GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

BULLETIN 64

GNEISSES OF THE KIPAWA DISTRICT, WESTERN QUEBEC, GRENVILLE SUB-PROVINCE OF CANADIAN SHIELD (31 L)

W. T. Harry

Price, 50 cents

1961

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PREFACE

The study on which this report is based arose out of the author's participation in a broad reconnaissance of the gneisses of the Grenville sub-province. At the end of the field season the author returned to University of St. Andrews, Scotland, where he studied the specimens collected and wrote the report.

The gneisses of the Grenville sub-province are complex and widespread and the light thrown on their nature and origin by this study can be broadly applied.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, November 20, 1959

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GNEISSES OF THE KIPAWA DISTRICT

Abstract

A banded gneiss complex at Lake Kipawa largely consists of foliated migmatitic granitic and granodioritic gneisses apparently emplaced by both intrusion and replacement of earlier gneisses, including recognizable metasediments. The granitic gneisses commonly vein and permeate the granodioritic gneisses but the reverse relationship has not been observed. Epidote is a common minor constituent of the gneiss complex and its formation presents a problem that is briefly discussed.

The banded gneiss complex has suffered much complex paracrystalline deformation. Folding along gently plunging axes of northeast to north-northeast trend and cross-folding roughly at right angles to these directions have taken place. The most prominent foliation planes are largely if not wholly due to slip, and the tectonic style is indicative of unrestricted transport. Quartz and mica fabric diagrams possess monoclinic or triclinic symmetry and show strong girdles with axes of variable but commonly subhorizontal northeast to north-northeast orientation.

Résumé

Le complexe gneissique rubané du lac Kipawa se compose en grande partie de gneiss feuilletés et migmatitiques qui sont soit granitiques soit granodioritiques; il semble que les gneiss aient été mis en place par intrusion et par substitution de gneiss plus anciens, y compris des sédiments métamorphisés qu'on peut reconnaître. Les gneiss granitiques se présentent fréquemment en filons et comme imprégnations au sein des gneiss granodioritiques, mais on n'a pas remarqué la relation inverse. On trouve souvent un peu d'épidote au sein du complexe gneissique, et la formation de ce minéral pose un problème que l'auteur examine brièvement.

Le complexe gneissique rubané a subi toute une série de déformations paracristallines. Il s'est produit un plissement suivant des axes à faible ennoyage et orientés de nord-est à nord-nord-est, ainsi que des plis transversaux presque perpendiculaires à ces directions. Les principaux plans de schistosité s'expliquent en grande partie, sinon entièrement, par le glissement, et le relief tectonique est un indice de transport sans obstacle. Des études structurales sur l'orientation du quartz et du mica ont donné des diagrammes avec symétrie monoclinique ou triclinique. Ces diagrammes montrent aussi des zones circulaires bien définies dont les axes varient mais qui sont souvent presque horizontaux et dont l'orientation est tantôt nord-est, tantôt nord-nord-est.

INTRODUCTION

The following account deals with a roughly rectangular area of about 500 square miles round Lake Kipawa, Timiskaming county, western Quebec, depicted in the centre of Figure 1 and designated "the investigated area". As this is a fairly representative part of an extensive banded granitic and granodioritic gneiss complex in the northwest part of the Grenville sub-province of the Canadian Shield, it will be helpful to include brief descriptions of a few significant exposures in adjacent parts of the complex south of the investigated area but within the limits of the district represented on Figure 1. These exposures, which are described in footnotes, occur along the highways between Timiskaming and North Bay, Mattawa and North Bay, and on the railroad near La Cave on the Ottawa River upstream from Mattawa.

The investigated area is part of an undulating upland a little less than 1,000 feet above sea-level, diversified by many lakes of which Lake Kipawa is one of the largest. The highly re-entrant shoreline of this waterway provides a lengthy and almost continuous outcrop, but between the lakes much of the ground is concealed under coniferous and deciduous forest. The small community of Kipawa is easily reached by road and serves as a base from which the district can be examined by boat during summer months. Because of the strong winds that arise from time to time it is not advisable for the inexpert to travel by canoe on Lake Kipawa.

The earliest geological investigations in the district appear to have been made by W. E. Logan in 1845 during a traverse along the Ottawa River from Montreal to Lake Timiskaming. About a half century later Barlow (1897)[1] described the common occurrence of interbanded acid and basic gneisses in the Timiskaming and Nipissing map-areas. Wilson (1918) in his memoir on Timiskaming county referred to the rocks around Kipawa as Ottawa gneisses, consisting of pre-Huronian batholithic intrusions that form an extensive belt of acid, banded gneisses, chiefly composed of biotite-granite with some probably metasedimentary schists and gneisses. The heterogeneous banded structure of the complex is said to simulate sedimentary bedding but is ascribed by Wilson to multiple intrusion and deformation during consolidation of magma within the interior of a now deeply denuded Precambrian mountain chain.

In a recent paper Wilson (1956, p. 1414) called this belt of banded gneisses the Ottawa Mountains. He described it (op. cit., pp. 1418-19) as comprising highly folded garnetiferous biotite schist or gneiss, presumably a metamorphosed argillaceous phase of the Grenville series. This forms bands and inclusions in grey biotite granite-gneiss with a potash content about equal to or exceeding that of soda, as in the batholithic granites of the Grenville sub-province to the south.

[1]Dates in parentheses are those of references cited at the end of this report.

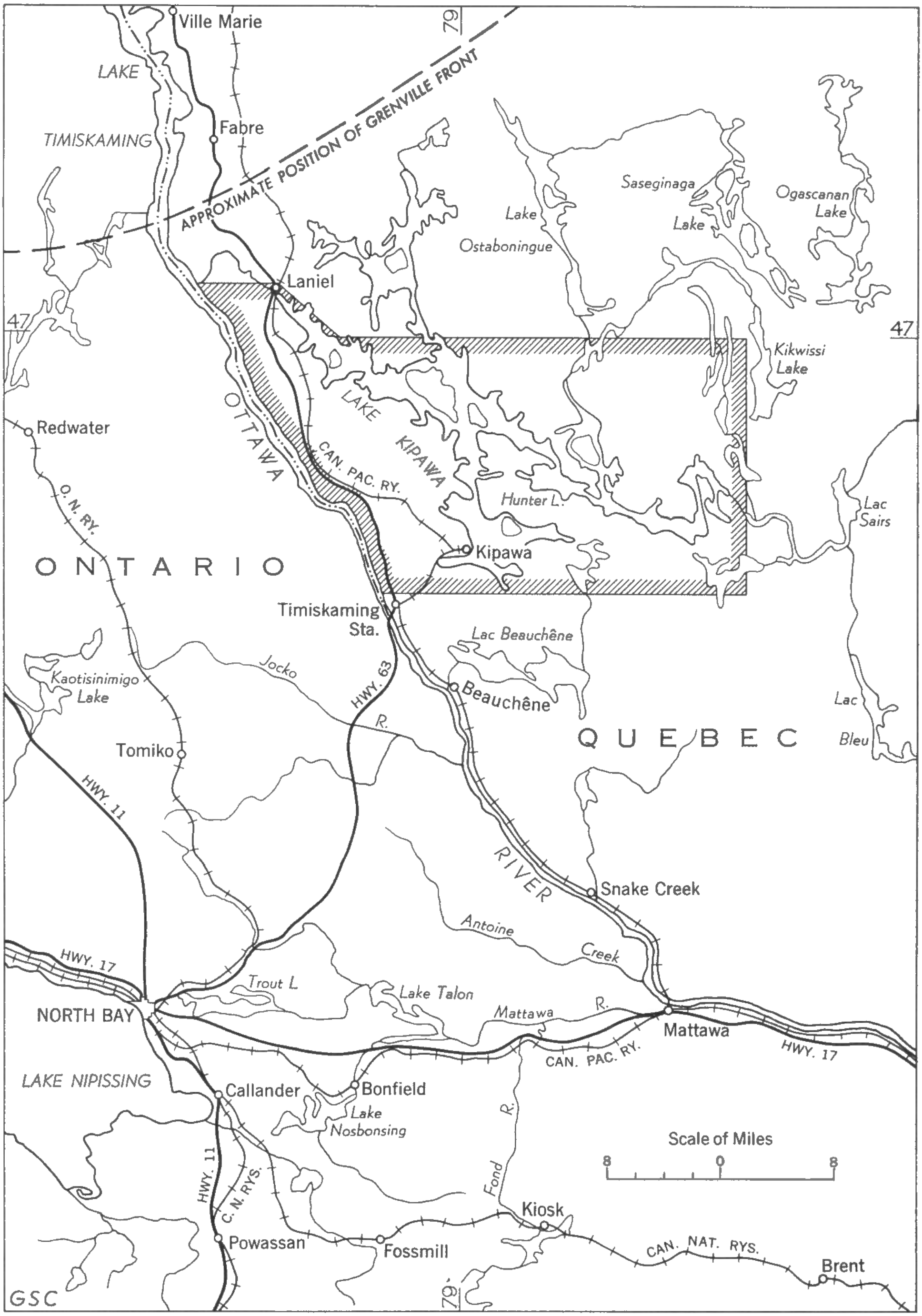

Figure 1. Index map showing general location of investigated area. Approximate position of Grenville Front taken from Derry (1950).

