THE UNIVERSITY OF MANITOBA

PETROLOGY OF THE ELBOW LAKE STOCK
ELBOW LAKE - GRASS RIVER AREA
MANITOBA

A Thesis
Presented to
The Faculty of Graduate Studies and Research
in Partial Fulfilment
of the Requirements for the Degree
Master of Science

by
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May 1967

ABSTRACT

A stock of quartz diorite, intrusive into greenstone, outcrops just south of Elbow Lake, about 40 miles east of Flin Flon, Manitoba.

Field examination established the internal homogeneity of the body, the concentration of inclusions near the contacts and the intrusive character of the contacts.

The distribution of joints, faults and foliation was mapped from the aerial photographs.

A study of thin sections revealed that the texture is hypautomorphic granular, with euhedral plagioclase crystals. This igneous texture is somewhat modified by deuteric alteration.

The main minerals are plagioclase and quartz, which occur in proportions which are roughly that of quartz - plagioclase - eutectic.

The variations of mineral compositions show no regular pattern. Deuteric alteration occurs with a concentric layered distribution pattern, with the most altered rocks in the center of the intrusive body.

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CHAPTER I

INTRODUCTION

A granitic intrusive rock outcrops in the Elbow Lake - Grass River area of Northern Manitoba between latitudes 54°42'N 54°49' N, and longitudes 100°49' and 100°58' W, extending from the south side of Elbow Lake in the north to Barb Lake in the south, and from Claw Lake in the east to Grass River on the west. The intrusion is roughly pear shaped in plan (see Figures 1[*] and 2), and is approximately 9 miles long north-south and 8 miles across east-west, covering an area of about 40 square miles.

The intrusion was mapped as "Quartz-eye granite" by Stockwell (1935). Although "quartz-eyes" are a prominent feature, this stock is not a granite by the petrographic definition, so the name "Elbow Lake Stock" is adopted here.

This report is concerned with the Elbow Lake Stock, considered under three major headings: 1) field relationships and megascopic characteristics; (2) textural and microscopic characteristics; and (3) deuteric alteration of the stock.

The first part of the study defined the contact relationships of the Elbow Lake Stock with the country rocks. The study of inclusions showed their abundance in the stock. The textural and microscopic study established a dominant paragenetic sequence of the major minerals and the variations

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[*] Figure 1 is in back pocket

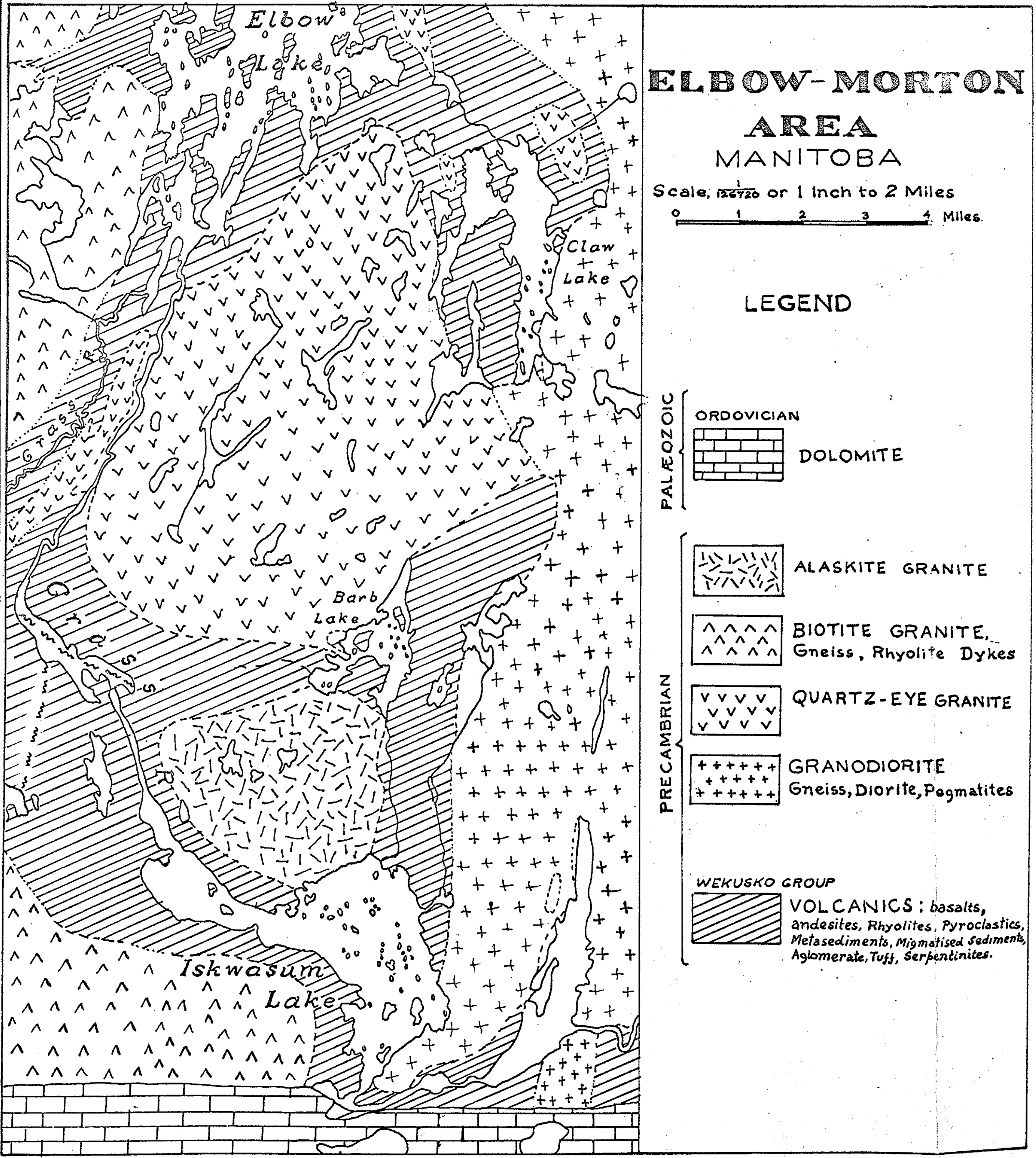


FIGURE-2. GEOLOGICAL MAP OF THE ELBOW LAKE - GRASS RIVER AREA AFTER STOCKWELL (1935) WITH MODIFICATION BY AUTHOR & HUNT (UNPUBLISHED).

in habit of each major mineral. It includes a treatment of plagioclase zoning and twinning and the development of perthite. The study of alteration of major minerals showed a pattern of definite type. The conclusion is that this stock was of magmatic origin and intruded into the greenstone - sedimentary series of the Precambrian Shield.

LOCATION AND ACCESSIBILITY

Elbow Lake - Grass River area is about 38 miles east of Flin Flon and about 90 miles northeast of The Pas (see Figure 1). The Canadian National Railway branch from Cranberry portage to Chisel Lake passes through the Elbow Lake stock. The nearest railway station is Roblaytin, which lies on the western bank of the Grass River. The stock can also be reached by canoe from both Cranberry Portage, down the Grass River, and from Iskwasum Lake, up the Grass River. Iskwasum Lake can be reached by an all weather road from The Pas, which is about 90 miles. There is a good camping ground at Iskwasum Lake. The Grass River flows southward from the Elbow Lake and falls into Iskwasum Lake, with three small portages close to the C.N.R. track.

From Iskwasum Lake, at its northernmost end, there is a foot track of about 4 miles to the Barb Lake.

The quickest mode of access to the area is by aircraft from The Pas.

TOPOGRAPHY AND DRAINAGE

The area has the broad rolling topography of low relief characteristic of much of the Canadian Shield. Within the area, however, two minor divisions can be made in a very general way, viz., the southern half of the area has greater relief than the northern part. The northern part, underlain by the Elbow Lake stock, is generally rather flat with extensive areas of muskeg and swamps. The depressions are overgrown with small spruce, poplar and underbushes whereas the ridges are barren of trees except for small hardy pines. Outcrops are more abundant in the southern part of the area, which is underlain by volcanics and metasedimentary rocks. There the terrain is rugged and rocky with long narrow swampy depressions.

The area is drained by the Grass River. There are a number of small lakes within the area underlain by the Elbow Lake stock. A few small intermittent streams drain them, but lose their identity in a maze of swamps and muskegs. Hills and plateaux of rocks rise beside the main water routes and large lakes.

Glacial striae are preserved on many outcrops, especially on the greenstone, and indicate that the continental ice sheet of Pleistocene time moved south 25 degrees west.

PREVIOUS WORKS

Stockwell (1935) was the first geologist to map the Elbow Lake area of the Northern Manitoba. Prior to Stockwell, exploratory works in the area by Bruce (1918) and Alcock (1920) were done, and gold was discovered at Elbow Lake by Gordon Murray in 1921. Several other gold deposits were found immediately after the original discovery was made, and the deposits were examined by Armstrong (1922) during the following summer. Wright (1930) examined a few of the deposits at Elbow and Morton Lakes.

Prospecting activity was continued in the 1930's and various companies and prospectors were granted lease properties. The Hudson Bay Mining Company was the biggest leassee in the area, and did detailed geological mapping and geophysical exploration works followed by diamond drilling in the area. No detailed geological informations of their works were available to the author. The northern half of Elbow Lake stock is included in the work of McGlynn (1959).

PRESENT WORKS

It was in the summer months of 1965 that a geological survey party was deployed by the Manitoba Mines Branch with Dr. G.H. Hunt as the party-chief, to carry out a detailed geological mapping in the area from the C.N.R. track south to Iskwasum Lake between latitudes 54°35' and 54°45' N, and longitudes 101°0' and 101°45'. The report of the geological mapping has not yet been published.

During the summer months between June and August, 1965, the author studied and mapped the Precambrian rocks of the Grass River - Iskwasum Lake area, Northern Manitoba, while in the employ of the Manitoba Mines Branch. Dr. G. H. Hunt was chief of the field party consisting of seven persons. This is an example of a scheme whereby graduate students in geology in the University of Manitoba could conduct field mapping as a part of post-graduate studies at the Master's level.

During the field season of 1965, traverses were run, where feasible, at intervals of fifteen hundred and two thousand feet. The outcrops were located by pace and compass and on aerial photographs. Detailed mapping and sampling of the Elbow Lake stock was made from the Canadian National Railway track south towards Iskwasum Lake. A few samples were collected from the Elbow Lake stock north of the railway track in one day with a helicopter.

In 1966 the writer undertook the mapping and detailed sampling of this stock, north of the C.N.R. track.

The results of the mapping and the study of aerial photographs were combined with petrographic works, done in the winters, for this thesis.

Approximately 150 samples were collected to obtain representative specimens of the rock types and any variations in them. The locations of the samples are shown in Figure 1.

An excellent cross-section of the stock is exposed in rock cuts along the Canadian National Railway track (see Figures 3 and 4), from the railway milepost 12 to 21. Samples were collected at the interval of 2640 feet approximately, plus additional samples for any local variations. Samples were also collected from both north and south of the railways track by pace and compass traversing.

The hand specimens were studied under binocular microscope. Thin sections were cut for petrographic descriptions. Suites of specimens representative of the contact phases and gradational types were studied.

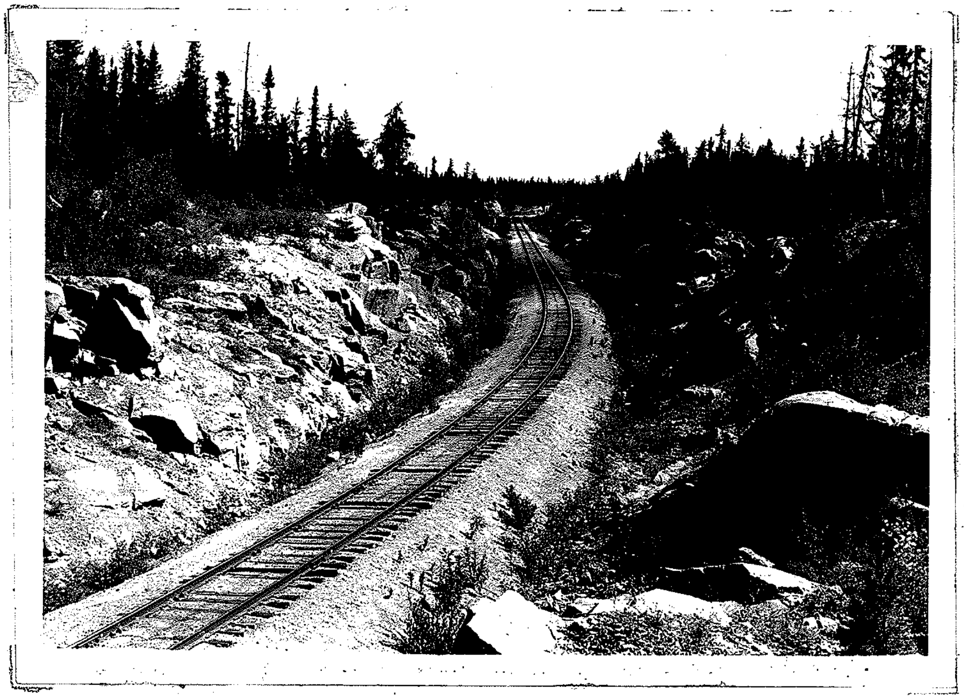
ACKNOWLEDGEMENTS

The author conducted his field studies of the Elbow Lake stock while mapping the Grass River-Iskwasum Lake area for the Manitoba Mines Branch.

The author is indebted to Dr. H.D.B. Wilson, Chairman of the Department of Geology, University of Manitoba, who made the original suggestions of this thesis problem. The writer gratefully acknowledges the help given by Dr. J.F. Davies, Chief Geologist of the Manitoba Mines Branch, who provided the opportunity to do the mapping and sampling of the Elbow Lake stock in 1965. The writer is also indebted to Dr. G. H. Hunt, Party Chief, who conducted the Geological Survey Party of the Manitoba Mines Branch in the area, for most of

FIGURE 3. Outcrop at R.R. Milepost 15 looking east.

FIGURE 4. Outcrop at R.R. milepost 15, looking west, showing well-developed joints.



the field data and valuable guidance in the field.

The writer most gratefully acknowledges the suggestions concerning the petrography by Dr.A.C. Turnock, Professor of Petrology, Department of Geology, University of Manitoba, who acted as adviser during the study and preparation of this thesis.

Thanks are due to Mr. K. Ramlal for doing the chemical analyses of the samples.

Dr. R.B. Ferguson and Dr.W.C. Brisbin provided much useful advice which is gratefully acknowledged.

The writer is very much grateful to Mr. Penner, Traffic Supervisor of the Canadian National Railway, Cranberry Portage, for providing transportation, particularly during the field work in 1966; without his help and co-operation it would have been very difficult.

He who prepares a compilation is in debt to many. My gratitude to many persons for their assistance is not less sincere because the space here available does not permit individual acknowledgements of the debt. To many persons encountered in the field as well as in the laboratory, thanks are due for information and assistance of great variety, and for the good fellowship which always greets the traveller in the bush.

CHAPTER II

GENERAL GEOLOGY OF THE ELBOW LAKE-GRASS RIVER AREA

The general geological setting of the Elbow Lake - Grass River area is a number of east-west trending belts of volcanic and sedimentary rocks with intrusions of massive and gneissic granitic bodies (see Figure 2).

