LEIDSE GEOLOGISCHE MEDEDELINGEN, Vol. 43, pp. 1—8, published separately 15-6-1968

THE LAC-CROCHE PLUTONIC COMPLEX, QUEBEC: BASEMENT OF GRENVILLE PARAGNEISSES ? [1]

BY

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ABSTRACT

A concordant body of presumably igneous, but deformed and at least partly recrystallized rocks, the Lac-Croche Plutonic Complex, consists of leuconoritic and mangeritic gneisses, and of monzonitic and granitic rocks. It is surrounded by gneisses, at least partly of sedimentary origin. Inclusions of the surrounding gneisses occur in the Complex.

From the similarity in orientation of lineations in the Complex and surrounding gneisses, and of fold axes further away from the Complex, it is concluded that all rocks were deformed together, at least once. The study of the pre-tectonic history of the rocks is hampered by the strong overprint of regional metamorphism.

From a number of conceivable sequences of events, the two simplest are chosen: either the Complex was part of the basement on which sediments (now paragneisses) were deposited, or the parent magma of the Complex intruded the paragneisses. Most field evidence (mainly structural) fits either sequence, but the absence of folds formed by groups of inclusions, does not fit the basement hypothesis. It is concluded that the Lac-Croche Plutonic Complex is younger than the "Grenville" paragneisses and intrusive into them.

INTRODUCTION

The problem

The purpose of this paper is to give a preliminary account of a part of the geological history of an area bordering the Morin Anorthosite Mass in the Grenville province of the Canadian shield. The study is not directly concerned with the origin of the Morin Anorthosite; in fact, rocks of a strictly anorthositic composition are rare in the area mapped by the author. However, rocks such as norites and mangerites (pyroxene-quartz monzonites), which are commonly associated with Precambrian anorthosite masses, are abundant. It is mainly the sequence of geological events that is of prime importance to the author in view of the disagreement between those who advocate the hypothesis according to which sediments (now "Grenville" paragneisses) were deposited upon an anorthosite-mangerite basement (e.g. Walton and de Waard 1963), and those according to whom the parent magma(s) of the anorthosite-mangerite suite of rocks intruded "Grenville" sediments or gneisses (e.g. Buddington 1939; Philpotts 1966).

Present work and Acknowledgements

The data for this paper were obtained during 15 months of field work carried out by the author for the Quebec Department of Natural Resources (Schrijver 1966*a*,*b*).

The author is grateful to Mr. S. T. Ahmedali, Prof. E. H. Kranck and Mr. F. M. G. Williams, all of the Department of Geological Sciences, McGill University, and the anonymous referees of the Canadian Journal of Earth Sciences for their criticism.

Location and Topography

The Lac-Croche Plutonic Complex comprises an area of about 150 square miles. Its center is 60 miles north-northwest of Montreal and 10 miles northeast of the northeastern border of the Morin Anorthosite Mass. The area is hilly and forest-covered; local relief rarely exceeds 150 m. The average elevation of the ground underlain by the Complex is greater than of that underlain by the surrounding rocks, and it is estimated that about 1 % of the Complex is exposed versus 0.5 % of the surrounding rocks.

GENERAL GEOLOGY

Lithology

The Complex has been subdivided into five units, as shown in Fig. 1. Each of these units is made up of virtually one rock type: leuconoritic gneiss; mangeritic augen gneiss; monzonite; granite; and potash feldspar-quartz gneiss. The basis of the subdivision is mineralogical composition and/or fabric, as visible in outcrops and hand specimens.

