ORIGIN OF THE APSLEY

PARAGNEISS

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By

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A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree
Master of Science

McMaster University
September 1960

MASTER OF SCIENCE (1966)
(Geology)

McMASTER UNIVERSITY
Hamilton, Ontario.

TITLE: Origin of the Apsley Paragneiss

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NUMBER OF PAGES: viii, 79

SCOPE AND CONTENTS:

The Apsley paragneiss, a belt of biotite-quartz-feldspar gneiss in eastern Ontario, was mapped on a scale of 4 inches = 1 mile. It is shown that the paragneiss is a member of the Dungannon formation, an important stratigraphic unit of the Grenville series.

Fifty hand specimens were collected for modal analyses and ten chip samples were collected for major and minor element analyses. The constituent minerals were separated from the rock for chemical analysis and were examined by optical and X-ray methods.

A sodic and a potassic type of paragneiss are recognized. The sodic type probably is the metamorphic equivalent of sodic graywacke and the potassic type the equivalent of shale interbedded with the graywacke. It is concluded that the metamorphism which affected the Apsley member was approximately isochemical and took place at about 400° C.

ACKNOWLEDGEMENTS

The writer gratefully acknowledges all the guidance and encouragement he has received from Dr. D. M. Shaw and Dr. T.N. Irvine who supervised the thesis work in 1959 and 1960 respectively.

Mr. D.A. Moddle, provincial assayer of the Ontario Department of Mines kindly analyzed 10 samples of paragneiss and four minerals for their major elements. Mr. J.N. Weber analyzed the 10 paragneiss samples for their trace element content. Partial chemical analyses of one mineral was done at the geological laboratories of the Université de Nancy. The work of the analysts is gratefully acknowledged.

The writer is indebted to Dr. G.V. Middleton of McMaster University and to Dr. D.F. Hewitt of the Ontario Department of Mines for many fruitful discussions.

Dr. M.E.Hurst, provincial geologist of the Ontario Department of Mines, made it possible for the writer to carry out his research while engaged as senior assistant on geological field parties of the Department of Mines.

In the academic year 1958-1959, the research was supported by a fellowship kindly given by the Consolidated Mining and Smelting Company of Canada.

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INTRODUCTION

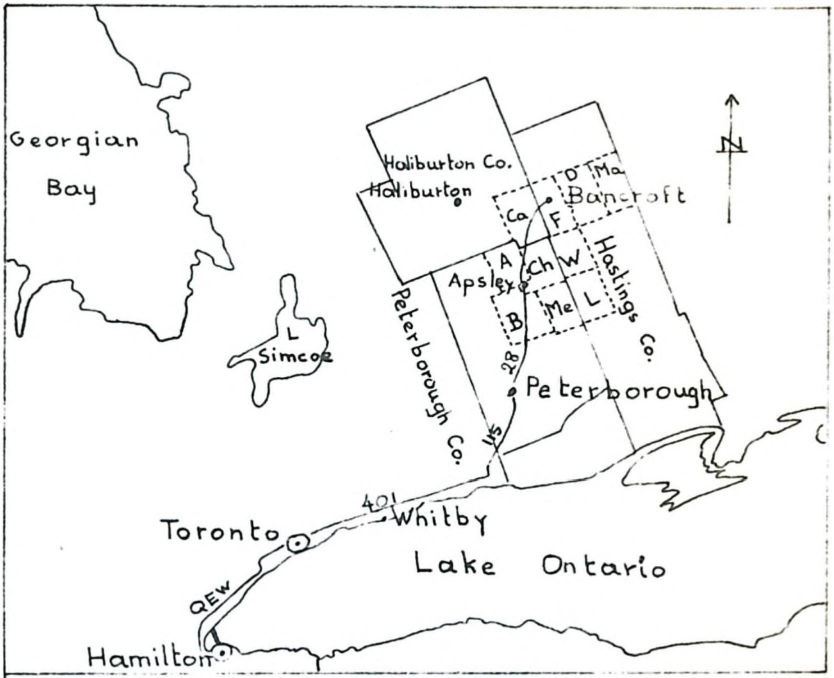
A belt of rusty weathering, biotite-quartz-feldspar paragneiss crops out in the townships of Anstruther, Burleigh, Chandos, Methuen, and Wollaston in the Haliburton - Bancroft area, eastern Ontario (Fig. 1). The belt has been traced continuously for about twenty miles and is best exposed near the village of Apsley in the township of Anstruther. The writer proposes that it be called the Apsley paragneiss.

Statement of the Problem

The principal problem in the study of the Apsley paragneiss has been to determine the nature of the original rock and the processes of metamorphism. Similar biotite-quartz-feldspar paragneiss occurs elsewhere in the Grenville geologic province of Ontario, Quebec, and the Adirondack Mountains of New York, and has generally been considered to be the metamorphic equivalent of shale or sandy shale of marine origin (e.g. Adams and Barlow, 1910, p.88; Hewitt, 1956, p.10). However, Engel and Engel (1953) have shown that the major paragneiss of the Adirondack Mountains probably is not derived from a shale because of its low $K_2O:Na_2O$ ratio. They point out that its composition is

Location Map.

South Eastern Ontario.



Legend:

28	Highway
⊙ •	City or Town

Townships: Anstruther, A; Burleigh, B;
Cardiff, Ca; Chandos, Ch; Dungannon, D;
Faraday, F; Mayo, Ma; Methuen, Me
Lake, L; Wollaston, W;
Scale: 1 inch = 40 miles.

more like that of a high rank (sodic) graywacke, and in other regions, it has been demonstrated that biotite-quartz-oligoclase gneiss can be derived from graywacke by metamorphism (Ambrose, 1936; Turner, 1938). However, in the Adirondack Mountains, such an interpretation presents the following difficulties:

1) The stratified rocks in the region are generally typical of the shelf facies of sedimentation, consisting of abundant carbonate and quartzite units and only rare volcanic rocks. Stratigraphically, the paragneiss lies between two marble units. Graywacke, on the other hand, most commonly occurs with volcanic rocks in the eugeosynclinal facies and is not generally associated with carbonate rocks and quartzites.

2) No clear evidence was found in the paragneiss to suggest a regular interbedding of graywacke and shale, a feature common to many graywacke sequences.

3) The chemical features of the gneiss may be equally well explained by any one of the following interpretations:

a) The parent rock was a sodic shale laid down in an evaporitic environment.

b) The parent rock was a dacitic tuff.

c) The parent rock was a shale and Na^+ has been added by pervasive metasomatism.

d) The parent rock was a shale, and during metamorphism, the alkali metals have been redistributed, the K^+ being concentrated as the granite bodies that occur locally in the paragneiss.

One other aspect in the formation of the Apsley paragneiss that has been investigated is the effect of temperature on the mineral phases.

Previous Work

The geology of the Haliburton-Bancroft area was first investigated by Adams and Barlow (1910). They recognised the Apsley paragneiss as a distinct unit and describe it briefly in their report. Recently, a more detailed study of the Haliburton-Bancroft area has been undertaken by the Ontario Department of Mines under the supervision of Dr. D.F. Hewitt. To date, reports have been published on Brudnell and Raglan townships (Hewitt, 1953), Monteagle and Carlow townships (Hewitt, 1954), Dungannon and Mayo townships (Hewitt and James, 1955) and Cardiff and Faraday townships (Hewitt, 1957).

The townships of Chandos, Glamorgan, Methuen, Monmouth, Lake, and Wollaston have been examined and reports concerning them are in preparation. Present knowledge of the region is well summarized on map 1957b of the Ontario Department of Mines.

Present Work

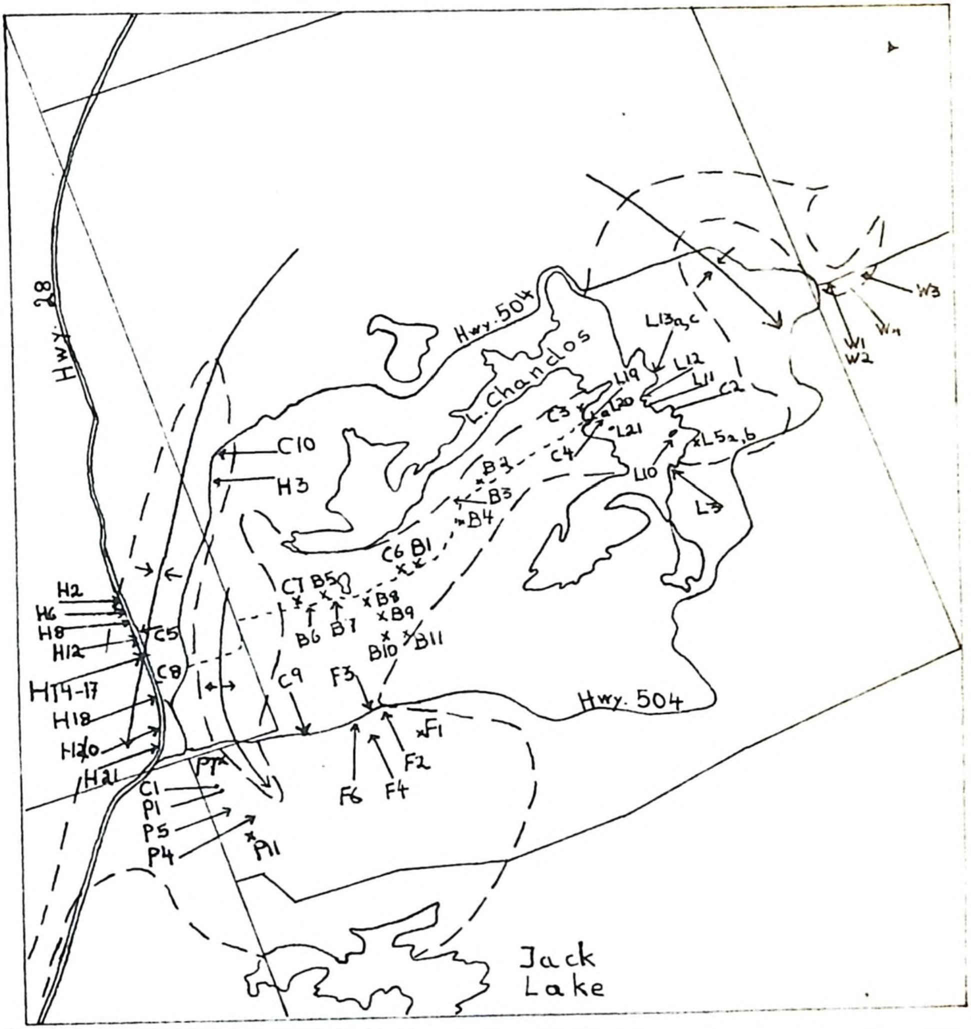
The field work for the present study was done during the summers of 1958 and 1959 while the writer was acting as senior assistant on field parties of the Ontario Department of Mines, involved in the geological mapping of Chandos and Wollaston townships. The scale of mapping was four inches to one mile.

The paragneiss was sampled for laboratory study by means of many specimens collected along lines transverse to the trend of the belt (Fig. 2). Ten samples, each consisting of six pounds of rock chips, were collected specifically for chemical investigation. Where chips were collected from several bands, one hand specimen was collected from each band for petrographic study.

Ten chip samples have been analyzed for major elements by Mr. D. Moddle, Provincial Assayer, Ontario Department of Mines. Their trace element content was determined by Mr. J.M. Weber at McMaster University. The equipment and methods used in the trace element determination and their precision are discussed in Weber (1959).

