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NATURE AND ORIGIN OF FOLIATION
AND LINEATION IN PORPHYRY,
KILLARNEY, ONTARIO

By

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ABSTRACT

The Killarney Igneous Complex, composed of an intrusive granite and a hypabyssal or extrusive porphyry was implaced near and at the surface in the general locality of Killarney, Ontario. The crystallization age of the intrusive portion of the complex is approximately 1740 million years. These rocks have experienced deformation by forces which in some instances produced complicated shearing motions. Mesoscopic samples show a foliation and a lineation supporting a history of deformation. The foliation is clearly the more visible fabric and is interpreted as a plane of flattening.

Kinematic indicators, specifically asymmetric pressure shadow wings, are present within the rocks; however the patterns are too complicated to interpret by a simple sense of shear. The geometry of these kinematic indicators does suggest an active plane of foliation.

ACKNOWLEDGMENTS

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CHAPTER 1

The rocks involved in this project were taken from the Killarney Igneous Complex (KIC) at a series of locations just east of the town of Killarney. The KIC is located north of the Lake Huron-Georgian Bay waters, (see fig.1). The zone is bordered to the north and west by the Huronian sediments of the Southern Province. The contact with the Southern Province intersects the contact with the Grenville Front just south of Johnnie Lake.

The KIC is a volcanic-plutonic association which can be divided into two parts. The northern-most part, which runs parallel to the boundary with the Southern Province, consists of massive, pink, leucocratic granite, which contains screens and xenoliths in some areas (Davidson, 1986). The rest of the KIC is comprised of a few separate groups: foliated Killarney granite, feldspar porphyry, rhyolite and felsic volcaniclastec rocks, and patches of quartz rich rocks (Davidson, 1986).

Within the KIC, the foliation generally increases in definition and "density" to the south and southeast (Davidson, 1986). The foliation generally has a steep dip, in some places to the north-west and in some places to the

Figure 1

1g: granite

1x: granite with abundant xenoliths

2a: nail-head porphyry

2b: pin-head porphyry

3: volcanic rocks

4: volcaniclastic(?), epiclastic rocks, metasediments

m: mylonite zone

K: Killatney

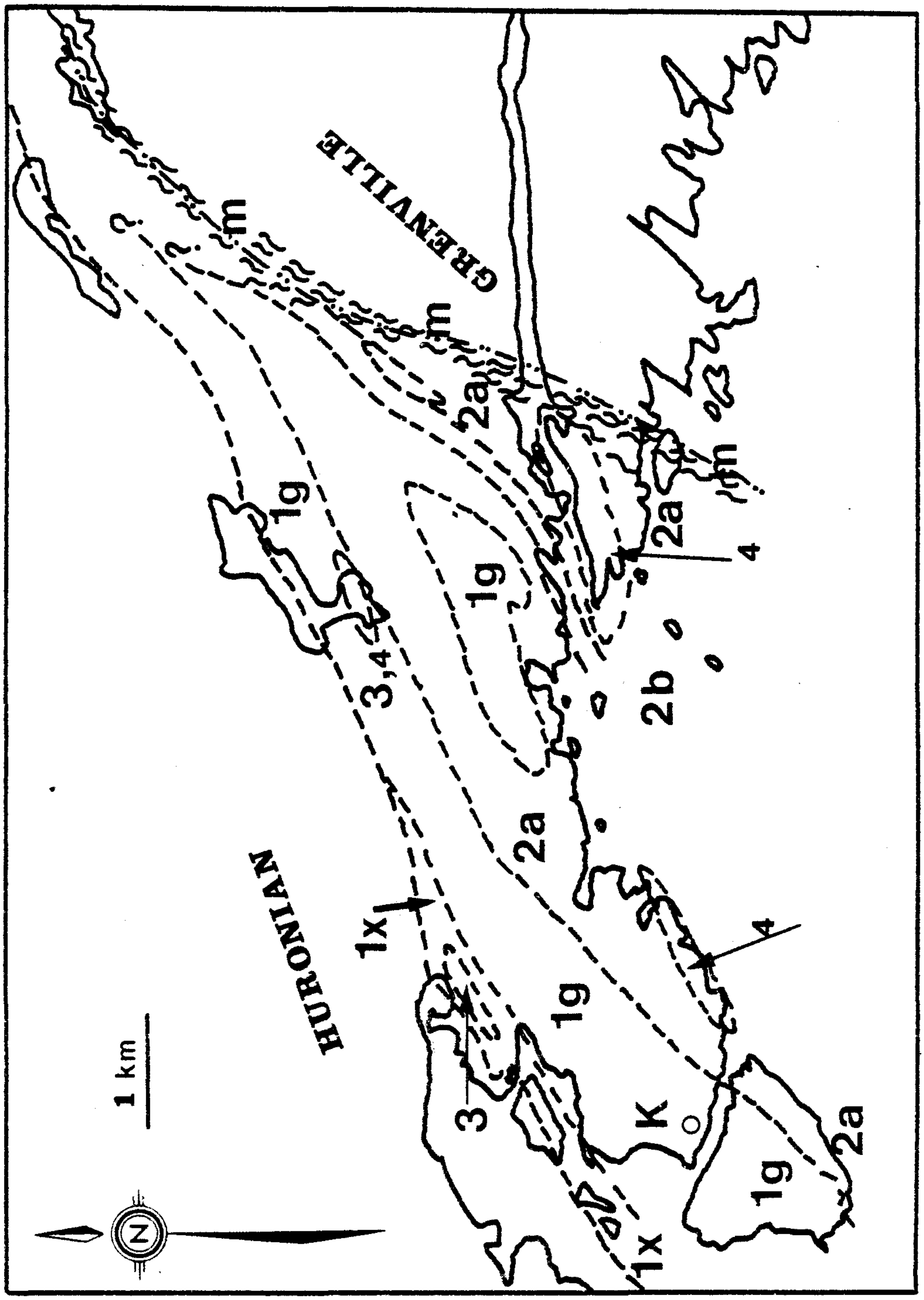


fig.1

southeast (Davidson, 1986). There is a lineation visible in these rocks due to the elongation of quartz grains and primary clasts. This lineation plunges between east and northeast, gradually becoming shallower in the northeast (Davidson, 1986).

The ultimate reason for studying this region is to establish where this intrusion fits into the geological history of the area. The particular project reported here is an attempt to determine aspects of the deformation history of the porphyry, specifically, strain and the degree to which grains are preferentially oriented. The Fry method (Fry, 1979) was used in an attempt to determine the orientation of the strain ellipsoid. A study was done to determine to what extent large, elongate feldspar grains were preferentially oriented. And lastly, kinematic indicators were analysed to help determine the deformation history of the rock.