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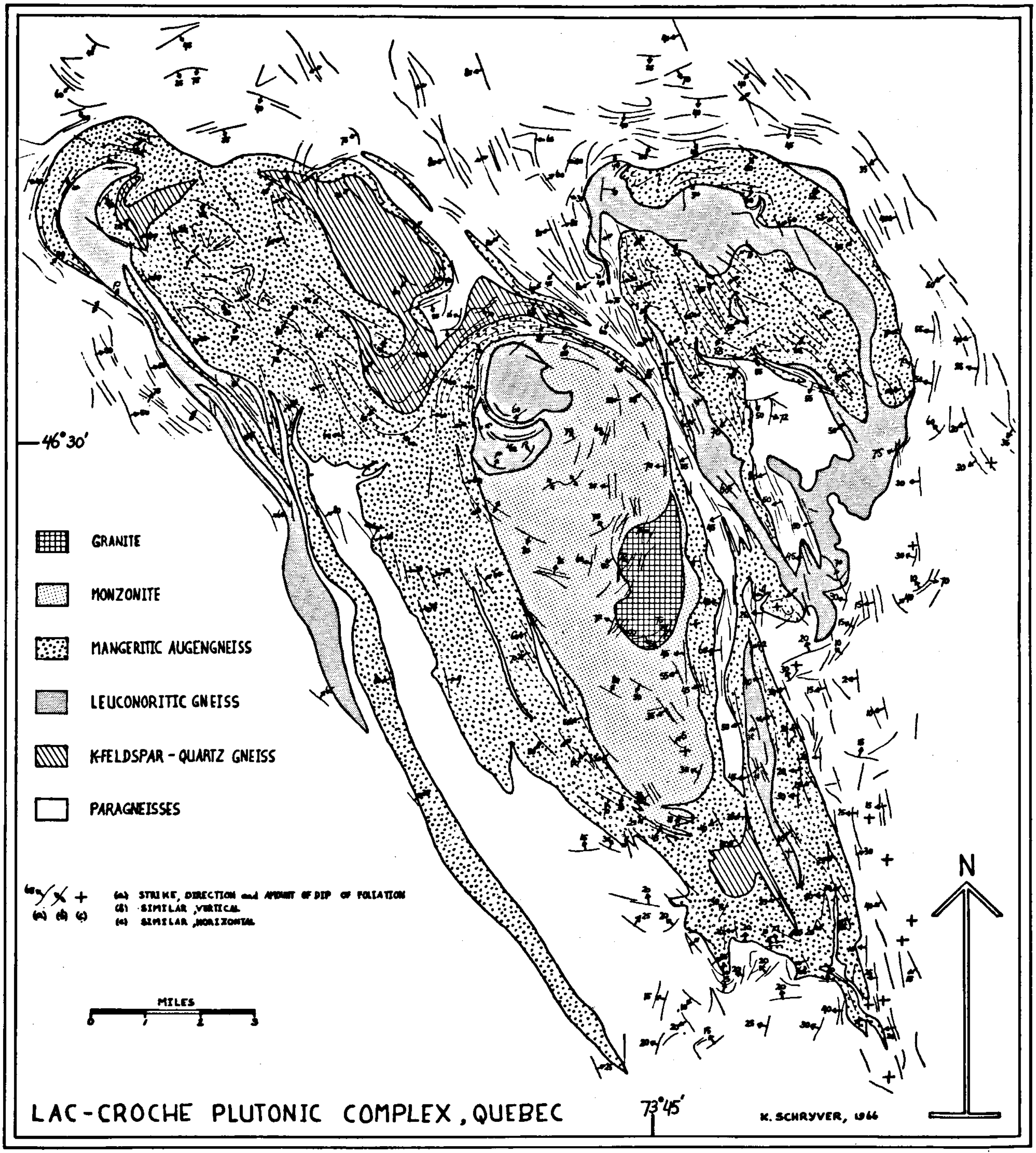

Fig. 1. Geological map of the Lac-Croche Plutonic Complex and surrounding paragneisses.

Evidence of metamorphism is ubiquitous in the Complex, and, therefore, the origin of the rocks is not self-evident. Subophitic textures are preserved locally in the leuconoritic gneiss and indicate the igneous origin of that rock type, and inverted pigeonite in the mangeritic augen gneiss is evidence for its igneous origin. Such direct evidence of origin is lacking for the other rock types. Like the leuconoritic and mangeritic gneisses they are compositionally homogeneous, in contrast to the surrounding rocks, and it is assumed, as a working hypothesis, that the Complex as a whole is of igneous origin.

The rocks surrounding the Complex are commonly layered and heterogeneous in composition. Some are

undoubtedly of sedimentary origin, such as garnet-sillimanite gneisses, quartzites, and crystalline limestones. Others are of unknown origin, such as the common leucocratic pyroxene-amphibole(-biotite) gneisses and pyroxene-amphibolites. It is assumed, as a working hypothesis, that the rocks surrounding the Complex are all of sedimentary origin, and they are referred to in Fig. 1 as paragneisses.
Whatever their origin, practically all rocks in the area bear the unmistakable imprint of regional metamorphism of pyroxene-granulite or hornblende-granulite facies. All rocks are foliated and lineated, with the exception of some exposures of monzonite and granite in the central part of the Complex. By far the most common types of foliation and lineation are preferred form-orientations of mineral grains (esp. quartz and feldspar megacrysts) and small granular aggregates (esp. feldspar plus quartz and mafic minerals plus quartz). This foliation is the only type of foliation commonly observed in the rocks of the Complex. In the surrounding gneisses, however, both layering and the above-mentioned foliation are present.