The modal composition of the chemically analyzed rocks and of 50 other hand specimens have been determined by the point-counting method. Each mode is based on one thin section cut approximately normal to the foliation in the rock. To enable rapid identification of minerals, each

Figure 2.
Sample Location Map

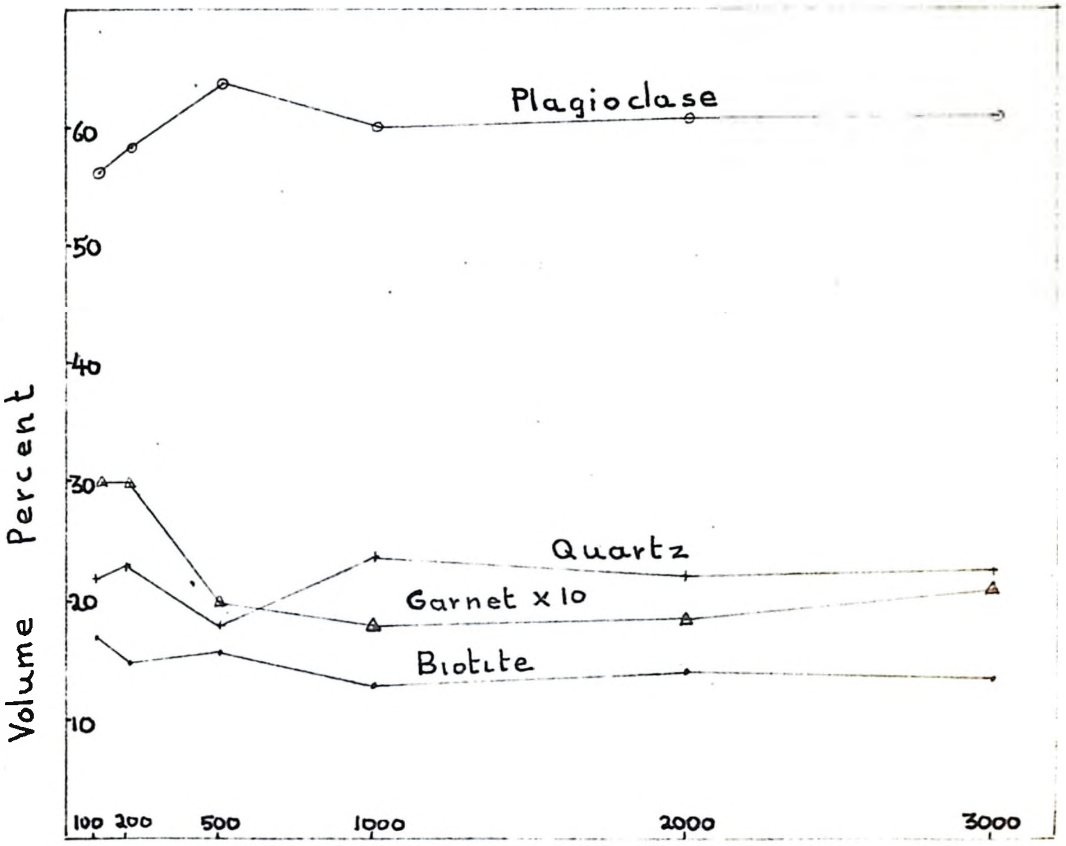


slide was etched for two minutes in fumes of warm hydrofluoric acid and then stained for one minute in a saturated solution of sodium cobaltinitrite. In this way, plagioclase and microcline are etched, microcline is stained yellow, and quartz is left untouched.

A replication experiment was carried out to determine the number of points that must be counted in a slide to obtain reproducible estimates of the more abundant minerals. The mode of one specimen (L19) was determined by counting 100, 200, 300, 400, 500, 1,000, 2,000 and 3,000 points evenly spaced over the total area of the slide. In Figure 3, the percentages of quartz, plagioclase, biotite, and garnet obtained at each stage of counting are plotted against the number of points counted. As shown, beyond 1,000 points, the slope of the curves is near zero, and counting 3,000 points does not seem to increase the precision materially. Replicate determinations on a number of other slides show that the percentages of microcline, biotite, and the sum of quartz plus plagioclase are reproducible to one per cent. In some specimens, determinations of quartz and plagioclase individually are reproducible only to three or four per cent because the etching is not equally effective over the whole area of the slide, and this results in errors in the distinction of quartz from plagioclase.

Figure 3.

Reproducibility of Modes.



Number of Points Counted

Individual minerals were separated using the Franz isodynamic separator and heavy liquids. Separates of biotite were purified by rolling the powder over large sheets of paper, the biotite clinging to the paper while other minerals roll off. Refractive indices were determined using the single variation method. The minerals were analyzed by the Provincial Assayer of the Ontario Department of Mines and by the mineralogical laboratories of the Université de Nancy, France.

The content of orthoclase (Or) in plagioclase and microcline from one specimen was checked using the X-ray method described by Tuttle and Bowen (1958). The plagioclase and microcline occur as discreet grains without visible perthitic structures or alteration. As an attempt to homogenize any submicroscopic perthite, the feldspars were crushed to a fine powder and heated at 900°C for twenty-four hours.

The content of anorthite equivalent (An) in plagioclase was determined in this section using the Rittmann zone method in conjunction with the curves for low temperature plagioclase given in Troger (1952).

General Geologic Setting

All consolidated rocks of the Haliburton-Bancroft area are Precambrian in age. A thick series of volcanic and sedimentary rocks have been strongly deformed and metamorphosed. Emplaced into this series are bodies of gabbro, diorite, nepheline syenite, and granite.

Hewitt (1956) recognises two major structural divisions in the Haliburton-Bancroft area: the Haliburton and Hastings Highland Gneiss Complex; and the Hastings Basin. In the Highlands, metamorphism has produced mineral assemblages indicative of the granulite facies and amphibolite facies (Hewitt, 1956). Original textures and structutes are destroyed, and there is much evidence of intense metasomatism. In the Hastings Basin, most of the rocks belong to the amphibolite facies, and deformation and metasomatism appear less intense than in the Highlands; original structures such as pillows and amygdules in the lavas and graded bedding and pebbles in the sediments are locally well preserved. Two stratigraphic units, the Hermon formation and the Dungannon formation, have been recognised in the Hastings Basin (Hewitt and James, 1955; and Hewitt, 1957). These can be traced into the area in which the Apsley paragneiss occurs.

Near Bancroft, the boundary between the Highlands Gneiss Complex and the Hastings Basin has a general easterly trend and is well defined, being marked by the McArthur Mills fault zone. However, it becomes indistinct to the southwest. Originally Hewitt proposed to draw it along the eastern margin of granite bodies in Methuen and Wollaston townships. However, in the opinion of the present author, more recent work indicates that the southwestern part of the boundary should be drawn along the eastern margin of the Burleigh and Anstruther granite gneiss complex (Map 1957b, Ont. Dept. Mines). By the latter definition, the Apsley paragneiss would be entirely within the Hastings Basin.

TABLE I

TABLE OF FORMATIONS FOR THE HALIBURTON-BANCROFT AREA

Pleistocene		Boulder clay; sand; gravel
		Great unconformity
		Granodiorite; syenite, granite; and granite pegmatite
	Plutonic Rocks:	Intrusive Contact
		Nepheline syenite; other alkali syenite
Precambrian		Intrusive Contact
		Gabbro; dionite; ortho-amphibolite
		Intrusive Contact
	Grenville	Lithologic Subdivision
	Series:	Metavolcanic rocks; basalt, andesite, thyolite, agglomerate tuff
		Metasedimentary rock; marble, amphibolite paragneiss; quartzite

STRATIGRAPHY AND STRUCTURE

The paragneiss is banded due to an alternation of layers rich and poor in biotite. The bands range in thickness from one quarter of an inch to six feet, but are commonly about six inches thick. They are considered to be relict beds because they are parallel to thin continuous marble layers that occur in the paragneiss, and to the contacts of the unit as a whole. Although biotite flakes are oriented parallel to the banding, the rock is not strongly schistose because it is rich in quartz and feldspar. The dip of the banding and, presumably, of the Apsley paragneiss is commonly 30° - 70°. Two structures that may indicate tops of beds were noted. They are:

(1) An apparent fracture cleavage that intersects the banding. This occurs in an exposure along highway 28 about 2½ miles north of Apsley and in an outcrop on the east shore of Chandos Lake, Concession IX Lot 24, Chandos township.

(2) A feature that may be relict graded bedding occuring in exposures of the paragneiss along highway 28, about 2 miles north of Apsley, and in Concession X, Lot 25, Chandos township. The presumed bottom part of each bed is medium-grained and rich in quartz. Upwards the rock be-

comes gradually poorer in quartz, richer in biotite, and possibly finer in grain. The contact with the overlying bed is sharp. Tentative top determinations based on these features combined with the overall structural interpretation suggest that the paragneiss unit is generally lying right way up.

The Apsley paragneiss is underlain conformably by a unit of interstratified marble and feather amphibolite. This unit is well exposed on the shores of West Bay in Chandos Lake, and the writer proposes calling it the West Bay marble. In Methuen township and adjacent parts of Chandos township, the paragneiss is overlain conformably by a thick unit of marble called the Jack Lake marble by Hewitt (oral communication). Northeast of the Chandos Lake pluton similar marble in the same stratigraphic position is called the Owenbrook marble by Shaw (oral communication). The West Bay marble and Owenbrook marble can be traced directly into rocks classified as part of the Dungannon formation, and it would seem that the Apsley paragneiss is a member of the Dungannon formation. The stratigraphic relations of the Dungannon formation are summarized in Table II.

The Apsley paragneiss generally has a thickness of about 2,000 ft. Near its southwest and northeast ends, it rapidly pinches between adjacent marble and amphibolite units. The upper and lower contacts of the paragneiss are

TABLE II

CORRELATION TABLE FOR THE DUNGANNON FORMATION

Anstruther and Chandos Townships			Wollaston Township		Dungannon and Mayo Township	
Hermon Formation			? ? ?		Hermon Formation	
Dungannon Formation	Jack Lake Marble	Amphibolite and paragneiss	Dungannon Formation	Amphibolite and paragneiss	Dungannon Formation (Mayo Anticline)	Marble Turriff rusty schist member Turriff basic volcanic member Marble and schist Wendsley Lake rhyodacite and tuff Marble Crooked Lake schist member Marble Grassy Lake quartzite member Marble
		Owenbrook marble		Owenbrook marble		
	Apsley paragneiss			Acid Volcanic Ap.P Amphibolite		
	West Bay marble and feather amphibolite			Marble and Amphibolite around Coe Hill		

gradational; as the adjacent carbonate units are approached, hornblende appears in the paragneiss and thin interbeds of marble and amphibolite become more abundant. In Chandos township, between the east shore of Chandos Lake and the north branch of highway 504, the thickness of the paragneiss is greatly reduced because of the appearance of marble and amphibolite beds in the upper and lower parts of the member. Only a thin band of paragneiss can be traced into Wollaston township.

Hewitt and James (1955) have shown that in Dungannon and Mayo townships, the Dungannon formation is conformably overlain by the Hermon formation. However, these units are overturned in the north limb of the east-trending Detlor anticline. To the southwest, in Anstruther, Chandos, Cardiff, and Faraday townships, the Hermon formation dips uniformly to the southeast at about 50° - 70°. The direction of tops of beds could not be determined for this part of the formation, and it may be overturned to the northwest inasmuch as it is approximately on strike with the north limb of the Detlor anticline.