The sedimentary and volcanic rocks are interbedded with one another, and are of the same age. They belong to the Wekusko Group of the Precambrian. The Wekusko volcanic rocks are extensively exposed about Elbow Lake, Claw Lake, Iskwasum Lake and Barb Lake. These rocks were mostly andesitic and basaltic lava flows with minor agglomerates and basic intrusions. They have been metamorphosed to dark green hornblende schists, banded garnetiferous hornblende gneiss, and chlorite schists, talc schists and serpentinites. A few of the andesitic and basaltic flows are porphyritic with phenocrysts of feldspars; others are amygdaloidal or exhibit pillow structure. The Wekusko sediments along the Grass River near Iskwasum Lake and east of Barb Lake are grey and black quartz mica gneiss, schists and quartzites. Beds and gneissic structure strike north-northeast and dip vertically or very steeply.

Several large and small bodies of quartz-diorite and granodiorite, which were mapped as "quartz-eye granite", including the Elbow Lake stock, outcrop in the area. Some contact relationships have been reported which suggest that granodiorite is older than Elbow Lake stock (Stockwell, 1935; Hunt, 1965).

In general the Elbow Lake stock is oval in shape, elongated in a northeast direction. On its western side it has an arm or narrow tongue which is separated from the main body by a thin septum of country rock consisting of diorite and schists.

The aeromagnetic map of the Elbow Lake area (see Figure 5) was of assistance. The quartz-diorite stock is clearly defined as a negative plateau by the magnetic contours surrounded by magnetic highs in the greenstone. The stock-to-greenstone boundary is thereby sharply defined, and is coincident with the boundary as established from the field mapping and aerial photographs. The magnetic pattern is continuous from the main body of the stock into its western extension (or arm) on the west side of the Grass River.

The Precambrian rocks in the Elbow Lake-Grass River area are thus divided into two main groups which are listed in Table 1.

SUMMARY OF THE GEOLOGICAL HISTORY OF THE AREA

The oldest rocks in the Elbow Lake-Grass River area are volcanic and sedimentary rocks of the Wekusko group of the

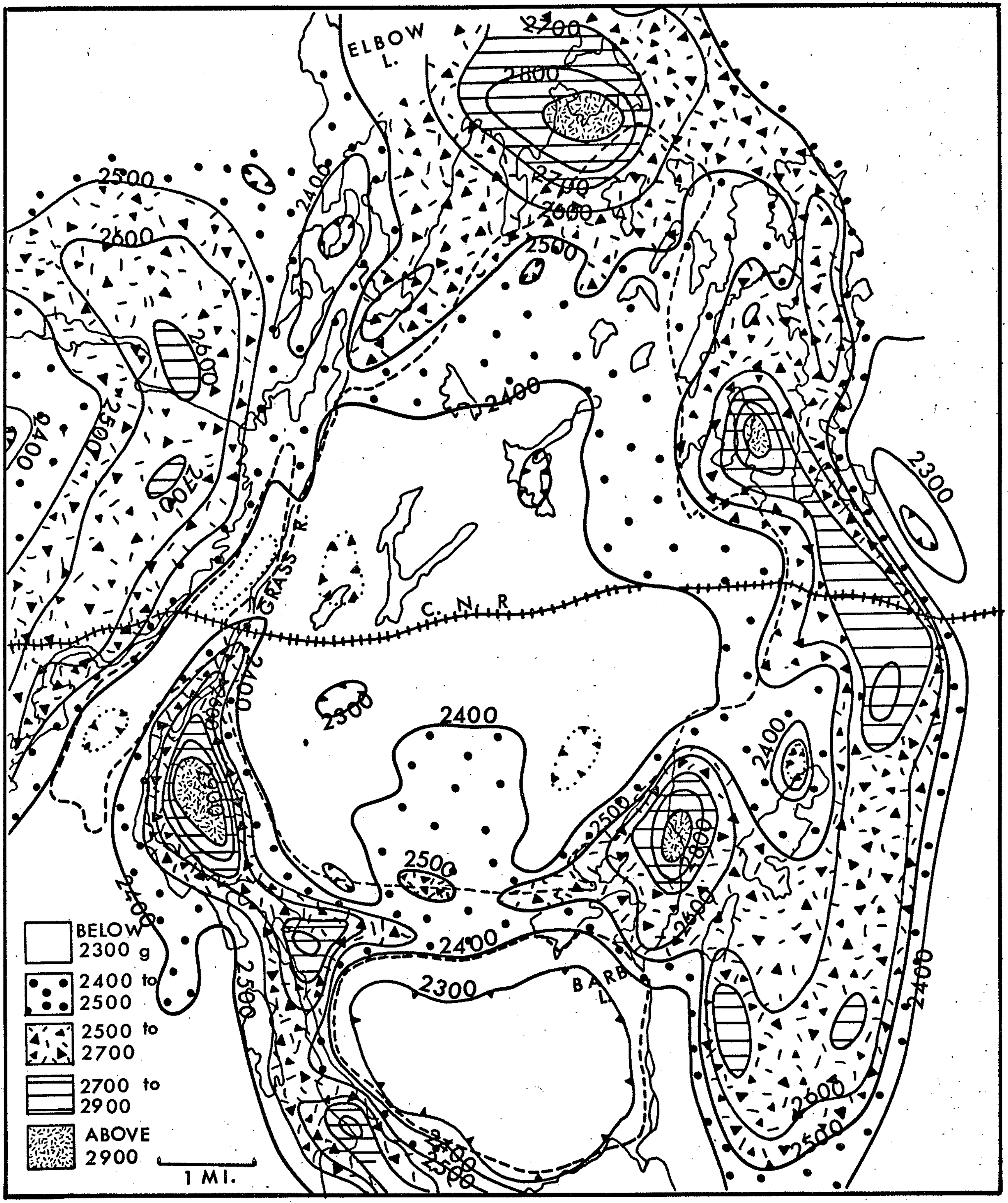


FIGURE 5. AEROMAGNETIC MAP OF ISKWASUM LAKE AREA (REPRODUCED FROM MAP 2461G OF THE DEPARTMENT OF MINES AND NATURAL RESOURCES, MANITOBA).

TABLE - 1

TABLE OF FORMATIONS *

PALEOZOIC	ORDOVICIAN	DOLOMITE, *Argillaceous dolomite, Dolomitic limestone*
UNCONFORMITY		
PRECAMBRIAN	INTRUSIVES	DIABASE, Meta-Gabro, Diorite ALASKITE GRANITE BIOTITE GRANITE, *Gneiss, Rhyolite Dykes* QUARTZ-EYE GRANITE, Biotite granite, Pegmatite, Quartz vein QUARTZ-DIORITE GRANODIORITE, *Gneiss, Diorite, Pegmatites*
	INTRUSIVE CONTACTS	
	WEKUSKO GROUP	SERPENTINITE, *Talc schist, Hematitic rock, Anorthosite, Pyroxenite* PYROCLASTICS, *Crystal tuffs, Agglomerate, tuffs* METASEDIMENTS, *Tuffs, minor volcanics, Migmatized Sediments* VOLCANICS, *Basalts, Andesites, Rhyolites, Pyroclastics, minor Sediments*

* after Stockwell (1935) and Hunt (1965)

Precambrian. The earliest history of the area is a period of volcanic activity. The rocks are largely flows of a type believed to be formed subaqueously, plus tuffs, pyroclastic and agglomerates. The surface upon which these were laid down is not exposed, or if exposed, has not been recognized.

Deposition of all these formations was followed by a period of uplift, erosion and then by folding, faulting, and regional metamorphism. Possibly this did not take place in one great revolution, but in two or more, which accompanied the intrusion of the granitic rocks of the massive batholiths.

During the rest of the Precambrian, and up to the invasion of the Ordovician sea, the area was probably undergoing continuous erosion which finally reduced it to a peneplain of low relief and hummocky character much like that at present found over the Precambrian rocks. The advance of the sea in the Paleozoic era upon this plain removed from it most of the soil which must have covered it, and in the quiet but shallow waters of the Ordovician (Trenton) continental sea, calcareous and magnesian sediments were deposited.

"The volcanic belts therefore, appear to represent Superior 'remnants' within the Churchill Province, and consequently have passed through two orogenies - the Kenoran of the Superior province and Hudsonian of the Churchill" (Davies, 1964, p.663, referring to the Flin Flon-Snow Lake volcanic belt, in which this area lies).

Opinions differ regarding the age of the Elbow Lake stock. The "quartz-eye granites" of the Elbow Lake - Grass River area are lithologically similar to "quartz-eye granite" at Gods Lake, to bodies on Lookout and Missi Islands in Amisk Lake, and to Cliff Lake in the Amisk-Athapapuskow Lake district. Wright (1930) gives evidence that the granite at Gods Lake may be older than Oxford sediments and that the granite on Lookout Island may be older than the Missi sediments. Bruce (1918) considers that it is pre-Missi, Alcock (1922) places it as post-Missi and Wright classified it as pre-Missi. Stockwell (1935) strongly believed that the "quartz-eye granite" in the Elbow-Morton Lake area is older than the Missi sediments. The relationship, however, can not be proved, for these sediments are not known to occur in the Elbow Lake - Grass River area.

CHAPTER III

STRUCTURAL FEATURES OF THE ELBOW LAKE STOCK

The Elbow Lake stock is mostly massive and homogeneous. However, there is some foliation, jointing, faulting and veins of pegmatite and "bull" quartz.

A statistical analysis of lineaments of the stock, drawn from aerial photographs, was made and plotted in a Rose diagram (see Figure 6, in back pocket). Two sets of lineaments are prominent, the most predominent one between 30 and 40 degrees azimuth, whereas the other prominent set is between 290 and 310 degrees azimuth. Joints which are actually observed in the field are plotted in Figure 7 (in back pocket). The contoured stereogram of poles of joints in Figure 7 shows that there is a prominent joint set at strike 35°, dip vertical, and another set, not as sharply developed, at strike 323°, dip vertical. The coincidence between the strike of observed joints and lineaments on the aerial photographs indicates that most of the topographic lineaments are caused by joints.

FOLIATION

Foliation is not widespread. A few observations are plotted in Figures 6 and 7. This foliation is marked by parallel alignment of minerals and inclusions. It is most clearly developed within a few hundred feet of the contact zones, and in shear zones. Whenever inclusions are markedly elongated, the enveloping intrusive rock is foliated parallel to the elongation of the inclusions.

Foliation parallel to the contact with the country rock is pronounced near the eastern and southern contacts and is progressively less conspicuously closer to the center of the stock. The foliation is best shown by mafic inclusions, which become progressively less tabular and less abundant with distance from the contacts with the older rocks. Near the contacts with the older rocks the foliation is also shown by orientation of the mafic minerals.

The central part of the stock shows roughly east-west foliation, very weakly developed (see Figure 8).

The most prominent trend of foliation in the country rock is northeast with a steep or vertical dip.

JOINTING

Most prominent structural features of the Elbow Lake stock is the widespread jointing. Jointing is heterogeneous. Close-spaced jointing, largely-spaced jointing and sheeting were found in the stock (see Figures 3,4,9 and 10). They account for most of the lineaments that can be seen in the air photographs.

Two sets of joints at right angles to each other are prominent, they strike N30°E with surfaces steeply

FIGURE 8. Outcrop at R.R. milepost 14 showing weakly developed foliation.

FIGURE 9. Outcrop at R.R. Milepost 15.3 looking north showing widely spaced joints which strikes N30°E and dip steeply to the west.


N

FIGURE 10. Outcrop at R.R. milepost 11 showing contact between stock and greenstone and jointing in the stock and cleavage in the greenstone.


Gr.

dipping towards southeast, and N50°W with steeply or vertically dipping joint surfaces towards southwest. A third set of joints strikes almost east-west with nearly vertical dips.

Two prominent sets of joints were found to be parallel to the foliation. This was particularly noticed at railway mile post 11 and 21, and sample location A-7 and west of Barb Lake and Claw Lake (Figures 8 and 9). Their fracture surfaces are granular and rough. Spacing in joints varies from less than a foot to about 4 feet.

Sheet jointing was also noticed, the joints are broadly undulating and are roughly parallel to the surface of the ground. They divide the rock into flat sheets or into lenticular slabs that lie so that the thick part of one rests upon the thin ends of the two underlying lenses. The vertical spacing of the blocks decreases downward.

The steeply dipping joints of the border region of the intrusive body are not filled by the pegmatite dikes, quartz veins and fissures, which dip into the granite body at an angle between 30 and 50 degrees. These could be classed as marginal fissures, probably caused by local stretching involved in the upthurst of the eruptive masses.

FAULTING

The faults shown in Figure 6 are well developed lineaments, seen on the aerial photographs, and interpreted to be faults. Topographically, they are broad valleys, several miles long, with shearing and deformation in the adjacent rocks. Their continuity across extensive stretches of water, swamp or muskeg is a question of interpretation. Their trend, roughly N50°W, is parallel to the second best developed joint set.

The Grass River follows a fault system in the southern part of the area (see Figure 2). It is the most prominent and well-defined fault in the area. The greenstone rocks are extremely sheared and deformed. This fault branches into two directions - one toward east and the other towards south. This fault does not extend into the Elbow Lake stock. This suggests that these fault systems are pre-intrusive. of the stock.

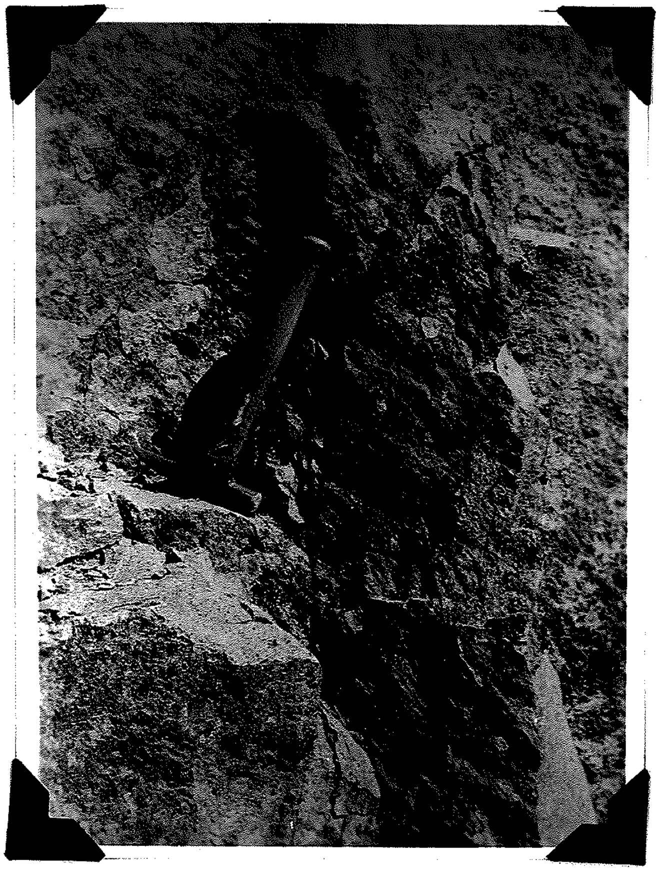
Shearing is very prominent in the central exposure (see Figure 11) of the stock, along the track in rock cuts. The shear planes strike northeast, parallel to the major joint set.

CONTACT RELATIONSHIP

The characteristic feature of the Elbow Lake stock is that it in part cuts across the bedding and cleavage of the adjacent greenstone, and the bedding in the greenstone is warped around the outlines of the stock.

