A KINEMATIC STUDY OF THE NGOMA GNEISS, ZAMBEZI BELT, ZAMBIA

A Thesis

Presented in Partial Fulfillment of the Requirements for
the degree Bachelor of Science

by

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1988

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ACKNOWLEDGEMENTS

I would like to thank all of the people who helped make this project possible; Felicia Laconi for the time off from work necessary for its timely completion; my mother, Ann Elliot, for technical editing, moral support, and the use of her word processor; my advisor, Terry Wilson, who spent as much time reading rough drafts as I did writing them, and whithout whose help none of this would have been possible; and my father, David Elliot, who on family camping trips out west, would infuriate us all by stopping to take pictures of rocks, and in so doing, somehow sparked my interest in geology.

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INTRODUCTION

Regional Setting of the Zambezi Belt

The Zambezi Belt of Zambia is an east-west trending orogenic belt that forms part of the Late Proterozoic Pan-African orogenic system that occupies much of southern Africa (Fig. 1). The Pan-African system is of particular interest as many of the belts in this system transect older orogenic belts without offsetting the older structural trends. These crosscutting relations preclude the opening of major ocean basins along the sites of the Pan-African belts, unless subsequent closure and collision fortuitously realigned the older trends. This, therefore, suggests that some mechanism other than Wilson-cycle plate tectonics may be responsible for the Pan-African orogenic belts. The Zambezi belt transects the Middle Proterozoic, north-east trending Irumide belt, and represents the type example of these cross cutting relations (Fig. 1).

The Zambezi belt is bounded to the south by the Irumide belt, Magondi belt, and the Kalahari Craton. To the east it merges with the Mozambique Belt, and to the west joins with the Damara Belt. It

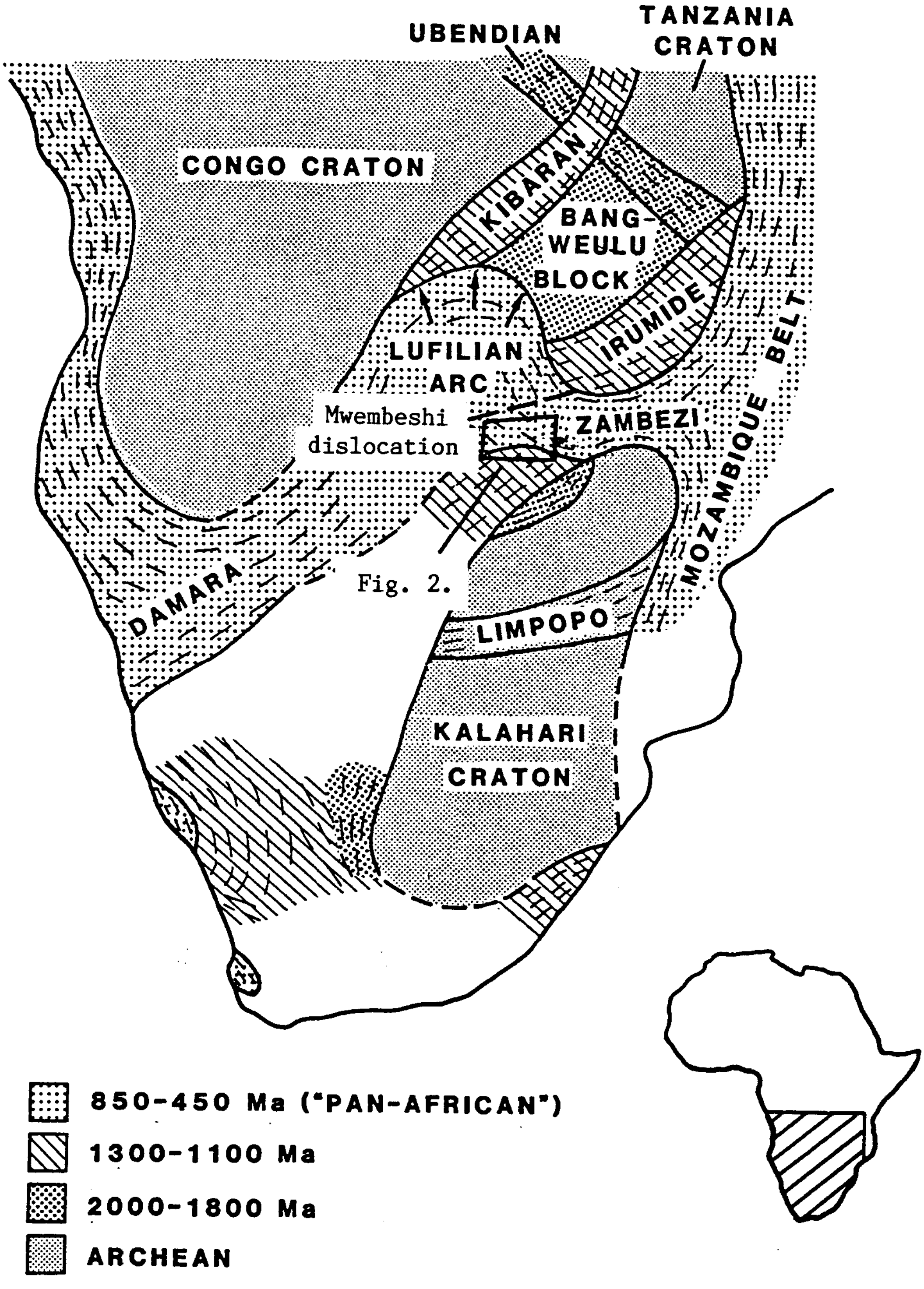


FIGURE 1. Simplified map of the Precambrian of central and southern Africa showing the distribution of cratons and mobile belts. Modified from Hunter and Pretorius (1981).

is bounded to the north by the Lufilian Arc, the boundary of which is generally taken to be the Mwembeshi dislocation (Fig. 1).

Geologic Setting of the Ngoma Gneiss

The Ngoma Gneiss is a north-west trending, linear belt of augen gneiss, ranging from 10 to 30 km in width, in the the southwestern part of the Zambezi belt (Fig. 2). The Ngoma Gneiss is exposed along strike for about 100 km. It is overlain by Mesozoic Karoo sedimentary rocks in the southeast and Cenozoic alluvium in the northwest. It is in apparent tectonic contact with deformed schists and quartzites to the southwest, and marbles and calc-silicate rocks to the northeast (Fig. 2). These metasedimentary rocks have been correlated with the Middle to Upper Proterozoic Katangan System to the north of the Mwembeshi dislocation on lithologic grounds, but this needs to be verified.

The Ngoma Gneiss was originally interpreted to represent remobilized Middle Proterozoic crystalline basement thrust to the surface during the Zambezi deformation event (Molyneux 1907; Murray-Hughes and Fitch 1929, in Newton 1960). Later, it was interpreted as feldspathized and granitized metasedimentary rocks of the Katangan System (Newton 1960). Brown (1966) recognized the granitic nature of the Ngoma Gneiss protolith, and reinterpreted the zone as remobilized basement. Brown also recognized that the flaggy aspect of the rock, interpreted by Newton (1960) as original bedding, instead represented a tectonic foliation formed due to intense shearing of the gneiss.

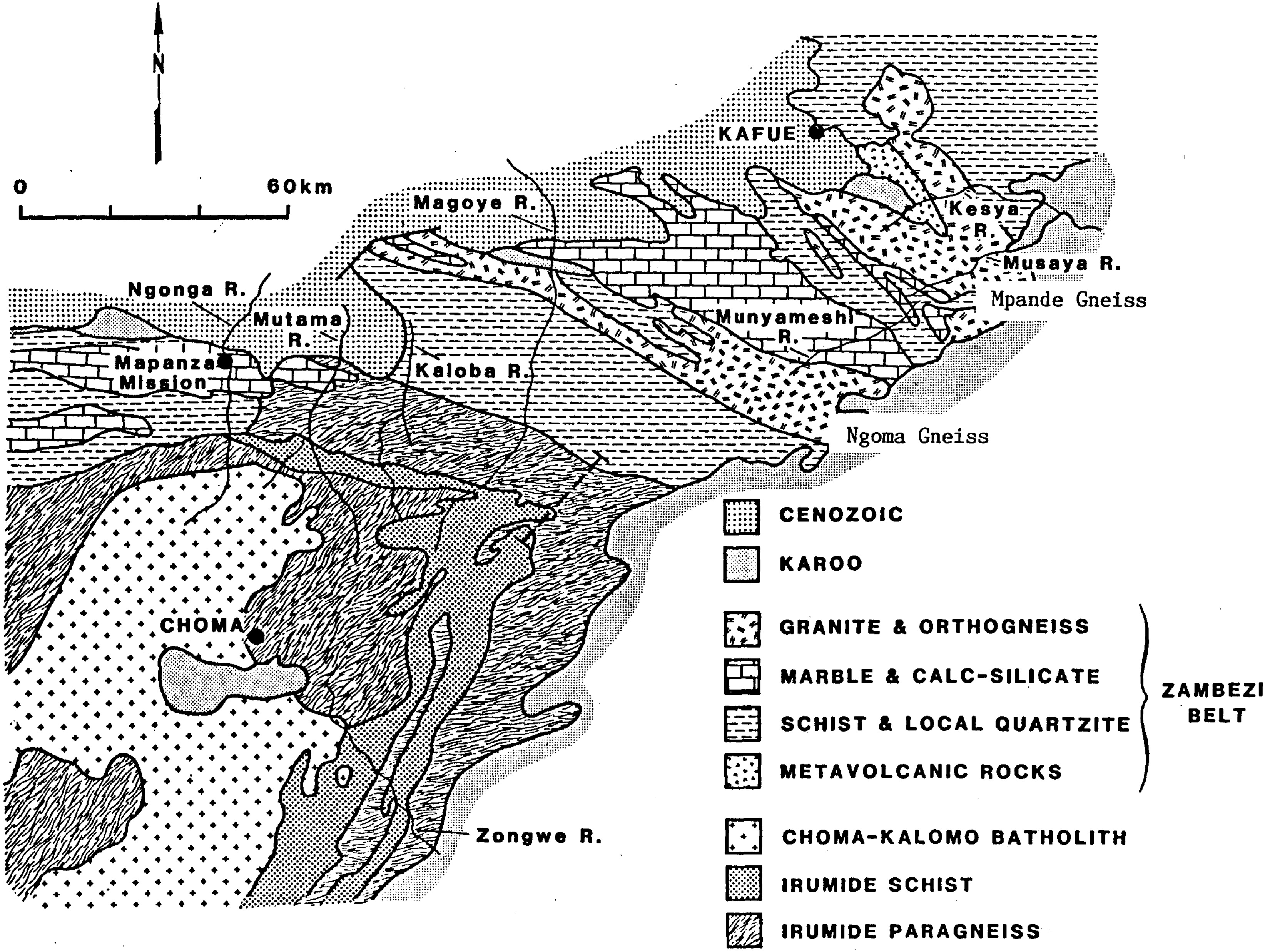


Figure 2. Geologic map of the Zambezi Belt in southern Zambia. From Hanson, Wilson, and Wardlaw -In press (1988).

Some parts of the gneiss are referred to by Brown as blastomylonites, which he believed formed as a result of brittle processes. This is attested to by his use of the term "crush-rock" for some parts of the Ngoma Gneiss, and by his reference to cataclastic processes in the region.

All of the previous interpretations of the Ngoma Gneiss were also applied to the Mpande Gneiss to the east (Fig. 2), and all failed to recognize the intrusive nature of the granitic protoliths of the gneisses. It was therefore believed that the Zambezi orogen lacked the voluminous igneous activity seen in Phanerozoic mountain belts. The igneous nature of the Ngoma Gneiss, as well as the Mpande Gneiss, has since been documented. The present interpretation of the Ngoma Gneiss is that it is a large, syntectonic mylonitized pluton, subjected to transverse shearing during the Zambezi orogenic event. An age of igneous crystallization of 820 ±7 Ma for the Ngoma Gneiss has been shown (Hanson, Wilson, and Wardlaw, In press). Because the gneiss has been sheared and mylonitized throughout its extent, it is interpreted to have been intruded into a major ductile shear zone, termed here the Ngoma Shear Zone.

Statement of the Problem

The purpose of this study was to determine the movement sense of the Ngoma Shear Zone, and thereby gain insight into the kinematics of the Zambezi Belt. Maps of the foliation patterns and lineation trends in three traverses of the shear zone were made, transitions in the mylonitic textures within the shear zone were documented, and microstructural techniques were applied to thin sections made from samples of mylonites within the shear zone to determine the sense of shear displacement.