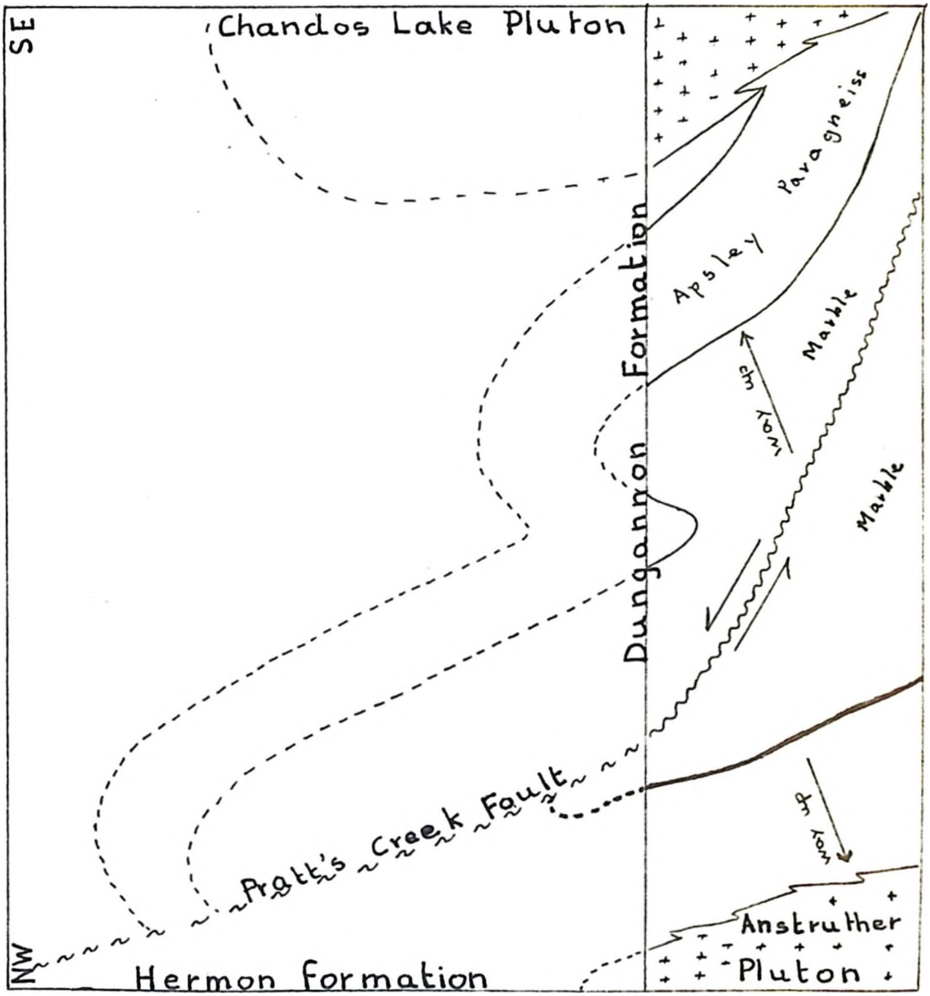
In Anstruther and Chandos townships, the northeast trending Pratt's Creek fault (Shaw, oral communication) separates the Hermon from the Dungannon formation. On the basis of drag folding observed on both sides of the fault, the author suggests that the fault is a thrust dipping southeast at about 60°. The Pratt's Creek fault has not been recognised in Faraday township and may die out in that area.

A possible interpretation of the structure in Chandos township is given diagramatically in figure 4. As shown, the Anstruther-Faraday segment of the Hermon formation and the marble adjacent to it on the south may form the northwest limb of an overturned anticline. The rocks southeast of the Pratt's Creek fault are in normal position and form the southeast limb of the same anticline; they are thrust over the northwest limb along the Pratt's Creek fault.

Mapping in Wollaston township has indicated the existance of a fault passing from the Unfraville gabbro, southwestward beneath Wollaston Lake into the Coe Hill granite (see map). Southeast of the fault there are thick units of marble, para-amphibolite, paragneiss and metavolcanic rocks. The metavolcanic rocks consist of metamorphosed andesite and basalt with recognizable pillow structures, intermediate and acid tuff, basic and acid agglomerate, and rhyolite. Exact correlation of this group of rocks with the Hermon and Dungannon formation is not possible, but they do not seem to be greatly different in age. Their lithologic types are the same and there is no evidence that they are separated by an important unconformity.

Figure 4

Diagramatic Cross-section in Chandos Township



The Apsley paragneiss is intruded by the Chandos Lake pluton of granite and syenite, the Glen Alda gabbro, and the Wollaston granite. The Wollaston granite has a metamorphic aureole only a few hundred feet wide, but the Chandos Lake pluton has an aureole as much as one quarter of a mile wide. Where the paragneiss lies within this aureole it is metamorphosed to the sillimanite-almandine subfacies of the amphibolite facies as defined by Fyfe, Turner and Verhoogen (1958) and is injected by granite and granite pegmatite.

Migmatite is only present in the Apsley paragneiss in the aureole of the Chandos Lake pluton and as narrow zones that cut marble, amphibolite and metagabbro as well as the paragneiss. In the narrow zones, the dark part of the migmatite looks much like the Apsley paragneiss but differs in that it contains abundant sphene and hornblende. It has the same composition regardless of the rock type it cuts and therefore does not seem to be genetically related to the Apsley paragneiss. Granite pegmatite and vein quartz are most common in the aureole of the Chandos Lake pluton but occur in all parts of the paragneiss belt. Tourmaline, magnetite and garnet are the common accessories in the pegmatite.

PETROGRAPHY AND CHEMISTRY OF THE APSLEY PARAGNEISS

Lithologic Character

The common rock type in the Apsley member is comprised of quartz, plagioclase, and biotite ± microcline. A little garnet and iron sulfide (pyrite and pyrrhotite) are generally present. Quartz and feldspar make up nearly 80 per cent of the rock and biotite, although it shows planar orientations, is not segregated into separate layers; consequently the rock is rather massive in appearance and not strongly schistose or gneissic. A sedimentary origin, though commonly assumed, needs proof and therefore the term "paragneiss" is a poor name. It is, however, used in this study because other geologists (e.g. Adams and Barlow, Hewitt, and Engel and Engel) have used it for the same and similar rocks.

The paragneiss is grey on fresh surfaces and weathers rusty brown because of 0.5 - 2.0 per cent disseminated iron sulfide. Quartz and feldspar grains are equant and generally have dimensions of 0.2 - 0.5 mm. The large dimension of biotite flakes is also about 0.2 - 0.5 mm. Relict coarse fragments are generally absent. No evidence for the presence of volcanic fragments such as bombs or lapilli was found. In a road cut about ½ mile north of

Apsley, there is a 6 foot thick conglomerate bed. The pebbles are similar in composition to the paragneiss that surrounds them but are commonly poorer in biotite and, hence, their rounded outlines are easily seen. They comprise about 10 per cent of the rock. The largest pebble found has a long diameter of 6 inches and a intermediate diameter of 2 inches. A marked Preffered orientation of pebbles is not apparent.

At a few localities, ovoid nodules occur in the paragneiss. They are generally 6 - 12 inches in length and 4 - 8 inches in median diameter. Their orientation gives rise to a lineation subparallel to the dip of the banding. They have a variable composition but generally consist of quartz, feldspar, calcite, hornblende and garnet. In some, the hornblende and garnet are segregated into concentric layers; in others, calcite predominates and the nodules have the composition of impure marble. The origin of the nodules in uncertain, but if the Apsley paragneiss is a metasediment, they may represent concretions in the parent rock.

A sodic and potassic variant of the paragneiss have been recognized. They are distinguished by their content of biotite plus microcline and may be classified chemically by their potash : soda ratio expressed in the form:

$$\frac{K_2O}{K_2O + Na_2O}$$

This form can only range between 0 and 1 and is preferable to the one, K_2O/Na_2O. The value 0.5 forms a natural subdivision, potassic paragneiss having a ratio greater than 0.5 and sodic paragneiss having a ratio smaller than 0.5.

In the western part of the belt, particularly along highway 28, microcline is commonly porphyroblastic, and the two paragneiss types are easily distinguished. However, in the eastern part, microcline is rarely porphyroblastic, and potassic paragneiss is often recognised only by microscopic examination. Except for the abundance of microcline and its local porphyroblastic character, the two paragneiss types are similar in mineralogy and texture. The major minerals show a typical "pavement" intergrowth.

As stated earlier, the Apsley paragneiss is visibly banded due to an alternation of layers rich and poor in biotite. The sodic and potassic paragneiss are also interbanded; the contacts between these bands are sharp and coincide with the biotite layers. Consequently, if the banding due to differences in biotite content is relict bedding, then the sodic and potassic paragneiss also occurs in beds. Where the two variants are distinguishable in the field, the volume ratio of potassic to sodic paragneiss is about 1 : 5.

Major Minerals

Plagioclase

Plagioclase is the most abundant mineral in the Apsley paragneiss. It is generally fresh, untwinned and uncleaved; commonly thin sections contain only 2 or 3 twinned grains. Twinning, where present, is on the albite law, only a few grains being twinned on both albite and pericline laws. Anorthite content could only be determined by the Rittmann zone method in those thin sections in which twinned and cleaved grains are present. Determinations on the same grain using two variations of the zone method agree within one per cent of anorthite equivalent. The same agreement was obtained for different grains in the same thin section. The results of these determinations are shown in figure 5. The average composition of the plagioclase in both varieties of paragneiss is An_{14} - An_{15}, and for most of the specimens its range is between An_{10} and An_{16}. Partial chemical analyses and optical properties of a plagioclase separate are given in Table 3 along with the composition determined by the X-ray method.

Microcline

Potash feldspar, where it occurs in the Apsley paragneiss, shows the cross-hatch twinning of microcline.

Figure 5.

Histogram of the An Content of Plagioclase

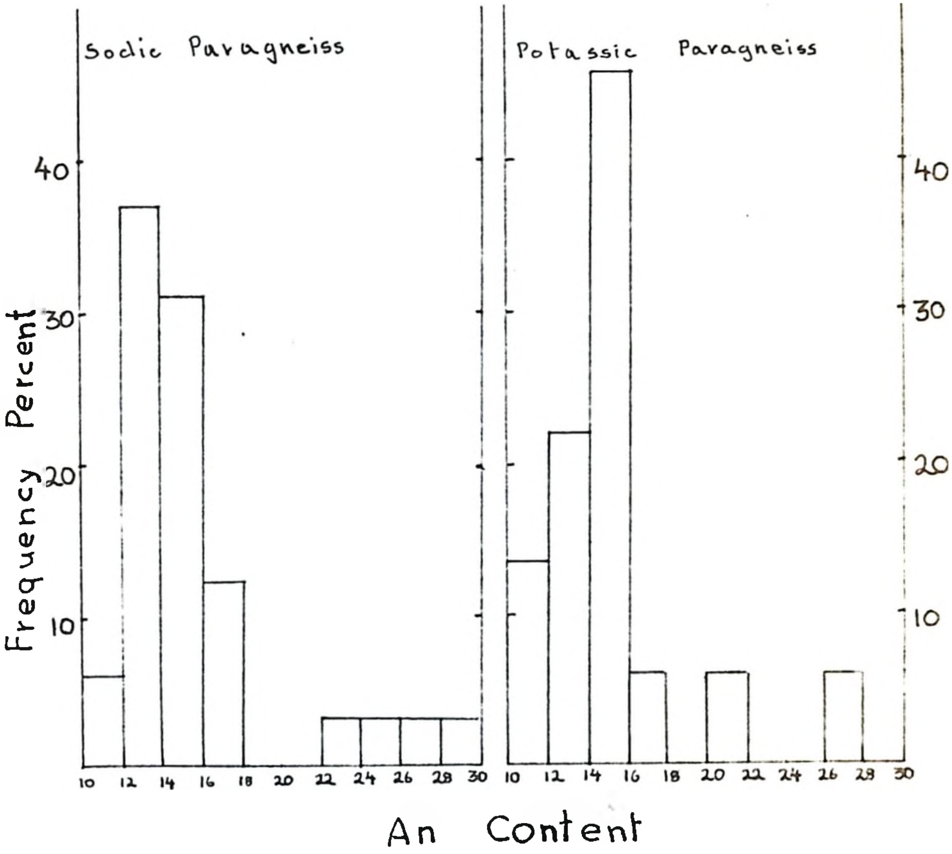


TABLE 3

COMPOSITION AND OPTICS OF THE FELDSPARS

Microcline MC1

SiO_2	62.75
Al_2O_3	20.66
Fe_2O_3	0.13
MgO	0.01
CaO	0.17
Na_2O	0.48
K_2O	15.24
Loss on ignition	0.64
	100.08

2V = -70°

Or Content by X-ray Method = 95 per cent

Molecular Composition from Analyses:

Or_{92}, Ab_6, An_2

D. Moddle, Analyst.

Plagioclase PC1

The Analyzed Powder is a Quartz + Plagioclase Mixture

$Na_2O = 6.20$

$K_2O = 0.30$

Nγ' on 010 cleavage flakes = 1.532

Max $X' \wedge (010) = 13°$

An. Content:

An_9 - from Refractive Index

An_9 - from Extinction Angle

Or Content by X-ray Method = 0 per cent

Molecular Composition from Analyses and Optical Properties:

Or_6, Ab_{85}, An_9

Partial Analyses at Universite de Nancy.