The cross-cutting relationship is well shown at the western side of the stock. At C.N.R. milepost 13, the stock

FIGURE 11. Outcrop at R.R. milepost 15.2 looking north showing shearing in quartz-diorite rocks.



cuts the foliation of the greenstone (see Figure 10). At C.N.R. milepost 13, the contact trends northeast at right angles to the cleavage planes which were apparently developed before the intrusion of the granitic body.

Warping and deformation of the country rock was also found to occur at the western shore of Barb Lake, where the greenstone rocks were warped intensely at the granite contact. Drag-folds of minor intensity with vertical plunge towards northeast are present. But away from the contact, deformation could not be found. Similar evidence of sharp contact occurs in the northwest extremity of the stock. The country rock near the contact is highly warped and drag folds of minor intensity with plunging axes towards northeast is noticed. The granitic contact here is discordant with the general foliation trend of the country rock.

Except in the southern part of the stock, everywhere the contact with the greenstone is sharp. At the southern contact 2 miles west of Barb Lake (sample location, Q-50, Figure 1), the quartz-diorite has intruded the layered country rock to form an interbedded sequence of 200 feet. The layered country rock at this contact is baked but no chilling effect was noticed in the quartz diorite intrusive rock.

DISTRIBUTION OF XENOLITHS

Numerous inclusions of the country rock of irregular shape, ranging from few inches to about one to two feet in diameter were seen in random patches through the stock (see Figures 12 and 13). There are good exposures of xenoliths along the C.N.R. track. They are mostly in random orientation but some are aligned parallel to the major sets of joints in the stock.

The concentration of the xenoliths is greatest in the outer margins of the stock. For example, in the exposures of the western margin near the Grass River and along the southern contacts, there are prominent concentrations of xenoliths.

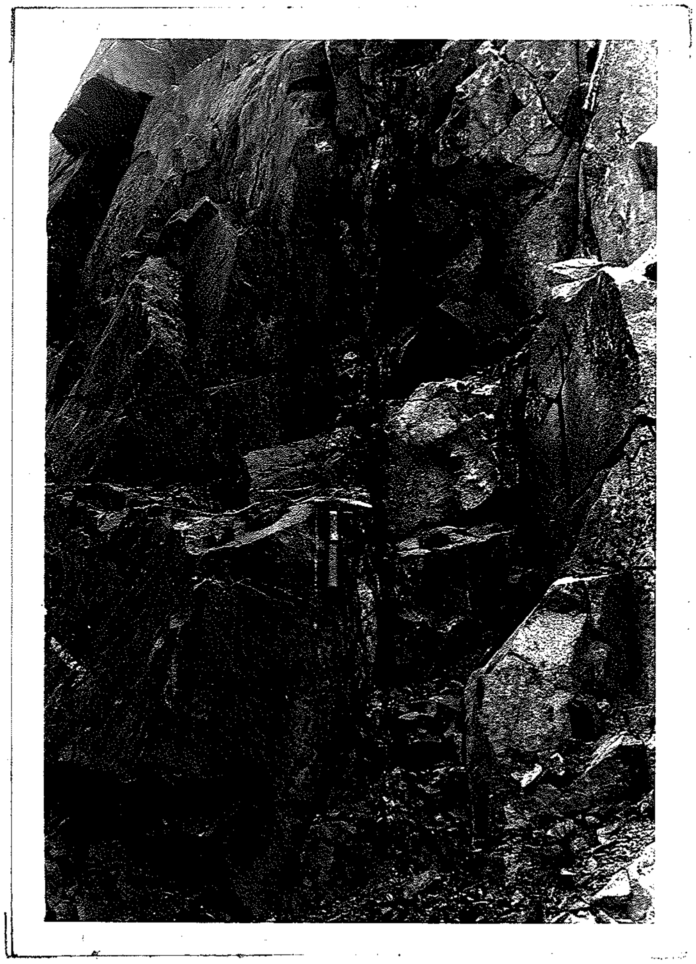
At the eastern margin (C.N.R. milepost 21), there is a contact breccia with angular fragments of greenstone. A small proportion of these inclusions are elongate and these are invariably aligned parallel with any foliation, that may be present in the quartz diorite. Thirty feet from the contact, within the stock, the fragments are rounded and smaller with diameter about 3 or 4 inches.

Most of the inclusions appear to be greenstone which has been recrystallised to a massive or gneissic texture. Petrologically they range in composition from hornblende gneiss or schists to banded metasediments (see Figures 12 and 13). They are fine grained, xenomorphic in texture and composed predominently of hornblende with plagioclase in hornblende gneiss and schists whereas the banded sediments are composed essentially of chlorite.

Xenoliths are lined up parallel to the contact at the

FIGURE 12. Outcrop at R.R. milepost 18.5 showing inclusion of greenstone in the Elbow Lake stock. Looking north.

FIGURE 13. Outcrop at R.R. milepost 13, showing inclusions of sedimentary rocks in the Elbow Lake stock. Looking south.



western bank of Grass River. There are patches of xenoliths some of which are about a foot wide, which have retained the original orientation, that is, they have not been rotated. It is just a pushing aside of the layered greenstone and they may be moved a foot or so.

PEGMATITE DIKES AND QUARTZ VEINS

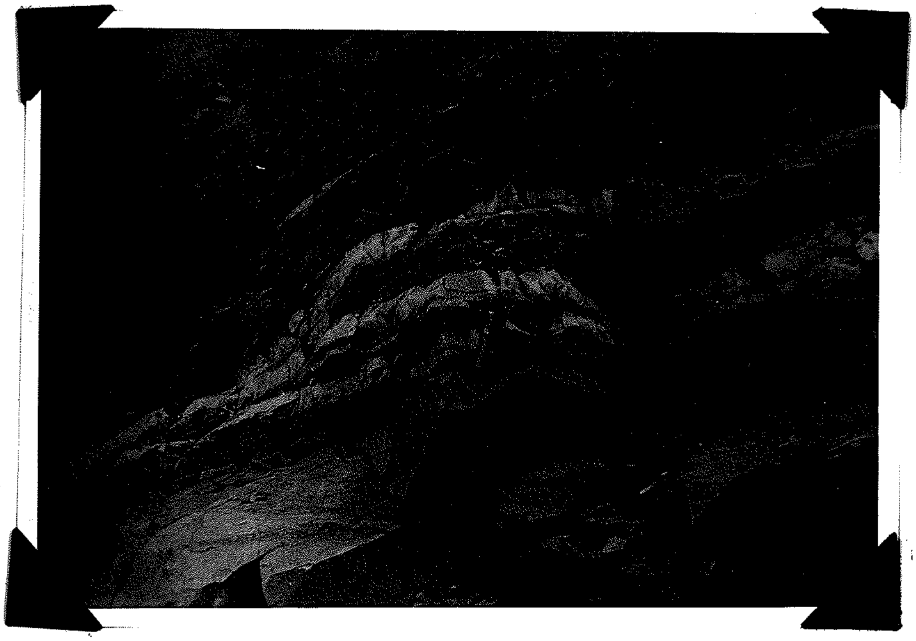
The Elbow Lake stock is cut by pinkish or rose coloured pegmatite dikes and milky white quartz veins. Some fill joint or fracture planes (Figure 14). Some of them cross the contact between the intrusive body and the country rocks (see Figure 15).

Pegmatites, disposed in dikes and crenulate veins, are from 2 inches to about 2 feet wide. Although some have been traced for several hundred feet in areas of good exposure, it is rarely possible to determine their lengths. The dominant trend of the pegmatites is north to northwest, mostly across the general northeast elongation of the stock. They are distributed throughout the area, with no obvious concentration.

The mineral constituents of the pegmatites are predominantly alkali feldspars and quartz. The feldspars are deep pink or rose in colour, coarse grained, grain size ranging from 3 mm to about 5 mm. No accessory minerals were noticed in pegmatites.

FIGURE 14. Outcrop at R.R. milepost 13 showing quartz-vein along joint planes. Looking south.

FIGURE 15. Outcrop at R.R. milepost 14, showing pegmatite veins and inclusions, looking east.



The quartz veins are distributed throughout the area of intrusion with obvious concentration in the central part of it.

The quartz veins range in thickness from half-inch wide stringers, to about one foot. They also occur as patches with sharp contacts. The quartz veins are essentially composed of quartz, very coarse grained, brittle and fractured. Where they are intruded into fragments of greenstone included into the intrusion, they contain sulfide minerals.

The location of quartz veins along the C.N.R. track are plotted in Figure 6.

Many of the quartz veins are aligned in the major joint planes (see Figure 14). However, quartz veins at angles to the major joint planes have been observed.

CHAPTER IV

PETROGRAPHY OF THE ELBOW LAKE STOCK

The Elbow Lake stock is roughly homogeneous, although there are some gradual or irregular variations in texture and mineralogy. The rock is massive or very faintly foliated. It is characterised by distinct "eyes" of quartz and hence the field name as "quartz-eye granite". The "eyes" of quartz are blue or white in colour and are very conspicuous on weathered surfaces. In some areas, particularly in the contact areas, it is more basic and without "quartz-eyes". Plagioclase and quartz are the major minerals, biotite, K-feldspar, hornblende and epidote are minor minerals, and chlorite, muscovite, zoisite, magnetite, sphene and garnet are accessory minerals.

TEXTURE

In general, the texture of the quartz diorite rocks of the Elbow Lake stock is hypautomorphic granular. Grain size is 1 to 4 mm. The average grain size of biotite-rich rocks is greater than the average grain size of hornblende-rich rocks. The grain size is slightly smaller close to the contacts. Rarely, there is an alignment of the plagioclase crystals in a macrotrachytic or flow pattern. This igneous type texture is in part modified by hydration alterations.

Plagioclase occurs usually in euhedral to subhedral crystals, rectangular in outline. Plagioclase crystals are anhedral when in contact with other plagioclase crystals but euhedral where contained in quartz,K-feldspar or biotite. No micro-inclusions of any major minerals are found in the plagioclase crystals. Deuteric alteration of plagioclase crystals obliterates their euhedral shapes.

Quartz occurs both in clusters of anhedral crystals ("eyes") and interstitial to the plagioclase crystals. Quartz may display partial euhedralism where it is in contact with potassium feldspar. It is generally free of inclusions. Alkali feldspars are completely anhedral and interstitial to the plagioclase crystals, in an intersertal and even poikilitic manner (slide #A-17,Figure 16). They are also generally free of micro-inclusions.

Biotite forms independent flakes with ragged edges or fine grained, irregular and discontinuous fringes on hornblende. They are irregularly shaped where in contact with plagioclase,euhedral against quartz, otherwise subhedral. Large crystals contain numerous inclusions of plagioclase crystals (see Figure 17).

Hornblende occurs both as fairly well-developed prisms, also as irregular crystals interstitial between plagioclase crystals. Regular form is favoured by abundant quartz. Micro-inclusions of major minerals are rare. The crystal shapes of both biotite and hornblende are obliterated by deuteric alteration of these mafic minerals to chlorite and epidote.

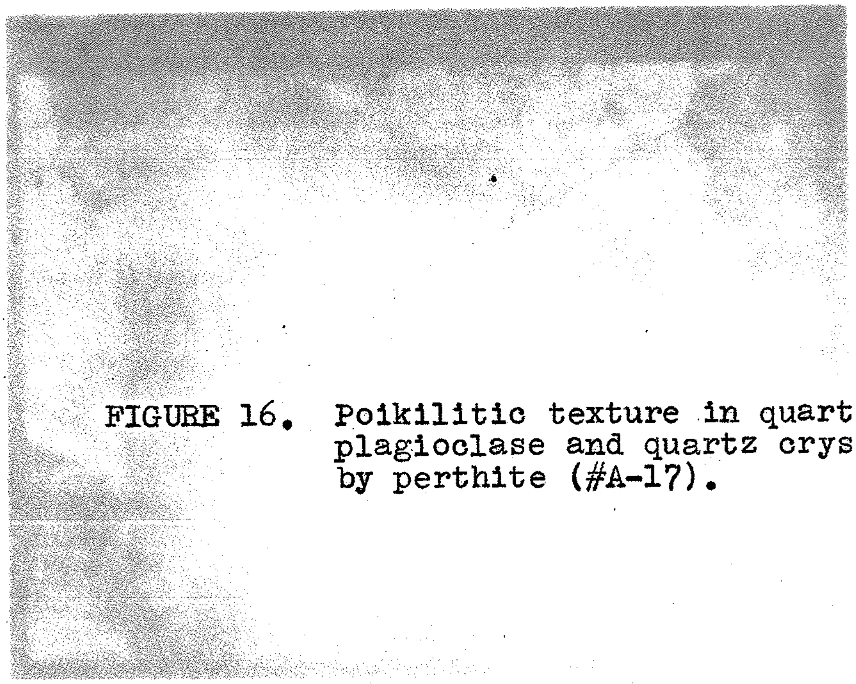


FIGURE 16. Poikilitic texture in quartz-diorite, plagioclase and quartz crystals enclosed by perthite (#A-17).

FIGURE 17. Plagioclase crystals surrounded by large biotite crystals (#A-19).

6 mm.

The mafic minerals tend to cluster into fine grained clots. The mafic mineral is commonly biotite, but may be hornblende or both. The size of the clots corresponds roughly to the average grain size of the rocks, but the grains comprising the clots are arranged in random pattern. They result, in part at least, from the replacement of large hornblende crystals by biotite. The process apparently may result in either one large biotite crystal pseudomorphic after hornblende, or a pseudomorphic clot of small biotite crystals. In some thin sections fine grained biotite is strung out along plagioclase crystal boundaries.

Rarely a cluster of chlorite crystals may have the shape of a pseudomorph after pyroxene (see Figure 18). Epidote appears to form in two ways during the crystallization period. Large euhedral crystals of epidote, interstitial to the plagioclase crystals and between plagioclase and biotite crystals, are interpreted to be primary igneous crystals. Smaller crystals of epidote or zoisite, found within plagioclase crystals in zonally arranged alteration products, are interpreted to be late igneous (deuteric) hydrothermal alteration products. Magnetite, apatite, zircon, sphene are associated intimately with biotite, or in grain boundaries, fracture planes, suggesting their late crystallization.

FIGURE 18. Pseudomorph of chlorite after pyroxene (#A-7).

6 mm.

MINERALOGY

Detailed description of the minerals are in Appendix I.

Modal analyses were made on 55 specimens of the Elbow Lake stock (Table 2,p.51) using a "Swift Automatic Point Counter", manufactured by James Swift & Sons Ltd., London. This was mounted on stage of a microscope. Each analysis was made by traversing thin sections and identifying the mineral at the intersection of the cross-hairs at every point on a grid. A spring stop is mounted on the frame of the stage and adjusted so that each translation of 0.3 mm is signalled to the operator by an easily audible click. A similar arrangement on the rack and pinion which controls the vertical motion of the stage insures equal spacing of the traverse lines; this wheel is calibrated so that each translation is 0.5 mm, and the traverses were systematically spaced 0.5 mm apart. For a ½ by 3/4 inch thin section, there may be 2000 to 3700 points. Small holes in the section may be passed over; but if there are many of them, the counting was stopped and a new traverse begun.

The tabulator will record counts for six constituents and a total of more than six constituents were to be counted in the analysis, so that a complete block of a separate veeder counter was used.