METHODOLOGY

Shear Zone Geometry

A shear zone is the deep crustal equivalent of a fault, and represents a planar zone of concentrated ductile flow that produces fault-like displacement of the blocks that bound the shear zone. Strain within a shear zone is measured in terms of a strain ellipsoid, derived from an original sphere with a center that is the origin of a three dimensional Cartesian coordinate system. The magnitude and symmetry of strain is related to the change in the ratios of the lengths of the three principal axes of the strain ellipsoid and their orientations in space. The most basic form of shear, or rotational deformation, is known as simple shear. It involves movement in just one plane of the strain ellipsoid. Figure 3 shows an ideal simple shear zone, where a circle in the xz plane is seen to be deformed into an ellipse. During movement in a simple shear zone, the direction of principal finite shortening for each infinitesimal increment of strain is oriented at 45 degrees to the direction of shearing and the shear zone walls. With finite

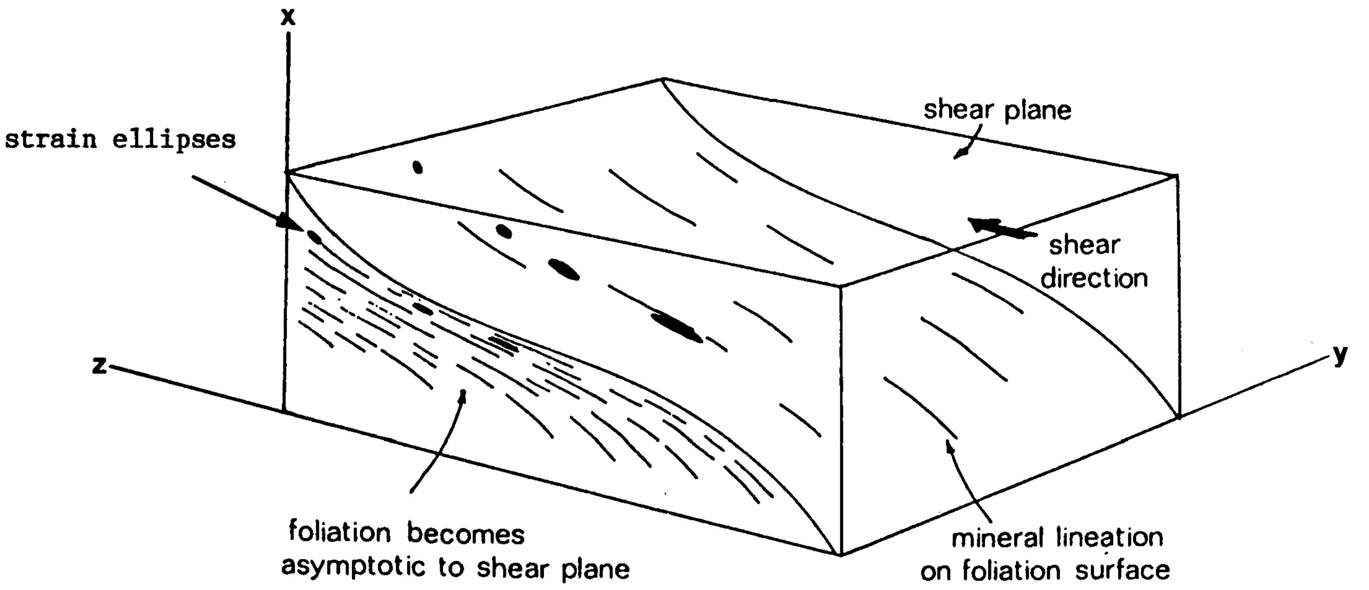


Figure 3. Geometry of a simple shear zone. Modified from Ramsay (1980).

quantities of strain the principal finite shortening direction is progressively rotated into parallelism with the shear zone walls (Fig. 3). Foliation planes develop normal to the direction of principal finite shortening and, therefore, with increasing shear strain the foliation planes develop a sigmoidal form, approaching parallelism with the shear zone walls near the center of the shear where the maximum shear strain occurs (Fig. 3). At the same time, a mineral stretching lineation develops on the foliation planes. The stretching lineation develops parallel to the direction of finite elongation, which is always perpendicular to the direction of finite shortening, and coincident with the direction of shear in the shear zone (Fig. 3). Thus, in shear zones that have undergone high shear strains, the attitude of the foliation planes approximates the orientation of the shear zone walls and the attitude of the mineral stretching lineation tracks the direction of shearing within the zone. Based on these principles, the geometry of shear was determined for the Ngoma Shear Zone through systematic mapping of foliation and lineation attitudes in the field.

In nature, it is rare to see a shear zone that has undergone ideal simple shear; however, shears involving more complex kinematics, i.e., strain in more than one direction, can be understood and described by dividing the shear zone into a large number of small blocks, within which the strain approximates that resulting from simple shear.

Development of Mylonites in Shear Zones

Mylonites are the foliated and lineated ductile fault rocks developed in shear zones. Bell and Etheridge (1973) propose the following definition: "A mylonite is a foliated rock, commonly lineated and containing megacrysts, which occurs in narrow, planar zones of intense deformation. It is often finer grained than the surrounding rocks, into which it grades." The key to mapping shear zones of wide areal extent is the recognition of the presence of mylonitic rocks. Recognition is based on both gradational relations with coarser-grained wall rocks observable in the field and on the presence of textural features typically developed during ductile flow. These textural features and their mode of development are described in the following paragraphs.

The fundamental characteristics that distinguish mylonites from the crystalline wall rocks outside a shear zone are the development of penetrative planar and linear fabrics and a reduction in grain size. A progressive grain size reduction is also characteristic of a transition in textures _within_ mylonites that, in general, is related to an increasing intensity in shear strain. The textural path marked by grain size reduction has been used to define a "mylonite series" based on the percentage of porphyroclasts, or relict host rock grains that have maintained their original size, relative to the percentage of fine-grained matrix. The mylonite series includes "protomylonites" with 10 to 50% matrix, "mylonites" with 50 to 90% matrix, and "ultramylonites" with greater than 90% matrix (Fig. 4;

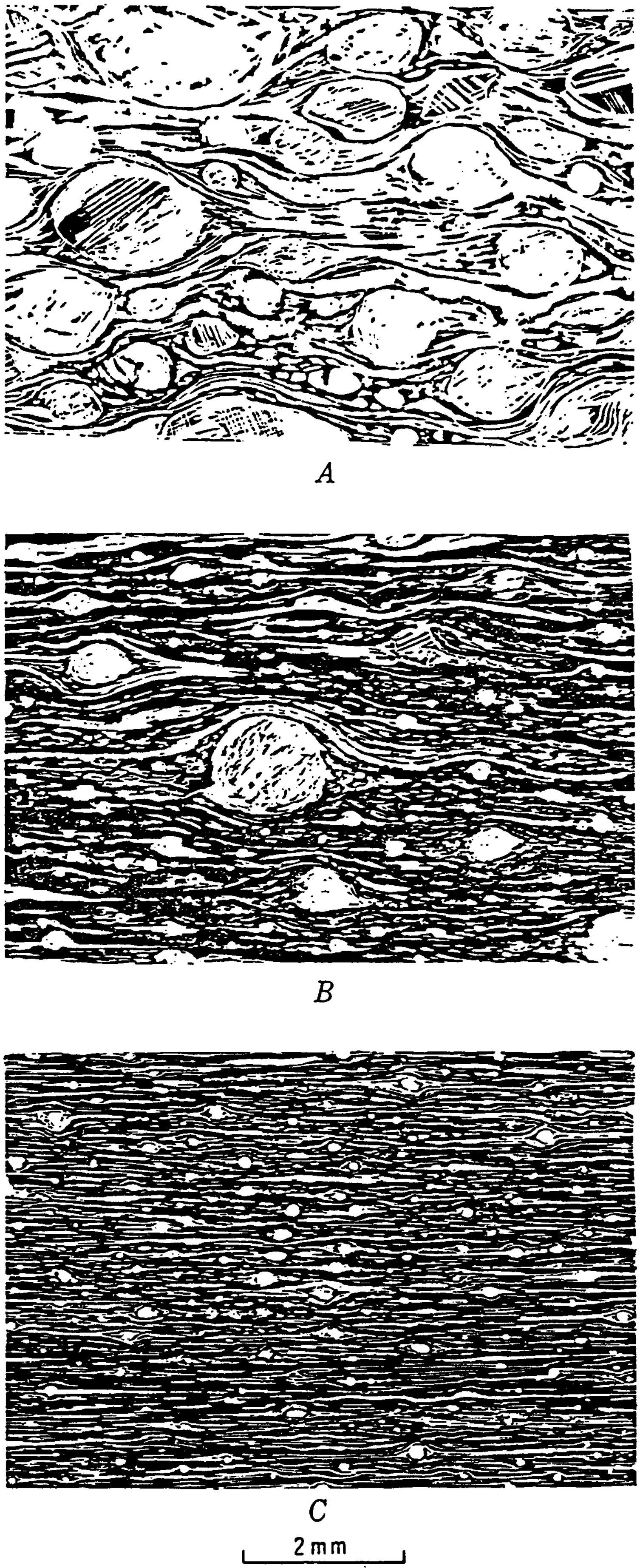


Figure 4. —Schematic sketches showing textures of protomylonite (*A*), mylonite (*B*), and ultramylonite (*C*). From Higgins (1971).

Sibson 1977). Associated with this progressive grain size reduction is a transition from wavy, anastomosing foliation planes in protomylonites to closely spaced, planar foliation planes in the mylonites and ultramylonites.

The grain size reduction that typifies mylonites was initially ascribed to brittle crushing and grinding of the rock mass, or cataclasis. It has since been shown to result from ductile processes, with brittle mechanisms playing an insignificant role (Bell & Etheridge 1973). Recent work has shown that mylonites have undergone a reduction in grain size through dynamic recrystallization. As shearing begins, strain is accommodated trough dislocation glide. As deformation continues, dislocation glide is obstructed due to tangling and pinning of dislocations within the crystal lattice, producing an effect known as work hardening. Work hardening is counteracted by the processes of recovery and dynamic recrystallization. Dynamic recrystallization occurs under stress during the deformation, and results in grains with high dislocation density being replaced by a fine grained mosaic of strain-free grains. The driving force for this process is a reduction in the internal strain energy of the deformed mineral grain. The reduction, rather than increase, in grain size is one of the key characteristics of dynamic recrystallization.

New grains are formed in a number of ways during dynamic recrystallization. If, within the crystal, a number of dislocations collect in a planar array, known as a wall, the lattice on one side of the dislocation wall will be rotated relative to that on the other side. This is reflected optically by the presence of subgrains within individual crystals. If enough dislocations are swept into the wall, the angle of misfit between the subgrains will exceed 10 degrees, and the two subgrains will have evolved into two discrete "new" grains that are relatively strain free. A second type of recrystallization occurs by grain boundary migration, in which relatively strain free grains with low dislocation densities consume their neighbors with high dislocation densities. A third possibility is the "nucleation of discrete strain-free grains which ultimately grow to produce an aggregate of polygonal grains" (Hobbs, Means, and Williams, 1976). These strain-free grains nucleate at points of high strain, which are often point defects in the crystal lattice. It is important to note that in all three of these processes, no new mineral species are introduced into the rock; rather, grains of one species are replaced by new grains of the same species. In contrast, grains are in some cases replaced by grains of another mineral species during deformation. This is known as neomineralization, and occurs when metamorphic reactions take place simultaneously with recrystallization.

Grains of different mineral species are more or less likely to recrystallize under given pressure and temperature conditions due to differences in the efficiency of dislocation glide and recovery. In the case of a granitic rock, like those from the Ngoma Shear Zone, quartz grains have a number of glide planes along which dislocations move, thereby allowing the processes described above to take place easily. Feldspar grains, on the other hand, have no easy glide planes, due to their crystallographic framework, and therefore dislocation glide and recovery are difficult. As a result of this difference, the strain is partitioned into the weaker quartz grains, which rapidly recrystallize into fine-grained aggregates that wrap around the large feldspar grains. This produces the anastomosing foliation, or "fluxion structure", that particularly characterizes protomylonites (Fig. 4).

Microstuctural Analysis

Determining movement sense in shear zones that cut crystalline rocks can pose a problem, as unequivocal evidence such as offset marker horizons is typically missing. Simpson and Schmid (1983), however, showed that various microstructural features can be used to determine the shear sense in these zones. In this study, microstructural features known as "asymmetric augen structures" were used to determine the shear sense. The term "augen" refers to large, relict porphyroclasts set in a finer-grained matrix. In the Ngoma Gneiss, the augen are feldspar porphyroclasts that behave as relatively rigid, coarse grains in a ductile quartz matrix. The feldspar porphyroclasts in the gneiss have undergone dynamic recrystallization along their margins, where strain is greatest, together with neomineralization, where the feldspar margins were replaced by fine grained aggregates of quartz. As the deforming matrix shears past the rigid augen, the weaker, dynamically recrystallized grains are drawn out into tails extending from the porphyroclasts. These tails develop asymmetrically with respect to the flattening foliation, extending from opposite "corners" of the porphyroclast in the direction of relative movement of the adjacent shear zone walls (Fig. 5a). In determining the sense of shear, a line of symmetry through the center of the porphyroclast and parallel to the foliation is located. The asymmetric disposition of the tails on either side of the line of symmetry indicates the sense of shear (Fig. 5b). Examining a large number of such "augen structures", viewed in a section cut perpendicular to the mylonitic foliation and parallel to the mineral lineation, will indicate the sense of shear in a ductile shear zone, though it will not yield information about the magnitude of displacement.

MESOSCOPIC STRUCTURAL ANALYSIS

Ductile shearing has affected the entire extent of the Ngoma Gneiss, so that the granite protolith has been everywhere tranformed into mylonite. The planar and linear fabric elements that characterize mylonites are well developed throughout the gneiss belt (Figs. 6a-6c).

During the course of 3 field seasons, measurements of the

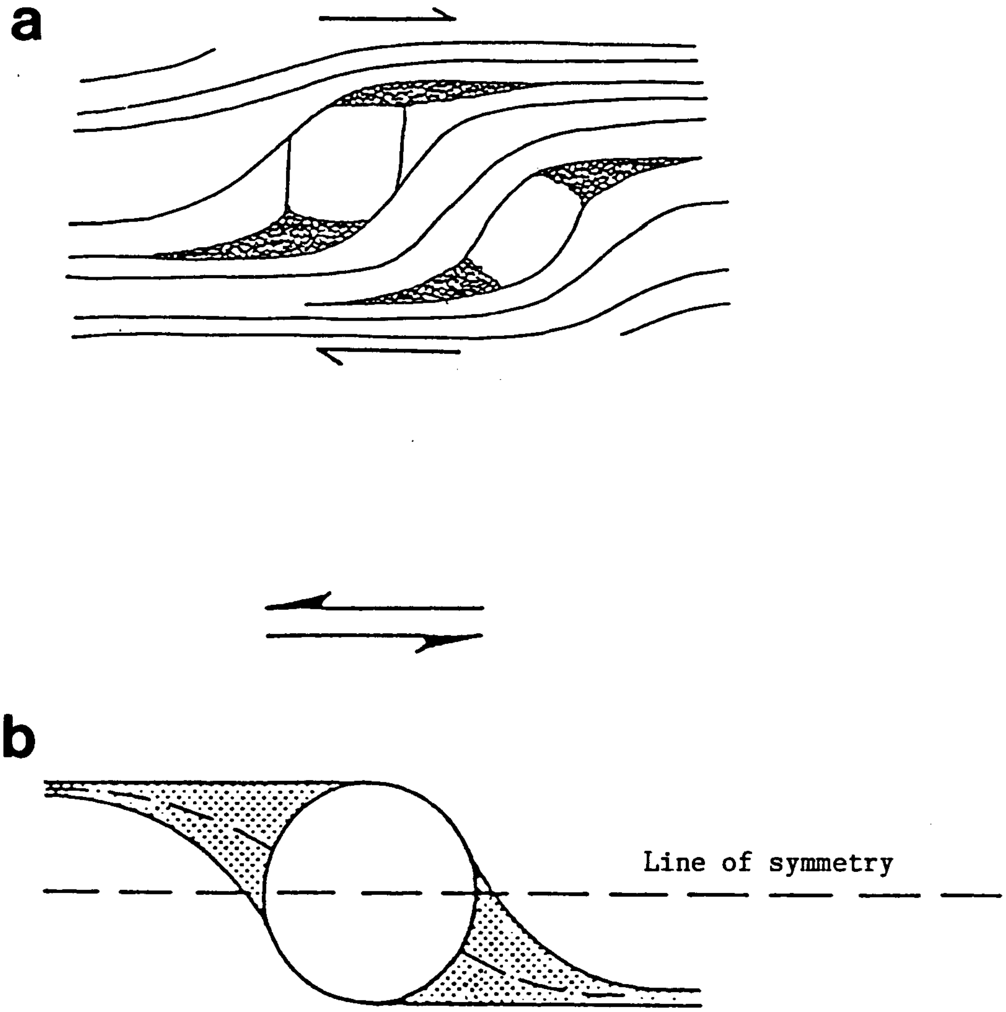


Figure 5. a) Schematic diagram of asymmetric augen structures within foliation planes. Modified from Simpson & Schmid (1983). b) Schematic diagram of asymmetric augen structure showing line of symmetry. Modified from Simpson (1986).