The granite-gneiss is considered to be intrusive, for in places it cuts transversly or diagonally across the garnetiferous bands. Locally it is of several ages; northwards from Lake Kipawa it gradually replaces the banded gneisses. Wilson believed that the Ottawa Mountains mark the site of at least two orogenic episodes, the last being accompanied by the intrusion of the granite.

The present paper is based on field observations made during the season of 1953 while the writer was independently responsible for mapping the Kipawa district as part of the reconnaissance of a much larger area of the Grenville sub-province under the direction of J. W. Hoadley of the Geological Survey of Canada. 'Foliation' is used in the broad sense advocated by Fairbairn (1949) to signify parallelism of planar elements including, but not being restricted to, compositional banding of schist and gneiss. Petrofabric axes are used in a descriptive symmetrological sense (Weiss, 1955) without kinematic implications. The texture of gneisses composed largely of roughly equant equidimensional crystals with regular outline is called 'granoblastic' and ascribed to either post-tectonic recrystallization or syntectonic crystallization that proceeded more rapidly than deformation. Quartz within these rocks shows little or no strain effects. 'Granulitized' gneisses, on the other hand, resulted from paracrystalline deformation that outpaced recrystallization; feldspar and quartz are reduced in grain size, the latter commonly showing highly sutured boundaries and pronounced strain effects.

The writer is deeply indebted to M. E. Wilson and J. W. Hoadley for introducing him to the problems of the Grenville sub-province and for most generous hospitality. To the Council of the Geological Society of London grateful thanks are due for a grant from the J. B. Tyrrell Fund that enabled the author to extend his field acquaintance with the Precambrian of Ontario and Quebec. Thanks also are due to Colin Methven for the preparation of many excellent thin-sections.

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FIELD RELATIONSHIPS

The gneisses of the Kipawa district are predominantly quartzo-feldspathic rocks of granitic or variable dioritic to granodioritic composition. They form a banded complex with some recognizable metasediments, amphibolite, and small irregular bodies of mafic gneiss, chiefly consisting of hornblende and/or clinopyroxene. The quartzo-feldspathic gneisses vein, migmatize, and enclose blocks of these other rock types. Many granitic gneisses are obviously younger than the granodioritic varieties that they vein and permeate; granodioritic gneisses have not been seen veining granitic gneiss.

The complex bears abundant evidence of intense penetrative deformation to which the widespread foliation seems largely due.

Field Relations of Granodioritic Gneiss

The granodioritic gneisses, like the granitic gneisses with which they so commonly are associated, are foliated rocks widely distributed in the area depicted by Figure 1. Acid, in places pegmatitic, granodioritic gneiss forms *lit-par-lit* folia from a few millimetres to several feet thick, some with central quartz zones in darker granodioritic or more basic quartz-feldspar-hornblende-mica gneiss. Many banded migmatites of this type contain concordant layers of granitic gneiss which, like the acid granodioritic folia, may bear thin marginal zones enriched with biotite.

Leucocratic granodioritic gneiss also forms discordant veins cutting slightly darker foliated granodioritic gneiss, as in exposures beside the Timiskaming road near Kipawa and in road-cuts along highway 17 between North Bay and Mattawa.

A number of small bodies of mafic gneiss are veined and permeated by granodioritic gneiss. The more extensively migmatized specimens tend to be rich in hornblende and those in which the acid gneiss forms only discrete veins tend to be pyroxene-rich. Details of some examples follow.

Foliated, hornblendic, granodioritic gneiss, containing angular inclusions and abundant wispy lenticular folia of biotite-hornblende rock, occurs beside the store at Laniel, where, in addition, some augen-gneiss has been formed by permeation of the mafic gneiss.

On a small island in the northern narrows leading from Hunter Lake, granodioritic gneiss passes into hornblende-biotite rock through several feet of migmatite comprising numerous mafic lenses from a few centimetres to several feet long in acid gneiss. On the north side of the eastern narrows on the same lake, hornblende-biotite gneiss contains tortuous granodioritic veins from less than an inch to about a foot wide that intersect each other without offset and locally soak the mafic gneiss. On the south side of these narrows acid gneiss forms *lit-par-lit* veins in dark gneiss consisting of highly corroded abundant biotite, oligoclase, some quartz, accessory epidote, apatite and sphene.

Four and one-half miles west-northwest of the northwest end of McKenzie Island, an outcrop of hornblende rock 150 yards long is cut by numerous well-defined quartz-oligoclase veins as much as a few feet thick running in all directions and occasionally permeating the mafic gneiss with the production of hornblende porphyroblasts several inches long. The mafic gneiss does not become biotitic against the veins. Nearby it forms many randomly oriented, slightly rounded inclusions up to a few feet long in granodioritic gneiss which occasionally displays a foliation enveloping the inclusions.

About one-quarter of a mile west along the shore from the last locality, coarse granodioritic gneiss bears randomly oriented, mafic inclusions composed of pale green clinopyroxene and green hornblende. Roughly 1¾ miles south-southwest of there similar pyroxenic, mafic gneiss, in conformable contact with foliated granodioritic gneiss, is cut by quartz-oligoclase veins with accessory microcline. The gneiss is enriched in hornblende and to a slight extent also in biotite against the veins. It also contains irregular masses and veinlets of hornblende rock and some pegmatitic patches surrounded by black hornblendic borders. The pegmatitic patches are composed of green pyroxene crystals an inch or so long, quartz and feldspar.

About 14.3 miles from the centre of Timiskaming, along the road to Laniel, mafic biotite- and hornblende-rich gneisses are soaked by granodioritic gneiss with the production of dark quartz-oligoclase-biotite gneiss. The hornblende rock (*see* Table I, specimen 111) contains some pyroxenic areas and becomes rich in biotite close to the acid gneiss, which locally soaks such biotitic sheaths to form grey quartz-oligoclase mica gneiss. Biotite also forms occasional thin ramifying veinlets in the hornblende rock.

Field Relations of Granitic Gneiss

The granitic gneiss is a microcline-rich rock, normally of medium or rather coarse grain-size, commonly constituting *lit-par-lit* folia or veins from an inch to several feet thick in foliated granodioritic gneiss. These veins or folia occasionally change direction and transgress the foliation of their host and may be sharply defined or fade into the surrounding gneiss which may then develop small quartz-feldspar augen. Many pinch, swell, and anastomose. Many of the smaller ones display marginal zones enriched in biotite, and the central parts of some larger well-defined veins are composed entirely of quartz.

In certain exposures the granitic gneiss forms a plexus of fairly regular veins that intersect without offset and divide the invaded granodioritic gneiss into angular blocks. Similar veins as much as a foot thick traverse hornblende rock at some localities as in a channel 2¾ miles N86°E of Kipawa, and on the west side of an island about 7 miles north of Kipawa.

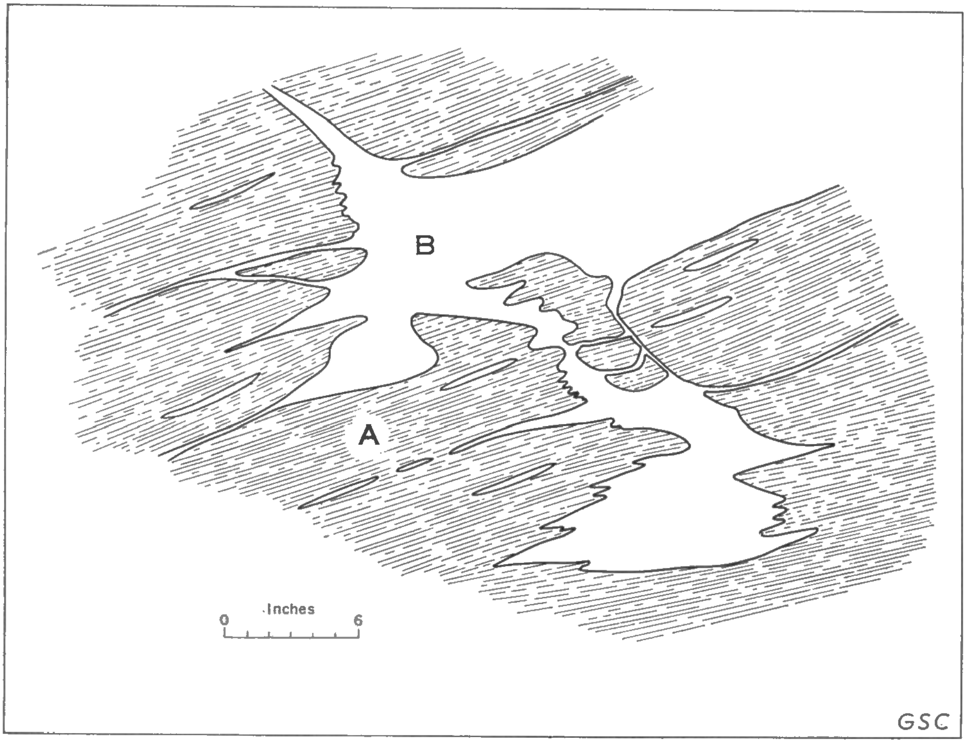

Figure 2. Sketch of specimen from about 2 miles east of east end of Hunter Lake. Dark, quartz-hornblende-biotite, metasedimentary gneiss (shaded) invaded by granitic gneiss. Vein pattern suggests considerable replacement of metasediment by granite; host not wedged apart by granite veins.

Dark, relatively fine-grained quartz-biotite-hornblende gneisses of apparently sedimentary origin occasionally occur in granitic gneiss as folia and highly corroded inclusions (*see* Fig. 2). The outline of these inclusions may show irregular embayments consisting of arcs that meet in points, resembling the 'caries texture' of ore mineralogists.

