" THE GEOLOGY OF THE RIGAUD MOUNTAIN. QUEBEC "

S. C. GREIG

ABSTRACT

Title : "The Geology of the Rigaud Mountain. Quebec."

Author : Stanley C. Greig.

Dept. : The Department of Geological Sciences. Mc Gill.

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The Rigaud Mountain is a shallow seated syenitic intrusion, which was emplaced by vertical upthrust into the Grenville Basement during late Cambrian to early Ordivician times. It consists of hornblende syenite into which a feldspar porphyry mass is intruded in the north. The porphyry grades eastwards through syenite and granite into a quartz porphyry. Aplitic rhyolitic dykes intrude all the rocks. Miarolitic cavities are present in some of the syenites.

The rocks are coarse grained, porphyritic and quartz-rich. Exsolution antiperthitic and microperthitic feldspars are extensively developed.

Potassium-argon age determinations of these rocks yield an average age of 450 million years. Similar ages were recorded for the syenites of the Chatham-Grenville stock. The stocks are genetically related.

Rigaud Mountain like the Mutton Bay Pluton and the syenitic stocks of the Saguenay Valley represent a syenitic stock in the graben of the postulated St. Lawrence Rift System.

THE GEOLOGY OF THE RIGAUD MOUNTAIN QUEBEC.

STANLEY C. GREIG

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

Department of Geological Sciences
Mc Gill University
Montreal

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INTRODUCTION

General Statement

The Rigaud Mountain is the most westerly of a line of igneous hills in the vicinity of Montreal. The other hills are collectively termed the Monteregian Petrographic Province.(Pouliot 1962). From both structural and stratigraphic evidence and from age determinations , it is confirmed that the Monteregian Hills are Lower Cretaceous in age. The age,origin and tectonic history of the Rigaud Mountain are unknown.

The purpose of this thesis is to present a petrographic study of the rocks of the Rigaud Mountain, with a view to determining not only its geological relationship , if any, to the other intrusives in the area, but also its age and tectonic history.

Location

Rigaud Mountain is the most westerly of the hills of igneous origin, which in the vicinity of Montreal form the principal topographic features of the St. Lawrence Lowlands. (Fig. 1). The Mountain,situated in the north-western part of Vaudreuil county, Province of Quebec, is bounded on the west and south by the meridians 74° 20' and 45° 25' respectively; on the north by the Ottawa River and on the east by the Raquette River.

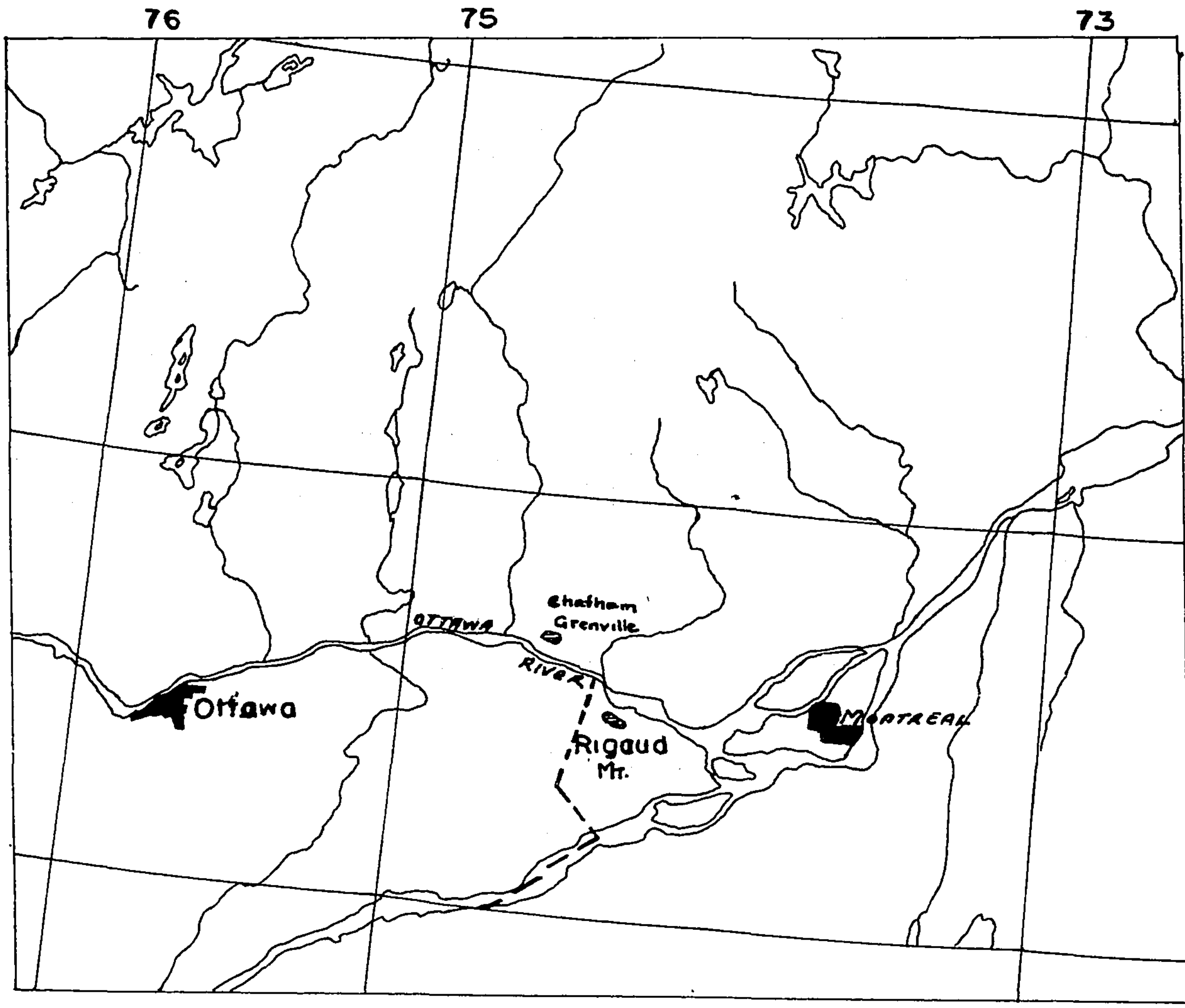

Fig. 1 Location of the Rigaud Mountain

It is situated 30 miles to the southwest of the city of Montreal and 14 miles due west of Oka.

Accessibility

The area can be easily reached by travelling southwest from Montreal on the Trans-Canada Highway or by the Canadian Pacific Railway. The mountain is traversed by numerous drivable roads and logging and hunting trails. Many small farms are found along the periphery of the mountain.

Previous Work Done

Sir William Logan in his petrological studies of the igneous intrusives in the vicinity of Montreal during the very late part of the nineteenth century, was among the first to indicate the age and petrographical difference between Rigaud and the rest of the intrusives.

Oswald E. LeRoy in 1900 studied the Rigaud rocks and concluded that " in all probability Rigaud had no genetic connection with the rest of the series" but that " from the proximity of the hornblende syenite mass in the Grenville township and that in Rigaud Mountain, that both masses are either continuous under the Paleozoic or are genetically related ".

Fitz Osborne (1934) in studying both the Chatham-Grenville and the Rigaud intrusives expressed agreement with LeRoy concerning the affinities of the stocks.

The presence of miarolitic cavities in the Rigaud rocks led Osborne to suggest that " the summit of the stock at Rigaud was 1000 ft. above that at Chatham-Grenville" and at this higher level the cavities developed at possibly lower external pressures.

Present Work

The first half the summer 1967 was spent mapping the Rigaud Mountain on the scale of 3 inches to one mile. Fresh and lightly weathered outcrops are exposed over 70 % of the mountain. The remaining area of 30 % is covered by thick deposits of drift and clayey soils. Sampling was difficult at times due to the massive nature of the rocks.

Acknowledgements

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PHYSICAL CHARACTERISTICS OF THE MOUNTAIN

Topography

The Rigaud Mountain rises abruptly from the St. Lawrence Lowlands. It is highest in the west and grades gently eastwards. The Mountain is roughly oblong shaped 6 miles long by 3 miles wide and trends WNW to ESE over an area of approximately 15 square miles.

The chief topographic features are rounded ridges, steep cliffs and knobs of rocks along with intervening flat bottomed drift floored valleys of varying widths. Feldspar porphyry and granite form the cliffs, while hornblende syenite forms the rounded ridges.

Along the periphery and in some places in the interior the mountain is well forested. Maples and poplars are the chief trees present. The rocks are well exposed over large areas or only covered by thin coatings of greyish green moss and scrubby growth.

On the basis of topographic features the area is divisible into three regions, the western, central and eastern. A generalised northwest - southeast profile of the mountain illustrates the variations in relief as encountered in the three regions. (Fig. 2).

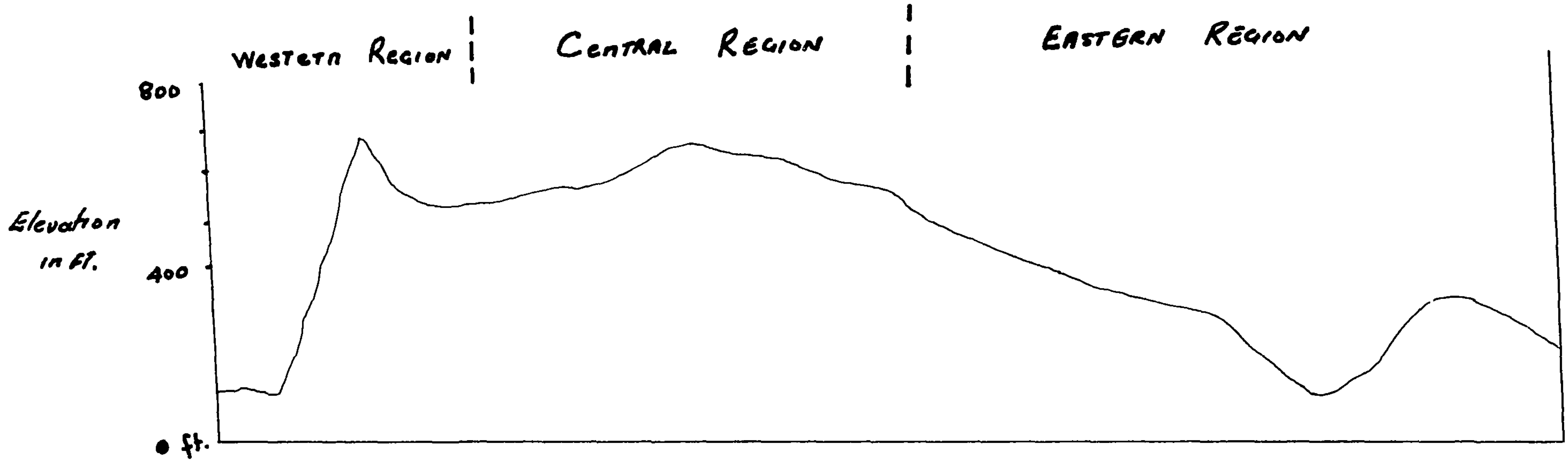


Fig. 2 Profile of Rigaud Mountain showing arbitrary divisions (Vertical Scale exaggerated)

The Western Region

In the northwest the topography is rugged and consists of a series of ridges trending ESE with flat drift floored valleys separating them. The average elevation in this area is 600 ft. The tops of the ridges are at approximately similar elevations thereby giving the area a plateau-like appearance.

The most prominent ridges face the Ottawa River on the north. Here they form steep, heavily jointed cliffs 30 - 90 ft. high and mark the northwestern boundary of the mountain.

The northern talus slopes are steep, with numerous small cliffs 10 - 40 ft. high, and strewn with large erratic blocks and boulders. The lower limits of the slopes are thickly wooded and covered with loose sandy soil. To the southwest the area is very flat, while towards the east it rises to the highest peak of the mountain at 730 ft. The north-eastern slopes are gentle . They display numerous ledges 10 - 20 ft. high and two large and unusual boulder beds, the larger of which is termed " The Devil's Garden ".(Fig. 3.).

Boulder Beds

The Devil's Garden approximately 50 acres in area is oval in form with its larger axis trending to the northeast. It is bounded by higher ground on all sides except in the northeast where it is lowest and terminates abruptly with a steep slope in the area of the Shrine.

The entire " Garden " is filled with well rounded and sub-angular boulders 2-15 inches in diameter. The spaces between the boulders are conspiciously free of any material. The " Garden " rises gently to the south.

LeRoy (1900) noted that the boulders of the Devil's Garden were derived from the mountain due east of it, while those of the smaller "bed" were from the high ground surrounding the"bed".

The origin of these boulder beds is uncertain, but the most probable postulate suggests that they resulted from drainage courses which developed while the ice impinged on the mountain. The force of water from the melting ice could both round the boulders as well aswwash away the inter-boulder material.

Subsequent wave action and submergence caused by the transgressive Champlain Sea after the retreat of the ice sheet, could have arranged the boulders in the ridge-like form they display. These boulder beds occuring at approximately 350 ft. represent remnants of beach deposits, and as such are indicative of the former sea levels in the area.

The Central Region

This area of average elevation 550 ft. is plateau-like but dips very gently towards the east along it's eastern end. The rocks are well exposed in most parts of this region. Heavily wooded forests occupy the eastern and southern sections of the area. Two large gravel pits occur in this area.

The Eastern Region

This consists of one long low thickly wooded ridge flanked by drift covered boulder strewn plains. To the east of the mountain and separated from it by the valley of the Raquette River is a ridge of dark grey amphibole-rich granitic gneiss trending to the northeast.

Drainage

The three major rivers in the general area are the Ottawa in the north, the Raquette in the east, and the Rigaud in the west. They all skirt the main stock rather than cut across it. The Ottawa river follows a straight course along the northern boundary of the mountain. This linear feature results from the river being controlled by an east-west trending fault which cuts across the northern end of the mountain. No large streams are found anywhere on the intrusion.

In the area west of the Shrine two small seasonal streams occur. Along the southwestern margin of the mountain two westwards flowing streams empty into the Rigaud river.

A weakly developed concentric pattern is displayed by the three major streams, while the smaller streams display a radial pattern. (Fig. 3.).

The southeastern border of the Mountain is separated from a ridge of dark grey to black Laurentian amphibolite-rich granite gneiss by the valley of the Raquette river. The ridge trends northeast to southwest, tapering somewhat towards the south. The average relief of the ridge is 80 ft.

The amphibole content is higher towards the upper parts of the ridge. Texturally the gneiss is a coarse to medium grained rock in which the gneissic foliation is more strongly developed in the amphibole-rich areas.

The cross section extending from north to south across the mountain shows the spacial relationship of the various units. (Fig. 4).

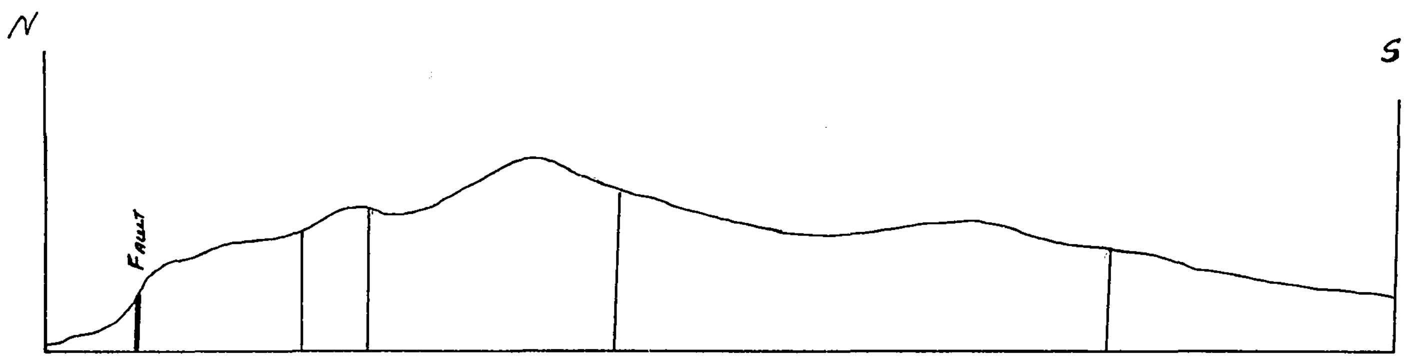
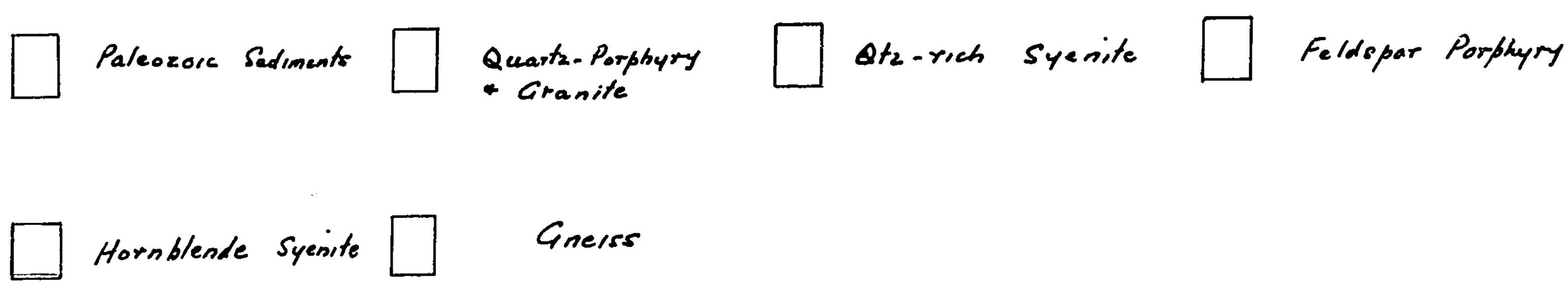


FIG. 4 GEOLOGICAL CROSS SECTION FROM NORTH TO SOUTH across RIGAUD MOUNTAIN



GENERAL GEOLOGY

Regional Setting

The Rigaud Mountain is a stock forming a knob-like intrusion into the Grenville Basement, along the eastern boundary of the Ottawa - St. Lawrence Lowlands. Here it forms part of the " Beauharnois anticline " which marks the eastern boundary of the Lowlands. (Wilson 1964). Paleozoic sediments overlying the Grenville Basement in this area, surround and abut against the stock.

Geology of Rigaud Mountain

General Statement

Rigaud Mountain for its greater part is composed of hornblende syenite, which is intruded in the north by a feldspar porphyry mass.

The rock sequence in the northern half of the mountain is from west to east -- hornblende syenite, feldspar porphyry porphyritic quartz-rich syenite, granite quartz porphyry and finally more hornblende syenite.

The southern half of the mountain is composed entirely of hornblende syenite with small intrusions of porphyritic syenite and feldspar porphyry in both the south-east and southwest regions. Thin aplitic dykes rhyolitic and syenite in composition cut all the above rock types.

The colour, granularity and topographic form are the three main characteristics which vary greatly from one rock type to the next. The hornblende syenite outcrops in shades of greyish buff to pink, but in many places purplish red to purple coloration occurs due chiefly to weathering effects.

The feldspar porphyry outcrops in shades of dark grey to greenish grey, but pink and light grey surfaces occur close to its contact with surrounding rocks. The syenite porphyries are usually a bright pink to light grey colour, while the granite and quartz porphyry outcrop in lighter shades of pink to greyish buff.

The variation in granularity and topographic form is even greater than in colour. The hornblende syenite is basically very coarse grained, holocrystalline and massive, with a slightly rounded to bumpy surface and gentle slopes.

The porphyries and granite show a random variation in granularity from very coarse almost pegmatitic to very fine. They form steep cliff-like massive slopes, but with a smoother surface than the hornblende syenite.

Throughout the mountain the percentage and grain size of the mafic components of the rocks decrease from west to east. This decrease is more evident in the triangular mass in the northwest than in the hornblende syenite, where the decrease is less intense.

The quartz content shows a steady increase from west to east, especially in the porphyries in the northwest section. In the hornblende syenite the quartz content remains consistently low throughout the mountain.

Geology of the Northern Half of the Mountain

General Statement

In the northern half of the mountain the hornblende syenite is intruded in the northwest by a feldspar porphyry mass, which grades eastwards through syenite and granite into a quartz porphyry. All the porphyries and granite together form a roughly triangular shaped mass. The base of the triangle forms the precipitous northern margin of the mountain.

Vertical and horizontal jointing are extensively developed throughout this half of the mountain.

The contacts between all the rock types in the triangular mass are gradational, while those between the hornblende syenite and the triangular mass are covered by drift.

The geology will be described as seen when travelling from west to east across the mountain.

Hornblende Syenite

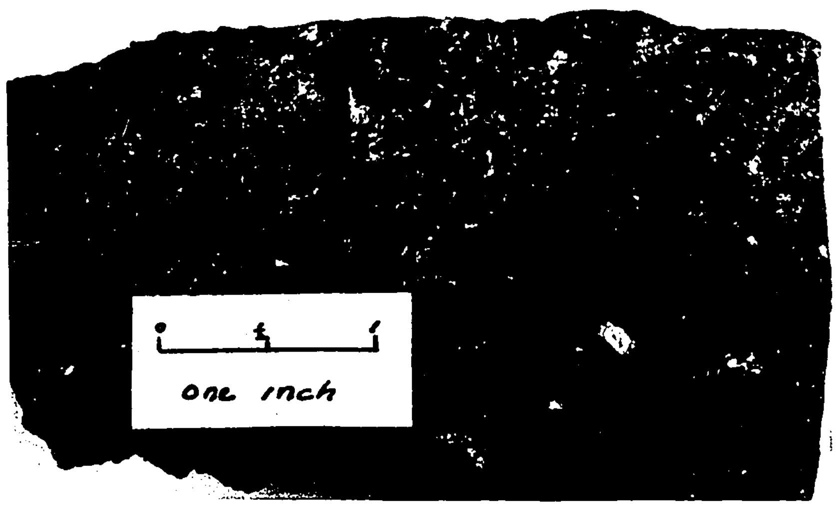


Fig. 5 Handspecimen of coarse grained Hornblende Syenite

Massive hornblende syenite outcrops in the northwestern corner of the mountain. The rock is very coarse grained and granitic in texture.(Fig. 5). The fresh surfaces vary in colour from light grey, pink, purplish grey to dark grey. It consists mainly of large feldspar crystals (over 80%), black hornblende (15%), and small quantities of grey vitreous quartz.

