THE GEOLOGY OF THE MOUNT BREAKENRIDGE AREA, HARRISON LAKE, B.C.

by

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We accept this thesis as conforming to
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ABSTRACT.

The metamorphic rocks of the Breakenridge and Cairn Needle Formations are correlated with the Upper Paleozoic and Mesozoic (Jurassic) strata respectively. Those of the Chilliwack Group - Peninsula Formation range in age from Upper Paleozoic to Lower Cretaceous. A gneissic granodiorite on Mount Breakenridge is cored by a younger (Early Tertiary) porphyritic quartz diorite. The Scuzzy granodiorite (Upper Cretaceous) is the main plutonic rock of the area.

Between the Jurassic and Mid-Cretaceous the formations were folded into northwest trending antiforms and synforms. Three phases of folding are recognised. Major faults were produced in Mid-Cretaceous time.

Contemporaneous with the folding the rocks were migmatized and regionally metamorphosed to form a kyanite-sillimanite facies series in which the metamorphic grade increases rapidly from South to North. The mineral assemblages in pelitic gneisses are considered to have approached equilibrium. The bulk composition of these gneisses may not only have controlled the presence of staurolite but also, through the opaque minerals present, the fs_2, fo_2 of the coexisting fluid phase. Extreme gradients in fluid phase composition ($X\ co_2$) are demonstrated to have existed during the metamorphism of closely associated calc -

silicate and dolomitic limestone. An episode of contact metamorphism, which produced andalusite and sillimanite bearing schists was associated with the emplacement of the Scuzzy Pluton. (U. Cretaceous).

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INTRODUCTION.

The geology of the Mount Breakenridge region, Harrison Lake, B.C., was completed on a reconnaissance scale in the summer of 1968. (Roddick and Hutchison, 1969). It is a mountainous region situated between latitudes 49°35' and 49°50' and longitudes 121°45' and 122°00'. (N.T.S. 92H/12W and 92H/13W). Logging roads on the east side of Harrison Lake and the Riv-Tow Marine ferry, make the area readily accessible.

The present study, which involved field mapping at the scale of 1:2500 in the summer of 1970, was designed to expand on the work of Roddick and Hutchison and relate the metamorphism, structure and plutonism of the area to the geological history of the Southern Coast Mountains.

PREVIOUS WORK.

Roddick and Hutchison (1969), described the broad structural, metamorphic and plutonic character of the area. Santer (1969) studied the petrology of the pelitic gneisses north of Mount Breakenridge. The metamorphic rocks of the Stokke Creek pendant, immediately to the west of the area, were described by Roddick (1965).

MAJOR LITHOLOGIC UNITS.

The major rock types are listed in Table 1, and their distribution is shown in the sketch map of Figure 1.

No fossils have been found in the rocks and sedimentary "way-up" structures are lacking. It has therefore been tentatively assumed that structurally deeper horizons are older. Thus the units listed in Table 1 are lithologic, tectonic units, not stratigraphic units. Attempts to correlate these rocks with others in surrounding areas are consistant with this general view of the structure, but the present data are inadequate for proof.

TABLE 1: MAJOR LITHOLOGIC UNITS

AGE AND EQUIVALENT	METAMORPHIC ROCKS	IGNEOUS ROCKS	TECTONISM, METAMORPHISM
L. Tertiary		Andesite dykes. Porphyritic qtz diorite of Mt. Breakenridge	continued uplift
U. Cretaceous		Scuzzy Pluton	Contact metamorphism
M. Cretaceous		Dunite, Peridotite	Faulting and retrograde metamorphism
L. Cretaceous	Peninsula Fm.		
U. Paleozoic	Chilliwack Gp.	Gneissic granodiorite on Mt. Breakenridge	
			Folding and Deep seated regional metamorphism
Jurassic	Cairn Needle Fm. conglomerate		Uplift
U. Paleozoic (Custer and Skagit gneiss)	Breakenridge Fm.		

Figure 1

Geological sketch map of Mt. Breakenridge area.

LEGEND

IGNEOUS ROCKS

Quartz andesine porphyry and
quartz diorite.

Scuzzy granodiorite-quartz diorite

Mt. Breakenridge gneissic granodiorite
quartz diorite

Dunite

METAMORPHIC ROCKS

Chilliwack Group - Peninsula Formation

calc - silicate
pelitic schist, grit and conglomerate.

Cairn Needle Formation

conglomerate
pelitic schist, calc - silicate, gt. hb. sch.
limestone
meta - igneous granulite.

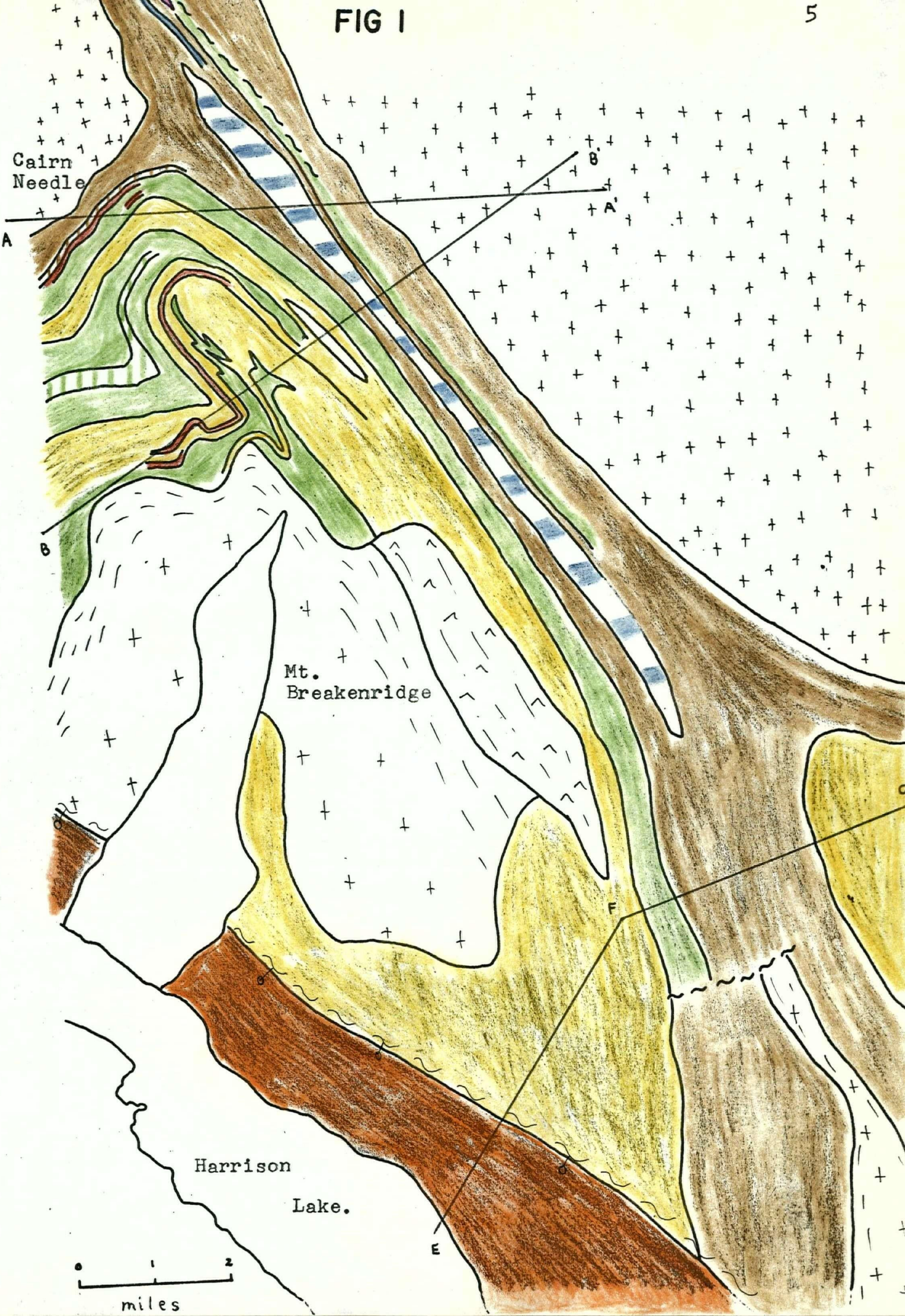
Breakenridge Formation

grey gneiss
amphibolite
striped amphibolite
pelitic gneiss

Fault

N.B. See fold out in back cover for localities
cited in the text.

FIG I



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B
B'
Mt.
Breakenridge
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E
C
Harrison
Lake.
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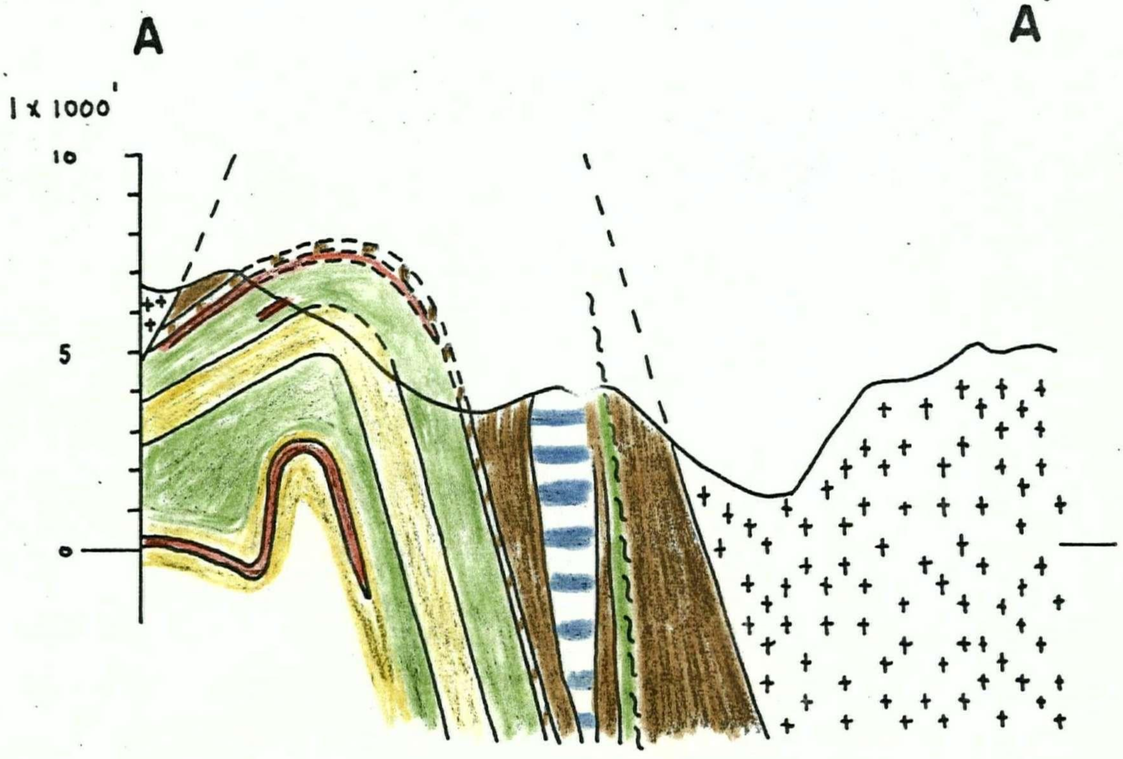
CROSS SECTIONS .

A - A'

B - B'

E - F - G

For Legend see **Figure 1**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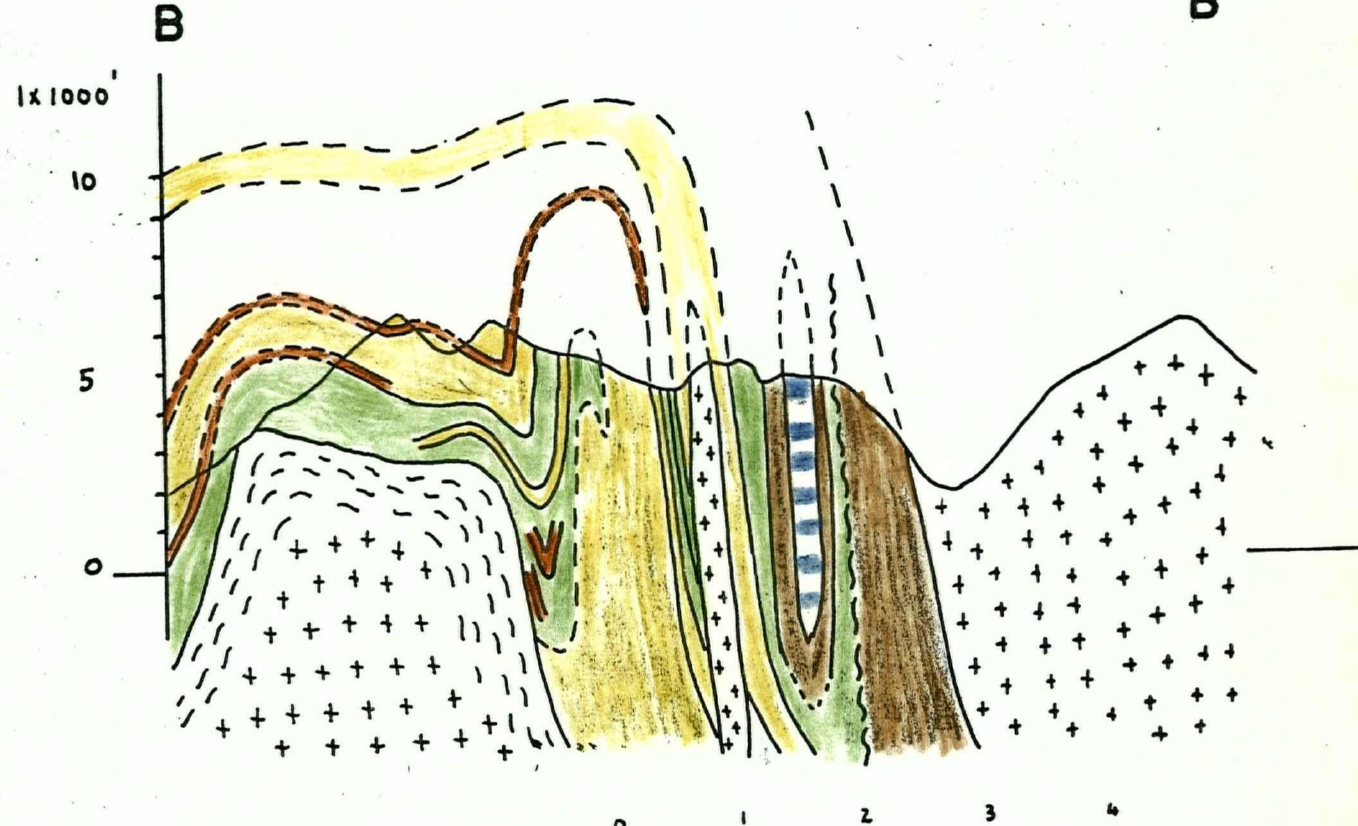
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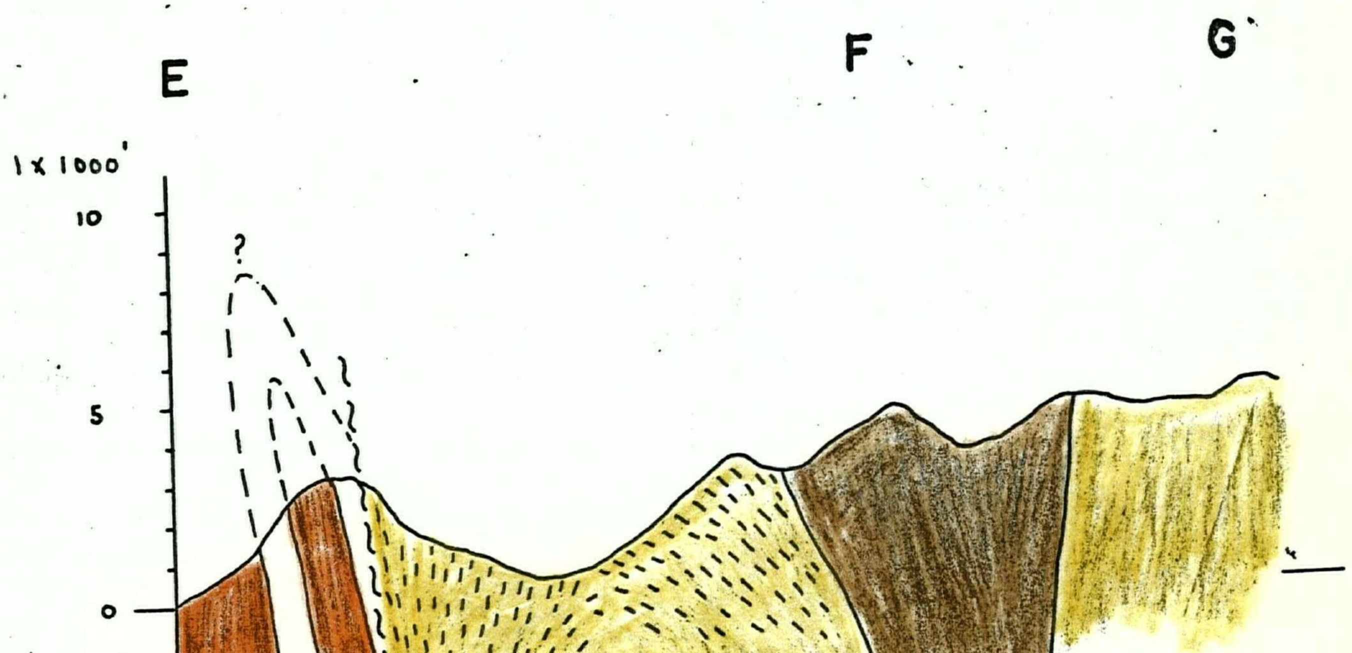
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BREAKENRIDGE FORMATION.

The Breakenridge Formation consists of the following rock types, listed in order of greatest abundance.

i) Homogeneous grey gneiss.

ii) Amphibolite.

iii) Pelitic gneiss.

iv) Migmatite.

v) Minor skarn.

The areal distribution of these unite is shown in Figure 1. The formation is considered to be a mixture of metavolcanic and metasedimentary strata. Amphibolites are presumably metavolcanic, while grey gneiss, which in its homogeneous or inclusion rich form is decidedly igneous in aspect, may be the metamorphic equivalent of graywacke. The lithological persistance of bands of grey gneiss, which can be traced for several miles, coupled with the association of migmatites, (which are possibly partially derived from mixtures of volcanics and graywacke), with the obvious metasedimentary units are strong arguments in favour of a metasedimentary origin for the migmatites. Kalsbeek (1970), on the basis of detailed chemical and petrographic data, considers a similar migmatitic terrane in South - West Greenland to be the result of metamorphism of mixtures of graywacke and basic volcanic rocks.

DESCRIPTION AND PETROGRAPHY.

1) Grey Gneiss:-

Most of the Breakenridge formation is homogeneous grey granodioritic gneiss. Migmatites are commonly developed in zones between grey gneiss and amphibolite units. Within the gneiss-migmatite transition zone the gneiss contains many mafic inclusions which impart an igneous "xenolothic" aspect to the unit.
Plate 1 is typical of much of the gneiss.

MINERALOGY.

The mineralogy and approximate modes of the gneisses studied are shown in Table 2. The modes were estimated by eye. The anorthite content of the plagioclase is shown in brackets. They are medium grained allotriomorphic granular biotite - quartz - plagioclase gneisses, with or without muscovite, garnet and microcline. The composition of the plagioclase (determined on flat stage by the ⊥'r a method)* varies from specimen to specimen. It ranges from An 10-34. Zoning is absent. Myrmekite commonly develops at the boundary between intergranular microcline and albitic plagioclase.

A pronounced foliation or lineation defined by biotite or lensoid augen of quartz and feldspar is characteristic of the gneiss. Deformation lamellae and strain extinction in quartz, kink bands in biotite, and granular blastic polygonization of quartz and feldspar are features common to all.

* extinction angle measured in sections cut perpendicular to 'a' .

11) Amphibolites:-

Two varieties of amphibolite are present in the Breakenridge Formation. The main type is homogeneous with well defined foliation, while within these are more schistose varieties with a characteristic striped appearance. Plate 2 is typical of the latter variety.

MINERALOGY.

The mineralogy and approximate modes of amphibolites studied are shown in Table 3. The modes were estimated by eye. Common mineral assemblages include;-

a) Hornblende- Plagioclase- Qtz (Amphibolite)

b) Hornblende- Plagioclase- Biotite- Qtz (Biotite - Amphibolite)

c) Hornblende- Plagioclase- Biotite- Garnet- Qtz (Biotite - - Garnet - Amphibolite)

d) Hornblende - Plagioclase- Diopside- Calcite- Qtz (Banded Amphibolite)

Epidote is common to all assemblages and occurs either as a primary mineral or as late veins, or the result of saussuritization of plagioclase. The plagioclase composition as measured in grains ⊥'r a, varies from specimen to specimen, ranging from An 30-44. Zoning is absent. In Table 3 the anorthite content of the plagioclase is shown in brackets.

The foliation or schistosity is defined by biotite, hornblende or lenticular quartz and feldspar. Garnet occurs in knots associated with hornblende and surrounded by quartzo - feldspathic 'depletion' haloes. It also occurs as idioblastic or xenoblastic crystals which poikiloblastically include quartz, magnetite and chlorite. Banded calcite diopside varieties are rare and consist of pale bands ($\frac{1}{2}$ c.m. wide) of calcite, diopside and plagioclase, which alternate with dark bands of hornblende, diopside and plagioclase.

111) Pelitic gneiss.

From Figure 1, it is apparent that the pelitic gneisses are a minor constituent of the Breakenridge formation. However they play a critical role in the elucidation of the structural and metamorphic history of the area. These medium to coarse grained gneisses are distinguished by bladed blue-grey kyanite, coarse garnet, and staurolites with well formed interpenetration twins. The most continuous horizon pinches and swells from a few feet to thirty feet as it is traced around the antiformal and synformal structures. Traced to its extremities on the limbs of folds the unit appears to pinch out completely. Plate 3 shows isoclinally folded gneiss within the main horizon. Closely assosciated with these gneisses are muscovite rich hornblende bearing staurolite kyanite gneisses. Hornblende crystallizes within the foliation in spectacular rosette form.

MINERALOGY.

The mineralogy and approximate modes of 29 pelitic gneisses studied is shown in Table 4. The modes were estimated by eye.

The anorthite content of the plagioclase is listed in brackets. Specimens in which chlorite appears to be texturally stable are indicated by (S), opposite chlorite.

The mineral assemblages noted all include muscovite and quartz and most include chlorite.

a) Kyanite.

b) Biotite - Garnet.

c) Biotite - Garnet - Staurolite.

d) Biotite - Garnet - Kyanite.

e) Biotite - Staurolite - Kyanite.

f) Garnet - Staurolite - Kyanite.

g) Biotite - Garnet - Staurolite - Kyanite.

h) Biotite - Garnet - Staurolite - Kyanite - Hornblende.

The main assemblage is g) as 20 of the 29 rocks studied contain those minerals.

A polished specimen from the H- series which contained assemblage g) was found to contain hematite, ilmenite and magnetite in that order of abundance, while the polished specimen of the graphite bearing assemblage d) (specimen 244/70) contained ilmenite in addition to the abundant graphite.

Textural features of these rocks are discussed fully in the section relating deformation to metamorphism.

iv) Migmatite:-

In Figure 1, migmatites are not differentiated from grey gneiss, but they occur in zones between the grey gneiss and amphibolites. The pelitic gneisses and skarn invariably occur within these migmatitic horizons. Plate 4 is of boudinaged pegmatite within the migmatites of the Breakenridge formation.

Though the following types are recognised, the dominant one is regularly to irregularly banded gneiss.

a) Grey gneiss with abundant mafic inclusions.

b) Amphibolite with leucogneiss screens and inclusions.

c) Grey gneiss with ptygmatic veins and disconnected "intestinal" quartzo - feldspathic lenses.

d) Banded to irregularly banded gneiss composed of leucocratic biotite gneiss, amphibolite and conformable or cross cutting pegmatites.

e) Speckled hornblende gneiss. Pale quartz plagioclase - biotite - gneiss with irregular porphyroblastic clots of hornblende which give the rock a speckled appearance.

f) Medium grained grey gneiss with distinctive magnetite porphyroblasts.

MINERALOGY.

The mineralogy and approximate modes of nine specimens studied are shown in Table 5. Modes were estimated by eye. Four specimens are from the gneiss dome to the East, while the rest are from the cirque 4 miles S.E. of Cairn Needle. The mineralogy of the leucocratic and melanocratic portions of specimen 206/70 are listed separately.