CHAPTER 2

The foliation in the KIC generally increases moving towards the southeast. The granites in the northwest display virtually no foliation or lineation; until its contact with the porphyry to the southeast at which point a weak foliation becomes evident. The area has been divided into four sub-areas, three of which are in the porphyry and the fourth is the mylonite. The sub-areas are defined by a similar orientation of foliation and attitude of lineation. The foliations in the porphyry have a strike between northeast and eastnortheast with a nearly vertical dip. The foliation in the mylonite strikes between northnortheast and northeast with a moderate to steep dip. Approaching the mylonite from the west the foliation in the porphyry gradually alters its orientation to become nearly parallel in strike to the mylonite foliation. This contrast in orientation of foliations indicates two deformational events, that which produced the mylonite being the most recent (personal communication, Clifford).

Associated with each foliation there is a lineation. On average, the attitude of this lineation is eastnortheast with a moderat plunge. This lineation does show a fairly wide range of attitudes, ranging from north to east.

The lineation lies within or very close to the foliation. Distorted clasts in the area produce a lineation with approximately the same attitude. However, the quality of this clast lineation can vary from one outcrop to another. These lineations help define the nature of the strain in the area (personal communication, Clifford).

The observations of foliation and lineation permit the area to be divided into four regions within which the general form and attitude of the strain ellipse can be estimated. Flattening within the foliation is generally better developed than stretching. However, at some locations stretching is very well developed, such as on Philip Edward Island (personal communication, Clifford).

The rocks involved in this study consist of six samples from six distinct locations. All samples show a foliation and a lineation. The quality of these fabrics varies across the samples. Two thin sections were cut mutually orthogonal to each other and to the plane of foliation for each location. One thin section was cut parallel, one perpendicular to the lineation.

On a fresh cut surface the rocks are a brownish red colour. Within any one particular sample the colour is not necessarily homogeneous; it tends to vary in layers parallel to foliation.

The minerals in the rock fall into three distinct grain size groups. They are: (i) a fine grain matrix (0.1 mm), (ii) large phenocrysts (1-2 mm) and (iii) medium sized grains (0.5 mm) which are associated with the phenocrysts. The fine grained matrix consists mostly of quartz, but also includes alkali feldspar, phyllosilicate (muscovite), and opaque minerals. The large phenocrysts are predominantly alkali feldspar which show some signs of alteration. The medium grain size material occurs almost exclusively in pressure shadow wings associated with the phenocrysts. This material consists of both quartz and feldspar. However, the amount of feldspar present appears to be higher in the wings than in the matrix.

In all thin sections the phenocrysts appear to be randomly distrubuted. The muscovite is not uniformly distributed throughout the rocks, there being layers of high and low concentrations (shown in fig.2). The variation in colour previously mentioned is probably related to this non-uniform distribution.

The foliation present in the rock is defined in two ways. The muscovite grains show a strong preferred orientation within the layers of high muscovite concentration. Muscovite scattered through the rock outside these layers has the same orientation. Many of the alkali feldspar phenocrysts are elliptical in cross section. There is a

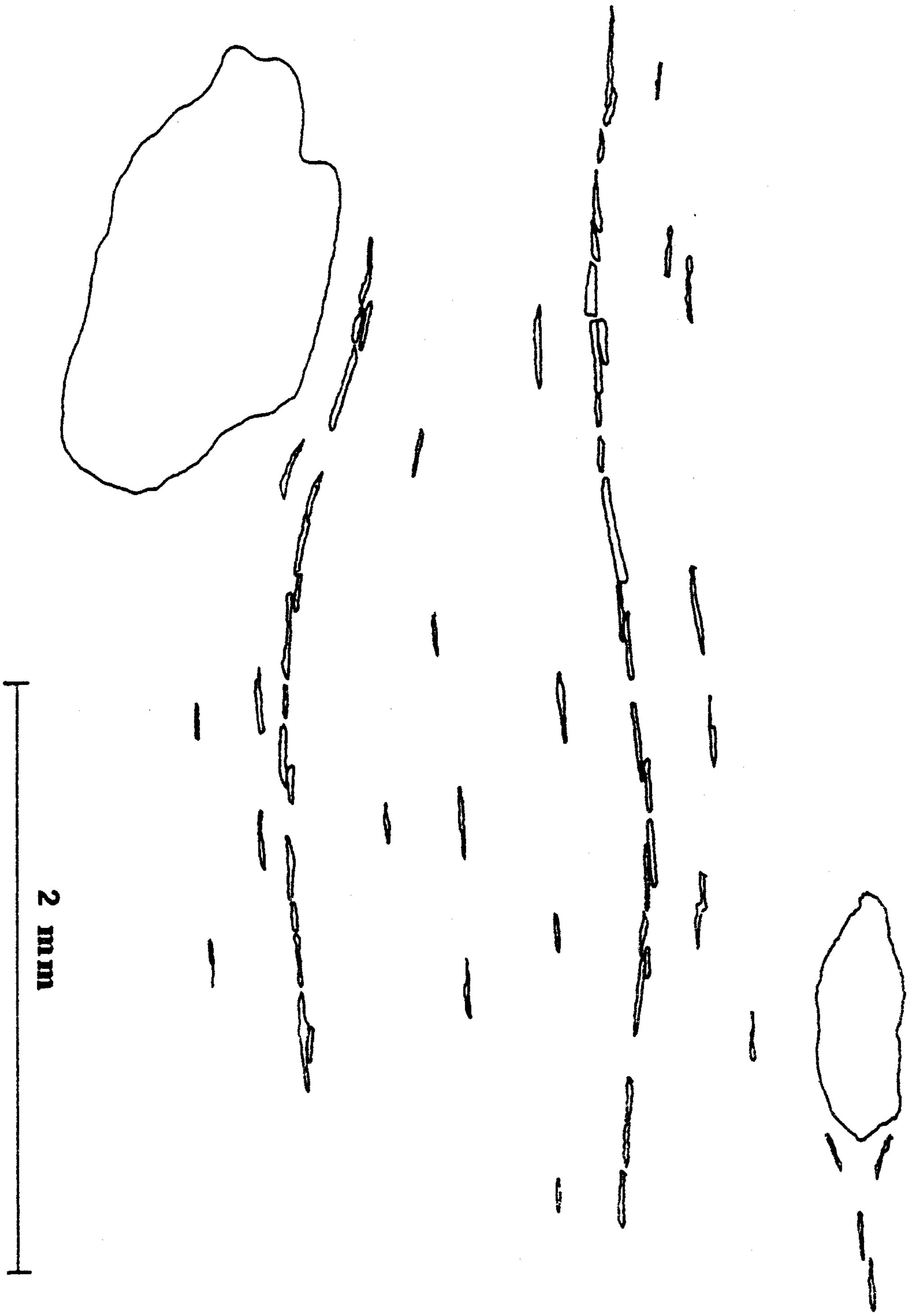


fig.2

weak tendency for the long axis of these ellipses to be oriented in the plane of foliation, but such orientation is probably not a significant contributor to the definition of foliation.