The feldspars vary in length from .5 - 1.5 inches, The larger crystals display well developed Carlsbad twinning. They occur as pink to grey subhedral crystals usually graphically intergrown among themselves, and with hornblende filling the interstitial spaces. Iron staining in shades of brownish grey to red occur along the cleavage planes and inter-crystal boundaries.

The hornblende is black with a high lustre, and varies in form from stubby crystals to laths .5 inch in length. Characteristic cleavages are promanent in the larger crystals.

Grey irregular shaped quartz grains occur interstitial to both feldspar and hornblende. Small grains of magnitite and ilmenite are also present.

Randomly occurring throughout the syenite are lenses and blebs of a fine grained light-grey syenite usually 2 - 10 inches wide, 4 - 6 ft. long, with a regional east-northeast trend. Sinuous quartz veins 1 - 4 inches wide also follow this trend.

Jointing along a northwest to southeast trend is well developed in the syenite. Contacts between the hornblende syenite and the feldspar porphyry to the east are overlain by drift covered plains.

Feldspar Porphyry

Massive coarse grained feldspar porphyry outcrops in the west. The rock is dark to greenish grey and consists of feldspar phenocrysts in a finer grained quartzo-feldspathic groundmass.(Fig. 6).

Both the phenocrysts and the groundmass vary in texture, grain size and colour from one part of the intrusive to the next.

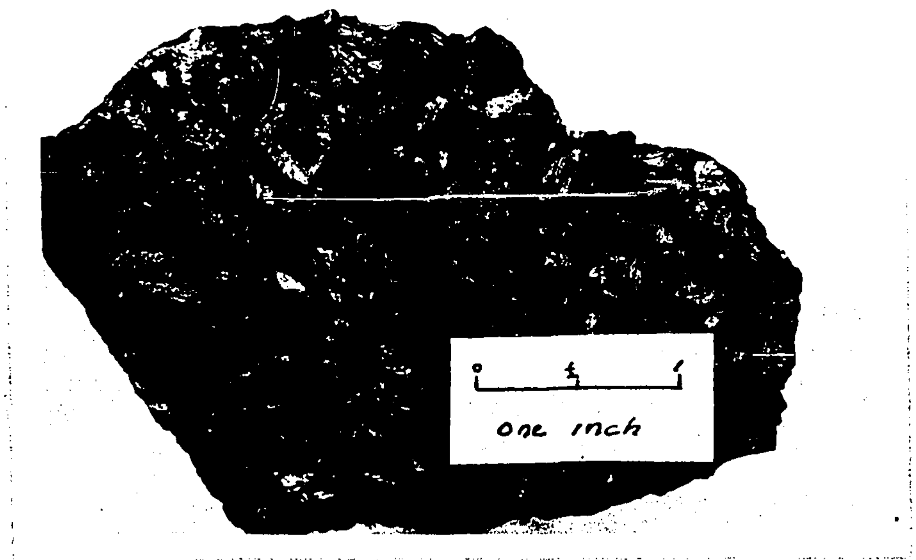


Fig. 6 Handspecimen of coarse grained feldspar porphyry.

In the coarse grained porphyry the feldspar phenocrysts range from .2 - .7 inch in size, and vary in colour from light grey to reddish brown. The porphyritic textures is well developed in these coarser varieties where the composition is feldspar phenocrysts 40%, feldspathic groundmass 60 %. Carlsbad twinning is seen in some of the larger crystals, the centres of which are usually black due to sericitic and kaolinitic alterations.

In the medium grained porphyry the phenocrysts comprise 25 %, the groundmass 75 % of the rock's composition. Minute black mafic inclusions are peppered throughout the groundmass. This porphyry is lighter in colour than the coarser varieties.

The fine grained porphyry consists of light-grey feldspar phenocrysts 15 %, in a fine grained quartzo-feldspathic groundmass 85 %. The phenocrysts vary from .5 - 2 mm. in size, and are randomly distributed throughout the groundmass.

In the northwest section of the mountain the massive feldspar porphyry is cut by many thin granitic and syenitic dykes. Lenses and blebs of pink syenite form inclusions in the porphyry. Towards the east the porphyry grades into a finer grained pinkish grey syenite porphyry. In this gradational zone quartz nodules appear in both the syenite and the feldspar porphyry.

Extensive rectangular jointing in the feldspar porphyry has resulted not only in the formation of steep cliff-like exposures 30 - 50 ft. high, but also in ridges with intervening flat bottomed valleys. Horizontal jointing is evident on some of the larger cliff faces, but generally it is weakly developed. The regional trend of the major joint planes varies between northwest and due north.

Contacts between the feldspar porphyry and the hornblende syenite to the south are generally covered, except towards the centre of the mountain where a sharp contact is visible over approximately 50 ft. The contact between the feldspar porphyry and the syenite to the east is gradational.

Quartz-rich Syenite

The syenite outcrops chiefly in the area west of the Devil's Garden. The rock is light to bright pink, medium to fine grained and massive to porphyritic in texture. In the massive varieties bright pink feldspar crystals (over 80%) , usually graphically intergrown characterise the rock. Clear irregular shaped quartz grains (2 - 8 %) occur interstitial to the feldspars. The massive quartz-rich syenite is usually the medium grained variety.

In the more porphyritic varieties the rock is lighter pink and finer grained. It consists of small feldspar phenocrysts (20 %) in a light grey quartzo-feldspathic fine grained groundmass (80 %). The feldspar phenocrysts .1 - .3 inches in size tend to aggregate. Clusters of quartz grains occassionally form phenocrysts. (Fig. 7).

Fig. 7 Handspecimen of fine grained quartz-rich syenite

Where the quartz content increases the syenite is lighter pink in colour and less porphyritic. In such areas it grades into granites. Areas are found within the quartz-rich syenite where intergrowths of feldspar porphyry, massive pink syenite, and granite occur. These areas are of very local extent and the contacts between the various rock types are either gradational or sharp.

No dykes are present in the syenites west of the Devil's Garden. To the east of the Garden pink granites and quartz porphyry outcrop. This indicates that the gradational contact between the quartz-rich syenite and the granite lies under the Garden.

Granite and Quartz porphyry

An intergrowth of these two rock types occupy the area east of the Garden. The granite is medium grained, equigranular and granitic in texture, It varies in colour from bright pink to dullish grey, the colour variation being directly related to the quartz content.

The granite consists of pink to flesh coloured feldspar crystals 60 %, grey vitreous quartz 30 %, and black mafics 10 %. The bright pink variety is almost mafic free, while in the dull pinkish grey variety the mafics, chiefly hornblende with minimal biotite, display a weakly developed lineation. The quartz content is highest in the pink granite. (Fig. 8).

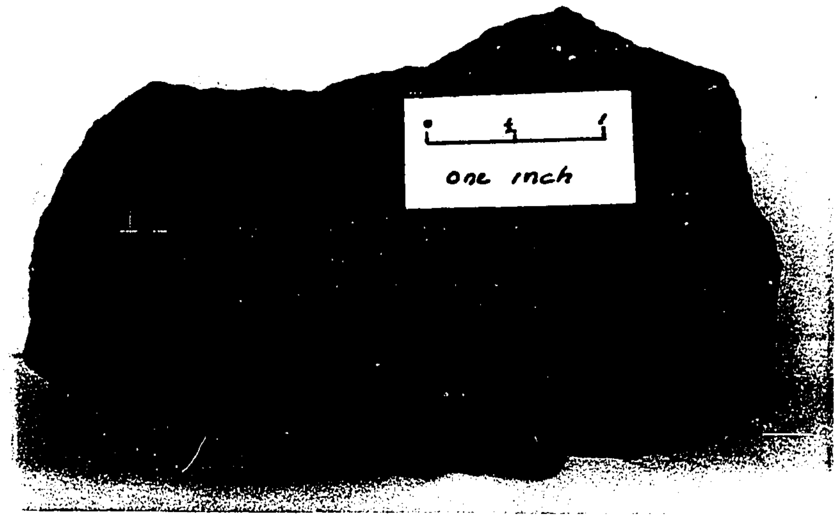


Fig. 8 Handspecimen of pink medium grained granite.

The quartz porphyry is a pinkish to medium grey fine grained porphyritic rock. It consists of phenocrysts of smoky grey rounded quartz grains 40 %, pink feldspar phenocrysts 10 %, in a grey fine grained quartzo-feldspathic groundmass 50 %.

There is a conspicuous lack of mafics in this rock. Concoidal fracturing is evident on many of the fresh surfaces.

Rectangular jointing in both the granite and the quartz porphyry forms 10 - 30 ft. high cliffs in the area east of the Shrine. Contacts between both rock types are sharp in places, but generally they are gradational. Numerous granitic dykes and quartz veins intrude both rock types.

Geology of the Southern Half of the Mountain

General Statement

The southern half of the mountain is composed entirely of coarse grained grey to pink hornblende syenite, into which an oblong shaped mass of pink syenite porphyry is intruded in the southeastern sector. The topography is less rugged than in the northern half of the mountain. Numerous dykes rhyolitic and syenitic in composition intrude the hornblende syenite.

Hornblende Syenite

The megascopic features of the hornblende syenite in outcrop have already been described for the area in the northwest. The hornblende syenite is massive and consistently coarse grained throughout the southern half of the mountain. Many irregular shaped and bleb-like inclusions of a fine grained pink mafic-poor syenite are randomly distributed throughout the hornblende syenite.

These inclusions display a weakly developed regional east-west trend. Other inclusions in the hornblende syenite are wedges of coarse grey feldspar porphyry and thin sinuous veins of smokey quartz and reddish brown chert.

Contacts between the hornblende syenite and the feldspar porphyry to the north are obscure, except for the 50 ft. exposure already mentioned. In this region the hornblende content of the syenite is noticeably reduced and the rock is brighter pink in colour, and denser.

Contacts between the hornblende syenite and the inclusions of feldspar porphyry are sharp, while those with the pink syenite inclusions are usually gradational.

The hornblende syenite is dissected by numerous dykes of two main orientations and thicknesses. These dykes like those in the northern half of the mountain are granitic and syenitic in composition. The larger dykes are 2 - 8 ft. thick, and 10 - 50 yards long. They consist of fine grained granite which is very quartz rich in places. These dykes intrude the syenite in the southwestern corner of the mountain.

They trend to the northwest , and their contacts with the hornblende syenite are sharp. Heavy fracturing along a rectangular pattern characterises these dykes, Three such were mapped in this area.

The thinner dykes occur more frequently in the southeastern sector of the mountain. They are rhyolitic in composition. Like their counterparts in the north they display a weak east-north-east trend.

These thin dykes are shorter and more numerous than the thicker dykes, but their contacts are similarly sharp. Together all the dykes intruding the hornblende syenite form less than 2 % of the entire rock mass.

Syenite Porphyry Intrusion

Towards the centre of the southeastern sector of the mountain the hornblende syenite is intruded by an oblong shaped mass of coarse to medium grained pink porphyritic syenite. It comsists of .1 - .5 inch long pink feldspar crystals 80 % , in light grey quartzo-feldspathic groundmass 20 % .

Generally the porphyry is characterised by its lack of mafics and quartz, its textural coarseness, and the low percentage of its matrix. Its porphyritic texture is accentuated on the exposed surfaces due to the differential weathering of the feldspar phenocrysts and matrix. The phenocrysts weather to a light grey to buff colour, while the matrix weathers to a darker greenish grey. The feldspars sometimes weather to a purplish colouration, similar to that seen in the northwest of the mountain.

Small blebs of granite are embedded in the porphyry. Rectangular jointing in the syenite porphyry gives rise to a rugged topography with 15 - 40 ft. high cliffs. Although its contact with the hornblende syenite is obscure, the rapid change from porphyry to hornblende syenite over 5 - 10 yards indicates that the contact between the two rock types is possibly sharp.

Thin dykes of two main types intrude both the syenite and the porphyry. The larger and more frequently occurring dykes consists of light grey rhyolitic material with shreads of black mafics scattered throughout. The thinner and less frequently occurring dykes are very quartz-rich, granitic, and aplitic in texture. They are younger than the thicker dykes.

The eastern contact between the porphyry and the massive hornblende syenite is gradational.

,Dykes and veins

When all the granitic, rhyolitic and syenitic dykes intruding the rocks of the Rigaud Mountain are viewed collectively, they are found to be randomly distributed and show no definite concentration in any particular rock type. Fig. 9 illustrates the frequency distribution of these dykes in the Mountain.

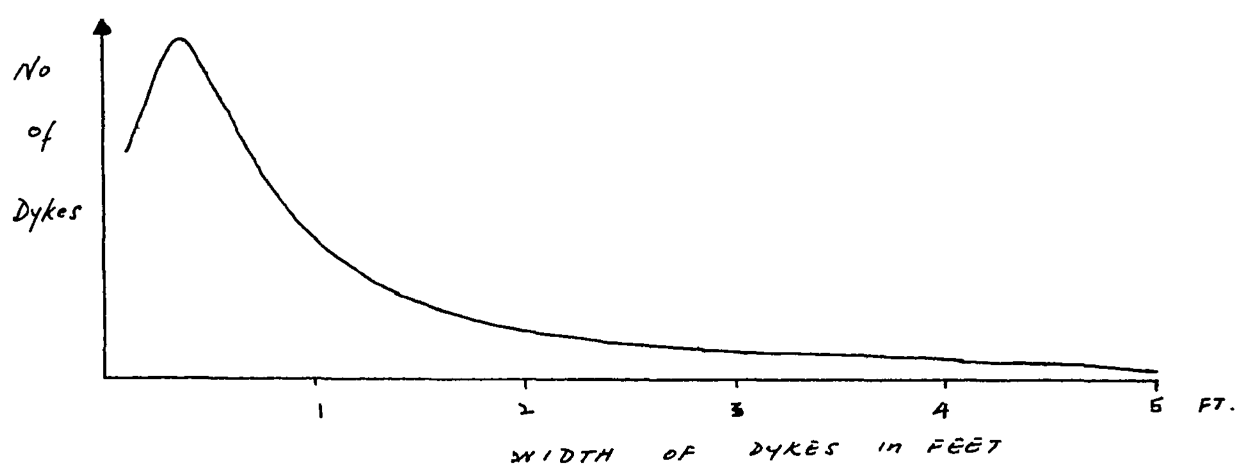


Fig. 9 Frequency distribution of the dykes in the Rigaud Mountain

The regional trend of the thicker dykes varies between northeast and due east, usually with vertical dips. However in the southwestern sector two of the larger dykes in the hornblende syenite trend to the southeast. Due to the massive form of the exposed rocks the relatively thin dykes and veins comprise an inconspicious part of the regional geology, and alltogether represent less than 2 % of the outcropping surface.

The mafic content of all the dykes is low, but where mafics occur they display a weak lineation trending at 060^{o}. The mafic content of the dykes is highest in the area east of the Devil's Garden. Here they are chiefly granitic in composition, sometimes containing .5 - 1 cm long feldspar crystals.

Most of the dykes are of very local extent, that is 5 - 10yds.long. The thicker dykes in the southwest are longer. They extend 20 - 60 yards. The contacts are sharp between most of the dykes and the country rock, but gradational contacts are seen especially in the area east of the Devil's Garden.

Thin sinuous quartz veins which pinch and swell from .2 - 3 inches wide, and thin brick red to brown cherty veins of similar thickness are randomly distributed throughout the mountain. The cherty veins generally occupy fractures and joint planes. The veins are usually 5 - 10 ft.

long, and their contacts are all sharply defined. The quartz veins are younger than all the dykes since the former cuts the later.

Miarolitic Cavities

One of the outstanding characteristics of the Rigaud rocks is the presence of small irregular to oval shaped miarolitic cavities , especially well developed in the hornblende syenite and feldspar porphyry towards the centre of the mountain. The cavities vary in size from .2 - .8 inch across.

Small euhedral quartz crystals are seen extending outwards from some of the cavity walls. The cavities occur in clusters confined to specific areas rather than randomly scattered throughout the rock.

A possible origin of the cavities involves the release of volatiles from the late residual melt of a basic magma.(Bowen 1928). The presence of abundant free quartz in the Rigaud rocks indicates a possible high volatile concentration. The hypabyssal nature of the Mountain along with the low water pressure prevailing at such shallow depths, together enhance the possibility of volatile release.

Weathering

Surface weathering especially in the southern half of the mountain has produced two noteworthy features, (a) small cavities in the large feldspar phenocrysts and (b) purple tinted syenites.

(a) Small cavities in the feldspars

Differential weathering in the larger feldspar crystals from their centres outwards has resulted in small cavities .1 - .5 inch across puckering the syenite surface in places. The larger cavities appear to be miarolitic in form, but close examination reveal that they are due only to differential weathering of the crystals.

The cavities are shallower than the miarolitic cavities seen elsewhere on the mountain. Chloritic alteration associated with the weathering gives them a dark greenish to black colouration, which extends beyond the outer boundaries of the cavities in some cases.

(b) Purple tinted Syenite

In some of the weathered hornblende syenite a layer varying in thickness from one inch to one foot acquires a purplish green to pinkish purple tint due to the weathering of the feldspar crystals. The colouration is always replaced at depth by either the pink or grey colour of the fresh syenite. These purple tinted areas are seen chiefly in the hornblende syenite.

PETROGRAPHY AND PETROCHEMISTRY

General Statement

A detailed petrographic study of the rocks of the Rigaud mountain was undertaken,in which ninety hand specimens and seventy thin sections were studied. A combination of standard ' wet method ' chemical analyses and X-ray flourescence spectrometry (See Appendix-A-) were used in arriving at the chemical analyses of the sixteen samples chosen from the different rock types.

Modal analyses of the coarse grained hornblende syenite and quartz-rich syenite were done on stained slabs using a Zip-A-Tone point count method. (See Appendix-B-). The composition and triclinicity of the potash feldspars were determined from X-ray diffraction.

The classification of the different rock types seen in this study follows that set out by Albert Streckeisen (1967) in his"Report on the Classification of Igneous Rocks". This classification was prepared from all the other notable classifications, and differs only slightly from them. The QAP diagram (Fig. 11) summarises the classification.

A plot of the 16 specimens from the Rigaud rocks by weight percentage is also shown on the Fig. 11. It indicates that the rocks are all syenitic and granitic in composition.