It is present in less than half the specimens examined but is a major mineral in the potassic paragneiss, constituting mote than 10 per cent of the mode. The microcline is commonly poikiloblastic, being crowded with inclusions of quartz, plagioclase, and biotite. The inclusions are smaller than the grains of the same minerals outside microcline and give the impression that they are relicts from reactions that went to form microcline. In about half the specimens in which it occurs, microcline forms porphyroblasts with irregular outline and may have dimensions of 3 - 4 mm.

Chemical analyses and the optic axial angle of microcline that has been separated are given in Table 3, along with the composition determined by the X-ray method. A negative optic axial angle of 70° - 75° is characteristic of all the microcline, whether porphyroblastic or not, and suggests that microcline has a narrow range of composition in the Apsley paragneiss as a whole.

Biotite

Two varieties of biotite are present. Both are strongly pleochroic and deeply coloured; one variety is pleochroic in dark and pale brown whereas the other is pleochroic in dark and pale reddish brown. The optic axial angle of both is generally 0° - 5°. A chemical analysis and the refractive index, Ny, of a separate of each is given in Table 4. Considerable difficulty was experienced in

TABLE 4

COMPOSITION AND REFRACTIVE INDEX OF BIOTITE

	L 21 - Reddish Brown	70-145-5 - Brown
SiO_2 -	35.25	35.29
Al_2O_3 -	14.52	13.09
Fe_2O_3 -	2.12	4.14
FeO -	23.70	23.93
MgO -	8.55	6.72
CaO -	0.38	0.51
Na_2O -	0.31	0.16
K_2O -	8.90	9.12
MnO -	0.12	0.59
TiO_2 -	2.80	2.37
Water -	1.81	1.88
	98.51	97.80

Ny = 1.637 ± 0.002 Ny = 1.639 ± 0.002

D. Moddle, Analyst, notes: There is the possibility that there might be a little CO_2 or other constituent which might bring up the totals slightly.

From comparisons with other biotite analyses, the author suggests that the figure for water is low by at least 1 per cent.

measuring the refractive index, the biotite being nearly opaque when immersed in the index liquid. Replicate determinations on grains from the same powder gave inconsistent results; the margin of error is given in Table 4. The reddish brown variety has less Fe_2O_3 and MnO, and more MgO and TiO_2 than the brown biotite.

Garnet

Although it does not generally constitute more than two per cent of the rock, pink almanditic garnet is widespread in the Apsley paragneiss. A porphyroblastic garnet associated with cordierite and sillimanite occurs abundantly in certain layers of paragneiss within the metamorphic aureole of the Chandos Lake pluton, but will not be considered here.

The garnet studied here occurs as small grains evenly distributed through the rock and rarely has dimensions larger than other mineral grains (0.2 - 1.0 mm.). It is commonly sieved with inclusions of quartz, the inclusions tending to be concentrated in the centre of the grains. In some places, a shell of garnet surrounds a core of quartz, plagioclase and biotite.

The chemical composition and refractive index of a garnet separate is given in Table 5. Unfortunately, the separate could not be freed of all included quartz and of a little feldspar. To correct for this, the molecular compos-

TABLE 5

COMPOSITION AND REFRACTIVE INDEX OF GARNET

Garnet L12(1)		Recalculated
SiO_2	40.50	37.6
Al_2O_3	19.25	20.8
Fe_2O_3	-	
FeO	30.40	33.2
MgO	2.44	2.8
CaO	2.75	3.1
Na_2O	0.07	
K_2O	0.12	
MnO	2.15	2.4
TiO	0.09	0.1
Total	97.77	100.0

Molecular Composition	
Gross:	9.0
Pyrope:	11.1
Almand:	74.3
Spess:	5.5
	100.0

Refractive Index

N = 1.801 ± 0.0005

D. Moddle, Analyst, notes: The garnet analyses is a little low, but otherwise appears quite satisfactory. There is a possibility that there might be a little CO_2 or other constituent which would bring up the total.

(1) Quartz and a little feldspar could not be separated from the garnet powder.

ition of the garnet was calculated from the analyses; Na_2O and K_2O were calculated as albite and microcline respectively and subtracted; and excess SiO_2 subtracted. The analyses was then recalculated to 100 per cent. In the final result there is a shortage of about 0.5 per cent Al_2O_3 suggesting a slight error in the analysis.

Modal Composition

As shown in figure 2, the specimens collected for modal analyses cluster along lines crossing the paragneiss belt. Each of the elongate clusters may be regarded as a group or category. Six such groups are recognized, and the specimens from each are designated by a letter. The average mode for sodic and potassic paragneiss from each group, progressing from east to west, is given in Table 6. No compositional trend is noticeable for either type; in fact, the differences between groups are small.

To test whether all samples of paragneiss may be considered to be part of one population and whether grand averages of the two paragneiss types may be calculated for the Apsley paragneiss as a whole, a model I analyses of variance (Dixon and Massey, 1957, p.145) was carried out. The results are summarized in Tables 7 and 8. The "F" test shows that, for the available data, at the 95 per cent level of significance, no differences can be detected between the means from the six groups. All the specimens may therefore

TABLE 6

MODES FROM THE GROUPS OF HAND SPECIMENS

Sodic Variety

Mineral	H	P	F	B	L	W
Quartz	26.2	32.6	33.9	30.7	28.3	31.6
K.Feldspar	2.2	1.3	5.9	1.3	1.3	-
Plagioclase	46.9	47.9	41.0	45.8	50.8	44.3
Biotite	22.2	17.0	17.3	21.1	16.7	23.2
Garnet	0.1	0.2	0.9	0.5	0.8	-
Muscovite	0.4	0.2	0.2	0.1	1.1	-
Others(1)	1.0	0.2	0	0.1	0.5	0.4
Opaque	0.9	0.6	0.8	0.4	0.5	0.5

Potassic Variety

Quartz	17.7	34.6	34.9	33.9	24.2	29.9
K.Feldspar	15.3	18.4	19.0	15.2	21.3	33.7
Plagioclase	35.0	30.6	31.6	31.9	34.6	26.2
Biotite	30.0	12.8	14.0	18.5	17.4	9.8
Garnet	0.5	-	0.2	-	-	-
Muscovite	1.0	0.4	Tr	-	0.5	-
Others(1)	1.0	0.1	Tr	-	0.4	-
Opaque	0.5	3.1	0.3	0.5	1.6	0.4

(1) Others are Apatite, Zircon, Tourmaline, Calcite and hornblende.

be regarded as being drawn from one population. The value of "P" in the tables is an indication of the propability that the hypothesis of equal means is incorrect. The smaller numerical value of P, the greater the probability that the hypothesis is correct.

The average and standard deviations for each of the main minerals in the two variants of Apsley paragneiss are given in Table 9 and are compared with least altered, incipiently granitized, and intensley granitized Adirondack paragneiss from the Emeryville area (Engel and Engel, 1958, p.1408). The sodic Apsley paragneiss is very similar to the least altered Adirondack paragneiss, whereas the potassic Apsley paragneiss closely resembles the incipiently granitized Adirondack paragneiss. The relatively small standard deviation for the four major mineral phases of the two types of Apsley paragneiss indicate the monotonous character of these rocks throughout the belt.

TABLE 7

ANALYSES OF VARIANCE OF SODIC TYPE

Minerals	Mean Squares		df	F	P
Quartz	For Categories	48.27	5	0.628	$0.50 < P < 0.75$
	Within Categories	76.87	32		
Microcline	For Categories	17.92	5	2.130*	$0.90 < P < 0.95$
	Within Categories	8.41	32		
Plagioclase	For Categories	58.97	5	0.805	$0.25 < P < 0.50$
	Within Categories	73.29	32		
Biotite	For Categories	47.71	5	1.006	$0.50 < P < 0.75$
	Within Categories	47.42	32		

TABLE 8

ANALYSES OF VARIANCE OF POTASSIC TYPE

Minerals	Mean Squares		df	F	P
Quartz	For Categories	116.71	5	1.52	0.50 < P < 0.75
	Within Categories	76.71	6		
Microcline	For Categories	60.72	5	0.722	0.25 < P < 0.50
	Within Categories	84.13	6		
Plagioclase	For Categories	17.47	5	0.585	0.25 < P < 0.50
	Within Categories	29.88	6		
Biotite	For Categories	133.31	5	0.75 < P < 0.90 (F = 3.014)	
	Within Categories	44.32	6		

TABLE 9

COMPARISON OF MODES OF APSLEY PARAGNEISS
WITH MODES OF ADIRONDACK PARAGNEISS

Minerals	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Quartz	29.70	8.54	37.86	25.93	9.74	36.62	32.68
Microcline	1.89	3.11	3.19	19.16	6.05	13.80	20.78
Plagioclase	46.87	8.46	38.86	32.89	4.93	34.00	35.50
Biotite	19.77	6.88	17.60	19.98	9.19	17.10	7.73
Garnet	0.42		0.03	0.21		Tr	-
Muscovite	0.46		0.86	0.43		0.69	1.30
Opaque	0.54		0.60	1.38		0.73	2.10
Others(8)	0.45			0.02			
An of Plag.	15		28	15		19	9

(1) Average Sodic Apsley Paragneiss
(2) Standard Deviation of Sodic Apsley Paragneiss
(3) Average Least Altered Adirondack Paragneiss (Engel and Engel, 1958, p.1408)
(4) Average Potassic Apsley Paragneiss
(5) Standard Deviation of Potassic Apsley Paragneiss
(6) Average Incipiently Granitized Adirondack Paragneiss
(7) Average Adirondack Granitic Gneiss from the Emeryville Area (Intensely Granitized Paragneiss)(Engel and Engel, 1958, p.1408).
(8) Apatite, Zircon, Tourmaline, Calcite and Hornblende.

Chemical Composition

Bias of Chemically Analyzed Samples

In order to test whether the ten samples analyzed for major and minor elements are representative of the paragneiss belt as a whole, the average modes of the 50 hand specimens are compared with the average modes of the chemically analyzed samples. The averages of the two groups of modes are given in Table 11 and are compared using the "Student's" "t" test. The value α is an indication of the probability that the hypotheses of equal means is correct. The larger the numerical value of α, the greater the probability that the hypothesis is correct.

The "t" test is, however, invalid if the variances S^2, of the two populations under comparison are significantly different. Therefore the variances are compared in Table 10 using the "F" test. "P" has the same meaning here as in Tables 7 and 8. For all the minerals except microcline, the variances are not significantly different and the use of the "t" test is valid. For microcline, a modified form of "t" test, given by Dixon and Massey (1957, p.123), is used.

At $\alpha = 0.05$, only quartz in the sodic paragneiss shows significantly different mean values for the chemically analyzed samples and the modally analyzed hand specimens. It is to be expected that the SiO_2 value in the average chemical composition of sodic Apsley paragneiss is slightly

TABLE 10

COMPARISON OF VARIANCE OF MODES OF HAND SPECIMENS AND CHEMICALLY ANALYZED SAMPLES

Mineral	Chemical S^2	Modal S^2	F	S	P
Sodic Type	$N = 18$	$N = 38$			
Quartz	66.81	73.01	1.10	N.S.	$.25 < P < .50$
K.Feldspar	2.63	9.69	3.69**	S.	$.995 < P < .999$
Plagioclase	45.92	71.35	1.55	N.S.	$.75 < P < .90$
Biotite	35.96	47.46	1.33	N.S.	$.50 < P < .75$
Potassic Type	$N = 7$	$N = 12$			
Quartz	51.03	94.89	1.859	N.S.	$.75 < P < .90$
K.Feldspar	153.22	36.56	0.239*	S	$.01 < P < .025$
Plagioclase	35.42	24.24	0.685	N.S.	$.025 < P < .050$
Biotite	181.22	87.71	0.469	N.S.	$.10 < P < 0.25$

TABLE 11

COMPARISON OF MEANS OF MODES OF HAND SPECIMENS AND CHEMICALLY ANALYZED SAMPLES

Mineral	Chemically Analyzed		Modally Analyzed				
	Mean	Stand. Dev.	Mean	Stand. Dev.	df.	t.	α
Sodic							
Quartz	36.25	8.17	29.70	8.54	54	2.35**	$.02 < \alpha < .05$
K. Feldspar	00.65	1.62	1.89	3.11	55	1.97	$.05 < \alpha < 0.10$
Plagioclase	44.49	6.77	46.87	8.46	54	1.07	$.20 < \alpha < .40$
Biotite	16.44	6.00	19.77	6.88	54	1.79	$.05 < \alpha < 0.10$
Potassic							
Quartz	29.04	7.15	25.93	9.74	17	0.738	$.40 < \alpha < .60$
K. Feldspar	17.87	12.40	19.16	6.05	5.2	1.97	$.60 < \alpha < .80$
Plagioclase	30.01	5.95	32.89	4.93	17	1.14	$.20 < \alpha < .40$
Biotite	17.20	13.50	19.99	9.19	17	0.542	$.40 < \alpha < .60$

high.