In the first attempt at Rosiwal analysis of these specimens, potash feldspar, plagioclase and quartz were distinguished with difficulty. To facilitate their distinction, a selective potash feldspar stain was applied to the thin sections according to the method of Baily and Stevens (1960). Using this method the author was able to distinguish between quartz, plagioclase and potash feldspars. As a consequence, the time consumed in making Rosiwal analyses is much reduced. The method followed by the author is shown in Appendix II.

Quartz, plagioclase, potash feldspars (orthoclase, microcline and perthite are lumped together), biotite, hornblende, epidote (both primary and secondary epidotes are lumped together), opaque minerals were counted separately, whereas the other constituents were lumped together.

Minerals which had altered from the primary minerals (e.g. chlorite from biotite, sericite and zoisite from plagioclase, and epidote from biotite and plagioclase) were counted as the original mineral.

All specimens but one contained more than 80 percent of quartz + plagioclase + potash feldspar. In general, these rocks are characterised by a high content of plagioclase and quartz and low content of potash feldspar, so they are quartz diorites (tonalite).

PLAGIOCLASE CONTENT

Plagioclase feldspar is the most abundant mineral in the Elbow Lake stock. The modal average is 58 volume percent, ranging from 35 to 66 percent. Only one of the specimens contains less than 40 percent plagioclase, and in this rock much of the plagioclase has been destroyed by alteration beyond recognition.

Figure 19 shows the distribution in the amount (volume percent) of plagioclase in the stock. The distribution seems to be aligned linearly with the elongation of the stock. The high concentration zone in the center appears to be closely parallel to the elongation of the stock. The concentration decreases towards southeast, forming a small low concentration, and then increases again at the contact region.

QUARTZ CONTENT

In the 55 modes in Table 2, the average quartz content is 23.8 percent, the range is from 8 percent to 39 percent. One specimen that contains 8.2 percent quartz is at the contact zone and it is possible that it is more basic because of contamination.

The contents as determined by Rosiwal analyses are plotted and contoured (see Figure 20). These contour lines show a general northeast-southwest trend, with some slight tendency to concentric closure at the northern and southern ends. There are two unconnected "highs" on the western side, both more than half a mile inside the boundary. There is an elongated "high" in the southeast, which has a trend parallel to the boundary and lies about a mile inside of it.

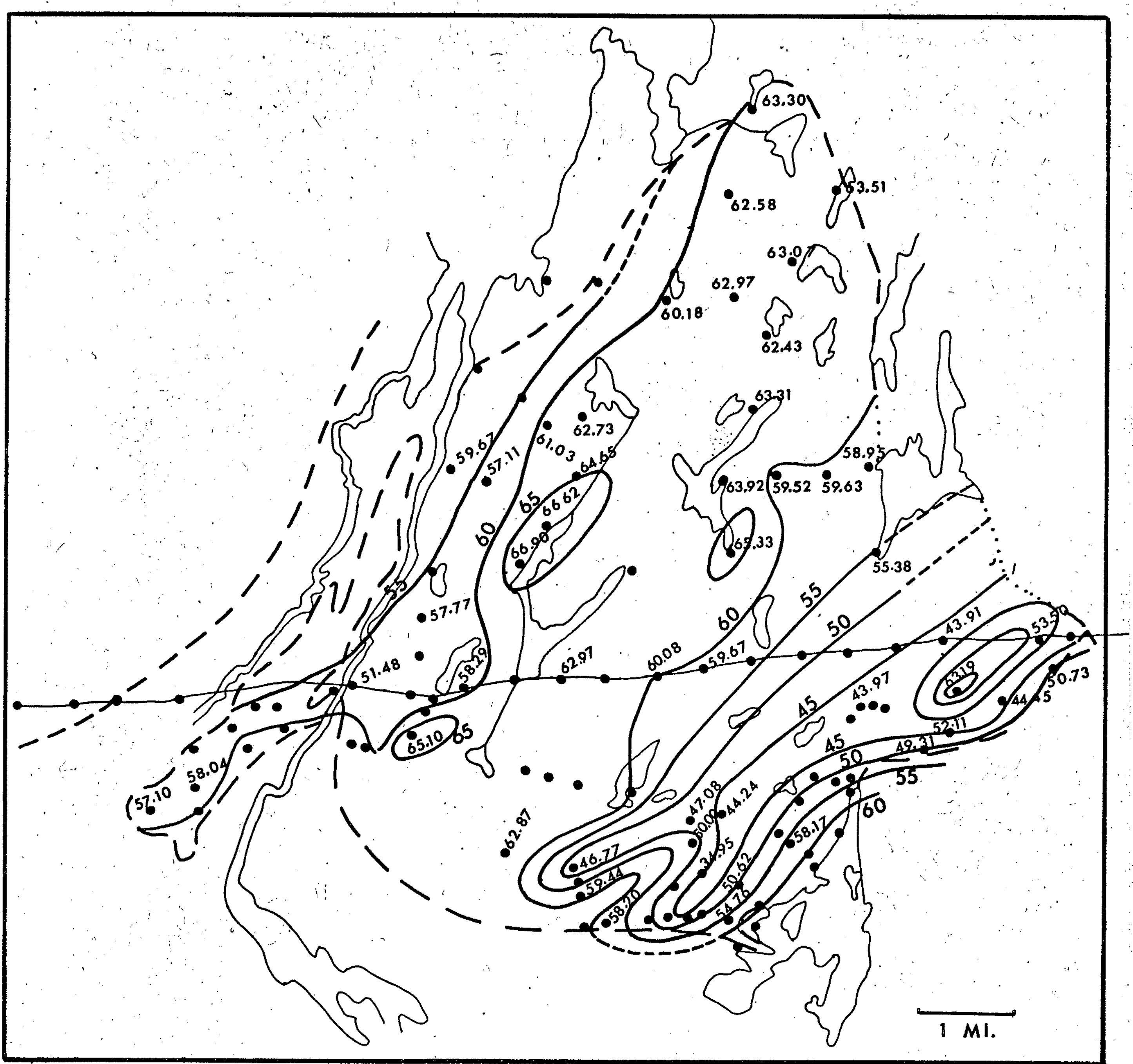


FIGURE 19. CONTOUR DIAGRAM SHOWING THE DISTRIBUTION IN THE AMOUNT (VOLUME PERCENT) OF PLAGIOCLASE FELDSPAR.

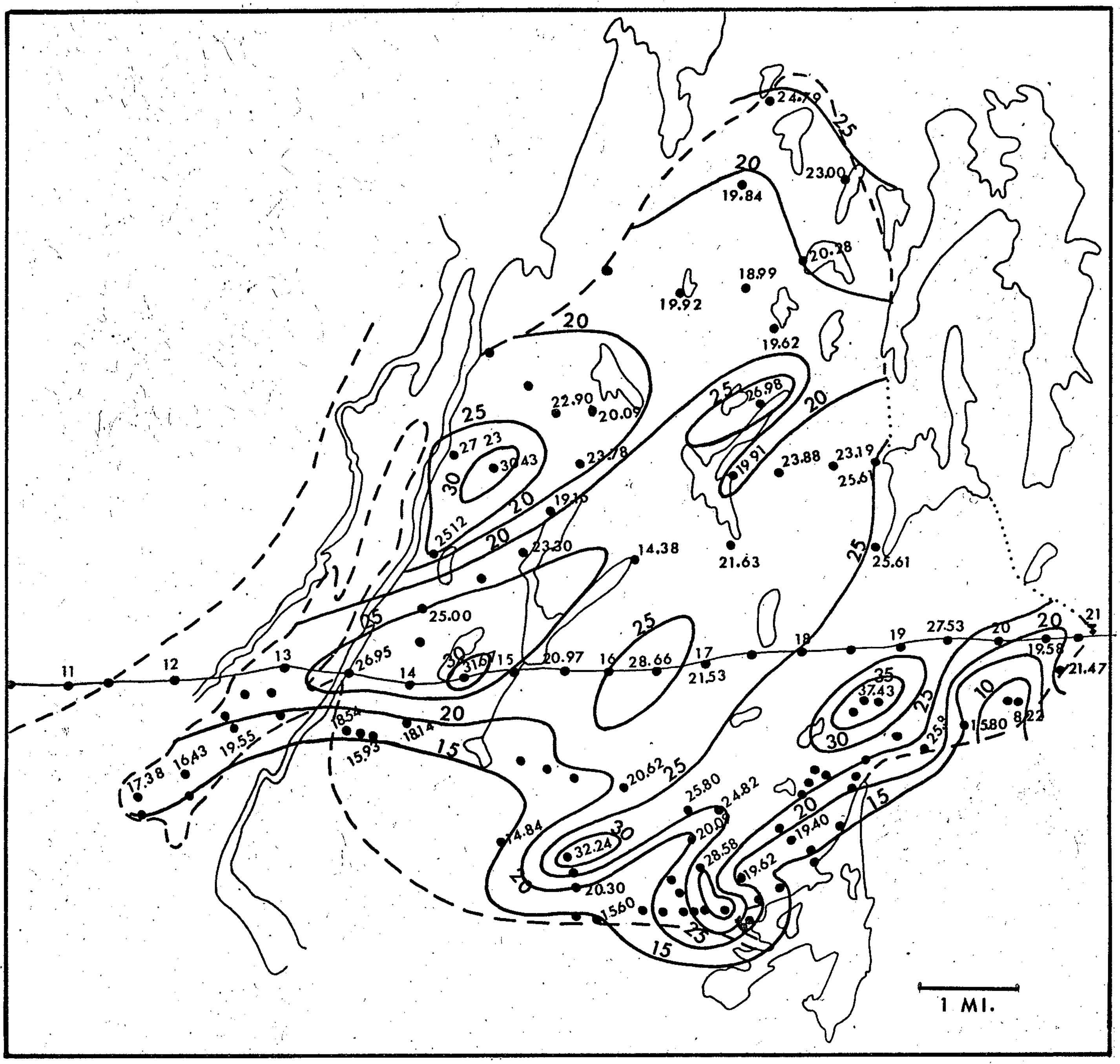


FIGURE 20. CONTOUR DIAGRAM SHOWING DISTRIBUTION IN THE AMOUNT (VOLUME PERCENT) OF QUARTZ.

POTASH FELDSPAR CONTENT

Potash feldspar including perthite averages 1.06 percent, and ranges from 14.0 to 0.0 percent. It varies inversely with the plagioclase content.

In the distribution of potash feldspar (see Figure 21) it appears that there is concentric high and low concentration of potash feldspar south of the C.N.R. tracks, the central part being a low concentration. Potash feldspar shows a high concentration in the southwestern arm of the stock. North of the C.N.R. track, the distribution shows no definite pattern.

MAFIC CONTENT

Biotite is the most predominant mafic mineral, with an average of 9 volume percent of total constituents of the rocks and a range from 1 to 16 percent.

The average mafic content (colour index) is 12 volume percent. There is no definite pattern in the distribution of the amount of the mafic minerals (see Figure 22), except for higher concentrations at the contact with the country rock.

QUARTZ-PLAGIOCLASE-POTASH FELDSPAR DIAGRAM

Figure 23 shows that 69 percent of specimens have compositions which plot on the quartz-plagioclase sideline, another 23 percent have less than 2 percent K-feldspar, only 8 percent have 2 to 5 percent potash feldspar.

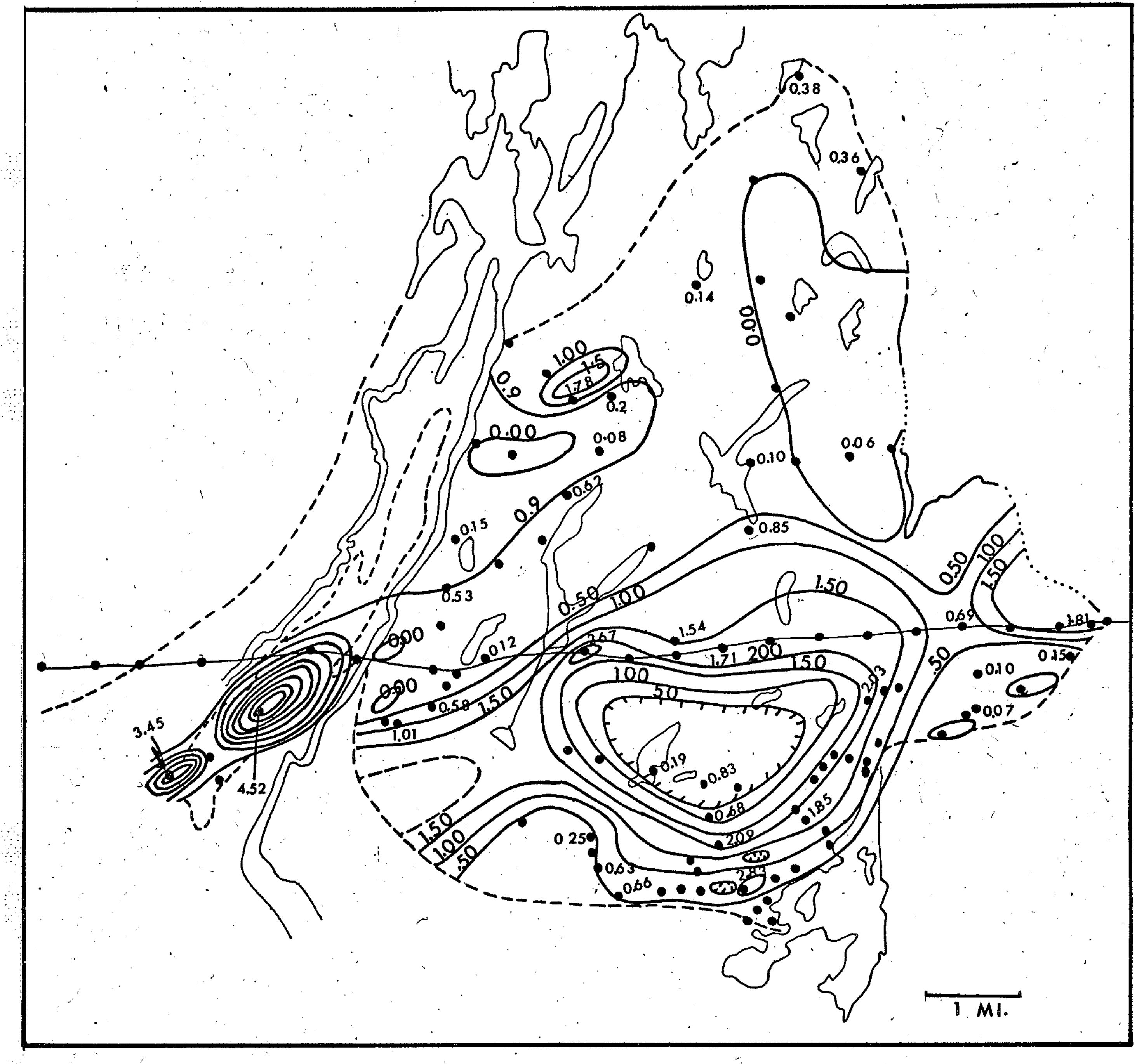


FIGURE 21. CONTOUR DIAGRAM SHOWING THE DISTRIBUTION IN THE AMOUNT (VOLUME PERCENT) OF POTASH FELDSPAR.