Some highly granulitized granitic augen-gneisses are present. For example, along route 63 between Laniel and Timiskaming 4.3 miles from the bridge at Laniel, pink augen-gneiss of this nature (*see* Table I, specimen 34) passes gradually into grey granodioritic gneiss (*see* Table I, specimen 32) containing vague ragged areas of mica schist. Normal granitic gneiss forms *lit-par-lit* veins as much as several feet thick in the augen-gneiss, granodioritic gneiss and hornblende-mica schist. By the roadside a mile nearer Laniel, granodioritic gneiss with non-persistent dark folia rich in hornblende and epidote contains *lit-par-lit* bands of the augen-gneiss and normal granitic gneiss.

Small pegmatitic pods and folia with thin marginal layers enriched in biotite are common in the granitic gneiss. Some larger granitic pegmatites also occur. On a small island about 5 miles N68°E of Kipawa one of these fades into medium-grained quartz-biotite-hornblende gneiss bearing numerous grey oval microcline porphyroblasts as much as 6 inches long.

The granitic gneiss occasionally forms agmatite (migmatite composed of numerous angular or rounded rock fragments in a matrix formed during granitization) with the characteristics of replacement breccia (Goodspeed, 1953).[1]

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[1]An easily accessible example occurs on the west side of the road between Timiskaming and North Bay about 1.6 miles towards North Bay from Salter Lake. About half this agmatite comprises dark, randomly orientated, commonly foliated metasediment fragments from a few millimetres to several feet across. These are either sharply or vaguely defined, and of angular, rounded, or highly irregular outline commonly thinned to slender 'hour-glass' waists. The fragments are fine- or medium-grained, granoblastic rocks containing quartz, hornblende, biotite, epidote, and oligoclase in various combinations, with accessory sphene and iron ore. Common assemblages are quartz-biotite-hornblende and quartz-hornblende-epidote-oligoclase. The agmatite matrix varies greatly, patches of medium-grained granoblastic granitic gneiss passing gradually into darker rock composed of quartz, oligoclase, microcline, hornblende, biotite, epidote, and scattered, highly poikiloblastic grey microcline porphyroblasts.

By the roadside opposite this exposure, pink granitic gneiss veins and permeates biotite-hornblende gneiss bearing small feldspar porphyroblasts. Elsewhere in many places along the same road between Timiskaming and North Bay, granitic gneiss migmatizes metasedimentary quartz-biotite, quartz-biotite-feldspar, and garnetiferous biotite-hornblende gneisses.

PETROGRAPHY

Metasediments

A few members of the complex are undoubted metasediments. They include mica-schists that may be garnetiferous, as at Camp Miwapanee near Kipawa where they occur near a lean ironstone band and microfolded muscovite-quartz gneisses. Muscovite-rich garnetiferous gneiss with some tourmaline is visible on the northeast shore of Turtle Island close to siliceous, occasionally kyanitic gneiss. Moderately kyanitic quartzite occurs at the south end of Little Birch Lake and the east end of Grindstone Lake. Some dark quartz-oligoclase-hornblende-biotite gneisses, approaching the more basic members of the granodioritic gneisses in chemical composition, seem most likely to be metasediments.

Mafic Gneisses

Most mafic gneisses (*see* Table I, specimen 111) consist chiefly of pleochroic deep green to light brown hornblende in crystals averaging a few millimetres in length commonly without obvious preferred orientation. Some rocks are composed largely of pale green clinopyroxene; in other rocks the clinopyroxene is intergrown with green hornblende, which also forms mantles round the pyroxene.

A little reddish or olive-brown biotite is commonly present but neither hornblende nor pyroxene has been seen partly replaced by mica. Accessory sphene, apatite, epidote, or zircon may occur; iron ore, commonly absent, is abundant in a few hornblende rocks and in some of the pyroxene-rich varieties. Quartz, oligoclase, and microcline may be present and by increase in quantity lead to amphibolitic and dioritic gneisses in which the dark minerals display a preferred orientation.

Granitic and Granodioritic Gneiss

Both of these are medium- to coarse-grained, in places pegmatitic, generally well-banded and foliated gneisses of variable composition. Granulitization is weakly present in many and may be intense, as in certain augen-gneisses, but granoblastic textures predominate. The granitic gneisses (*see* Table I, specimen 34 for chemical analysis) differ from the granodioritic gneisses in containing abundant microcline. They are generally pink, occasionally grey in hand specimens, whereas the reverse is true of the granodioritic gneiss. The composition of the latter extends between fairly wide limits and may approach that of diorites.

The following minerals in various proportions compose the granitic and granodioritic gneisses:

Quartz is plentiful, mostly showing strain extinction. In highly granulitized rocks rupture bands subparallel to [0001] are common and some crystals are highly lenticular.

Oligoclase, absent or subordinate to microcline in the granitic gneiss, is the predominant and sometimes the only feldspar in the granodioritic gneisses. Most of it is unzoned, some is twinned on the albite law and pericline-albite combinations occur, although untwinned crystals are common. Many of the twin lamellae are slightly bent and many wedge out towards the crystal boundary. Sericitization, occasionally present, tends selectively to attack certain twin lamellae. Thin rims of clear, slightly more sodic plagioclase surround and are crystallographically continuous with some sericitized crystals. They are broadest at oligoclase-microcline junctions but may occur between oligoclase and any other essential mineral in the gneisses. Many of them are untwinned, but some show albite twinning continuous with that of the enclosed oligoclase. Clear plagioclase veinlets of similar composition follow the cleavage of a few sericitized oligoclase crystals.

Microcline generally exhibits good cross-hatching. It is unaltered and may be slightly microperthitic. Most crystals are well shaped, like microcline in the late kinematic Precambrian granites of Marmo (1955). This is true even in pronouncedly migmatitic granulitized gneisses.

Grey microcline porphyroblasts are sporadically distributed in various quartzo-feldspathic gneisses of the complex. Antiperthitic microcline areas occur in some oligoclase crystals.

Biotite in small or moderate quantities occurs in nearly all quartzo-feldspathic gneisses as either reddish or olive-brown undeformed plates with straight cleavage. No tendency, like that reported by Engel and Engel (1953, p. 1069), for reddish brown biotite to be closely associated with microcline-rich gneisses has been observed and either variety of biotite may accompany hornblende in the same slice. Some of the biotite is highly corroded by quartz and oligoclase which send numerous microscopic tubules with blunt terminations reminiscent of myrmekite along, or occasionally across, the mica cleavage. Similar quartz-biotite textures in the Bergeller granite have been ascribed to replacement of biotite by quartz (Drescher-Kaden, 1948, pp. 67, 173).

Muscovite does not occur in all specimens. Much of it is ragged and may form several optically continuous patches within one oligoclase crystal, as if replaced by the latter. But in one slice ragged muscovite patches traverse the boundaries of many seemingly older granulitized quartz and feldspar crystals.

Microscopic quartz, oligoclase, and microcline tubules form symplektite with some muscovite crystals. The quartz tubules are occasionally continuous with large crystals outside the mica. Certain slices contain both ragged muscovite with vermiform quartz inclusions and idioblastic biotite flakes without inclusions.

Hornblende, pleochroic deep green to light brown, occurs in some slices with or without biotite.

Epidote in accessory or moderate amounts occurs in many rocks as well crystallized grains or stubby prisms apparently in equilibrium with their host and not infrequently containing partly altered orthite cores.

Accessories. Apatite and sphene are common, zircon is less so. Garnet in small clear gum-like drops is occasionally present. Myrmekite occurs at many, but not all, microcline-oligoclase junctions. Iron ore is generally absent or present in only very small amounts.

Table I

Chemical Analyses of Rocks from the Kipawa District, Western Quebec

	32	34	111
SiO_2	66.08	71.08	45.06
Al_2O_3	15.84	15.06	13.28
Fe_2O_3	0.26	0.06	3.22
FeO	3.74	1.24	9.10
CaO	3.42	1.86	10.06
MgO	2.28	0.62	14.78
Na_2O	3.65	3.48	1.12
K_2O	2.76	5.23	1.28
H_2O+	0.83	0.52	0.99
H_2O-	0.12	0.05	0.16
CO_2	0.46	0.19	0.05
TiO_2	0.42	0.12	0.34
P_2O_5	0.17	0.21	Traces
MnO	0.08	0.04	0.27
Cr_2O_3	—	—	0.14
	100.11	99.76	99.85

Analyst W. H. Herdsman.

32. Route 63, 4.3 miles south of the bridge at Laniel. Foliated, granulitized granodioritic gneiss formed by permeation of pelitic schist. Quartz (strained), oligoclase, and abundant biotite (slightly olive-brown); epidote common, some muscovite and microcline; apatite is accessory, iron ore absent. Average grain size ½ mm.

34. Same locality as specimen 32. Pink granulitized granitic augen-gneiss formed by synkinematic soaking of pelitic schist by pink granite veins. Quartz (strained), abundant well-twinned microcline (very slightly microperthitic), biotite, a little muscovite and oligoclase; accessory epidote and apatite, no iron ore. Average grain size 1 mm.

111. Side of route 63, 14.3 miles northwest of centre of Timiskaming. Mafic gneiss almost wholly deep green hornblende; a little biotite, accessory plagioclase. Average grain size about 2 mm.