The modal composition was determined through a line counting method. The thin sections were traversed perpendicular to the foliation at 0.33 mm increments. The following table (fig. 3) indicates the range, across all thin sections, and the average for each category.

CHAPTER 3

An independent estimate of strain has been made using diffusion bands and quartz veins. The diffusion bands are defined by near planar concentrations of hematite. An estimate of their stretching cannot be made because these diffusion bands have not boudinaged. They have collapsed in folds in some places which indicate shortening on axes whose attitude is approximately northnortheast. The quartz veins however have collapsed in boudinage and folds which permits measurements of positive and negative extensions. The negative extension direction is perpendicular to the foliation. The positive extension direction is nearly

GRAIN SIZE				MINERALOGY			
	SM	MED	LG	OP	PHYLL	FSP	QTZ
RANGE	58-90%	7-25 %	2-24 %	0-5 %	5-14 %	23-48 %	44-65 %
AVG	77 %	14 %	12 %	2 %	8 %	31 %	59 %

fig.3

parallel to the lineation. The quartz veins were not originally all parallel, as a result, after deformation their axes are not all parallel.

The data for the measurements of diffusion bands and quartz veins suggests the xy plane of the strain ellipsoid is parallel to foliation and the x axis of the strain ellipsoid is approximately parallel to the lineation. Flattening of the strain ellipsoid is more dominant than the extension of it (personal communication, Clifford).

THE R_f/ϕ METHOD

When an object which is originally elliptical in form, is homogeneously deformed, the resultant form will also be elliptical. There are four factors which will determine the shape of the final ellipse; the shape and orientation of the initial ellipse and the shape and orientation of the strain ellipse.

Elliptical feldspar grains were used in an R_f/ϕ analysis to help determine the orientation of the strain ellipse. R_f is the ellipticity of the elongate grains. ϕ is the final orientation of the long axis of the elliptical grains with respect to datum. The datum for the angular measurements was perpendicular to the foliation, so that an angular measure of 90° is parallel to foliation. The curves produced are a best fit envelope of the data. The curves will be symmetric about the long axis of the stain ellipse

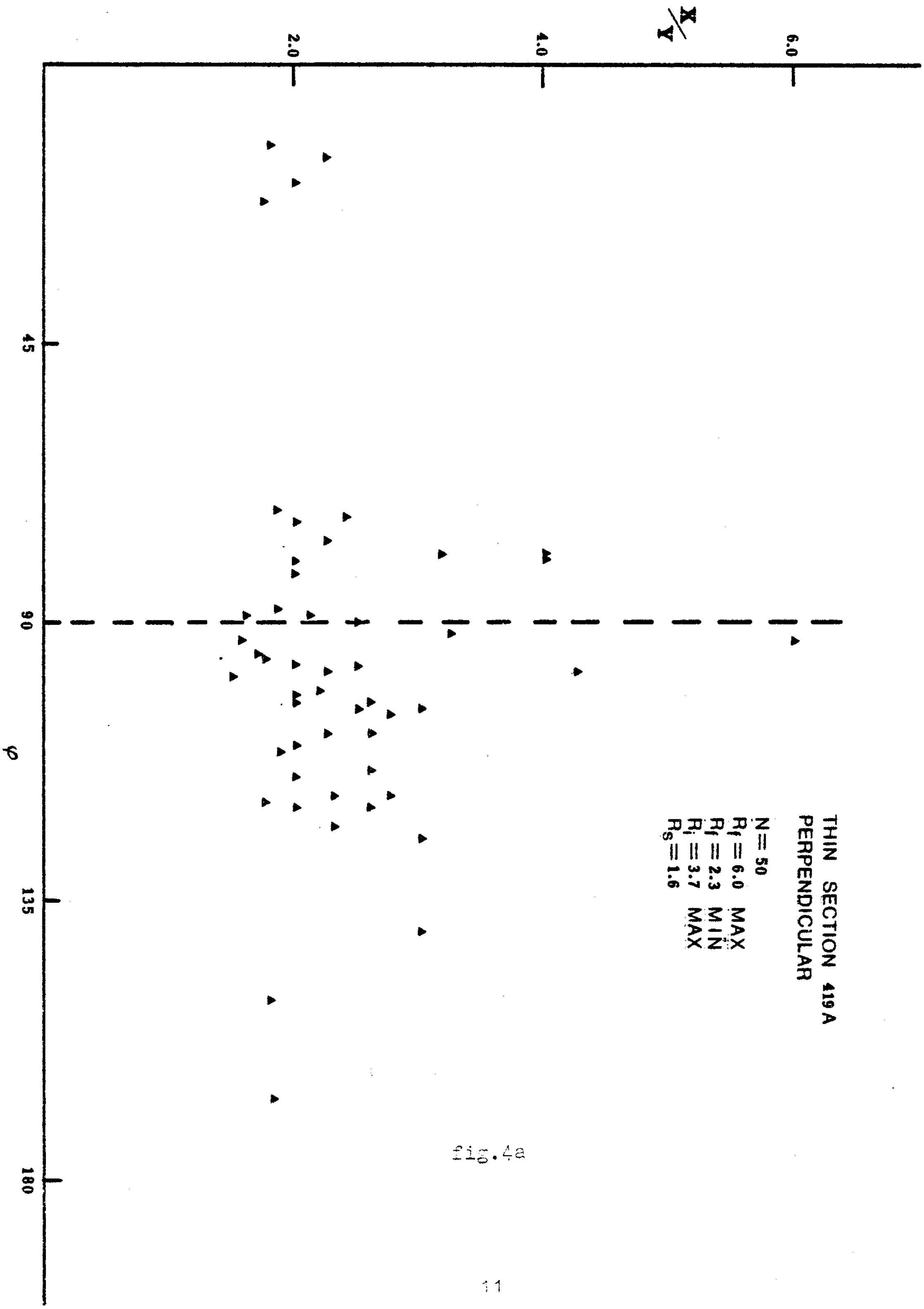

THIN SECTION 419 A
PERPENDICULAR
N= 50
R_f = 6.0 MAX
R_f = 2.3 MIN
R_i = 3.7 MAX
R_s = 1.6
X/Y
6.0
4.0
2.0
45
90
135
180
φ