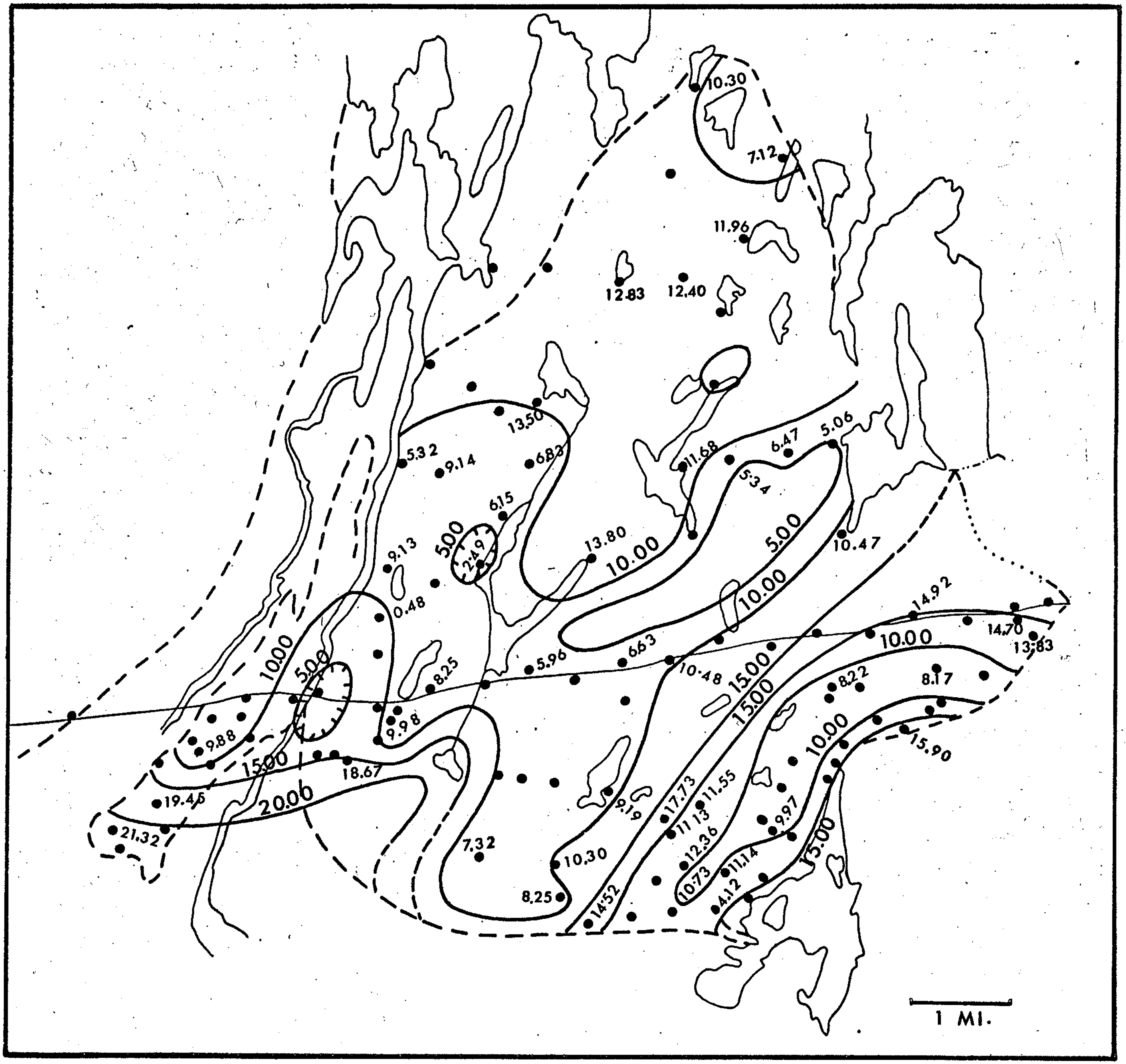


FIGURE 22. CONTOUR DIAGRAM SHOWING DISTRIBUTION IN THE AMOUNT (VOLUME PERCENT) OF MAFIC MINERALS.

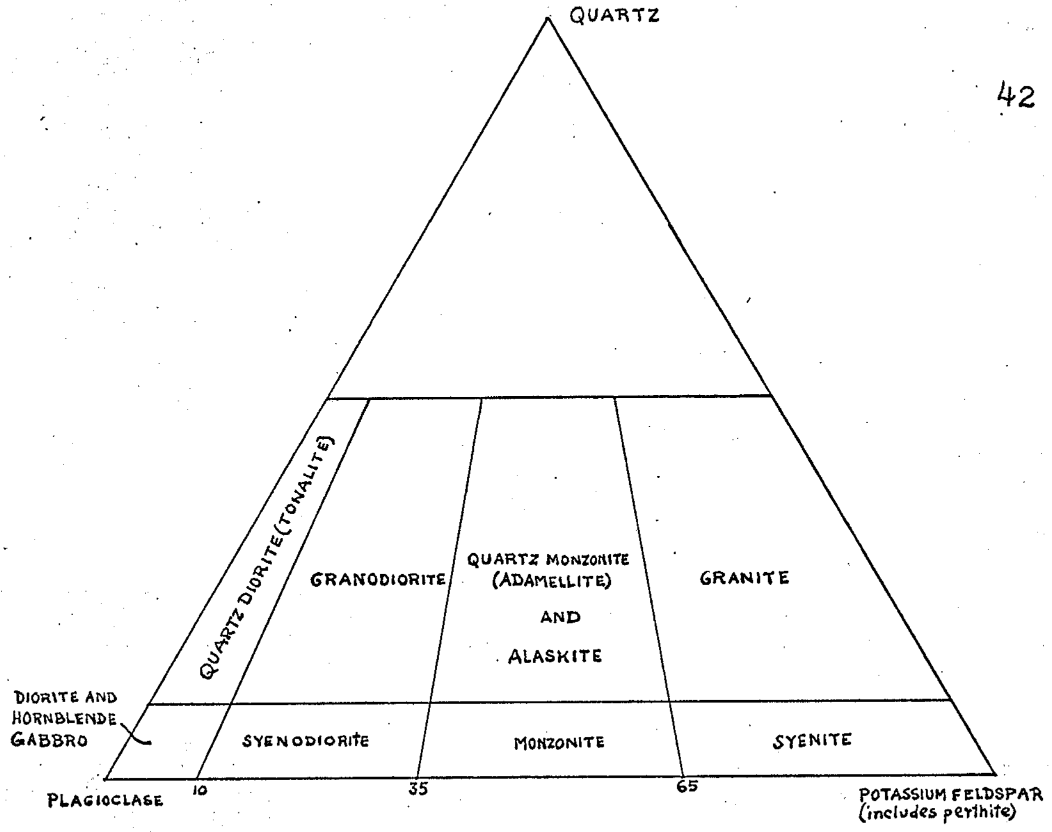


FIGURE 24 CLASSIFICATION SYSTEM FOR GRANITIC ROCKS AFTER BATEMAN (1960).

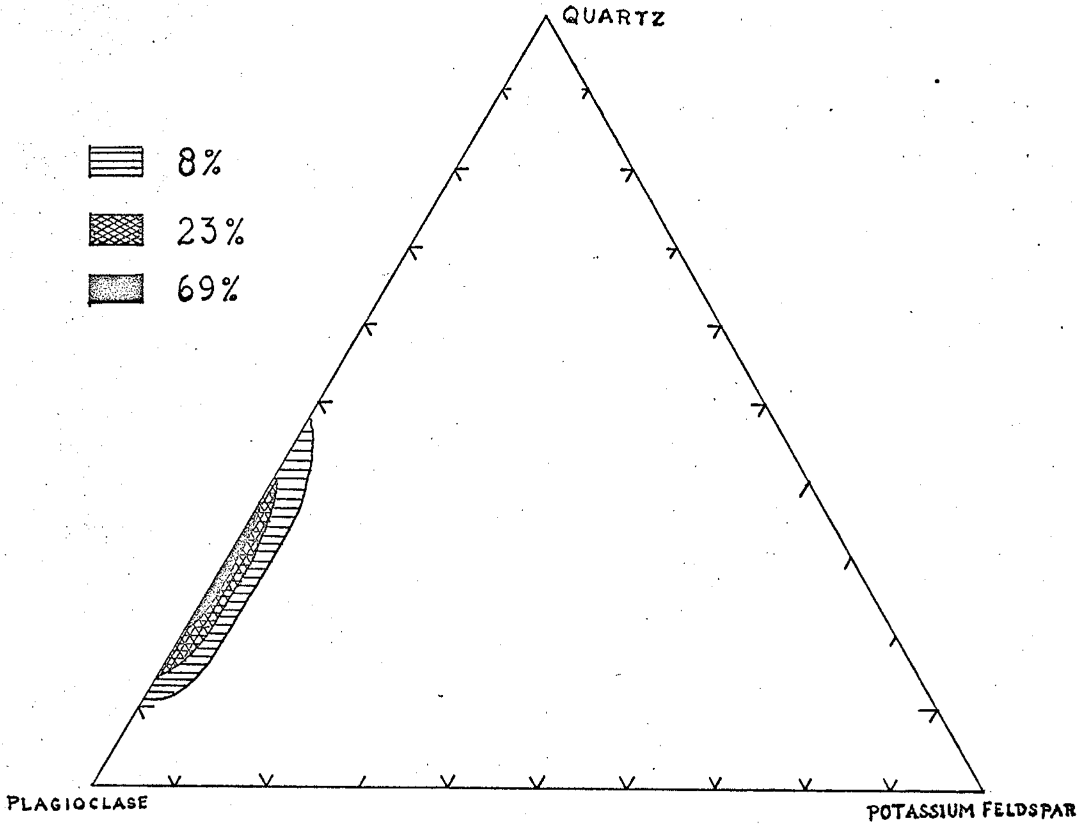


FIGURE 23 TRIANGULAR VARIATION DIAGRAM OF QUARTZ-PLAGIOCLASE-K-FELDSPAR OF ELBOW LAKE STOCK.

According to Bateman (1961):

> The compositional classification used (see Figure 24) is modal....The granitic rocks contain at least 10 percent quartz. Boundaries between the different rocks in terms of the ratio of potash feldspar (including perthite) to total feldspar as follows: quartz diorite, 0-10 percent; granodiorite, 10-35 percent; quartz monzonite, 35-65 percent; granite, more than 65 percent.

Therefore, the Elbow Lake stock is a quartz diorite - the ratio of the potash feldspar to the total feldspar is within 0 - 5 percent.

QUARTZ-FELDSPAR-MAFIC DIAGRAM

Quartz, feldspars (both plagioclase and potash feldspars) and mafic minerals (biotite, hornblende and opaque minerals lumped together) are also plotted in a triangular variation diagram (see Figure 25). All the points are clustered close to the quartz-feldspar sideline. This indicates the homogeneity of the Elbow Lake stock in composition. It could be inferred from the homogeneity of the mineral composition of the granitic body that the Elbow Lake stock is one intrusive body.

DEUTERIC ALTERATION OF THE ELBOW LAKE STOCK

A most interesting and characteristic feature of the Elbow Lake stock is the alteration of the major minerals, which includes sericitization, chloritization and saussuritization. No rocks were seen which had completely escaped these alterations.

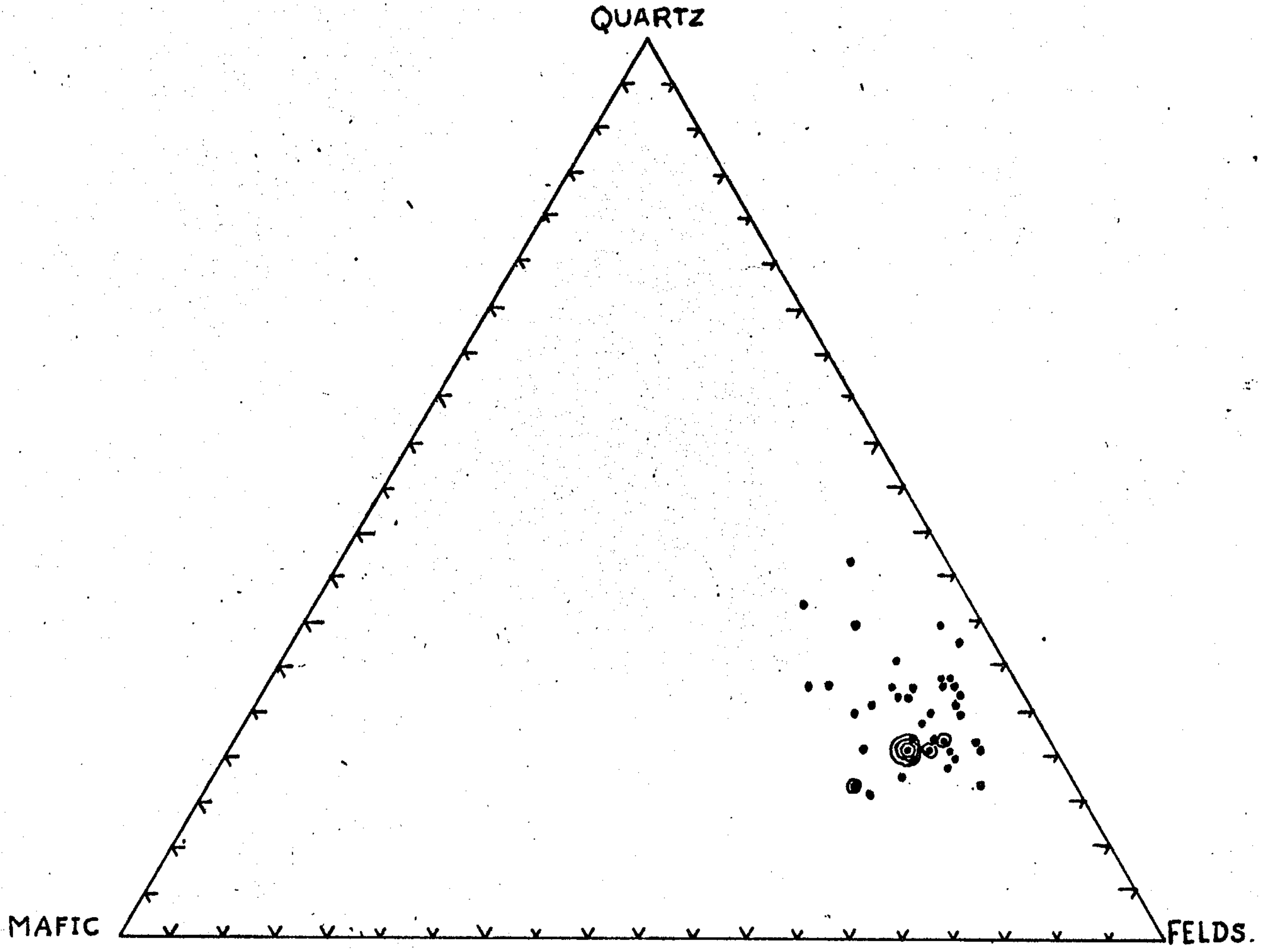


FIGURE 25 TRIANGULAR VARIATION DIAGRAM OF QUARTZ-FELDSPARS-MAFIC. DOT AND CIRCLE REPRESENT ONE SAMPLE EACH.