The most abundant rock type of the Complex is mangeritic augen gneis and, as such, merits a separate description. It consists of feldspar, quartz, pyroxene, amphibole and iron (-titanium) oxide; garnet and biotite are rare. The weathered surface is whitish to light buff; the fresh surface is greyish green, *Feldspar* (plagioclase and perthite in roughly equal amounts) occurs in grains ranging in size from a fraction of a millimeter to 5 cm. The larger grains are subhedral crystals, the finer ones are, at least in part, still recognizable as products of granulation and recrystallization of larger crystals and they commonly form lenticular aggregates (see Fig. 2). Well-preserved stubby prismatic to ellipsoidal feldspar megacrysts make up 10 to 60 % of the rock. Thin, white-weathering fine-grained rims and zoning can be observed in some of the feldspar megacrysts on glacially polished outcrops. *Quartz* occurs as anhedral grains, up to 3 mm in diameter; it makes up 5 to 20 % of the rock. The other minerals have a grain size similar to that of quartz. *Pyroxene* (ortho- and clino-pyroxene in roughly equal amounts), or less commonly *hornblende* are the dominant mafic minerals and account for 5 to 10 % of the rock. *Magnetite* is invariably present and makes up approximately 3 % of the rock. Pyroxene, amphibole, magnetite and most of the quartz occur together in thin discontinuous well-oriented aggregates curving around the feldspar megacrysts (see Fig. 2).

The main difference between mangeritic augen gneiss and monzonite is in fabric, as implied by their names. The monzonite commonly is a hypidiomorphic granular rock, without feldspar megacrysts and without lineation. Differences in mineralogical composition also exist; the monzonite contains little or no quartz, and the dominant or only mafic mineral is hornblende.

Contacts and Contact Relations

Topographic contours are generally parallel to the

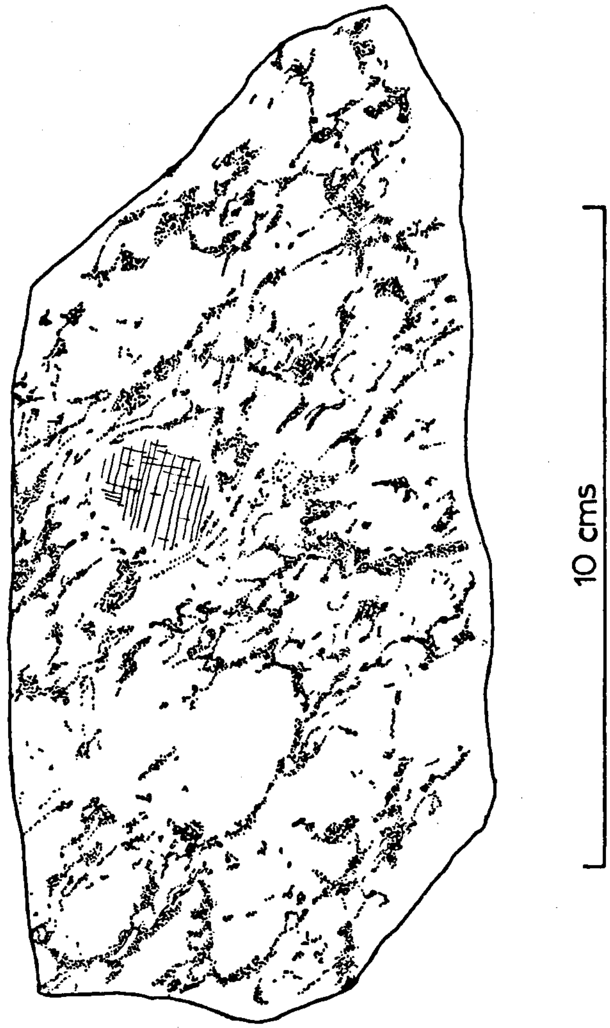

Fig. 2. Sketch of polished and stained slab of mangeritic augen gneiss, cut at right angles to the lineation. The dotted pattern represents aggregates of quartz, pyroxene and magnetite; the blank spaces are occupied by intergrowths of potash feldspar and plagioclase; the latter commonly is concentrated in the rim of the intergrowths. The largest single crystal of potash feldspar is indicated by its cleavage traces.