STRUCTURE

The rocks of the Kipawa district are banded by the alternation of various gneisses in layers up to several yards in thickness. These are expressed topographically by gentle ridges and valleys clearly visible in aerial photographs despite a cover of dense vegetation (*see* Wilson, 1956, pl. 5).

Within the scale of a hand specimen most of the gneisses display a prominent foliation S_1 due to preferred orientation of dark minerals and commonly accentuated by the concentration of those minerals in thin folia. Generally but not invariably S_1 is concordant with the large-scale layering. Discordance occurs, for example, at places on the northwest shores of Hunter Lake. There granitic gneisses with coarse-grained, quartzo-feldspathic folia up to an inch thick, separated by thin biotitic folia, contain many mafic hornblende-biotite gneiss lenses. The foliation S_1 within the acid gneiss is inclined to the long axes of the mafic lenses and generally ends abruptly against the lenses. These lenses generally lack foliation although one shows a strong preferred orientation of dark minerals parallel, and presumably cogenetic, with S_1 in the adjacent acid gneiss. Clearly the foliation of the latter is at least partly tectonic in origin and not simply a magmatic flow structure or relict bedding.

In many large exposures of acid gneiss S_1 is obviously intricately folded, but in others it is close-spaced, planar, and parallel with gently inclined large-scale layering, so that the rocks at first sight look like undisturbed bedded metasediments. Even in these sections, however, the effects of intense folding can often be detected, for instance inconspicuous fold closures can be found demonstrating many highly compressed small folds with axial planes parallel with the banding of the gneisses.[1]

Some granitic, granodioritic, and psammitic gneisses display a faint foliation S_2 akin to slaty- or flow-cleavage, due to the alignment of uniformly distributed biotite flakes and minute quartz-feldspar lenticles inclined to S_1. In some specimens S_2 can be seen to be an axial plane foliation affecting folds in S_1 of several feet amplitude. These may be *similar* folds with thickened hinges and attenuated limbs in which S_2 has been a plane of transposition, or else flexures contradicting

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[1] This is well seen in a railway-cut near La Cave beside the Ottawa River (*see* Fig. 3) where medium-grained, pink granitic gneiss, without cataclasis indicative of cold shearing, lies sandwiched between grey quartzo-feldspathic gneisses with an apparently undisturbed close-spaced planar foliation. A cursory glance suggests that the granitic gneiss foliation is similar, but close examination shows it to be thrown into numerous small isoclinal folds with limbs parallel with the banding of the exposure. The granitic gneiss has been folded upon itself. To achieve this in such a rock extensive recrystallization must have accompanied deformation and, simultaneously, to accommodate the structural disharmony between the granitic and granodioritic gneisses, the planes separating the two gneisses must have functioned as slip surfaces which, like similar surfaces in the Adirondacks (Engel and Engel, 1953), bear no necessary relationship to any sedimentary bedding that might have been present. A similar tectonic style in Scottish quartzites has been described by McIntyre (1951).

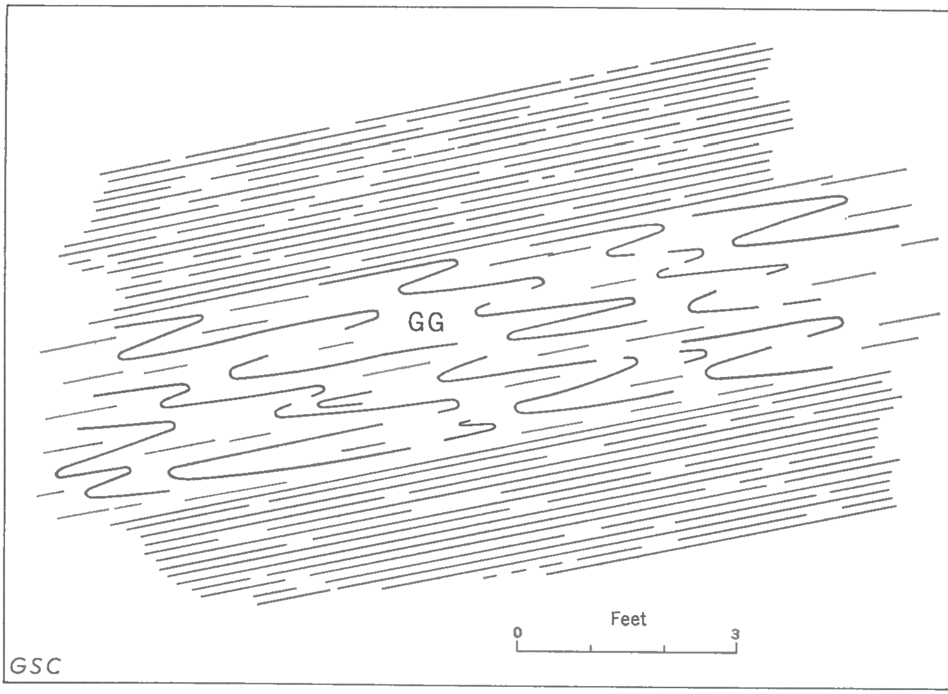

Figure 3. Sketch of band of pink granitic gneiss (GG) between grey granodioritic gneiss with straight, parallel, close-spaced foliation. Miniature isoclinal folds in granitic gneiss (shown diagrammatically) with axial planes parallel with banding.

the occasionally held contention (also opposed by Swanson, 1941, p. 1257) that platy minerals follow the arches of flexure folds whereas axial plane foliation accompanies shear folding only.

Microfolding of S_1 in mica and hornblende schists commonly results in 'strain-slip' (or 'slip') cleavage: the axial planes of the microfolds are parallel, about 0.5 to 1 cm apart, and marked by fractures or slip planes along which the dark minerals are commonly deflected into parallelism with the cleavage.

In some exposures psammitic ribs describing flexure folds of several feet amplitude are intercalated with schists that show a 'strain-slip' cleavage parallel with both the axial plane of the fold and a weak S_2 foliation in the psammites, thus illustrating the close relationship between slaty cleavage and fracture cleavage emphasized by de Sitter (1956).

In the northwest part of the investigated area, S_2 and 'strain-slip' cleavages dip roughly northwest, and the macrofolds with which they are generally seen to be associated possess subhorizontal northeast to north-northeast-trending axes. Examples of these folds occur on the northwest shores of McKenzie Island and specimens from one have been petrofabrically analysed (*see* Figs. 5 to 7). Microfolding of schists effects a lineation that is often demonstrably parallel with macrofold axes. Weak lineation due to aligned biotite and hornblende may affect rocks with or without microfolding and may be parallel with or oblique to microfold axes.

Another linear element occasionally present is the result of gentle folds only a few centimetres in amplitude that effect thin psammitic bands and, although of tectonic origin, bear some resemblance to wave ripples.

Boudinage can sometimes be seen in cross-section, for instance near the northern narrows of Hunter Lake where ellipsoidal masses of hornblendic, mafic gneiss several feet long in quartzo-feldspathic gneiss are arranged end to end and separated by pegmatitic quartz-oligoclase nodes.

Equal area projections of structural elements are shown in Figure 4. Figure 4A is compiled from poles to S_1 and coincident large-scale layering, measured at numerous localities covering the investigated area as evenly as possible. The strike of S_1 varies considerably, in places within a few yards. Dips are mostly between 20° and 45° recalling to mind the 'quasi-plateau' structure described by Osborne and Lowther (1936) from gneisses near Montreal. No simple pattern of folding is revealed by the diagram, but the normals to S_1 tend to fall along two great circles with subhorizontal poles, one trending roughly north-northeast and the other approximately east-southeast (Fig. 4B, P_1 and P_2).

A number of gneisses were selected for detailed petrofabric study. From each hand specimen several slices were cut at right angles to one another. No significant textural variation is detectable between slices from the same specimen. Most slices are granoblastic, equant, and medium grained. Use of the gypsum plate suggests that the preferred orientation of quartz is essentially homogeneous. Microscopic tension fractures a few centimetres apart lie at about 80° to S_1 in many gneisses.

Petrofabric diagrams of quartz and mica possess monoclinic or triclinic symmetry (*see* Figs. 5 to 10). Figures 5 to 7 were compiled from specimens taken from a synform flexure fold several yards in amplitude with a northeast subhorizontal axis, a vertical northwest limb and subhorizontal southeast limb. The quartz and mica fabric of this structure is not homogeneous and homogeneity cannot be achieved by simple unrolling. Figure 5A shows two incomplete quartz girdles and a maximum parallel with microfold and macrofold axes and the axis of the mica girdle, Figure 5B. Figure 6 shows coaxial *ac* quartz and mica girdles and a weak quartz girdle normal to *ac*. The mica girdle contains maxima due to an axial plane foliation dipping northwest and a weak vertical foliation parallel with the lithological layering in the vertical northwest limb of the macrofold from which the sample was collected. In Figure 7A an *ac* quartz girdle is coaxial with the macrofold and an incomplete mica girdle Figure 7B.

Figure 8A shows crossed quartz girdles with a maximum parallel with the subhorizontal north-northeast microfold axis and the axis of the mica girdle Figure 8B.

Figure 9 shows a quartz girdle normal to *ab* (S_1) with a roughly northward-plunging axis. The microfractures subnormal to S_1 'lean back' in the manner of fractures subnormal to the movement direction (Fairbairn, 1949) but the quartz maxima seem the result of slip along planes parallel with these microfractures.