fig.4a

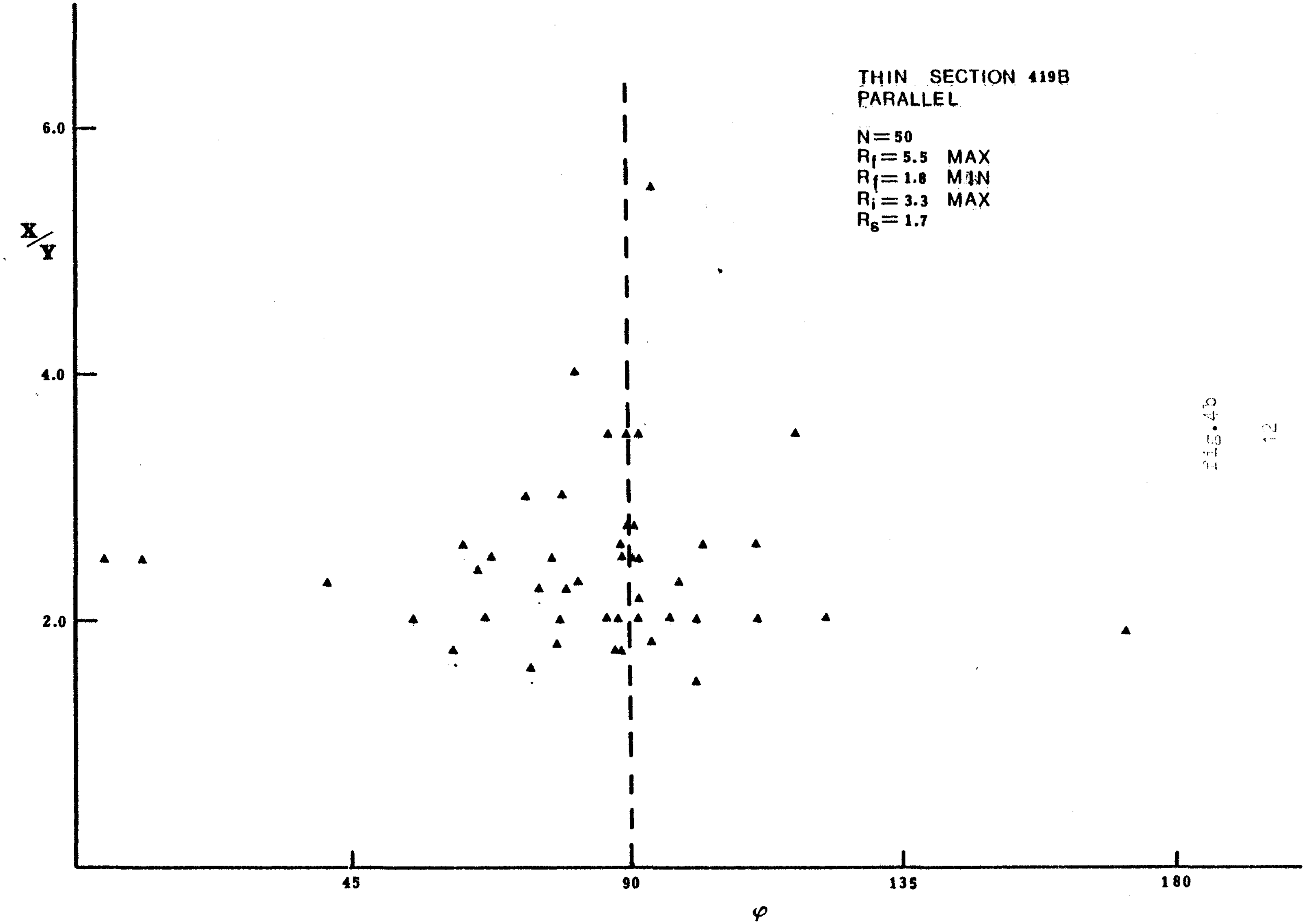

THIN SECTION 419B
PARALLEL
N = 50
Rf = 5.5 MAX
Rf = 1.8 MIN
Ri = 3.3 MAX
Rs = 1.7
X/Y
6.0
4.0
2.0
45
90
135
180
φ

fig.4b

(Ramsay, 1967), as projected into the plane of section, if the feldspar did not initially have a preferred orientation.

The twelve R_f/ϕ graphs produced (two are shown in figs. 4a and 4b) generally show good symmetry about the 90° direction. This indicates the long axis of the strain ellipse in each case lies in, or very close to, the trace of the plane of foliation.

CENTRE TO CENTRE TECHNIQUE

The Fry method is one type of centre to centre technique which can be used to measure strain. This type of study requires that the rock have an initially isotropic distribution of points. In the deformed rock these points are represented here by the centres of large feldspar grains which are surrounded by a finer grained matrix. The Fry test was performed twice on each thin section, covering different areas of the thin section. A description of the method can be found in the appendix.

Measurement of strain is not possible for random distribution in which the object positions are mutually independent. If the object positions deviate from this special case towards either clustering or anticlustering, the strain should be measurable. The more the distribution deviates from independence, the more confidence one can have in the results (Fry, 1979)

Fry (1979) has suggested the following definitions for random and homogeneous distributions.

(i) If the properties of the whole field in which the objects lie contain no information from which the position of any particular object can be specified the distribution in said to be random.

(ii) A distribution is homogeneous if before the position of any particular object becomes known, the expectation that an object exists at a specific point is the same at every point in the field.

The results of the twenty-four tests performed by the Fry method were consistent. An example is illustrated in fig. 5. This simply indicates the distribution of the feldspar grains was originally random. When a random distribution of points is homogeneously deformed, the resulting distribution is also random. In such a case, it is impossible to use the point distribution for strain calculations. However, the initial spatially random distribution of phenocrysts is compatible with the inference that the porphyry was actually a volcanic rock (Clifford, 1986).