The intensity or relative amount of alteration was estimated for each thin section, and they were judged into three stages of alteration, viz:

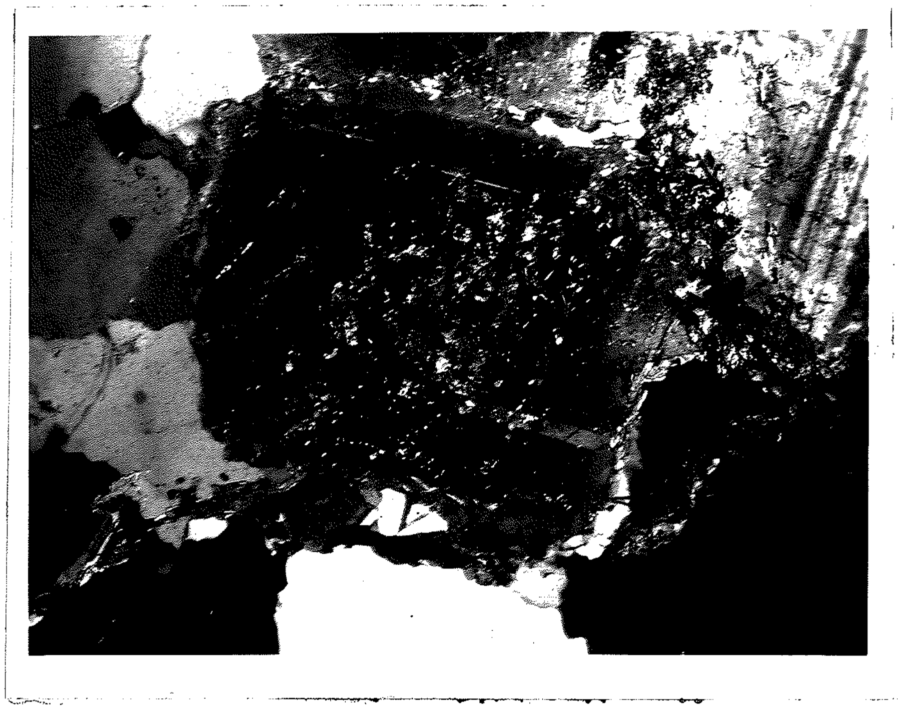
Stage I: Low degree of alteration (see Figure 26)
Zoning and twinning in plagioclase are well-defined, and only a few flakes of sericite have grown in them. Biotite and hornblende are unaltered. In Figure 18 there is shown a mass of chlorite and magnetite which has the shape of pyroxene pseudomorph. Sphenes are not corroded.

Stage II: Medium degree of alteration (see Figure 27)
Plagioclase crystals show zonal alteration to fine grained sericite but still maintain their crystal shapes, twin lamellae and zoning. Sphene crystals are found with reaction rims of ilmenite. Small amounts of chlorite replace the edges of biotite and hornblende crystals.

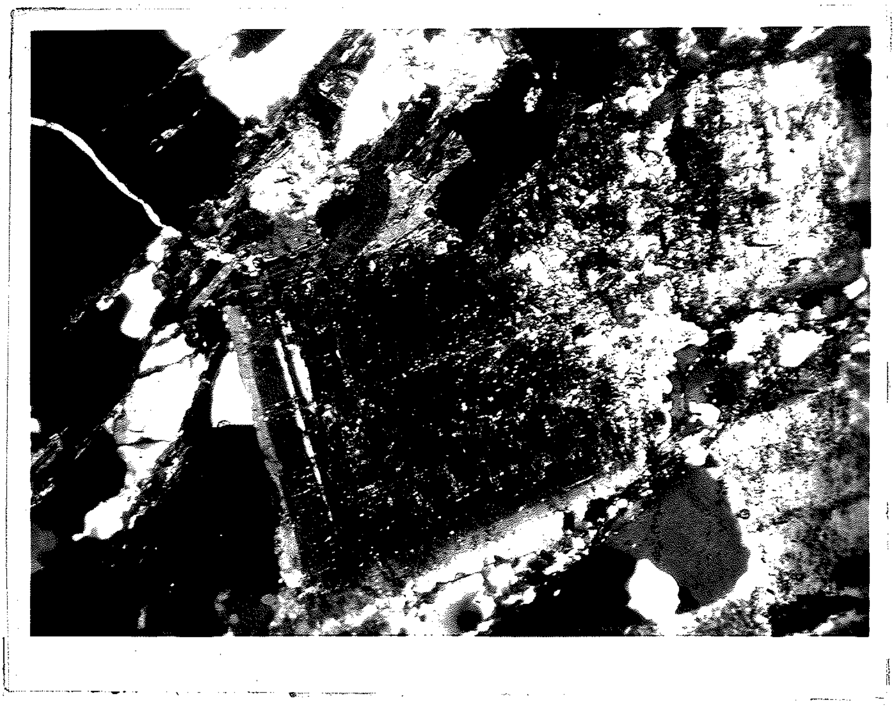
Stage III: High degree of alteration. (see Figure 28)
Plagioclase crystals are extremely affected by sericitization and saussuritization, such that the outlines of the euhedral crystals of the plagioclase are destroyed. The twinning and zoning are completely obliterated by such alteration. Biotite is altered to chlorite and epidote.

FIGURE 26. Zoned plagioclase crystal with small flakes of sericite developed in the core and in certain zones. Alteration stage I. (#A-11).

FIGURE 27. Zoned plagioclase crystal which has been sericitized in the intermediate zones, and replaced by biotite at one edge. Alteration stage II. (#A-11).



6 mm.



6 mm.

Secondary magnetite usually accompanies chlorites, in this zone of alteration. Sphene is mostly altered to ilmenite.

For more description of the alteration minerals, see Appendix I.

The intensity of the alteration has a zonal or concentric pattern in the stock, as shown in Figure 29.* The greatest effects of alteration are found in the core, and the least effects near the edge. This pattern suggests that the source of the hydrothermal fluids was from within the stock itself.

PARAGENESIS

On the assumption that the minerals formed by precipitation from a magma, the order of crystallization in the quartz diorite rocks of the Elbow Lake stock is interpreted from their shapes and mutual relationships and presented graphically in Figure 30.

Epidote, zoisite, sericite, muscovite, chlorite, calcite appear to be late, deuteric minerals.

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*Figure 29 in pocket.

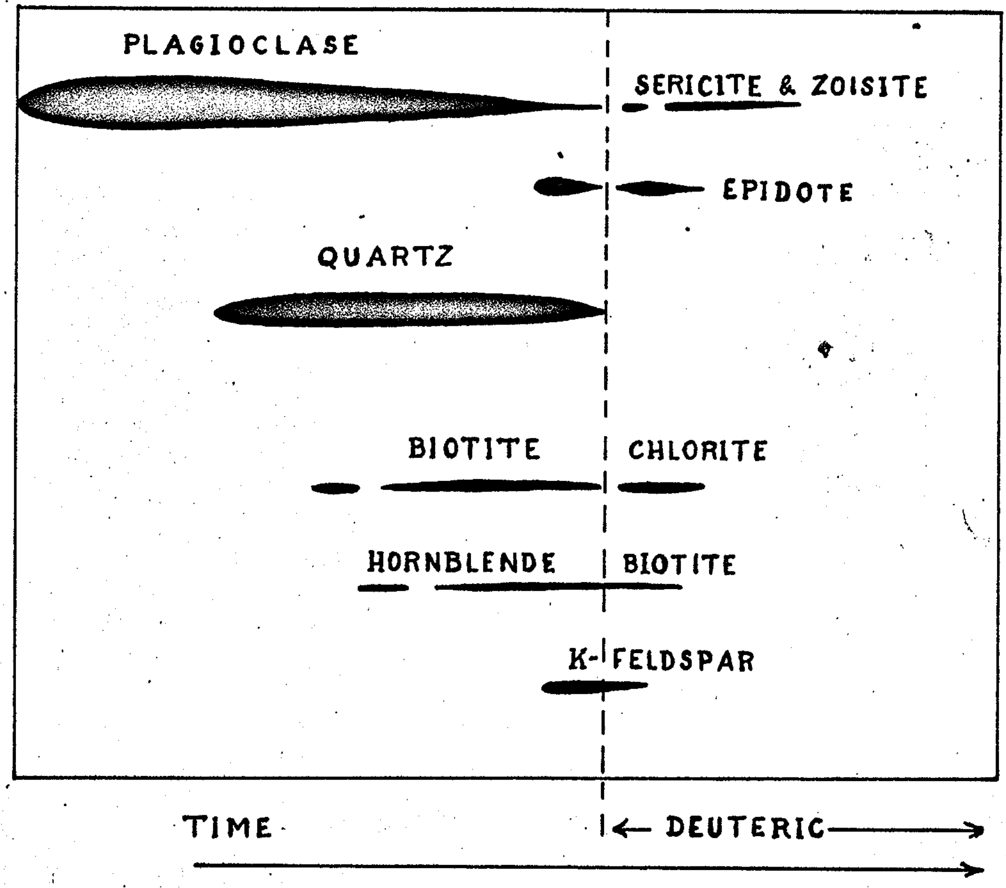

FIGURE 30 GRAPHIC REPRESENTATION OF THE PARAGENESIS OF THE ELBOW LAKE STOCK.

CHAPTER V

CHEMICAL ANALYSIS

Six samples of the Elbow Lake stock, chosen to have minimum alteration and some range of colour index, were chemically analysed (see Table 3). Niggli norms are listed in Table 4.

SILICA VARIATION DIAGRAM

The variation in the amounts of major elements of the six chemically analysed samples of the Elbow Lake stock are plotted in Figure 31 against silica content. Alumina, lime, magnesia, and total iron show generally consistent decrease with the increase of silica content. Soda, and potash show a general increase with the increasing silica. Titanium and P_2O_5 show peaks.

The trends of major oxides are consistent with what would be expected in a differentiated intrusion.

ALKALI LIME INDEX

Figures 32 is a plot of CaO and ($Na_2O + K_2O$) against SiO_2. These curves cross at a silica content approximately 64 percent. The value of the alkali-lime index of the Elbow Lake stock is, therefore, 64 and corresponds to the calcic group in the classification of Peacock (1931).

TABLE 2

MODAL ANALYSES OF ELBOW LAKE STOCK

Specimen Nos.	Quartz	Plagioclase	K-feldspar	Biotite	Hornblende	Epidote	Opaque	Others*
A-1-65	25.12	55.42	0.15	8.83	-	10.18	Trace	0.30
A-3-65	23.79	62.30	0.57	9.36	-	2.47	1.44	Trace
A-4-65	23.00	63.51	Trace	7.12	-	5.05	0.72	Trace
A-5-65	26.98	63.31	-	5.80	-	2.81	0.57	0.53
A-6-65	23.30	66.90	4.90	2.49	-	2.10	0.11	Trace
A-7-65	20.42	60.21	0.19	9.19	-	9.85	0.14	Trace
A-11-65	19.98	53.50	2.19	10.13	4.57	7.16	1.37	Trace
A-13A-65	27.53	43.91	0.69	14.92	-	12.71	0.19	Trace
A-18-65	21.53	59.67	1.71	10.48	-	5.28	1.33	-
A-19-65	28.66	60.08	2.96	6.29	0.34	1.90	0.24	Trace
A-21-65	20.97	62.97	2.67	5.91	Trace	6.97	0.38	0.54
A-24-65	31.67	58.24	Trace	8.16	Trace	1.0	0.57	-
A-26-65	26.95	51.48	-	0.13	-	19.23	0.80	1.41
A-32-66	25.00	57.77	Trace	10.43	-	6.29	Trace	0.40
A-34-66	19.15	66.42	0.62	7.93	-	3.37	Trace	2.22
A-35-66	23.78	64.65	Trace	6.83	-	4.55	Trace	Trace
A-36-66	20.03	62.73	Trace	13.56	-	3.04	Trace	Trace
A-37-66	22.90	61.03	1.78	9.21	-	4.40	Trace	Trace
A-39-66	30.43	57.11	-	8.86	-	3.02	Trace	Trace
A-40-66	27.23	59.67	-	5.07	-	6.74	Trace	1.00
A-41-66	24.38	54.34	Trace	13.80	-	6.94	Trace	Trace
A-42-66	21.63	65.33	0.85	6.61	2.92	1.78	Trace	Trace

continued

Specimen Nos.	Quartz	Plagioclase	K-feldspar	Biotite	Hornblende	Epidote	Opaque	Others*
A-43-66	19.91	63.92	Trace	8.92	2.76	3.68	0.42	Trace
A-44A-66	23.88	59.52	-	4.46	-	6.32	0.88	4.92
A-45-66	23.19	59.63	Trace	6.35	Trace	10.23	Trace	Trace
A-46-66	25.61	58.95	-	4.88	-	10.62	Trace	Trace
A-47-66	26.65	55.38	-	10.74	-	7.57	Trace	0.65
A-50-66	19.92	60.18	Trace	12.83	-	5.22	Trace	1.70
A-51-66	18.99	62.97	-	12.40	-	4.62	Trace	0.62
A-52-66	19.62	62.43	-	13.08	-	4.28	Trace	0.54
A-53A-66	20.28	63.07	-	10.11	-	4.15	1.35	1.04
A-54-66	19.84	62.58	-	13.50	-	2.79	Trace	1.24
Q-43-65	33.49	54.76	2.89	4.12	-	3.60	-	1.14
Q-45-65	24.75	56.70	-	10.73	-	7.70	Trace	-
Q-49-65	15.60	58.20	0.66	7.87	6.65	10.81	Trace	Trace
Q-51-65	20.50	59.44	0.63	6.48	1.77	10.06	0.99	Trace
Q-53-65	32.24	46.77	Trace	10.30	-	10.11	Trace	Trace
Q-79-65	19.40	58.17	2.50	8.12	1.85	7.43	1.78	0.70
Q-81-65	24.82	44.24	14.04	11.55	-	3.80	0.50	1.06
Q-82-65	25.80	47.08	0.83	15.50	2.23	8.40	Trace	1.03
Q-83-65	20.09	58.00	1.48	10.33	0.83	8.79	0.51	Trace
Q-84-65	28.58	34.95	2.09	11.19	1.17	17.22	0.46	4.44
Q-85-65	17.62	50.62	-	11.14	-	5.05	0.72	Trace
R-100-65	25.83	49.31	-	9.00	6.90	7.84	1.12	-
R-102-65	15.80	52.16	Trace	10.11	35.67	6.20	Trace	Trace
R-104065	8.22	44.45	-	2.41	43.86	1.06	Trace	-
R-106-65	21.47	50.73	Trace	13.75	Trace	12.59	1.23	Trace
R-108-65	13.48	63.15	Trace	8.07	Trace	15.00	Trace	Trace

continued

Specimen Nos.	Quartz	Plagioclase	K-feldspar	Biotite	Hornblende	Epidote	Opaque	Others*
E-4-65	19.55	60.99	4.52	Trace	9.60	3.91	Trace	1.17
E-12-65	16.43	58.04	1.08	1.77	17.68	4.89	Trace	Trace
E-27-65	18.54	64.76	-	5.93	-	10.39	Trace	-
E-32-65	15.93	60.59	1.01	18.67	0.67	3.13	Trace	Trace
E-33-65	18.14	65.10	0.58	9.98	-	6.05	Trace	-
E-40-65	14.84	62.87	-	7.32	-	14.97	Trace	-
E-49-65	17.38	57.10	3.45	1.02	20.30	0.62	Trace	-

* Sphene, calcite, apatite, chlorite, muscovite etc.

Trace indicates less than 0.5 percent.