Major Element Composition

The major element composition of the ten chemically analyzed samples is given in Table 12; two samples, C_1 and C_{10}, belong to the potassic variety and eight to the sodic variety. In Table 13, the average of the sodic type is compared with the average eugeosynclinal sandstone (mainly sodic high rank graywacke) computed by Middleton (1960) and with least altered Adirondack paragneiss (Engel and Engel, 1958, p.1408). In Table 14, the potassic type is compared with average pelitic rock (Shaw 1956) and incipiently granitized and intensely granitized Adirondack paragneiss from the Emeryville area (Engel and Engel, 1958, p.1408).

The sodic paragneiss is generally similar to least altered Adirondack paragneiss and to average eugeosynclinal sandstone. The latter appears to be higher in MgO and CaO, but examination of histograms of the concentration of these oxides in eugeosynclinal sandstone (Fig. 6) shows that the difference is not significant.

Potassic Apsley paragneiss is similar to slightly granitized Adirondack paragneiss and to average pelitic rock. Its values for Al_2O_3, MgO, Na_2O, and K_2O may be different, but comparisons with histograms prepared by Shaw (Fig. 6) show that for common pelitic rocks the differences are not significant.

Figure 6.

Distribution of Some Oxides in Shale and Graywacke

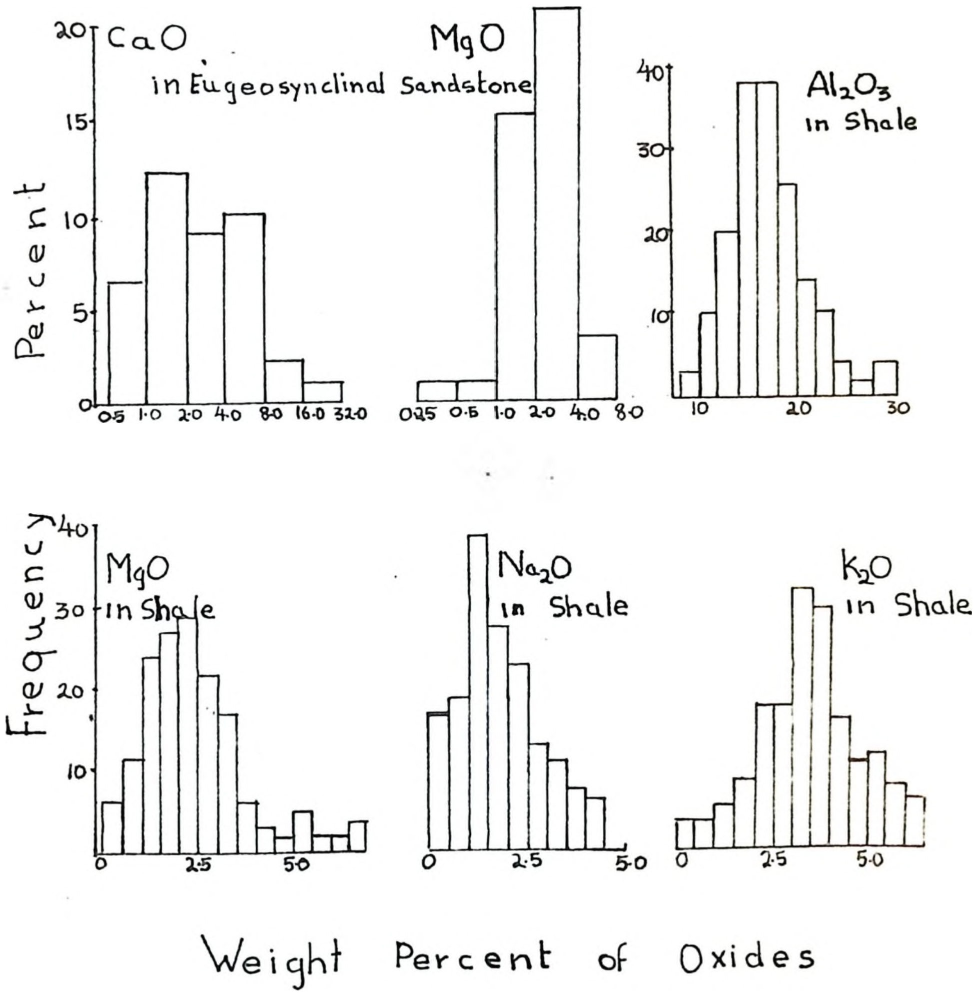


TABLE 12

CHEMICAL ANALYSES OF APSLEY PARAGNEISS

Oxides	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
SiO_2	72.80	65.05	68.66	67.75	69.72	77.37	70.00	67.10	70.61	66.49
Al_2O_3	11.91	14.44	12.90	15.31	13.98	10.55	13.87	15.60	14.63	15.88
Fe_2O_3	0.70	1.70	1.16	1.30	0.92	1.24	0.93	0.84	0.82	0.00
FeO	3.60	5.30	4.93	3.98	4.19	2.97	3.67	4.27	3.46	3.98
MgO	0.92	1.84	1.71	1.58	1.13	0.66	0.95	1.29	1.16	2.25
CaO	0.54	2.62	2.31	2.12	1.89	1.56	1.57	1.58	1.46	2.23
Na_2O	2.82	3.77	3.46	3.83	4.22	2.99	4.88	4.24	4.28	2.78
K_2O	4.51	1.89	2.05	1.87	1.99	1.40	1.50	2.65	2.05	4.63
H_2O+	0.46	0.73	0.57	0.61	0.46	0.51	0.34	0.44	0.40	0.42
H_2O-	0.01	0.02	0.02	0.01	0.01	0.02	0.01	0.00	0.00	0.01
P_2O_5	0.00	0.00	Tr	Tr	Tr	0.00	Tr	Tr	0.00	Tr
TiO_2	0.26	0.71	0.69	0.53	0.61	0.22	0.41	0.58	0.37	0.69
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	Tr	Tr	Tr	Tr	Tr
MnO	0.06	0.11	0.15	0.11	0.13	0.22	0.11	0.12	0.11	0.06
V_2O_3	0.00	0.00	0.01	0.01	0.00	0.00	Tr	0.01	0.01	0.01
CO_2	0.28	0.37	0.10	0.01	0.22	0.00	0.09	0.00	0.03	0.13
S	0.90	0.35	0.30	0.22	0.54	0.50	0.46	0.38	Tr	Tr
F	0.24	0.11	0.10	0.11	0.18	0.13	0.05	0.16	0.23	0.08
Totals	100.01	99.01	99.14	99.40	100.19	100.34	98.84	99.26	99.61	99.64

D. Moddle, Analyst.

TABLE 13

SODIC APSLEY PARAGNEISS COMPARED WITH GRAYWACKE AND LEAST ALTERED ADIRONDACK PARAGNEISS

	(1)	(2)	(3)
SiO_2	69.53	69.12	70.25
Al_2O_3	13.91	13.40	14.14
Fe_2O_3	1.11	5.36	0.55
FeO	4.10		3.83
MgO	1.28	2.53	1.76
CaO	1.88	4.42	2.20
Na_2O	3.96	3.20	3.43
K_2O	1.93	1.97	2.40
P_2O_5	Tr		0.07
H_2O^+	0.51		0.72
TiO_2	0.52		0.67
MnO	0.13		0.05

(1) Average Sodic Apsley Paragneiss

(2) Average Eugeosynclinal Sandstone (Mainly High Rank Graywacke, Middleton, 1960).

(3) Average Least Altered Adirondack Paragneiss from Emeryville, (Engel and Engel, 1958, p.1408).

TABLE 14

POTASSIC APSLEY PARAGNEISS COMPARED WITH SHALE AND GRANITIZED ADIRONDACK PARAGNEISS

	(1)	(2)	(3)	(4)
SiO_2	69.96	64.10	69.25	72.31
Al_2O_3	13.90	17.70	14.63	14.76
Fe_2O_3	0.35	2.70	0.70	0.30
FeO	3.79	4.05	3.45	1.76
MgO	1.58	2.65	1.74	0.79
CaO	1.39	1.88	1.97	1.40
Na_2O	2.80	1.91	3.06	3.57
K_2O	4.57	3.60	3.79	4.27
P_2O_5	Tr	-	0.05	0.03
H_2O+	0.44	-	0.71	0.44
TiO_2	0.48	0.86	0.63	0.63
MnO	0.06	-	0.02	0.04

(1) Average Apsley Potassic Paragneiss.

(2) Average Pelitic Rock (Shaw, 1956).

(3) Average incipiently Granitized Adirondack Paragneiss

(4) Average intensely Granitized Adirondack Paragneiss.

(3) and (4) are from the Emeryville Area (Engel and Engel, 1958, p. 1408).

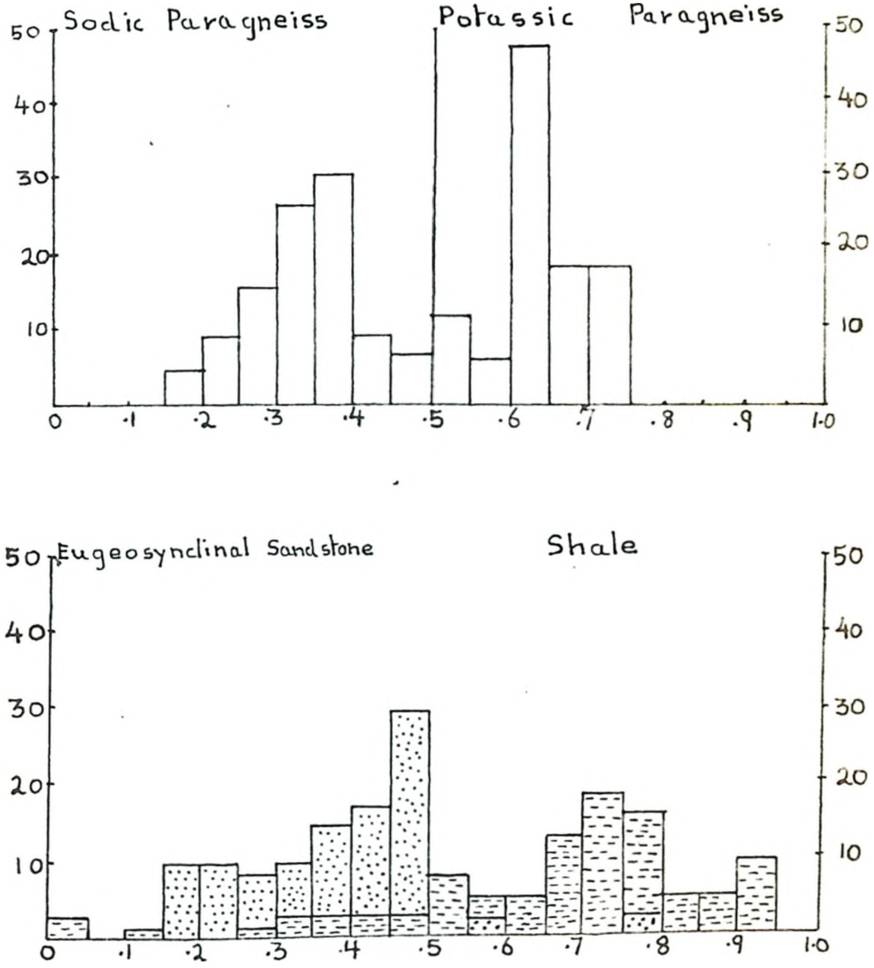
Using the Na_2O and K_2O content of biotite, microcline and plagioclase, the potash : soda ratio was calculated for the 50 hand specimens. It was also calculated for the chemically analyzed samples from both their modes and from their chemical analyses; the ratio obtained by the two methods are very similar, and hence, the values obtained from the 50 modes may be used. They are summarized as a histogram in figure 7, and are compared with histograms for shale and graywacke. As shown, the distribution of the potash : soda ratio in the two variants of Apsley paragneiss is very similar to that in shales and graywacke. Out of 60 values only 9 have a ratio falling between the modal classes.