Gneisses of the dome are banded and have a medium grained hypidiomorphic granular texture. Biotite or Hornblende define the foliation and the lineation. Mafic bands of hornblende and biotite alternate with quartz and feldspar. Other essential minerals include garnet and muscovite. Some banded gneisses within the cirque S.E. of Cairn Needle are similar to those of the dome but contain intergranular microcline myrmekite. The plagioclase (as determined on grains 'r a) is homogeneous, but varies from specimen to specimen. This variation ranges from An 28-44, though most are around An 30.

The microfabric of the boundary between mafic and leucocratic portions of the migmatites exhibit features commonly noted at 'leucosome - melanosome' boundaries. (Mehnert 1968 p. 60).

The leucogneiss is in places convex towards the concave shaped part of the melanosome. Within this leucocratic portion are trains of biotite and hornblende which appear to have been left behind as the leucosome 'advanced' to incorporate the melanosome. These textural features may be the result of a migmatitic front. A more likely explanation, however, is cited in Ramsay (1967 p 382). When a single plane surface separating two rocks of different viscosity is deformed in such a way that the principal compressive strain is parallel to the boundary surface, the surface is folded. As deformation progresses the folded surface develops a series of broad rounded antiforms (competent rock) separated by synforms (incompetent rock) which have a tighter cross section and a characteristic "pinched" appearance. The small scale structures noted in the above migmatites may be explained by this model.

vi) Skarn;-

Spectacularly coloured calc - silicate pods and boudins are associated with the migmatites and pelitic gneisses of the Breakenridge formation.

These skarns have a high CaO, FeO content reflected in their mineralogy which consists of orange andradite, bright green hedenbergitic pyroxene, green epidote and quartz. (Specimen 194/70.- Table 5). In addition they are cut by pegmatites with large crystals of hornblende and epidote.

CAIRN NEEDLE FORMATION.

The areal extent of the Cairn Needle Formation is shown in Figure 1. The formation can be traced out of the map area to the southeast and is also encountered in the valley of Stokke Creek immediately West of the map.

The group consists of;-

1) Conglomerate.

11) Calc - Silicate schists.

111) Limestone.

iv) Garnet Hornblende Schist and Amphibolite.

v) Pelitic schists.

vi) Meta - basic igneous granulite.

The rusty weathering pelitic and garnet hornblende schists form the bulk of the metasedimentary part of the group, as the calc silicates, limestone and conglomerates are comparatively rare. The meta igneous portion forms a broad band half - to - one mile wide which extends from Hunger Creek in the north, southwards along the valley of Big Silver Creek for 12 miles.

The depositional environment of these rocks varied between terrestial (as indicated by the conglomerate) and shallow water marine (as indicated by the limestone).

DESCRIPTION AND PETROGRAPHY.

1) Conglomerate;-

The boundary between Breakenridge and Cairn Needle formations, in the vicinity of Cairn Needle is marked by six thin conglomeratic horizons which range in thickness from 3 to 15 feet. Intercalated with the conglomerates are calc-silicate schists and kyanite gneiss. The lowermost conglomerate can be traced for three miles from the headwaters of Butter Creek into the Northeast tributary of Stokke Creek.

The conglomerates have granitic (granite - granodiorite) quartz - dioritic, amphibolitic and quartzitic clasts, set in a dark medium grade matrix of biotite garnet amphibolite. The pebbles have been strained into pancake ellipsoids having their long axes sub-parallel to the antiformal axes of the region. These meta-conglomerates are lithologically similar to those described by Roddick (1965) in the Snowcap Lake and Stokke Creek pendants. A typical sheared meta-conglomerate is shown in Plate 5.

11) Calc - Silicates:-

Banded calc - silicates are confined to the lowermost portion of the formation. They are rusty weathering with thin bands alternately rich in garnet, diopside, hornblende, epidote and plagioclase. Pods of banded calc - silicate gneiss appear to have been tectonically rotated producing a spectacular ' mega - snowball' effect. (Plate 6).

MINERALOGY:-

The mineralogy and approximate modes of five calc - silicates sectioned is shown in Table 6. Modes were estimated by eye.

The mineral assemblages are as follows;-

a) Plagioclase - Epidote - Hornblende - Garnet - Qtz.
b) Plagioclase - Epidote - Hornblende - Garnet - Diopside - Qtz.
c) Plagioclase - Clinozoisite - Diopside - Tremolite - Qtz.

They all contain quartz, sphene, mica and retrograde chlorite. The garnet of specimens 441/70, and 446/70 is $Pyrope_{46}$ $Grossular_{31}$ $Almandine_{23}$. The detailed mineralogy, and possible origin of banding in these calc silicates is fully discussed in the section on metamorphism.

The granular polygonal or decussate texture of these rocks is indicative of static recrystallization either during an interkinematic phase of the regional metamorphism or during the contact metamorphism which accompanied emplacement of the Scuzzy Pluton.

iii) Limestone:-

One thirty foot wide horizon of banded black and white crystalline limestone with intercalated garnetiferous calc - silicate was found immediately to the West of Hunger Creek.

The medium grained white limestone has a schistosity defined by white mica while tiny yellow brown flecks of weathered olivine give the rock a spotted appearance. The coarse red green garnet diopside calc - silicates have been folded and boudinaged. Plate 7 shows the white limestone with associated red calc - silicate.

MINERALOGY.

The mineralogy and eye-estimated modes of the meta - limestones studied is shown in Table 7. The laminated grey limestone is essentially calcite with minor magnetite. The white crystalline limestone was originally dolomitic as indicated by the mineral assemblage forsterite, tremolite and calcite. Pelitic impurities include muscovite and retrograde chlorite. The garnet of the associated calc - silicates is $Grossular_{78}$ $Almandine_{17}$ $Andradite_5$.

iv) Garnet Hornblende Schist and Amphibolite.

Garnet hornblende schists form a major portion of the Cairn Needle formation. They are unlike the striped amphibolites of the Breakenridge formation as they are rusty weathering and are intercalated with the calc - silicates, limestones and pelitic schists.

MINERALOGY.

The mineralogy and approximate modes of the rocks sectioned are shown in Table 8. They are characterised by assemblages of biotite garnet and hornblende or biotite and hornblende. The plagioclase is homogeneous, and varies from specimen to specimen within the range An_{32} - An_{44}.
The relationship of the garnet to the well defined schistosity varies. On the one hand it may idioblastically overprint the schistosity, while on the other, sieve textured poikiloblasts surrounded by quartzo - feldspathic "depletion" haloes are wrapped around the schistosity.

v) Pelitic Schists:-

The pelitic schists of the Cairn Needle group are fine to medium grained rusty weathering rocks. Their red colour is due to the weathering of abundant pyrite.

The areal distribution of these schists is widespread, rusty weathering pelites outcropping as far South as Hornet Creek and beyond, and Westwards within the valley of Stokke Creek. The schists envelope the domal structure on Clear Creek.

MINERALOGY.

The mineralogy and approximate modes of twenty two pelitic schists sectioned is shown in Table 9. In addition to the assemblages listed below, the majority of the specimens contain muscovite and quartz. In Table 9, specimens with stable chlorite are indicated by (S) opposite chlorite.

a) Chlorite - biotite - garnet.

b) Garnet - biotite - gedrite.

c) Staurolite - garnet - biotite - chlorite.

d) Kyanite - staurolite - garnet - biotite.

e) Sillimanite - staurolite - garnet - biotite.

f) Sillimanite - garnet - biotite.

g) Sillimanite - andalusite - garnet - biotite.

Texturally the rocks have a well developed schistosity or folded schistosity, defined by either muscovite, biotite, fibrolite, sillimanite or opaques. Porphyroblasts include garnet, staurolite, kyanite, sillimanite and chiastolite.

Sillimanite may have crystallized during the regional and contact metamorphic events, while andalusite is related to the contact event. The sillimanite in schistose rocks commonly occurs as fibrolitic needles closely associated with biotite. Within the contact aureole of the Scuzzy Pluton, it occurs as robust crystals with diamond shaped cross section and good (010) cleavage. Andalusite, with well developed chiastolite cross occurs singly or in association with sillimanite. There is good textural evidence which shows all stages of replacement of the alumino - silicates within the aureole by platey aggragates of muscovite and tiny needles which are possibly fibrolite.

The relationship between metamorphic recrystallization and deformation is discussed in the appropriate section.

vi) Meta Basic Igneous Granulite:-

The elongate unit of metamorphosed basic igneous granulite consists of garnet hornblende, and biotite cummingtonite granulites and minor hornblendite. This unit is extensively veined by gneissic garnetiferous pegmatite while at its Southern extremity it is associated with bronzite peridotite which may be of a younger age.

PEGMATITES:

Pegmatites are major constituents of both the Breakenridge and Cairn Needle formations. The pegmatites of the migmatites of the Breakenridge formation have been previously mentioned, while Plate 8 amply demonstrates their abundance within the rusty weathering Cairn Needle formation.

The pegmatites can be classified into three types on the basis of features noted in the field.

i) Thin quartzo - feldspathic layers which are either conformable with the foliation or transgressive and hence ptygmatically folded.

ii) Thick coarse grained pegmatites which have been folded or boudinaged. (see Plate 8)

iii) Transgressive coarse grained pegmatites some of which are compositionally or texturally banded.

The first two types have been involved in the deformational events of the area while the transgressive pegmatites apparently post-date the youngest non-brittle deformation.

MINERALOGY:-

The mineralogy and approximate modes of the pegmatites sectioned is shown in Table 10. Modes were estimated by eye. Plagioclase composition was determined by sections ⊥'r to a and is shown in brackets.

Earlier Pegmatite:-

The mineral assemblage common to earlier pegmatites is;-

a) Quartz - plagioclase - muscovite - biotite - epidote ± garnet ± chlorite.

The plagioclase is unzoned and varies from specimen to specimen within the range An_4 - An_{12} . Accessories include garnet, apatite and zircon. Microscopic textures of the early pegmatites indicate that they have been subjected to complex deformation. All the features noted in the gneisses with which they are associated, i.e. - strain extinction and deformation lamellae of quartz, bent plagioclase twins, kink bands in mica and granular mortar texture of quartz are common.

Later Pegmatite:-

The mineral assemblage of the "later" pegmatites is;-

b) Quartz - plagioclase - microcline - muscovite - biotite - garnet.

Thus the later pegmatites contain potassium feldspar and generally have a true pegmatitic aspect. Micrographic intergrowths of cuartz and alkali feldspar are common. The plagioclase is An_8 .

CHILLIWACK GROUP OR PENINSULA FORMATION:-

The rocks on the northeast shore of Harrison Lake between Big Silver and Stokke Creeks include;-

i) Meta rudites. Grits and conglomerates.

ii) Pelitic schists.

iii) Calc - silicates.

To the northeast these rocks are in fault contact with grey gneiss of the Breakenridge formation.

DESCRIPTION AND PETROGRAPHY:-

i) Meta rudites.

Grits and sheared conglomerates are found on the lake shore immediately northwest of Big Silver Creek. These conglomerates, though containing fine grained 'granitic' pebbles are unlike those of the Cairn Needle formation. Granitic, white and dark quartzite or chert pebbles are set in a fine micaceous matrix. Though many of the pebbles have been flattened and elongated within the plane of schistosity some retain their roundness.

The meta grits have clasts of feldspar and opalescent blue quartz in a matrix of pale green chlorite and quartz.

ii) Pelitic schists:-

Pale green quartz mica schist, garnet schist and rusty weathering sulphidic schists form the major portion of rocks on Harrison Lake shore.

MINERALOGY.

The mineralogy and approximate modes of 8 meta - rudites and pelites sectioned are shown in Table 11. The anorthite content of plagioclase is shown in brackets and stable chlorite is indicated with (S).

The following mineral assemblages which in addition include muscovite and quartz are noted,

a) Chlorite.
b) Biotite - chlorite.
c) Garnet - biotite - chlorite.

The grits have porphyroclasts of quartz and saussuritized plagioclase set in a schistose matrix of chlorite and granular quartz. Well defined pressure shadows of quartz have developed at the margins of the clasts.

The pelites have a pronounced schistosity defined by chlorite, micas, quartz and feldspar. In some specimens a strain slip cleavage has developed sub - perpendicular to this schistosity. Idioblastic garnets with marginal pressure shadows include straight trains of quartz inclusions which are interpreted as an even earlier schistosity. These garnets have been extensively pseudomorphed by retrogressive chlorite.

iii) Calc - silicates.

Two thick horizons (500') of calc - silicate have been mapped. Common mineral assemblages, and approximate modes are shown in Table 12, and include garnet - actinolite - plagioclase ± epidote ± biotite ± muscovite.

Randomly oriented sheaves of actinolite and bright red garnet (Pyrope $_{54}$ Grossular $_{36}$ Almandine $_{10}$.) set in a white matrix of granular quartz and feldspar ensure that this unit is readily mappable. In places it displays a crude banding; garnet - hornblende layers alternating with quartz - plagioclase layers. In some outcrops thin garnetiferous layers which have been intricately folded can be traced for several feet.

Microscopic examination shows blue green actinolite laths and idioblastic garnets set in a granular polygonal matrix of quartz and plagioclase. The plagioclase is unzoned and varies from specimen to specimen within the range An_{20} - An_{40} . Where developed, the schistosity is defined by micas and chlorite, while biotite porphyroblasts are sometimes kinked. Thus though textural features are indicative of static recrystallization the rocks have had a complex deformational history.

IGNEOUS ROCKS.

The distribution of plutonic igneous rocks in the area is shown in Figure 1.

Two major "granitic" bodies are recognised.

i) The plutonic complex underlying Mount Breakenridge and related rocks.

ii) The Scuzzy Pluton.

In addition minor ultramafic rocks and andesitic dykes have been found in the area.

MOUNT BREAKENRIDGE PLUTONIC COMPLEX.

The plutonic complex which makes up most of Mount Breakenridge consists of grey medium grained gneissic hornblende biotite diorite (Hb < Bi) and granodiorite, with 10% rounded to elongate mafic inclusions which are rich in biotite and hornblende. The core of the complex is occupied by younger "high level" porphyries and quartz diorites. In plan view the core is elongate (1.5 x 7 miles) and is composed of pink quartz biotite andesine porphyry marginally zoned by mesocratic porphyritic quartz diorite. These epizonal intrusions have small rounded xenoliths of fine to medium grained granitic and dioritic rocks.

Gneissic Granodiorite - Quartz Diorite.

The most striking feature of the gneissic granodiorite is its well developed foliation and lineation which are most pronounced towards the contact with the gneisses of the Breakenridge formation. In places this foliation is subconcordant tothat of the gneisses, making it difficult to mark a definite contact between gneissic plutonic rock and Breakenridge gneiss. Further, biotite rich mafic inclusions within the pluton have been strained into cigar - shaped ellipsoids with long axes approximately parallel to the lineation of the region.

To the east on Big Silver Creek, the granodiorite is in sharp contact with a gneissic, mesocratic, garnet bearing hornblende - biotite quartz diorite (Hb>Bi). This marginal zone of quartz diorite is in abrupt concordant contact with vertically dipping gneisses on Big Silver Creek. The long axes of stretched inclusions are parallel to lineations in the gneiss.

MINERALOGY.

the mineralogy and approximate modes of seven rocks sectioned is shown in Table 13. They range from granodiorite to quartz diorite (Bi>Hb). Texturally they are allotriomorphic granular with a foliation defined by biotite, hornblende and quartz feldspar lenses. These lenses often have long axes parallel to biotite grain alignments. The plagioclase is homogeneous and varies from specimen to specimen within the range An_{10} - An_{38}. In specimen 369/70 the plagioclase of the hornblende biotite inclusion was An_{38}, while that of the host rock was An_{37}.

The boundary between inclusions and host exhibit features similar to those found in the inclusion rich Breakenridge gneisses. In fine detail quartzo - feldspathic host is convex towards the hornblende - biotite inclusion and would appear to be invading and partially assimilating the xenolith. Specimen 313/70 has glomero - porphyritic aggragates of biotite, epidote and quartz which may represent remnants of original inclusions in the igneous rocks. Specimen 311/70 has textural features indicative of late stage deformation and recrystallization;

i) Plagioclase twins have been bent.

ii Biotite has been kinked.

iii) Hornblende has recrystallized in a xenoblastic manner and includes granular quartz crystals.

The mesocratic foliate quartz diorite (Hb > Bi) on Big Silver Creek shows the same effects of shearing and recrystallization. The mineralogy and approximate modes of two sections studied are shown in Table 14. Note that the plagioclase (An $_{43}$) though extensively saussuritized is more basic than the adjacent igneous rocks. This basic margin was emplaced contemporaneously with the biotite quartz diorites although absolute relationships cannot be determined as any chilled margins which may have existed at their contacts have since been destroyed by shearing.

Epizonal Core:-

The elongate core of the Mount Breakenridge plutonic complex has the following features of epizonal intrusions.

i) Porphyritic to sub - porphyritic texture.

ii) Miarolitic cavities filled with quartz, calcite and black biotite. These cavities are common in rocks of porphyritic aspect but also occur in medium grained quartz diorites.

MINERALOGY.

The mineralogy and approximate modes of seven specimens sectioned is shown in Table 15. In the porphyries quartz, biotite and hornblende, in addition to complexly zoned plagioclase, are common phenocrysts. The groundmass is composed of fine grained granular quartz, muscovite, plagioclase and alkali feldspar. The plagioclase has a maximum variation from An $_5$ - An $_{48}$ within specimen 367/70. Medium grained diorites have plagioclase of a similar composition but no alkali feldspar. Generally the biotite content is greater than hornblende.

Detailed contact relationships of the epizonal core to the foliate exterior of the complex are mostly obscured by snow. However one specimen of biotite gneiss from the contact contained nodules of green globular spinel (pleonaste) and polygonal quartz. These nodules are possibly the product of contact metamorphism by the epizonal core. It is concluded that the epizonal core post dates the gneissic exterior of the complex.

SCUZZY PLUTON.

The Marginal Phase of the Pluton underlying Cairn Needle.

The hornblende biotite quartz diorite (Hb > Bi) on Cairn Needle is part of the large Scuzzy Intrusion. The body also crops out on Stokke Creek and becomes part of intrusions mapped by Roddick (1965). Plutons in Stokke Creek include coarse melanocratic diorite and foliate quartz diorite very similar to that on Cairn Needle.

Around Cairn Needle the contact between rusty schists and the quartz diorite dips steeply to the northwest. The pluton is transgressive to structures within the schists, but has a pronounced marginal foliation which was produced during emplacement. In the course of emplacement this foliation has also been drag folded. The contact zone of the Scuzzy Pluton at the head of Big Silver Creek has a similar foliation which gives way to a typical holocrystalline texture deeper within the intrusive.

MINERALOGY.

The mineralogy and estimated modes of rocks sectioned are shown in Table 16.

The plutonic rock on Cairn Needle has a foliated hypidiomorphic granular texture. Bent plagioclase twins and strain extinction in quartz point to the shear which probably accompanied emplacement. The diorite on Stokke Creek however has no foliation and has crystallised with good hypidiomorphic granular texture.

The Scuzzy Pluton to the east of Cairn Needle is predominantly granodiorite (Roddick and Hutchison 1969). The rocks of the marginal foliated phase of this pluton are richer in dark minerals and slightly more basic than those of the interior.

OTHER IGNEOUS ROCKS.

On the Eastern limb of the antiform which crops out on Big Silver Creek, two types of basic igneous rock are found intercalated with the gneisses, amphibolites and schists.

A dyke-like body of hypersthene - augite diabase occurs within the grey gneiss and amphibolite of the Breakenridge formation. The areal extent of the intrusion is unknown but its contacts are sub - parallel to the gneissic foliation.

A fresh medium grained dyke of bronzite - augite - peridotite was found on Fir Creek, within the metamorphosed mafic igneous rocks of the Cairn Needle formation. Rounded olivine crystals are poikilitically included in large crystals of pinkish bronzite. The bronzite has a pronounced schiller texture produced by fine parallel inclusions of opaques, and augite is marginally altered to hornblende. Thus the rock has the texture of an orthocumulate with cumulous augite and olivine set in large intercumulus crystals of bronzite.

On Hunger Creek a partially metamorphosed dunite pod outcrops on strike with a well defined lineament. Olivine has been metamorphosed to pink weathering talc which has crystallized along irregular fractures in the brown weathering dunite.

Andesine porphyry dykes cut the Breakenridge Plutonic complex. These East - West trending dykes have a trachytic texture with phenocrysts of oscillatory zoned intermediate plagioclase set in a felted mass of feldspar laths, interstitial chlorophaeite, and disseminated magnetite and pyrite.

CORRELATION AND AGES OF ROCK UNITS:

Breakenridge Formation;-

The formation is lithologically similar to the Custer gneiss (McTaggart and Thompson 1967), and the Skagit gneiss (Misch 1966). The former is the migmatitic equivalent of the Permian Hozameen group and the latter the tentative equivalent of the Upper Paleozoic Chilliwack Group.

Cairn Needle Formation;-

Although it contains minor limestone and pelite the Cairn Needle formation lacks the abundant chert and greenstone to be a direct lithologic equivalent of the Hozameen group. Rocks within the Hope Map Sheet (Monger 1970) which contain conglomerates with granitic clasts, include;-

a)	Ladner Group.	L-M Jurassic.
b)	Kent Formation.	U. Jurassic.
c)	Dewdney Creek Group.	U. Jurassic.
d)	Peninsula Formation.	L. Cretaceous.
e)	Jackass Mountain Group.	L. Cretaceous.

In the Ashcroft area (Duffel and McTaggart 1952) there are granitic conglomerates at the base of the Jurassic, and also within the Lower Cretaceous Brew group.

The description of conglomerates within the Snowcap Lake and Stokke Creek pendants, described by Roddick (1965) in the Pitt Lake map sheet, which have been assigned to the pre - Jurassic Twin Islands formation, is similar to the conglomerates in the Cairn Needle formation. Thus, generally the age of the formation is problematic but it may contain rocks of Jurassic Age.

Chilliwack Group -- Peninsula Formation rocks.

The clastic rocks on the northeast shore of Harrison Lake are lithologically similar to the Peninsula Formation (L. Cretaceous). The pelitic and calc - silicate units may be ecuivalent to older Chilliwack group strata. (Monger 1970).

Igneous Rocks;

Scuzzy Pluton;-

Recent K - Ar age dates on the Scuzzy Pluton are as follows.

Biotite K - Ar age = 70 ± 4 m.y.

Hornblende K - Ar age = 72 ± 4 m.y.

Ages on the Spuzzum Pluton are;-

Hornblende K - Ar 73 ± 4 m.y.

Biotite K - Ar 74 ± 4 m.y.

(Hutchison 1971 pers. comm.)

These data indicate that the Scuzzy Intrusion is presumably a leucocratic core within the Spuzzum quartz diorite, and that, providing they reflect time of emplacement, the Scuzzy phase is no younger than the Spuzzum phase.

<u>Breakenridge - Plutonic complex</u>:

The textural features of the gneissic plutonic complex on Mount Breakenridge suggest that it was in place during the waning stages of regional metamorphism and deformation, and is thus older than the Scuzzy which post - dates these events.

The fresh epizonal core is probably equivalent to younger Tertiary high level intrusions such as Hells Gate Pluton. This has been dated at 35 m.y. (Baadsgaard, Folinsbee and Lipson, 1961), and more recently with both biotite and hornblende giving ages of 44 ± 3 m.y. and 40 ± 4 m.y. respectively.

(Hutchison 1971 pers. comm.)

Other Igneous Rocks:

The partially metamorphosed dunite may have been emplaced during mid - Cretaceous faulting.

The bronzite peridotite is similar to rocks 7 miles Northwest of Hope.(Aho 1956). These rocks are possibly Cretaceous in age.

SEQUENCE OF EVENTS.

a) There is no structural evidence to indicate that the Breakenridge Formation was subjected to major deformation and metamorphism prior to the deposition of the Cairn Needle formation. The presence of conglomerates in the latter formation however may point to a minor discontinuity between the two formations.

b) The main formations underwent deep seated deformation and metamorphism between the earliest Jurassic and Mid - Cretaceous time. During the late stages of this episode of metamorphism and folding the gneissic portion of the Mount Breakenridge Plutonic complex was emplaced.

c) Uplift, with the development of a major thrust fault between Breakenridge formation gneisses, and Chilliwack group and Peninsula formation rocks probably occurred in the Mid - Cretaceous as this fault may be the northern extension of the Mid - Cretaceous Shuksan Thrust. (Misch 1971). Minor retrogressive metamorphism accompanied the thrusting. The outcrop pattern of the ultrabasic rocks, in conjunction with the well defined fault in the northern map region, may define a mid - cretaceous zone of crustal weakness, along which the ultrabasics were emplaced or intruded.

d) The intrusion of the Scuzzy Pluton and accompanying contact metamorphism occured in the Upper Cretaceous.

e) Early Tertiary intrusion of the Epizonal Core of the Mount Breakenridge Plutonic complex. If this intrusion was emplaced to within 4 km. from the surface, and the Scuzzy Intrusion was emplaced at pressures low enough to stabilize andalusite which is found in its contact aureole (approx. 5kb = 17 km), the rate of uplift from Upper Cretaceous (70 m.yrs.) to Lower Tertiary (40 m.yrs.), was about 2 - 3 km/million years, or 1 cm. every 3 or 4 years.

f) Intrusion of Andesite dykes.