The quartz girdle in Figure 10A is roughly coaxial with the mica girdle, Figure 10B, which is developed around a weak southeast-plunging lineation due to faint microfolding.

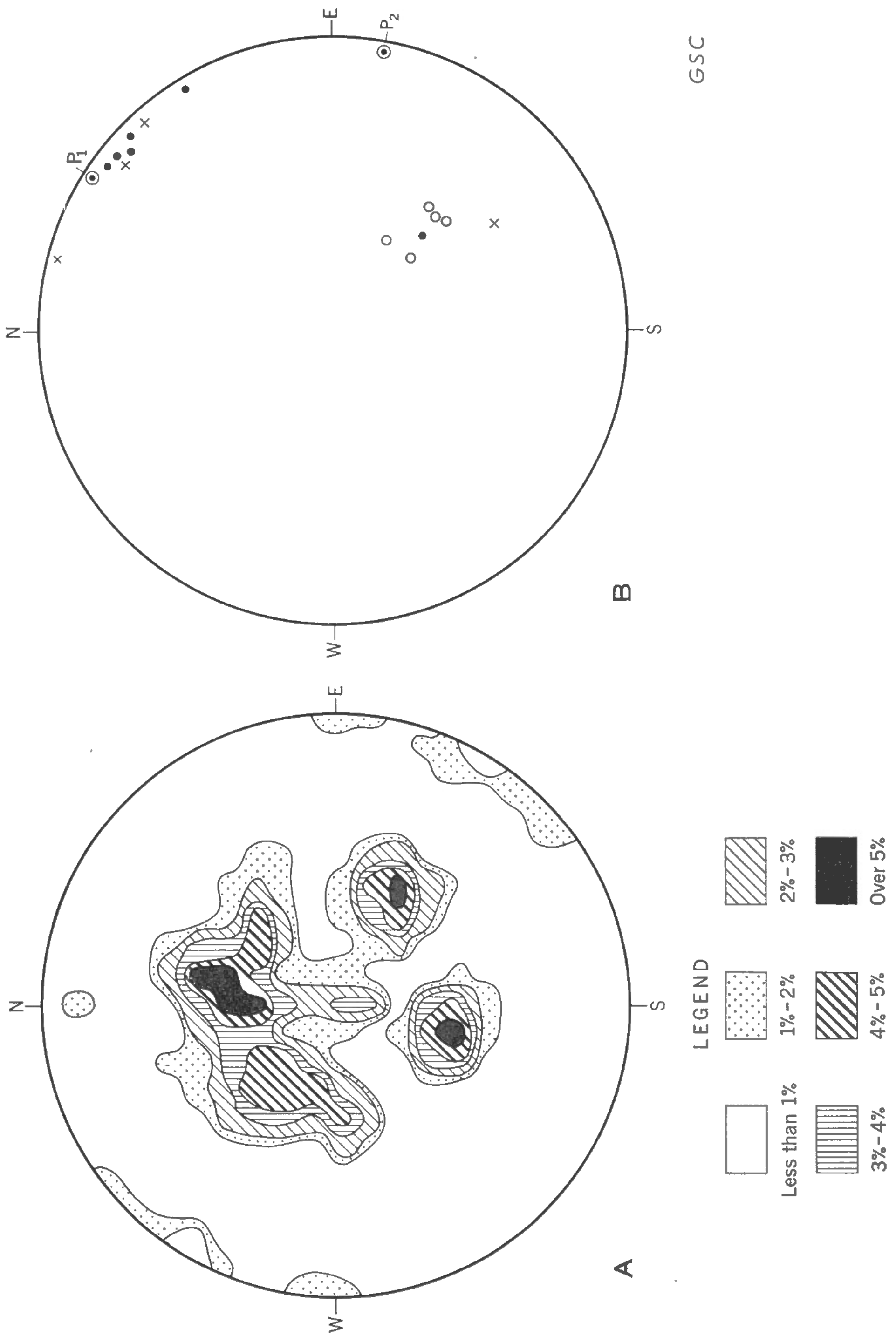

Figure 4. Horizontal equal area lower hemisphere projections.

A. Projections of 240 poles to S planes (foliation and coincident lithological layering) in gneisses; contours 1, 2, 3, 4, and 5% per 1% unit.

B. Projection of microfold axes (•), poles to strain-slip cleavage planes and axial plane foliation (o), and lineation due to preferred orientation of dark minerals (x) in gneisses. P_1 and P_2 are poles to great circles on which poles in 4A tend to lie.

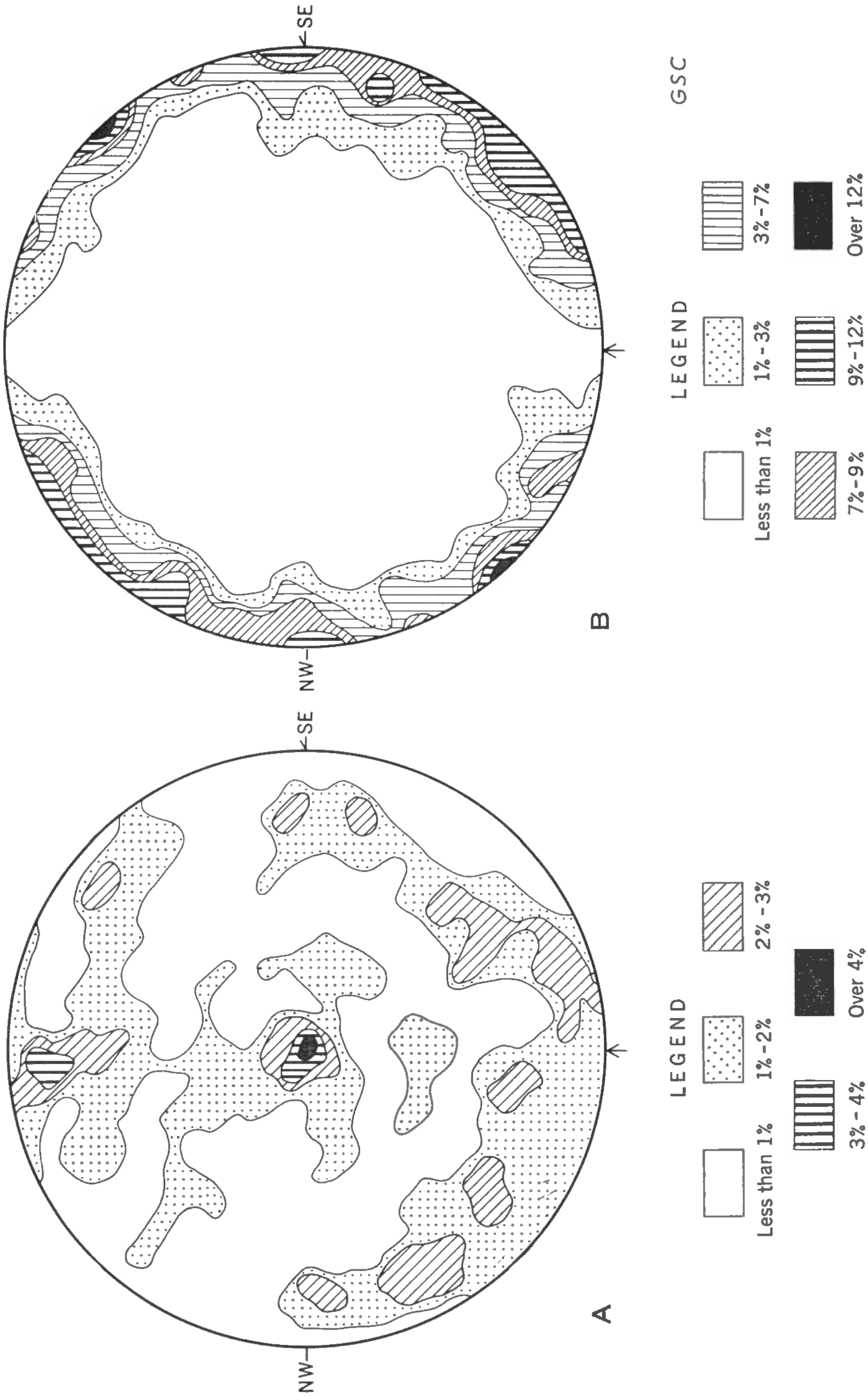

Figure 5. Equal area lower hemisphere projections in a vertical plane, the geographical orientation of which is shown by two coordinates each within the plane of projection: double barbed arrow indicates lower pole (nadir) of vertical geographic coordinate, single barbed arrow indicates a pole of a geographically horizontal line in the plane of projection, its bearing given as measured from true north. Dioritic, medium-grained, quartz-oligoclase-biotite gneiss from northwest shore of McKenzie Island, in the vertical, northwest limb of flexure fold several yards in amplitude with a subhorizontal, northeast axis normal to the plane of projection.

A. S_1 is microscopically folded on subhorizontal axes trending northeast normal to projection plane; 175 quartz [0001] axes; contours 1, 2, 3, and 4% per 1% unit.