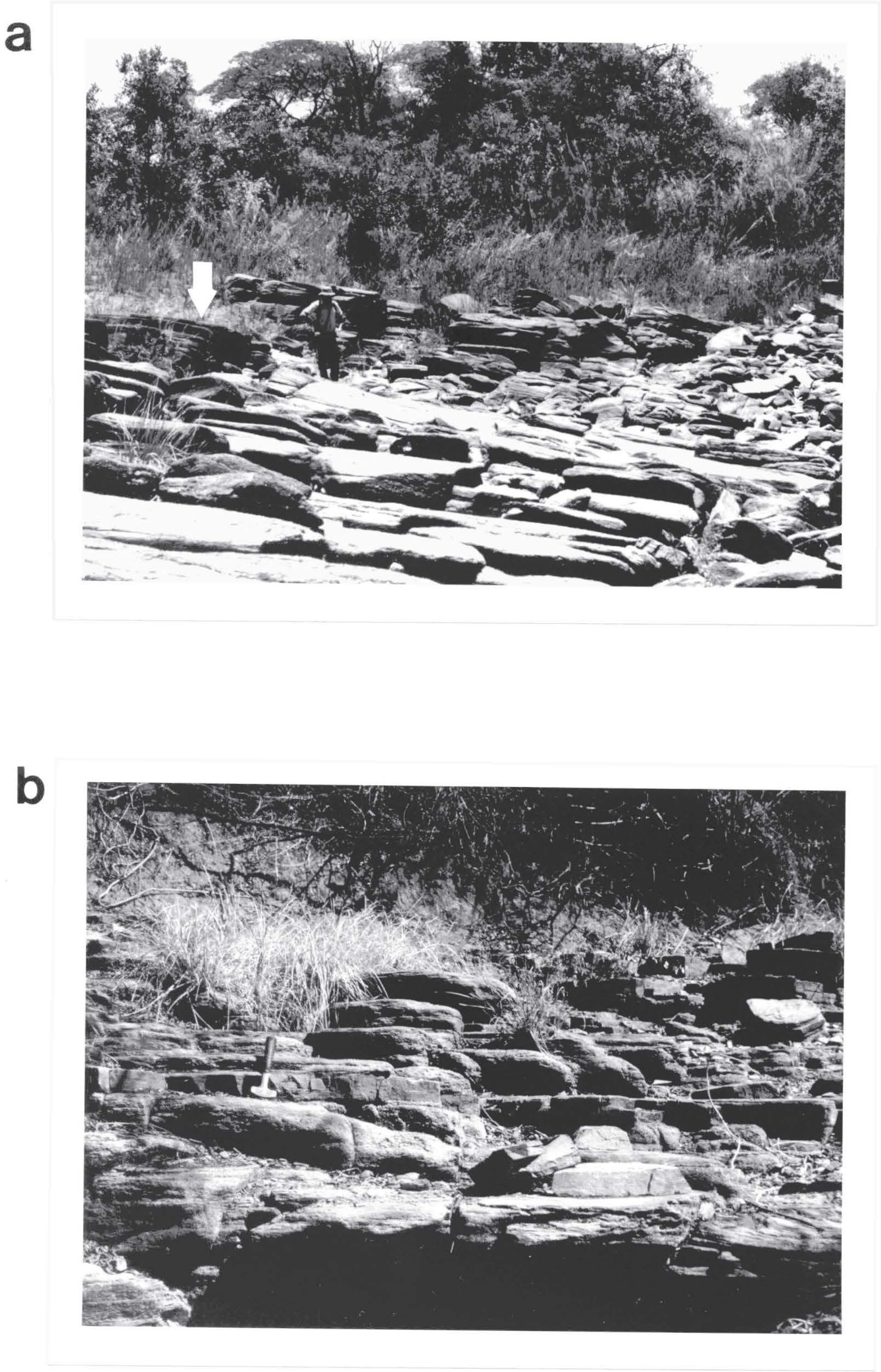


Figure 6. a) Outcrop of mylonites in the Magoye River showing the typical flaggy aspect of the foliation planes (arrow) dipping to the north. b) Flaggy mylonites in Kaya Stream. Hammer rests on a more massive horizon of ultramylonite.

C

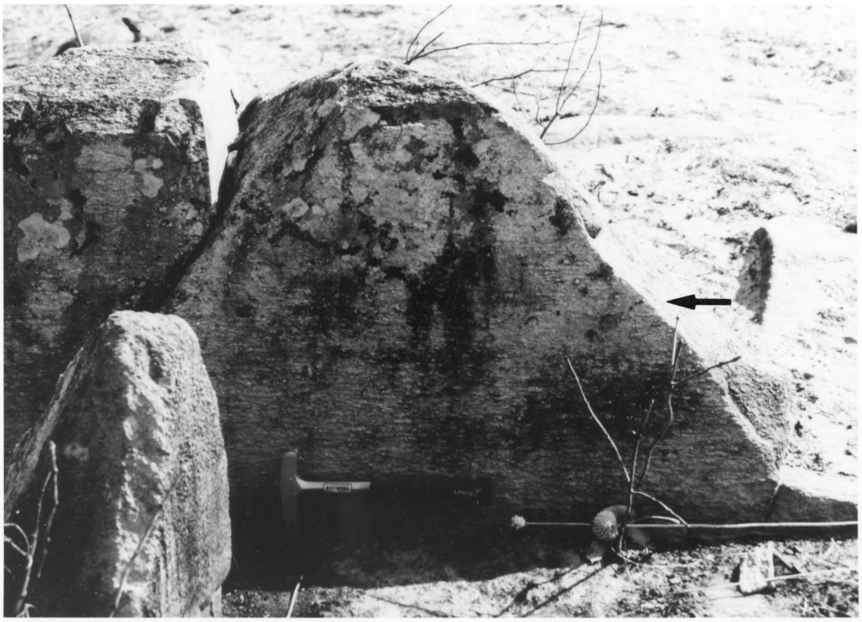


Figure 6c. Mylonite in the Nkonkola traverse showing horizontal mineral stretching lineation developed on mylonitic foliation surface.

attitudes of mylonitic foliation planes and associated mineral stretching lineation attitudes were made by T.J. Wilson and R.E. Hanson along 3 traverses across the strike of the Ngoma Gneiss. As part of this study, maps of the foliation and lineation attitudes were made, and equal area projections of the lineations and poles to the foliation planes were constructed for each traverse to illustrate the average orientations in each, and to expose variations or systematic changes in the orientation of the fabrics along strike.

A geologic map of the Ngoma Gneiss, showing the location of the three traverses from which data were collected is presented in Figure 7. A detailed map of the structural data collected along the Nkonkola traverse is shown in Figure 8, and Figure 9 shows these data plotted on an equal area projection. One can see that the poles to the mylonitic foliation planes are all clustered in the southwest quadrant of the stereoplot, indicating a dominant west-northwest strike and a moderate to steep north-east dip of the foliation. The lineations are horizontal or close to horizontal, and trend nearly parallel to the strike of the foliation (Fig. 6c).

A structural map and stereoplot of data from the Magoye River traverse are presented in Figures 10 and 11. As in the Nkonkola traverse, the lineations are nearly horizontal and trend to the west-northwest or east-southeast close to the strike of the foliation. The poles to foliation, however, show two distinct clusters: one in the northeast quadrant and a denser second one in the southwest quadrant. The two clusters approximate a girdle distribution,

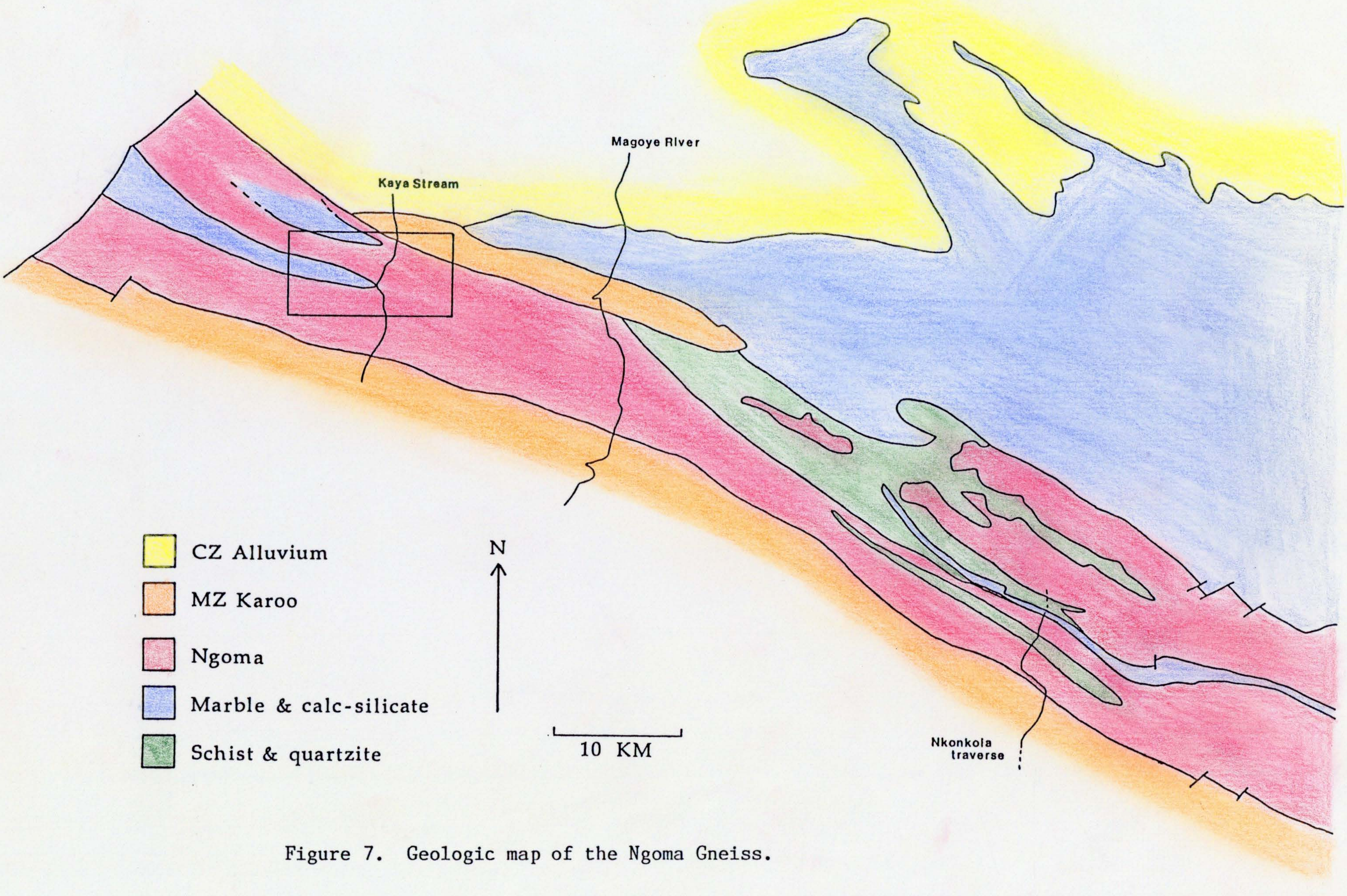


Figure 7. Geologic map of the Ngoma Gneiss.