STRUCTURE.

The lithological units which were helpful in defining the gross regional structure have been shown in Figure 1. Of these the pelitic units, grey gneiss bands and amphibolites within the Breakenridge group, and the conglomeratic horizons within the Cairn Needle group proved to be the most useful marker horizons.

The important structural elements recognised in the area are shown in Figure 2. The major antiforms and synforms have a predominantly northwest - trend and plunge. A least squares fit to 265 poles to foliation and compositional layering of gneisses has a pole of 329 / 56 . (Computations were carried out on the I.B.M. 360/67 U.B.C. Programme used was "Main Program Testing Pifit and Stddev" by R.L. WHEELER. Princeton University).

The girdle formed by poles to foliations measured around the area is shown in Figure 3. This girdle has a pole of 315/ 40-60 .

In addition to the gross regional structure which is defined by lithology, individual minor fold patterns within the lithologic units indicate three phases of minor folding. Evidence for the earliest phase is scanty but is deduced from refolded fold relationships such as shown in Plate 9. The style elements of the three folding episodes

FIGURE 2:

Important structural elements of Mount Breakenridge area.

KEY:

strike and dip of foliation

antiform

synform

fault

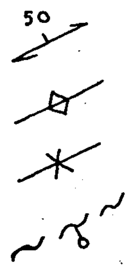
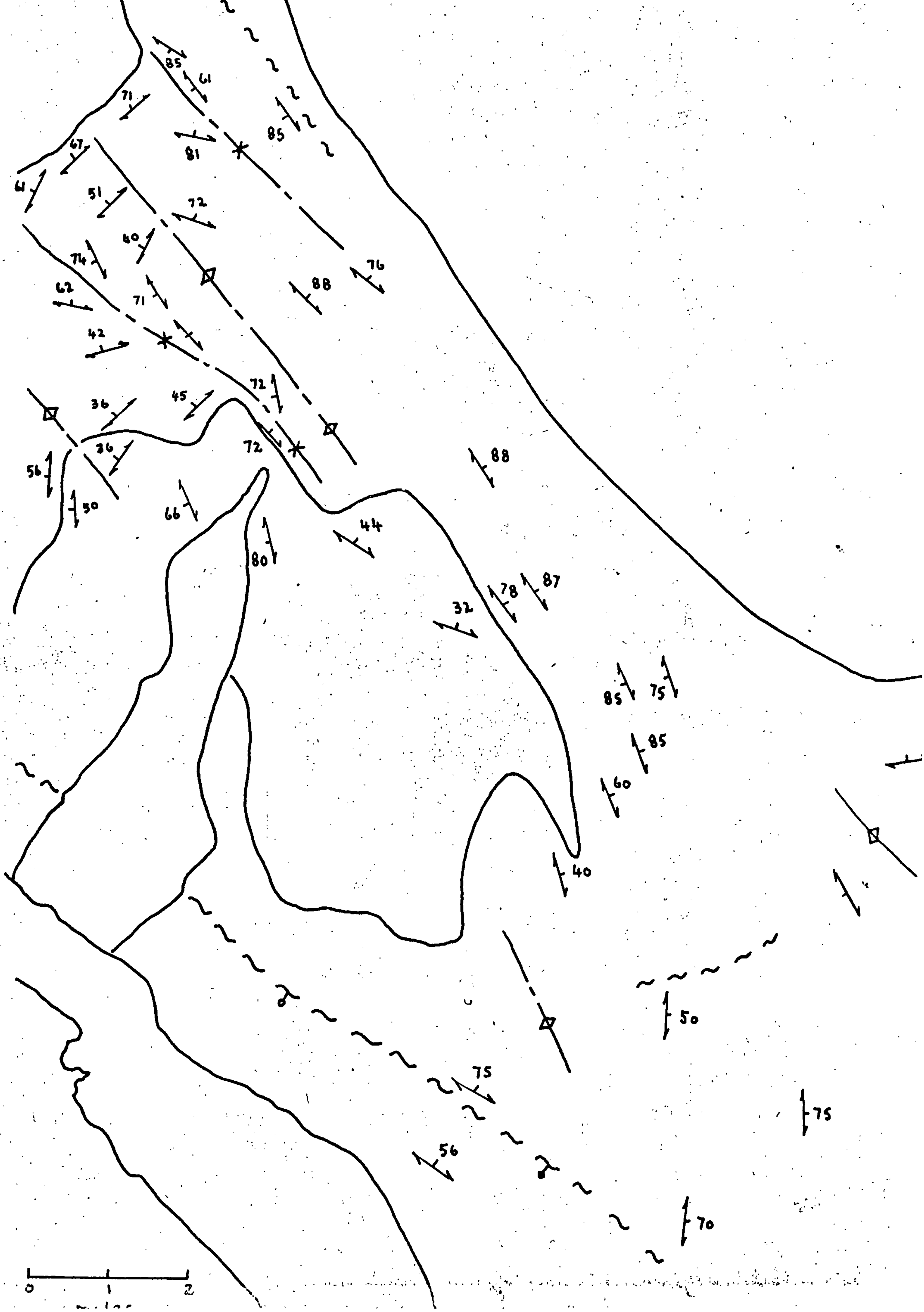


FIG 2


75
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88
80
44
78
87
32
85
75
85
60
40
50
75
75
56
70
0
1
2

Figure 3

Equal area plot of 157 poles to foliation and compositional layering.

Contours 1% 3% 5%

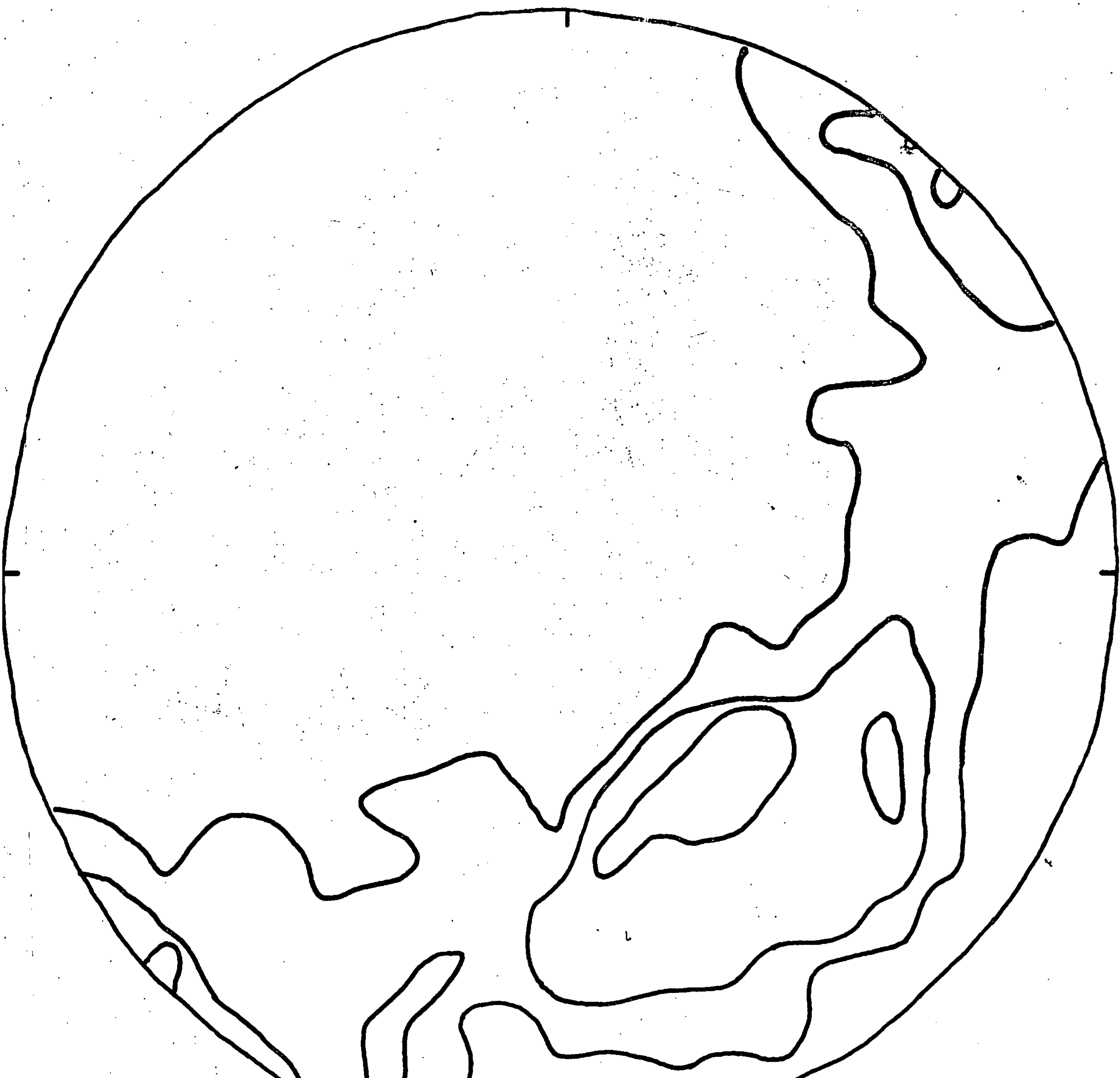


FIG 3

TABLE 17

STYLE ELEMENTS OF FOLDS

F_A	F_B	F_C
rootless, isoclinal.	sub-isoclinal limbs sometimes sheared off.	open to chevron
similar	similar	similar, but where layer anisotropic more concentric
tight curved hinge	broadly curved hinge	sharp hinge
straight to broadly curved limb	broadly curved limb	straight limb
	moderately harmonic	harmonic
		HINGE LINE may be short and straight or long and curved
folded compositional layering with axial schistosity	folded comp. layering with axial schistosity	mainly folded comp. layering (schistosity) with little axial schistosity.

are listed in Table 17.

In addition to these elements of fold style, a measure of the relative asymmetry of the folds can be obtained by measuring the ratio of the perpendicular <u>height</u> between adjacent antiformal and synformal hinge areas, to the perpendicular <u>width</u> between adjacent axial traces, as viewed down the fold axis.

Height / width data collectd for F_B and F_C folds are shown in the histograms of Figures 4 and 5. F_B data have a mean of 2.56 with a standard deviation of 1.05. The 68% confidence interval is 1.51 to 3.62. F_C data have a mean of 1.43 with a standard deviation of 1.36. The 68% confidence interval is 0.08 to 2.79. (Computation carried out on I.B.M. 360/67 U.B.C. with programme "XMEAN, S, single HISTOGRAMS" by R.L.Wheeler, Princeton University).

It is evident that the modes are not significantly different within the 68% confidence interval.

The wide spread of H/W ratios within each fold generation is doubtless the result of the wide angular variations between surfaces being folded (compositional layering, schistosity) and the axial surface of the "refolding" fold. (Ramsay, 1967 p.539). Thus the wide range of H/W ratios which are theoretically possible within any one folding episode make these ratios unreliable criteria to use in the classification of successive generations of folds.

FIGURE 4.

Histogram of Height/Width ratios of F_B minor folds.

mode = 2.56

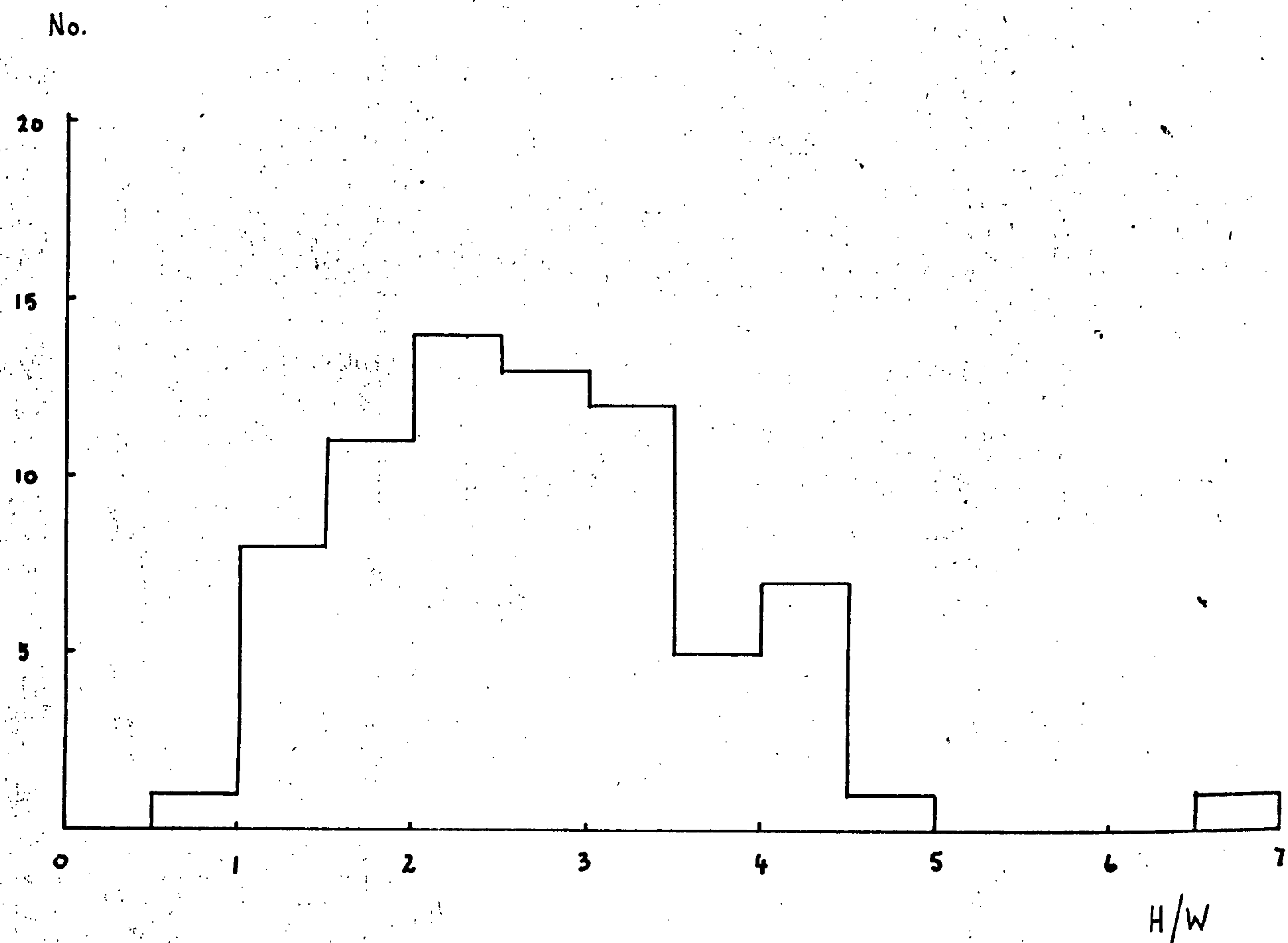


FIG 4

FIGURE 5.

Histogram of Height/width ratios of F_C minor folds.

mode = 1.43.

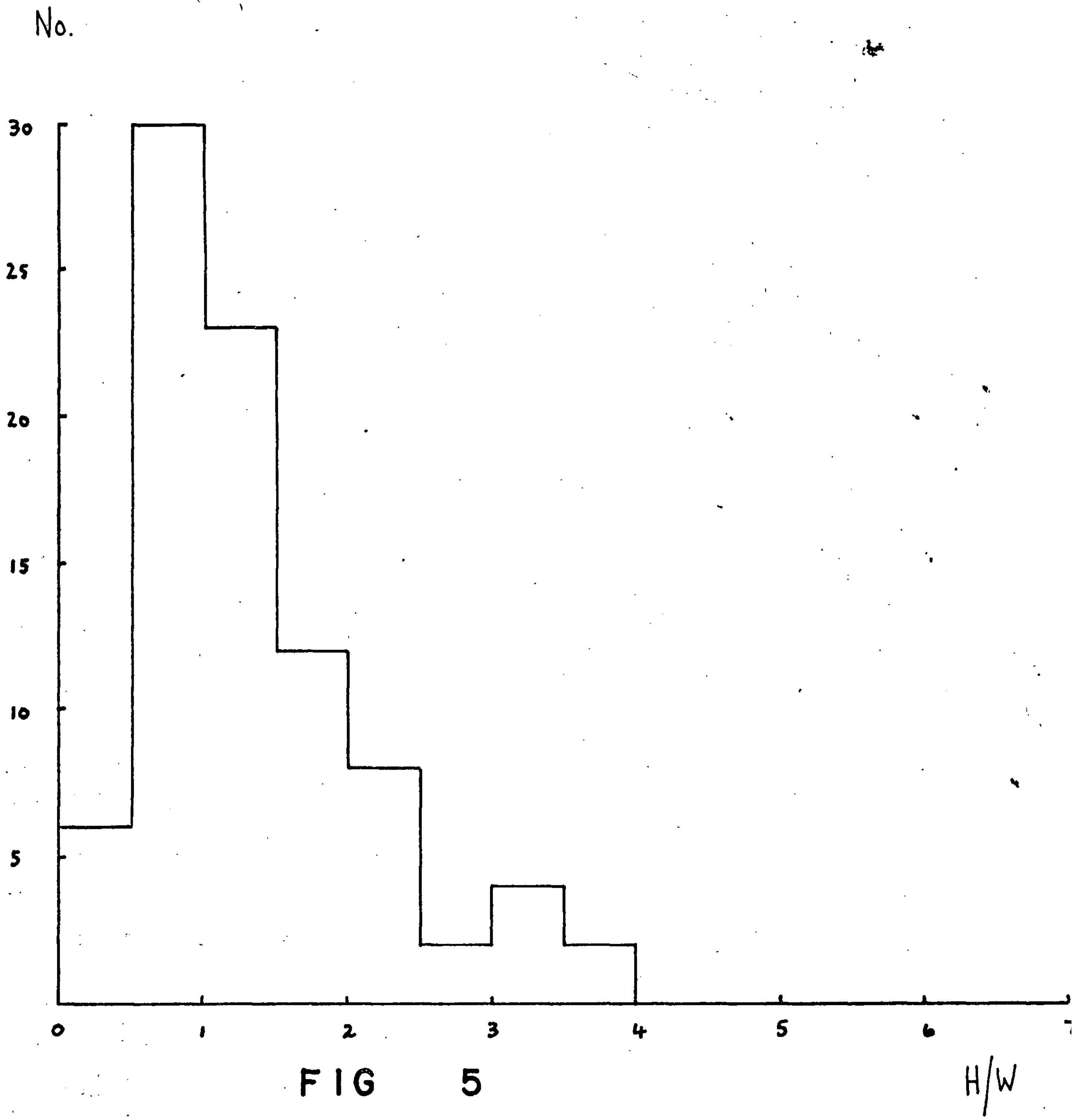


FIG 5

MINOR FOLD AXIAL SURFACE DATA.

F_A :- The axial surfaces of F_A folds generally lie within the local foliation.

F_B :- The angular variation between foliation and F_B axial surface varies between 2 and 19 . The partial girdle formed by the poles to the axial surfaces of F_B folds (Figure 6) indicates that these folds have been refolded about an axis of 311 /40 , which is sub - parallel to the regional F_C axes.

F_C :- The poles to axial surfaces of F_C folds are shown in Figure 7. Their northwest subvertical trend compares favourably with the regionally defined axial surfaces.

MINOR FOLD AXIAL DATA:-

F_A :- Very little axial data exists for F_A folds.

F_B :- A plot of 19 F_B minor fold axes is shown in Figure 8. There is a maximum trend and plunge at 315 / 42 .

Figure 6

Equal area plot of 17 poles to axial planes

of F_b minor folds .

Contours 5% 10% 15% .

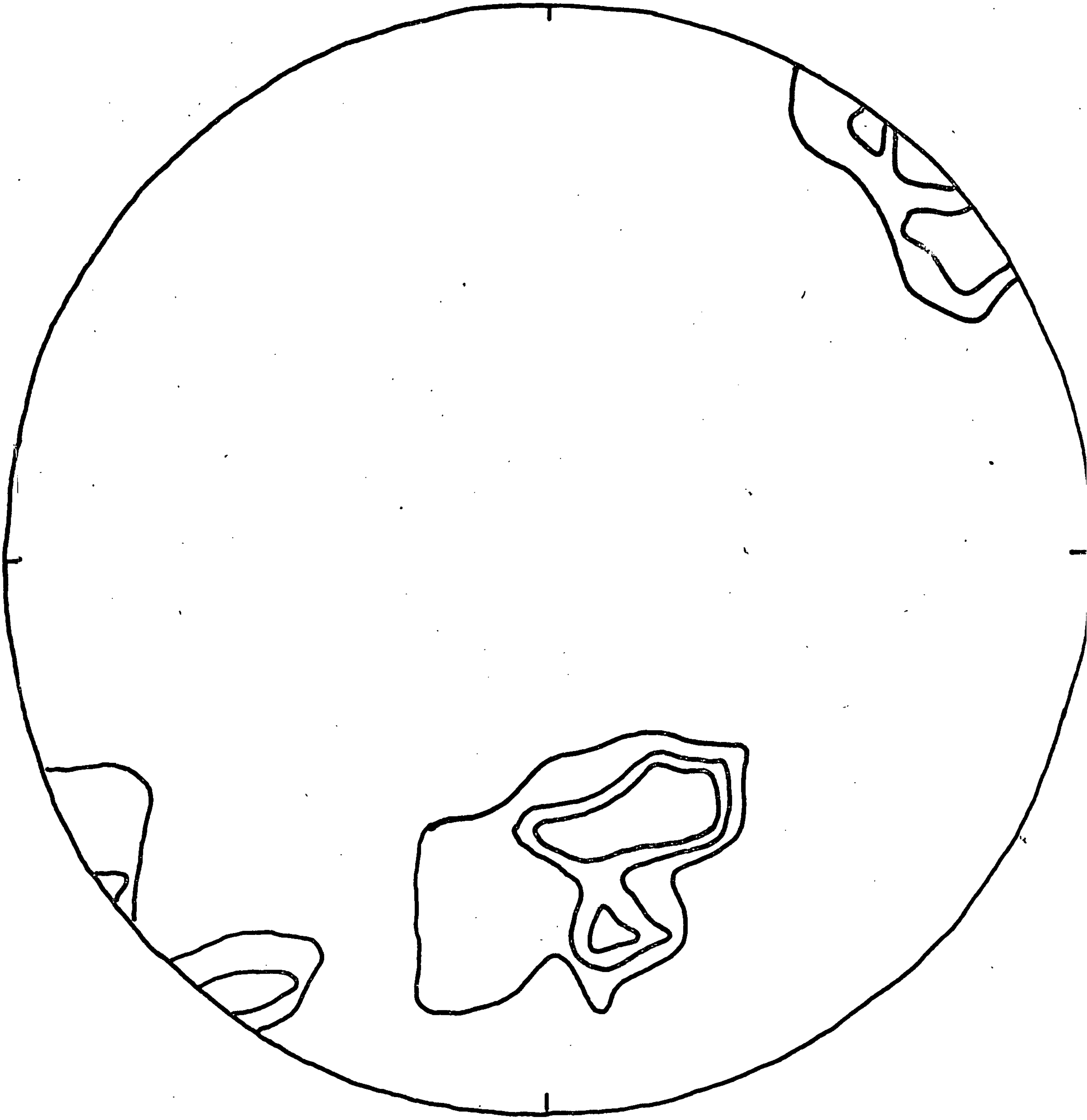


FIG 6

Figure 7

Equal area plot of 20 poles to axial surfaces of F_C minor folds.

Contours 5% 10% 20% .