The results of the tests by the Fry method were repeated on one thin section by an alternative method, known as the centre to centre method. The results of this test are consistent with those done by the Fry method (fig.6). A periodic arrangement of points on the graph would enable

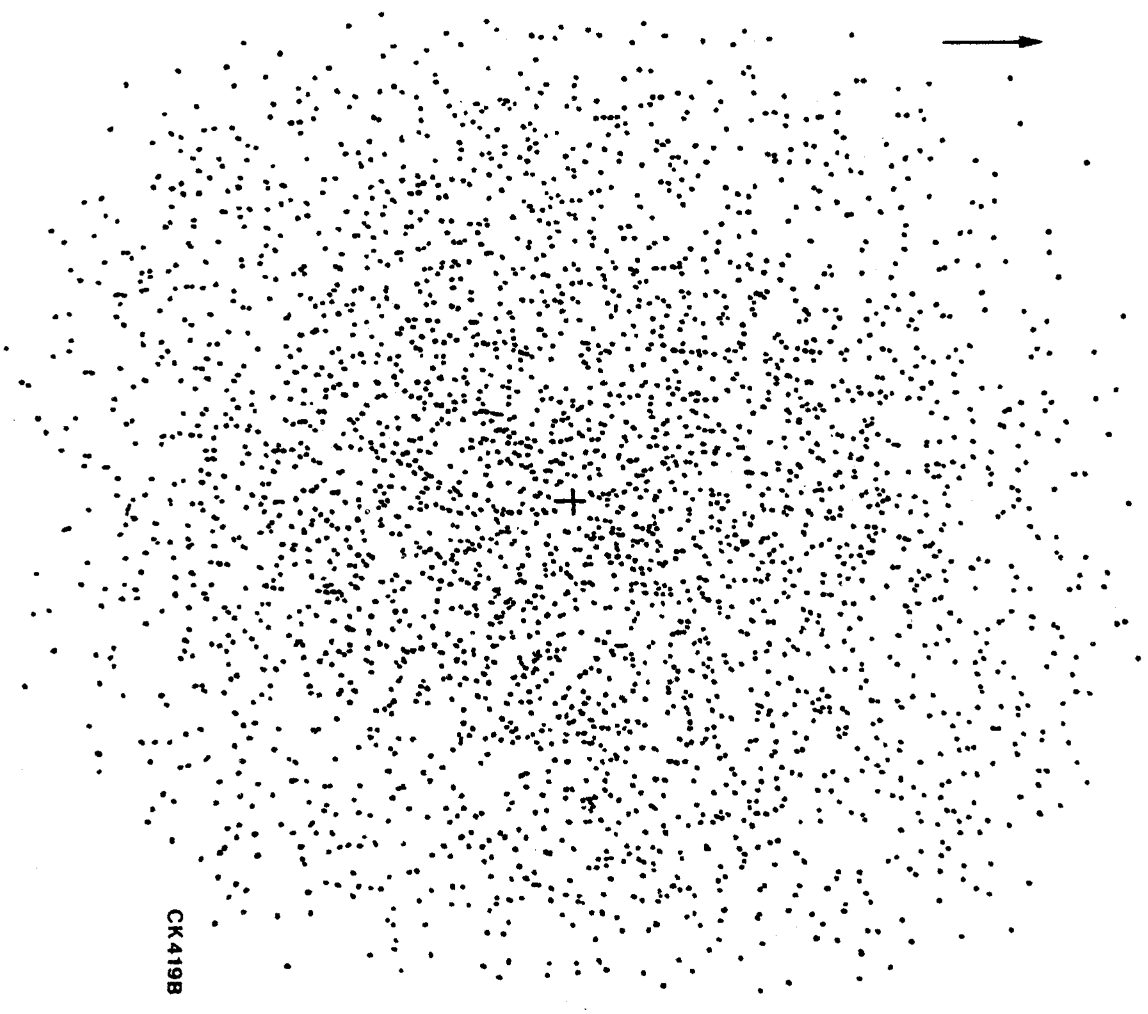
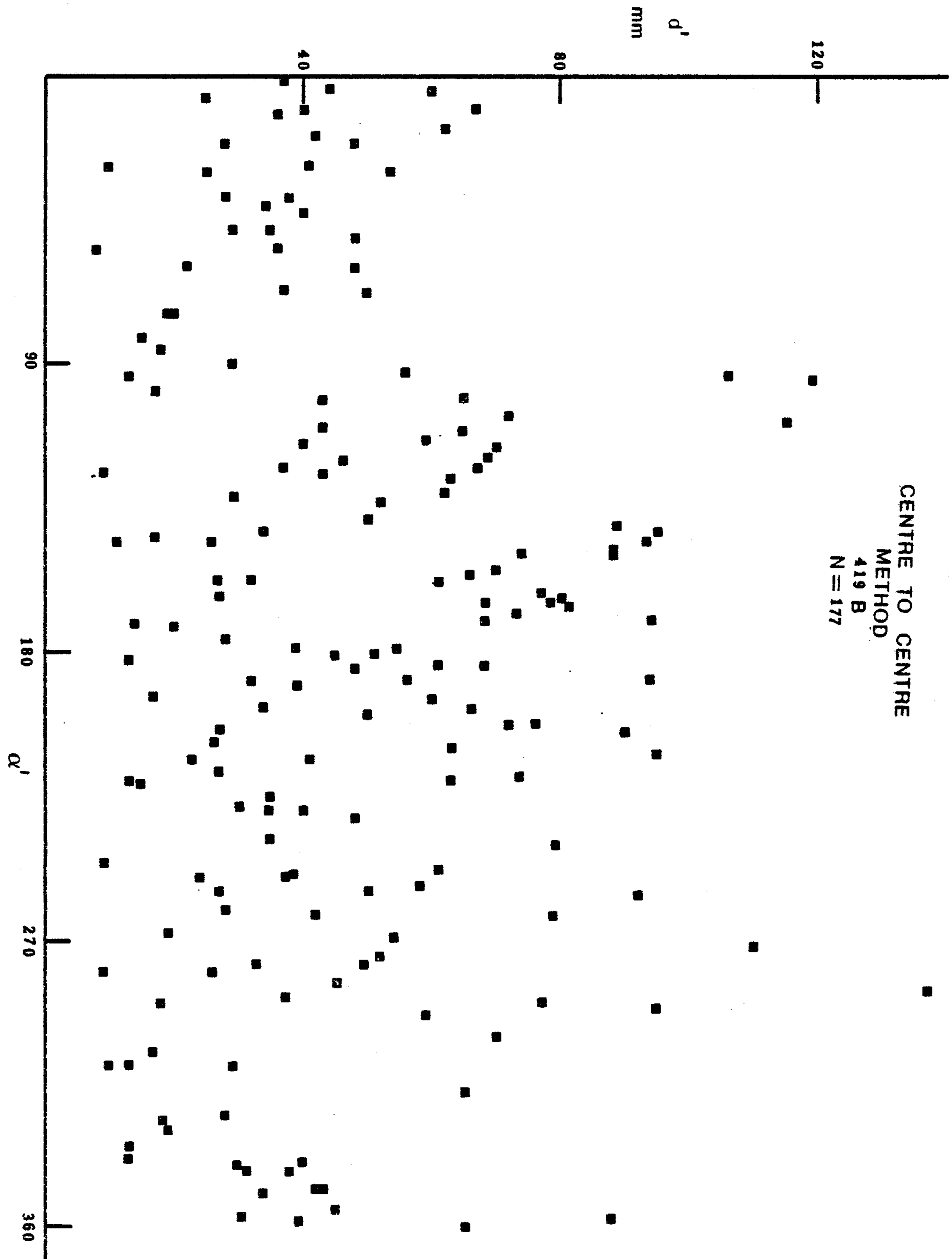


fig.5


CENTRE TO CENTRE
METHOD
419 B
N = 177
d'
mm
40
80
120
α'
90
180
270
360
fig.6

one to determine the orientation of the projection of the strain ellipse in the plane of the thin section. The points on the graph show a random scatter, preventing such a determination.