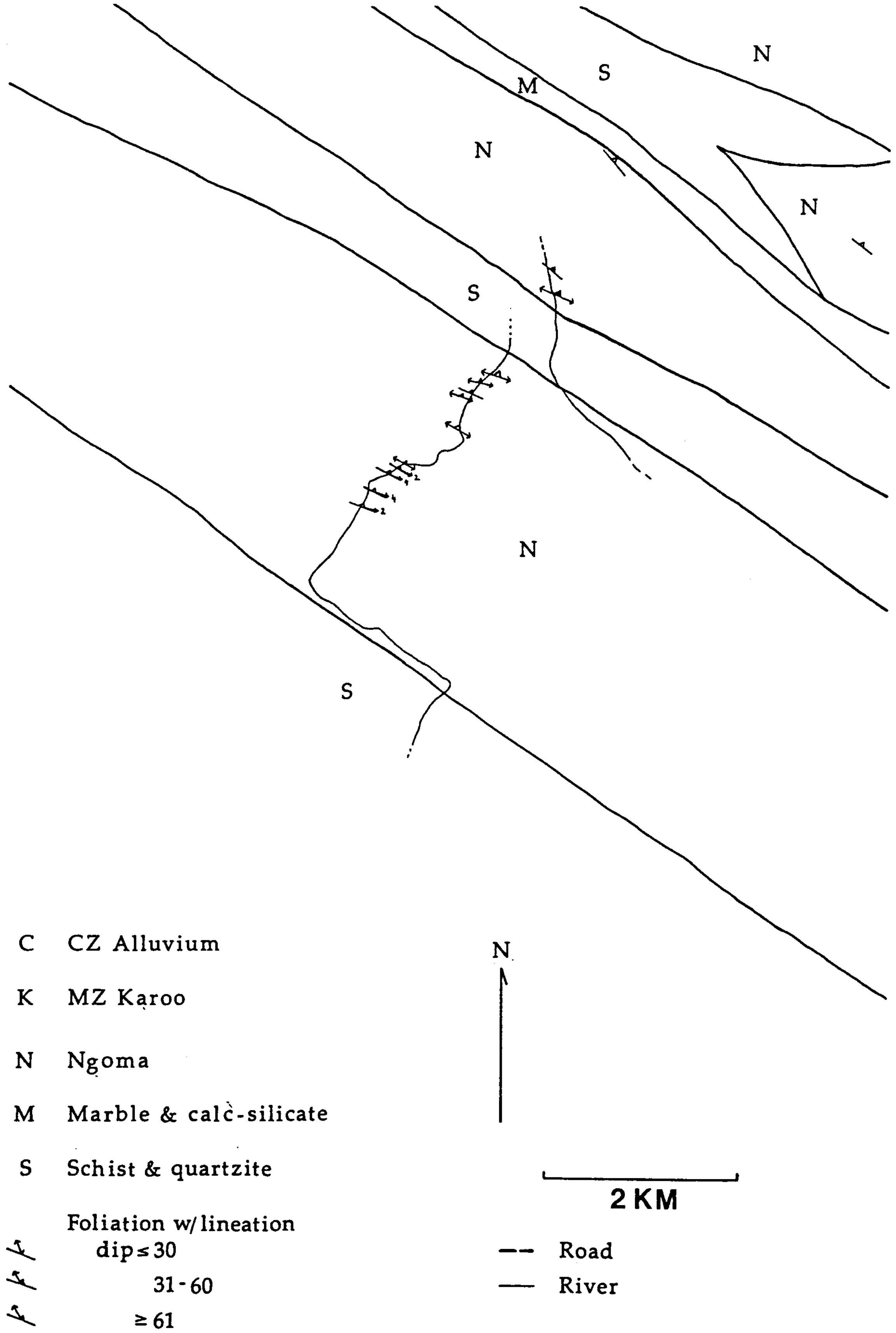


Figure 8. Structural map of the Nkonkola traverse.

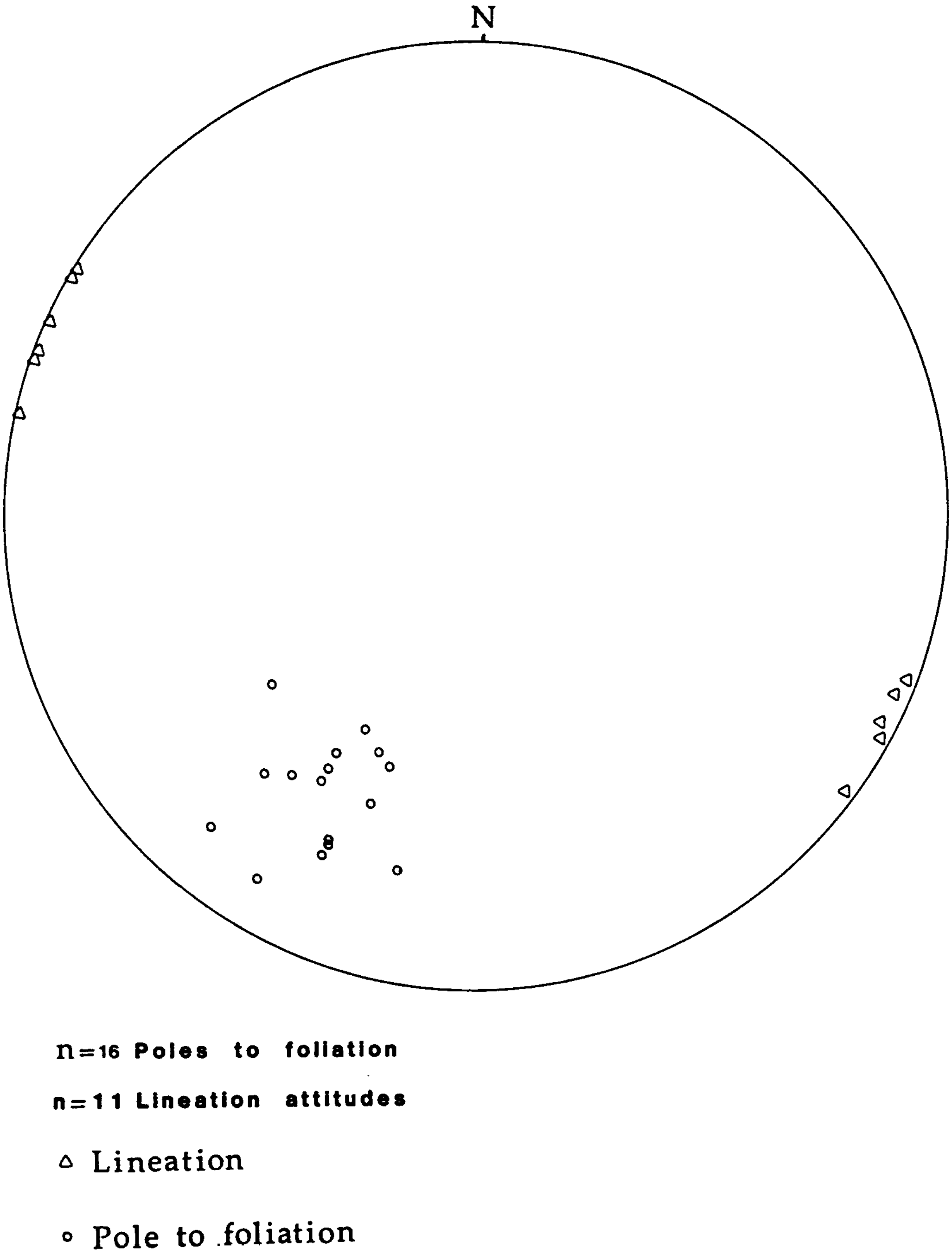


Figure 9. Equal area projection of data from Nkonkola traverse.

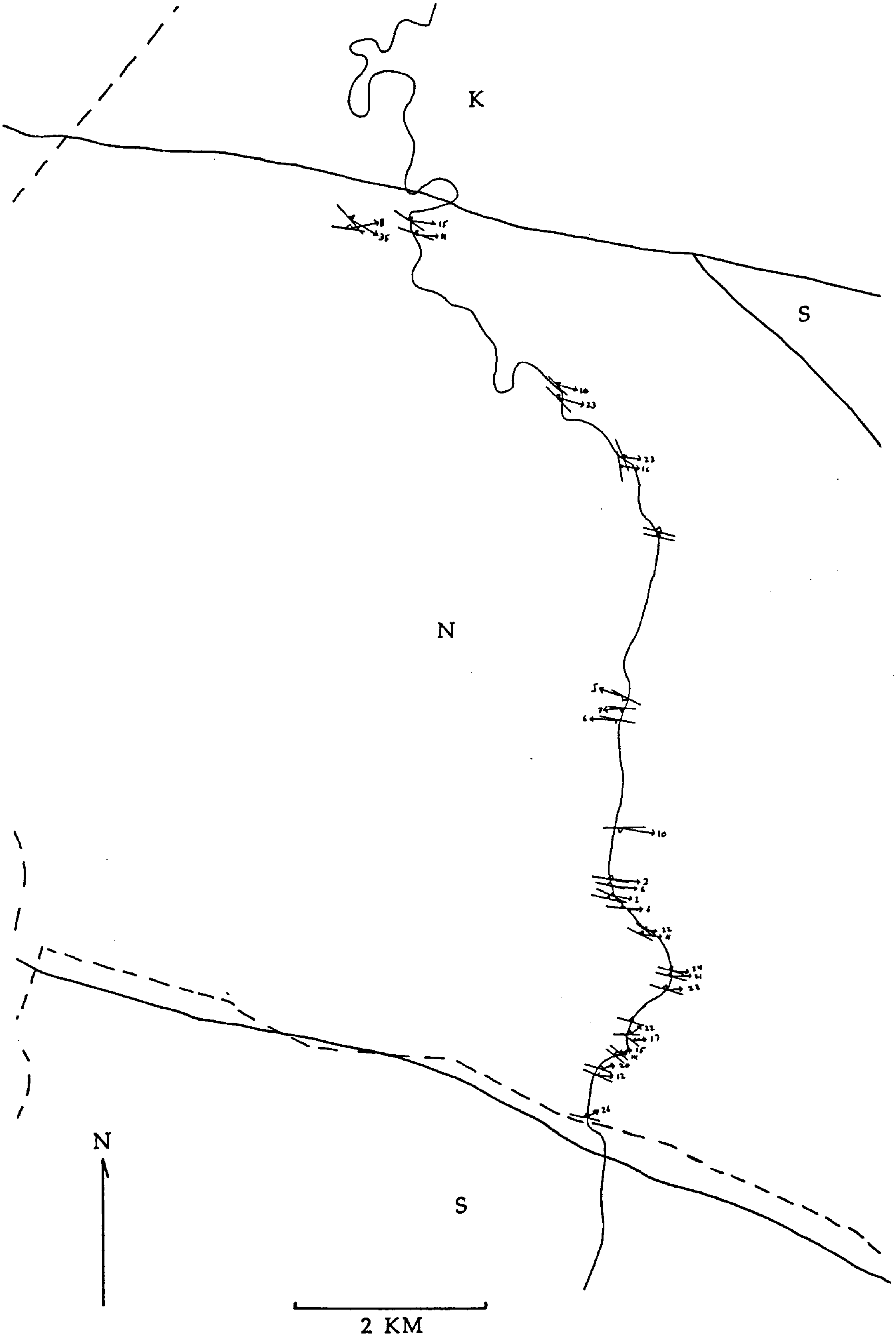
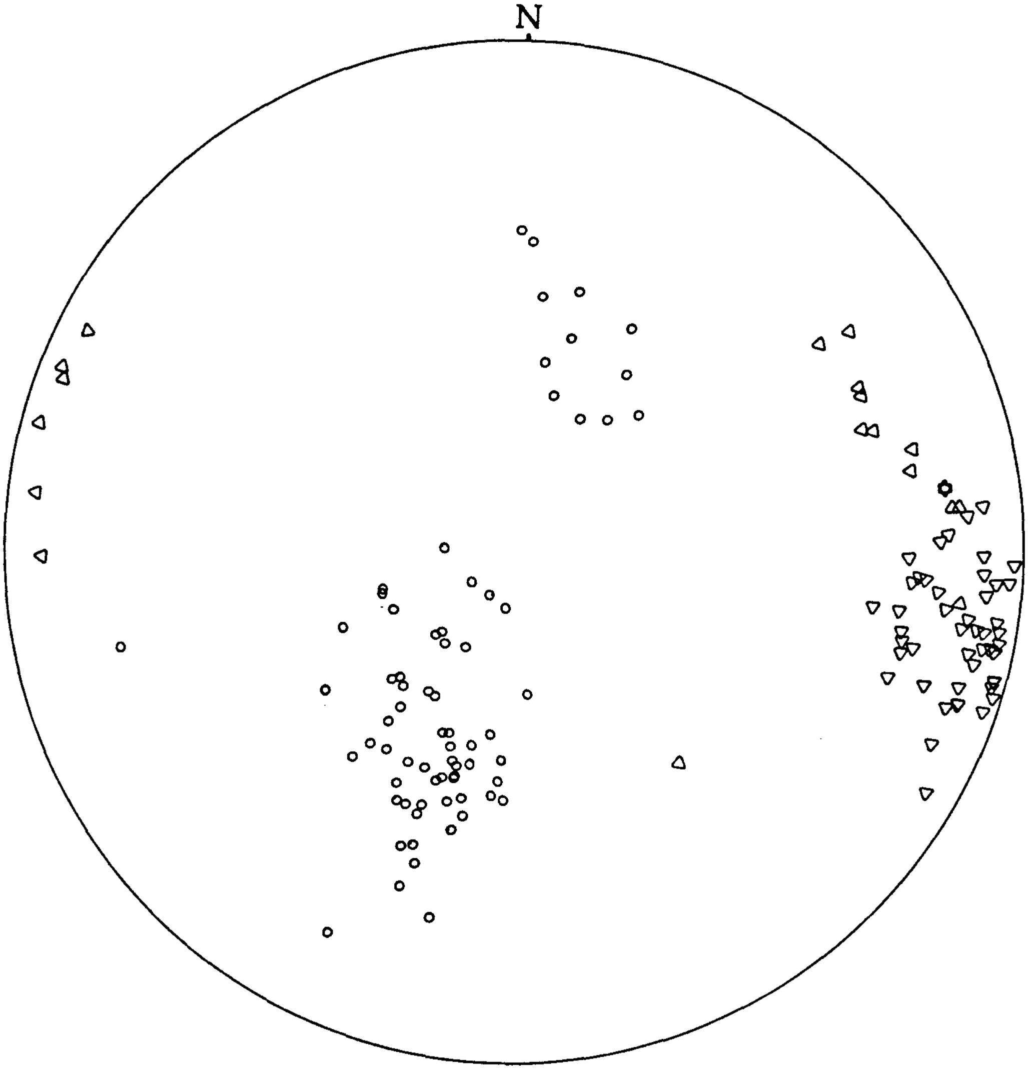


Figure 10. Structural map of the Magoye River traverse. See Fig. 8 for key to symbols.



n=69 Poles to foliation

n=65 Lineation attitudes

Figure 11. Equal area projection of data from the Magoye River traverse. See Fig. 9 for key to symbols.

reflecting an episode of late- or post-Zambezi folding that locally affected this area. The dense point maximum in the southwest quadrant indicates a dominant northeast dip in this area.

The structural map and stereoplot of the Kaya Stream traverse is shown in Figures 12 and 13. In this area the data are somewhat more dispersed. The lineations are still close to horizontal, trending west-northwest or east-southeast, and the distribution of foliation poles is again denser in the southern half of the plot, indicating a dominant northerly dip direction. The poles to foliation in this traverse display a more typical girdle distribution than the one seen in Figure 10, and again reflect the late, local folding.