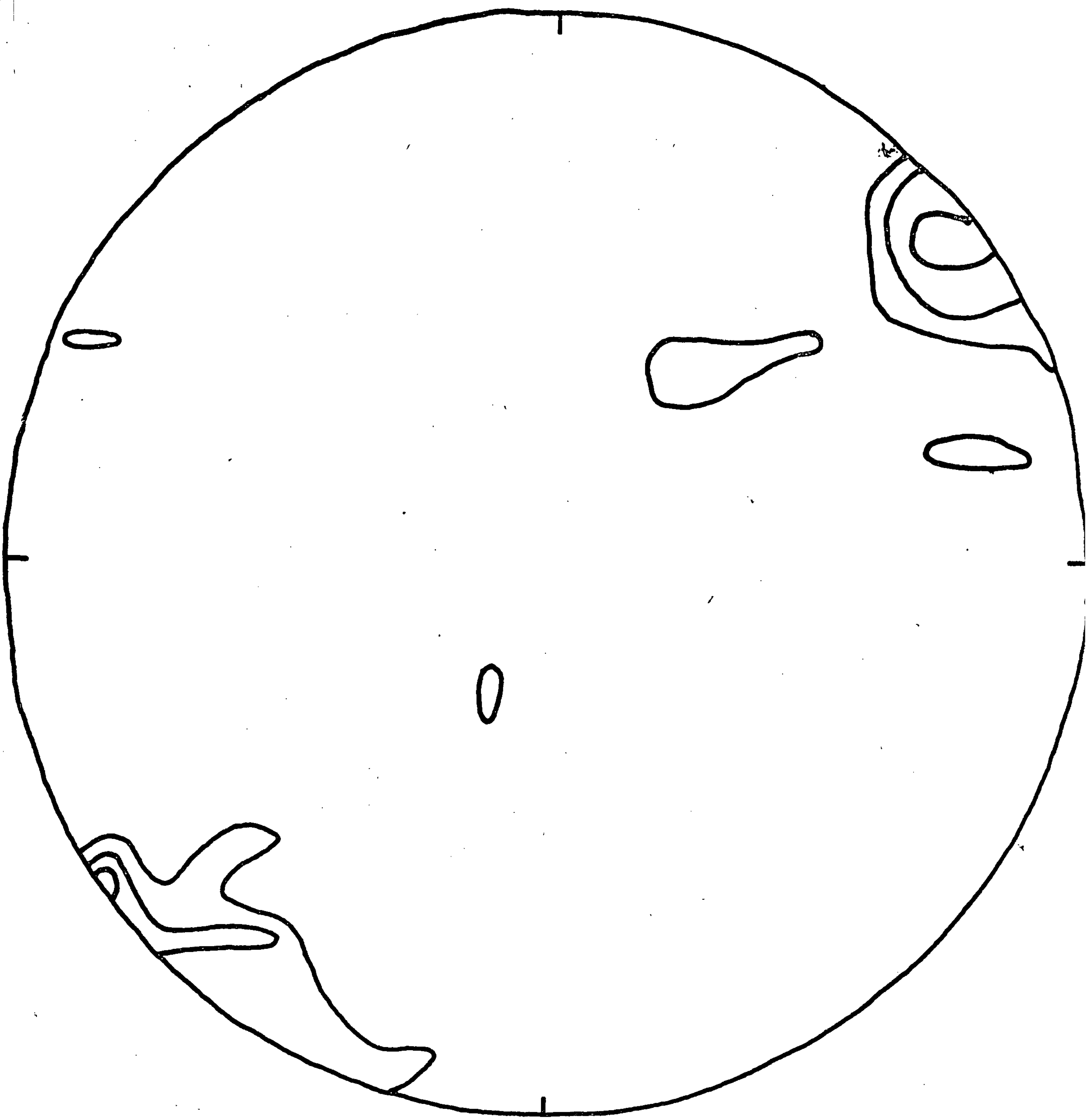


FIG 7

FIGURE 8:

Equal area plot of nineteen F_B minor fold axes.

Contours. 5% 10% 20% 30%

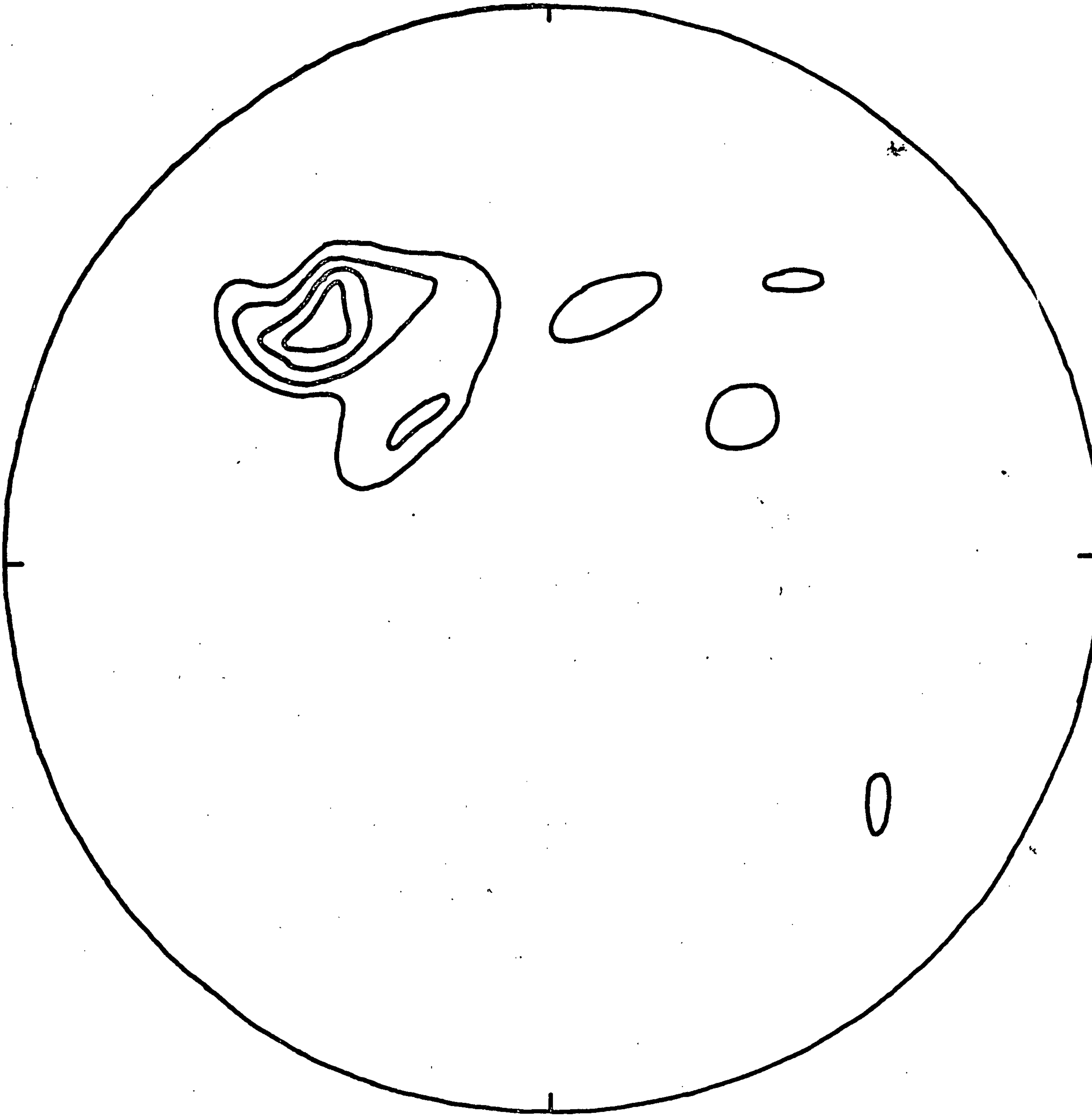


FIG 8

Figure 9

Equal area plot of 25 axes of F_C minor folds.

Contours 10% , 15% , 30% ,

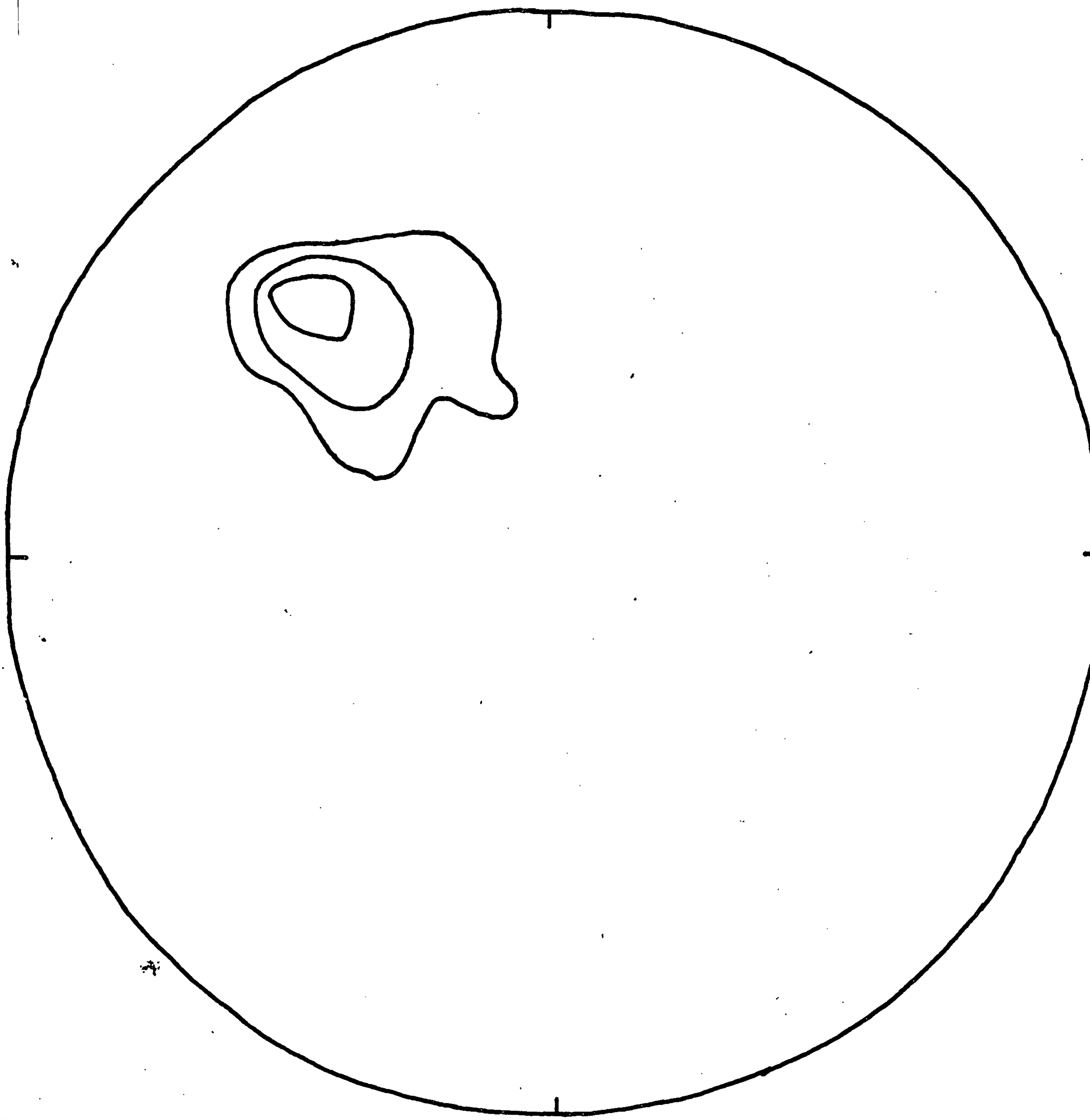


FIG 9

F_C :- A plot of 25 F_A minor fold axes is shown in Figure 9. There is a maximum trend and plunge at 316 / 37 .

The high directional stability between the F_B and F_C fold axes would appear to indicate that the successive folding episodes were virtually homoaxial.

LINEATIONS AND MINERAL GRAIN ALIGNMENTS.

The map (Figure 10) shows representative lineations measured in the area. A plot of 137 mineral grain alignments (Figure 11) has a greater spread than fold axial data, but the maximum trend and plunge at 328 / 41 is comparable with the minor fold axial maxima and the general structural trend of the region. The absence of a pronounced girdle of lineations would appear to indicate that these grain alignments are mostly sub - parallel to the later F_C fold axes. Further, the pronounced homoaxiality between F_B and F_C precludes the differentiation on a regional scale, between F_B and F_C lineations.

However, a few lineations which have been refolded by F_C minor folds have been found in the field. The manner of redistribution of the earlier lineations is a

FIGURE 10:

Representative lineations of Mount Breakenridge Area.

KEY:

Trend and plunge of lineation 

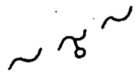
Fault. 

FIG 10


63
62
60
50
53
49
39
43
30
41
47
40
31
40
36
29
25
25
36
28
25
35
5
10
18
60
18
1
46
70
0
1
2
miles

FIGURE 11.

Equal area plot of 137 mineral grain alignments from the Mount Breakenridge area.

Contours 1% 5% 10% 15%

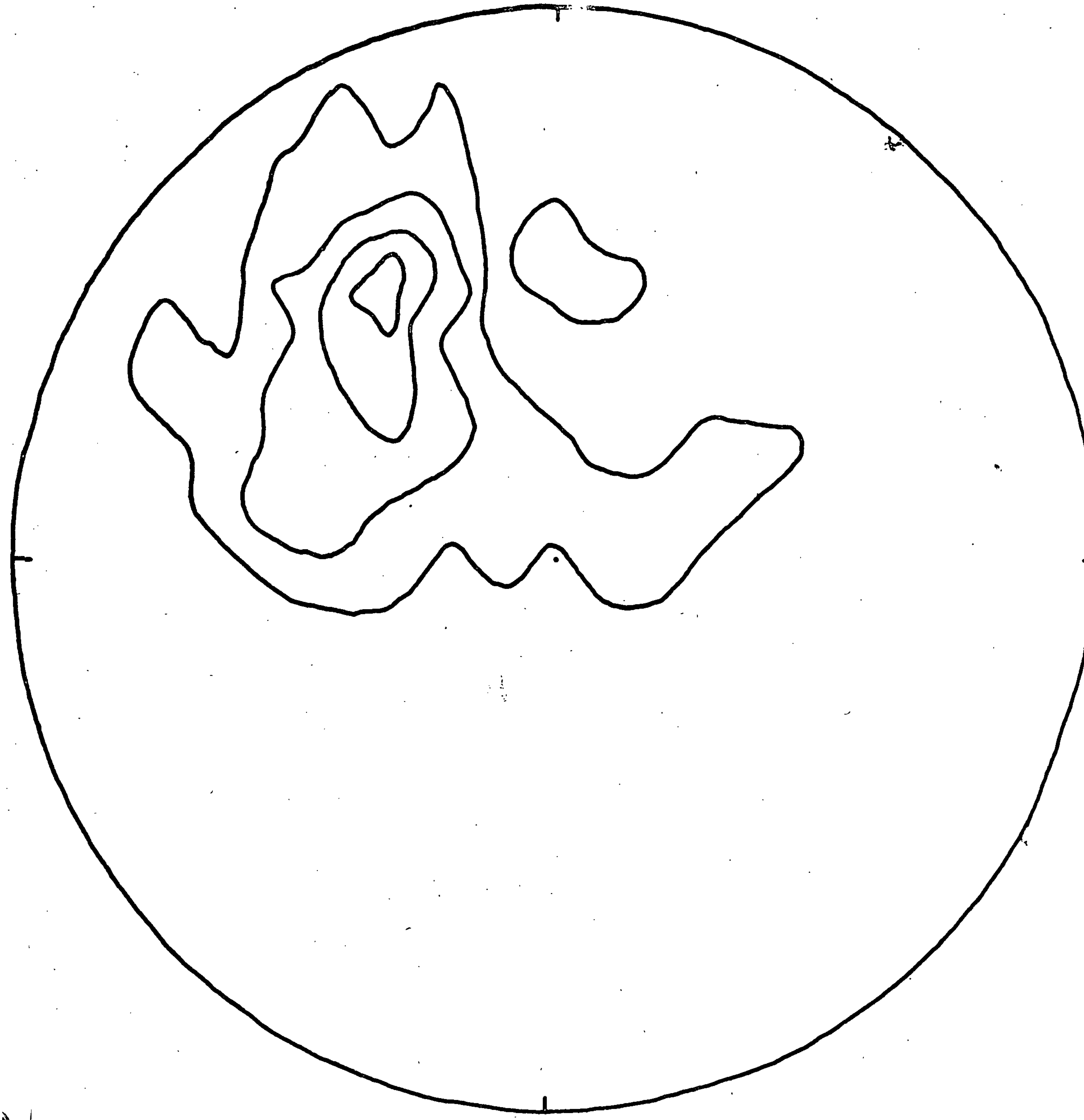


FIG 11

FIGURE 12:

Slip lines of F_C folds, Mount Breakenridge Area.

KEY:

B = F_C fold axes.

A.P. = axial plane of F_C minor fold.

R.P. = rotation path of folded lineations.

S.L. =,slip line.

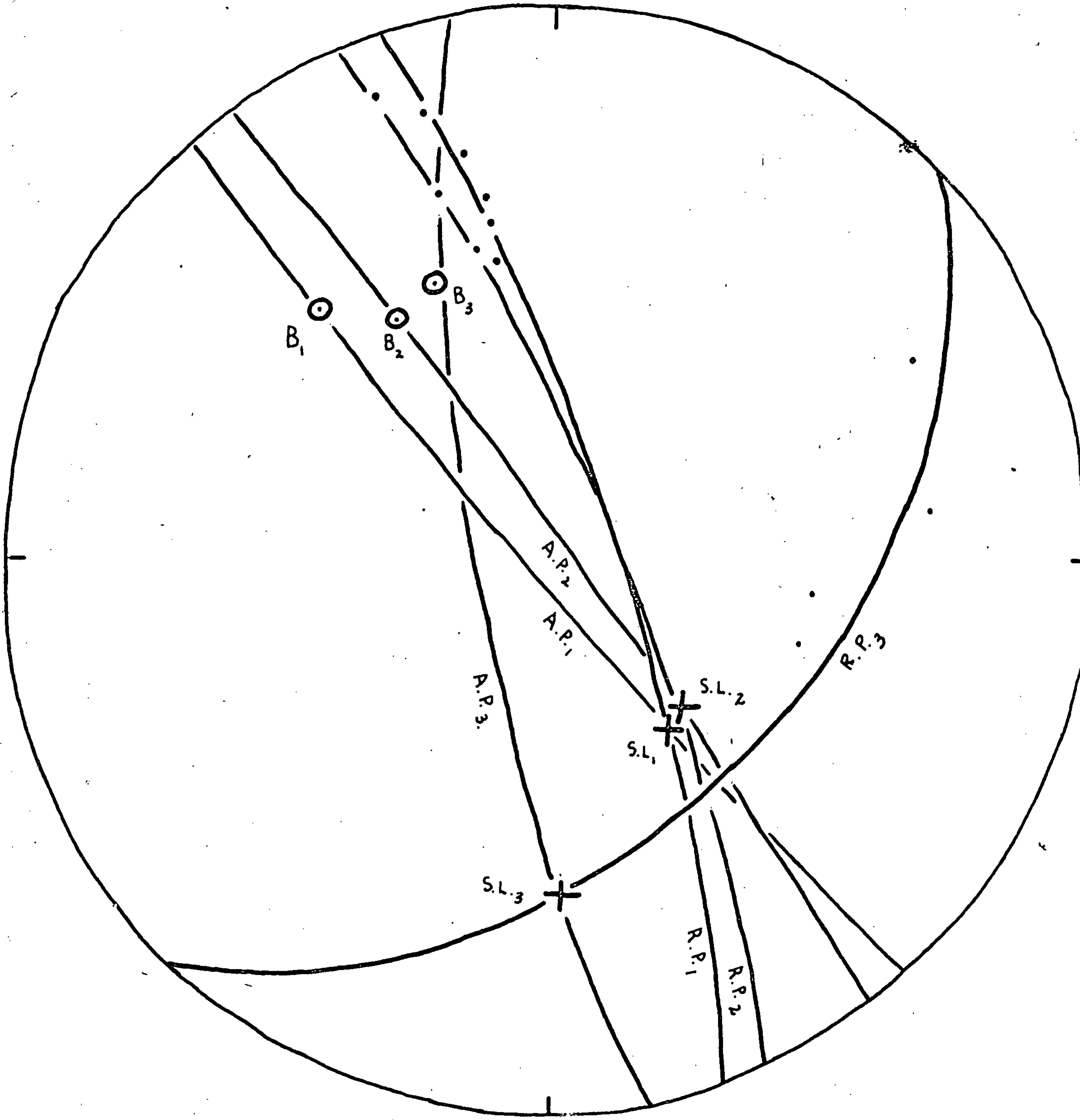


FIG 12

valuable index of the type of fold mechanism involved in the refolding. (Ramsay, 1967). Figure 12 shows the rotation paths of the refolded lineations and the slip lines of the fold mechanism involved. A similar (slip) mechanism is deduced for F_C folding. The slip lines are sub - perpendicular to F_C fold axes.

The scarcity of lineations refolded by F_C minor folds may be due to extreme recrystallization which followed the F_C folding, thus essentially obliterating the earlier lineations.

<u>Lineations, minor fold axes and axial surfaces in Chilliwack Group Peninsula Formation Strata:-</u>

Lineations and minor fold axes strike 315 and plunge northwards or southwards between 5 and 20 . Minor fold axial surfaces strike between 305 - 318 , and dip steeply at 65 - 83 to the northeast.

These minor fold trends may be associated with a major fold which has similarly oriented axial surface and axis. This fold may be the reason for the two horizons of calc - silicate noted, but the present data are inadequate for proof.

Note on strained pebbles in the meta - conglomerate of the Cairn Needle Formation.

The pebbles within the sheared meta - conglomerates in the Cairn Needle formation have widely varying shapes. The pebbles have been flattened within the foliation into pancake ellipsoids whose longest axis X (X>Y>Z) is parallel to the steeply plunging fold axis in the area. The wide variation in pebble shape is demonstrated at Station 225, where the pebbles have the following range in Y'/Z' ratio.

GRANITIC: 42 pebbles Y'/Z' = 1.96 - 57.66 with 52.3% in the 0 -10 range.

GRANODIORITIC: 17 pebbles Y'/Z' = 1.4 - 31.25 with 64.7% in the 0 - 10 range.

DIORITIC: 7 pebbles Y'/Z' = 3.63 - 18.5 with 71.4% in the 0 - 10 range.

AMPHIBOLITIC: 11pebbles Y'/Z' = 7.4 - 17 with 90.9% in the 10 - 20 range.

QUARTZO - FELDSPATHIC:

7 pebbles Y'/Z' = 6 -42.4 with 42.8% in the 0 -10 range and 28.4% in the 40 - 50 range.

The wide range of shape within granitic and quartzofeldspathic rocks may be a reflection of the fact that during high grade metamorphism these rocks were close to their minimal melting temperatures. The variable shape may also be the result of initial shape variation coupled with some competence difference during deformation. Thus, as stated by Ramsay (1967 p. 222), even if the restrictions resulting from the original differences could be overcome, the wide range in pebble shape makes it extremely difficult to calculate the bulk rock strain.

What can be said of the pebbles is that they form ellipsoids of flattening type (Flinn 1956) with long axes sub - parallel to the major fold axes. If their shape was only controlled by F_C similar folding, one would not expect to find ellipsoids of this form around the fold nose. The XY plane of strain ellipsoids in similar folds is always inclined at some angle to the layers, a high angle around fold noses a low angle on fold limbs. (Ramsay 1967 p. 429). In this case the XY plane of the ellipsoids lies within the foliation and the conglomerate occurs around the antiformal fold nose. Thus the shape of the pebbles was predominantly controlled by stress regimes operative during the earlier F_A or F_B fold episodes. Alternatively, they may have been flattened byemplacement of the Scuzzy Pluton. The earlier hypothesis is a possibility as striped amphibolites immediately below the conglomerate have amphibolitic layers which have been boudined (stretched within the foliation) by an earlier event, and then refolded by the F_C event. (see Plate 9).

MAJOR STRUCURE:

The three cross sections A - A', B - B', E - F - G, show successively deeper structural levels which are exposed as one goes from North to South.

The main fault in the area separates the Chilliwack group - Peninsula Formation rocks on Harrison Lake from the Breakenridge gneisses.

The northwest trending lineament in the north is interpreted as a shear zone which extends to great depth as a partially metamorphosed dunitic pod has been emplaced along it.

RELATIONSHIP BETWEEN METAMORPHISM AND DEFORMATION.

The time relationships between metamorphic recrystallization and deformation are critical to the elucidation of the geological history of any metamorphic terrain. The textural relationships between porphyroblasts and schistosity enable one to clarify the sequence of events which led to the final high grade recrystallization of the metamorphic rock. These features have been well documented by Zwart (1962), and Spry (1969), and enable one to assign the crystallization of a porphyroblast to a pre - syn or post - tectonic stage.