boundaries of the lithological units, in particular to the boundaries of the Complex with the surrounding rocks. Most of the contact between the Complex and the surrounding rocks lies in topographic depressions and is covered by thick overburden. At the few places where the contact has been observed, it is parallel to the foliation in the rocks on either side of the contact. Also, wherever the contact could be drawn accurately, owing to an abundance of outcrops straddling the contact zone, the foliation is parallel to the contact, at least in strike. This parallelism seems to hold even for major curves in the contact, and, as such, has been used to draw contacts where outcrops are not abundant. Parallelism of contacts and foliation also holds commonly within the Complex, and consequently

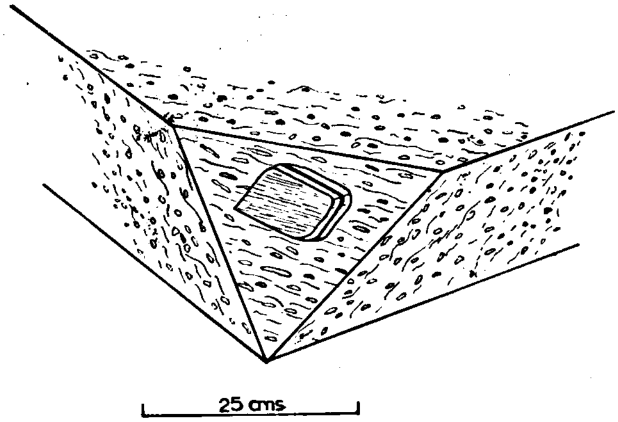

Fig. 3. Schematic diagram of laminated quartzite inclusion in mangeritic augen gneiss. Note parallelism of (*a*) foliation in augen gneiss, (*b*) planes of contact of inclusion and augen gneiss, and (*c*) lamination in inclusion.

Fig. 1 is a picture of a nearly concordant sequence of rocks.

Very small parts of a few contacts between the major lithological units have been observed. If these observations are considered representative, then:

(a) The contact between the Complex and the surrounding paragneisses is sharp, except in the southeastern tongue, where augen gneisses are so rich in quartz and garnet, locally, that they are indistinguishable from the leucocratic paragneisses. In general, neither the rocks of the Complex nor the surrounding gneisses change noticeably towards the contact, either in structure or in composition.

(b) The contacts between the rocks of the Complex are gradational in texture as well as in mineralogical composition, but the zones of gradation are too small to be shown on Fig. 1, their widths ranging from 1 to 100 m.

Inclusions

Mangeritic augen gneiss is the only rock type of the Complex in which inclusions of foreign bodies are not rare. Most abundant are inclusions of quartzite. Their distribution is erratic, some outcrops containing numerous small inclusions and others containing few or none. The most common inclusions range in size from 10 × 5 × 1 cm to 100 × 70 × 10 cm, and have the shape of roughly rectangular slabs with subrounded corners. The largest faces of the slabs are parallel to the layering in the inclusions as well as to the foliation in the augen gneiss (Figs. 3 and 4). The contacts are sharp, and quartz-enrichment of augen gneiss near the inclusions has rarely been observed. The behavior of the foliation around the inclusions is not well known, owing to the very coarse preferred orientation in the augen gneiss. It does seem, however, that the foliation curves gently around the inclusions. In any case, the foliation in the augen gneiss rarely abuts against the contact between augen gneiss and inclusion. The inclusions are strongly lineated, a good form-orientation of individual grains and a strong corrugation being present in the inclusions, as well as on the planes of contact with the augen gneiss.

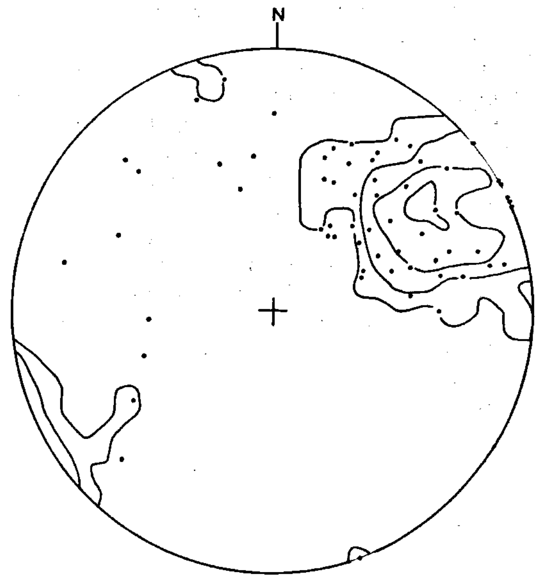

Fig. 4. Equal-area projection of 75 poles to foliation planes in augen gneiss (contours) and of 63 poles to laminae in inclusions (dots), from northeastern part of Complex. Contours 12-8-4-1.3 % per 1 %-area.
In this and the following equal-area projections, the lower hemisphere is used.