Because the dominant dip direction in all domains of the Ngoma Gneiss is to the northeast, and foliation in areas unaffected by the later folding dips to the northeast, it is inferred that the foliation throughout the shear zone originally dipped to the northeast. Fold hinge lines observed in the field were measured and found to be parallel to the mineral lineations. The fold axes derived from the girdle distributions in the stereoplots are also seen to be parallel to the mineral lineations. These relations indicate that the lineations were not reoriented during folding, and represent the direction of shearing throughout the shear zone.

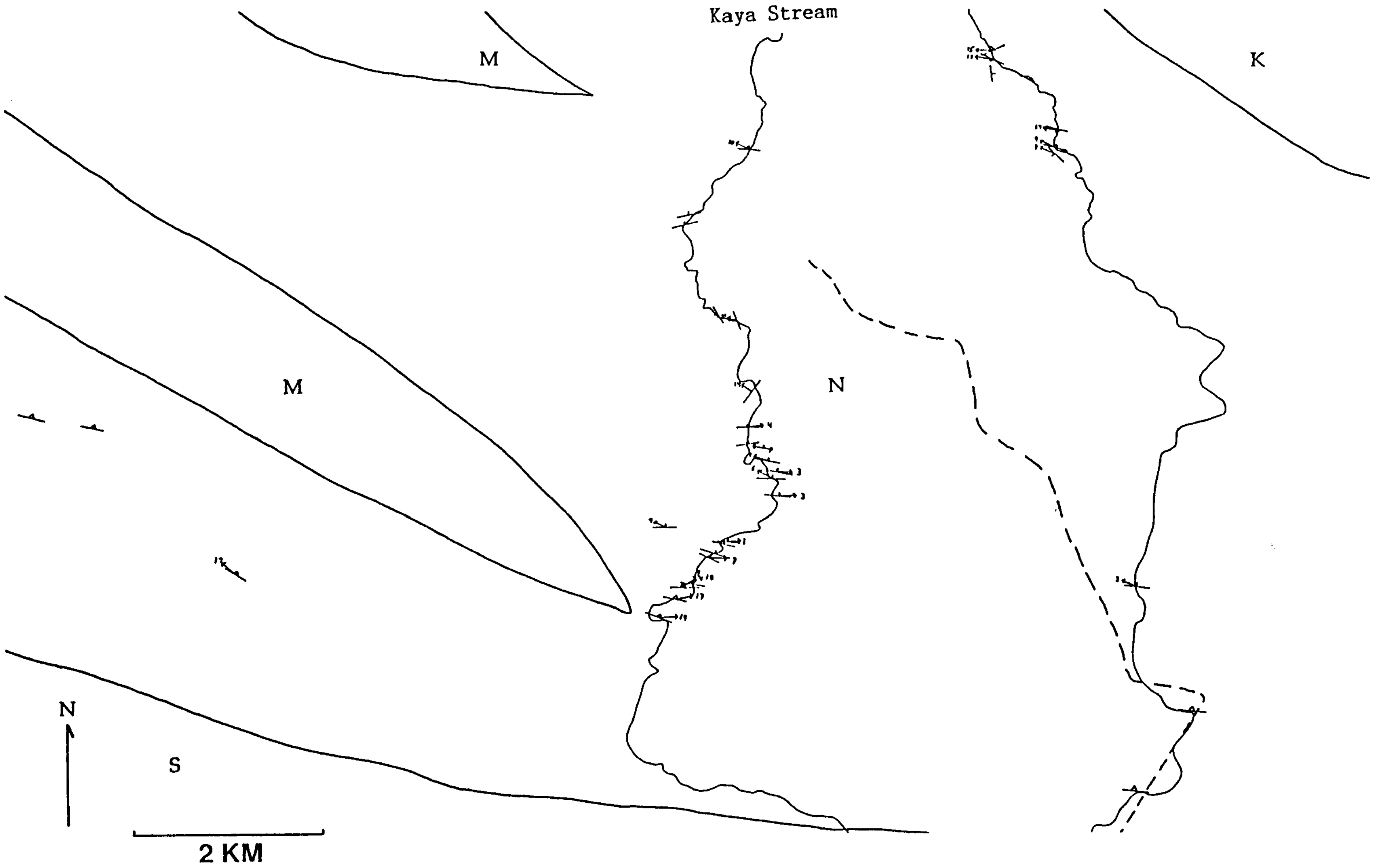


Figure 12. Structural map of the Kaya Stream traverse. See Fig. 8 for key to symbols.

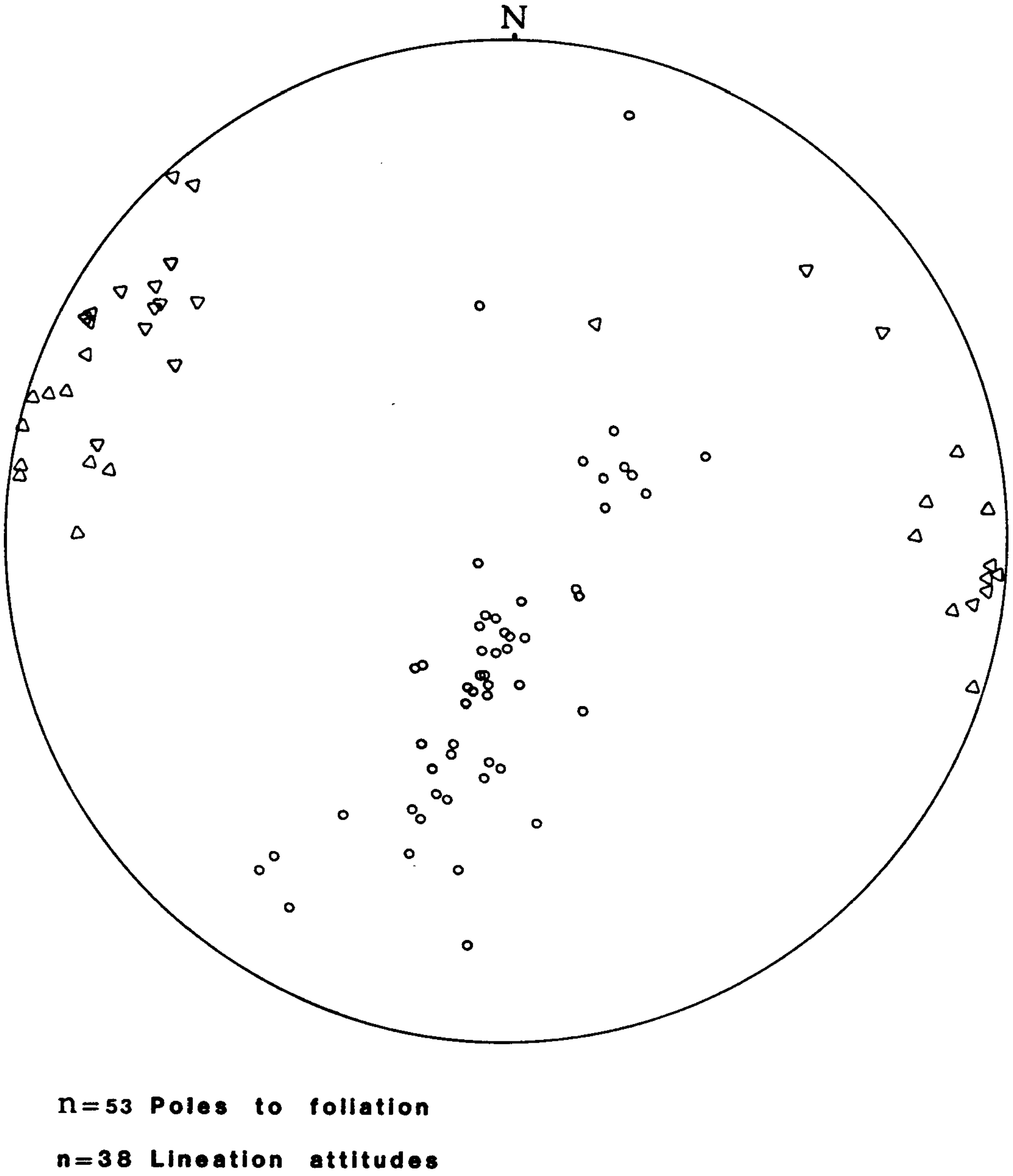


Figure 13. Equal area projection of data from the Kaya Stream traverse. See Fig. 9 for key to symbols.

MICROSCOPIC STRUCTURAL ANALYSIS

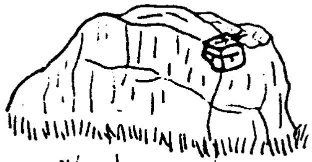
Sample Preparation

Hand samples of mylonitic rocks were collected along each of the traverses and oriented by marking a horizontal strike line on a foliation surface, with an arrow in the recorded strike direction and a tick mark on the strike line indicating the dip direction (Fig. 14a). From a number of these samples, thin sections were made in three mutually perpendicular orientations: perpendicular to foliation and parallel to lineation, perpendicular to foliation and perpendicular to lineation, and parallel to foliation and parallel to lineation. These three sections from each sample are referred to as sections "a", "b", and "c", respectively (Fig. 14b). From the remaining samples, thin sections were made only in the "a" orientation (Table 1). In the "a" sections, notches were cut down plunge of the lineation and in the dip direction of the foliation. Notches were cut in the dip direction of foliation and down dip of the foliation in the "b" sections, and down dip of the foliation and down plunge of the lineation in the "c" sections. These notches allow one to reconstruct the orientations of the samples as they were in the field, after the thin section has been examined.

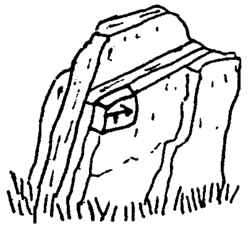
Microstuctures in the Mylonites

In the suite of rocks used in this study, it was found that the feldspar porphyroclasts in the protomylonites are very coarse,

MARKING ORIENTED HAND SAMPLES



horizontal lines with dip marks on 2 surfaces of sample, N arrow.



horizontal strike line with arrow in recorded strike direction and dip mark.

Orientation of all foliations, lineations, fold axes + axial planes, etc. must be carefully measured on the outcrop where specimen is collected and clearly marked on sample where appropriate.

CUTTING AND MARKING 3 ⊥ ORIENTED THIN SECTIONS

1. Cut oriented slices A, B, C
2. Cut oriented chips A, B, C
3. Cut notches in each chip to mark orientation.

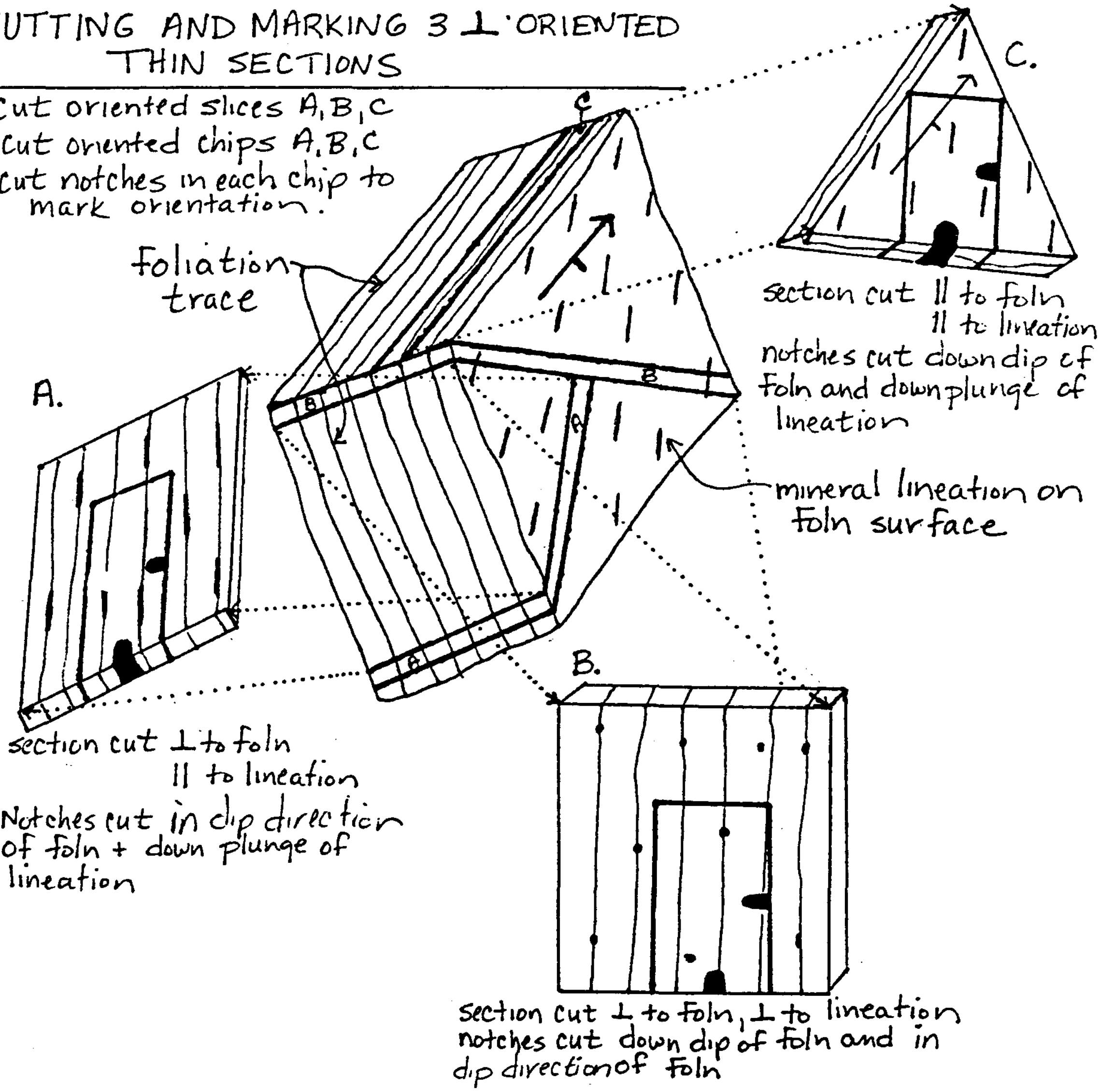


Figure 14. a) Technique used to orient hand samples in the field.
b) Orientation of "a", "b", & "c" samples.