In this study the pelitic rocks of the Breakenridge and Cairn Needle formations, and the Chilliwack group - Peninsula Formation have been treated separately and an attempt has been made to relate similar generations of folds within each formation. With these folds and their related schistosities as reference points the metamorphic index minerals can be assigned to the appropriate stage of recrystallization. Examples from the rocks studied are shown in Plates 10 through 14.

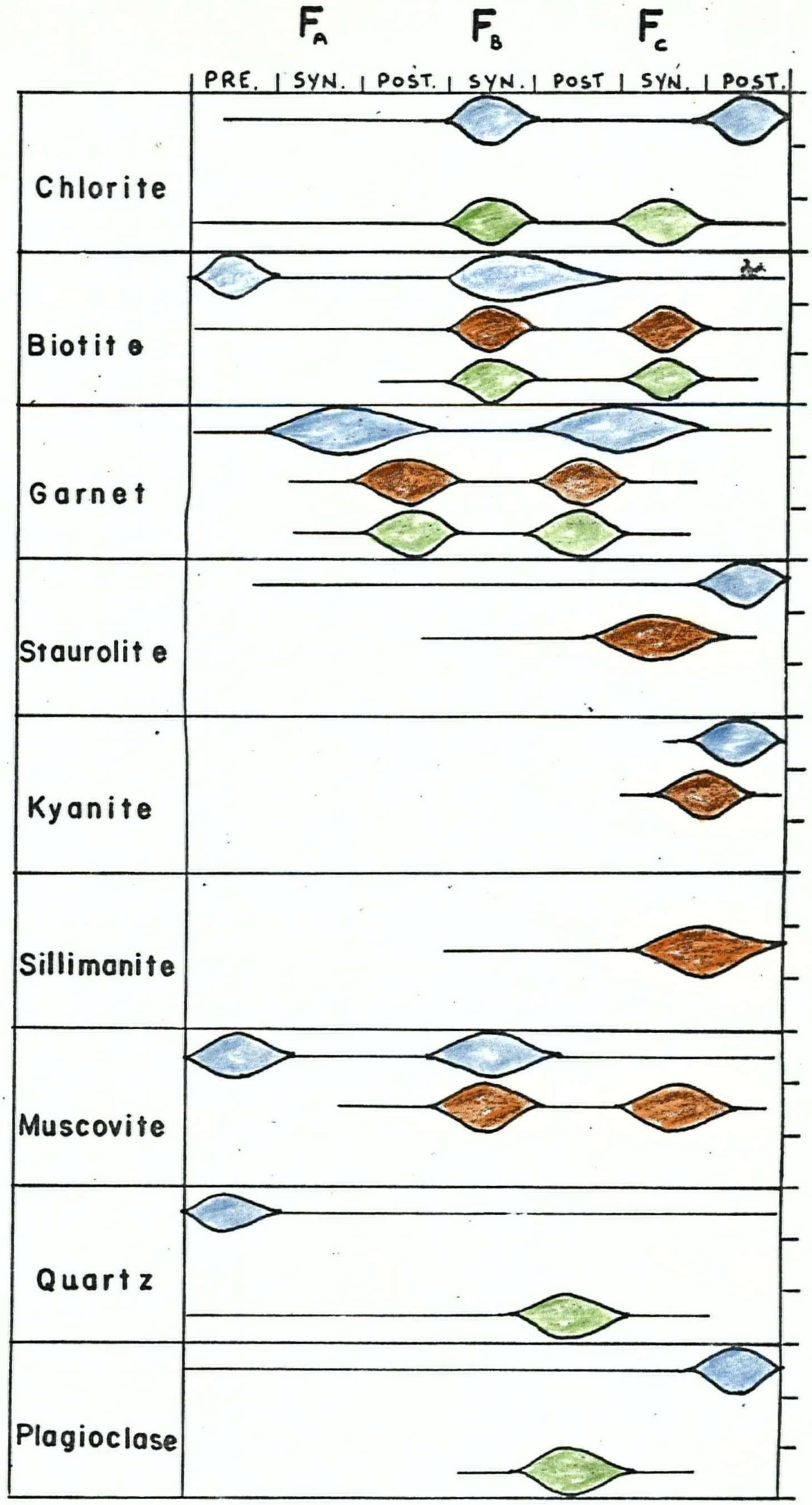
FIGURE 13.

Relationship between metamorphic recrystallization and folding episodes in the Mt. Breakenridge Area.

Green = Chilliwack Group- Peninsula Formation.

Blue = Breakenridge Formation.

Red = Cairn Needle Formation.



F_A
F_B
F_C
PRE.
SYN.
POST.
SYN.
POST
SYN.
POST.
Chlorite
Biotite
Garnet
Staurolite
Kyanite
Sillimanite
Muscovite
Quartz
Plagioclase

FIG 13

The history of recrystallization and deformation is summarised in Figure 13. The following conclusions can be drawn;-

i) Matrix formers (chlorite - biotite - muscovite) have a long history of crystallization and recrystallization having responded chemically and mechanically to every event both thermal and deformational.

ii) All the rock groups studied were at least at garnet grade before F_B.

iii) Within the Breakenridge group, staurolite is found included in pre - F_B garnets, but the main period of staurolite recrystallization is post - F_C. Similarly, Kyanite crystallized post - F_C.

iv) Staurolite in the Cairn Needle formation crystallized pre - kinematically to syn - kinematically with F_C, while sillimanite may be pre - F_C (plate 13), but mainly post - F_C. (Plate 14).

v) The major metamorphic recrystallization post - dated F_C. The simultaneous post - F_C crystallization of Kyanite in the Breakenridge formation and sillimanite in the Cairn Needle schists implies that a temperature gradient existed between the two formations at this time.

vi) Retrograde effects include chloritization of garnet and sericitization of kyanite. Within the rocks on Harrison Lake pre - F_B garnets are wholly retrogressed to chlorite. This retrogression may well be associated with the phase of thrusting.

Figure 14

The distribution of pelitic metamorphic index minerals which define the zones of metamorphism of the Mt. Breakenridge area.

Ch= Chlorite

Bi= Biotite

Gt= Garnet

St= Staurolite

Ky= Kyanite

S = Sillimanite

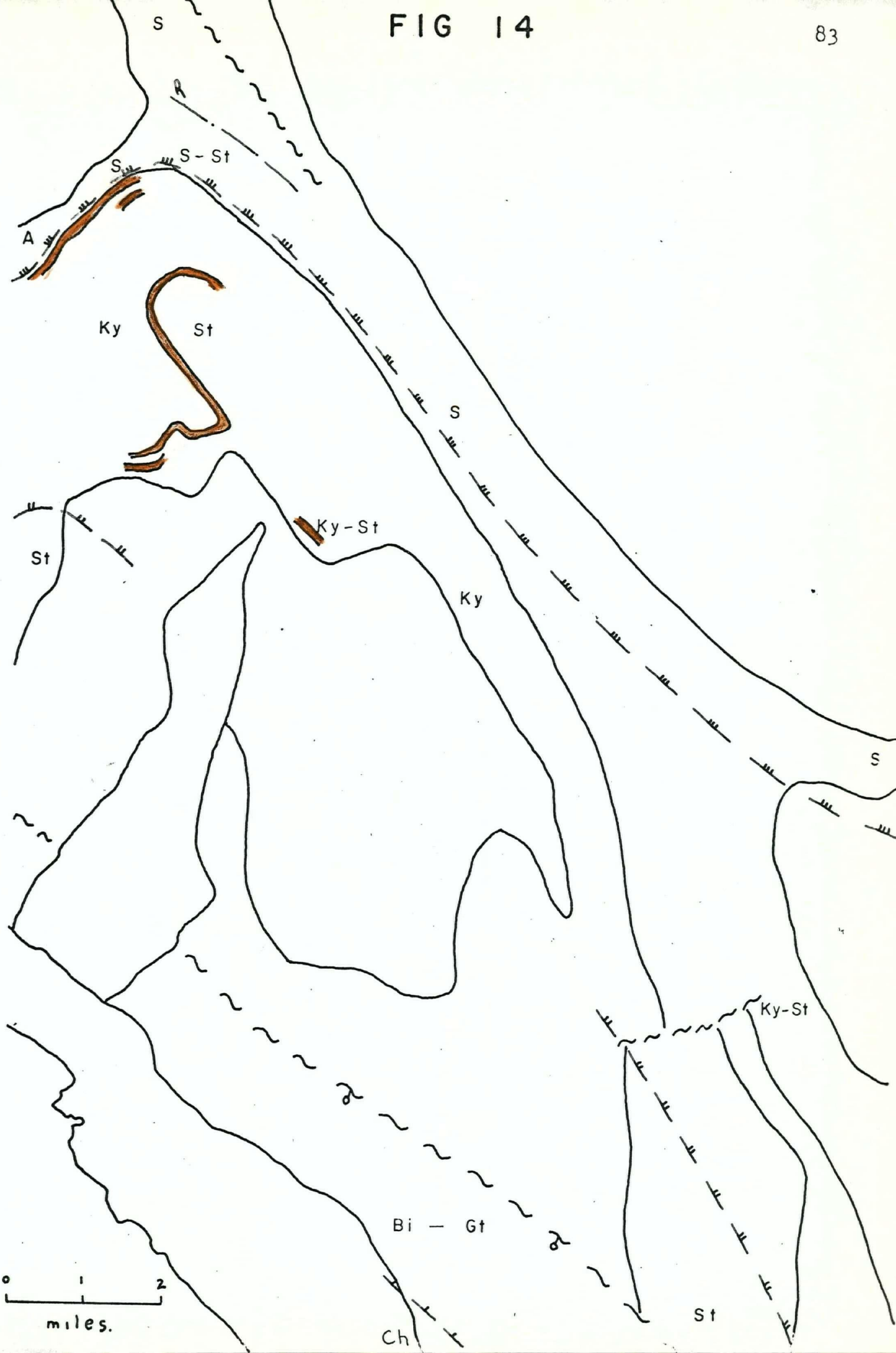
A = Andalusite

R = Reaction isograd

St + musc. + qtz = Sill. + bio.+ H_2O

Ky-st-gt-bi. gneiss shown in red

FIG 14



METAMORPHISM.

Two main phases of metamorphism are recognised in the area;-

a) A deep seated regional event which is broadly contemporaneous with the folding.

b) A higher level contact event which post dates all folding and is related to the emplacement of the Scuzzy Pluton.

a) Regional Metamorphism;

From the map Figure 14, it is apparent that the grade of metamorphism increases from the South to North, going through zones of chlorite, biotite - garnet, staurolite (ill - defined), staurolite - kyanite, and sillimanite bearing rocks. This facies series corresponds to the Kyanite - sillimanite (Barrovian) type of Miyashiro (1961).

The co-existing pelitic minerals within the successive zones plotted on AFM diagrams (Thompson 1957) of Figure 15, form one, two, three, four and five (if in some cases chlorite is consifered to be stable) phase assemblages. For divariant eouilibrium at constant P, T, in the simple six component model system, the presence of

FIGURE 15.

AFM diagrams of pelitic assemblages.
Chlorite to sillimanite grade.

FIG 15

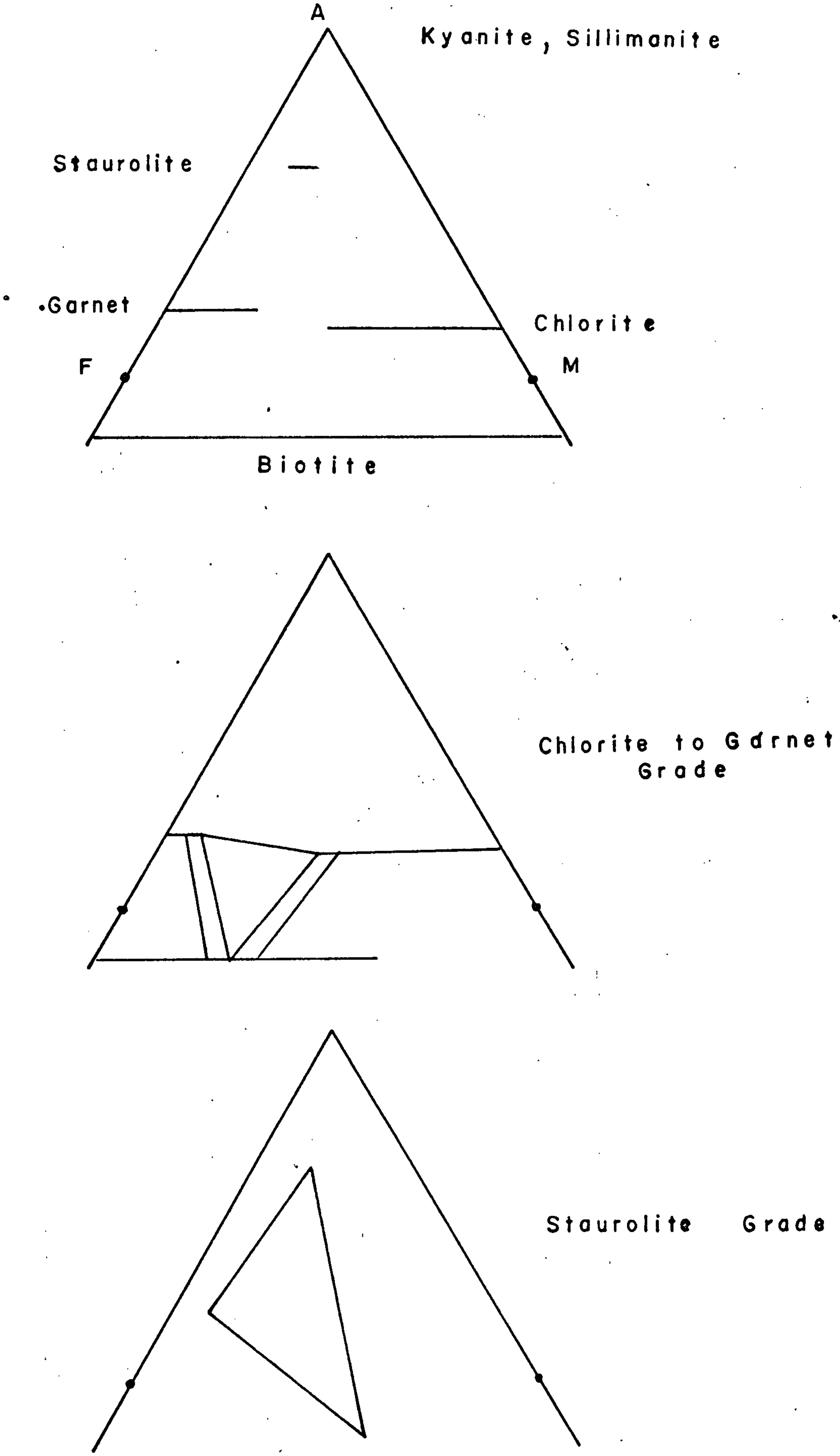

A
Kyanite, Sillimanite
Staurolite
Garnet
Chlorite
F
M
Biotite
Chlorite to Garnet Grade
Staurolite Grade

FIG 15a

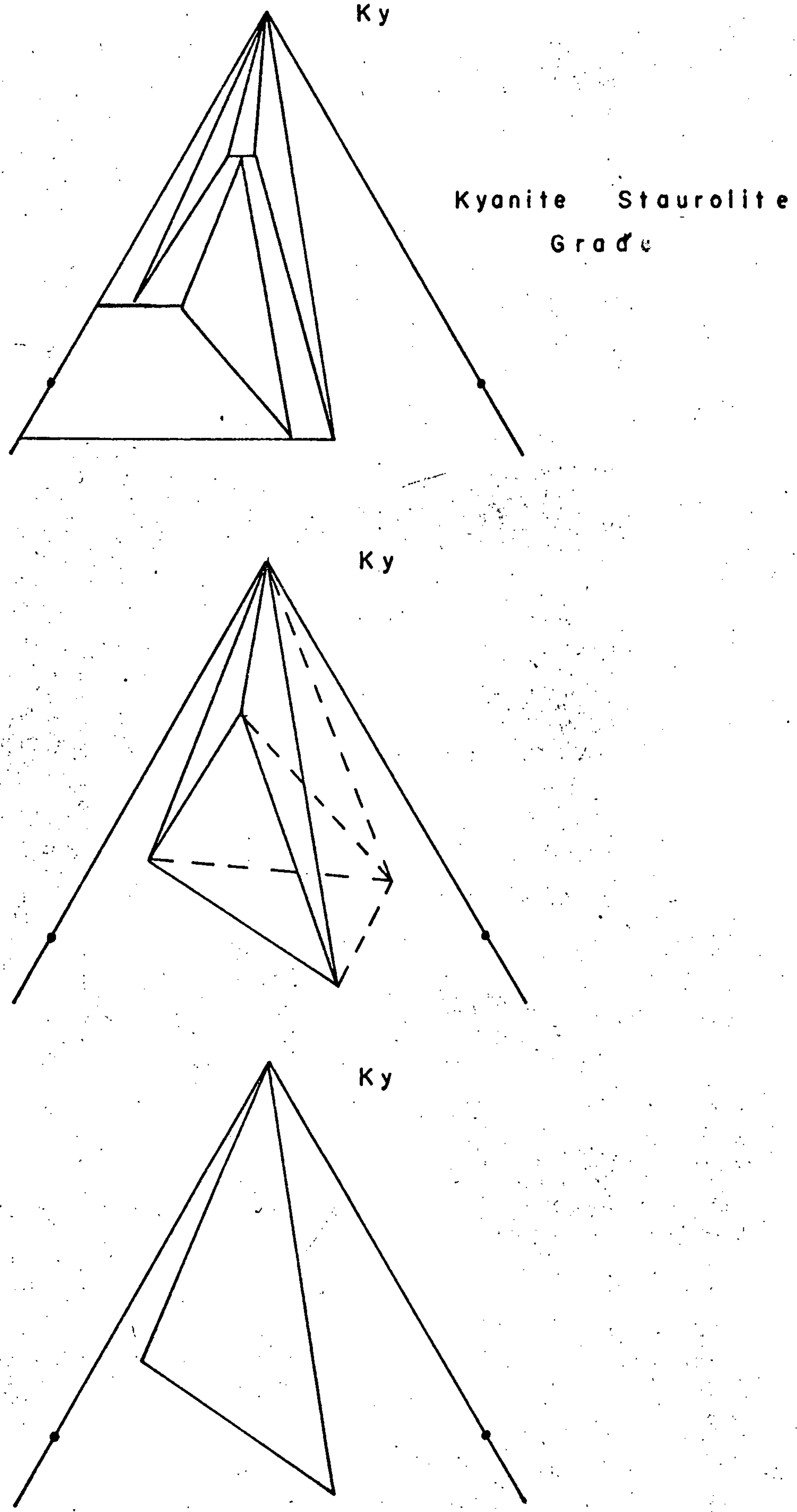
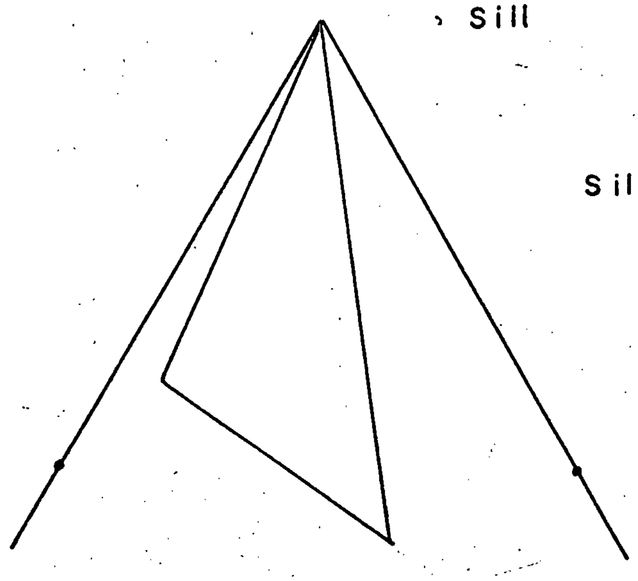
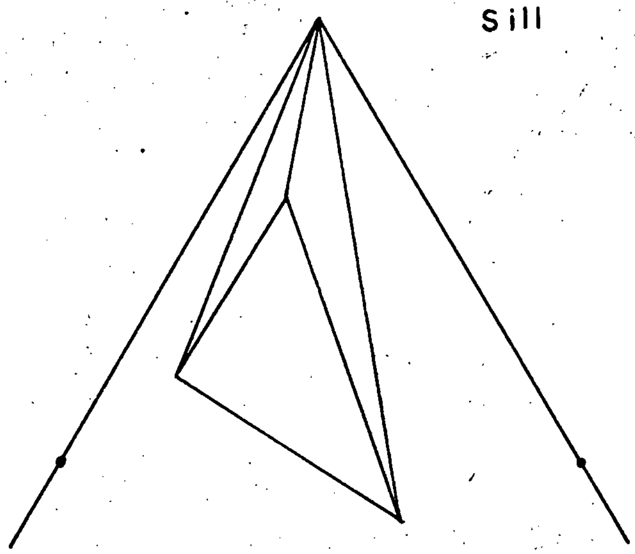


FIG 15 b





greater than three co-existing minerals plus muscovite and quartz, violates the phase rule. If the rocks are considered to approach equilibrium extra components (e.g. CaO, MnO in garnet, ZnO in staurolite) could stabilize the excess mineral within the A.F.M. diagram, thus satisfying the assumption of equilibrium.

Santer (1969) demonstrated that the assemblage biotite - garnet - staurolite and kyanite in the Breakenridge formation approached equilibrium and that the CaO content of the garnet was sufficient to stabilize this mineral within the system. However, Hollister (1966) has demonstrated that excluding a retrograde zone of MnO the outer zone of garnet in pelitic schists is often of pyrope almandine composition. Thus if the rock only has equilibrium relations with this portion of the garnet, the CaO, MnO contents are insufficient to stabilize the mineral within the system. In this case, the zinc content of staurolite may be important. Detailed microprobe analyses are required to resolve this problem.

The four phase assemblage staurolite - sillimanite biotite, garnet within the Cairn Needle schists has also been noted in the lower sillimanite zone of the Oquossoc area, Maine (Guidotti 1970). Here the excess phase has been explained by the fugacity of H_2O being buffered and internally controlled by such relations as :-

Low Zn. St. + Na musc. + Qtz. = Sill. + bio. + Zn. rich St. + K rich musc. + H_2O + Ab. ± Gt.

In this way water would have to be treated as an immobile component within the A.F.M. system and thus account for the extra phase.

A favourable model to view reaction processes within a polymetamorphic terrane is that used by Hollister, (1969) and Naggar and Atherton (1970). In this model early formed porphyroblast indicator minerals crystallize by groundmass reactions which attain equlibrium, and once formed are no longer involved in successive reactions. By the refractory nature of the early porphyroblasts the reacting system could be continuously changing composition. Thus in spite of the fact that the total assemblage did not crystallize together the progressive reaction assemblage could have attained equilibrium. In this way the assemblage biotite - garnet - staurolite - kyanite, which apparently violates the phase rule , is the result of an early reaction which produced garnet and a later equlibrium reaction which produced biotite - staurolite and kyanite.

POSSIBLE REACTIONS.

Staurolite.

As no chloritoid has been found in the pelites, staurolite may be the result of the following reaction.

-- Chlorite + muscovite = Staurolite + biotite + Qtz. + H_2O.

(Hoschek 1969)

Spec. 35/70 has the above assemblage plus garnet and may be close to this reaction.

Staurolite - Kyanite.

Within the staurolite - kyanite zone these minerals have crystallized simultaneously . As garnet may have acted as a refractory constituent it was not involved in the formation of staurolite and kyanite.

-- Mg/Fe chlorite + muscovite = biotite + staurolite + kyanite + H_2O.

(Naggar and Atherton 1970)

Sillimanite.

There is no textural evidence for the formation of sillimanite from kyanite. It is closely associated with micas or occurs as independent needles which mimic minor folds. Muscovite is stable with quartz and no potassium feldspar has been found. If magnesium rich chlorite is still stable to within the sillimanite zone the earliest sillimanite forming reaction may be;-

-- Mg chlorite + muscovite = Mg biotite + sillimanite + H_2O.

(Naggar and Atherton 1970)

In schists close to the boundary of Breakenridge and Cairn Needle Formations, sillimanite is associated with a minor amount of staurolite. Farther north, staurolite is absent. This could be the result of variable rock composition or of the reaction;-

--Staurolite + muscovite + quartz = Sillimanite + biotite + H_2O.

(Hoschek 1969)

OPAQUE MINERALS.