Minor Element Composition

The concentration of 20 minor elements in ten samples of Apsley paragneiss are given in Table 15. The precision of Weber's work as indicated by the relative error of triplicate analyses and expressed as a percentage of the mean are given in Table 16. His analyses of the standards G-I and W-I agree well with the accepted values. In comparisons with the data of Weber, there is no problem of interlaboratory correlation; all analyses were done concurrently on the same apparatus. For G-I and W-I the results of Weber are in fair agreement with those of Chodos

Figure 7.

Distribution of the Soda:Potash Ratio in Apsley Paragneiss, and Graywacke and Shale.



and Codjin (Engel and Engel, 1958), therefore minor element analyses of the Adirondack and Apsley paragneiss may be compared.

In Table 17, the minor element content of the sodic type is compared with the least altered Adirondack paragneiss (Engel and Engel, p.1408) and with the average of 12 analyses of sodic high rank graywacke presented in Weber (1959). As shown, the sodic Apsley paragneiss is similar to least altered Adirondack paragneiss; the only differences are that in the Apsley paragneiss, Mn and V are higher and Ni is lower. For the sodic graywacke, the average and standard deviations of each element have been calculated and are assumed here to be representative of sodic graywacke. Intervals of one and two standard deviations on either side of the mean are used as approximations of the 68 and 95 per cent confidence intervals respectively. At the 68 per cent level of significance, both the Apsley paragneiss and the Adirondack paragneiss are low in B, Co, Cr, Ni, and Ti, and high in Mn, and V as compared to sodic graywacke. At the 95 per cent level of significance, they are only high in Mn and V.

In Table 18 the potassic Apsley paragneiss is compared with average figures for pelagic shale (Weber, 1959), the Littleton formation (Shaw, 1956), and shales from the Normanskill formation and the Quebec group (Weber, 1959). For most elements, differences are not very great. In the

TABLE 15

TRACE ELEMENTS IN THE APSLEY PARAGNEISS

	B	Ga	Mg	Ti	Li	Cu	V	Zr	Mn	Sc	Sr	Ba	Rb
C 1	tr	tr	.48	1600	26	75	87	160	730	tr	190	high	120
C 2	27	11	1.6	4100	28	69	220	150	1200	15	175	310	46
C 3	22	7	1.4	3400	23	45	160	110	1200	11	175	300	40
C 4	19	12	1.3	3300	21	30	200	150	1100	13	240	310	52
C 5	tr	12	1.1	4900	23	45	120	290	1800	12	195	550	38
C 6	tr	15	.63	1700	21	56	63	170	2100	14	140	245	28
C 7	tr	20	.58	2200	26	31	100	250	1200	tr	330	180	26
C 8	tr	6	.41	1300	24	15	97	63	520	6	190	490	60
C 9	tr	17	.73	2500	27	31	150	150	1100	14	260	440	57
C10	tr	34	2.9	6100	44	12	205	230	950	14	345	800	117

Traces of the following elements (sensitivity in ppm): Be(1), Y(2), Ag(1), Ni(1), Co(5), Cr(5), La(100)

Not detected (sensitivity in ppm): Mo(5)

TABLE 16

RELATIVE ERROR FOR TRIPLICATE ANALYSES AS PERCENT OF THE MEAN AFTER WEBER (1959)

Ag	11.6	Cu	14.6
B	19.4	Ga	12.4
Ba	12.6	Mg	8.9
Be	14.0	Mn	11.1
Co	9.0	Mo	11.6
Cr	13.5	Ni	8.4
Sc	11.3	V	11.8
Sr	13.2	Y	-
Ti	7.5	Zr	7.6

TABLE 17

COMPARISON OF SODIC PARAGNEISS WITH SODIC GRAYWACKE AND LEAST ALTERED ADIRONDACK PARAGNEISS

	(1)	(2)	(3)	(4)	(5)	(6)
B	9	40	17	10	15	6
Ba	353	371	243	612	1200	375
Co	5	25	17	8	12	5
Cr	5	162	79	35	45	25
Cu	40	22	20	16	40	6
Ga	13	9	5	11	15	8
Mg	9700	22000	17000	1100	-	-
Mn	1277	431	297	356	575	135
Ni	1	60	33	15	20	12
Sc	11	10	8	12	16	11
Sr	213	217	82	310	490	225
Ti	2925	5169	1577	2800	3000	2000
V	139	61	17	56	65	50
Zr	167	281	94	171	200	130

All concentrations are given in parts per million

(1) Average of sodic Apsley paragneiss
(2) Average of sodic graywacke
(3) Standard deviation for sodic graywacke
(4) Average least altered major paragneiss (Engel and Engel, 1958, p.1408)
(5) Max. for least altered major paragneiss (Engel and Engel, 1958, p.1397)
(6) Min. for least altered major paragneiss (Engel and Engel, 1958, p.1397)

paragneiss, B, Co, Cr, Ni, and possibly Ti are low, and Mn is high.

Both the sodic and potassic paragneiss are lower than average graywacke and shale in Ni, Co, Cr and Ti. If the paragneiss represents a metamorphosed sedimentary rock, the differences might be the result of a low concentration of these elements in the area from which the sediment was eroded.

The low B values in the Apsley paragneiss are not in harmony with a marine environment of deposition. Landergren (1945) and Degens Williams and Keith (1957) have shown that marine clay sediments generally contain 80 - 200 ppm. B, whereas fresh water clay sediments contain 10 - 40 ppm. However, the metasedimentary rocks associated with the Apsley paragneiss in the Hastings Basin suggest a marine origin. If the Apsley paragneiss is a metasediment, the B may have left the rock during metamorphism and concentrated in tourmaline occuring in pegmatite dikes and quartz veins that are common in the area.

In Table 19 the minor element content of sodic and potassic paragneiss is compared with graywacke and shale and with least altered and granitized Adirondack paragneiss. For Co, Ga, Sc, Sr and Zr, the differences within rock groups are probably not significant. For Ba and Mn, the differences between sodic and potassic paragneiss, between graywacke and shale, and between least altered and granitized Adirondack

TABLE 18

COMPARISON OF POTASSIC PARAGNEISS WITH SHALES

	(1)	(2)	(3)	(4)	(5)
B	Tr	220	-	130	92
Ba	800	520	570	360	1000
Co	5	22	18	32	17
Cr	5	110	110	87	67
Cu	43	58	18	37	38
Ga	17	13	19	20	24
Mg	17000	16000	13000	24000	3000
Mn	840	180	590	400	79
Ni	1	64	64	58	
Sc	7	12	14	15	11
Sr	272	150	710	150	320
Ti	3850	6000	7000	7000	4300
V	146	150	120	79	46
Zr	195	340	200	230	230

All concentrations are given in parts per million

(1) Average of potassic paragneiss from Apsley member
(2) "Average" pelogic shale from Weber (1959)
(3) Average from Littleton formation (Shaw, 1956)
(4) Normanskill shale (Weber, 1959)
(5) Quebec shale (Weber, 1959)

TABLE 19

COMPARISON OF SODIC AND POTASSIC PARAGNEISS WITH GRAYWACKE AND SHALE AND WITH LEAST ALTERED AND GRANITIZED ADIRONDACK PARAGNEISS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
B	9	Tr	40	220	10	22	12
Ba	353	800	371	520	612	750	910
Co	5	5	25	22	8	7	4
Cr	5	5	162	110	35	16	4
Cu	40	43	22	58	16	4	19
Ga	13	17	9	13	11	10	12
Mg	9700	17000	22000	16000	11000	10900	5000
Mn	1277	840	431	180	356	434	260
Ni	1	1	60	64	15	12	4
Sc	11	7	10	12	12	10	6
Sr	213	272	217	150	310	320	270
Ti	2925	3850	5169	6000	2800	1800	750
V	139	146	61	150	56	53	24
Zr	167	195	281	340	171	172	150

(1) Average sodic paragneiss from Apsley member
(2) Average potassic paragneiss from Apsley member
(3) Average sodic graywacke
(4) "Average" pelagic shale Weber (1959)
(5) Least altered Adirondack paragneiss (Engel and Engel, 1958 p. 1408)
(6) Slightly granitized Adirondack paragneiss (Engel and Engel, 1958 p.1408)
(7) Strongly granitized Adirondack paragneiss (Engel and Engel, 1958 p. 1408)

paragneiss are of the same sign and of approximately the same magnitude. There is more B and Cu in shale than in graywacke, but the differences for minor elements within the paragneiss pairs is not significant. For Cr, Mg, Ni and Ti, a real decrease seems to result from granitization of sodic Adirondack paragneiss, whereas no significant difference exists between sodic and potassic Apsley paragneiss or between graywacke and shale.

DISCUSSION AND CONCLUSION

In a petrological study such as this investigation of the origin of the Apsley paragneiss, one is dealing with the final product of a long process of rock evolution in which individual steps may be indiscernible. It is difficult, therefore, to chose between different mechanisms of origin, when their end products are known to be alike. Conclusions concerning the origin of Apsley paragneiss must, therefore, be considered tentative even when all available evidence has been examined.

The simple "pavement" texture of the Apsley paragneiss, and the simplicity and monotonous character of its mineral assemblage suggest that there has been a close approach to thermochemical equilibrium during metamorphism. This may be shown by application of the mineralogical phase rule which is, to some extent, a measure of equilibrium. It states that, at equilibrium,

$$\Phi \leqq C.$$

where Φ is the number of mineral phases and C the number of components. The minimum number of components in the Apsley paragneiss is probably the following five: SiO_2; (Fe_2O_3, Al_2O_3); K_2O; Na_2O; and (MgO, FeO). It is observed that the number of essential mineral phases never exceeds five.

If for a given set of physical conditions, equilibrium is attained, the mineralogy of the rock depends only on its chemical composition. Attainment of equilibrium may destroy all traces of the previous steps in the evolution of the rock. Thus, if more than one possible parent rock fits the chemical composition of the paragneiss, or if a common metasomatic process can produce that composition, it may be difficult to choose between the possible modes of origin.

The Origin of Sodic Paragneiss

Four modes of origin of the sodic Apsley paragneiss are considered most probable.

1) Soda metasomatism of a soda-poor rock type such as common shale.

2) Isochemical metamorphism of dacitic tuff.

3) Isochemical metamorphism of sodic shale.

4) Isochemical metamorphism of sodic graywacke.

The Apsley paragneiss is a unit of rather monotonous composition about 2000 feet thick and 20 miles long. If it is the product of metasomatism of a soda-poor rock such as shale, vast quantities of Na must have been added and distributed uniformly throughout the belt. If such a process was operative, one might expect other units in the Hastings basin to have been affected. Pelitic and arkosic units that may have been suitable for soda metasomatism occur within a few miles of the Apsley paragneiss, but show no evidence of the addition of soda. This suggest that some other mode of origin for the Apsley paragneiss is more likely.