Table 1

Sample	Number of Sections			Shear Sense
	a	b	c	
1-22	1	1	1	N
1-27b	1	1	1	N
1-33	1		1	N
1-34	1	1	1	N
1-37	1			A
1-38(3)	1			N
1-38(3)a	1			R
1-38(3)b	1	1	1	L
B-61	1			L*
B-62	1			A*
B-64	1			L*
B-66	2	1	1	L
B-68	2			L
B-69	1			L
B-70	1			L
B-71	2			R
B-72	2	1	1	L
B-87	1			L
B-88	2	1	1	R
B-89	2	1	1	L
B-90	2			L
B-91	2	1	1	L
B-92	1	1	1	L
B-93	2			L
B-94	2	1	1	L
B-95	2			L
3-91	1	1	1	R
3-92	1			L
3-94	1			A
3-94	1			L
3-95	1			L
3-96	2	1	1	L
3-97	2	1	1	L
3-128	1			A
3-128c	1			A

Key: L = Left lateral
R = Right lateral
A = Ambiguous
N = Not oriented
* = Not plotted on maps

reaching a diameter of up to 1 cm. The feldspars typically show only a small number of twins cutting across the grain, and most have a number of fractures running across them. The length of the tails of recrystallized material developed from these grains is hard to determine, as other porphyroclasts interfere with them. The tails are distinct, and the degree of asymmetry tends to be higher than in the mylonites and ultramylonites. The foliation planes in these rocks are defined, in part, by laminae of quartz grains that are coarser than the bulk of the quartz grains in the matrix. These laminae of relatively coarse-grained quartz typically are the tails of the augen structures. The quartz grains show a large range in size, and display very little undulose extinction. The foliation planes anastomose more strongly around the porphyroclasts in the protomylonites than in the other mylonites (Fig. 15a). A type of microstucture known as S-C fabric is displayed by the protomylonites, and is more easily seen in outcrop and hand sample than in thin section (Fig. 16). S-C fabric results when two distinct planar surfaces are developed in a mylonite. The "S" or "schistosité" surfaces mark the flattening foliation developed at 45 degrees to the direction of shearing. The "C" or "cisaillement" surfaces are "shear surfaces", that form parallel to the direction of shearing, and "are considered to be spaced slip surfaces with a sense of shear the same as that of the over-all shear zone" (Simpson & Schmid, 1983).

Porphyroclasts in the mylonites are highly fractured and twinned. Many of them are replaced by quartz on their margins, and

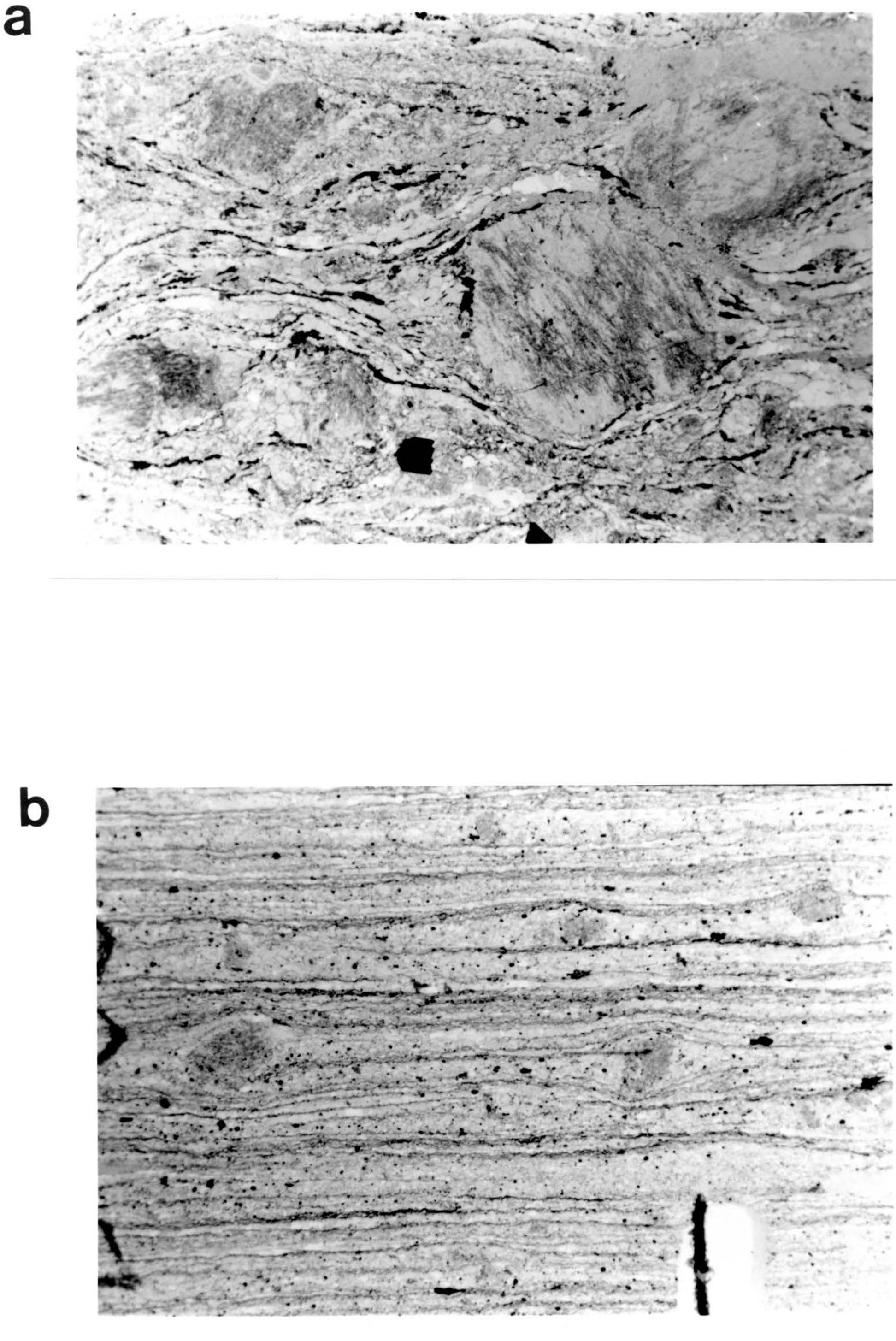


Figure 15. Photomicrographs of typical a) protomylonite, b) mylonite & c) ultramylonite from the suite of samples used in this study. Field of view in each is 18 mm.

C

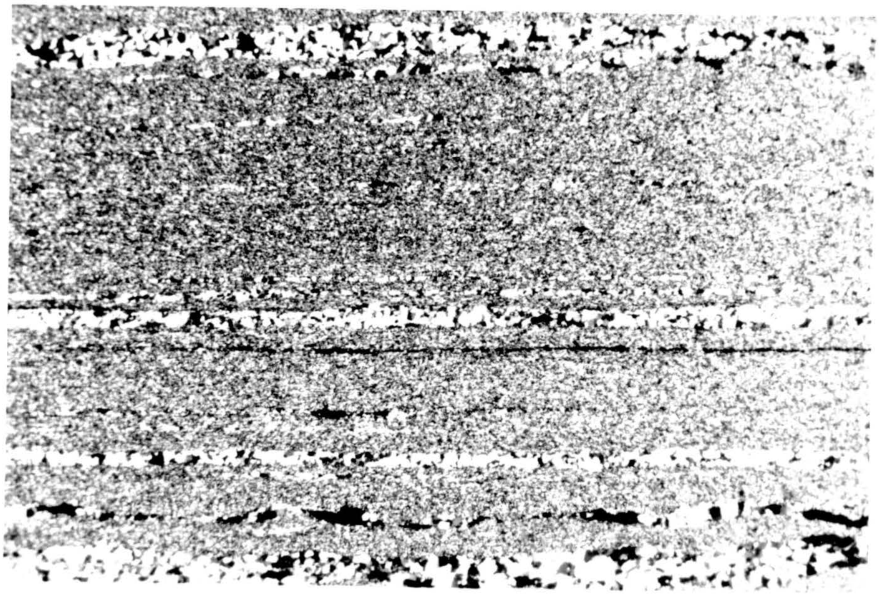


Figure 15c.

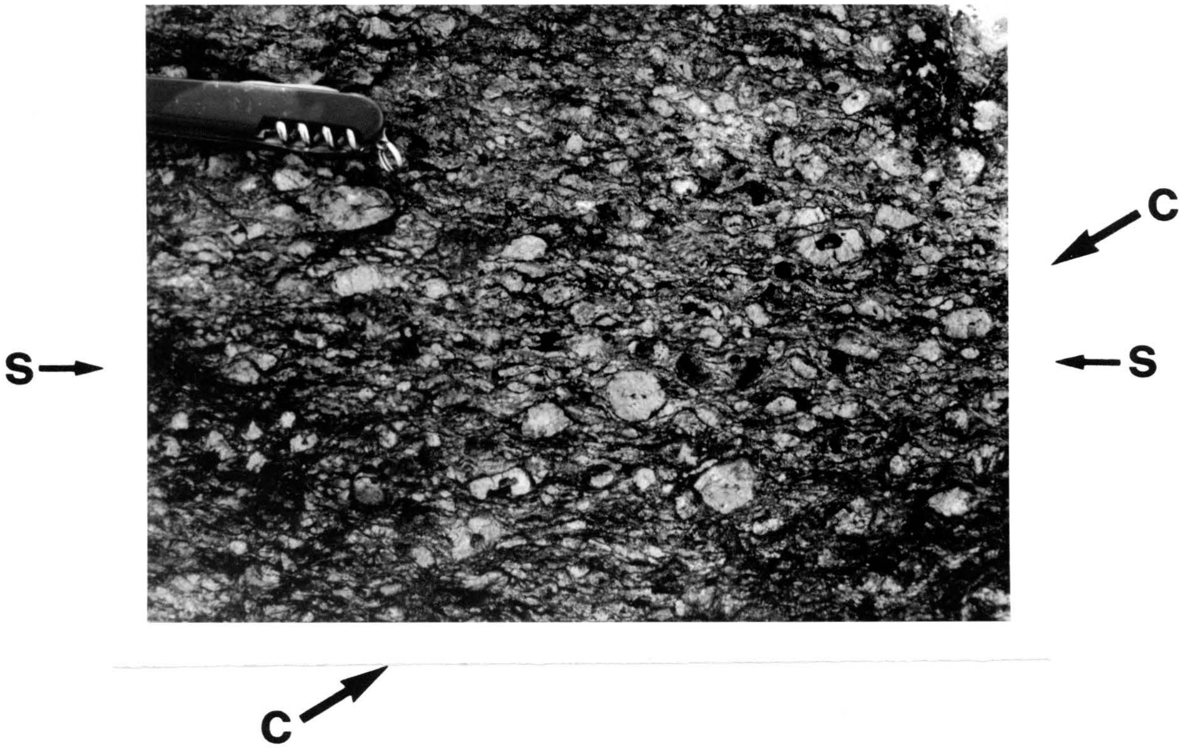


Figure 16. Protomylonite with well developed S-C fabric (arrows).

show core and mantle structure, in which the "core" porphyroclast is "mantled" by very fine grains of the same mineral species. This structure forms due to the preferential development of new grains aound the more highly strained margin of an older grain. The porphyroclasts in the mylonites are finer grained than those in protomylonites, ranging in diameter from approximately 1 mm to 5 mm. The volume of the rock that the porphyroclasts represent is less than in the protomylonites; however, because of their finer grain size, there are more of them in a given volume of rock. The tails are less asymmetric than in the protomylonites, and not as well defined, because the grains in the tails look much like those in the matrix (Fig. 15b). Their length is variable, ranging from a length on either side about equal to half the diameter of the porphyroclast, to a length about four times the diameter of the porphyroclasts. Quartz grains show two distinct size populations, and the foliation planes are defined by alternating horizons of fine and coarse grains. Many of the grains show undulose extinction, indicating they are in a strained state.

The feldspars in the ultramylonites are much closer in size to the quartz matrix. These porphyroclasts are highly twinned, and are replaced by quartz on their margins. Many of them have been completely replaced by quartz. This is evidenced by aggregates of coarse quartz grains that have the shape of a feldspar porphyroclast when viewed in plane light. Feldspar porphyroclasts are only marginally coarser grained than the matrix, the largest of them being less than 1 mm in diameter. Some of the ultramylonites completely lack porphyroclasts (Fig. 15c). The tails around the feldspar porphyroclasts have been largly replaced by quartz and, where they are visible, appear to be close to symmetric. The quartz is very fine grained and equigranular. Foliation planes are defined by laminae of slightly coarser grained quartz matrix, by laminae of quartz which have the same crystallographic orientation and therefore go extinct at the same position, and by thin laminae of mica. Only a few of the larger quartz grains show undulose extinction.