CHAPTER 4

If it is assumed that when a rock forms it is relatively stable then any substantial change in the conditions surrounding the rock, such as pressure and temperture, will cause the minerals making up the rock to be out of equilibrium. Equilibrium can be restored through changes in the mineral assembleges. This process is called metamorphism.

During metamorphism the minerals in the rock can be altered to new minerals that are more stable in the new enviroment. These new minerals may form in such a way that there physical orientation is also more suited to the enviroment that produced them. Parallel or banded structures form as a result of stress, whereas uniform pressure leads to the production of granular, or non-oriented structures.

KINEMATIC INDICATORS

A kinematic indicator is a structure which indicates the sense of movement of material surrounding a porphyroclast.

Passchier and Simpson (1986) offer a classification scheme based on the symmetry of wings attached to porphyroclasts. These wings are typically formed by material which has recrystallized within a pressure shadow region. Two line drawings (fig. 7) and two photomicrographs (fig.8) illustrate this structure. Parts of a mineral which are under stress show a higher solubility than parts of the same mineral which are relatively stress free. Wings attached to porphyroclasts essentially form by the dissolution of a grain at stressed points, the diffusion of the material to stress free zones and the recrystallization of the material under the new conditions. Of the five pollible geometries presented by Passchier and Simpson only two are present in the thin sections studied. See fig.9.

Fig.9.1: This symmetry indicates movement if material around the grain and rotation of the grain itself, as shown.

Fig.9.2: This symmetry indicates the grain, and the surrounding rock has been squeezed. The direction of the forces are indicated by the arrows. The quantity, quality and geometry of the kinematic indicators varies across the thin sections. The breakdown is shown in fig. 10.

If a thin section is labelled as left or right handed we can relate this motion back to the outcrop. Right handed motion indicates the northwest side is up relative

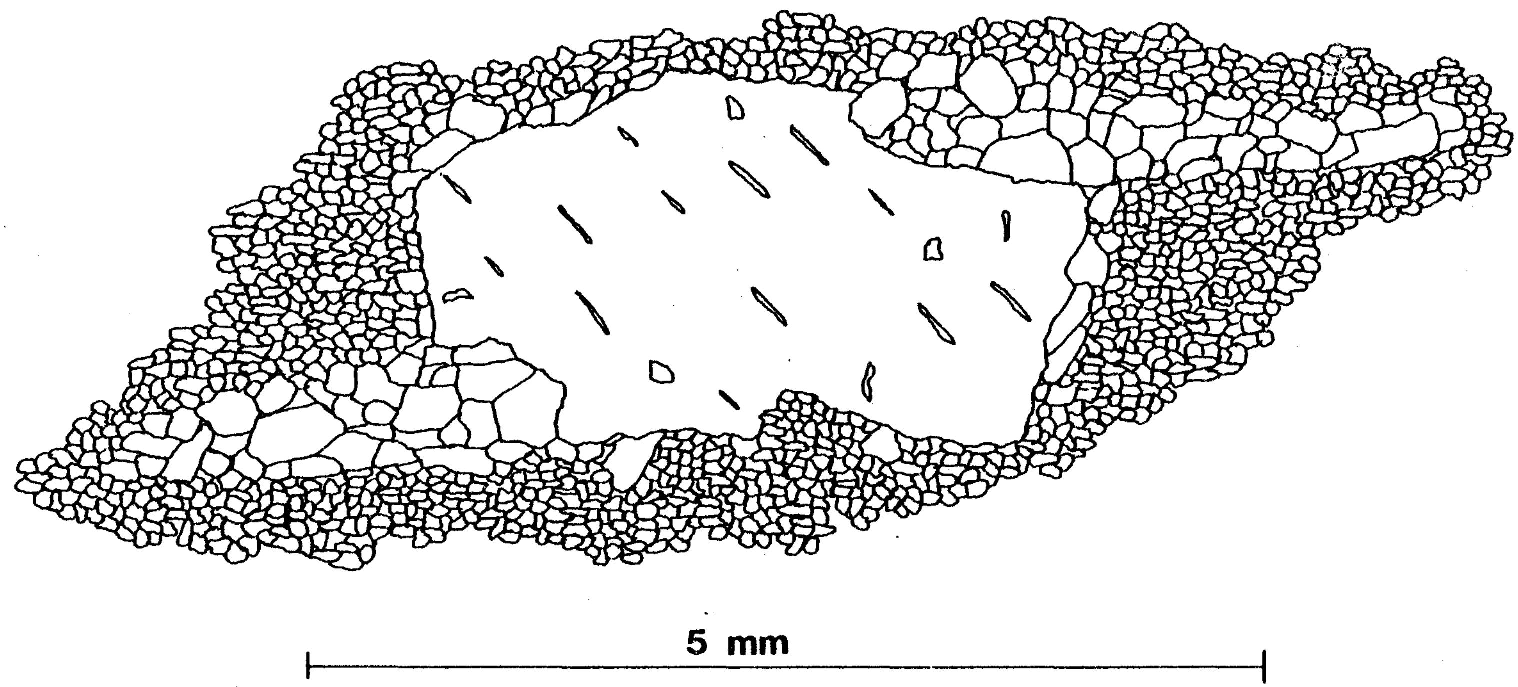
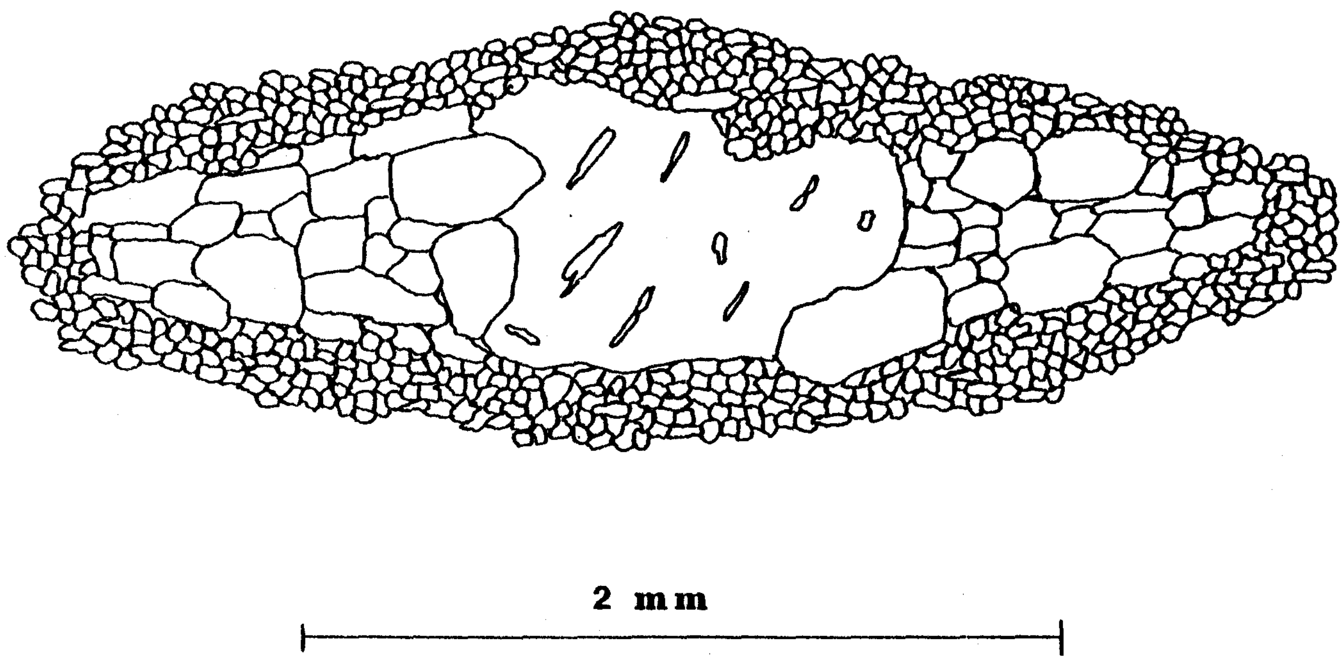