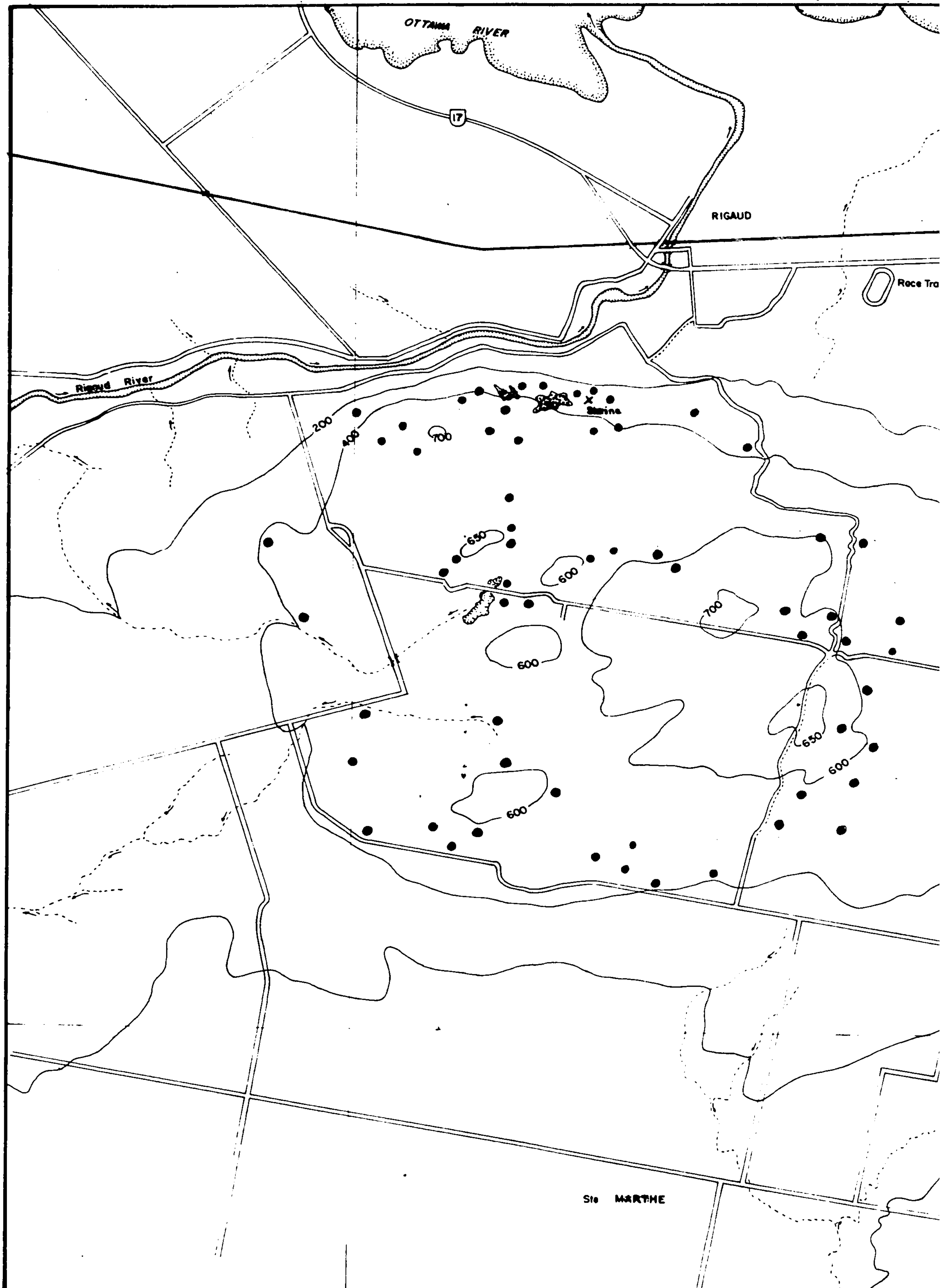
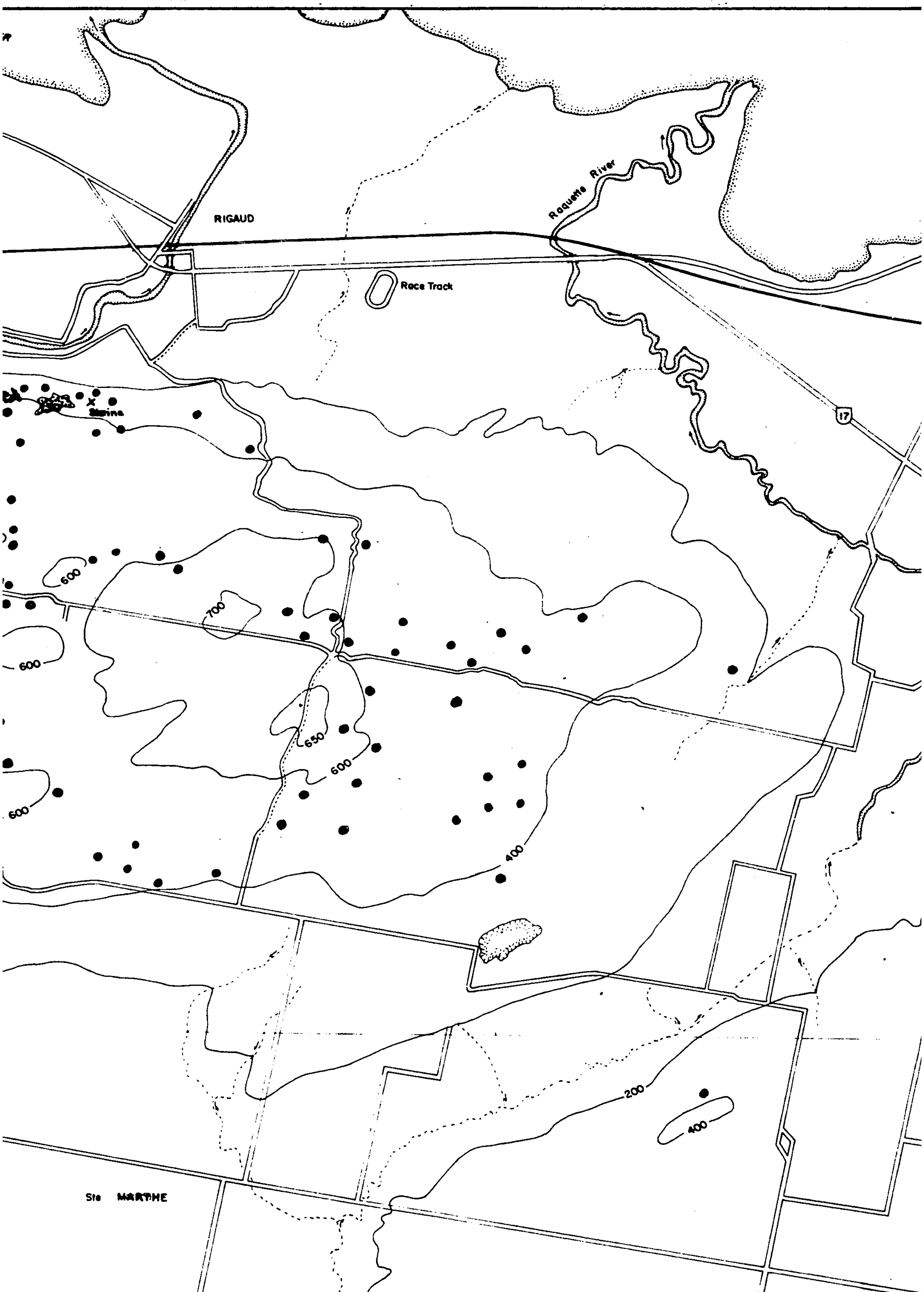
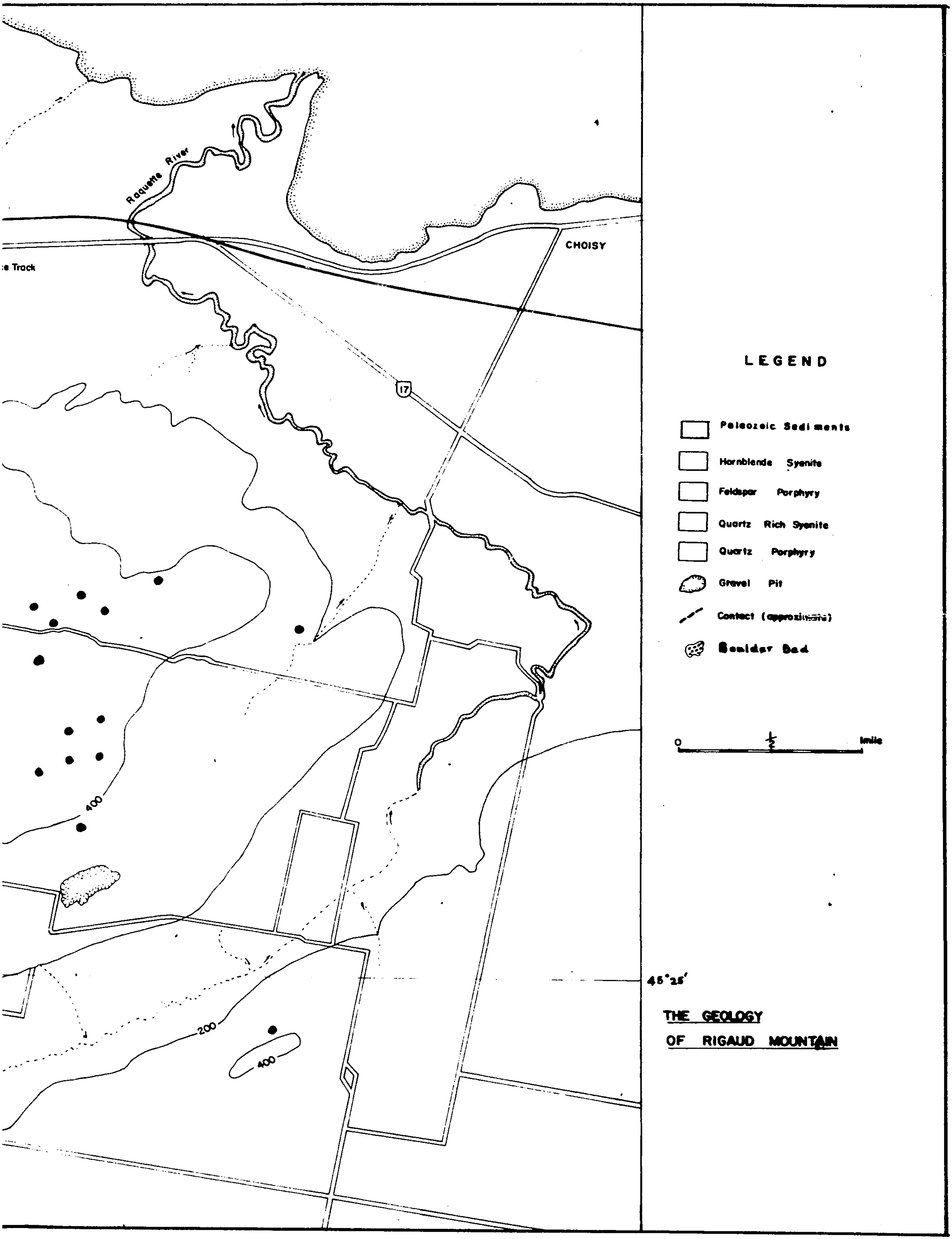
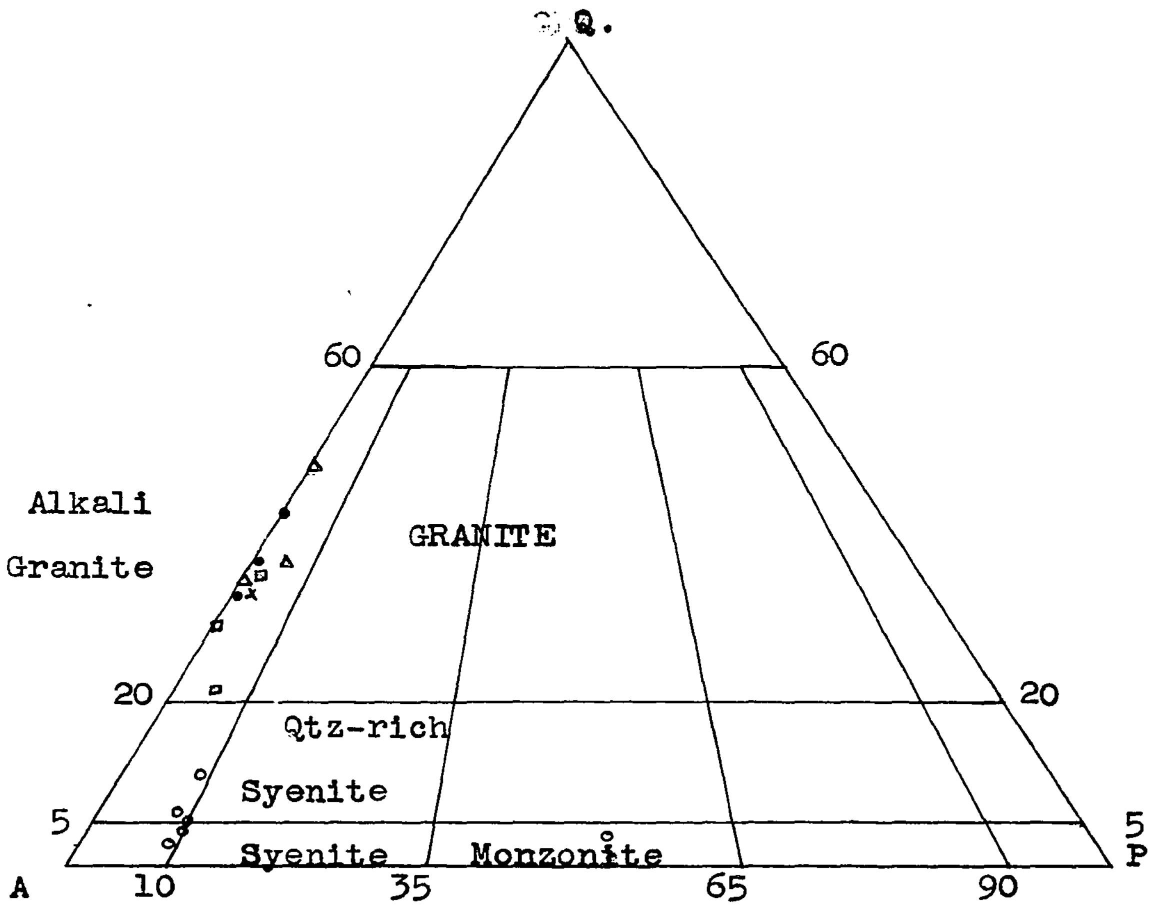


FIG. 10 MAP SHOWING LOCATIONS OF SAMPLES COLLECTED



NS OF SAMPLES COLLECTED


Raquette River
Track
CHOISY
17
400
200
400
45°25′
LEGEND
Paleozoic Sediments
Hornblende Syenite
Feldspar Porphyry
Quartz Rich Syenite
Quartz Porphyry
Gravel Pit
Contact (approximate)
Boulder Bed
0
½
1mile
THE GEOLOGY
OF RIGAUD MOUNTAIN



Q -- Silica mainly quartz

A -- Alkali feldspar including albite An_0 - An_5.

P -- Plagioclase An_5 - An_{100}

Fig. 11 APQ compositional diagram for the classification of quartz-rich igneous rocks. (Classification by Albert Streckeisen 1967).

o-- Hornblende syenite

•-- Aplitic dykes

Δ-- Feldspar porphyry

×-- Quartz porpyhry

□-- Quartz-rich syenite

Using this classification as a base, the Rigaud rocks may be futher subdivided , from macroscopic and microscopic evidence, into the following rock types,in order of decreasing silica;- quartz porphyry, feldspar porphyry, granite, quartz-rich syenite and hornblende syenite. The overall percentages of these rock types throughout the mountain are as follows -- hornblende syenite 60 % , feldspar porphyry 20 % , quartz-rich syenites 5 % , granite and quzrtz porphyry 15 % . Fig. 12 shows the frequency distribution of the rocks.

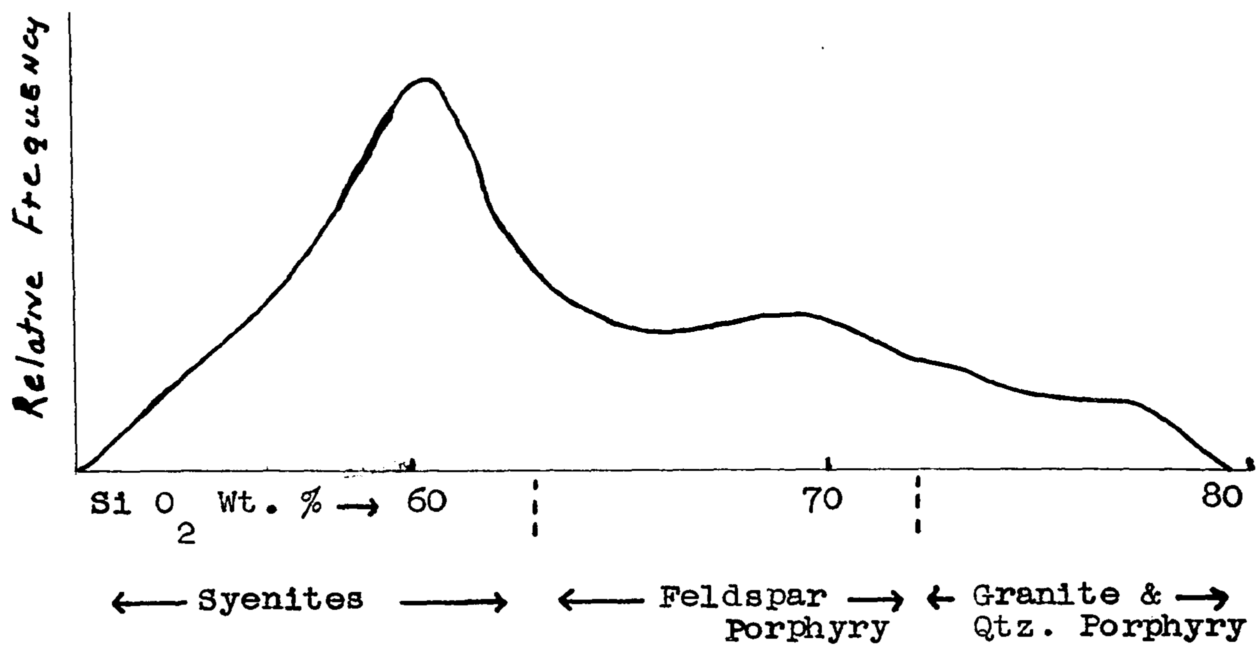


Fig. 12. Frequency distribution of Rigaud rocks.

Definitions

The term SYENITE will be used to describe leucrocratic granitic textured rocks in which the alkali feldspars constitute over 70 % of thr rock's composition. Here alkali feldspar includes both potassic and sodic (albite) members. The quartz content in the syenite should not exceed 10 % . QUARTZ-rich SYENITE will indicate a quartz content of 10 - 20 % . The remainder of the rocks composition is allotted to the mafic components.

The term GRANITE will be used to describe a leucrocratic granitic textured rock with the following composition :- alkali feldspars over 60 % , quartz 20 - 40 %, mafics 5 - 15 % .

The term QUARTZ PORPHYRY implies a rock similar to the granite except that in the porphyry the quartz present chiefly as phenocrysts exceeds 35 % .

The term FELDSPAR PORPHYRY implies a melanocratic rock, coarse grained, with the composition -- alkali feldspar over 90 % , quartzo-feldspathic groundmass 10 % .

The rocks will now be discussed in order of importance.

Hornblende Syenite

General Statement

Twenty-five thin sections of hornblende syenite were studied. Microscopically the rock displays a hypidiomorphic granitic texture. It consists chiefly of antiperthitic feldspars 50 - 70 % , microcline microperthites 20 - 40 % , orthoclase microperthites 5 - 15 % , hornblende 5 - 15 % , quartz 1 - 5 % , diopsidic pyroxene 1 - 5 % .

Other constituents include minor quantities of sodic-rich plagioclase, biotite, and accessory zircon, apatite, allanite, quartz, flourite and magnetite.

Antiperthitic Feldspar

The antiperthitic feldspars $Or_{30}An_{70}$ occur as large irregular anhedral grains with highly indented borders. They vary in length from 5 - 55 mm. The crystals show low relief, but are cloudy due to extensive kaolinization and sericitization. Twinning is poorly developed or absent in the larger crystals, but the smaller subhedral laths display weakly developed polysynthetic twinning , sometimes accompanied by Carlsbad twinning.

The feldspars display a biaxial positive figure,with a 2V of 80 degrees. Many of the antiperthitic grains are poikilitic, the inclusions being hornblende, pyroxene, quartz and apatite blebs. The antiperthite is sometimes associated with later formed microcline, the intergrowth being graphic in places. (Plate 1 Fig. 1).

Microantiperthitic textures consisting of blebs of potash feldspar in soda-rich plagioclase are well developed throughout the hornblende syenite. In order of decreasing abundance, patchy, braid and rod antiperthites are the types present. Within each crystal the potash blebs show a preferred crystallographic orientation oblique to (010) , but in the overall rock this orientation appears random.

The perthitic texture is developed throughout the entire crystal. This fact along with the uniformity in size, shape and frequency of the perthitic blebs indicate that over 90 % of the crystals are exsolution antiperthites.

Sericite and kaolin form the chief alteration products, sometimes completely replacing the crystals. More often the alteration is patchy and extends from the centre of the crystal outwards.

Anhedral grains of clear albite occur intergrown with both the antiperthites and the microcline. These grains show low relief and weakly developed polysynthetic albite twinning. Carlsbad twinning was noted in a few of the larger crystals. The maximum extinction on plates parallel to (001) is 4^{o} . The crystals are biaxial positive with a large 2V. Clear quartz is associated with the albite.

PLATE 1.

Fig. 1 Graphic intergrowth of antiperthitic feldspar with microcline. (X - 25).

Fig. 2 Patch an rod micro perthites in microcline. (X- 25).

Microcline Microperthites

The microcline microperthites Or_{57} An_{43} occur as large irregular shaped subhedral to anhedral crystals 5 to 40 mm. long. The crystals are cloudy due to sericitic alterations. 'Tartan' twinning is well developed and the crystals display biaxial negative figures with a maximum extinction angle on (001) of 15°.

The crystals are generally intergrown with antiperthitic crystals of similar habit. In places the microcline grades into antiperthite, but usually the contacts between them are sharp. Poikilitic textures are displayed by some of the larger crystals with apatite, quartz and magnitite grains as inclusions.

Patch and rod perthites (Plate 1 Fig 2) are both well developed in the microcline microperthites. The uniformity in size, shape and frequency of these blebs indicate that most of the microcline crystals are exsolution microperthites. The irregular growth of some of the patch perthites, somewhat independent of the crystal structure, suggest them to be of replacement origin. The albitic rod inclusions are generally oriented parallel to (001).

Although many of the microcline microperthites are fresh, most show extensive sericitic alterations. Light brownish green hornblende is sometimes seen replacing the microperthites.

Subhedral microcline crystals free of perthitic blebs are found intergrown with both the microperthites and the anitperthites. In these clear microcline crystals polysynthetic albite twinning is well developed. This along with traces of pericline twinning and a biaxial negative figure indicate that the crystals are microcline.

Orthoclase

Anhedral grains of orthoclase 5 to 10 mm. across occur intergrown with the antiperthites. These grains are generally clear, free of inclusions, with low relief, lacking in twinning, and biaxial negative with a large axial angle.

Orthoclase microperthite occurs as anhedral grains intergrown with the antiperthites. The perthitic blebs are of the rod and string variety. Their extensive development and uniformity indicate them to be of exsolution origin.

Orthoclase and microcline microperthites were not seen in the same thin section. The orthoclase microperthites occur in the rocks which are finer grained and richer in quartz. Generally the orthoclase crystals are smaller than the microcline and less abundant.

Hornblende

The hornblende occurs as subhedral to anhedral grains either interstitial to the feldspars or as inclusions in them. It is chiefly of the green variety but minor quantities of the reddish brown variety are also present. The green variety is strongly pleochroic in shades of X - yellow green Y - olive green Z - dark green. Cleavages are well developed especially in the sections parallel to (010). The hornblende has a very relief with a maximum extinction angle of 26° $Z \wedge C$; and a 2V of 75°.

Euhedral crystals are rarely seen, rather the hornblende occurs in four main forms, namely:

1. as large subhedral poikilitic grains interstitial to the feldspars.
2. as small prismatic sections with well developed cleavages and forming triangular interstitial wedges.
3. as alteration rims surrounding and replacing pyroxene.
4. as inclusions in the microperthites.