TABLE-3. CHEMICAL ANALYSES

Chemical Analysis	SAMPLES					
	A-5-65	A-6-65	A-11-65	A-19-65	A-23-65	A-24-65
SiO_2	66·20	67·80	62·80	66·40	65·70	63·00
Al_2O_3	15·50	15·50	15·75	16·20	15·85	16·80
Fe_2O_3	3·43	2·24	3·10	2·13	1·67	2·79
FeO	1·14	1·24	2·54	1·68	2·12	2·24
MgO	3·00	2·10	3·25	2·50	2·35	2·55
CaO	4·03	3·17	5·45	4·10	3·85	5·40
Na_2O	2·77	3·19	2·70	3·06	3·40	3·06
K_2O	2·04	2·64	2·64	2·55	2·32	1·72
H_2O^+ H_2O^-	0·95	0·83	0·84	0·48	0·81	0·76
CO_2	0·28	.....	.....	.....	.....	.....
TiO_2	0·29	0·19	0·26	0·15	0·35	0·26
P_2O_5	0·12	0·12	0·25	0·16	0·44	0·32
MnO	0·17	0·06	0·12	0·09	0·08	0·12
TOTAL	99·80	99·10	99·18	99·69	99·15	99·24

ANALYSED BY K. RAMLAL

TABLE 4

NIGGLI MOLECULAR EQUIVALENT NORMATIVE MINERALS

Sample Nos.	A-5-65	A-6-65	A-11-65	A-19-65	A-23-65	A-24-65
Saturation Index	28.7	28.0	22.4	24.7	24.3	22.2
Diffr.Index	66.4	73.4	58.7	68.0	69.7	61.0
Colour Index	12.0	8.7	14.4	10.4	10.6	11.8
Calcite	.724	.000	.000	.000	.000	.000
Apatite	.256	.257	.539	.340	.943	.689
Pyrite	.000	.000	.000	.000	.000	.000
Ilmenite	.412	.271	.373	.212	.499	.000
Chromite	.000	.000	.000	.000	.000	.000
Orthoclase	12.349	16.035	11.361	15.351	14.077	10.483
Albite	25.422	29.377	25.005	27.930	31.278	28.277
Anorthite	17.861	15.354	26.148	19.651	16.655	25.467
Acmite	.000	.000	.000	.000	.000	.000
Magnetite	2.084	2.398	3.337	2.260	1.786	2.997
Hematite	1.050	.000	.000	.000	.000	.000
Corundrum	2.595	2.128	.000	1.458	1.993	.934
Wollastonite	.000	.000	.041	.000	.000	.000
Enastite	8.535	5.995	9.330	7.073	6.701	7.304
Ferrositite	.000	.096	1.453	.921	1.669	1.566
Hyperothene	.000	.000	.000	.000	.000	.000
Quartz	28.707	28.084	22.407	24.799	24.395	22.279
Diopside	.000	.000	.000	.000	.000	.000
Olivine	.000	.000	.000	.000	.000	.000
Nephetine	.000	.000	.000	.000	.000	.000
Leucite	.000	.000	.000	.000	.000	.000
Kaliophitite	.000	.000	.000	.000	.000	.000

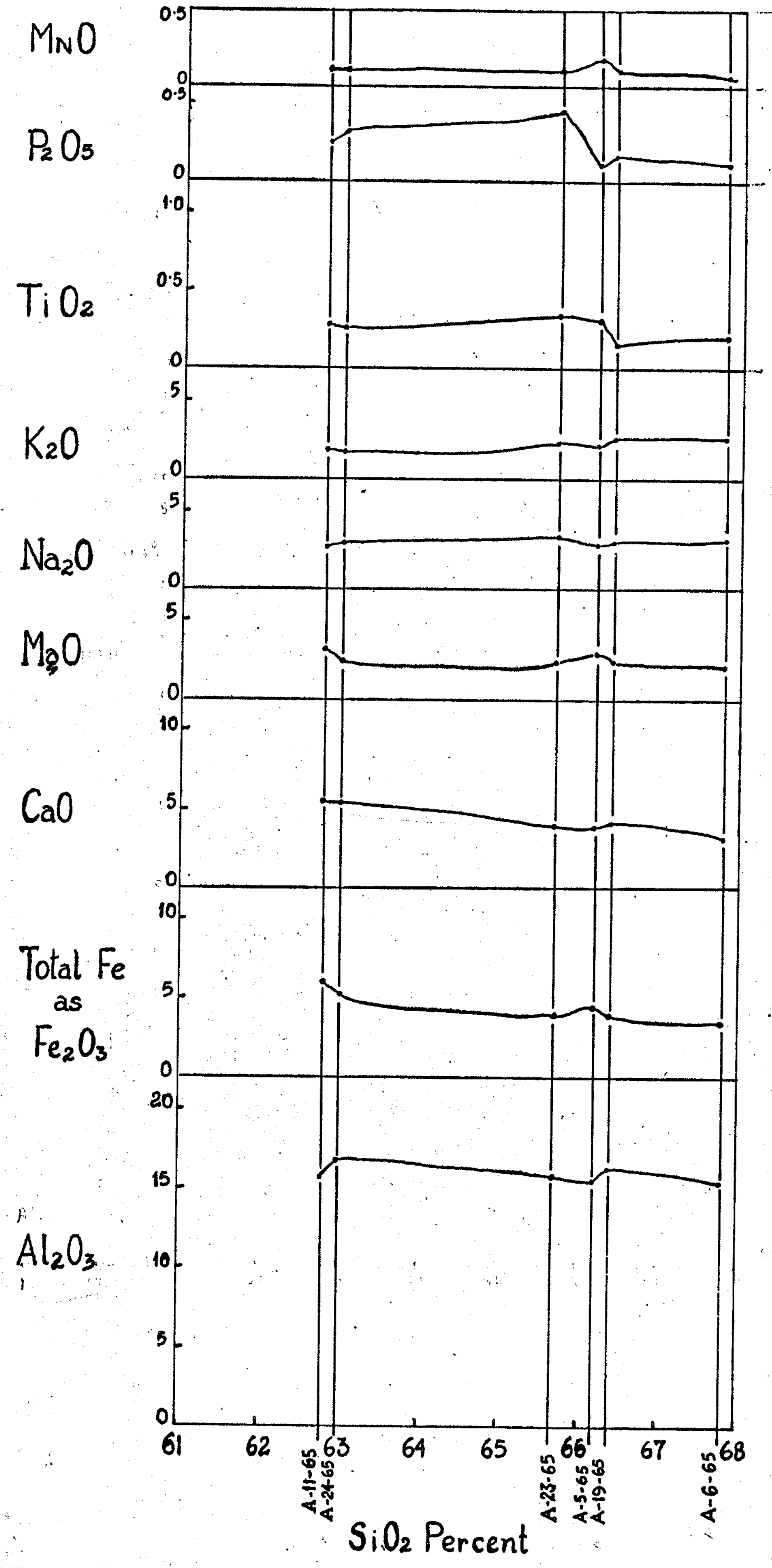

FIGURE 31 VARIATION DIAGRAM OF MAJOR OXIDES AGAINST SILICA VALUES.

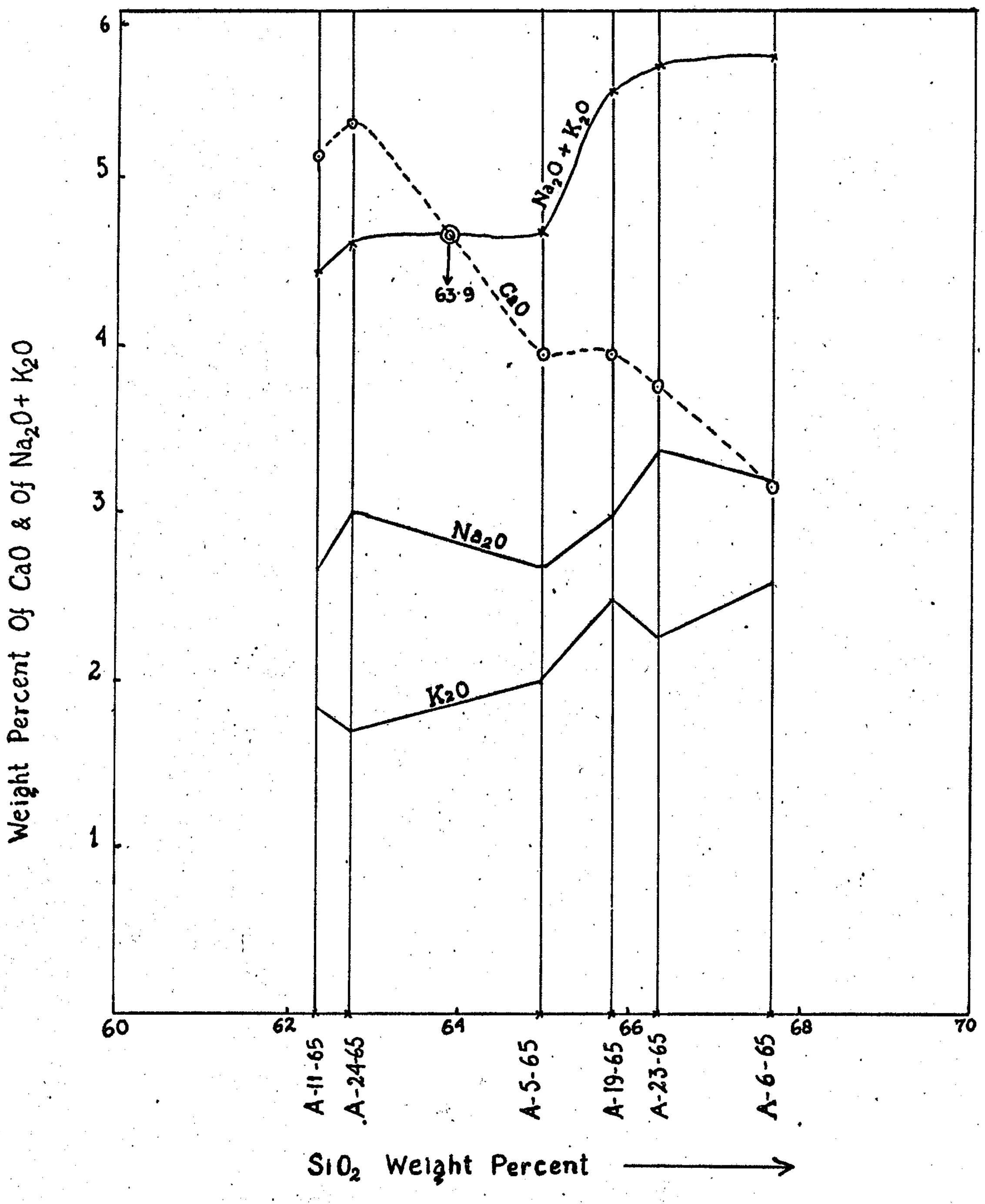

FIGURE 32 COMPARISON OF CONTENTS OF LIME AND ALKALIS.

DIFFERENTIATION INDEX

The differentiation index (Thornton & Tuttle, 1960), is the sum of the weight percentages of CIPW normative quartz + orthoclase + albite + nepheline + leucite + kalsilite. No more than three of these normative minerals will appear in any given norm, thus the differentiation index is simply the sum of the percentages of the three normative minerals. It is the opposite of "basicity".

The diagrams of Thornton and Tuttle (1960), contoured to show the variations of oxides against the differentiation index of 5000 analysed igneous rocks (Washington Tables), are used for comparison in Figures 33 to 40. Figures 33, 34, 35 and 38 show that the contents of K_20, Na_20, Ca0 and Fe0 respectively of the Elbow Lake stock plot onto a trend which is similar to, but slightly lower values than, the average igneous trend as shown by Thornton and Tuttle contours.

Figures 36 and 40 show that the contents of Mg0 and $Si0_2$ of the Elbow Lake stock plot onto a trend which is similar to but with slightly higher values than the average igneous trend as shown by the contour lines.

Figures 37 and 39 show that the contents of Fe_20_3 and Al_20_3 of the Elbow Lake stock plot onto a trend which is similar to that of the average igneous trend, with a small amount of scatter.

The variations of the major components indicate, by their similarity with variations in other igneous rocks, that some relatively small amount of igneous differentiation has occurred during the magmatic episode of the Elbow Lake stock.

In figures 36-40 the contour lines are taken directly from Thornton and Tuttle (1960). They contoured density of frequency of occurrence of plots of 5000 igneous rocks. Their contour interval is 25 points per 0.16 percent area, except in silica diagram, where the interval is 12.5 points in the same area. 'H' equals high concentration of points.

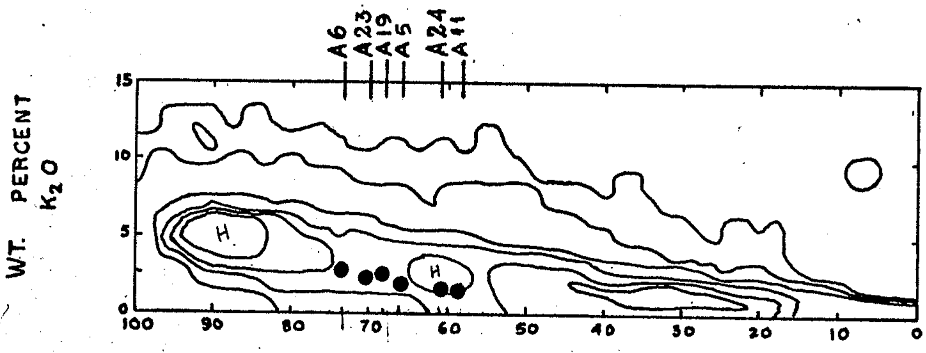

FIGURE 33 K_2O CONTENTS PLOTTED AGAINST DIFFERENTIATION INDEX (THORNTON & TUTTLE, 1960). THE CONTOUR LINES SHOW THE AVERAGE TREND OF IGNEOUS ROCKS.

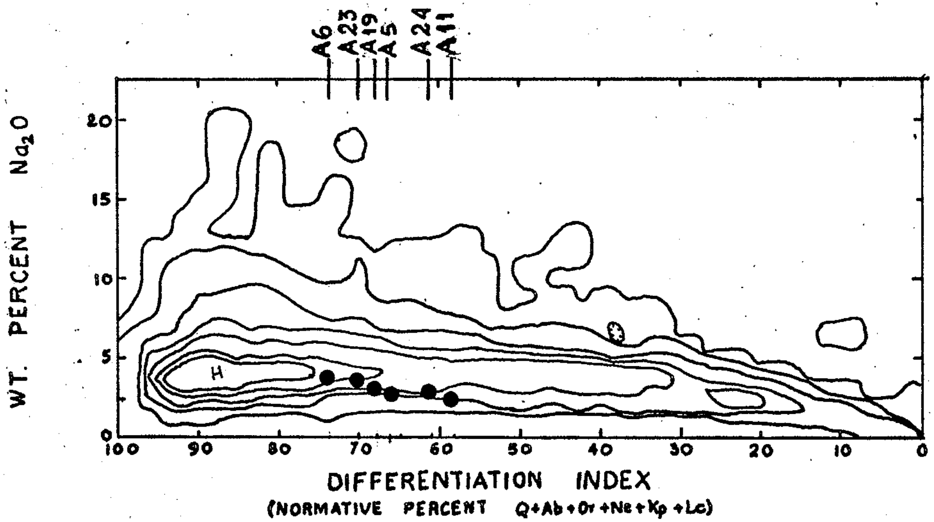

FIGURE 34 Na_2O CONTENTS PLOTTED AGAINST DIFFERENTIATION INDEX.