The opaque minerals present in pelitic rocks offer an important means of gaining information on the composition of the fluid phase present during metamorphism, and hence fugacities of oxygen and sulphur (P_{O_2} P_{S_2} etc.) Opaque minerals within the staurolite - kyanite zone and their associated silicates include :-

<u>FIGURE 16.</u>

Schematic chemical potential diagram of the system Fe - S - O - TiO_2 showing phases in equilibrium with ilmenite. (after Hounslow and Moore 1967)

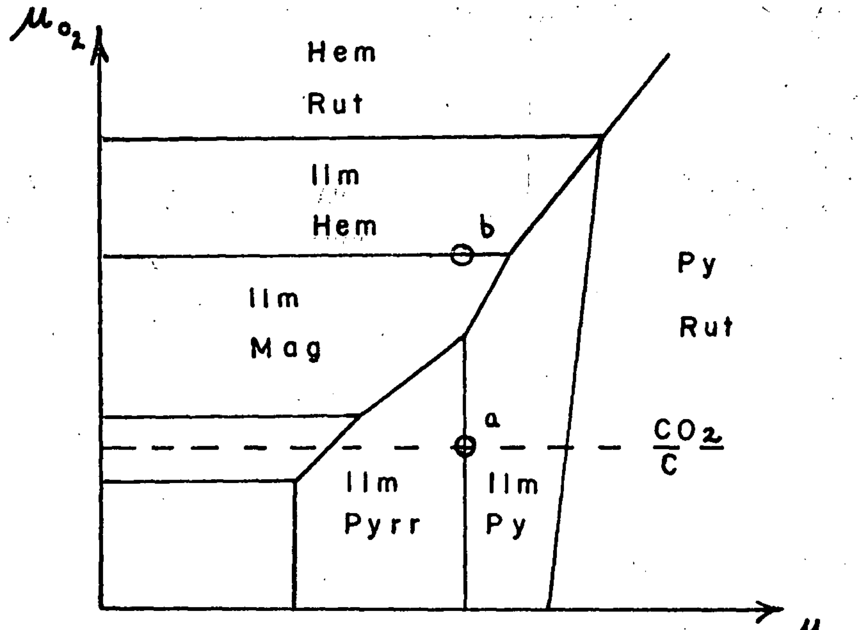


FIG 16

a) pyrrhotite - pyrite - ilmenite chalcopyrite - graphite.	biotite - garnet - staurolite - kyanite.
b) hematite - ilmenite - magnetite	"
c) ilmenite - graphite	biotite - garnet - kyanite.

The opaque assemblages buffer the f_{O_2} , f_{S_2} within a range similar to that of the staurolite grade rocks studied by Hounslow and Moore (1967). See Figure 16.

The distribution of staurolite is considered to be restricted by the host rock composition. (Williamson 1953) Ganguly (1968) has shown that in addition to this, the stability "field of staurolite is restricted to a limited range of f_{O_2} defined mostly in the upper part of the magnetite field, and has a narrow range of thermal stability". (Figure 17).

Further, the f_{O_2} dependant reaction ;-

-- 6St. + 3Qu. + $2O_2$ = 27Ky. + 4Mt. + $3H_2O$

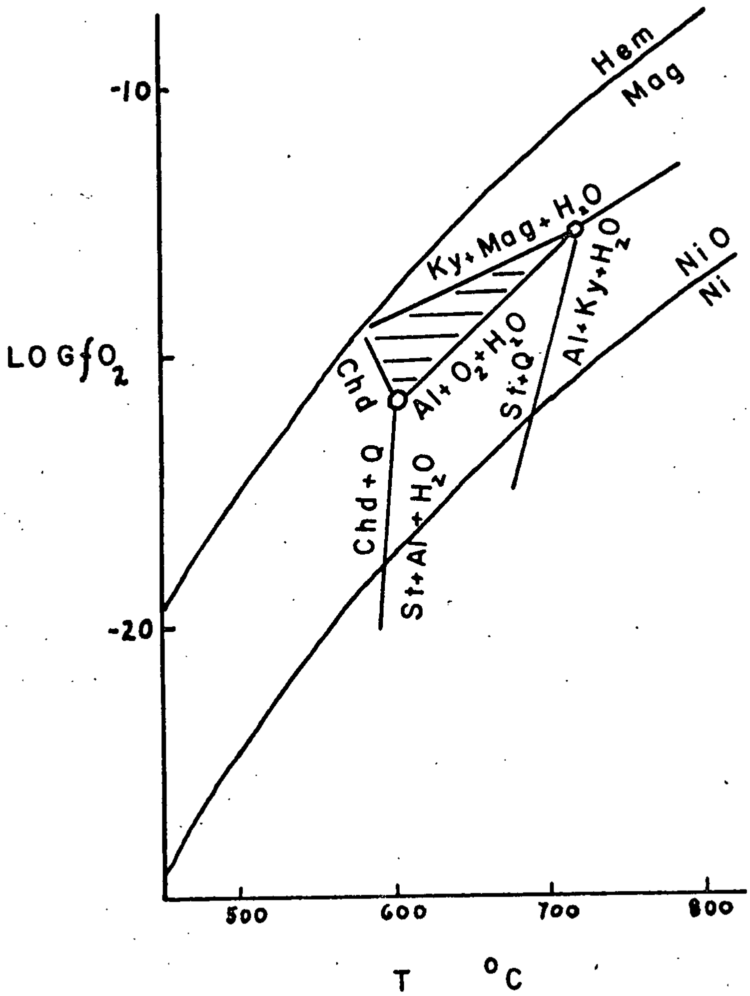
is cited to explain the restriction of staurolite to less

FIGURE 17.

Phase relations in the system $FeO-Al_2O_3 - SiO_2 - H_2O - O_2$. as functions of fo_2 and T. (10kb total pressure) aft er Ganguly 1968.

The stability field of staurolite and magnetite is shown cross-hatched.

FIG 17


Hem
Mag
-10
LOG fO_2
-20
Ky+Mag+H_2O
Chd
Al+O_2+H_2O
St+Q+O
Al+Ky+H_2O
Chd+Q
St+Al+H_2O
NiO
Ni
500
600
700
800
T °C

oxidized environments and kyanite to more oxidized ones. However in this study Staurolite is found in association with kyanite in both oxidized and reduced environments.

The staurolite and non staurolite assemblages, are closely associated within the main pelitic gneiss horizon in the Breakenridge formation. Staurolite, according to Ganguly, is incompatible with magnetite in f_{O_2} conditions equivalent to the lower magnetite field. (Figure 17). Such conditions may be realized by the presence of graphite in the rock. Thus the graphitic non staurolite bearing assemblage (c) could have passed directly to kyanite grade, by-passing staurolite by the reaction;

-- 12St + 46Mt. + 114Qu. = 54Alm. + $6H_2O$ + $23O_2$.

However if this was invariably the case one would not expect to find staurolite associated with assemblage (a). Thus, although theoretically staurolite stability may be restricted by f_{O_2} dependant reactions, the conflicting evidence discussed above suggests that rock bulk composition not only controls the presence of staurolite but also the f_{O_2}, f_{S_2} of the rock.

METAMORPHISM OF CALC SILICATES AND LIMESTONES.

Banded calc - silicates in Cairn Needle Formation;

The calc - silicates of the Cairn Needle formation are banded in a crudely symmetrical fashion. (Plate 15). Specimens 429/70 and 479/70 have the following zones, in which zones B to E are repeated on either side of the central zone A.

429 ;--

ZONE	ASSEMBLAGE	THICKNESS
A	Gt-hb-ep-sphene-qtz-plag (An44)	6 mm.
B	Hb-ep-gt-apatite-qtz-plag	4 mm.
C	Plag-qtz-ep-sphene-apatite	2 mm.
D	Hb-plag (An40)-sphene-qtz	10 mm.

479 ;--

ZONE	ASSEMBLAGE	THICKNESS
A	Di-gt-cz-plag(An66)-sphene-qtz	15 mm.
B	Plag-qtz- (hb-gt-sphene)	2 mm.
C	Hb-gt-sphene-qtz-plag(An56)	3 mm.
D	Hb-sphene-plag-qtz	5 mm.
E	Bi-qtz-plag-gt-sphene	10 mm.

The outer zones in specimen 479/70 are pelitic. These bands may be the result of chemical reactions which take place between carbonate rich rocks and interlayered carbonate free pelitic rocks, under open system conditions. Orville (1969 p.78) fully discusses how reaction between incompatible phases of the pelitic and calc - silicate rocks can produce zones rich in compatible phases such as garnet - clinopyroxene, plagioclase - clinopyroxene, hornblende - plagioclase and plagioclase - biotite. Vidale (1969) has carried out experimental reactions between limestone and pelite bands in the presence of chloride bearing hydrous fluid, which produce zones not unlike those of specimen 479/70. The high mobility of Ca, and K cations during these reactions may be reflected in the variation in plagioclase composition from central to outer zones, the composition of the garnet (Py_{46} Gr_{31} Al_{23}), and the lack of muscovite in the outer pelitic layers.

LIMESTONE.

The crystalline limestones and associated calc - silicates of the Cairn Needle formation are in the sillimanite zone. The mineral assemblages present are;-

LMST:- Calcite - tremolite - forsterite - muscovite.

Calc - Sil:- Grossular - diopside - clinozoisite - calcite - qtz.

FIGURE 18

Isobaric (1kb) T - X_{CO_2} diagram for reactions in metamorphosed siliceous dolomites. (after Metz and Trommsdorff 1968)

The stability field of the assemblage Forsterite + Tremolite + Calcite is shown ruled.

FIG 18

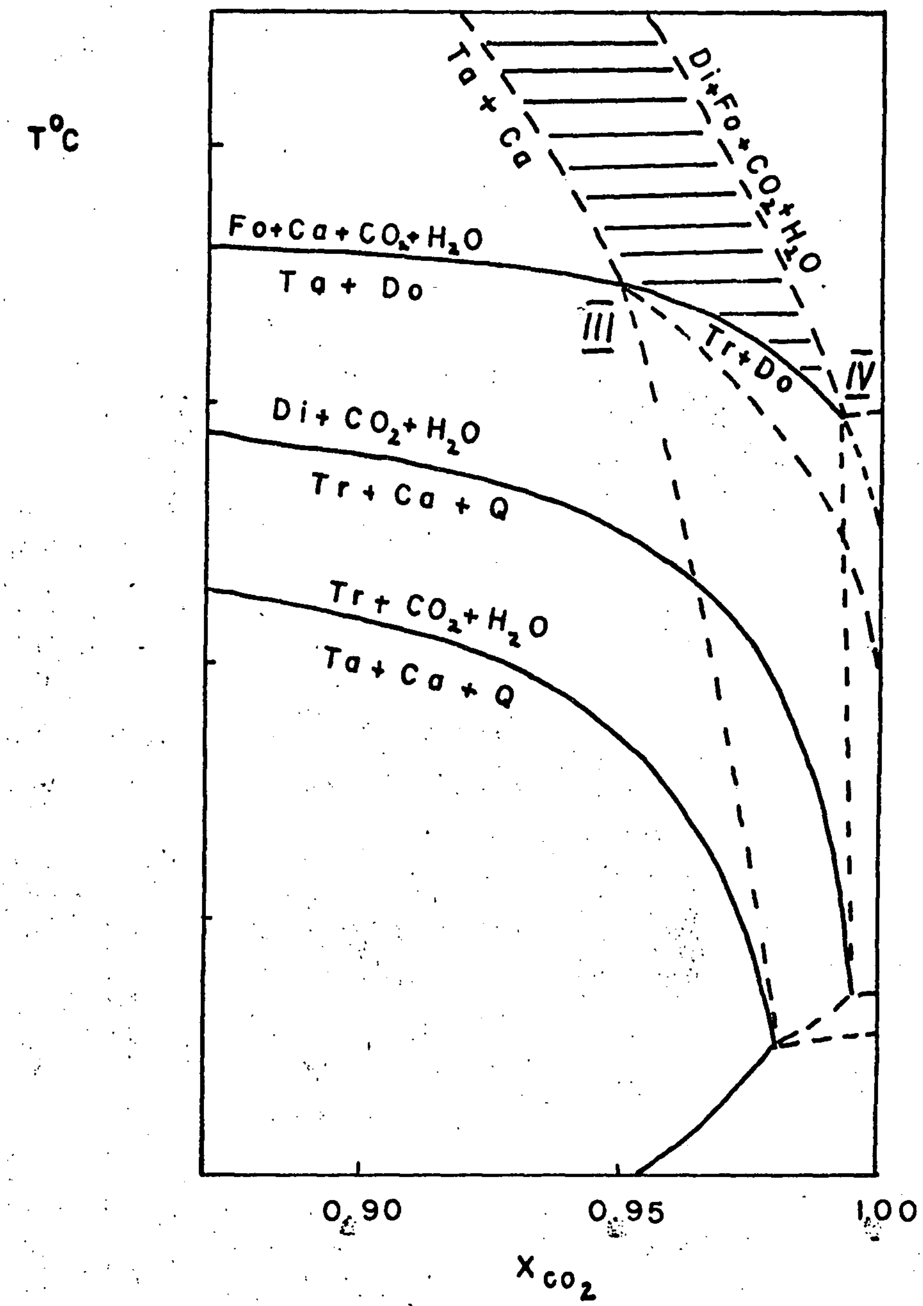
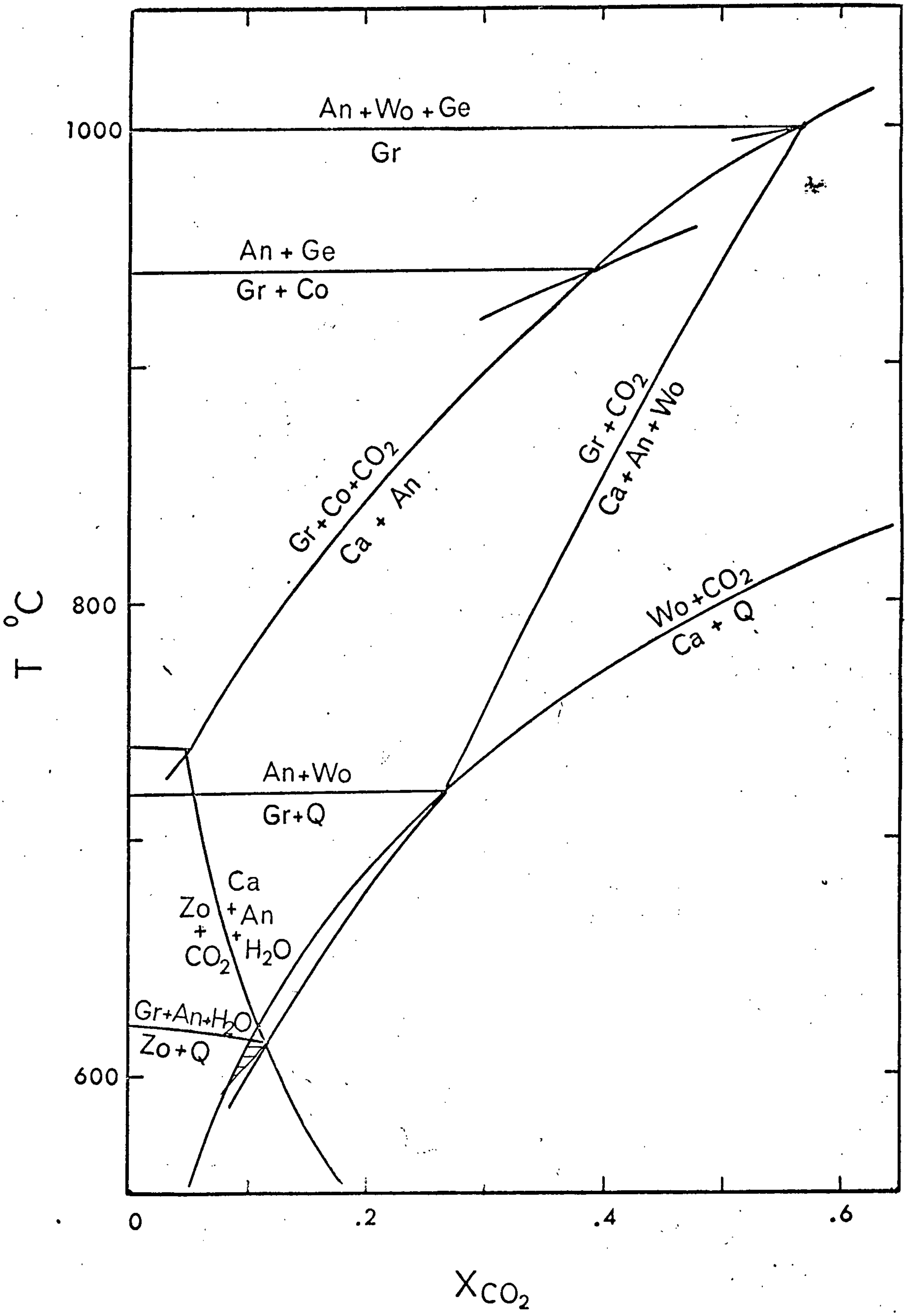

T°C
Ta + Ca
Di+Fo+CO2+H2O
Fo+Ca+CO2+H2O
Ta + Do
III
Tr+Do
IV
Di + CO2 + H2O
Tr + Ca + Q
Tr + CO2 + H2O
Ta + Ca + Q
0.90
0.95
1.00
X CO2

FIGURE 19.

Calculated T-X diagram for the CaO- Al_2O_3- SiO_2 - H_2O- CO_2 system at 5000 bars total pressure. (after Gordon 1968).

The stability field of the assemblage Calcite - quartz-zoisite - grossular is shown ruled.

FIG. 19.



An + Wo + Ge
Gr
An + Ge
Gr + Co
Gr + Co + CO2
Ca + An
Gr + CO2
Ca + An + Wo
Wo + CO2
Ca + Q
An + Wo
Gr + Q
Ca
+ An
+ H2O
Zo
+
CO2
Gr + An + H2O
Zo + Q
1000
800
600
T °C
0
.2
.4
.6
XCO2

The limestone assemblage has a stability field, in the system $CaO - MgO - SiO_2 - H_2O - CO_2$, which is shown in Figure 18. (Metz and Tromsdorff. 1968)

It is probably the result of the reaction;-

1 Tremolite + 11 Dolomite = 8 Forsterite + 13 Calcite+ $9CO_2$ +$1H_2O$.

Equlibrium temperatures of reactions in Figure 18 were determined at 1 Kb. As the forsterite forming reaction occured at pressures above the alumino - silicate triple point (5.5 Kb), the extrapolated temperature would be around 670^oC. The assemblage forsterite - calcite - tremolite is stable with a fluid phase which has a high mole fraction of CO_2 (X_{CO2}).

The calc - silicate assemblage can be represented in the system $CaO - Al_2O_3 - SiO_2 - H_2O - CO_2$. The stability field of zoisite, grossular, calcite and quartz is fixed within a very narrow temperature and X_{CO_2} range. Figure 19, after Gordon (1968), shows that at 5 Kb this assemblage would co-exist with a fluid phase with $X_{CO_2} = 0.1$, ata temperature of $600^o \pm$. It is likely that no temperature gradient existed between these assemblages, as they are so closely associated. However, the composition (X_{CO_2}) of the fluid phase was buffered and internally controlled by the mineral assemblage with which it co-existed. Thus extreme gradients in fluid composition existed during metamorphism.

b) <u>Contact Metamorphism.</u>

Assemblages of pelitic minerals around the Scuzzy Pluton on Cairn Needle include;-

i) Andalusite - garnet - biotite.

ii) Andalusite - sillimanite - garnet - biotite.

iii) Sillimanite - garnet - biotite.

In addition they contain muscovite and quartz, and no cordierite has been found. Andalusite has only been found immediately to the South of Cairn Needle, forming elongate (4cm.) crystals with striking chiastolite crosses. The sillimanite forms similar robust elongate crystals with good (010) cleavage.

The alumino - silicates appear to have crystallized independantly of one another, the association of both apparently being due to the metastable persistence of an earlier porphyroblast.

A striking feature of the alumino - silicates is their ubiquitous replacement by large plates of muscovite. Varying stages of replacement are shown in Plates 16, 17, 18. Within these platey aggregates are tiny needles of sillimanite. Thus the waning stages of metamorphism may have been marked by a stage of metasomatism not unlike that noted in the aureole of the Thorr granodiorite in Donegal. (Pitcher and Read, 1963).

PETROGENETIC GRID :-

The P.T. conditions of metamorphism are estimated by comparing the natural mineral assemblages with experimental data. Figure 20 shows the physical conditions which existed during the regional and contact metamorphism of this study, as defined by the data for the alumino - silicates (Richardson, Gilbert, Bell. 1969), staurolite (Hoschek 1969) and the breakdown of muscovite. (Evans 1965).

The P.T. conditions of regional metamorphism ranged from 300 to 670°C, above 5.5 Kb, while those of the contact metamorphism were around 550 to 650°C at 3 to 5.5 Kb.

Figure 20

Petrogenetic grid showing P.T. conditions of regional (R) and contact (C) metamorphism as defined by

a) Aluminum silicate curves and triple point with uncertainty area .(Richardson, Gilbert, and Bell. 1969)

b) Ch. + musc. = St + bio. + qtz. + H_2O

(Hoschek , 1969)

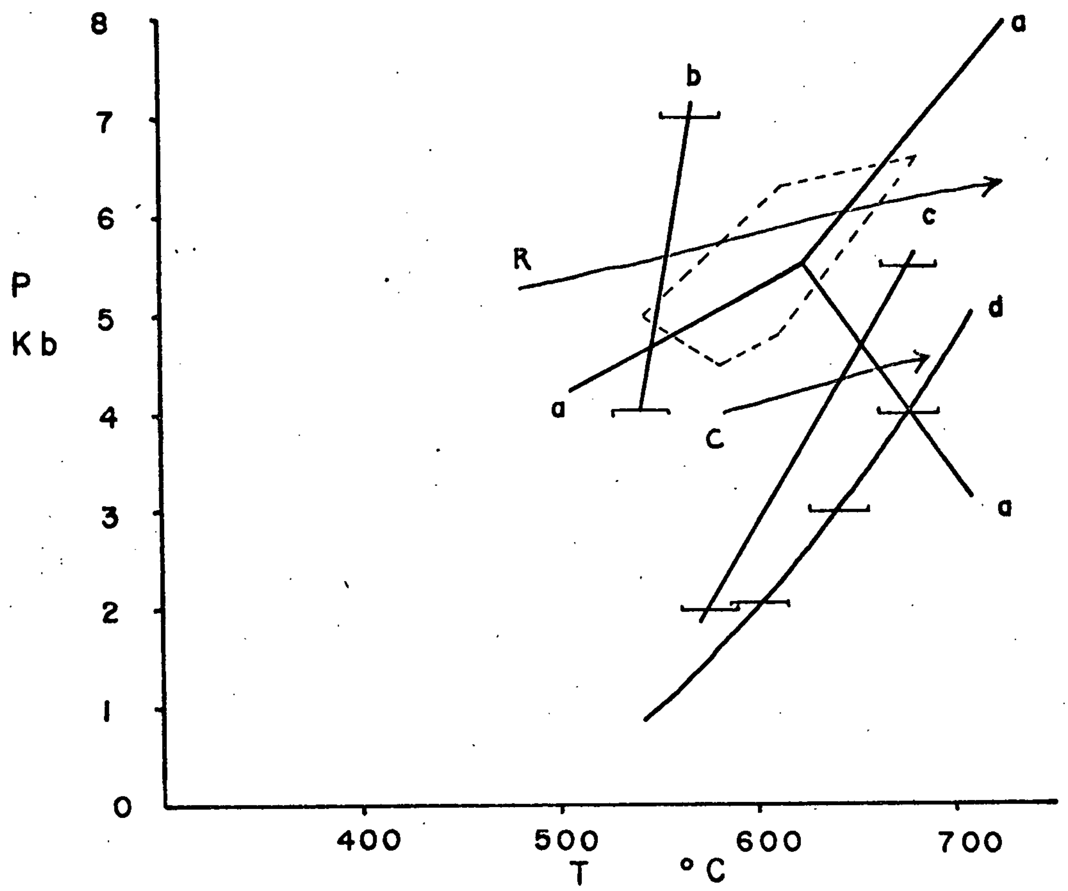
c) ST +musc. + qtz. = Al-Sil. + bio. + H_2O

(Hoschek , 1969)

d) Musc. + qtz. = K-feldspar + Al_2SiO_5 + H_2O

(Evans,1965.)