fig.7


2 mm

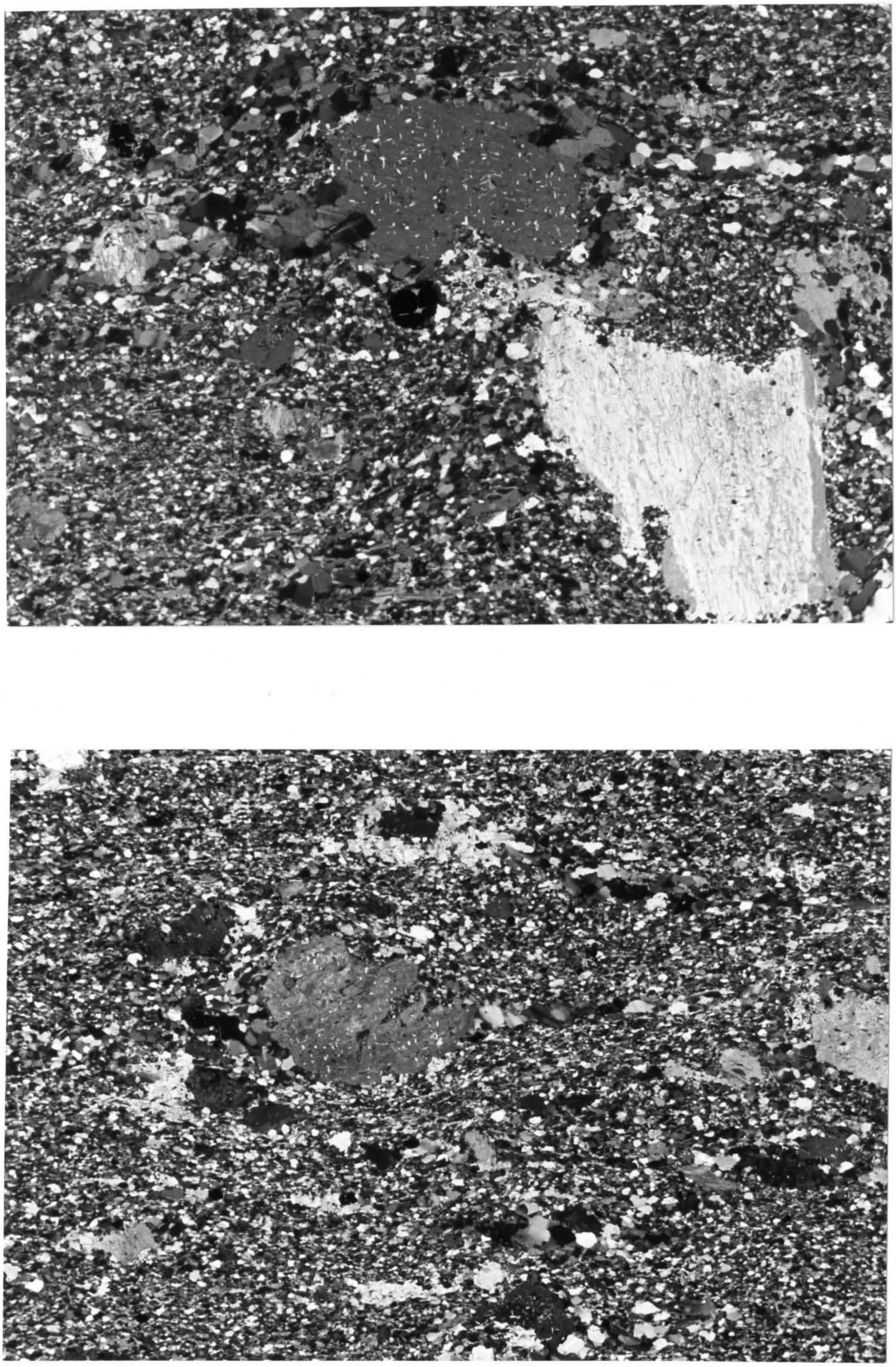


FIG 8

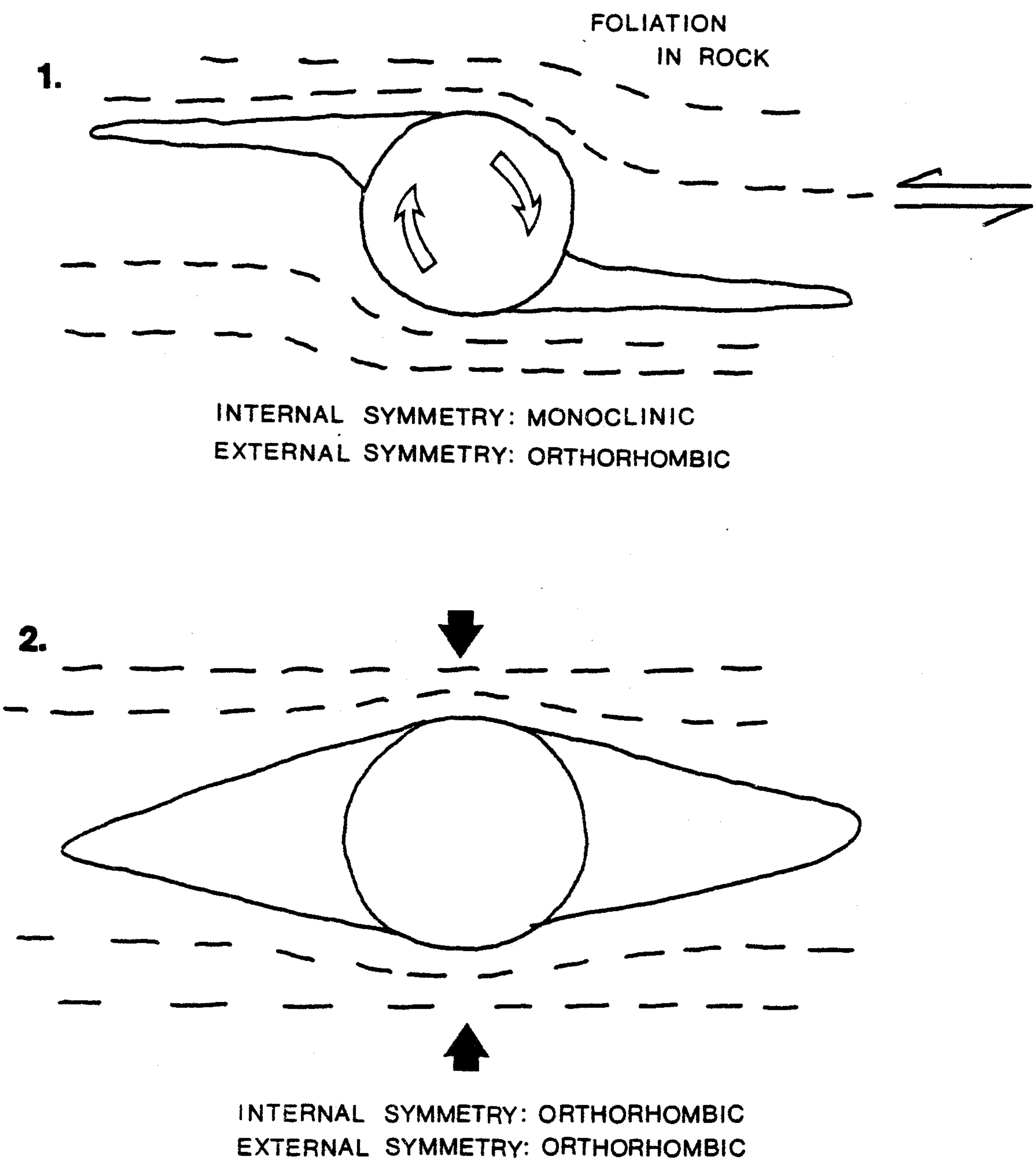

1.
FOLIATION
IN ROCK
INTERNAL SYMMETRY: MONOCLINIC
EXTERNAL SYMMETRY: ORTHORHOMBIC
2.
INTERNAL SYMMETRY: ORTHORHOMBIC
EXTERNAL SYMMETRY: ORTHORHOMBIC

fig. 9

	ASYMMETRIC		SYMMETRIC
SAMPLE	LH	RH	
CK412	0	0	9
CK414	1	4	14
CK416	1	1	21
CK417	1	0	8
CK418	1	1	17
CK419	2	3	18

fig.10

to the southeast side. Left handed motion indicates the northwest side is down relative to the southeast side.

The observations indicate there has been some shearing motions within all the rocks, with the exception of sample CK412. Sample CK412 did not show any asymmetric wings. The observed geometries are not consistent enough to label the movement withina thin section as left or right handed.

DISCUSSION

The centre to centre technique (by the Fry method) and the R_f/ϕ analysis are both tests used to help determine the orientation of the strain ellipse. The results of the analysis indicate the long axis of the strain ellipse lies in, or very close to, the plane of foliation. However, the Fry method did not reveal information concerning the orientation of the strain ellipse. This indicates the initial distribution of points (centres of alkali feldspar phenocrysts) must have been random.

At all sample locations the thin section which was cut parallel to the lineation contains alkali feldspar phenocrysts which have medium grain size wings associated with them. These pressure shadow wings can potentially be used as kinematic indicators. This is true for a situation where all the asymmetric wings suggest the same sense of motion. In a case such as this the sense of movement can be related back to the hand samples and the outcrops. However, within individual thin sections studied both left and right handed systems were recognized. These observations lead to the conclusion that shearing motions have definitely occured within these rocks. However, a single sense of motion cannot be determined.

CONCLUSIONS

The KIC has been divided into four sub-areas, three of which are in the porphyry and the fourth is the mylonite. There is a contrast in the orientation of foliation and attitude of lineation between the porphyry and the mylonite. This contrast indicates two deformational events, that which produced the mylonite being the most recent.