Most common are large subhedral to anhedral grains 10 to 40 mm. long with either straight sharp borders or irregular indented ones. These larger grains usually have some crystal faces well developed and display poikilitic textures, the inclusions being remnants of pyroxene apatite, magnetite and quartz grains. Cleavages in sections parallel to (010) are prominent.

Two interesting structures formed by these larger hornblende plates are,

1. triangular and polygonal shaped wedges 5 to 15 mm. long interstitial to the feldspars, and often associated with clear quartz. (Plate 2 Fig 1.)
2. skeletal crystals formed by thin extensions of the hornblende into the adjacent feldspar, sometimes forming graphic intergrowths.

In many instances the poikilitic grains are intergrown, sometimes graphically, with minor quantities of brown biotite and augite. In some of these aggregates the pyroxene alters to uralite, (Plate 2 Fig. 2) while both the biotite and hornblende show chloritic alteration. Magnetite is always associated with these aggregates, either completely replacing the biotite or forming bead-like rims around it.

Large sphene crystals and yellowish brown iron staining are also commonly associated with the aggregates.

The smaller prismatic sections of the green hornblende vary in length from 5 to 25 mm., and always display sharp boundaries. Concentric zoning is present in many of these crystals. The zones are .5 to 1 mm. thick and vary in colour from yellowish green to dark green.

These zoned crystals have well developed prismatic cleavages. They are generally free of inclusions except for slight chloritic alteration products. The crystals form wedges interstitial to the large feldspar crystals. No quartz or magnetite is found associated with these wedges.

The hornblende also occurs as rims surrounding and replacing clinopyroxenes. (Plate 3 Fig. 1). The rims vary in thickness from .1 to 3 mm., and display sharp outer boundaries. The inner boundary of the rims may be sharp and clean, or fringed by chloritic alteration, or accentuated by biotite grains. In these rims the maximum extinction angle $Z \wedge C$ is 14°. Inclusions and or alterations are seldom found within them.

Thin hornblende rims are also found surrounding and replacing perthitic crystals. No quartz or magnetite is associated with these rims. Minor quantities of chloritized hornblende occur as small blebs and inclusions in some of the microperthites.

From its occurrence in the syenites the green hornblende appears to have begun crystallising after the pyroxene but before the feldspar, with however the bulk of the hornblende crystallising after the feldspar. The strong bluish green tint of the hornblende especially in the aggregates, indicates it to be soda-rich.

The reddish brown variety of the hornblende occrus chiefly in the finer grained syenite, and is associated with the brown biotite. Here the hornblende forms small stubby plates with very high relief and strongly pleochroic. The plates are usually fresh or partially replaced

PLATE 2.

Fig. 1. Hornblende (black) - Quartz (clear) wedge interstitial to perthitic feldspars. (X- 25).

Fig. 2. Chloritic hornblende rim surrounding uralitic pyroxene (X - 25).

by magnetite and display a extinction angle of 24° $Z \wedge C$.

Quartz

In the hornblende syenite the quartz occurs either as interstitial grains or as inclusions within the feldspars. The interstitial grains occur in two main forms;

1. as triangular and rectangular wedges associated with the green hornblende. (Plate 2 Fig. 1). Here the borders of the quartz grains are sharp and straight, and the quartz always forms the thicker end of the hornblende-quartz wedges. The quartz also forms skeletal crystals partially surrounding the feldspars.
2. The Quartz also occurs as irregular shaped and rounded grains 1 to 8 mm. across interstitial to the feldspars. (Plate 3 Fig 2). Here the quartz-feldspar interfaces are sharp and straight, but marginal myrmekitic intergrowths occassionally develop. Graphic intergrowth of quartz with both hornblende and or feldspar is common. The interstitial nature of the quartz in these environments indicate that is crystallised later than the feldspars.

When quartz occur as inclusions it forms small grains 1 to 4 mm. across which are randomly scattered in feldspar hornblende, and pyroxene. The inclusions are

PLATE 3

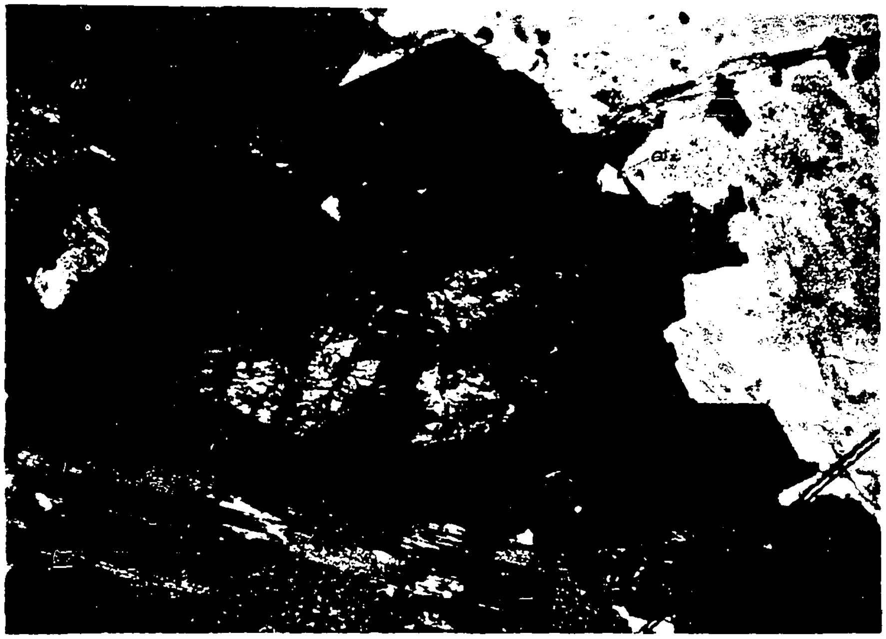


Fig. 1. Green hornblende surrounding and replacing pyroxene. (X - 25).

Fig. 2. Angular quartz wedge interstitial to antiperthitic feldspar. (X - 25).

prominent in the poikilitic textured crystals, where they generally have graphic outlines.

All three forms of the quartz are very clear, free of inclusions and exhibit a wavy extinction. The quartz occurs chiefly as large single grains rather than as aggregates, and is chiefly associated with hornblende, sometimes displaying a graphic intergrowth with it. Minor inclusions of gas bubbles and liquid inclusions are present chiefly along the outer margins of the crystals.

Pyroxene

Most of the pyroxene is either highly altered or partially replaced by hornblende. Pale green diopsidic-augite with poorly developed cleavages is the chief type present. Usually the larger crystals are enclosed by rims of green honrblende. (Plate 3 Fig. 1). The pyroxene is weakly pleochroic in shades of olive green to light yellow, with a maximum extinction angle $Z \wedge C$ of 39°. The larger pyroxene crystals sometimes display poikilitic textures with sphene, apatite, magnetite and quartz grains as inclusions. Cleavages are either absent or are poorly developed, but wherever present they are continuous with those of the surrounding hornblende rims.

Uralite is the chief alteration product of the pyroxene, sometimes completely replacing it. (Plate 4 Fig 1).

Another alteration product of the pyroxene occurs as a yellowish brown, iron rust material which tends to completely replace the pyroxene. In the less altered crystals the yellowish brown alteration is concentrated along the cleavages planes.

Small anhedral blebs of pale green clino-pyroxene form inclusions in some of the larger feldspar crystals, indicating the earlier crystallising of the pyroxene.

Biotite

In the hornblende syenite brown biotite forms less 1% of the rocks mineral content. It occurs as large anhedral grains 5 to 30 mm. long, strongly pleochroic in shades of reddish brown to yellowish brown. The larger plates are slightly bent and display perfect cleavage in (001) direction. The plates are generally fresh, with uncorroded margins, but thin borders of green hornblende fringe some of the altered plates.

The larger crystals display poikilitic textures with zircon, quartz, magnetite and feldspar laths as inclusions. Most of the biotite show parallel extinction but the bent plates display wavy extinction. Small biotite laths form inclusions in the microperthites. Generally the biotite is associated with the green hornblende, and is replaced by magnetite in many places.

Accessory Minerals

In the hornblende syenite accessory minerals form less than 2 % of the total mineral content. The minerals in order of decreasing abundance are magnetite, zircon, sphene, allanite and flourite.

Magnetite occurs as subhedral to rounded grains varying in length from dust-like particles to grains 4 mm. long. It is usually associated with hornblende and pyroxene, sometimes forming poikilitic inclusions and at other times completely replacing the pyroxene crystals. The larger grains contain zircom and apatite inclusions.

Apatite occurs as prismatic hexagonal ctystals with sections 1 - 3 mm. wide, and forms inclusions in feldspars , hornblende, pyroxene and magnetite.

Zircon appears in two main forms, either as square basal sections, or as stout prisms with pyramid terminations. The later vary in length from .5 - 2 mm. It's occurrence is similar to apatite but in both hornblende and biotite the zircons form prominent haloes..5 mm thick.

Sphene occurs as subhedral to euhedral grains 2 - 8 mm. long showing prominent partings. It is associated with hornblende and biotite as inclusions.

Brown allanite is present in a few thin sections as inclusions in feldspar with which it is graphically intergrown. It also occurs as rounded grains and blebs in both hornblende and pyroxene.

PLATE 4.

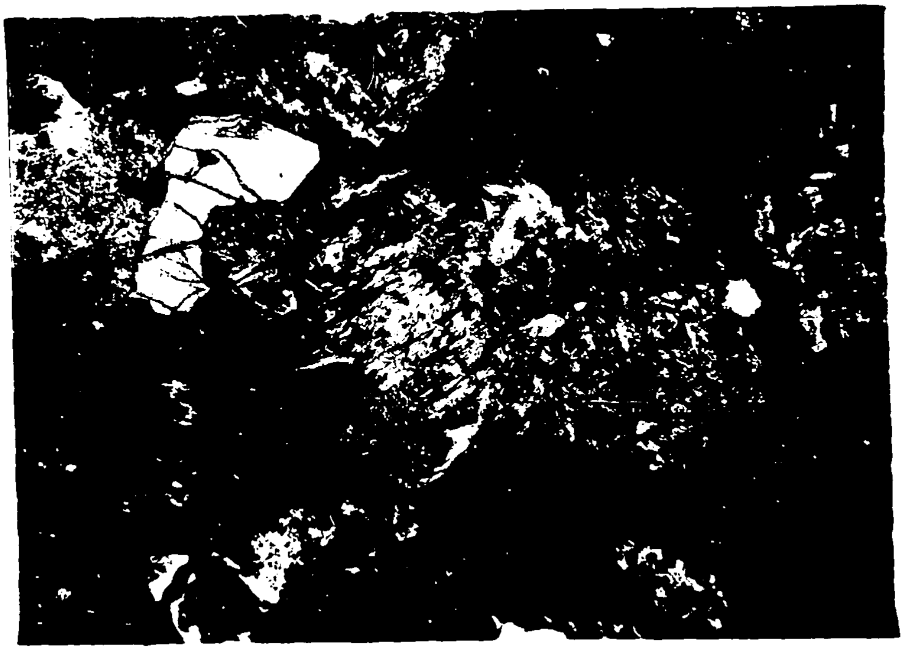


Fig. 1. Uralite completely replacing pyroxene. (X - 25).

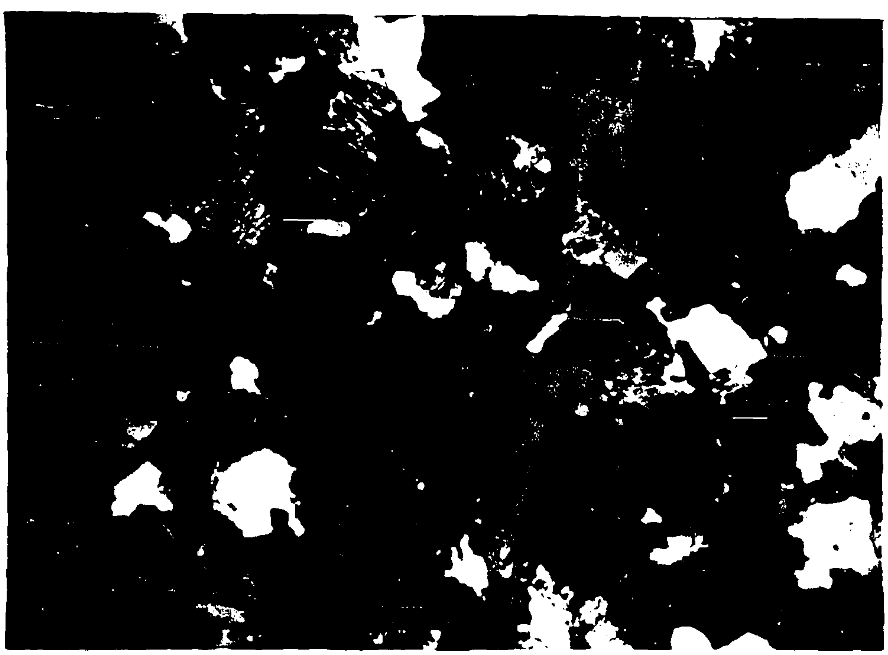


Fig. 2. Antiperthitic feldspar showing Carlsbad twinning in medium grained syenite (X - 25).

MEDIUM GRAINED SYENITE

General Statement

In places the hornblende syenite grades into a medium grained variety. The writer prefers to classify this finer grained , dark grey, mafic-poor rock as a medium grained syenite.

Megascopiscally it differs from the coarse hornblende syenite only in its granularity and mafic content. It occurrence throughout the coarser hornblend syenite is random, although it appears to occur more frequently in the southwestern sector of the mountain.

Microscopically the rock is medium grained, holocrystalline, with almost equigranular crystals which give it a uniform appearance. It consists of antiperthites 70 - 90 % , orthoclase microperthites 10 - 30 % , quartz 1 - 2 % , with minor quantities of hornblende and accessory minerals.

Antiperthites

The antiperthites occur as subhedral to anhedral grains 5 - 15 mm. long with highly indented borders. The crystals are biaxial positive, with a large 2V, and show well developed Carlsbad twinning. (Plate 4 Fig. 2). The potash blebs form string and rod perthites. Patch perthites are developed to a lesser extent in the larger crystals. The uniformity in size and frequency of the blebs suggests the crystals are exsolution antiperthites.

Sericitic alteration of the feldspars is at a minimum, while myrmekite is developed at some of the quartz-feldspar interfaces. Films of reddish brown iron staining occur along the intergranular boundaries.

Orthoclase Microperthites

Minimal quantities of orthoclase microperthite occur as subhedral to anhedral grains 3 - 10 .. long intergrown with the antiperthites. Twinning is absent in most crystals, but Carlsbad twinning is present in a few. The crystals are biaxial negative.

The rod and string perthites show a similar occurrence to those in the hornblende syenite. A few anhedral grains of clear orthoclase occur interstitial to the antiperthites.

Quartz

In these syenites the quartz occurs in two main forms ; (1) as rounded grains interstitial to the microperthites and (2) as large rounded grains replacing and engulfing the microperthites. In both forms the quartz is clear free of inclusions and gives a wavy extinction. The crystals aggregate in clusters of three to six grains with sharp intergranular boundaries.

The quartz also occurs as inclusions within a few of the microperthites. The quartz occurs more commonly engulfing and replacing the microperthites. The two occurrences of quartz suggest that there were two phases of quartz crystallisation, one preceeding and the other after the feldspars crystallised.

Hornblende

The hornblende occurs as anhedral crystals interstitial to the feldspars. The grains are dark green , strongly pleochroic in shades of olive green to yellowish brown, with a maximum extinction angle $Z \wedge C$ of 20°. These grains are usually poikilitic in texture, the inclusions being quartz and feldspar laths.

A yellowish brown to rust coloured alteration product occurs in most of the hornblende crystals. Magnetite and allanite are the only accessory minerals present.

The chemical and modal analyses of these rocks are given in Tables 1, 2 and 3.

TABLE 1

HORNBLENDE SYENITE

Sp. No.	5	68	67	6	11	A
SiO_2	63.00	61.65	61.00	52.00	61.60	62.70
Al_2O_3	16.25	17.49	17.15	25.30	16.50	16.90
Fe_2O_3	4.50	3.84	4.00	2.16	3.94	4.56
FeO	-	-	-	1.86	2.67	-
MgO	0.66	0.48	0.59	1.55	0.91	0.62
CaO	3.20	2.30	2.90	10.44	2.40	1.51
Na_2O	5.76	5.47	5.47	4.12	5.46	5.17
K_2O	4.05	4.86	4.80	0.88	4.19	6.36
H_2O	0.82	0.71	0.44	1.00	1.08	-
TiO_2	0.69	0.42	0.46	0.33	0.97	0.64
P_2O_5	0.31	0.11	0.14	0.26	0.31	-
MnO	-	-	-	0.04	0.21	0.14
CO_2	-	-	-	-	-	-
Total %	99.24	97.33	96.95	99.94	100.24	98.60
Color Ind.	13.37	9.47	11.61	9.80	11.09	

No. 5. Medium grained purplish grey hornblende syenite (Greig)

No. 68. Coarse grained light pink hornblende syenite (Greig)

No. 67. Coarse grained pink hornblende syenite (Greig)

No. 6. Coarse grained purplish grey hornblende syenite. (John Stevenson)

No. 11 Grey medium grained hornblende syenite. (J. Stevenson)

NO. A. Coarse grained pink syenite - (Mutton Bay) analyst (Zoltan Katzendorfer)

TABLE 2

Normative Minerals for Hornblende Syenite

Sp. No.	5	68	6	67	11
Qtz.	5.38	3.42	0.67	2.29	8.37
Ort.	23.93	28.72	5.20	28.37	24.76
Ab.	48.73	46.27	34.85	46.27	46.19
An.	6.52	8.81	47.92	8.06	8.13
Cor.	-	-	-	-	-
CaCpx.	3.08	0.79	0.91	2.27	0.74
MgCpx.	0.62	0.17	0.64	0.44	0.55
FeCpx	2.67	0.72	0.19	1.98	0.10
Ens.	1.03	1.06	3.22	1.03	1.71
Feros.	4.46	5.64	0.97	4.60	0.33
Mag.	-	-	3.13	-	5.71
Hem.	-	-	-	-	-
Ilm.	1.31	0.80	0.63	0.88	1.85
Rut.	-	-	-	-	-
Ap.	0.74	0.26	0.62	0.34	0.74
Cal.	-	-	-	-	-
Total %	98.42	96.62	98.94	96.51	99.16

The chemical analyses of the Rigaud syenites compare favourably with those of the Mutton Bay Pluton. In In both cases the sodic content is slightly higher than the potassic. The higher Ca O content of the Rigaud rocks is due to the presence of much hornblende.

The normative values of the Rigaud syenites show good agreement with these modal values.

TABLE 3

Minerals	Normative	Modal
K & Na Feldspars	74.99	75.00
Quartz	5.01	6.70
Hornblende & Pyroxene	11.88	12.10
Plagioclase	7.90	6.20
TOTAL %	99.78	100.00

PORPHYRIES

General Statement

Since the porphyries vary from a syenite in the west to a quartz porphyry in the east, the writer will for clarity classify them as follows :

(1) As Feldspar Porphyry all rocks in which the quartz content does not exceed 2% and is confined to the groundmass.

(2) As Quartz-rich Syenite Porphyry all the rocks in which the quartz content varies from 2 - 20 % .

(3) As Quartz Porphyry all rocks in which the quartz content exceeds 20 % .

FELDSPAR PORPHYRY

General Statement

The following descriptions are based on studies made on twenty thin sections, Microscopically the rock is coarse grained with a porphyritic texture. It consists of phenocrysts of albite 10 - 30 %, orthoclase 5 - 10 %, in a quartzo-feldspathic groundmass 60 - 80 %. Blebs of altered clinopyroxene and hornblende occur in the groundmass. Magnetite, apatite and zircon are the accessories. All the crystals are extensively altered to sericite.

Albite

The albite crystals occur as subhedral to anhedral crystals 5 - 35 mm. long. Some crystals however have well developed faces. The crystal boundaries are sharp, but in the more highly altered regions they are gradational into the groundmass. Twinning is absent in most of the crystals, and they are biaxial positive.

Sericitic alterations develop from the centre of the crystals outwards. This gives them a zoned effect with the outer border of the crystal being less altered. (Plate 5 Fig. 1)

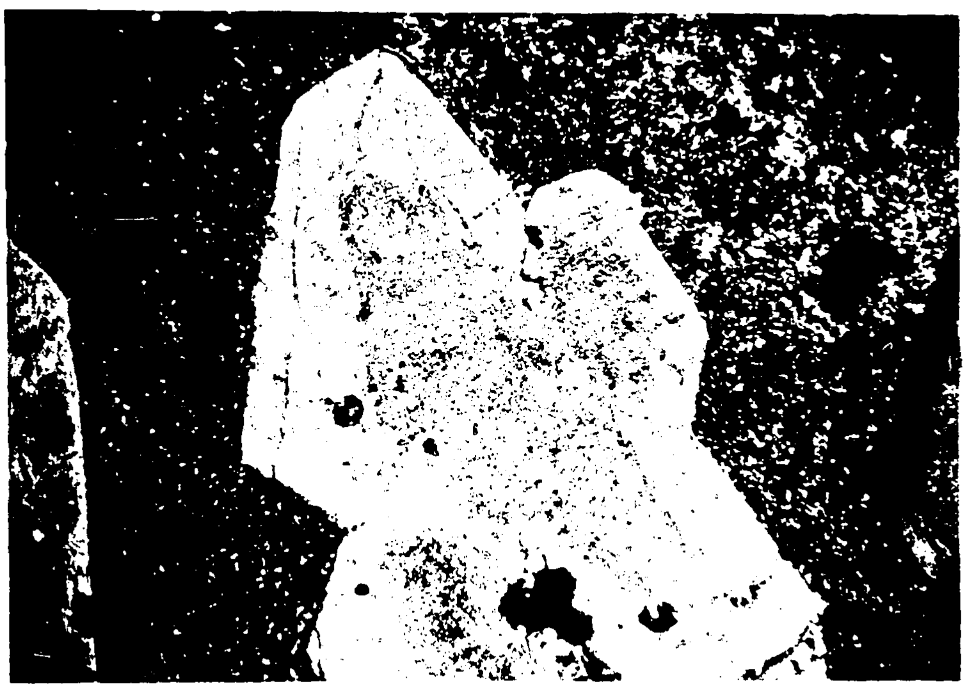


Plate 5 Fig. 1 Zoned feldspar phenocryst in quartzo-feld - spathic groundmass of feldspar porphyry. (X-25).