Structure and Structural Relations

In the rocks outside the Complex large structures could not be outlined owing to the absence of marker horizons and the discontinuity of exposures. Thus, knowledge of the structure of these rocks is based on the analysis of mesoscopic fabric elements only (foliation, lineation and minor folds).

Both layering (S_1) and the "common" foliation described on page 3 (S_2) are present in the paragneisses. These two fabric elements are commonly parallel, but where the layers are folded, S_2 cuts across the hinges of recumbent, isoclinal folds and is parallel to the axial planes. Near the contact with the Complex, folds in S_1 and non-parallelism of S_1 and S_2 are too rare to determine whether the contact is parallel to S_1 or S_2. Minor recumbent, isoclinal folds are common east and northeast of the area shown in Fig. 1, and the distribution of the orientations of their fold axes is shown by the contours in Fig. 5. The distribution of 1000 lineations from that same area is similar to that of the fold axes, occupying the same girdle with a similar maximum, in equal-area projection.

The area southwest of the Complex has not been mapped by the author, and the style of folding there is not known.

In the Complex itself, "marker horizons" are present; in fact any one of the lithological units can be walked out and mapped with considerable accuracy. The diffi-

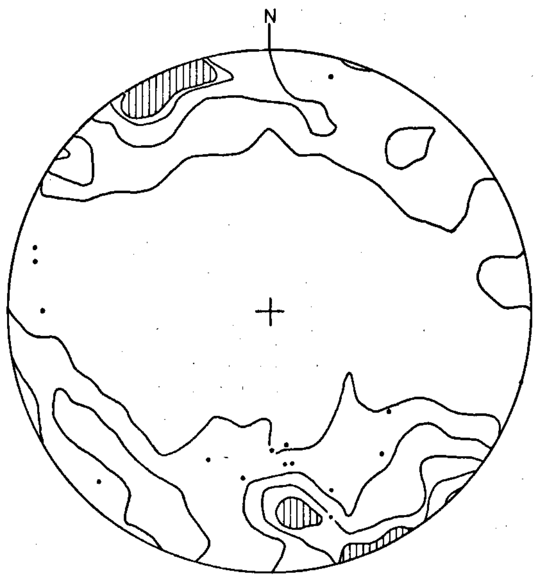

Fig. 5. Equal-area projection of 202 fold axes of minor recumbent folds from an area of paragneisses east and north-east of Complex (contours), and of 16 fold axes of minor folds in inclusions in Complex (dots). Contours 5-4-2-0.5 % per 1 %-area.

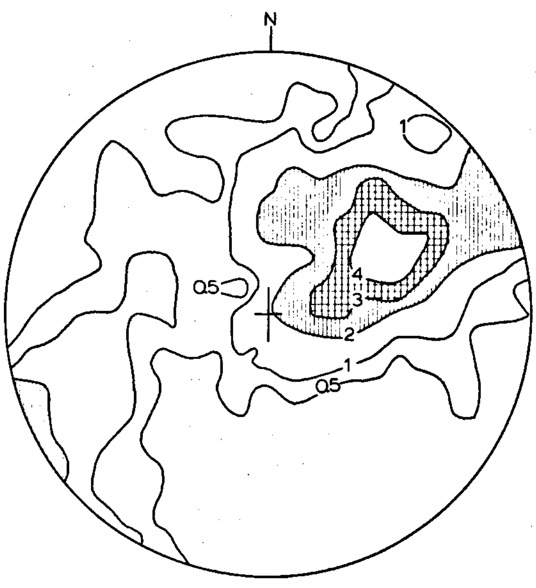

Fig. 6. Equal-area projection of poles to 1011 foliation planes in Complex and 1-mile aureole adjacent to Complex. Contours 4-3-2-1-0.5 % per 1 %-area.

culty in establishing the three-dimensional shape of the Complex mainly lies in the fact that one cannot assume that the units were ever bounded by planar surfaces. Thus, also in the Complex, knowledge of the structure of the rocks is based mainly on the analysis of mesoscopic fabric elements.