FIG 20



SUMMARY

a) The major map units studied include;

i) BREAKENRIDGE FORMATION:

A eugeosynclinal sequence of volcanics, graywacke and minor pelite which has been metamorphosed to amphibolite, grey granodioritic gneiss, kyanite gneiss and migmatite.

ii) CAIRN NEEDLE FORMATION.:

A sequence of pelitic schist, garnet hornblende schist, calc - silicate, crystalline limestone, sheared conglomerate with granitic clasts, and metamorphosed basic igneous granulite. The meta sedimentary units were deposited in a shallow water marine environment.

iii) CHILLIWACK GROUP - Peninsula Formation.

A sequence of clastic grits, conglomerate (with granitic clasts), pelite and calc - silicate which is in fault contact with the Breakenridge and Cairn Needle Formations.

iv) IGNEOUS ROCKS:

The main plutonic rocks are the gneissic granodiorite/quartz diorite of Mount Breakenridge which is cored by quartz andesine porphry and quartz diorite, and the Scuzzy granodiorite/ quartz diorite. Minor intrusions of dunite, peridotite and andesite dykes are also present.

b) CORRELATION AND AGES.

The ages of the metamorphosed rocks based on correlation with similar lithologies of known ages are:

Breakenridge Formation:- Upper Paleozoic.
Cairn Needle Formation:- Mesozoic probably Jurassic.
Chilliwack Group - Peninsula Formation:- Upper Paleozoic-L. Cretaceous.

The Scuzzy Pluton is Upper Cretaceous in age ((70 m.yrs.). The epizonal core of the Mt. Breakenridge plutonic complex is probably of Early Tertiary age (40 m.yrs.) while the gneissic granodiorite is post-Jurassic, pre-Mid Cretaceous in age.

c) STRUCTURE AND DEFORMATION.

Between the Jurassic and Mid-Cretaceous the rocks were folded into antiforms and synforms with a northwest trend and plunge (329/56). Minor fold relationships indicate at least three phases of folding with the latter two (F_B, F_C) being essentially homoaxial.

A similar mechanism is deduced for the latest phase of folding (F_C). A Mid-Cretaceous reverse fault juxtaposed Breakenridge and Cairn Needle formations against Chilliwack Group - Peninsula Formation rocks.

d) The relationship between recrystallization and deformation.

Prior to the second episode of folding (F_B) the metamorphic rocks were at least at garnet grade. Maximum recrystallization occured after the latest phase of folding (F_C) as both kyanite and sillimanite post date this event.

e) METAMORPHISM.

The metamorphic rocks form a kyanite - sillimanite facies series, with grade increasing rapidly from South to North. The P.T. conditions of regional metamorphism range from 300-670° above 5.5 Kb. Multiphase mineral assemblages in pelitic gneiss are considered to have approached equilibrium. The mineral assemblages of pelitic and calcareous rocks are considered to have played an important role in controlling the composition of the fluid phase. Retrogressive metamorphism accompanied the phase of Mid - Cretaceous faulting. Contact metamorphism associated with the emplacement of the Scuzzy Pluton (U. Cretaceous) produced andalusite and sillimanite bearing schists.

CONCLUSIONS.

Upper Paleozoic and Mesozoic strata of the Mount Breakenridge region were folded, metamorphosed and migmatized between the Jurassic and Mid-Cretaceous. A period of uplift, faulting and minor retrogressive metamorphism in the Mid-Cretaceous was followed in Upper Cretaceous by the intrusion of the Scuzzy Pluton. Andalusite and sillimanite bearing schists were produced in the contact aureole of the latter intrusion. Uplift continued at the rate of 2-3 km/million years. In the early Tertiary a porphyritic quartz diorite intruded the core of the gneissic granodiorite on Mount Breakenridge.

FURTHER WORK

Mapping will be continued to the East and Southeast of the present area, between latitudes 49°35' and 49°45', and longitudes 121°40' and 121°45', to relate the structure, metamorphism and plutonism of that area to the present work.

Detailed microprobe analyses will be carried out on minerals of pelitic gneisses to determine how closely, and by which reactions, the rocks approached chemical equilibrium, and to document chemical variation in minerals with increasing grade of metamorphism.

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APPENDIX.

TABLE 2

Grey gneiss of Breakenridge Formation;

SPEC. NO.	18/70	44/70	202/70	206/70	298/70	381/70	511/70
Qtz.	30	35	30	30	35	35	35
Plag.	30(12)	30(10)	40(12)	25(24)	25(32)	35(30)	40(10)
Bio.	20	25	15	20	30	20	10
Musc.	5	1	1	-	-	5	5
Garnet	2	5	1	2	3	1	-
Chlorite	2	1	5	-	1	1	-
Epidote	2	1	5	3	5	1	2
Sphene	1	-	1	-	-	-	-
Apatite	1	1	1	1	-	1	3
Pyrite	-	-	-	-	-	-	-
Magnetite	1	1	-	-	-	1	-
Sericite	-	-	1	-	1	-	-
Calcite	-	-	1	-	-	-	-
Microcline	-	-	-	20	-	-	5
Zircon.	-	-	-	-	-	-	-

Modes estimated by eye.

Anorthite content of plagioclase is shown in brackets.

TABLE 2 (contd.)

SPEC. NO.	23/69	HS68/29	HS68/72	41/69
Qtz.	35	45	40	15
Plag.	20(16)	10(10)	20(20)	60(34)
Bio.	15	5	25	15
Musc.	-	3	10	5
Garnet	15	-	-	1
Chlorite	3	1	-	1
Epidote	1	-	-	-
Sphene	-	-	-	-
Apatite	1	1	1	1
Pyrite	-	-	-	-
Magnetite	2	1	1	1
Sericite	-	-	3	-
Calcite	-	-	-	-
Microcline	-	35	-	-
Zircon	-	-	-	1

TABLE 3

Amphibolites of Breakenridge Formation.

SPEC. NO.	HS68/43	12/69	42/69	12b/69	47/69	HS68/73
Qtz.	35	20	15	25	20	20
Plag.	25(43)	30(38)	35(42)	30(34)	30(42)	20(36
Bio.	5	2	5	25	-	-
Garnet	5	-	10	-	10	-
Hornblende	30	25	30	15	30	60
Epidote	-	15	-	4	5	-
Apatite	1	-	1	-	-	1
Magnetite	1	-	3	-	2	1
Chlorite	1	2	-	-	1	-
Sericite	-	1	-	-	-	-
Sphene	-	1	-	1	1	-
Zircon	-	-	1	-	-	-
Pyrite	-	-	-	-	1	-

Modes estimated by eye.

Anorthite content of plagioclase is shown in brackets.

TABLE 3 (contd.)

SPEC. NO.	331/70	388/70	485/70	HS68/70
Quartz	20	15	25	20
Plag.	30	25(40)	25(36)	30(40)
Bio.	-	-	5	1
Garnet	-	5	-	10
Hornblende	30	50	40	30
Epidote	5	1	1	5
Apatite	1	1	-	1
Magnetite	1	2	-	3
Chlorite	10	-	-	5
Sericite	-	-	3	-
Sphene	-	-	3	-
Zircon	-	-	-	-
Pyrite	-	-	-	-
Diopside	-	-	-	-
Calcite	-	-	-	-
Muscovite	-	-	1	-

TABLE 3 (contd.)

SPEC. NO.	HS68/57	149/70	191/70	218/70	263/70
Qtz.	10	20	20	30	25
Plag.	10(43)	30(40)	20(38)	20(30)	25(30)
Bio.	-	1	5	-	10
Garnet	-	10	-	-	10
Hornblende	30	30	50	55	10
Epidote	5	5	-	1	5
Apatite	1	1	1	1	1
Magnetite	-	3	-	5	1
Chlorite	-	5	1	-	-
Sericite	-	-	1	-	-
Sphene	1	-	1	-	-
Zircon	-	-	-	-	-
Pyrite	-	-	-	-	-
Diopside	30	-	-	-	-
Calcite	10	-	-	-	-
Muscovite	1	-	1	-	-

TABLE 4

Pelitic gneiss of Breakenridge Formation

SPEC. NO.	H3	H4	H5	H6	H7	H8
Qtz.	40	20	20	20	20	20
Plag.	20	10	50(40)	15	20	20(42
Chlorite	1	1(S)	1(S)	1	1(S)	1
Bio.	20	10	15	15	15	10
Muscovite	10	3	2	10	2	2
Garnet	3	50	6	25	30	40
Staurolite	2	2	3	15	3	5
Kyanite	5	5	2	-	10	3
Apatite	1	-	1	1	1	-
Zircon	1	-	1	-	1	-
Magnetite	1	1	1	1	1	1
Sphene	-	1	1	-	1	1

Modes estimated by eye.

Plagioclase content is shown in brackets. % Anorthite.

Texturally stable chlorite indicated by (S).

TABLE 4 (contd.)

SPEC. NO.	HS68 47-1	HS68 47-3	159/70	217/70	235/70	243/70
Qtz.	25	15	20	20	20	10
Plag.	35(49)	25	15(34)	10(32)	30	10(32)
Chlorite	1	2(S)	5(S)	5(S)	1	1
Bio.	25	10	1	5	5	5
Muscovite	5	5	20	5	5	3
Garnet	5	30	15	30	15	45
Staurolite	-	2	5	30	20	15
Kyanite	-	6	-	10	10	15
Sillimanite	-	3	-	-	-	-
Apatite	1	-	-	-	-	-
Zircon	-	1	-	-	-	-
Magnetite	5	1	5	5	-	2
Sphene	-	1	-	1	-	-
Epidote	1	-	-	-	-	-
Hornblende	-	-	25	-	-	-

TABLE 4 (contd.)

SPEC. NO.	244/70	251/70	264/70	280/70	303/70	304/70
Qtz.	20	20	30	25	20	20
Plag.	25	10(28)	15	15(34)	10(44)	20(36
Chlorite	1	-	1	1	1	1
Bio.	5	-	5	5	5	10
Muscovite	5	5	10	5	20	3
Garnet	25	25	20	30	20	20
Staurolite	-	5	5	5	10	5
Kyanite	15	20	10	15	5	15
Opaque	5	5	5	1	5	1
Sphene	-	-	-	1	-	1
Graphite	5	-	-	-	-	-

TABLE 4 (contd.)

SPEC. NO.	325/70	361/70	376/70	377/70	378/70	383/70
Qtz.	20	20	40	15	10	20
Plag.	20(34)	40(45)	-	35	30(48)	10(50)
Chlorite	1	-	1	2	1	5
Bio.	5	20	-	-	15	5
Muscovite	10	1	15	1	1	5
Garnet	20	-	-	5	20	30
Staurolite	20	5	-	2	20	10
Kyanite	5	5	40	30	5	10
Apatite	-	-	-	1	1	-
Zircon	-	1	-	-	-	-
Opaque	1	10	1	1	3	5
Sphene	-	-	2	-	1	-
Epidote	-	1	1	5	-	-
Hornblende	-	-	-	25	15	-
Tourmaline	-	-	1	-	-	-

TABLE 4 (contd.)

SPEC. NO.	387/70	447/70	453/70	467/70	468/70
Qtz.	10	30	40	20	25
Plag.	20(50)	10	5	15(37)	10
Chlorite	2	1	1	-	-
Bio.	1	20	5	20	5
Muscovite	20	10	25	3	5
Staurolite	5	1	5	1	10
Kyanite	15	15	15	30	10
Sillimanite	-	-	-	1	-
Apatite	-	1	-	-	-
Opaque	3	1	1	5	1
Sphene	-	1	-	-	-
Tourmaline	-	-	-	1	1

TABLE 5

Migmatites of Breakenridge Formation.

SPEC NO.	HS6859	HS6860	HS6871	206/70/L	206/70/M
Qtz.	30	30	30	45	25
Plag.	30(33)	30(28)	30(44)	45(28)	25(35)
Bio.	15	20	20	10	20
Hornblende	15	10	15	-	20
Garnet	-	1	1	-	-
Chlorite	1	2	-	-	-
Epidote	2	2	4	5	6
Muscovite	-	2	-	1	-
Apatite	1	1	1	-	1
Magnetite	1	1	1	-	-
Sericite	1	1	-	-	-
Zircon	-	-	1	-	-
Sphene	-	-	-	-	4

TABLE 5 (contd.)

SPEC NO.	HS6869	319/70	330/70	373/70	194/70
Qtz.	30	30	35	30	20
Plag.	30(31)	40(30)	35(30)	35(30)	-
Bio.	20	20	5	25	-
Hornblende	10	-	20	-	-
Garnet	5	-	1	2	50
Chlorite	1	-	1	1	-
Epidote	2	2	1	1	20
Muscovite	1	2	-	5	-
Apatite	1	1	1	1	-
Magnetite	1	1	-	4	-
Sericite	1	-	-	1	-
Sphene	-	-	-	-	-
Microcline	-	5	-	-	-
Hedenbergite	-	-	-	-	10

Anorthite content of Plagioclse shown in brackets.

Modes estimated by eye.

TABLE 6

Calc - Silicates of Cairn Needle Formation.

SPEC. NO.	429/70	441/70	446/70	479/70	504/70
Qtz.	25	30	15	20	30
Plag.	35	20	30	30	5
Epidote	10	5	30	-	-
Chlorite	1	-	5	-	1
Garnet	10	20	5	10	-
Hornblende	20	15	10	10	-
Diopside	-	5	-	5	20
Apatite	1	-	-	2	-
Sphene	1	2	2	5	5
Magnetite	-	1	-	3	5
Sericite	-	1	3	-	-
Bio.	-	-	-	5	-
Clinozoisite	-	-	-	5	5
Tremolite	-	-	-	-	10
Pyrite	-	-	-	-	1

Modes estimated by eye.

TABLE 7

Limestone of Cairn Needle Formation.

SPEC. NO.	494/70	495/70	500/70
Qtz.	-	10	-
Calcite	95	5	55
Tremolite	-	-	15
Diopside	-	25	-
Olivine	-	-	20
Garnet	-	40	-
Clinozoisite	-	15	-
Chlorite	-	-	5
Muscovite	-	-	-5
Magnetite	5	-	-

TABLE 8

Garnet - Hornblende Schist and Amphibolite of Cairn Needle Formation.

SPEC. NO.	24/69	HS68 73-2	HS68 74	445/70	505/70	139/70
Qtz.	25	35	25	25	30	30
Plag.	25(37)	25(38)	25(32)	25(44)	25	15(40)
Muscovite	-	1	-	-	-	-
Chlorite	-	2	-	-	-	-
Bio.	15	20	12	2	1	5
Garnet	5	5	-	5	10	20
Hornblende	25	7	35	40	30	30
Pyrite	-	-	-	-	3	-
Sphene	-	-	1	-	-	-
Magnetite	3	2	1	2	2	-
Apatite	2	1	1	1	-	-
Sericite	-	1	-	-	-	-

Modes estimated by eye.

Anorthite content of Plagioclase shown in brackets.

TABLE 9

Pelitic Schists of Cairn Needle Formation.

SPEC. NO.	HS68/53	25/69	39/69	HS68/4-1	HS68/78-2
Qtz.	25	35	20	40	25
Plag.	10	10	20(26)	30(40)	10
Chlorite	-	2	3	1	7(S)
Bio.	30	20	25	25	10
Garnet	10	8	5	4	5
Staurolite	-	6	-	-	-
Kyanite	-	3	-	-	-
Sillimanite	15	-	3	-	-
Muscovite	-	5	5	-	-
Gedrite	-	-	-	-	40
Tourmaline	-	1	-	-	-
Apatite	1	-	1	1	1
Zircon	1	-	1	1	-
Magnetite	3	-	5	1	1
Pyrite	-	5	-	-	-
Rutile	-	-	1	-	-
Sphene	-	-	-	-	1

Modes estimated by eye.

Anorthite content of Plagioclase shown in brackets.

Texturally stable chlorite shown by (S).

TABLE 9 (contd.)

SPEC. NO.	HS68 45	HS68 4-2	HS68 54	HS68 75	HS68 77	HS68 78
Qtz.	20	30	25	50	40	55
Plag.	30(15)	30(10)	25(36)	10(26)	20	5
Chlorite	5	2	5	2	1	1
Bio.	35	20	25	30	20	25
Garnet	5	15	10	10	10	10
Staurolite	-	-	-	-	5	3
Sillimanite	-	-	5	-	-	-
Muscovite	5	1	1	1	-	-
Tourmaline	1	-	-	-	1	1
Apatite	-	1	1	2	1	-
Zircon	-	-	1	-	1	-
Magnetite	-	1	1	5	2	2
Pyrite	2	-	-	-	-	-

TABLE 9 (contd.)

SPEC. NO.	HS68/79	35/70	427/70	459/70	460/70
Qtz.	30	45	15	25	35
Plag.	25(33)	5	10(28)	10	10(31)
Chlorite	-	15(S)	-	-	-
Bio.	5	15	10	15	30
Garnet	5	10	30	15	5
Staurolite	15	5	5	-	-
Sillimanite	-	-	20	-	10
Andalusite	-	-	-	10	-
Muscovite	18	1	5	20	10
Tourmaline	1	1	-	-	-
Apatite	1	-	-	-	-
Magnetite	1	1	1	-	3
Sphene	-	-	1	1	-

TABLE 9 (contd.)

SPEC. NO.	462/70	465/70	503/70	510/70
Qtz.	20	30	30	15
Plag.	15(34)	5(32)	5	20(44)
Bio.	25	15	15	5
Garnet	8	15	10	50
Staurolite	-	5	-	1
Sillimanite	-	20	20	10
Muscovite	30	10	15	1
Magnetite	3	-	5	2
Sphene	-	-	-	1

TABLE 10

Pegmatites of Breakenridge and Cairn Needle Formations.

SPEC. NO.	142/70	269/70	285/70	338/70	396/70
Qtz.	30	30	30	50	30
Plag.	25(8)	40(12)	50(4)	45(10)	50(8)
Microcline	15	-	-	-	-
Orthoclase	10	-	-	-	-
Muscovite	5	1	3	3	-
Bio.	5	15	15	1	15
Garnet	1	-	-	-	1
Chlorite	1	-	1	-	1
Epidote	1	5	1	1	1
Apatite	1	-	-	-	1
Zircon	-	-	-	-	1

Modes estimated by eye.

Anorthite content of Plagioclase shown in brackets.

TABLE 11

Metarudites and Pelites of Chilliwack Group or Peninsula Formation.

SPEC. NO.	HS68 80-2	HS68 40-1	HS68 40-2	HS68 80-1	HS68 80-3
Qtz.	30	30	25	30	30
Plag.	10	25(42)	20(5)	10	5
Chlorite	30(S)	1	1(S)	30(S)	5(S)
Bio.	-	8	10	-	40
Garnet	-	5	5	-	10
Muscovite	10	1	10	10	10
Epidote	20	10	30	20	-
Hornblende	-	20	-	-	-
Apatite	-	1	-	-	-
Sphene	1	-	1	1	-
Magnetite	-	1	-	-	5
Sericite	-	-	1	-	-
Pyrite	1	-	-	-	-

Modes estimated by eye.

Anorthite content of Plagioclase shown in brackets.

Texturally stable Chlorite shown by (S).

TABLE 11 (contd.)

SPEC. NO.	95/70	93/70	118/70	HS68/45
Qtz.	40	25	20	20
Plag.	30(12)	30	15	30(2)
Chlorite	15(S)	15(S)	15(S)	5
Bio.	-	20	-	20
Garnet	-	-	-	10
Muscovite	1	5	15	10
Epidote	15	10	10	-
Magnetite	-	-	20	5
Graphite	-	-	5	-

TABLE 12

Calc - Silicates of Chilliwack Group or Peninsula Formation.

SPEC. NO.	15/69	42/69	131/70	132/70
Qtz.	30	35	30	30
Plag.	20(20)	10(38)	10(40)	5
Actinolite	30	25	30	20
Garnet	15	20	10	10
Epidote	1	10	5	1
Zoisite	1	-	-	1
Chlorite	2	1	5	5
Magnetite	2	1	5	1
Muscovite	-	-	5	20
Bio.	-	-	-	15
Zircon.	-	-	-	1
Apatite	-	-	-	1

Modes estimated by eye.

Anorthite content of Plagioclase shown in brackets.

TABLE 13

Mount Breakenridge Plutonic complex.

Gneissic Granodiorite - Quartz Diorite.

SPEC. NO.	L 312/70	M 312/70	313/70	358/70	L 366/70	M 366/70
Qtz.	50	30	35	20	35	30
Plag.	35(25)	20(30)	30(10)	35(30)	45(29)	20(32
Bio.	5	35	20	30	5	25
Epidote	1	1	10	-	1	1
Chlorite	-	1	-	1	1	2
Magnetite	-	1	-	10	1	5
K-spar	10	-	-	-	5	-
Hornblende	1	5	-	-	2	15
Apatite	1	1	3	-	1	1
Sphene	-	-	2	-	1	1
Spinel	-	-	-	5	-	-
Sericite	-	-	-	1	-	-

Modes estimated byeye.

Anorthite content of Plagioclase shown in brackets.

TABLE 13 (contd.)

SPEC. NO.	L 369/70	M 369/70	370/70	311/70
Qtz.	35	30	35	30
Plag.	35(37)	20(38)	40(32)	30(35)
Bio.	15	25	25	5
Epidote	-	-	5	2
Chlorite	-	-	1	2
Magnetite	3	5	-	1
K-spar	-	-	1	-
Hornblende	10	15	-	25
Apatite	1	1	-	1
Sphene	1	1	-	1

TABLE 14

Mount Breakenridge Plutonic complex.

Gneissic Quartz Diorite.

SPEC. NO.	5/69	48/69
Qtz.	20	10
Plag.	30(43)	35(43)
Bio.	5	-
Hornblende	35	30
Garnet	2	5
Chlorite	2	2
Epidote	1	5
Magnetite	5	5
Apatite	-	1
Sericite	-	2

TABLE 15

Epizonal Core of Mount Breakenridge Plutonic complex.

SPEC. NO.	345/70	349/70	354/70	355/70	356/70
Qtz.	30	30	20	10	15
Plag.	40	45	50	60	60
K-spar	20	15	5	-	-
Muscovite	5	-	-	-	-
Bio.	5	5	15	15	15
Hornblende	-	-	10	15	10
Chlorite	1	5	1	-	1
Epidote	-	1	-	-	-
Magnetite	1	-	2	2	3
Apatite	1	1	-	1	-
Sphene	-	-	1	-	-
%Anorthite	5-30	5-30	5-37	10-39	12-45

Modes estimated by eye.

TABLE 15 (contd.)

SPEC. NO.	361/70	367/70
Qtz.	25	10
Plag.	45	60
K-spar	5	5
Bio.	15	15
Hornblende	10	15
Chlorite	1	1
Sphene	-	1
% Anorthite	5-47	5-48

TABLE 16

Scuzzy Pluton.

The Marginal Phase of the Pluton underlying Cairn Needle.

SPEC. NO.	405/70	410/70	170/70
Qtz.	20	25	10
Plag.	45(30)	40(32)	30
Bio.	15	15	-
Hornblende	15	20	60
Sphene	3	1	-
Apatite	2	1	-
Chlorite	-	1	1
Magnetite	-	1	-
Sericite	-	1	-

Modes estimated by eye.

Anorthite content of Plagioclase shown in brackets.

PLATES.

PLATE 1:

Grey gneiss of Breakenridge Formation, with well developed F_B mega strain slip foliation.

PLATE 2:

Striped amphibolite of Breakenridge Formation with well developed F_C minor folds.

PLATE 3

Kyanite gneiss of Breakenridge Formation which has been isoclinally folded. (F_B).

PLATE 4

Migmatite of Breakenridge Formation, with boudinaged pegmatite.

PLATE 5

Sheared conglomerate at base of Cairn Needle Formation. Note granitic clasts.

PLATE 6

Calc silicate pod and symmetrically zoned layers within Cairn Needle Formation.