Dacitic tuff is very similar chemically to the sodic Apsley paragneiss and must therefore be considered as a possible parent. Thick units of volcanic rocks do occur in the Hastings Basin and tuffaceous units might be expected near them. Pyroclastic rocks are present in Wollaston and Lake townships and, although deformed and metamorphosed to the amphibolite facies, they contain easily recognized fragments of volcanic origin. In a tuff unit 2000 feet thick and 20 miles long, fairly large pyroclasts should be common, and inasmuch as they can be recognized elsewhere in the Hastings Basin, they would certainly have been noted in the Apsley paragneiss if they were present. In the absence of such evidence a pyroclastic origin for the Apsley paragneiss is rejected.

If a sedimentary parent for the Apsley paragneiss is envisaged, both sodic graywacke and sodic shale have the requisite chemical composition. In the Adirondack mountains, the assemblage of rocks associated with the paragneiss is typical of the shelf facies, consisting of limestone and quartzite and having few or no volcanic rocks. Engel and Engel (1953) therefore point out that sodic graywacke, characteristic to eugeoaysclinal assemblages, is not expected, and they consider the possibility that the Adirondack paragneiss was derived from sodic shale, a rather rare rock type generally restricted to an evaporitic environment of deposition. The Apsley paragneiss is conformably overlain and underlain by thick marble units but thick volcanic units to the southeast in Wollaston township are not far removed geographically and probably stratigraphically. Volcanic units occur in the Hermon formation in Chandos township and even in the Dungannon formation in Wollaston and Mayo townships. The Hastins Basin, therefore, need not have been a stable shelf area in Grenville times despite the abundance of carbonate rock, and hence, a graywacke unit is not incongruous. The auther suggests, therefore, that the parent of the sodic Apsley paragneiss was sodic graywacke

The Origin of Potassic Apsley Paragneiss

Two possible modes of origin are envisaged for the potassic Apsley paragneiss. They are particularly applicable if the sodic type is derived from graywacke.

1) Granitization (potash metasomatism) of certain layers within the Apsley paragneiss.

2) Isochemical metamorphism of shale associated with Apsley graywacke.

The close similarity of potassic Apsley paragneiss, shale, and incipiently granitized Adirondack paragneiss has been shown in the section "Petrography and Chemistry". Because of these similarities, it is difficult to use the chemical composition as a guide to origin.

The great similarity of potassic Apsley paragneiss and slightly granitized Adirondack paragneiss in mineralogic, major element, and minor element composition could indicate that these two rock types have the same origin, but in the author's opinion, there are several features that point to a mode of origin other than granitization. In the Adirondack paragneiss certain compositional changes result from granitization (Engel and Engel, 1958). For many elements these changes are not significant until granitization is well advanced, but for Ba, Mn, Cr, Ni, and Ti, the changes are noticable at an incipient stage. As noted earlier, for Ba and Mn, the differences between least altered and granitized paragneiss, and between graywacke and shale are the same; these two elements cannot therefore be used to choose between the two possible modes of origin. The other elements, Mn, Cr, Mg, Ni, and Ti, decrease as a result of granitization of Adirondack paragneiss, but are just as concentrated or more concentrated in the potassic than in the sodic Apsley paragneiss. This suggests that a granitization process of the Adirondack type did not form the potassic paragneiss,

In the Adirondack mountains, Engel and Engel (1953 and 1958) demonstrate the existence of a complete mineralogic and chemical gradation between least altered and granitized paragneiss. This gradation can be observed in the field. In the Apsley paragneiss, the sodic and potassic types are interlayered parallel to the bedding and are in sharp contact with each other; they may, therefore, be interbedded. Their potash : soda ratio has a strongly bimodal distribution (fig. 7), which would not be expected if a complete gradation existed between the two rock types as a result of granitization. The two peaks fall close to those for graywacke and shale respectively and have the same separation, suggesting that the two types of Apsley paragneiss are the metamorphic equivalents of shale and graywacke. The peaks are slightly to the left of those of shale and graywacke. This could be the result of incipient soda metasomatism of a graywacke shale unit, but it could equally well be a pre-metamorphic characteristic of the Apsley member, reflecting either the character of the source area of the original sediment or an addition of soda to that sediment during or shortly after deposition.

If the conclusion that the potassic paragneiss layers represent metamorphosed shale beds is correct, two further conclusions may be made.

1) Metamorphism of the Apsley paragneiss was approximately isochemical except for water and, possibly, boron.

2) There is not a problem of absence of shale interbedded with the graywacke. The conclusion that the sodic paragneiss is derived from graywacke is thereby strengthened.

Temperature of Metamorphism and the Composition of the Mineral Phases

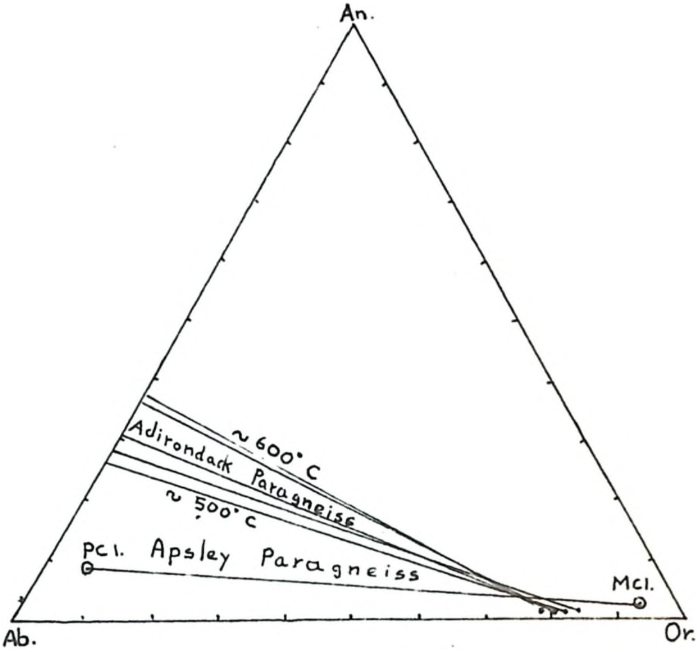
Engel and Engel (1960, p.51) plot the composition of coexisting potash feldspar and plagioclase on an An - Ab - Or ternary diagram and show that the tie lines joining the feldspar pairs from the lower temperature part of the Adirondack area have shallower slopes than the ones from the higher temperature area. This is consistent with the experimental work of Yoder, Stewart and Smith (1957). The composition of plagioclase and microcline occuring as discreet grains in a specimen (M^{o}C1) of Apsley paragneiss are given below:

Plagioclase: Or_6 Ab_{85} An_9
Microcline: Or_{92} Ab_6 An_2

Their plot is compared in figure 8 with plots of the Adirondack feldspars. As shown, the tie lines for Apsley feldspars has the shallowest slope, suggesting that they came to equilibrium at the lowest temperature. (The slope of the tie lines is also pressure dependent, but there is no evidence that the depth of burial of the Apsley paragneiss, during its meta-

Figure 8.

Ab – Or – An. Plot of Apsley and Adirondack Feldspar Pairs.



morphism, was much different from that of the Adirondack paragneiss). The problem is, how much lower?

If the Or content of the two feldspars is compared with the solvus for low temperature feldspars given by Tuttle and Bowen (1958, p.28), a temperature of formation of about 400° is indicated. However, the solvus curve is not well calibrated and is only a rough guide.

Barth (1956) proposes to use the "k" value of feldspars to estimate their temperature of formation where:

$$k = \frac{\text{Moles per cent Ab in Microcline}}{\text{Moles per cent Ab in Plagioclase}}$$

Fundamentally this method is the same as shown by the crossing of the tie lines in figure 8. For the Apsley feldspars k is 0.07 which, according to Barth's curve (1956, p.15, fig. 9), indicates a temperature of 350° C. His curve, however, is only estimated and is also just a rough guide. Engel and Engel (1958 and 1960) compare the solvus method and the "k" method with other geologic thermometers and find the agreement to be good. Therefore the values of 400° C and 350° C probably are first approximations of the temperature of regional metamorphism. It should be noted that temperature determinations based on the composition of coexisting feldspars do not give the maximum temperature reached during the metamorphic reaction, but that temperature at which the reaction was finally "quenched".

Saha (1958) used a solid inclusion decrepitation method to determine the temperature of formation of the Chandos Lake pluton, the Wollaston pluton, and of biotite paragneiss adjacent to the Wollaston pluton. His results are summarized below:

	Average	Minimum	Maximum
Chandos Lake pluton:	710°C	700°C	720°C
Wollaston pluton:	680°C	650°C	730°C
Biotite paragneiss:	657°C	640°C	670°C

The biotite paragneiss is from the metamorphic aureole of the Wollaston pluton and the temperature of 657°C must be higher than the temperature of regional metamorphism and thus represents an upper limit.

Figures 9, 10, and 11 show the variation of FeO Fe_2O_3, MgO, TiO_2, and MnO as well as that of the ratio $(Fe^{++} + Mn^{++}) : Mg^{++}$ for biotite and garnet from the Adirondack paragneiss as a function of the temperature of formation. The curves are based on temperature and chemical data given by Engel and Engel (1958 and 1960, figs. 6, 8, and 11). Biotite and garnet from the Apsley paragneiss are compared assuming a temperature of metamorphism of 400°C. The comparison is valid here, inasmuch as the Apsley and Adirondack paragneiss are so similar chemically and mineralogically. The values of Fe_2O_3, TiO_2 and MgO for biotite and the values of MgO and $(Fe^{++} + Mn^{++}):Mg^{++}$ for garnet from the Apsley paragneiss agree well with, and thus confirm, the

Figure 9.

Variation in Composition of biotite with Temperature of Metamorphism.

