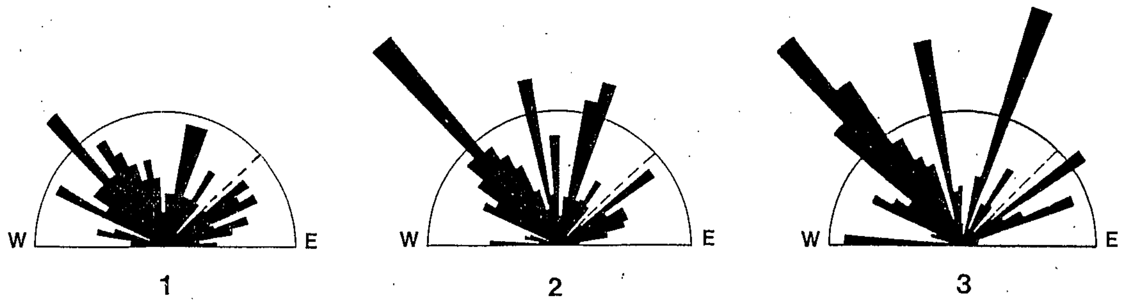

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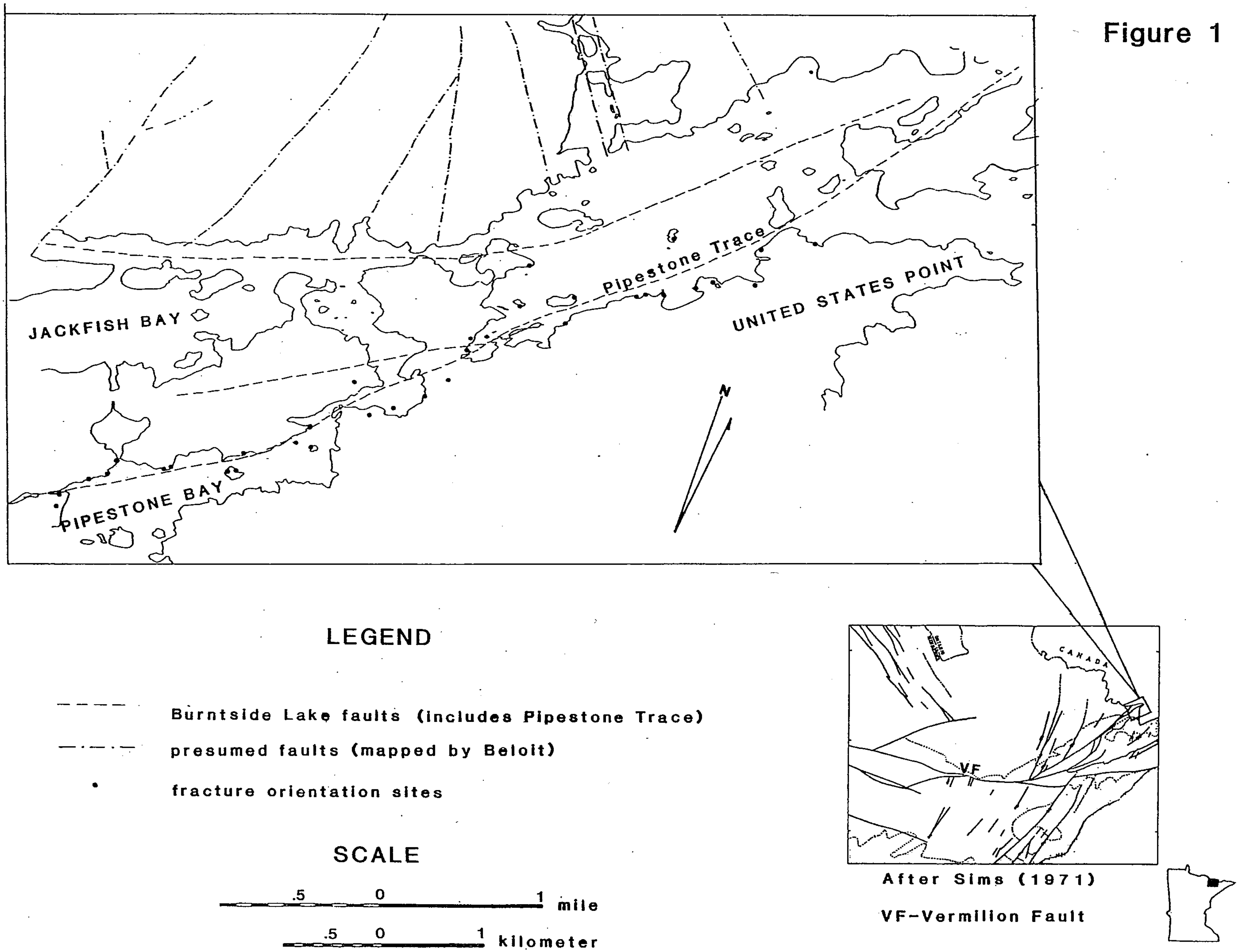
JACKFISH BAY
PIPESTONE BAY
Pipestone Trace
UNITED STATES POINT
N
LEGEND
Burntside Lake faults (includes Pipestone Trace)
presumed faults (mapped by Beloit)
fracture orientation sites
SCALE
.5 0 1 mile
.5 0 1 kilometer
CANADA
VF
After Sims (1971)
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