Orthoclase

Generally the orthoclase occurs in a form similar to that of the albite phenocrysts. Sericitic and kaolinitic alteration products have in many cases completely replaced the crystals. Inclusions present chiefly towards the centre of the larger crystals consists of small aggregates of fine grained quartz, euhedral apatite grains, blebs of magnetite and altered hornblende psuedomorphic after pyroxene. Weakly developed perthitic textures are evident in some crystals.

Groundmass

The groundmass consists of a chloritic and feldspathic material 80 %, aggregates of fine grained quartz 5 % , and altered mafics 15 % . The quartz grains are strained and display wavy extinction. The mafics consists of randomly distributed angular to rounded magnetite grains and altered grains of clinopyroxene.

Irregular shaped grains of light green hornblende are scattered throughout the groundmass.

The chemical, normative and modal analyses are given in Tables 4 , 5 , and 6 .

TABLE 4

Feldspar Porphyry

Specimen No.	12	7	24
SiO_2	75.50	74.10	74.85
Al_2O_3	13.75	13.80	12.10
Fe_2O_3	1.62	0.81	2.95
FeO	-	0.61	-
MgO	0.24	0.09	0.27
CaO	1.20	0.14	0.15
Na_2O	3.62	3.12	2.14
K_2O	3.65	6.16	4.58
H_2O	0.46	0.41	0.50
TiO_2	0.13	0.16	0.11
P_2O_5	-	0.04	0.06
MnO	-	0.02	-
CO_2	-	-	-
Total %	100.17	99.46	97.71
Colour Index	5.28	3.80	9.88

No. 12 Dark grey medium grained feldspar porphyry. (Greig)

No. 7 Light grey medium grained feldspar porphyry.(J.Stevenson)

No. 24 Dark grey coarse grained feldspar porphyry. (Greig)

TABLE 5

Normative Minerals for Feldspar Porphyry

Specimen No.	12	7	24
Qtz.	36.29	31.96	41.94
Ort.	21.57	36.40	27.07
Ab.	30.62	26.39	18.10
An.	5.95	0.43	0.35
Cor.	1.66	1.84	3.49
CaCpx.	-	-	-
MgCpx.	-	-	-
FeCpx	-	-	-
Ens.	0.60	0.22	0.67
Fer.	2.76	0.22	5.24
Mag.	-	1.17	-
Hem.	-	-	-
Ilm.	0.25	0.30	0.21
Rut.	-	-	-
Ap.	-	0.10	0.14
Cal.	-	-	-
Total	99.71	99.05	97.21

These chemical analyses indicate the porphyry to be very similar to the normal syenites of Oslo, Norway, or the Diana Complex of the northwest Adirondacks. In all three cases the total alkali percentages are similar.

TABLE 6

Minerals	Normative	Modal
K & Na Feldspars	62.79	70.20
Plagioclase	2.20	5.00
Quartz	31.96	21.60
Mafics	2.76	3.20
TOTAL %	99.71	100.00

The porphyritic texture of the rock is partially responsible for the slight disagreement in the normative values as compared with the modal. The contrast between the aphanitic groundmass and the feldspar phenocrysts made the thin section count an inaccurate estimate.

QUARTZ-RICH SYENITE

General Statement

In the northeast the syenites show a variation in quartz content from one region to the next. For clarity the writer will divide the syenites into three groups :

(1) The coarse grained variety with quartz content greater than 10 % .

(2) The medium grained variety with quartz content between 2 - 10 % .

(3) The fine grained variety with quartz content less than 2 % .

It should be noted that these divisions would not be recognizable in the field as separate units, since the contacts are gradational between the units. Of the three groups the fine grained variety is the most porphyritic.

The following descriptions are based on studies made on nine thin sections.

The coarse grained variety

General Statement

This syenite is holocrystalline, coarse grained and granitic in texture. It consists of antiperthites 65 % , orthoclase 15 % , quartz 15 % , and traces of hornblende and magnetite.

Antiperthites

They occur either as subhedral laths with prominent Carlsbad twinning , or as anhedral to rectangular grains void of twinning. In both cases the crystals vary in size from 10 - 20 mm. The crystals are intergrown among themselves in a mixture of graphic and mosaic textures.

The crystals are generally free of inclusions, except for quartz blebs. Patch and rod perthites are well developed, and are of exsolution origin.

Orthoclase Microperthites

They occur as both perthites and clear grains interstitial to the feldspars. The crystals form aggregates, and sometimes send out finger-like projections which invade the antiperthites.

Quartz

The quartz forms irregular shaped grains 2 - 6 mm, in size interstitial to the feldspars. The grains are clear and free of inclusions.

Magnetite is the only accessory present.

Medium grained variety

In this variety the texture is slightly porphyritic. The antiperthites occur in a form similar to that in the coarse grained variety. Quartz is seen invading and replacing feldspar.

Stubby crystals of greenish brown biotite occur interstitial to the feldspars. The biotite contains inclusions of quartz. This indicates an early phase of quartz crystallisation.

Fine grained variety

This variety is markedly porphyritic in texture. It consists of poorly defined poikilitic phenocrysts of orthoclase and albite in a fine grained quartzo-feldspathic groundmass. The inclusions in the orthoclase are stubby laths of feldspar, altered blebs of hornblende and rounded quartz grains.

The feldspar laths are oligoclase An_{30}, and they display sharp polysynthetic twinning with a maximum extinction angle $Z \wedge C$ of 15°.

Anhedral albite and antiperthitic grains form smaller phenocrysts in the groundmass. Quartz forms the bulk of the groundmass and consists of a mosaic intergrowth of rounded grains.

Flourite grains occur among the quartz. Thin flakes of biotite and magnetite grains are scattered throughout the groundmass.

TABLE 7

Syenite

Specimen No.	3	B
SiO_2	59.50	61.86
Al_2O_3	15.60	16.91
Fe_2O_3	5.38	2.32
FeO	-	2.63
MgO	1.35	0.96
CaO	4.00	2.54
Na_2O	5.17	5.46
K_2O	3.86	5.91
H_2O	0.48	0.53
TiO_2	1.15	0.58
P_2O_5	0.50	0.19
MnO	-	0.11
CO_2	-	-
Total %	96.99	100.00
Color Index	17.77	

No. 3 Coarse grained grey syenite Analyst Greig.

No. B Average alkali syenite Analyst Nockolds 1954.

TABLE 8

Normative Minerals for Syenite

Specimen No.	3
Qtz.	3.72
Ort.	22.81
Ab.	43.74
An.	7.95
Cor.	-
CaCpx.	3.62
MgCpx.	1.11
FeCpx.	2.63
Ens.	2.25
Feros.	5.35
Mag.	-
Hem.	-
Ilm.	2.19
Rut.	-
Ap..	1.20
Cal.	-
Total	96.51

QUARTZ PORPHYRY

General Statement

The quartz porphyry consists of quartz phenocrysts 35 % , antiperthites 10 % , in a fine grained groundmass 55 %. The phenocrysts are randomly distributed throughout the groundmass.

Quartz

The quartz phenocrysts occur as irregular and rounded grains 5 - 20 mm in size. The margins of the crystals are either sharp or gently crenulated, the indentations being filled with the quartz-rich groundmass. The crystals are clear and exhibit sharp extinction.

The crystals usually occur as single grains embedded in the groundmass. (Plate 6 Fig. 1). The crystals are traversed by randomly oriented cracks. Strings of minute quartz grains accentuate these cracks. Finger-like intrusions of the fine grained groundmass invade some of the phenocrysts. Clusters of small quartz grains form inclusions towards the centre of the larger phenocrysts. This indicates the possibility of two phases of quartz crystallisation.

Growth of secondary quartz is evident in many

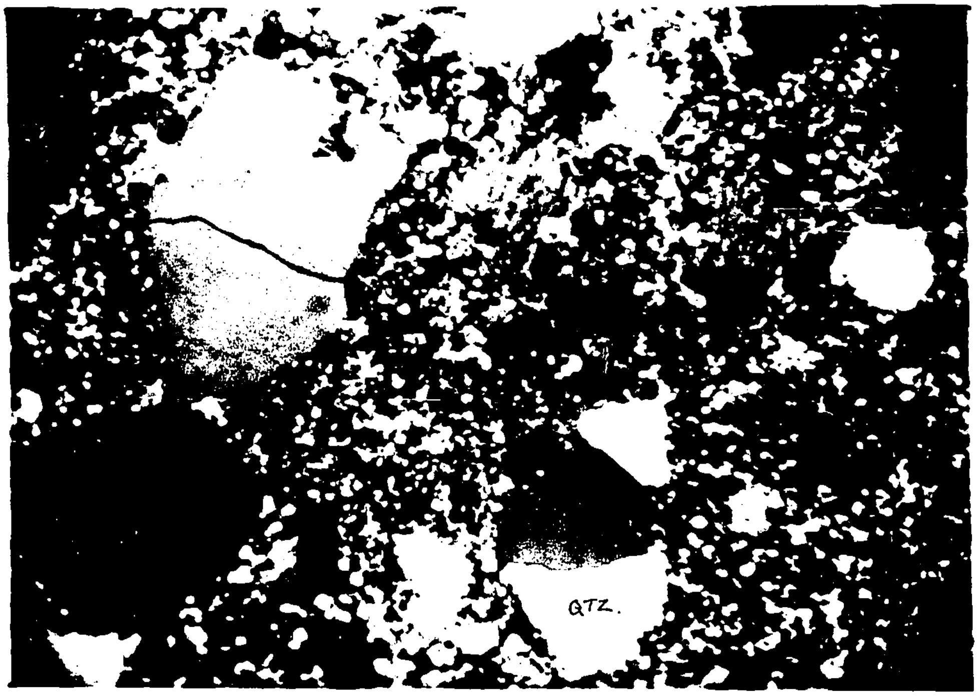


Plate 6 Fig. 1. Quartz phenocrysts in quartz porphyry. (X- 25)

places where large irregular shaped quartz grains completely enclose other quartz grains. Some of the crystals appear zoned due to the effects of the secondary quartz.

Antiperthites

The antiperthitic feldspar phenocrysts occur as subhedral to rectangular grains 2 - 25 mm. long with well developed rod and string perthites. The crystals are free of inclusions and alterations.

Orthoclase occurs both as microperthites and as clear grains intergrown with the antiperthites.

Groundmass

The medium to fine grained groundmass consists of a mosaic intergrowth of interlocking quartz grains with minor quantities of stubby feldspar laths, green hornblende, and accessory zircon and flourite.

The quartz, average grain size 1mm., contain inclusions of minute gas bubbles. Magnetite occurs associated with both the hornblende and the biotite, partially replacing them in places.

The feldspar laths are possibly oligoclase. They exhibit excellent polysynthetic twinning with a maximum extinction angle of 5^{o}. Iron staining occurs along some of the interlocking quartz boundaries.

The chemical, normative and modal analyses are given in Tables 9 , 10 , and 11 .

TABLE 19

Quartz Porphry

Specimen No.	73
SiO_2	74.50
Al_2O_3	12.80
Fe_2O_3	1.52
FeO	-
MgO	0.25
CaO	1.15
Na_2O	4.48
K_2O	3.65
H_2O	0.20
TiO_2	0.11
P_2O_5	0.02
MnO	-
CO_2	-
Total %	98.68

TABLE 10

Normative Minerals for Quartz Porphyry

Specimen No.	73
Qtz.	30.84
Ort.	21.57
Ab.	37.90
An.	4.03
Cor.	-
CaCpx.	0.65
MgCpx.	0.13
FeCpx.	0.56
Ens.	0.49
Feros.	2.05
Mag.	-
Hem.	-
Ilm.	0.21
Rut.	-
Ap.	0.05
Cal.	-
Total	98.48

TABLE 11

Normative Minerals for Quartz Porphyry

Minerals	Normative	Modal
K & Na Feldspars	59.47	55.62
Plagioclase	4.03	2.50
Quartz	30.84	38.34
Mafics	4.14	3.54
Total %	98.48	100.00

Modal analyses were derived from point counts on 6 thin sections.

GRANITE

General Statement

The rock displays a hypidiomorphic granitic texture, and consists of antiperthites 50 % , orthoclase perthites 20 % , quartz 20 % , oligoclase 5 % , and hornblende and accessories 5 % . In the pink granites the hornblende and accessories form only 1 %, while the quartz content increases to 25 % .

Antiperthitic feldspars

They occur as irregular shaped grains lo - 20 mm. across with indented and rounded borders. They are conspiciously free of inclusions except for rounded quartz grains. Rod and string perthites are well developed in these crystals. (Plate 7 Fig. 1.)

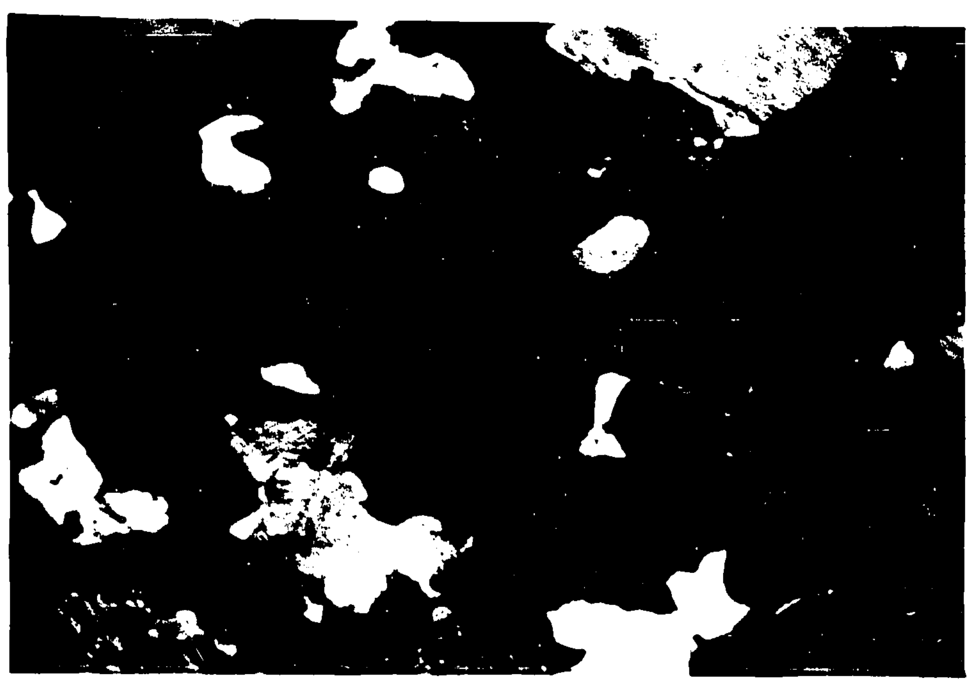


Plate 7 Fig. 1 Rod and string perthites in granites. (X- 25).

Orthoclase

The orthoclase occurs in two main forms :

(1) as rounded and irregular shaped perthitic grains.

(2) as large irregular shaped clear crystals.

The orthoclase is usually intergrown with the antiperthitic feldspars. Euhedral hornblende crystals are seen at the centre of some of these orthoclase crystals. Coarse rod and string perthites are well developed in the larger orthoclase crystals.

Remnants of the oligoclase laths are intergrown with the microperthites. The laths are subhedral, with well developed polysynthetic twinning and a maximum extinction angle $Z \wedge C$ of 14°.

Quartz

The quartz occurs as rounded and irregular shaped grains 2 - 15 mm. in size, generally interstitial to the perthites. It is clear, free of inclusions and exhibit a wavy extinction. The grains usually form aggregates.

Hornblende

The green hornblende occurs as anhedral grains and blebs 1 - 4 mm. in size, usually with prominent cleavages developed. It displays high relief and is strongly pleochroic

X -- dark green , Y -- yellowish green , Z -- light green. All the contacts between the hornblende and the surrounding minerals are sharply defined and free of alteration.

The hornblende occurs both interstitial to the perthites and as inclusions within them. Extensive fracturing is common in the hornblende. It displays a maximum extinction angle $Z \wedge C$ of 25°.

Euhedral apatite grains and biotite blebs are intergrown with the hornblende. Altered grains of clinopyroxene partially replaced by magnetite are found associated with the hornblende.

The chemical, normative and modal analyses are given in Tables 12 , 13 , and 14.

TABLE 12

Chemical Analyses of Granite

Specimen No.	59	28	71	C
SiO_2	70.80	74.70	72.00	74.16
Al_2O_3	15.25	13.35	14.75	12.32
Fe_2O_3	1.34	1.40	1.60	2.51
FeO	-	-	-	0.75
MgO	0.33	0.19	0.36	0.31
CaO	1.20	0.53	0.09	0.60
Na_2O	5.42	4.38	4.75	4.18
K_2O	4.00	3.39	4.30	4.04
H_2O	0.39	0.41	0.64	0.47
TiO_2	0.20	0.16	0.21	-
P_2O_5	0.04	0.03	0.04	-
MnO	-	-	-	-
CO_2	-	-	-	-
Total %	100.97	98.54	98.74	99.34
Col. Indx.	3.48	4.76	6.22	

No. 59. Fine grained light grey granite. Analyst Greig.

No. 28. Medium grained quartz-rich granite. (Greig)

No. 71. Coarse grained grey granite (Greig)

No. C. Granite Chatham-Grenville stock. Analyst G. W. Bain University of Vermont.

TABLE 13

Normative Minerals for Granite

Specimen No.	59	28	71
Qtz.	20.10	33.87	26.16
Ort.	23.64	20.03	25.41
Ab.	45.85	37.05	40.18
An.	5.46	2.43	0.19
Cor.	-	1.58	2.21
CaCpx.	0.10	-	-
MgCpx.	0.03	-	-
FeCpx.	0.07	-	-
Ens.	0.79	0.47	0.90
Feros.	2.06	2.31	2.59
Mag.	-	-	-
Hem.	-	-	-
Ilm.	0.38	0.30	0.40
Rut.	-	-	-
Ap.	0.10	0.07	0.10
Cal.	-	-	-
Total.	98.58	98.13	98.10

TABLE 14

Minerals	Normative	Modal
K & Na Feldspars	69.49	66.00
Plagioclase	5.46	2.10
Quartz	20.10	26.61
Mafics	3.53	5.20
Total %	98.58	99.91

APLITIC DYKES

The dyke rocks are medium grained to aphanitic, dark or light grey to buff coloured rocks which display concoidal fracturing. In the lighter grey variety minute clear quartz crystals form phenocrysts in the finer grained material. The finer grained dykes are all quartz-rich.

Microscopically the dykes consists of a granular intergrowth of quartz and feldspar , along with grains of orthoclase, brown biotite, plagioclase and sphene. The dykes are granitic and syenitic in composition.

The aplitic dykes consists of a mosaic intergrowth of quartz and orthoclase. Myrmekite is extensively developed along some of the contacts between syenite and the dyke rocks.(Plate 8 Fig. 1.)

Plate 8. Fig. 1. Myrmekite along contact of syenite and dyke.

In places the quartz tends to aggregate forming larger crystals which give the rock a porphyritic texture. In composition the dykes are made up of quartz 70 %, orthoclase 20 % , biotite and accessories 10 % .

A very fine grained variety of the granitic dyke occurs in which the quartz content is very much reduced. Here the larger orthoclase grains are cloudy with dust-like inclusions of magnetite grains.

Minor quantities of sphene and apatite are the only accessory minerals present. Plate 9 displays the textures in the aplitic dykes.

PLATE 9

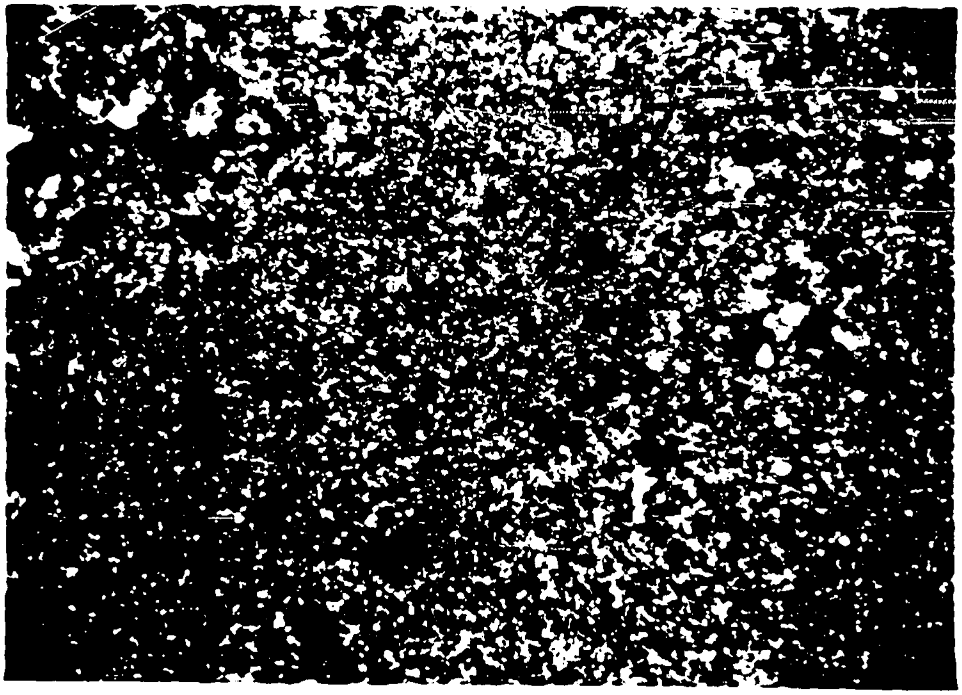


Fig. 1 Fine grained rhyolitic dyke rock. (X - 25).