B. Same slice as above; 150 poles to biotite cleavage; contours 1, 3, 7, 9, and 12% per 1% unit.

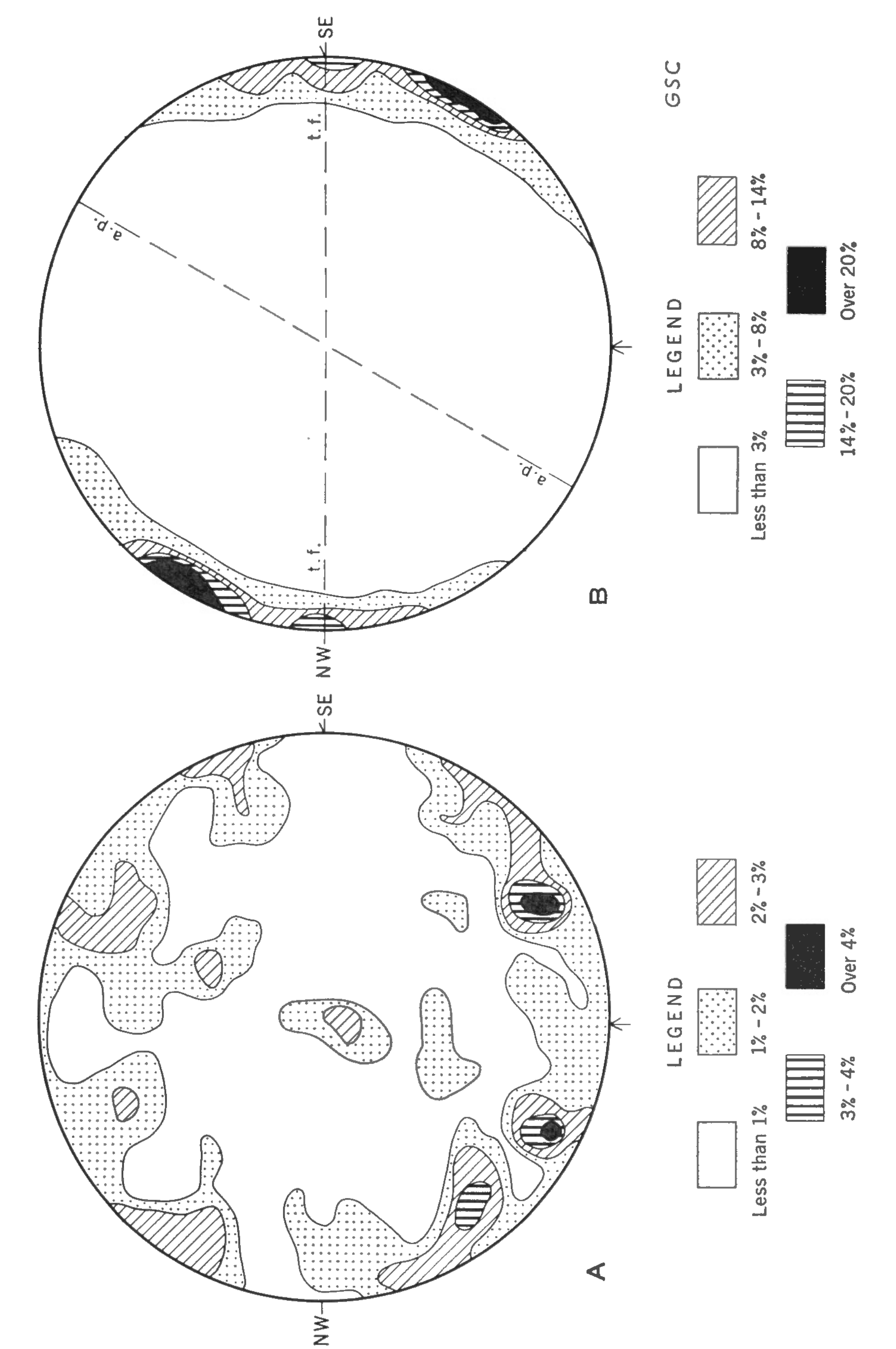

Figure 6. Equal area lower hemisphere projections in a vertical plane (coordinates described in Figure 5). Medium-grained, psammitic gneiss with some feldspar and mica from near and in same fold-limb as specimen of Figure 5.

A. 200 quartz [0001] axes; contours 1, 2, 3, and 4% per 1% unit.

B. Same slice as above; 145 poles to biotite cleavage; contours 3, 8, 14, and 20% per 1% unit; a.p.—trace of plane parallel with axial plane of flexure fold; t.f.—horizontal tension fractures.

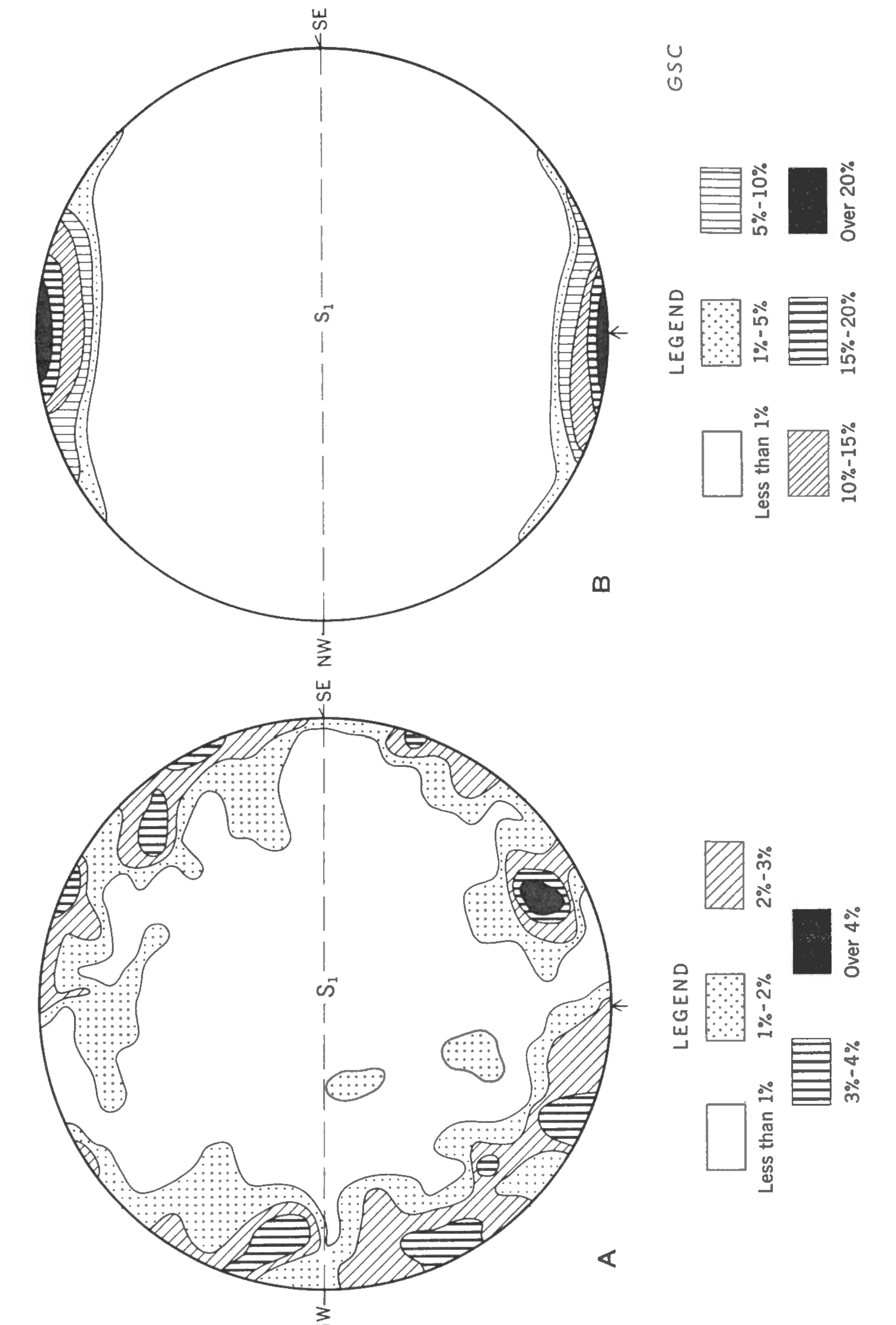

Figure 7. Equal area lower hemisphere projections in a vertical plane (coordinates described in Figure 5). Dark, dioritic, quartz-feldspar-hornblende-biotite gneiss a few yards from specimen of Figure 6 but on the subhorizontal southeast limb of the flexure fold.