An independent study of positive and negative extensions, in diffusion bands and quartz veins, has been performed in the area. The negative extension direction is perpendicular to the foliation in the porphyry. The positive extension direction is approximately parallel to the lineation in the porphyry. These results suggest the xy plane of the strain ellipsoid is parallel to foliation and the x axis of the strain ellipsoid is approximately parallel to lineation.

The results of the tests for strain by the Fry method and the centre to centre method were negative. This is a result of the fact that the phenocrysts are presently randomly distributed in the rock. This indicates the distribution of phenocrysts was random prior to homogeneous deformation. This conclusion is consistent with the inference that the porphyry was actually a volcanic rock.

Many alkali feldspar phenocrysts had wings of medium grain size material which could be used as kinematic indicators. These wings were only recognized in thin sections cut parallel to lineation. Asymmetric and symmetric geometries were present. The asymmetric geometries can be used to interpret left and right handed shearing motions. Within individual thin sections, left handed, right handed and symmetrical geometries were present. This clearly suggests an active plane of foliation. Yet because both left and right handed indicators exist in a single thin section no conclusions can be drawn regarding relative motions.

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APPENDIX

As described by Ramsay the Fry construction is as follows:

1. On a sheet of paper mark the centres of all particles. Number the points.
2. Take a transparent overlay and mark a central reference point. Place this reference point over one of the central points (1). Trace the positions of all other points (2,3,...etc.) on the overlay.
3. Move the overlay keeping a constant azimuth so that the overlay reference point lies over point (2). Trace the positions of all other points (1,3,4..etc.) on the overlay.
4. Repeat for all other points on the base sheet.