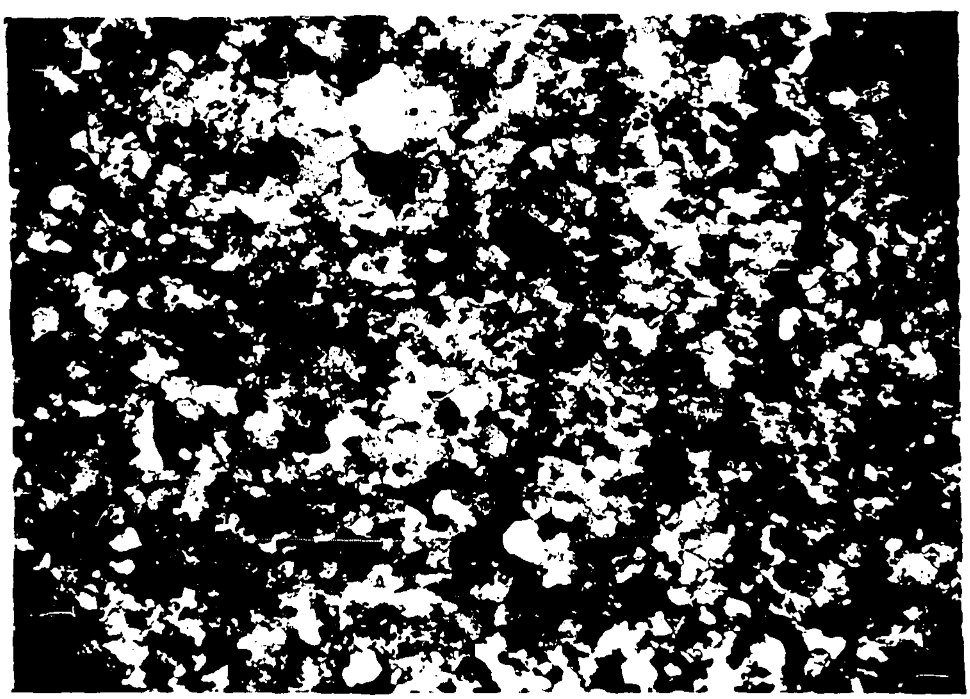


Fig. 2 Coarse grained granitic dyke rock. (X - 25).

TABLE 15

Aplitic Dykes

Specimen No.	2	44	18
SiO_2	73.90	77.90	74.00
Al_2O_3	14.60	15.22	13.00
Fe_2O_3	1.86	0.44	2.30
FeO	0.05	-	-
MgO	-	0.22	0.33
CaO	0.57	0.08	0.44
Na_2O	3.97	3.93	3.63
K_2O	5.20	3.92	4.30
H_2O	0.17	0.26	0.42
TiO_2	0.11	0.03	0.16
P_2O_5	0.01	-	0.03
MnO	0.01	-	-
CO_2	-	-	-
Total %	100.45	102.00	98.61

TABLE 16

Normative Minerals for Aplitic Dykes

Specimen No.	2.	44	18
Qtz.	29.72	39.20	33.28
Ort.	30.73	23.17	25.41
Ab.	33.52	33.25	30.71
An.	2.76	0.40	1.99
Cor.	1.43	4.36	1.64
CaCpx.	-	-	-
MgCpx.	-	-	-
FeCpx.	-	-	-
Ens.	-	0.55	0.82
Feros.	-	0.76	3.96
Mag.	-	-	-
Hem.	1.86	-	-
Ilm.	0.13	0.06	0.30
Rut.	-	-	-
Ap.	0.02	-	0.07
Cal.	-	-	-
Total	100.28	101.74	98.19

Discussion of chemical data

A survey of all the chemical analyses reveal the following significant data;

(1) In most cases the sodium (Na) content is higher than the potassium (K) content usually by 1%. This relationship is in keeping with the microscopic studies which reveal that the greater part of the feldspar content is soda-rich or antiperthitic in composition.

The higher soda content suggests the possible presence of anorthoclase, the absence of twinning in the feldspar, as well as the biaxial positive figure of the twinned feldspars, eliminate this possibility.

The closeness of the Na - K content is also in keeping with the perthite - antiperthite ratio, the later being greater in most rocks. This closeness indicates that during crystallisation of the feldspars the sodium was at some stages confined to the one feldspar phase and at other times to the 2 feldspar phase. This suggests that crystallisation took place between 600° - 700° C, i.e. close to the top of the 2 feldspar curve in Bowen and Tuttle(1950) equilibrium diagram for the Or - Ab system.

(2) The calcium (Ca) content is directly proportional to the hornblende concentration in the various rock types.

The Ca content is highest in the hornblende syenites and lowest in the dyke rocks.

(3) The iron (Fe) content is highest in the hornblende syenite due to the presence of much magnetite, and a high content of Fe in the hornblende.

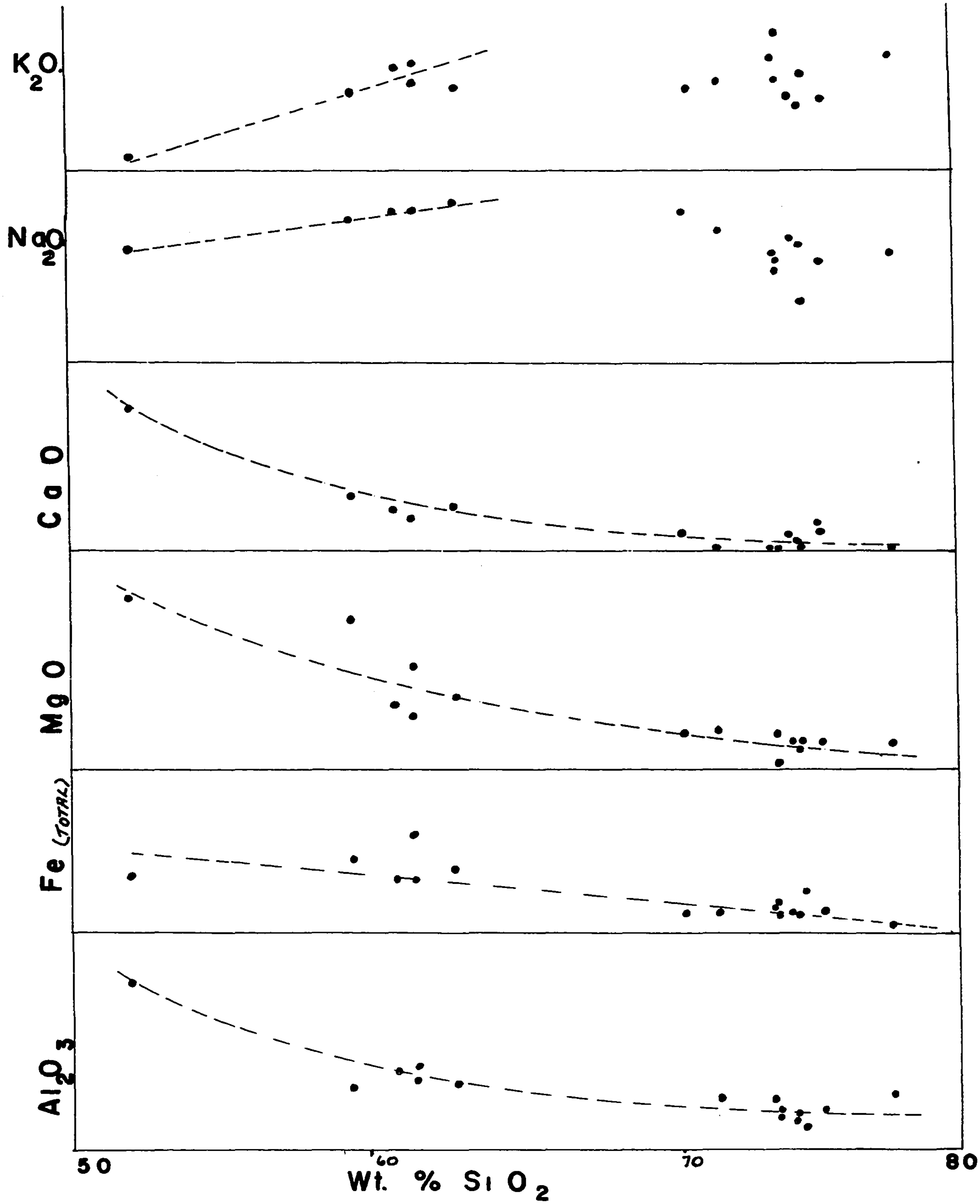


FIG. 15 Variation Diagram of Oxides in RIGAUD Rocks

The variation diagram Fig. 13 showing the plot of oxides against silica percentage reveals three main features:

(1) For all the oxides there are two concentrations of percentages; one (A) at 60 - 65% SiO_2 representing the hornblende syenites and the other (B) at 73 - 76% Silica indicate the differences in the nature of the magma at their times of intrusion.

(2) At (A) both the Na_2O and K_2O concentrations increase with increasing silica content. At (B) although the concentration points are more scattered, both the Na_2O and K_2O concentrations appear to decrease with increasing silica concentration. This agrees with the overall decrease in alkali concentration as seen in the alkali-lime index plot (Fig. 16)

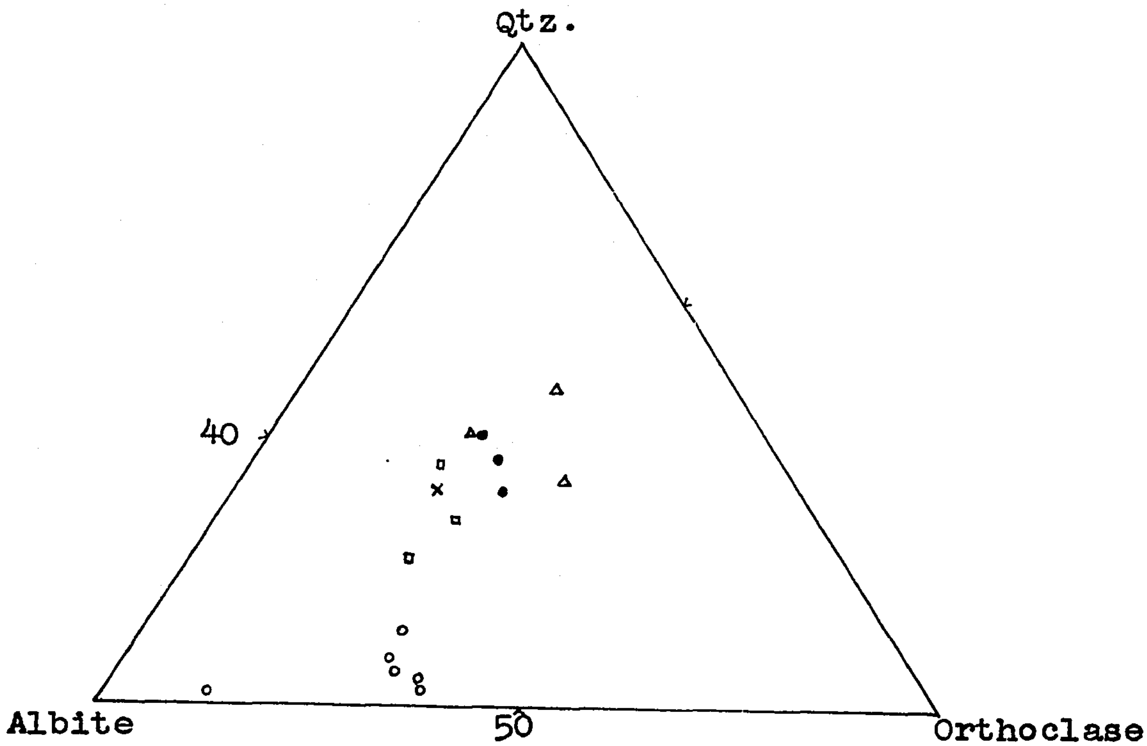


Fig. 14 Variation diagram of Qtz: Alb: Or system

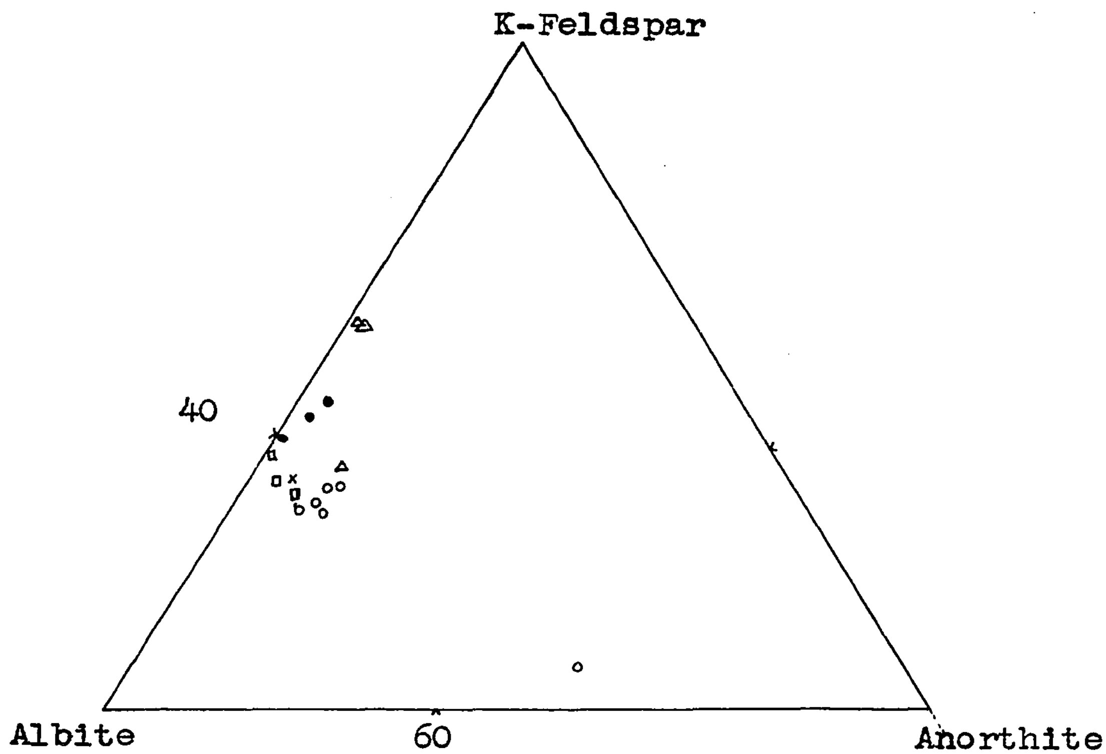


Fig. 15 Variation diagram of the K-Fsp. : Alb : An system

o - syenite ▫ granite • aplitic dyke x qtz. porphyry

▵ - feldspar porphyry

In. Fig. 14 Bowen's "Residua System" the plots of the various rock types from the Rigaud Mountain all fall within the belt of low melting temperatures. Bowen (1928) postulated that if liquids approaching in composition pure alkali - alumina liquids are residual magmas, then their compositions will be related to the belt of minimum melting liquids.

The location of all the plots of the Rigaud syenites, granites, dykes and porphyries within this belt indicates

(1) that the rocks of Rigaud Mountain were formed from a residual magma which resulted from fractional chrystallisation of a parent magma, possibly basaltic.

(2) that the crystal liquid equilbrium was the dominant factor controlling the composition of these rocks.

The plot of the syenites towards the base of the triangular confirms their alkaline trend, while the rhyolitic composition of the dykes is evident from the position of their plots.

In Fig. 15 the K - fspar: Ab: An. variation diagram confirms the alkalinity of all the rocks of Rigaud Mountain.

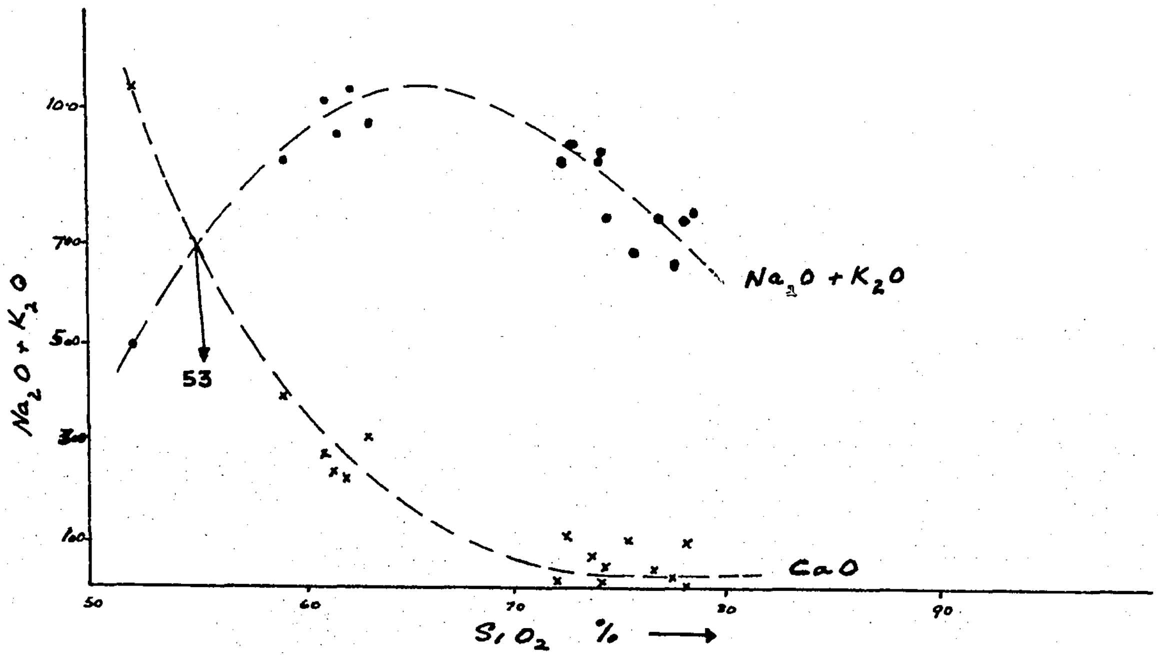


Fig. 16. Variation diagram showing the alkali-lime index for the Rigaud Rocks

The four fold classification for the alkali-lime index (Barth 1952) is :

alkalic < 51% < alkali - calcic < 56% < calc - alkalic < 61% < calcic .

From Fig. 16 the Rigaud rocks are alkali-calcic in composition. This is in keeping with their non-orogenic origin. The figure also reveals the overall decrease in total alkali concentration with increasing silica content.

Deuteric Alterations

The writer will use the term deuteric alteration as does Sederholm, who refers to it in its broader context as " albitization and other metasomatic changes caused by solution given off from the same magma from which the rock itself crystallised, which percolated through the already solid or almost solid but still hot rock ".

Both the syenites and the porphyries show characteristic effects of deuteric alteration. In both rock types extensive albitization has resulted in the following:

(1) The large stubby and club-like form of the albitic exsolutions in the microcline and orthoclase microperthites. The more club-like forms tend to extend inwards from the margin of the crystals. This irregular coarsening of the albitic inclusions is decisively indicative of albitization.

(2) Thin albitic rims of irregular thickness are seen surrounding some of the perthitic crystals.

(3) Small clear albitic grains occur interstitial to the perthites.

The effect of albitization is further emphasized by the development of "injection perthites" in which the albitic inclusions and the interstitial albite grains show optical continuity, both extinguishing at the same time.

Some microline microperthite crystals with characteristic "cross hatched" twinning display biaxial positive figures. It appears that the volume of Na and K-phases varies slightly from one region to the next within individual crystals. This variation results not only in an interference figure bias towards one or other of the components, but also in a range for the 2V measurements.

From the coarseness of the perthitic inclusions the writer suggests that the positive figures result from the addition of secondary albite to the microcline. Some of the antiperthite developed in these syenites appear to be due to deuteric alteration resulting from albitization.

Deuteric alterations due to the introduction of late residual SiO_2 results in the formation of the following features:

(1) Myrmekitic peripheral growth associated with the perthites.

(2) Interstitial quartz grains and stringers ramifying through the perthites.

(3) Corroded quartz phenocrysts especially in the quartz porphyries.

Extensive sericitic alteration of the feldspar inthe porphyry confirms the presence of metasomatic and chemical changes in the rocks. Many of the larger phenocrysts in the porphyry are completely altered to sericite, sometimes with small areas of carbonate alteration.In the porphyries the seritization also affects the matrix resulting in many instances in complete sericitization of the rock.

Very minimal deuteric alteration of the mafics is seen in these syenites. The hornblende is generally fresh but in places it alters to brown biotite. Alteration of the clinopyroxenes to fibrous uralite was not noted in four thin sections. Brown biotite occasionally alters to chlorite and is often replaced by magetite, especially when it occurs in aggregates with hornblende.

Perthitic Textures

In all the rocks of the Riguad mountain microperthitic textures are well developed in the feldspars. All the perthitic forms, string, braid, rod, patchy and vein are displayed in one place or the other. In most of the alkali feldspars rod and string microperthites are the chief form. The average thickness of these perthitic blebs is .1 mm. From the uniformity in size, shape and frequency in distribution of these blebs, as well as their control by the crystal outline, it appears that these microperthites are of exsolution origin. (Alling 1936).