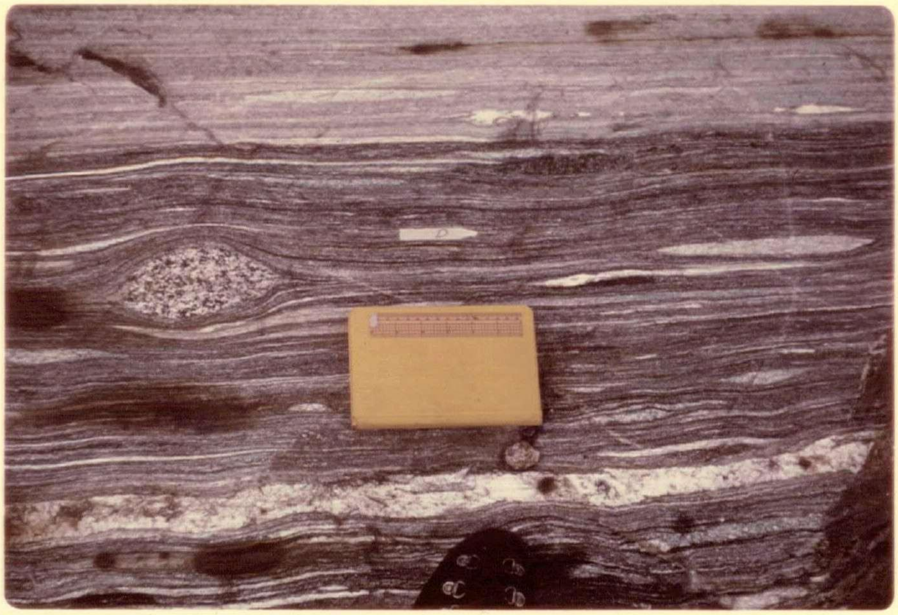


PLATE 7

White crystalline limestone and red calc silicate of Cairn Needle Formation.

PLATE 8

Folded and boudinaged earlier pegmatite within rusty schist of Cairn Needle Formation.

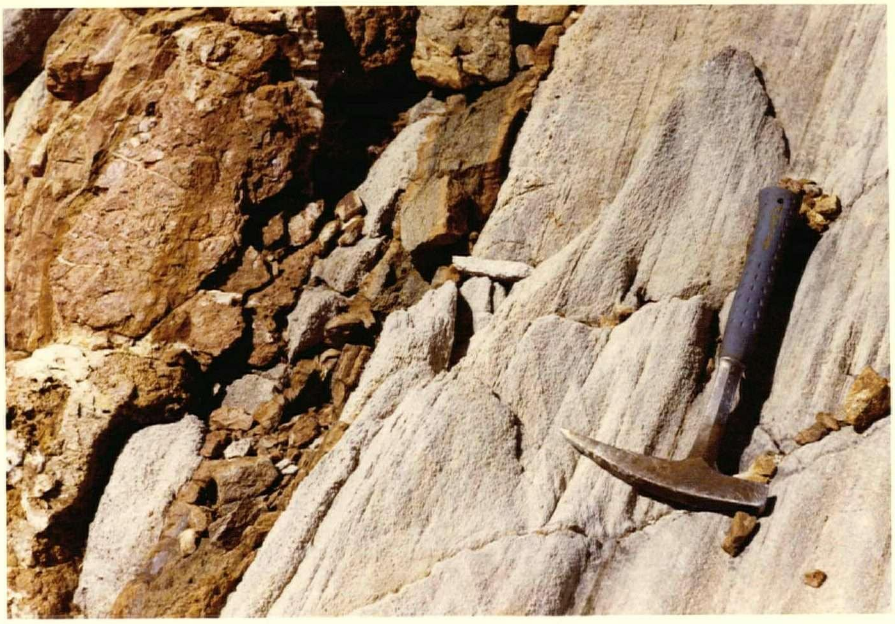


PLATE 9

Three phases of folding in striped amphibolite of Breakenridge Formation.

Rootless F_A isocline, refolded by F_B fold.

F_C minor folds refold boudinaged amphibolitic layers at top of plate.

PLATE 10

Kyanite staurolite garnet gneiss of Breakenridge Formation.

Idioblastic post F_A garnet (internal schistosity F_A) included in post F_c staurolite which is mimetic on a strain slipped F_B schistosity.

×32

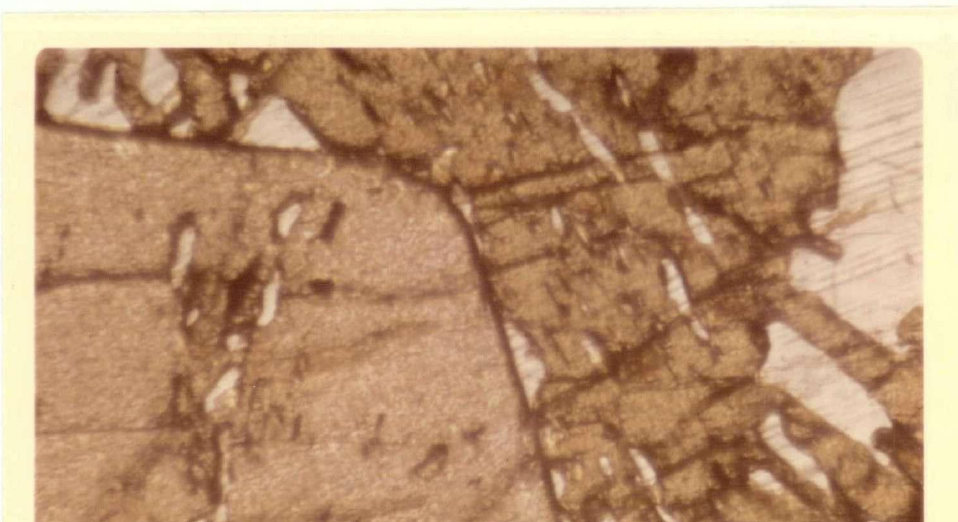


PLATE 11

Kyanite staurolite schist from Cairn Needle Formation.

Staurolite porphyroblast with sigmoidal internal inclusion trains of graphite which can be traced out into external schistosity. Thus the staurolite may have crystallized syntectonically or post tectonically with F_c .

× 32

PLATE 12

Kyanite garnet gneiss of Breakenridge Formation

F_c minor fold defined by graphite and ilmenite trains on which kyanite has post tectonically crystallized.

× 32

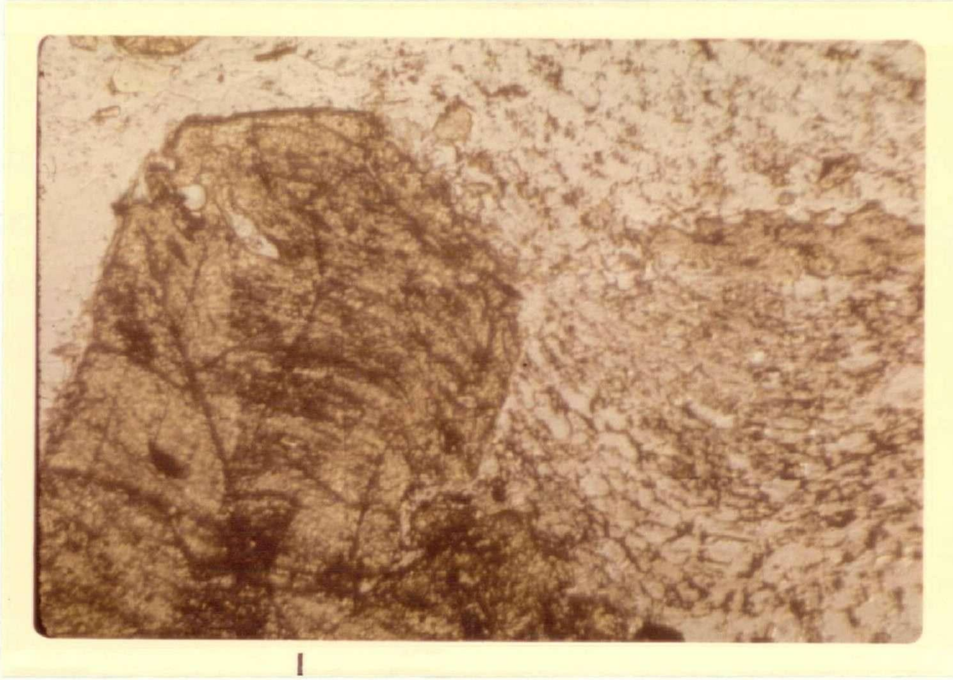


PLATE 13

Sillimanite garnet schist of Cairn Needle Formation

Sillimanite flattened around a pre F_C garnet. Thesillimanite could have crystallized prior to F_C folding.

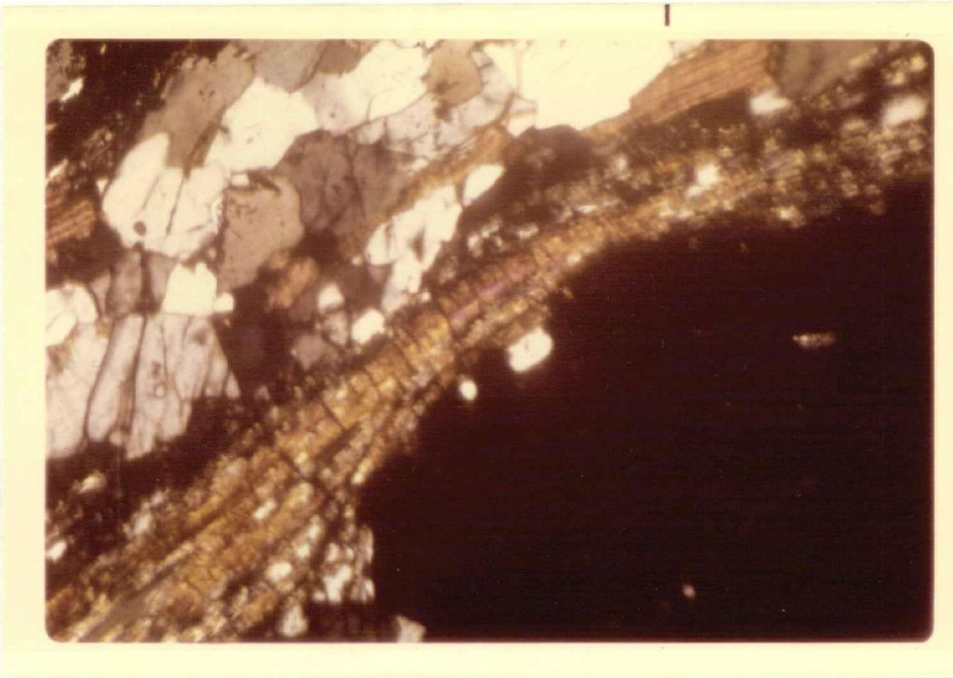
x 32

PLATE 14

Sillimanite garnet schist from Cairn Needle Formation.

A polygonal arc of sillimanite needles mimetic on F_C minor fold. Thus the sillimanite is post F_C

x 32



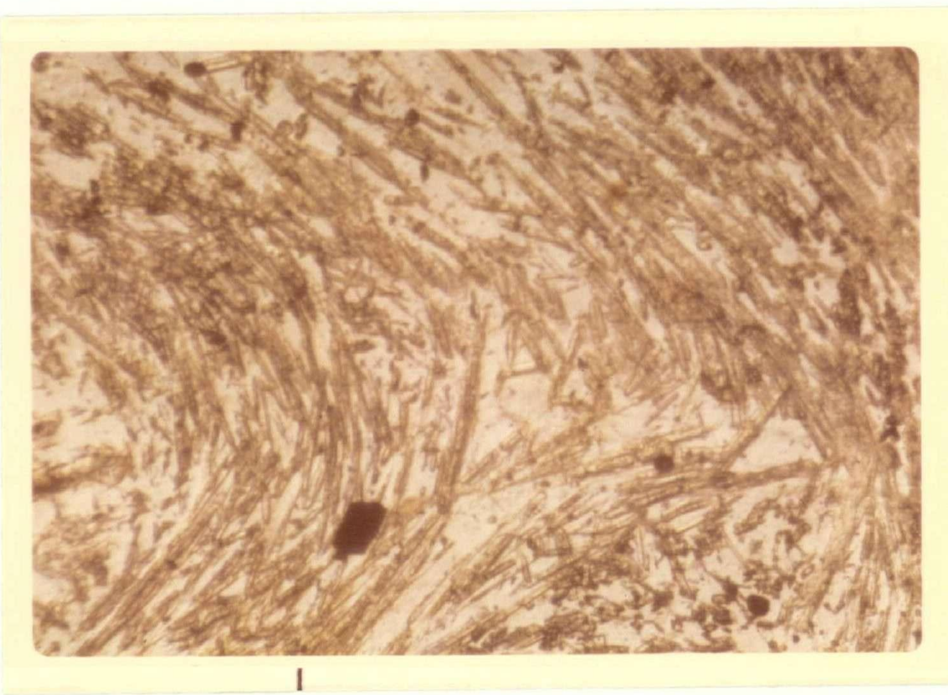


PLATE 15

Folded and symmetrically zoned calc silicate of Cairn Needle Formation.

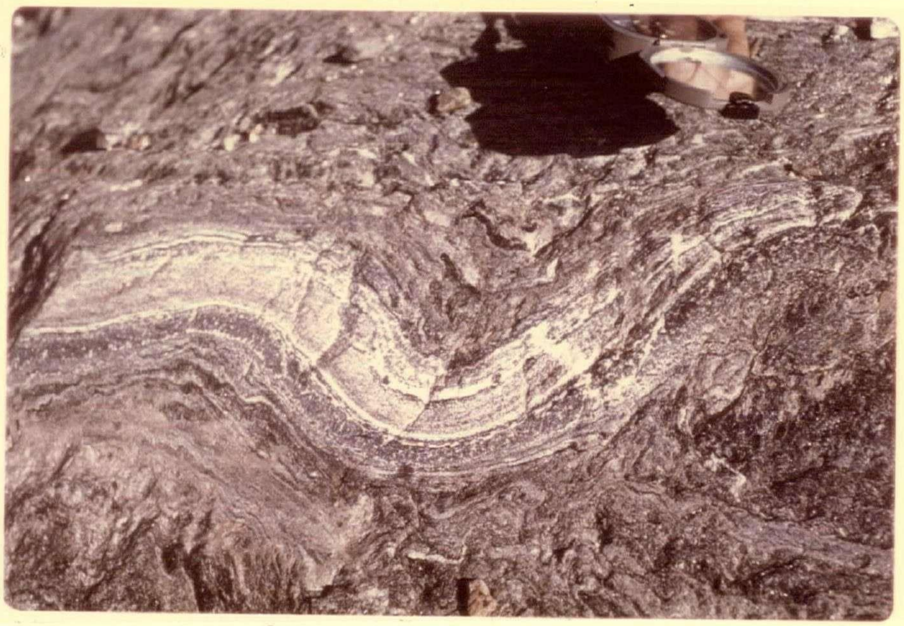
The calc silicates are associated with pelitic schists.

PLATE 16

Sillimanite partially pseudomorphed by muscovite.

Contact aureole of Scuzzy Pluton.

x 32 crossed nicols.



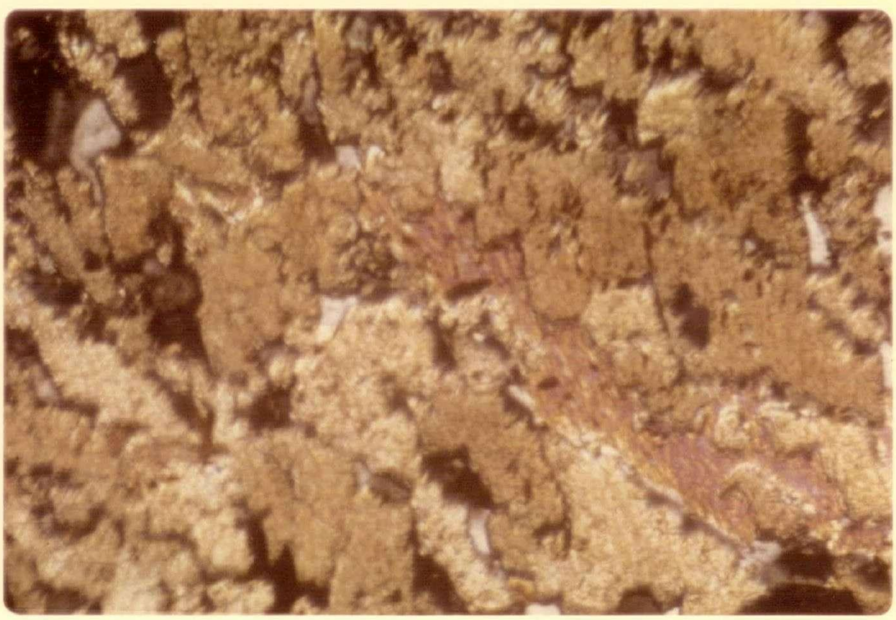


PLATE 17

Andalusite , partially pseudomorphed by muscovite

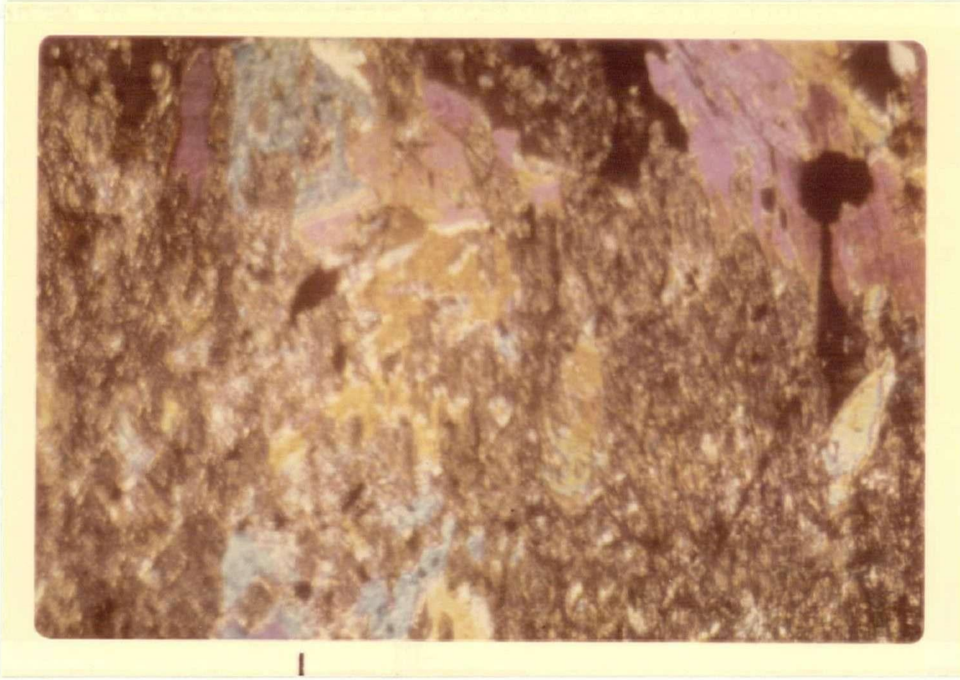
Contact aureole of Scuzzy Pluton.

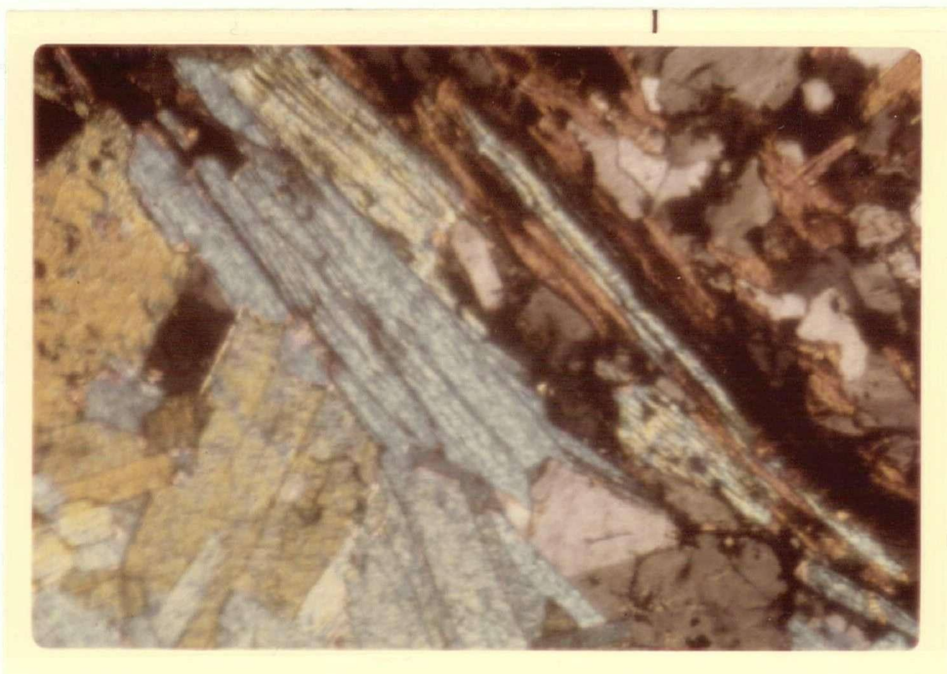
crossed nicols x 32 .

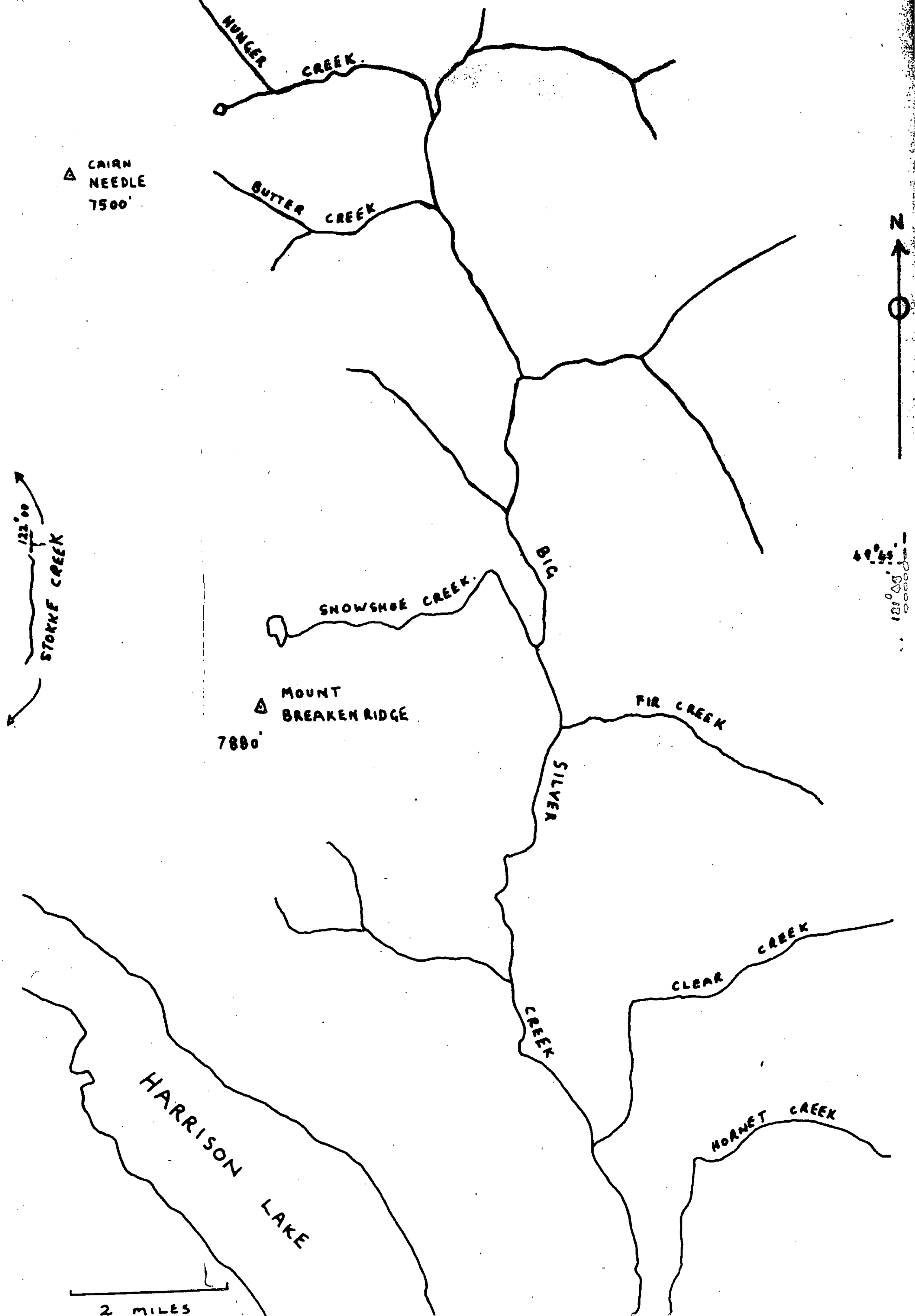
PLATE 18

Platey aggragates of muscovite after alumino silicates of the contact aureole of Scuzzy Pluton.

crossed nicols x 32 .






HUNGER CREEK
CAIRN NEEDLE 7500'
BUTTER CREEK
N
SNOWSHOE CREEK
BIG SILVER CREEK
STOKKE CREEK
122°00
MOUNT BREAKENRIDGE
7880'
FIR CREEK
CLEAR CREEK
HORNET CREEK
HARRISON LAKE
2 MILES