Shear Sense Determinations

Because the plane perpendicular to the foliation and parallel to the lineation records the maximum shear displacement, only the "a" sections were utilized to determine the sense of shear, using the methods of Simpson and Schmid (1983) discussed previously. This was fairly straightforward for some samples. Many of the samples, however, contain augen with tails that are close to symmetric. Figures 17a & 17b show typical asymmetric and symmetric augen structures from this suite of samples. One cannot unambiguously determine asymmetry by visual inspection alone in the more symmetric augen structures. To try and determine the asymmetry of these augen, a drawing tube was used. The image of an individual augen was projected onto graph paper, and then the sample rotated with the stage and the paper moved up or down until the line of symmetry of the augen and one of the horizontal lines of the graph paper

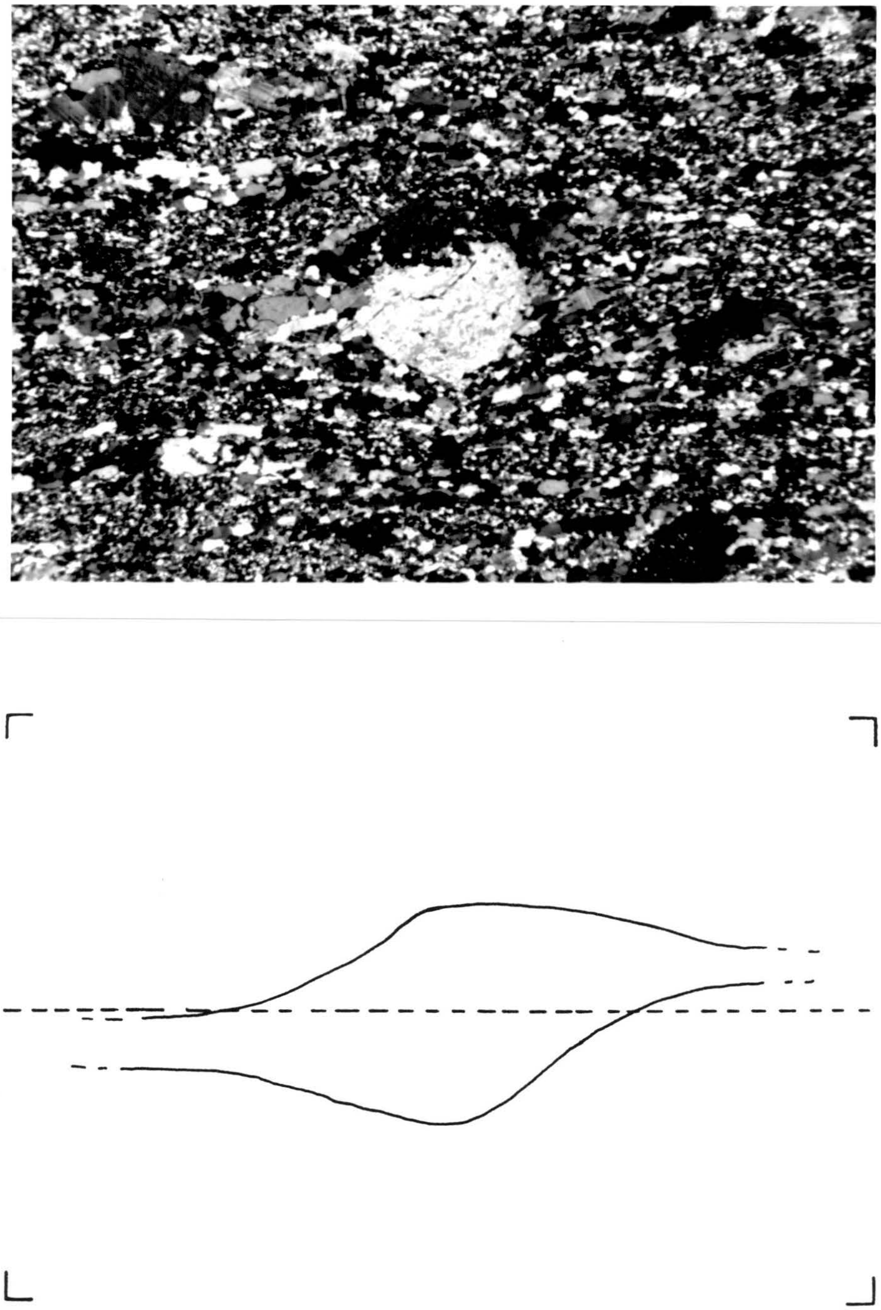


Figure 17a. Photomicrograph of typical asymmetric augen structure from suite of samples used. Field of view is 14 mm.

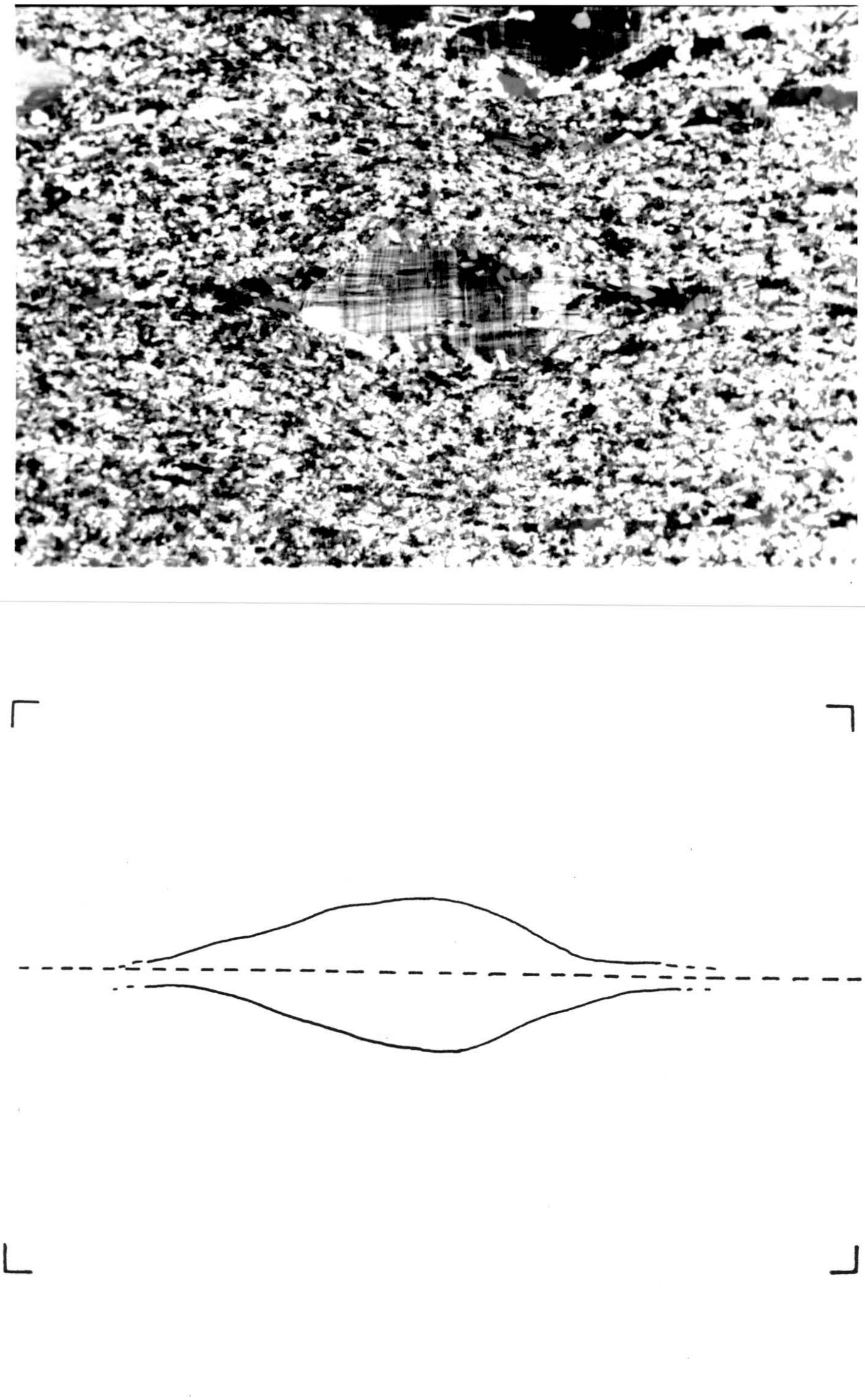


Figure 17b. Photomicrograph of typical symmetric augen structure from suite of samples used. Field of view is 18 mm.

coincided. The outline of the porphyroclast and tails was then traced out. From this tracing it was possible to detect minor asymmetries not otherwise apparent (Fig. 18). The shear sense determinations were then plotted on the stream traverse maps, and from these the overall sense of shear for the shear zone was determined.

Table 1 lists all the sections used in determining the sense of movement in the Ngoma Shear Zone. I examined the entire suite of samples once and recorded the shear-sense results, then examined them all a second time without looking at the original results. A comparison of the two data sets indicated that the results were consistent for all but two of the sections. The sections that yielded inconsistent results are ultramylonites that were very ambiguous, as all the augen structures were very close to symmetric, and yielded conflicting results within a single section. A sense of shear for these sections was obtained by counting the number of augen structures in each section showing left-lateral shear and the number showing right-lateral shear, and assuming that the sense of shear represented by the majority of augen structures was the true shear sense. Apparently, individual augen structures in these sections were close enough to symmetric to yield opposing results on different examinations. From 13 samples, more than one "a" section was made (Table 1). Shear sense determinations from multiple sections of the same sample were 100% consistent. Each section was also examined by Dr. Wilson and those results were compared to mine. Of 42 sections

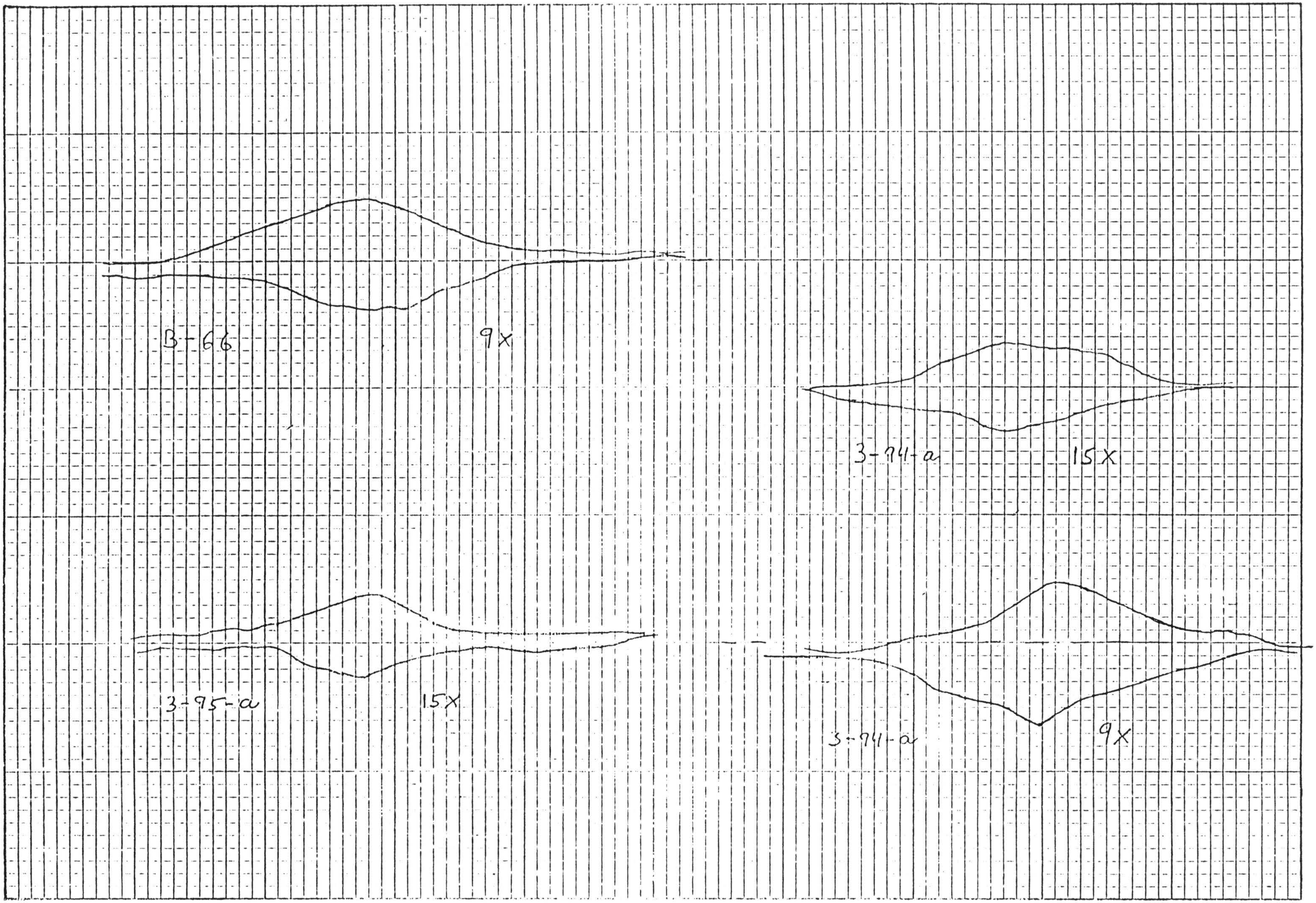


Figure 18. Drawing tube tracings of near-symmetric augen structures.

examined by both of us, the results of 36 were consistent. This indicates that the methods used are reliable.

Of 48 sections total, 5 were rejected as ambiguous, and 5 were not of use either because they were not oriented in the field or because the attitudes of the foliation and lineation where they were collected were not recorded (Table 1). Three of the sections used, denoted by an asterisk in Table 1, were collected from localities outside of the three traverses, and therefore are not shown on any of the maps.

A total of 25 shear sense determinations were made 21 of them (84%) indicate left-lateral shear displacement. They are distributed on the maps as follows: 6 in the Nkonkola south traverse, 5 of them sinistral (Fig. 19), 9 in the Magoye River traverse, 8 of them sinistral (Fig. 20), and 8 in the Kaya Stream traverse, 6 of them sinistral (Fig. 21). Two from the Magoye traverse, one showing left-lateral and one showing right-lateral displacement, are in localities where late, local folding reoriented the foliation planes so that they now dip south. These samples, denoted on the map by an asterisk, have been plotted with the shear sense as it would be if the folding were removed, as the folding took place after shearing.