In many of the antiperthites the perthitic form indicates an exsolution origin. The syenites of the Oslo district, Norway, also exhibit exsolution antiperthites. (Barth 1945). These syenites like those at Rigaud are somewhat hypabyssal in nature. The Rigaud exsolution antiperthites support the postulate that exsolution antiperthites are usually associated with near surface crystallising intrusives.

Antiperthites of replacement origin, are seen in the Rigaud syenites and granites. The replacement antiperthites show patch and braid perthitic forms, as compared with the exsolution antiperthites which are usually in the form of rods. The replacement antiperthites are coarser than their exsolution equivalents.

In both perthites and antiperthites the blebs show a preferred orientation within each crystal but for the overall rock the perthitic form is random. Thickening of the blebs especially in the microperthites indicates the effect of albitization.

The extensive development of microperthites in all these rocks indicates that crystallisation temperatures were in the range of 600° to 700° during crystallisation of the perthites. The large size of many of the microperthite crystals indicate that crystallisation progressed slowly during the formation of the perthites. The tardiness of the process is also evident in the sodium to potassium percentages in many of the feldspars. For example microcline with 'tartan' twinning is sometimes found exhibiting biaxial positive interference figures. This is indicative of the extremely high sodium content of the feldspars at that phase of crystallisation.

Significance of porphyritic textures

The feldspar and quartz porphyries as well as the syenites, all three show characteristic porphyritic textures. This textural form assists in explaining the possible mode of intrusion and rate of crystallisation on the Rigaud rocks.

Porphyritic textures are attributed to rapid cooling of a magma after emplacement. (Tuttle 1952). The hypabyssal nature of the Rigaud stock substantiates the idea. This in part explains the porphyritic nature of the Rigaud rocks.

In the feldspar porphyries the large size of euhedral feldspar phenocrysts indicate early slow crystallisation, while the finer grained quartofeldspathic groundmass shows later rapid crystallisation. Therefore the porphyritic textures reflect the fluctuations in the cooling rate within the stock.

STRUCTURAL GEOLOGY

On a regional scale the Rigaud Mountain lies within the Ottawa - Graben of the St. Lawrence Rift system. (Kumarapeli 1968). See Fig. 19

Locally a study of the Paleozoic sediments surrounding the Mountain reveal that the fault which cuts across the northern part of the stock is post Ordivician in age, therefore post intrusive. To the north of the Lowlands a similar east-west trending fault marks the southern limit of the Grenville Province. (Fig 17)

Petrologically the only evidence of deformation seen in the Rigaud rocks are a few bent flakes of biotite in the hornblende syenite. From all available evidence it appears that since its emplacement Rigaud was unaffected by any tectonic activity except for the faulting.

The linear nature of the Raquette River and the rightangular bend present along its course, suggest that faulting may be responsible for the river's present course.

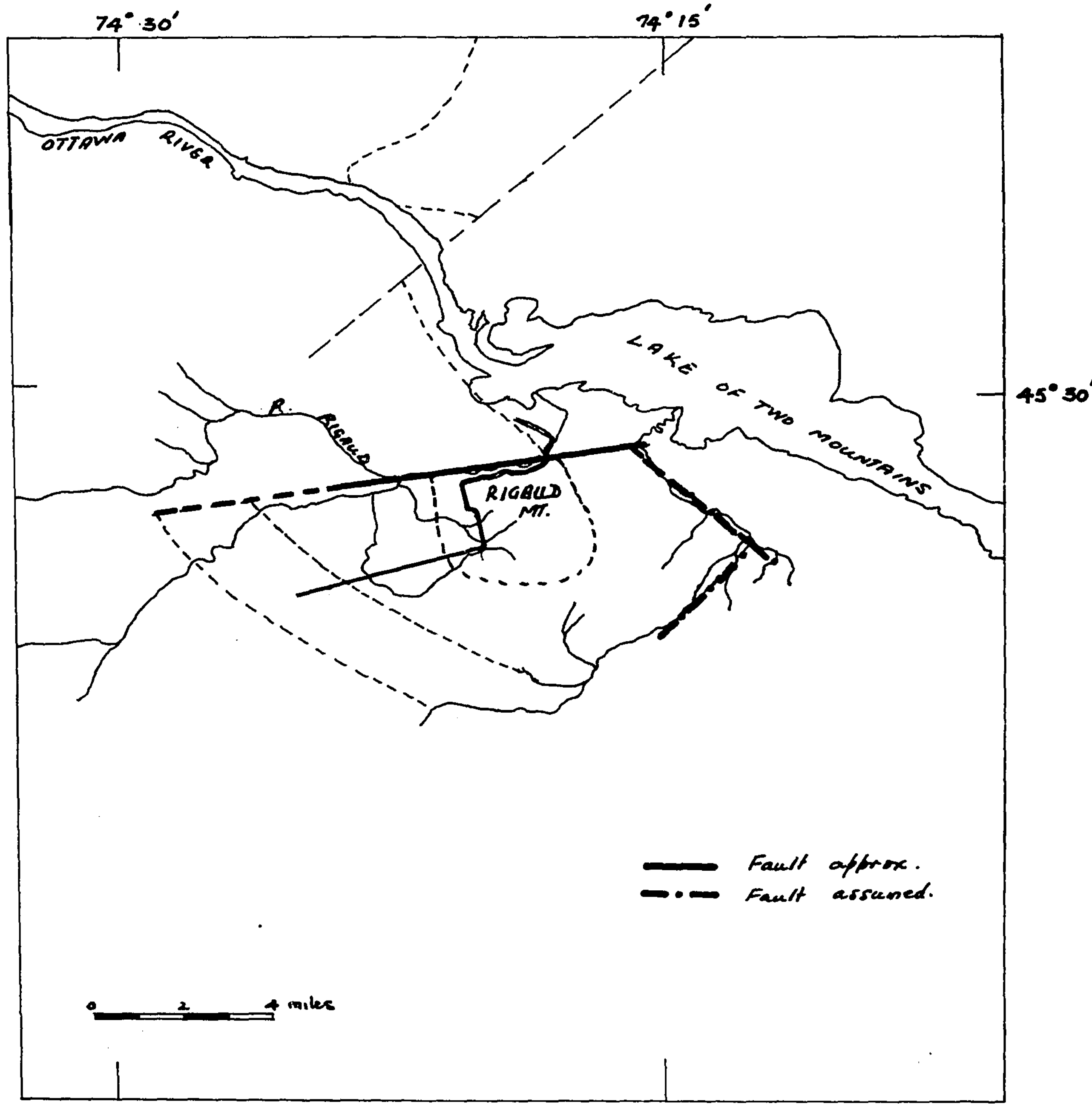


FIG. 17 FAULTING in the area of the RIGAUD MOUNTAIN

PETROGENETIC CONSIDERATIONS

Temperature of Crystallisation

The feldspathic content of all the Rigaud rocks is over 70 percent. The diversity in form and occurrence of these feldspars make them good indicators of the possible temperature of crystallization of these rocks.

The possible range of temperature of crystallisation is defined by the solidus in the ternary feldspar system at zero water pressure, and the temperature of the intersection of the solidus and solvus for the composition concerned at higher pressures. From Bowen and Tuttle's (1952) phase diagram for the $NaAlSi_3O_8$ - $KAlSi_3O_8$ system the lowest temperature on the liquidus at zero water vapour pressure is 1063 ^oC, and feldspars crystallise as single homogeneous phases at water pressures of 200 - 300 bars. With subsequent cooling these homogeneous feldspars may unmix yielding perthitic intergrowths. At 650 - 600 ^oC the feldspars from Rigaud occur both as homogeneous single phase crystals and as perthites.

Therefore the syenites of Rigaud appear to have crystallised under temperature-pressure conditions in the range 1060 ^oC - 650 ^oC, and between zero and 300 bars pressure of water respectively.

The plots of the Rigaud rocks on the upper part of Bowen's Residua system (Fig. 14) show them to be concentrated in the trough area related to the belt of minimum melting liquids. This indicates crystallisation at temperatures of approximately 1020 - 1100 $^{\circ}$C.

The order of Crystallisation

Petrological study of the Rigaud rocks shows the stock to be a typical epizonal intrusive that suffered no metamorphism after consolidation. The term epizone as used by Buddington refers to a depth of 0 - 4 miles. Rigaud according to this zone concept would be regarded as occuring in the upper part of the epizone, and may therefore be classified as a hypabyssal intrusive. (Rosenbusch classification).

The mode of occurrence, holocrystallinity and mineralogy of these rocks provide sufficent criteria to regard them as having cooled relatively slowly. The coarse to medium grained character of the rocks indicate that the various factors influencing crystal growth were well equilibriated. Also the occurrence of hornblende indirectly suggests that the magma contained water and volatiles.

The more direct criteria used to arrive at the possible order of crystallisation in these rocks is as follows:

(1) Where euhedral crystals of one mineral (A) form inclusions in another mineral (B), then mineral

(A) crystallised first.

(2) Where mineral (C) is invaded by mineral (D) which forms embayments or finger-like projections into it, then mineral (C) crystallised before mineral (D).

(3) Where the mineral (E) forms wedges and thin veins filling interstitial spaces between larger crystals, then mineral (E) crystallises later than the larger crystals.

(4) The relationship between soda and potash rich feldspars and perthites is considered.

(5) Evidence of secondary growth of crystals is considered.

The significance of a porphyritic texture is related to the rate of cooling in magmas was also taken into account. By applying these criteria the order of crystallisation in the Rigaud rocks is as follows:

TABLE 17

Order of crystallisation.

1. Accessories
2. Quartz
3. Pyroxene
4. Hornblende
5. Biotite
6. Plagioclase
7. Orthoclase
8. Microcline
9. Hornblende and boitite
10. Quartz
11. Accessories

The accessory minerals zircon, magnetite and apatite were the first to crystallise. They occur as euhedral and subhedral inclusions towards the centre of both the mafics and feldspathic crystals. Augite was the next mineral to begin crystallising, only to be closely followed by green hornblende which in places formed rims around the pyroxene.

Biotite made its first appearance shortly after the hornblende or possibly simultaneously with it as both are found forming aggregates of interlocking crystals. Small subhedral to rounded clear quartz grains occur as inclusionsin these mafics, thereby suggesting an earlier phase of quartz crystallisation.

As the magma continued to cool plagioclase was the next to crystallise. In the quartz feldspar porphyries the matrix consists of a micrographic intergrowth of stubby laths of andesine-oligoclase with quartz, an intergrowth which suggests crystallisation near a eutectic temperature. If this was the case the early phase of quartz crystallisation postulated above seems likely.

The more calcic feldspar (oligoclase-andesine) occurs only as stubby laths entirely confined to the fine grained metrix of the porphyries. The small size of the plagioclase crystals suggest a possible increase in the cooling rate when the plagioclase began crystallising.

The rate of crystallisation then slackened because the albite and orthoclase which were the next minerals to crystallise, formed large euhedral to subhedral grains, some of which contain stubby plagioclase inclusions. Further crystallisation and cooling of these soda and potash-rich feldspars produced perthites which varied according to the magma involved. In the hornblende syenite magma the orthoclase inverted to microcline, while in the later feldspar porphyry and syenite magma which intruded the hornblende syenite the orthoclase show minimal inversion to microcline.

Orthoclase and microcline microperthites as well as antiperthites; all were crystallising out at this stage of cooling. Poikilitic inclusions of quartz, oligoclase-andesine, hornblende, biotite and accessory minerals in the microperthites indicate the products of the earlier phases of crystallisation.

A second and more intense phase of mafic crystallisation followed the formation of the perthites. Hornblende and biotite wedges interstitial to the larger perthitic crystals are indicative of this phase of crystallisation. The writer then postulates the presence of a late silica rich residue melt asociated with crystallisation of the residual magma. There is evidence of intense quartz crystallisation following the mafic phase.

This quartz phase is seen chiefly as large irregular shaped crystals encroaching on perthites or interstitial to them, or as aggregates intermingling with the later mafics. Accompanying this quartz phase was a second phase of accessory mineral crystallisation. In this phase chiefly magnetite, sphene and flourite were produced.

Later deuteric alterations led to the development of uralite, kaolin, sericite and chloride.

Generally the variation in crystal size with the order of crystallisation tends to suggest an initially slowly cooling magma, which rate of cooling increased rapidly immediately after emplacement. Yielding porphyritic textures, eg. (feldspar porphyry), but with time the rate slackened and larger crystals were allowed to develop, eg.

(perthites and late hornblende in the syenites).

The variation further suggests that possibly the magma was initially intruded to a shallow depth. Here drastic temperature - pressure changes induced rapid cooling. With time the factors influencing crystal growth were more equilibriated thereby slowing down the rate of crystallisation.

The loss of volatiles during this readjustment period could explain not only the formation of the miarolitic cavities but also possibly the spongy nature of the perthites as revealed in their poiklitic textures.

The overall mode of crystallisation envisaged by the writer compares well with that postulated for other hypabyssal intrusives.

Order of Intrusion and mode of Emplacement

The units making up the Rigaud stock appear to have been emplaced in a manner which may be most profitably discussed from the field relationship of the various rock types. From the field evidence the order of intrusion is as follows :

Hornblende syenite --- feldspar porphyry -- pink syenite.

The general homogenuity of all the rock types as well as their constant granularity suggest that they are all members of one intrusive phase.

Magma will be used in this report for a liquid with suspended crystals or the liquid alone that is sufficiently mobile to form intrusive bodies or to move without cataclasis. It would best be described as a " magmatic mush".

The hornblende syenite which forms the greater part of the stock contains dykes and irregular inclusions of all the other rock types. This indicates that the syenite magma formed the primary phase of intrusion.

The feldspar porphyry magma intrudes the hornblende syenite, and both are then intruded by the pink syenite magma. The gradation from pink syenite through granite to quartz porphyry is marked only by the steady increase in quartz content. This variation is possible due to a late silica-rich residual melt invading the syenite and altering it in places to granite or quartz porphyry dependent on the quartz content in the region.

The appearance of quartz-rich aplitic dykes and quartz stringers intruding all three rock types also support this postulate. Alterations by the silica-rich liquid were most intense in the northeast where a quartz porphyry was produced, but the effects of the liquid diminished in intensity westwards yielding granites and quartz syenites.

The thin quartz veins and stringers which intrude all the other rock types show their greatest concentration in the northeast. This fact enhances the postulate that the late silica-rich residual melt was introduced in the east.

The Chatham-Grenville area to the northeast of Rigaud contains a similar suite of rocks, and here also the field evidence indicates the order of intrusion to be similar to that postulated for Rigaud. The influence of the silica-rich residual melt is more widespread in the Chatham-Grenville stock. In both stocks bluish grey quartz phenocrysts indicate the presence of abundant quartz.

Since the contact between the intrusion and the surrounding Paleozoic sediments is not seen anywhere in the field, it is impossible to determine the true nature of its mode of emplacement.

From topographic and structural evidence an intrusion along a fault may be postulated. Emplacement could be associated with the fault along the Raquette valley.

Rigaud mountain shows both topographic and petrologic similarity to the syenitic stocks of the Saguenay Valley. These stocks were emplaced by vertical upthrust. (Davies 1968). By analogy it appears possible that Rigaud was also emplaced by vertical upthrust. There is no direct field evidence to support this postulate in the case of Rigaud except for the abrupt changes in elevation and cliff-like boundaries of the mountain especially along the northern boundary.

From the proximity and similarity of the Rigaud and Chatham-Grenville stocks , the writer is led to suggest that Rigaud like Chatham-Grenville is most likely emplaced by vertical upthrust.

The high quartz content and presence of miarolitic cavities suggest very little erosion has affected the emplaced stock.

AGE DETERMINATION ON RIGAUD ROCKS

Age determinations were done on both whole rock (syenite) and pure hornblende crystals from the Rigaud rocks. Potassium - argon determinations were done on 7 samples by Dr. R. Doig. The average of the ages derived from these seven samples is 450 million years.

The results show a standard deviation σ of 17 million years, and a standard deviation in the mean σ_m of 7 million years.

Determinations done on similar syenites and hornblende from the Chatham-Grenville to the northwest of Rigaud yielded similar ages to Rigaud's. The similarity in age suggest that both stocks were emplaced during upper Cambrian to lower Ordovician times.

They may have arisen from the same parent magma at depth. The age similarities add weight to Osborne's postulate that the stocks are genetically related, and may be joined at depth. Aeromagnetic data from the area does not indicate this junction.

The Monteregian rocks are Cretaceous in age. The difference in age between these and the Rigaud rocks confirm that the stocks are not genetically related.

Age determinations on the syenites of the Mutton Bay Pluton yield ages of approximately 600 million years.(Davies 1968). This indicates that the pluton was emplaced at an earlier date than Rigaud. The possibility of a genetical relationship between these two bodies will be discussed later.

ORIGIN OF SYENITES

Rocks of syenitic compositon are relatively rare in nature, but they must have crystallised from a magmatic liquid rich in potash. Either liquid immisibility or gaseuos transfer within a granitic magma could produce such a liquid, but there is lack of petrographic evidence to support either of these postulates as a possible means of obtaining a magmatic potash-rich liquid.

The three main postulates advanced to explain the origin of syenites are as follows :

(1) Processes involving the contamination of a granitic magma by materials which may reduce its silica content.

(2) Differentiation of a basaltic magma by fractional crystallisation as postulated by Bowen (1928).

(3) Partial anatexis of a basaltic magma (Rittmann).

Potash-rich rocks and syenitic bodies in general are often found associated with rift valley systems. eg. The Western Rift of the African Rift Valley System (Bowen 1938). The possibility has to be considered that the Rigaud syenitic stock is associated with the St. Lawerence Rift System.

If this postulate holds , then the Rigaud syenites could represent the late residual melt associated with fractional crystallisation of a basaltic magma. However the very low mafic and high potassium content of the syenites is not in keeping with such an origin.

A more favourable postulate involves anatexis and contamination of possibly the Grenville Basement at depth. This postulate is supported by both the high quartz content of the Rigaud rocks and the absence of any basic rocks associated with the stock.

The possibility of an origin associated with a primary syenitic magma should also be considered.

Relationship of Rigaud to other igneous intrusives in the vicinity of the Ottawa-St. Lawerence Lowlands.

Relationship of Rigaud to the Monteregian Hills

The syenites of the Monteregian Hills are alkali and feldspathoid rich, quartz-poor and associated with basic rocks such as theralites and essexites. The Rigaud syenites on the other hand are quartz-rich, completely feldspathoid free and show no association to any basic rocks. It would require a phenomenal change in the magma's composition if it is to be postulated that both syenites originated from it. The likelihood of such a change taking place is remote.

The above petrological evidence along with the differences in age of the intrusives, substantiates the fact that there is no genetic relationship between the Monteregian Hills and Rigaud Mountain.

Relationship of Rigaud to the Chatham-Grenville stock

The stock showing the greatest similarity to Rigaud is the Chatham-Grenville stock, which lies 13 miles to the northwest of Rigaud. It pierces the Laurentians on three sides, but to the south is unconformably overlain by upper Cambrian sandstones. Like Rigaud it is pierced in the west by a mass of feldspar porphyry.(Osborne 1934).

Megascopically the syenites, granites and quartz porphyries of both stocks show great similarity in colour, texture, granularity and composition. In both intrusives the granites are finer grained than the syenites and grade imperceptively into quartz porphyry. More quartz is visible in the Chatham-Grenville stock than in the Rigaud rocks.

Microscopically the similarity between these two bodies is even more striking with both consisting of oversaturated rocks. The quartz content is higher in the Chatham-Grenville rocks. In both areas antiperthites and microperthites are the chief and most abundant minerals of the syenites. However they show greater diversity in grain size, and alterations in the Chatham-Grenville as compared with their form in the Rigaud rocks.

Albitization in the form of coarser perthitic inclusions and thin albitic margins surrounding microperthitic crystals is evident in both stocks. Widespread kaolinization and sericitization is common to all the feldspars especially in the porphyries. Granophyric intergrowths of quartz and feldspar occur in all the syenites.

Green hornblende occurs more abundantly in the Rigaud syenites than in the Chatham-Grenville. The strong allotriomorphism shown by the hornblende towards feldspar is more commonly displayed in the Rigaud rocks. Hastingsite , a frequent constituent of the granites and syenites of the Chatham-Grenville area , has not been noted in the Rigaud rocks.

Brown biotite, augite and quartz are more frequently encountered in the Chatham-Grenville rocks, but accessory apatite, zircon, sphene, magnetite and allanite show similar concentrations in both stocks.

One prominent difference in these two stocks is the absence of miarolitic cavities in the Chatham-Grenville rocks. If these cavities were ever present here, movement during the crystallisation of the mass of the Chatham-Grenville could possibly have destroyed them, or the stock may have crystallised at a depth where temperature-pressure conditions were not conducive to the formation of these cavities.

The petrographic similarity of the areas may be considered further by means of a cross section (Fig. 18) extending from Rigaud Mountain northwestwards across the Paleozoic plains to the Chatham-Grenville stock.