The foliation planes represented in Fig. 1, and projected and contoured in Fig. 6, do not form an

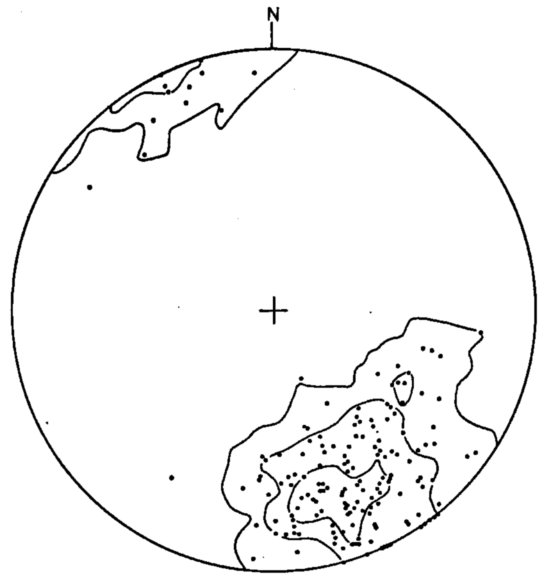

Fig. 7. Equal-area projection of 163 lineations in Complex. Contours 8-4-0.6 % per 1 %-area.

Fig. 8. Equal-area projection of 102 lineations in/on inclusions in Complex. Contours 8-4-1 % per 1 %-area.

unambiguous girdle, especially in view of the low density values of the contours.

The mangeritic augen gneiss is the only rock type of the Complex in which folds have been observed, and even in such rocks they are very rare. One exceptionally good exposure shows the foliation (feldspar-megacryst alignment) in the augen gneiss and a dark fine-grained dike folded together into a recumbent fold.

An interesting comparison can be made between the

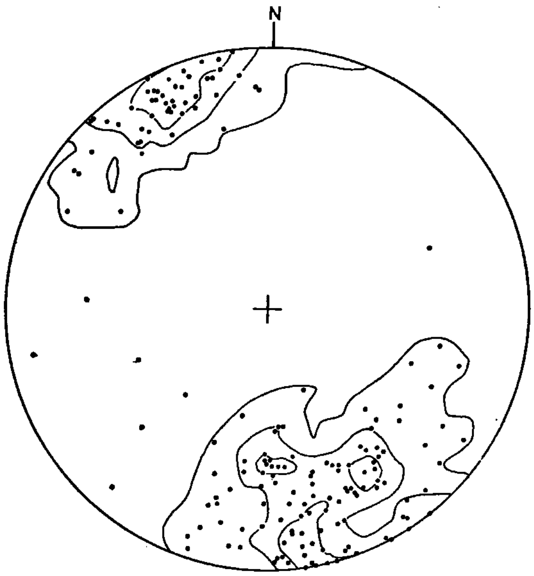

Fig. 9. Equal-area projection of 166 lineations in 1-mile aureole adjacent to Complex. Contours 6-3-0.6 % per 1 %-area.

distribution of orientations of lineations (*a*) in the rocks of the Complex, (*b*) in the inclusions enclosed in the Complex, and (*c*) in a 1-mile aureole around the Complex. From the contoured diagrams (Figs. 7, 8, and 9) it can be seen that the average orientations are roughly similar, the small discrepancies probably being due to differences in areal distribution of measurement locations.

Folds in inclusions are rare, although it is possible that some very tight isoclinal folds have been overlooked. Both isoclinal folds and rather open folds (apex angle up to 120°) are present. Most inclusions are bounded by their folded laminae, and the fold axes are sub-parallel to the lineation in the surrounding augen gneiss (compare Figs. 5 and 7); axial-plane foliation is absent. Very few inclusions have been observed in which laminae abut abruptly against the contact of inclusion and augen gneiss.
It should be noted that the above descriptions of folds in inclusions only treat of folds in individual inclusions. Groups of inclusions have not been observed to form folds, although large (e.g. 100 × 200 m) bare rock surfaces are present in some of the inclusion-rich parts of the augen gneiss.