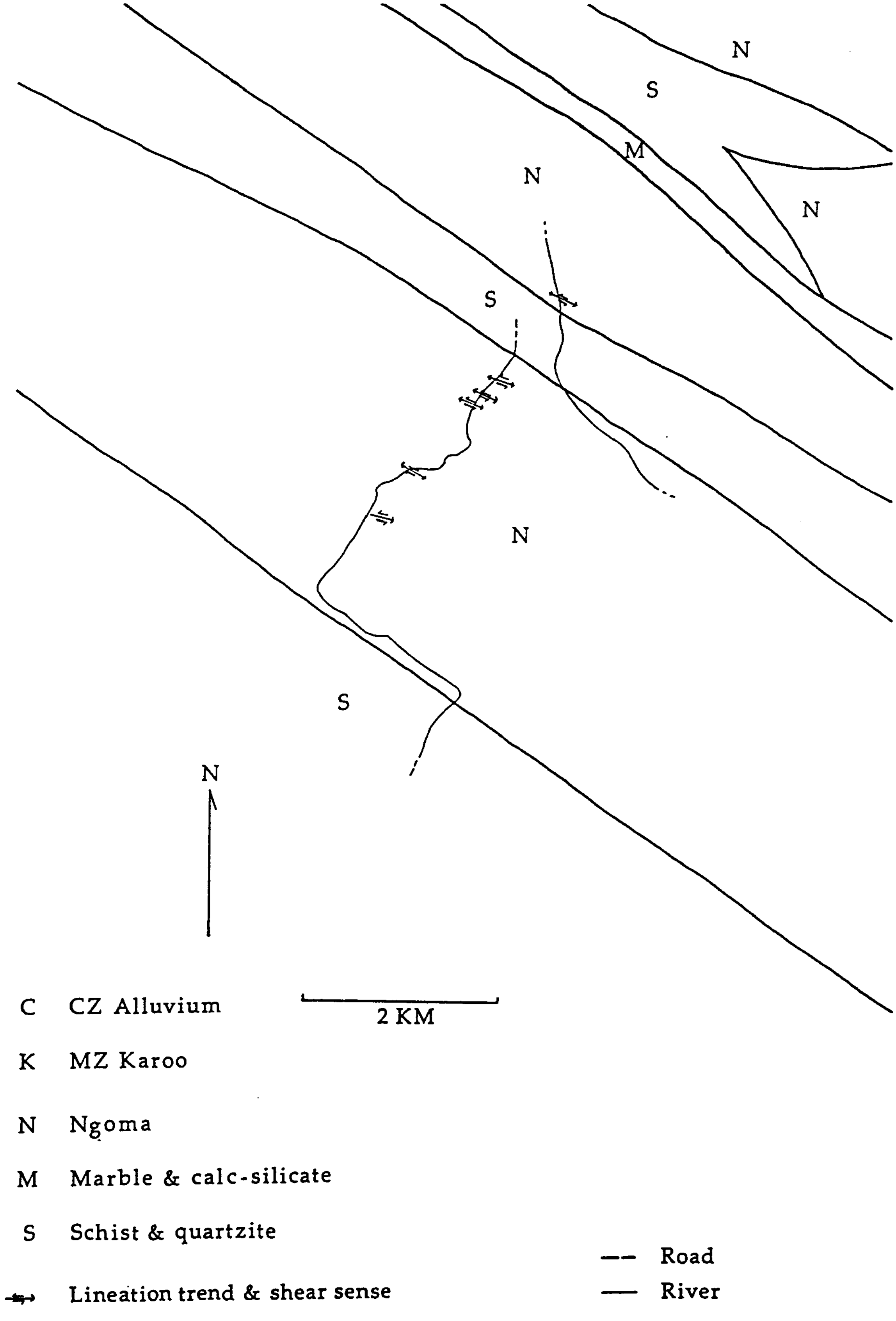


Figure 19. Map of Nkonkola traverse showing shear sense determinations.

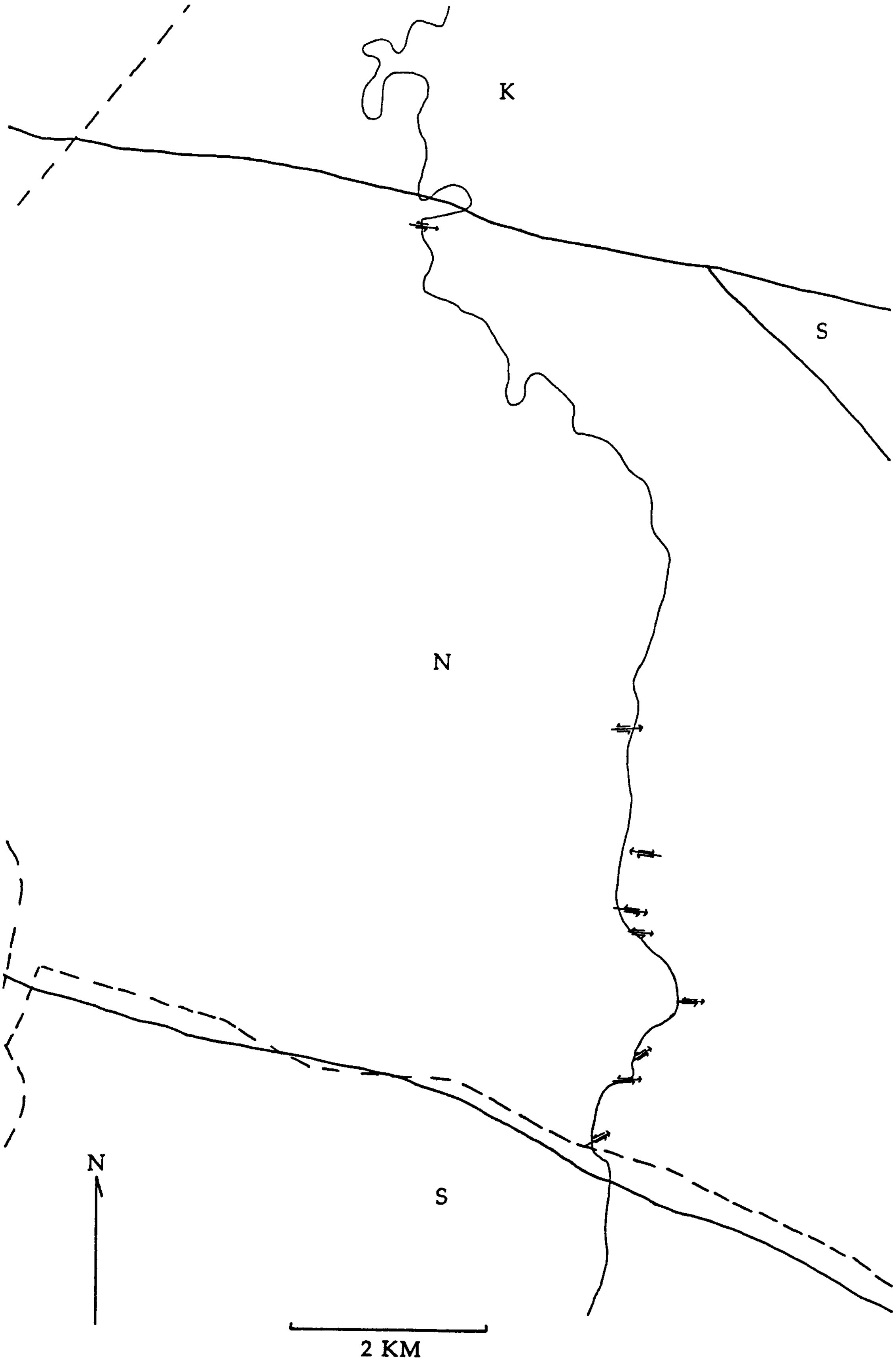


Figure 20. Map of Magoye River traverse showing shear sense determinations. See Fig. 19 for key to symbols.

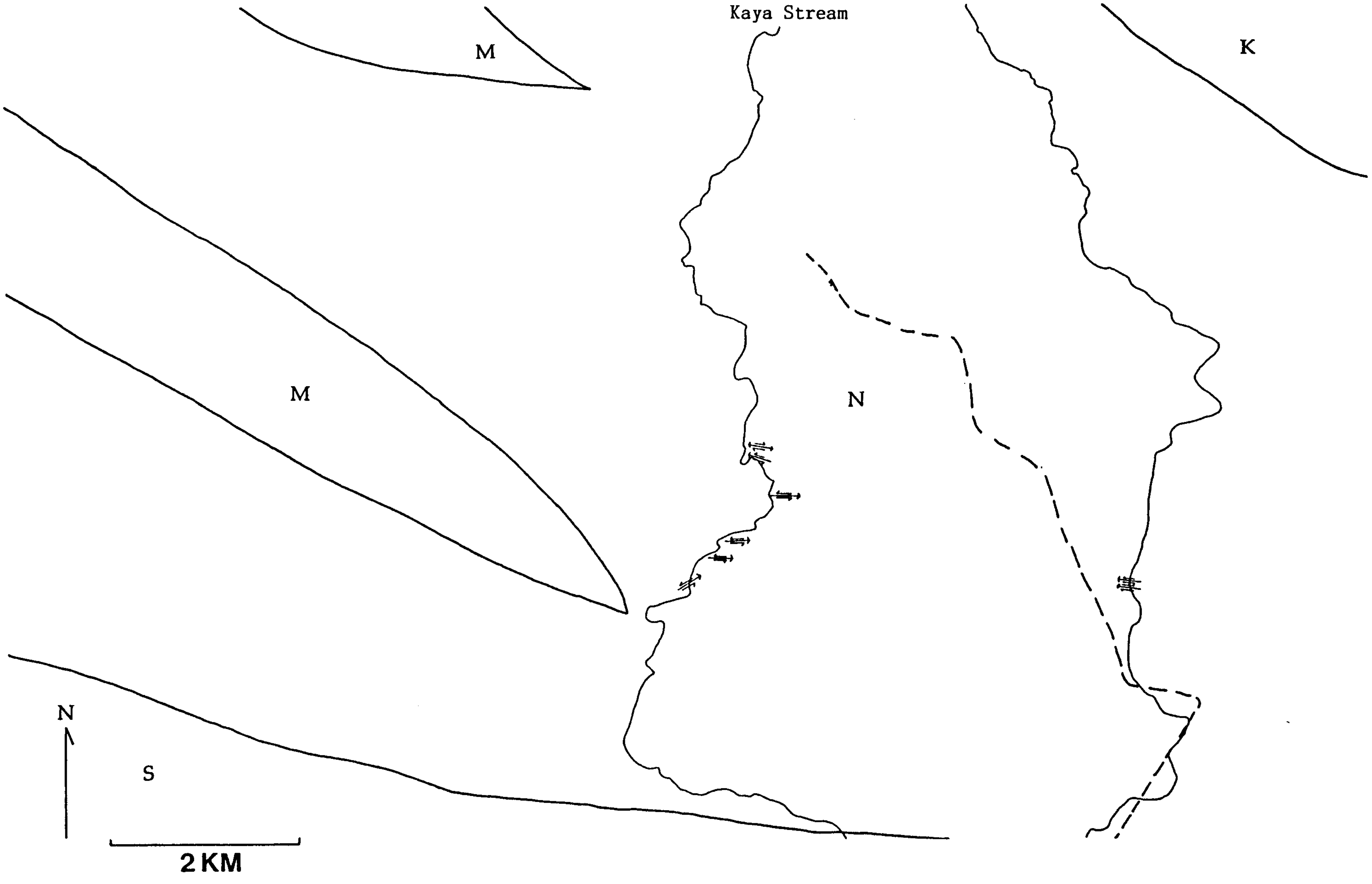


Figure 21. Map of Kaya Stream traverse showing shear sense determinations. See Fig. 19 for key to symbols.

DISCUSSION

Reconnaissance structural mapping in the Late Proterozoic Zambezi Belt has shown that the Ngoma Gneiss consists dominantly of mylonitic rocks and therefore represents a crustal-scale ductile shear zone (Hanson, Wilson, and Wardlaw, In press). Although the magnitude of shear displacement has yet to be determined, this study has documented the geometry and sense of shearing within the Ngoma Shear Zone.

The regional dip of foliation planes in the Ngoma Gneiss is to the north. This geometry lead previous workers to interpret it as a zone of south-directed thrusting (De Swardt & Drysdall, 1964). At the time, the relation between lineation attitudes and movement sense in sheared rocks was not fully understood and, thus, the the lineation trends were not seen as evidence against this model. As described previously, it is now recognized that mylonitic foliation planes develop parallel to the shear zone walls, and that lineations developed on mylonitic foliation planes are parallel to the movement direction in a ductile shear zone.

The orientations of foliation planes and of lineations developed on the foliation were measured along three traverses within the Ngoma Gneiss. Each of these traverses spans nearly the entire width of the gneiss belt, and the three are spread along 60 kilometers, almost the entire length of the shear zone. The data collected from these traverses show that the mylonitic foliation planes in the Ngoma Gneiss possess a regionally consistent, moderate dip towards the north, with only local reorientation to a southward dip in discrete zones of open, late- to post-Zambezi folding. The gneiss belt therefore represents a northward-dipping ductile shear zone. Lineation trends developed on the foliation planes are consistently close to horizontal, and were not reoriented by the later folding. The Ngoma Shear Zone therefore represents a zone of transcurrent movement, not thrusting.

The sense of shear was determined using the methods of Simpson and Schmid (1983). The consistency tests applied in this study indicate that these methods yield reliable results. The methods are easily applied to protomylonites and mylonites displaying low to moderate strains in which the augen structures are distinctly asymmetric. In highly strained rocks such as the ultramylonites, the augen structures tend to become nearly symmetric, and ultimately completely disappear due to pervasive dynamic recrystallization and neomineralization. To try and resolve the sense of shear in these rocks, a modification of the method was devised in this study. A drawing tube was used to trace the augen structures on graph paper in order to determine whether subtle asymmetries were present. In general, this method produced more convincing results than visual inspection alone.

The modified method was not always successful in obtaining a satisfactory shear sense result. In some samples the near-symmetric augen structures yielded opposing shear directions, and these samples had to be rejected as ambiguous. A possible explanation for the mixed results in these ambiguous sections is that the sense of asymmetry in near-symmetric augen structures is easily reset by minor, late-stage shearing. For example, small magnitude movements with shear sense different from the overall sense may occur during relaxation after the main stress regime is relieved, and may only be recorded in the near-symmetric augen structures in high strain zones.

The problem of symmetric augen structures does not preclude the utilization of microstructural shear sense determinations in high strain shear zones. Because the mylonites in a shear zone typically grade into the blocks that bound them, and because zones of relatively high and low strain commonly develop within large-scale shear zones, if one traverses a shear zone, these regions of low and moderate strain should be encountered. Samples taken from these regions should contain asymmetric augen structures which can be used to determine the sense of shear.

The shear-sense determinations made in this study show the Ngoma Shear Zone to be the site of left-lateral transcurrent shearing. The shear-sense data are reasonably consistent across the span of the shear zone. Although a number of sections did yield a right-lateral shear sense, they are spread throughout the belt, and are everywhere outnumbered by those showing left-lateral movement. It is known that some late- or post-Zambezi folding has taken place in the region.

This indicates that there was some tectonic activity after the main shearing event, and this movement may have been responsible for changing the sense of shear shown by some of the augen structures, and could account for the dispersion in the results.

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