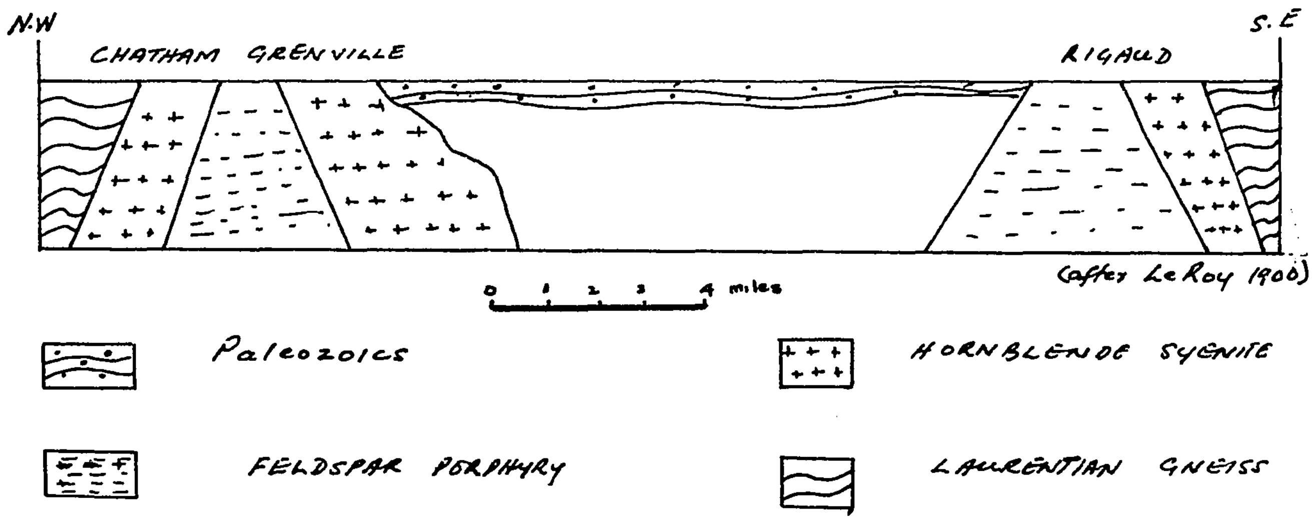


Fig. 18 Cross section from Rigaud Mountain northwestwards to the Chatham-Grenville stock.

The section implies that the two masses are continuous under the Paleozoic cover.(LeRoy 1900). This relationship would place both Rigaud and the Chatham-Grenville on the periphery of the Grenville Province, a position occupied by other syenitic stocks associated with similar granitic gneissic bodies. F.F.Grout mapped six such syenitic bodies in the vicinity of the Vermillion Granite.

If the above association holds true then the intrusion, as in the case of the Chatham-Grenville, took place after the processes responsible for the metamorphism of the Laurentian System had ceased and before the deposition of the Nepean sandstones.

Other Intrusions

Intrusions of similar compositions are found in the PreCambrian rocks of Quebec, particularly close to the folded Timiskaming rocks that extend eastwards from Kirkland Lake. Of these, one that bears close resemblance to Rigaud is that in the Beauchastel Township about 12 miles west of Rouyn, Quebec. This stock was described by Gunning 1927, as being 1½ miles in diameter and consisting of saturated and slightly oversaturated syenites and alkaline mafic minerals.

Syenitic intrusins are sometimes associated with Rift Valley Systems. In the postulated St. Lawerence Rift System four syenitic intrusions have been found. They are

(1) The Rigaud Mountain (2) The Lac-A-La-Croix syenite
(3) The Shipshaw syenite (4) The Mutton Bay Pluton
(See Fig. 19.)

The syenite present in all four intrusions is coarse grained, pink, holocrystalline and mafic rich. Petrographically this similarity is also evident.

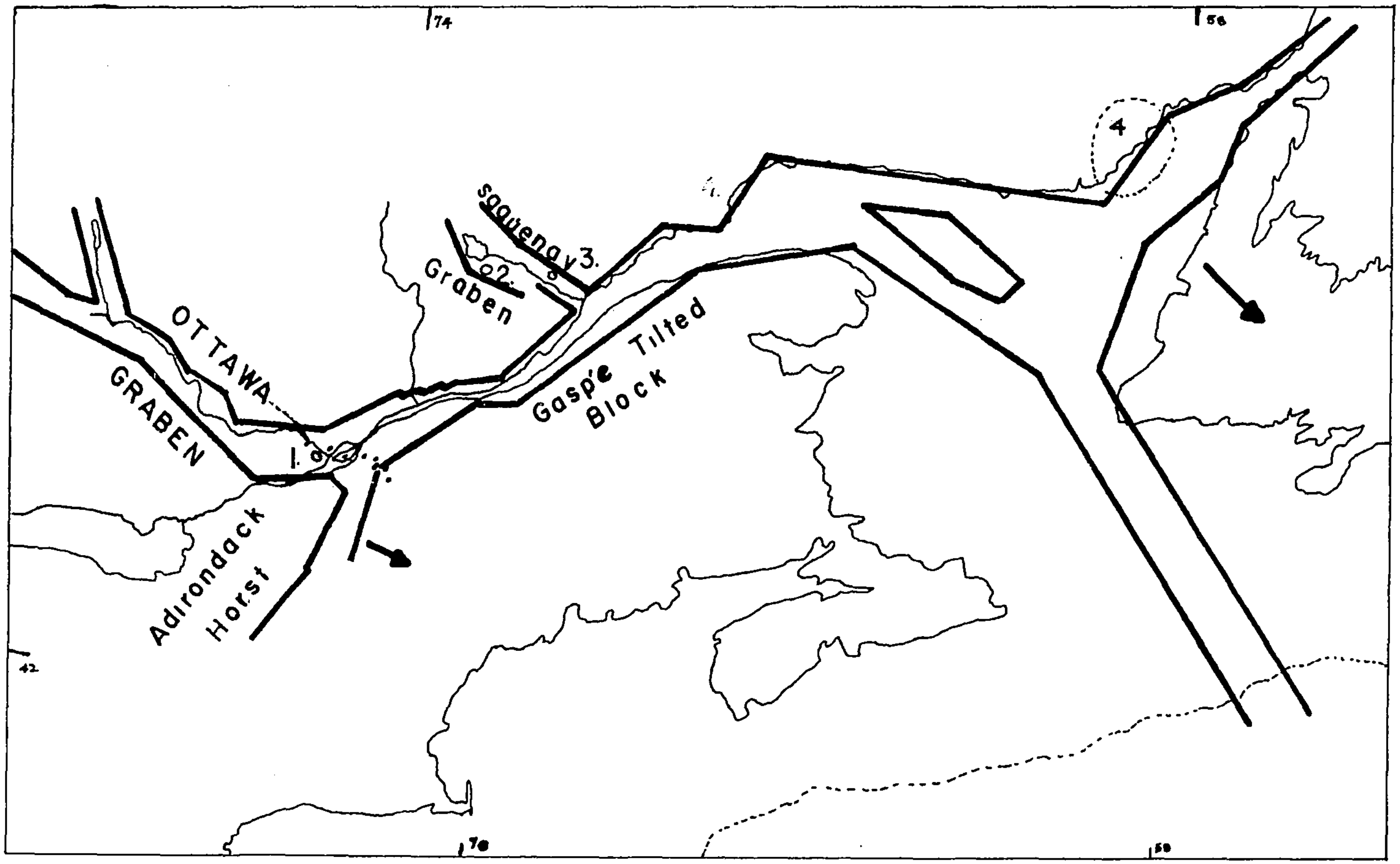


FIG. 19. Rift Zones of the St. Lawrence System (after Kumarapeli, 1968)

1. Riguad Mt. 2. Shipshaw Syenite 3. Lac-A-La-Croix Syenite 4. Mutton Bay Pluton

Aplitic rhyolitic dykes associated with these syenitic bodies show great similarity in size, occurrence and chemical composition from one stock to the next.(Gold et.al 1967).

Both the Mutton Bay Pluton and the Saguenay Valley syenitic bodies have yielded ages of approximately 600 million years. (Davies 1968). This makes them much older than the Rigaud Mountain. However if all four bodies originated from similar type residual magmas, then the higher silica content of the Rigaud rocks may be explained by its being the youngest intrusion, and possibly the least eroded.

CONCLUSIONS

The Rigaud Mountain is a shallow seated syenitic intrusion, which was emplaced by vertical upthrust into the Grenville Basement during late Cambrian to lower Ordivician times. No metamorphic effects associated with its emplacement are seen in the rocks of the stock.

The shallow seated nature of the intrusion is confirmed both by the porphyritic textures of the rocks, as well as by the widespread development of exsolution antiperthitic feldspars. These feldspars are often associated with near surface intrusions eg. the granites in the Oslo Region (Barth 1945).

The presence of miarolitic cavities in the rocks indicate the following :

(1) The high volatile content of the magma.

(2) That the stock has suffered very little erosion since these cavities usually develop close to the upper surface of an intrusive body.

(3) That the upper part of the intrusion is still present.

Petrographic and petrochemical data reveal that all the rocks of the Mountain are more granitic than syenitic in composition, and would therefore more fittingly be classified as syenogranites.

The highly developed perthitic textures and the plots of the rocks on Bowen's Residua System (Fig 14) confirm that the rocks represent a late alkali-rich residual melt which crystallised at temperatures as low as 650 °C.

The parent magma of the Rigaud rocks is either syenitic or granitic in composition rather than basaltic. Evidence favouring this postulate is :

(1) The high quartz content of all the rocks. This could be due to the introduction of a late silica-rich residual melt, or it could represent the late quartz which is usually associated with anatexis and contamination of a magma.

(2) The restricted range of the mafic minerals and their low concentration.

(3) The absence of any basic rocks associated with the intrusion.

From the petrographic and age similarity of the Rigaud Mountain and the Chatham-Grenville stock, it appears that the stocks are genetically related and may have arisen from the same parent magma. Aeromagnetic evidence show them to be separate stocks rather than one continuous body under the Paleozoic, as postulated by LeRoy (1900) Fig. 18.

On a regional scale the Mountain represents a syenitic stock in the graben of the postulated St. Lawrence Rift System. In this respect it is related to the Mutton Bay Pluton and the syenitic stocks of the Saguenay Valley.

The geological map of the Rigaud Mountain Fig. 3 strongly suggests that the intrusion may be a ring complex, the northern half of which is down-thrown and possibly displaced by east-west faulting in the area. Features which support this postulate are :

(1) The general circular form of all the contacts.

(2) The occurrence of the younger quartz-rich intrusive phases towards the centre of the area.

(3) The presence of ring complexes of similar size in the nearby Monteregian Hills. eg. Mt. Johnson.

The widening of the outcrop surface from the younger granite and quartz porphyry to the older hornblende syenite suggests that the intrusion could possibly be slightly cone shaped.

These postulates concerning the shape and form of the Mountain could only be confirmed by extensive drilling in the area of the Mountain.

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APPENDIX

(A) Method used in X-ray Flourescence Spectrometry

The sample is ground to a powder fine enough to pass through a -200 mesh sieve. The powder is then compressed into a circular pellet under approximately 20 lbs. of pressure for 1 minute. The pellet along with a'standard sample pellet' is introduced into the X-ray machine.

The X-rays are recorded as counts. The ratio of the unknown sample counts to the'standard sample'counts is calculated for each element. The result is plotted onto a standard graph from which the percentage of the element in the unknown sample can be read off. The standard graph for each element is prepared from X-ray studies on approved standards.

The ratio method was used since it minimises error due to drift of the machine.

(B) Methods used for Modal Analyses

For the granite and porphyries modal analyses were done on standard 1½ inch. thin sections. Although the phenocrysts in some of the porphyries exceed 5mm. , the aphanitic texture of the groundmass necessitated the use of a thin section counting method.

For the coarse grained syenites a technique for modal analysis of medium and coarse grained rocks (Jackson and Ross 1956) involving a Zip-A-Tone count on a stained slab was used.

Staining for K - Feldspar

Immerse the ½ inch rock slab in concentrated hydrofloric acid at room temperature for 30 seconds. Dip the slab in gently running water to remove the excess acid.

Submerge the slab in sodium cobaltinitrate solution (50gm. in 100 ml. water) for 20 seconds. Rinse slab in gently flowing water, then allow to dry. Protect stained surface with a few coats of clear liquid plastic sprayed on.

K- Feldspar appears bright yellow : plagioclase --chalky white ; quartz -- clear ; and hornblende and biotite -- black.

A 4 inch square stained slab is covered with Zip - A - Tone No. 3. Traverses of 40 counts are then made across the surface. 1000 dot coumts were made on each slab.

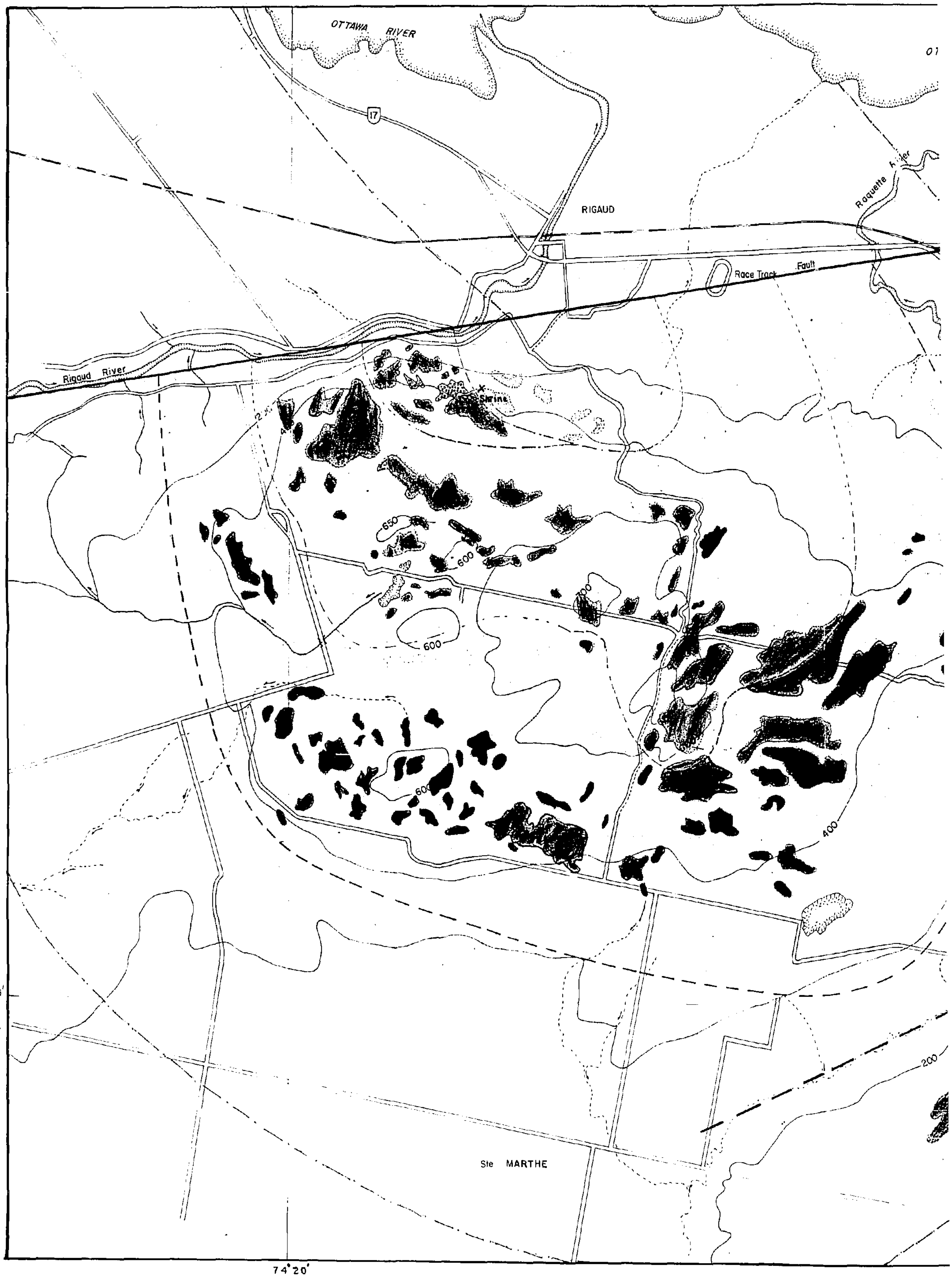
The slab point counting method presents a rapid reasonably accurate modal analyses of these medium to coarse grained rocks.

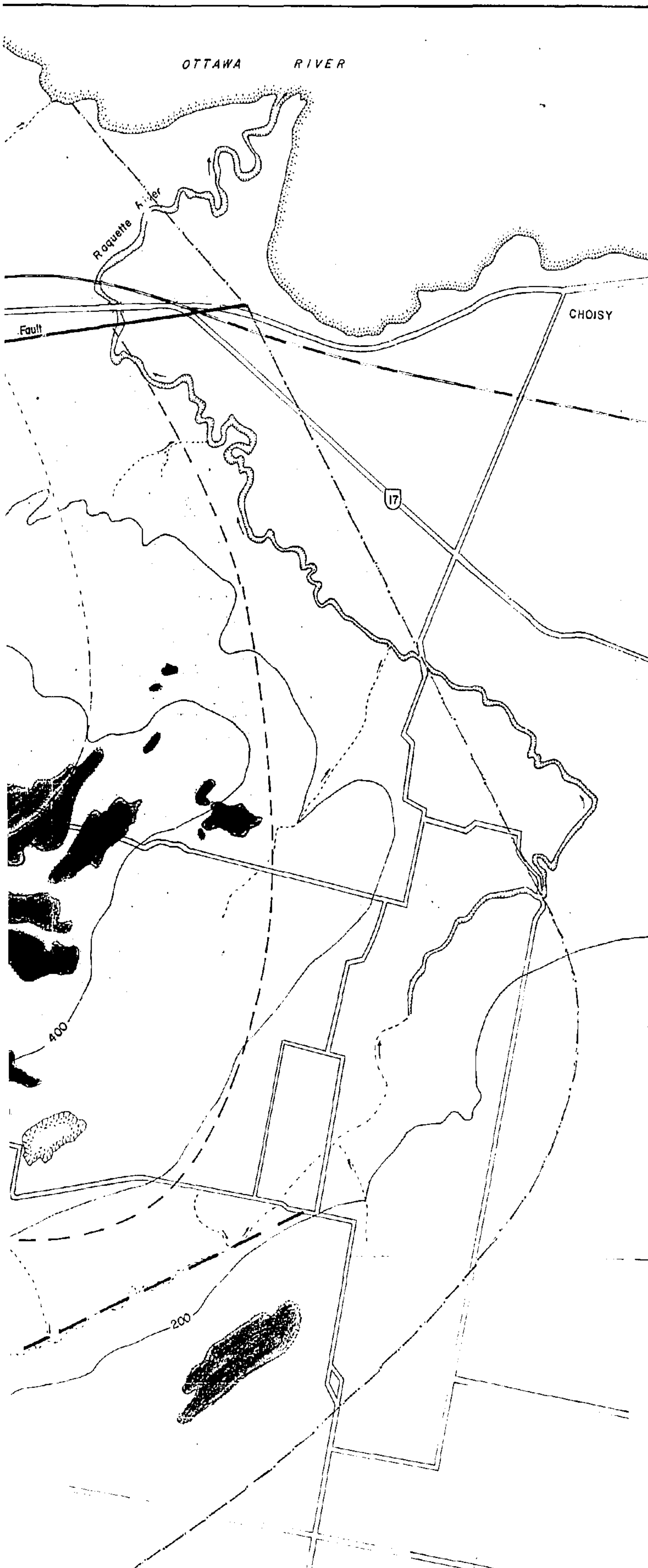
PETROLOGY COLLECTION CATALOGUE

Locality RIGAUD MOUNTAIN Province of Quebec.

Collected By Stanley C. Greig.

Collector's No.	Location	Description	McGill No.
S 1	S. W. corner of Mntn.	Light pink hbld.-rich granite	P 8760
S 3	N.W. of Devil's Garden	Light grey. fine gr. granite	P 8761
S 7	East of the Shrine	Pink. qtz-rich.med. gr. syenite	P8762
S 6	S.W. of Shrine on rd.	Grey. cr. gr. feldspar porphyry	P 8763
S 16	300 yds S.W of the Devil's Garden	Grey.coarse gr. " "	P 8764
S 18	1 mile from west tip of rd. crossing Mntn.	Purplish grey. aphanitic dyke	P 8765
S 26	$\frac{1}{2}$ mile S.W. of Shrine	L.grey. rhy.,aphanitic dyke	P 8766
S 42	$\frac{1}{2}$ mile S.E. of the cross rd. at centre Mt.	Pink cr. gr. hbld. syenite	P 8767
S 44	" " "	L. grey. rhy., aphanitic dyke	P 8768
S 57	$1\frac{1}{2}$ ml.N.W. of St. Marthe.	Purple f.gr., hbld. syenite	P 8769
S 65	Western tip of Mtnt.	L.gr., cr.gr., Feldspar porphyry	P 8770
S 70	N.W. section of Mtnt.	Grey coarse grained hbld. syenite	P 8771
S 71	N.W. tip of mountain	L. pink c.grained " "	P 8772
S 73	N.W. of Devil's Garden	Dark gry. f. gr. quartz phyry.	P 8773
S 74	West of Devil's Garden	Hbld. rich gr. c. grnd. fsp. phyry	P 8774


OTTAWA RIVER
17
RIGAUD
Roquette River
Race Track
Fault
Rigaud River
Shrine
650
600
700
600
600
400
200
25'
Ste MARTHE
74°20'



LEGEND

Heavily drift covered areas

Lower Paleozoic
Sediments
ORDOVICIAN

OXFORD FORMATION. limestone, dolomite.

MARCH FORMATION: Sandstone, dolomite.

CAMBRIAN OR ORDOVICIAN

NEPEAN FORMATION: sandstone.

Intrusives
K/Ar ages from 440 to 485 million years.

Granite and Quartz Porphyry.

Quartz-rich Syenite.

Feldspar Porphyry.

Hornblende Syenite.

PRECAMBRIAN (GRENVILLE)

Gneiss.

Fault approximate.

Fault inferred.

Dykes (2" to 5 ft wide), vertical.

Joints: vertical, dipping steeply

Approx. outline of intrusion.

Geological contact: approximate, assumed.

Boundary of drift covered areas.

Area of outcrop.

Boulder Bed (Devil's Garden).

600 Topographic contour in feet.

0 ½ 1mile

THE GEOLOGY
OF RIGAUD MOUNTAIN

Fig. 3