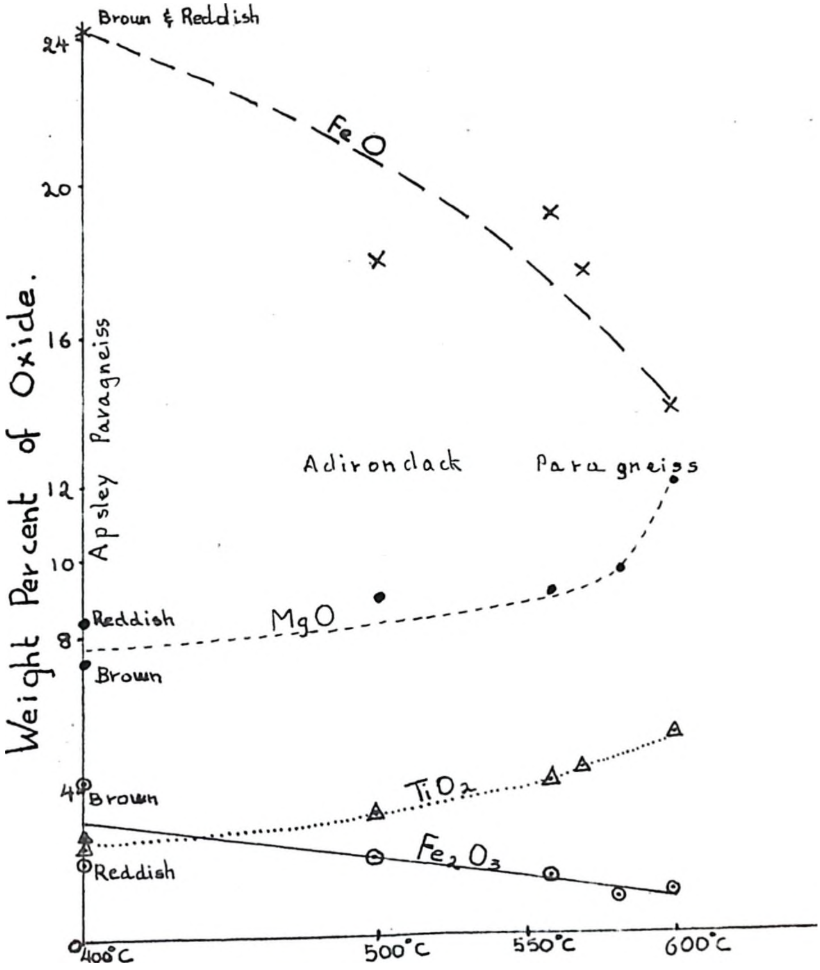
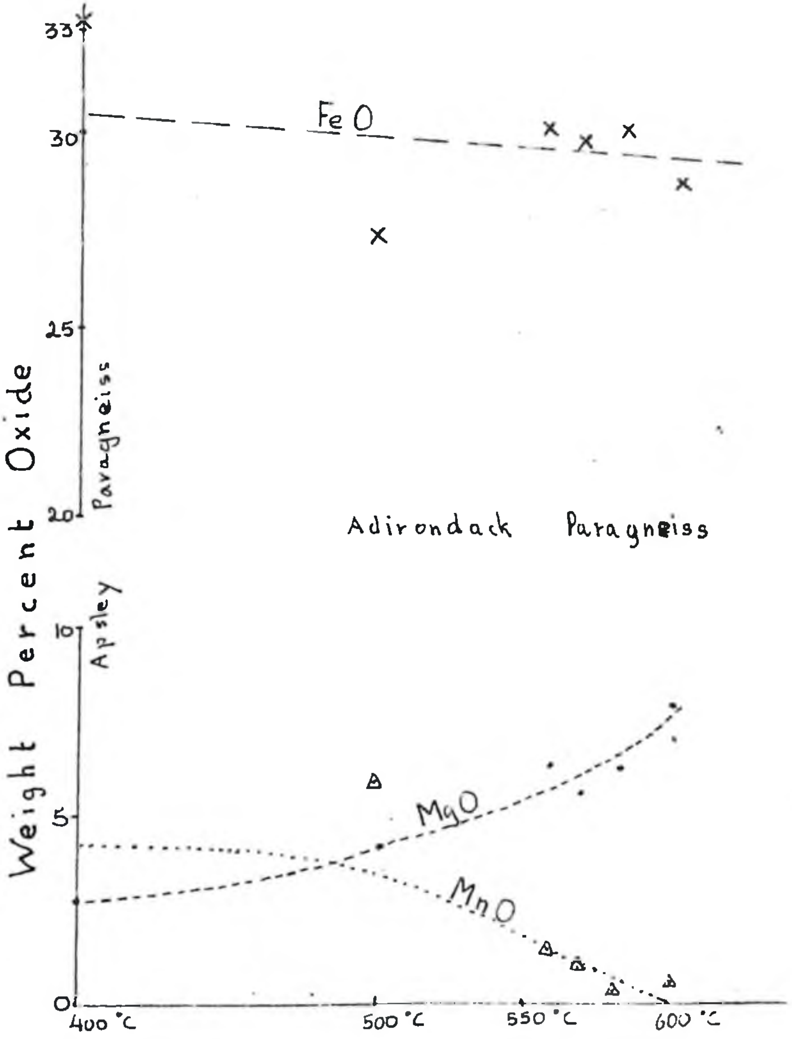


Figure 10

Variation in Composition of Garnet with Temperature of Metamorphism.



trends suggested by Engel and Engel (1960).

Brown and reddish brown biotite from the Apsley paragneiss differ in the same way as their analogues in the Adirondack paragneiss. In the Adirondacks, the appearance of reddish brown biotite can be correlated with an increase in the intensity of metamorphism, and the content of potash feldspar of the paragneiss (Engel and Engel, 1953, 1960). No such correlation is apparent in the Apsley paragneiss; reddish brown and brown biotite occur in rocks rich and poor in microcline and, both varieties are found in approximately equal abundance throughout the paragneiss belt. Their erratic distribution may be the result of subtle, erratic variations in the composition of the paragneiss.

Summary

The Apsley paragneiss is a member of the Dungannon formation and is believed to have formed by approximately isochemical metamorphism of a unit of interbedded sodic graywacke and shale. The graywacke is now represented by a biotite-quartz-oligoclase rock and the shale is represented by a biotite microcline-quartz-oligoclase rock. The temperature of regional metamorphism was probably about 400°C and its effect on the composition of the minerals in the Apsley paragneiss was the same as on those from the Adirondack paragneiss, a rock unit, chemically and mineralogically similar to the Apsley member.

FIGURE 12

Typical Outcrop of Apsley Paragneiss

on an Island in Lake Chandos

FIGURE 13

Drag Fold in Apsley Paragneiss

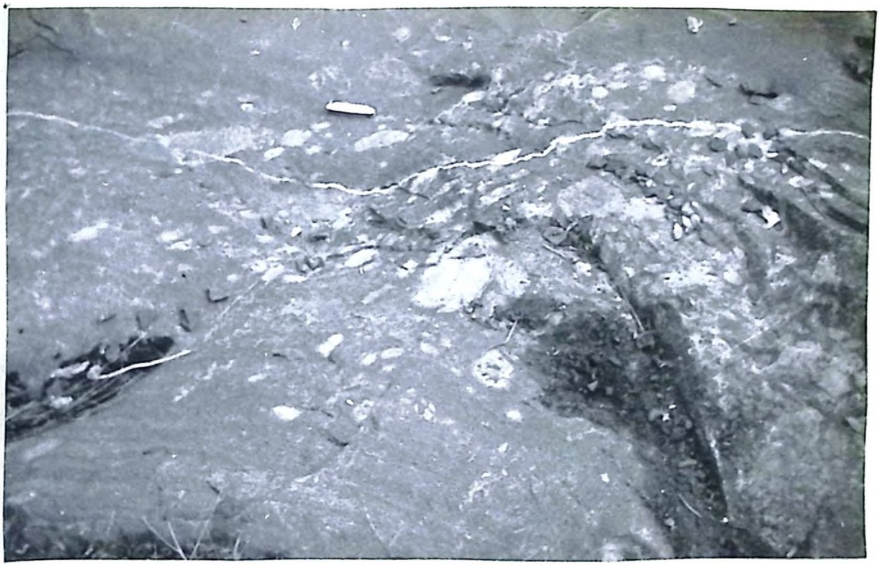
Showing Banding. Lot 4

Con. VI, Chandos.

FIGURE 14

Light Coloured, Calcareous Layer
in Paragneiss near Lower Contact
of Apsley Member on Highway 28.

FIGURE 15



Conglomerate Band in Apsley Paragneiss. On Highway 28, North of Apsley

FIGURE 16

Ovoid Nodules in Apsley Paragneiss.

Road Cut on Highway 28,

at North Entrance to Apsley

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APPENDIX I

MODES OF THE HAND SPECIMENS

Minerals	L3	L5A	L5B	L10	L11	L12	L13A
Quartz	31.9	17.9	29.2	25.0	32.8	17.3	25.5
Microcline	-	34.4	21.4	0.0	7.0	0.0	8.2
Plagioclase	47.5	30.9	29.1	48.6	45.2	58.8	44.0
Biotite	15.8	14.4	17.2	27.7	14.4	21.9	20.6
Garnet	0.7	-	-	-	-	0.9	0.2
Muscovite	2.8	-	0.5	0.4	0.4	0.2	1.1
Others	1.3	-	-	-	-	-	0.4
Opaque	0.1	2.4	2.5	0.3	0.2	0.9	Tr

	L13C	L19	L20	H2	H3	H4	H6
Quartz	43.6	22.4	7.6	16.1	37.7	17.5	12.9
Microcline	1.4	0.1	-	0.1	9.3	4.4	19.9
Plagioclase	40.5	60.9	71.4	45.8	26.6	35.0	39.0
Biotite	13.5	13.0	11.8	33.0	19.7	41.6	26.7
Garnet	Tr	2.1	-	0.2	Tr	0.8	0.7
Muscovite	0.5	0.9	3.2	Tr	4.3	0.2	0.2
Others	Tr	Tr	4.8	4.7	2.0	0.2	0.2
Opaque	0.5	0.5	0.8	0.1	0.4	0.3	0.5

Others: Apatite, Zircon, Tourmaline, Hornblende, Calcite.

Tr. : Less than 0.1 per cent, but observed in slide

Minerals	H8	H12	H14	H15	H16	H17	H18
Quartz	9.2	22.0	24.3	29.0	25.8	28.3	18.1
Microcline	27.4	-	1.0	-	0.5	0.8	1.4
Plagioclase	29.6	48.2	50.6	44.2	61.0	47.7	63.0
Biotite	32.6	28.8	23.3	23.6	11.7	24.7	15.5
Garnet	0.6	-	-	0.2	-	-	0.6
Muscovite	Tr	0.2	0.5	-	-	-	0.2
Others	0.4	-	-	2.2	-	0.2	-
Opaque	0.2	0.8	0.4	0.8	1.0	0.3	1.2

	H20	H21	F1	F2	F3	F4	F6
Quartz	33.1	31.0	34.9	28.9	37.5	37.0	32.0
Microcline	9.3	5.9	19.0	5.5	-	14.1	4.2
Plagioclase	37.0	36.2	31.6	43.1	36.5	41.0	43.8
Biotite	19.9	21.0	14.0	20.5	22.5	7.2	19.2
Garnet	0.1	-	0.2	-	2.5	0.1	0.4
Muscovite	-	2.2	Tr	0.9	-	-	-
Others	-	0.2	-	-	-	0.2	-
Opaque	0.6	3.5	0.3	1.2	1.0	0.5	0.4

	P1A	P1B	P4	P5	P7	P11	B1
Quartz	26.8	42.4	43.9	31.4	32.3	23.0	33.9
Microcline	26.4	10.4	2.5	-	0.5	2.3	15.2
Plagioclase	30.2	31.0	43.1	46.8	53.0	48.5	31.9
Biotite	13.5	12.0	9.7	20.4	13.4	24.3	18.4
Garnet	-	-	-	0.6	-	0.2	-
Muscovite	0.7	0.2	-	-	-	-	-
Others	Tr	0.2	Tr	-	-	1.2	-
Opaque	2.4	3.8	0.1	0.9	0.9	0.5	0.5

	B2	B3	B4	B5	B6	B7	B8
Quartz	27.5	19.3	27.5	38.2	24.3	47.1	30.5
Microcline	-	-	-	4.7	0.3	1.3	2.0
Plagioclase	41.0	41.5	45.2	39.1	52.1	40.5	52.7
Biotite	27.9	38.2	25.8	17.0	22.4	10.7	14.7
Garnet	2.5	0.3	1.0	-	0.5	0.1	-
Muscovite	-	-	-	-	-	-	-
Others	0.3	0.3	-	0.5	0.1	Tr	Tr
Opaque	0.8	0.4	0.6	0.5	0.3	0.3	0.1

	B9	B10	B11	W1	W2	W3	W4
Quartz	31.9	28.6	32.4	41.2	27.3	29.9	26.4
Microcline	4.8	0.3	-	-	-	33.8	-
Plagioclase	46.1	50.7	48.6	47.3	39.5	26.2	46.1
Biotite	16.7	18.3	18.9	10.9	31.7	9.8	27.1
Garnet	0.1	0.1	-	-	-	-	-
Muscovite	-	1.7	-	-	-	-	-
Others	-	0.1	-	0.1	1.0		0.1
Opaque	0.4	0.2	0.1	0.4	1.3	0.4	0.3

APPENDIX II

MODES OF THE CHEMICALLY ANALYZED SAMPLES

Minerals	C1	C2	C3	C4	C5
Quartz	32.55	29.9	32.90	36.68	37.41
Microcline	21.43	10.0	-	2.77	-
Plagioclase	29.20	37.0	39.90	45.73	37.39
Biotite	12.05	22.6	25.70	14.65	21.60
Garnet	0.22	-	0.35	0.35	1.70
Muscovite	-	-	0.05	-	0.12
Others	0.05	-	0.80	0.05	1.05
Opaque	4.00	0.6	0.05	0.20	0.70

	C6	C7	C8	C9	C10
Quartz	48.8	31.95	31.63	33.6	25.83
Microcline	-	-	2.23	-	13.55
Plagioclase	38.1	56.10	49.10	50.2	38.90
Biotite	10.1	11.05	16.33	14.3	20.40
Garnet	1.1	0.55	0.03	0.9	0.07
Muscovite	-	-	0.03	-	0.40
Others	-	0.05	0.37	0.3	0.62
Opaque	0.9	0.30	0.30	0.7	0.23