HISTORICAL GEOLOGY

Age of Deformation

From the similarity in orientations of fold axes and lineations (Figs. 5, 7, 8 and 9), it is clear that virtually all rocks in the area were already present during the formation of recumbent folds in the paragneisses. In other words, the best preserved ("main") phase of deformation has affected all rocks, those of the Complex as well as the surrounding gneisses.

Formulation of Hypotheses

Before any hypothesis concerning the relative ages of formation of the Lac-Croche Plutonic Complex and surrounding gneisses can be formulated with some degree of exactness, the following points should be noted:
(1) The Complex is considered an entity with a single geological history for the following reasons: the occasional lineation in the monzonite and granite is sub-parallel to the lineation in the surrounding rocks, and there is no evidence for a later deformation co-axial with the main phase of deformation. This point is of considerable importance as it excludes from consideration a sequence of events such as: (*a*) formation of the norite-mangerite suite, (*b*) deposition of sediments on a basement consisting of this suite of rocks, and (*c*) emplacement of the monzonite-granite suite.
(2) Similarly, the paragneisses are considered an entity, comprising the gneisses surrounding the Complex as well as the inclusions in the Complex. Thus, excluded from consideration is a sequence of events such as (*a*) deposition of the first generation of sediments (on an unknown basement), (*b*) intrusion of the parent magma of the Complex into those sediments, enclosing fragments of them, and (*c*) deposition of the second generation of sediments on a basement then composed of the Complex and the first generation of sediments. One piece of evidence that makes such a sequence tenable, is the fact that the most abundant inclusions in the Complex are quartzitic, even though quartzite is not the most abundant rock type in the surrounding gneisses. But it is extremely difficult to establish the presence of inclusions of leucocratic pyroxene-amphibole gneisses, as they are very similar in habit to the finer-grained parts of the mangeritic augen gneiss. In the opinion of the author, the apparent abundance of inclusions of quartzite is partly due to the ease with which they can be recognized, and partly to the refractory nature of that rock type. Thus, if it is concluded that the inclusions in the Complex are, in fact, xenoliths, then it is implied that the parent magma of the Complex is intrusive into the gneisses that now surround the Complex.

We can now envisage two hypotheses concerning the sequence of events:

(1) The Complex is part of a basement, which has been deformed together with its cover (the surrounding gneisses and the inclusions): the "basement-hypothesis".

(2) The Complex is deformed together with the rocks it intruded (the surrounding gneisses and the inclusions): the "alternative hypothesis".

Discussion and Conclusion

The absence of any obvious indication of magmatic intrusion of the Complex into the paragneisses could be interpreted as an argument against the "alternative hypothesis". This argument would be valid if it had been established that the Complex was originally a shallow intrusion. Philpotts (1966) has shown, in a petrological study of a similar complex, that differentiation of a postulated parent magma must have taken place under high temperatures and pressures. In such an environment it is not uncommon that chilled and discordant contacts, as well as other obvious indications of magmatic intrusion are absent. Therefore, the author does not consider this absence to be evidence for or against either hypothesis.

The fact that the contacts between the lithological units within the Complex are generally parallel to the outer boundary of the Complex can be explained by co-folding of contacts and boundary. Presumably, this must have happened at least once, during the main phase of deformation. The strong overprint of that phase obscures the previous history of the rocks. Even if it could be established (which the author doubts because of the small size of most outcrops), that the enveloping surfaces of S_1 (bedding?) in the surrounding gneisses are parallel to the outer boundary of the Complex, it would not make the choice between the two hypotheses much easier. Each structural pattern of the surrounding gneisses can be matched with a similar one in the Complex. It is clear that information other than field data from the present scale of mapping ($\frac{1}{2}$ mile to the inch) is needed about the pre-main-phase history, and the author opines that detailed mapping and micro-fabric analysis will reveal differences in structural patterns (e.g. between augen gneiss and impure quartzite), which might be interpreted as differences in tectonic history.

It is the absence of folds formed by groups of inclusions that does not fit the "basement hypothesis". If that hypothesis should hold, then the inclusions could only be interpreted as remnants of a sedimentary cover co-folded with the basement, and one would expect that at least some groups of inclusions would still line up in fold shapes. Instead, folds have only been observed in single inclusions, although a diligent search was made for such groups.

Therefore, the "basement hypothesis" is tentatively rejected, although most data would fit either sequence of events. Under the limitations noted under points 1 and 2 on page 6, the author concludes that the Lac-Croche Plutonic Complex is younger than the paragneisses and intrusive into them.

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