A. 150 quartz [0001] axes; contours 1, 2, 3, and 4% per 1% unit.

B. Same slice as above; 100 poles to biotite cleavage; contours 1, 5, 10, 15, and 20% per 1% unit.

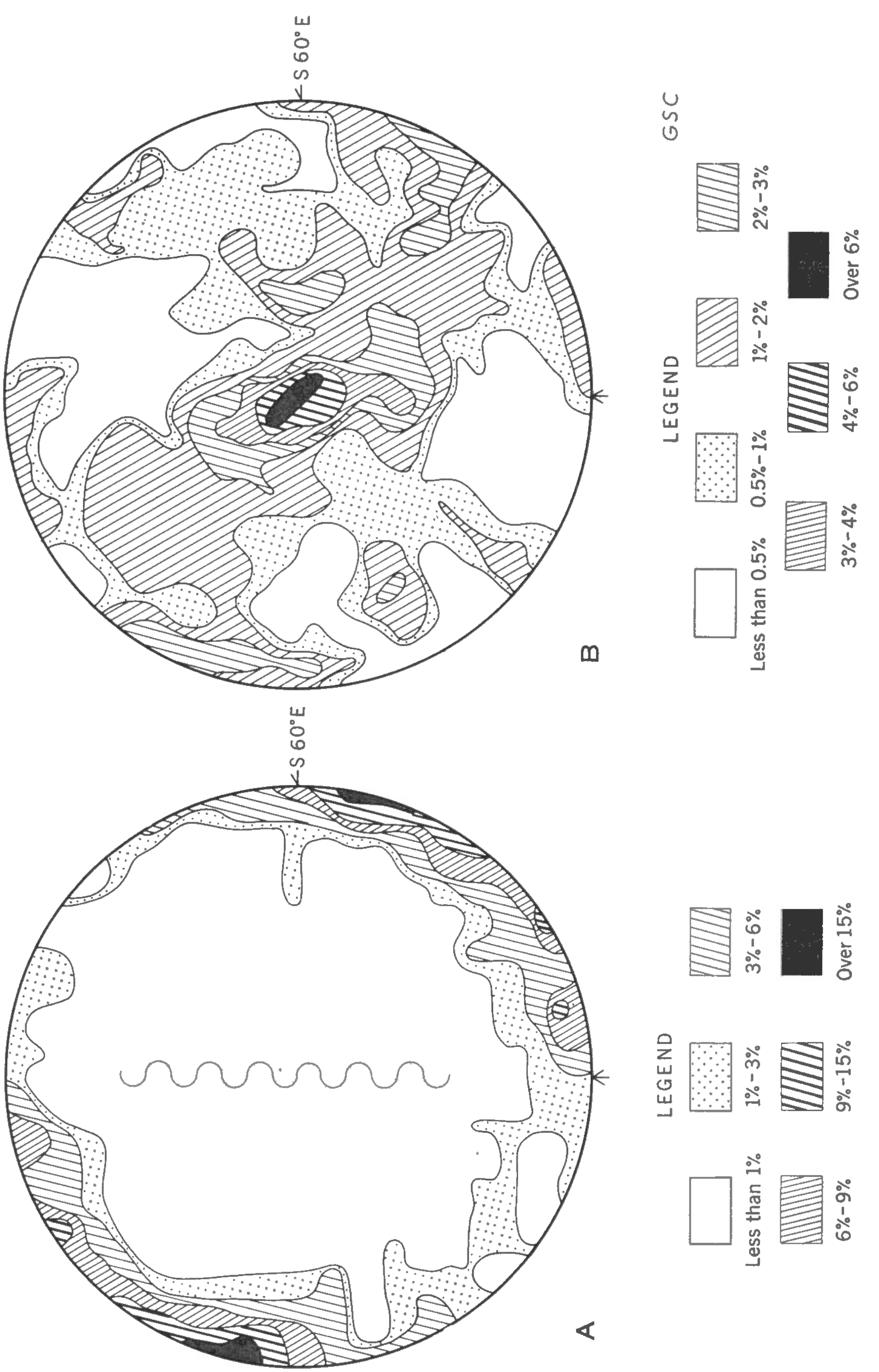

Figure 8. Equal area lower hemisphere projections in a vertical plane (coordinates described in Figure 5). Dark grey, medium-grained, granodiorite gneiss from about 4 miles northwest of the most westerly part of McKenzie Island; macroscopically S_1 strikes N30°E and dips vertically; microscopically it is folded on similar trending, subhorizontal axes normal to the projection plane (traces of folds shown in centre of A).

A. 150 poles to biotite cleavage; traces of small folds in statistically planar vertical S_1 shown as wavy line in centre of diagram; contours 1, 3, 6, 9, and 15% per 1% unit.

B. Same slice as above; 200 quartz [0001] axes; contours 0.5, 1, 2, 3, 4, and 6% per 1% unit.

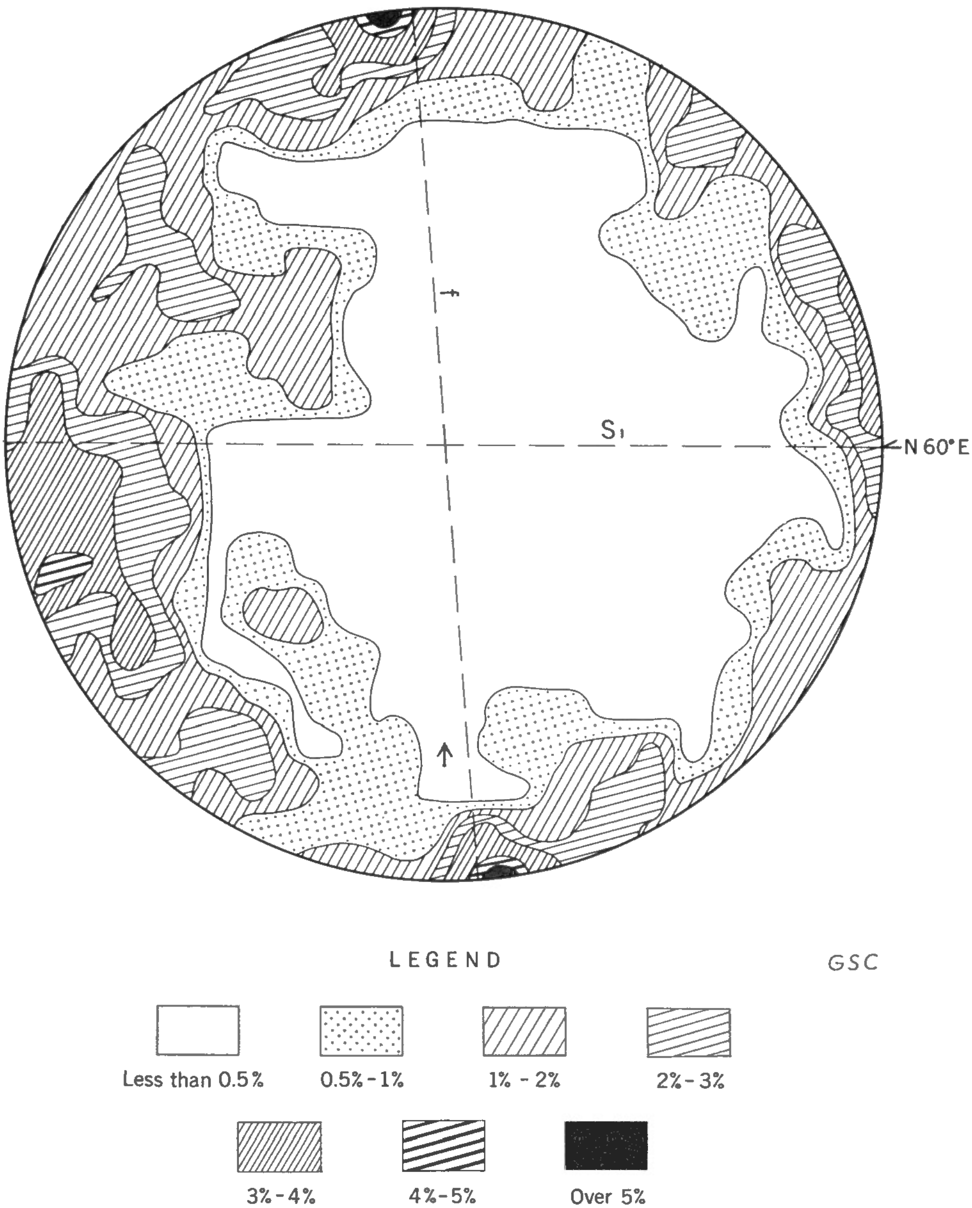

Figure 9. Equal area lower hemisphere projections (trace of S_1 on projection plane is horizontal; projection of lower pole of geographical vertical is shown by arrowhead). Grey, granodioritic gneiss from south side of island $16\frac{1}{2}$ miles N33°W of Kipawa; S_1 dips 30°NNW; subnormal to it are microfractures (f); 225 quartz axes; contours 0.5, 1, 2, 3, 4, and 5% per 1% unit.

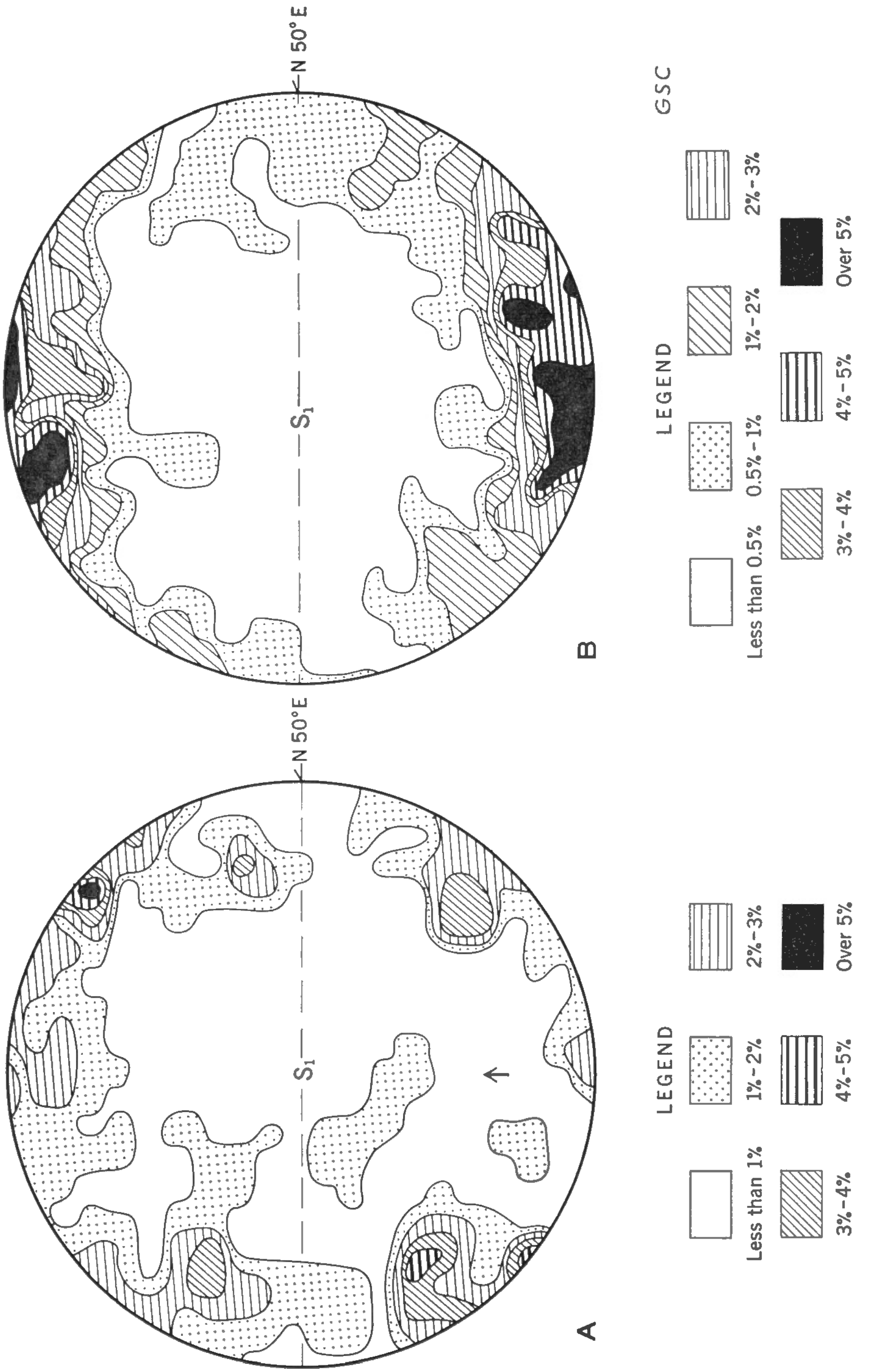

Figure 10. Equal area lower hemisphere projections (coordinates described in Figure 9) for granodioritic gneiss from west side of island about 7 miles north of Kipawa. Strike of S_1 N50°E, dip 35°SE; projection normal to lineation due to faint microfolding of S_1 and plunging southeast.

A. 150 quartz axes; contours 1, 2, 3, 4, and 5% per 1% unit.

B. Slice from same specimen parallel with above; 125 poles to biotite cleavage; contours 0.5, 1, 2, 3, 4, and 5% per 1% unit.

CONCLUSIONS

The formation of the granodioritic gneisses was accompanied by considerable metasomatism. Granodioritic gneiss permeates dark and mafic gneiss to form nebulitic migmatites and commonly contains quartz-oligoclase lenses and folia with biotite enriched margins that, like similar bodies in some Scottish gneisses (Harry, 1954), seem to be metamorphic differentiates. Development of hornblende and biotite in some pyroxene rocks adjacent to granodioritic gneiss appears due to metasomatic introduction of K, Mg, and Fe from the gneiss, and the manner in which this hornblende and biotite form irregular bodies and ramifying veinlets in the pyroxene rock indicates that the metasomatizing materials possessed a high degree of mobility.

Many of the darker granodioritic-dioritic gneisses present no convincing evidence of igneous origin and may well be metasediments that have, perhaps, been slightly altered in bulk composition by regional metasomatism. They are closely banded rocks petrographically resembling rocks described from other parts of the world as greywacke-type sediments metamorphosed under amphibolite facies conditions.

The veins of leucocratic granodioritic and granitic gneiss may be replacements or intrusions. An intrusive origin seems likely for those well-defined *lit-par-lit* homogeneous granitic gneiss veins several feet thick that in places transect the foliation and banding of their host. But metasomatic processes seem to have been generally active in the emplacement of the granitic gneisses for the following reasons:

(1) Many granitic gneisses diffusely migmatize their country rocks and bear sporadic feldspar porphyroblasts, like those common in the latter.

(2) Some granitic gneisses are associated with agmatites that display the characteristics of replacement breccias.

(3) Quartz-feldspar pods and folia, with thin marginal biotite-enriched zones apparently due to metamorphic differentiation, are common in the granitic gneisses.

(4) Thin-sections of the granitic gneiss show textures indicative of alkali metasomatism.

Examples of granitic gneisses that may be largely of replacement origin are the veins illustrated in Figure 2 and the analysed specimen 34 in Table I.

Epidote is a common well-crystallized minor constituent of the Kipawa gneisses which appears to have formed in stable equilibrium with its mineral associates, as in the similar gneisses described by Johnston (1954) from nearby parts of the Grenville sub-province. The Kipawa rocks are referable to Turner's (1948) staurolite-kyanite subfacies of the amphibolite facies in which, according to that author, shearing stress limits the lime content of plagioclase in quartzo-feldspathic assemblages with excess potash, excess lime forming minerals of the epidote family. Penetrative movement certainly was operative in the formation of the Kipawa rocks, but it is doubtful if their epidote content can be ascribed primarily to stress. They are similar in chemical composition and metamorphic state to the quartzo-feldspathic oligoclase-bearing gneisses of Ardgour, Scotland (Harry, 1954), which bear the imprint of intense paracrystalline deformation but are totally devoid of epidote—the chief mineralogical distinction between them and the Kipawa gneisses. It may also be questionable, as Thompson (1955, p. 77) pointed out, if extreme plasticity, like that possessed by the Kipawa gneisses during their formation, is compatible with great shearing stress.

A high ratio of ferric iron to alumina (Ramberg, 1952, p. 53) or lime to soda will favour formation of epidote, but in the Kipawa gneisses these ratios are not high and are no greater than in the Ardgour rocks.

Both areas are believed to show extensive migmatization and alkali metasomatism so that it does not seem likely that epidote in the Kipawa district is chiefly due to a lime metasomatism like that discussed by Harpum (1954) controlled by alkali metasomatism during regional metamorphism leading to migmatization. It is, however, noteworthy that in some granodioritic Kipawa gneisses fresh unsericitized plagioclase contains abundant epidote rods and grains that could be the result of soda metasomatism of lime-bearing plagioclase.

Water is an obvious factor in the separation of hydrous phases like epidote and great importance is attached by Yoder (1955) to its relative abundance in metamorphic systems. But there are also good reasons for the customary and contrary assumption that temperature and pressure determine the role of water during metamorphism (Thompson, 1955), and if this view is accepted the following suggestion can be advanced for consideration. Oligoclase-bearing quartzo-feldspathic rocks in Turner's (1948) staurolite-kyanite subfacies might be divisible into two groups of different metamorphic grade. In one group, represented by the Kipawa rocks, epidote is stable; whereas in the other, to which the Ardgour gneisses might belong, it is unstable. The second may perhaps be the higher grade group although this problem requires further consideration with special reference to pressure. In the amphibolite facies Grenville-type gneisses of the Surprise Lake area, clear epidote disappears with increasing metamorphism (Deland, 1956, p. 140).

The suggested subdivision of the staurolite-kyanite subfacies will not be easy to apply generally. Epidote can, and often does, form at several different times in the history of a rock and its status is often uncertain. But the subfacies is certainly large enough for partition, for this has recently been effected by Turner (1958) following Francis (1956). Their division, however, can only be recognized in pelitic rocks and is based on mineral assemblages excluding epidote. It is not likely to coincide with that suggested in the present paper.

Most of the granitic and granodioritic gneisses suffered strong plastic deformation with considerable tectonic transport during their formation. Those composing relatively undeformed crosscutting veins appear to have intruded more or less static brittle rock, but this does not demonstrate a post-tectonic origin for them. They might have grown in comparatively rigid 'rafts', 'floating' in a more plastic moving framework from which they possibly were derived by some, perhaps palingenetic, process. However this may be, foliation in the gneisses is almost ubiquitous and largely or wholly of tectonic origin. It locally transects large-scale layering, and slip on S_1, as shown on Figure 3, has in places been demonstrably considerable.

Many linear structures and the axes of quartz and mica girdles trend northeast to north-northeast and lie near P_1 on Figure 4B. On a small scale the fabric in places closely approaches monoclinic symmetry. Descriptively speaking, without inferring any fixed kinematic relationship between the fold axes and the plane of deformation, it appears that folding on gently plunging axes trending northeast to north-northeast has taken place, a common structural trend in the Grenville sub-province which has been discussed by Gill (1948).

Dips of axial plane foliation and cleavage (*see* Fig. 4B) indicate southeasterly overturn of a number of folds. But there are other orientations of quartz and mica girdles, linear structures and fold axes. Cross-folding along moderately inclined axes trending roughly from east-southeast to southeast has been effected. On a regional and often much smaller scale the fabric is triclinic. Whether or not this was achieved by one single deformation is problematical. It may be due to the successive orogenic episodes proposed by Wilson (1956) whose conclusions are compatible with the writer's results and seem likely to be correct in view of the complicated petrological history of the area. But crossed-strain cannot at present be ruled out as an operative factor. Further work on this problem is required in adjacent areas.

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