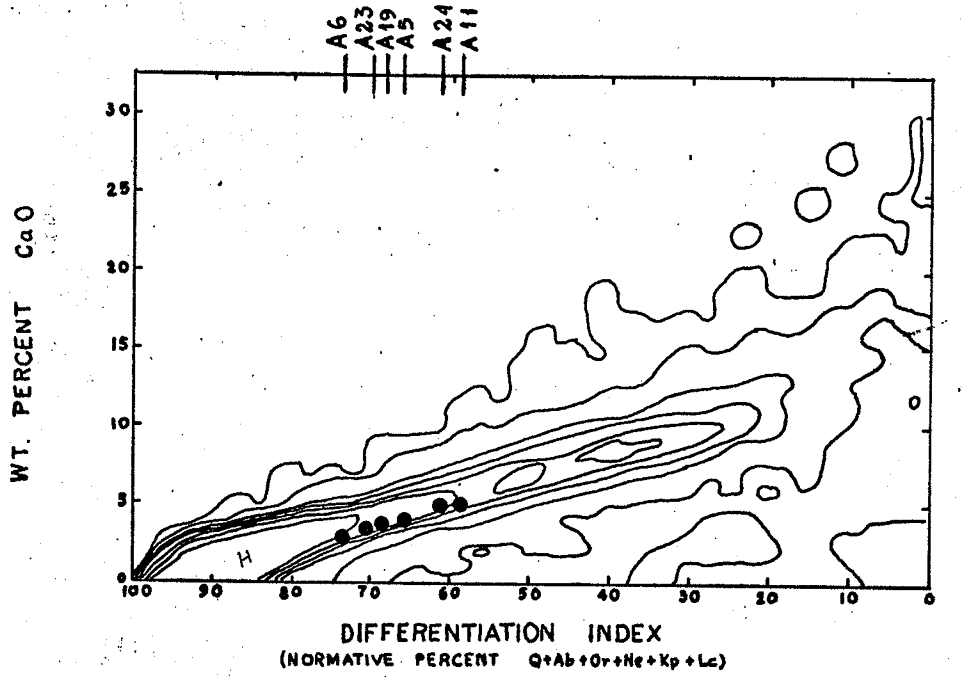

FIGURE 35 CaO CONTENTS PLOTTED AGAINST DIFFERENTIATION INDEX.

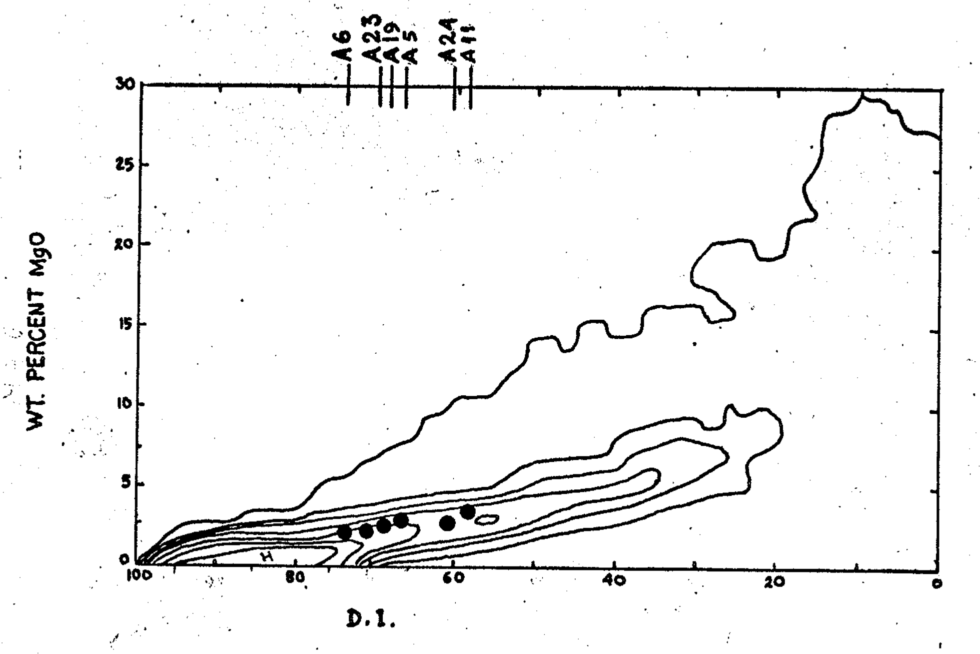

FIGURE 36 MgO CONTENTS PLOTTED AGAINST DIFFERENTIATION INDEX.

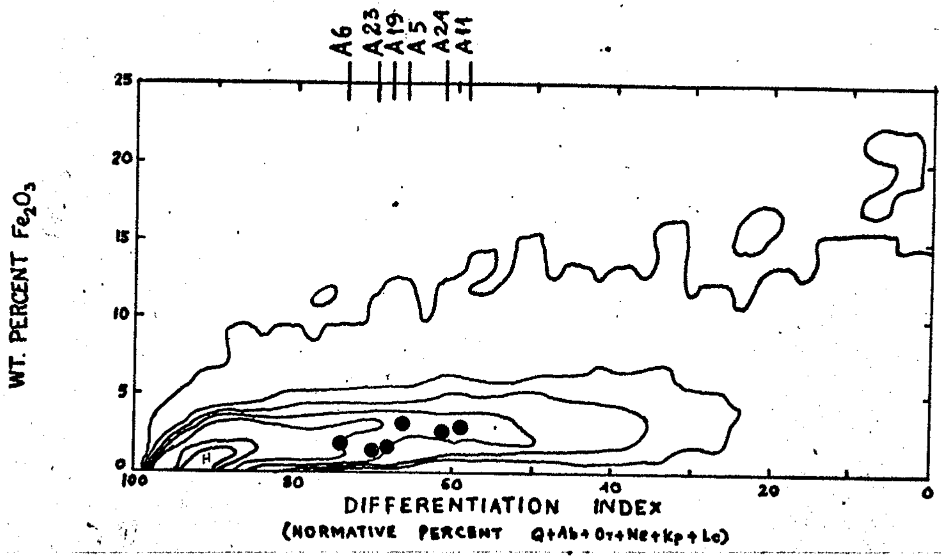

FIGURE 37 Fe_2O_3 CONTENTS PLOTTED AGAINST DIFFERENTIATION INDEX.

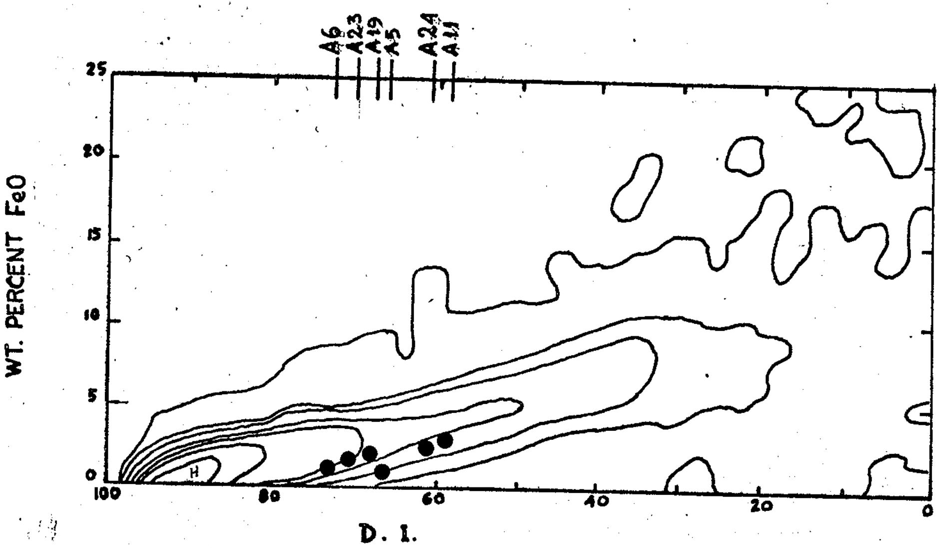

FIGURE 38 FeO CONTENTS PLOTTED AGAINST DIFFERENTIATION INDEX.

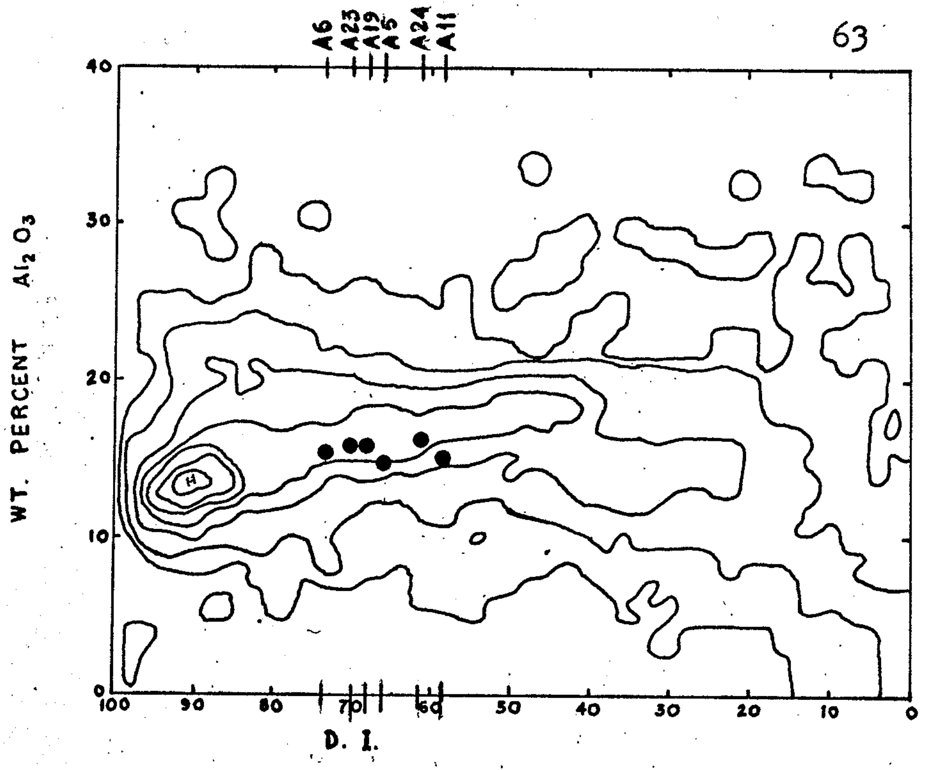

FIGURE 39 Al_2O_3 CONTENTS PLOTTED AGAINST DIFFERENTIATION INDEX.

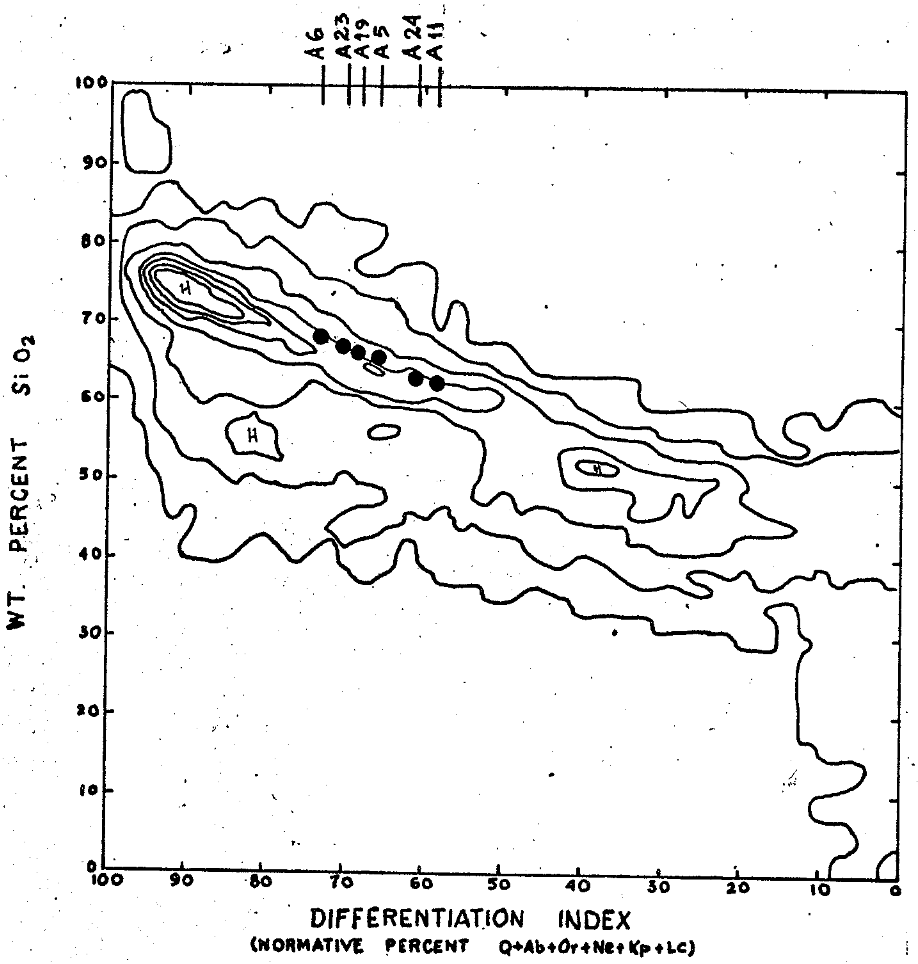

FIGURE 40 SiO_2 CONTENTS PLOTTED AGAINST DIFFERENTIATION INDEX.

CHAPTER VI

CONCLUSIONS

The Elbow Lake stock is interpreted to be an igneous rock, as indicated by its textural, mineralogical, chemical and structural characteristics.

The texture, with euhedral crystals of the major mineral plagioclase forming a network of the crystals with other minerals filling in interstices, is characteristic of igneous rocks.

The mineralogy is similar to other quartz diorites. The shapes and sizes of each of the mineral components fits the pattern established for igneous crystal growth. The nature of the alteration of the major minerals is characteristic of late stage igneous hydration reactions. Furthermore, the concentration of this alteration in the center of the stock indicates an internal source of the agents (H_2O, etc.) of alteration.

The chemical composition is typical of igneous rocks, and the variations in the amounts of the major elements fits the patterns established for the other igneous rocks.

The igneous intrusive nature of the stock is established by the observation of inclusions of fragments of country rock and deformation of country rock at the contact. Other structural features which are characteristic of igneous rocks are the roughly homogeneous composition, the lack of any regular pattern in the maps of variation in mineral content, and a pattern of two major vertical joints.

The Elbow Lake stock contains strained and slightly granulated quartz, but no other evidence of deformation except in the shear zones adjacent to the large faults. It is, therefore, interpreted that after consolidation, the stock was subjected to relatively light stress, but not extensive internal shearing or deformation.

The quartz diorite has not been subjected to metamorphism, except for the alterations which have been described as late igneous (deuteric). The only recrystallization that can be found that may be post-magmatic is the growth of epidote in joints and fractures. It is, therefore, interpreted that the intrusion of the stock was after the regional metamorphism of the country rock.

A "quartz-eye granite" in the Chisel Lake area, 60 miles east of Elbow Lake, was studied by Williams (1966). He concluded that the rock was a metamorphosed crystal tuff, and that it must be re-named "quartz-eye gneiss". His interpretation is based upon structural, textural, and chemical features. Structurally the Chisel Lake "quartz-eye gneiss" is a sill or flow-shaped bed concordantly lying in the layered Amisk Group. It has been folded with this Group. From irregular mineral distribution, variable grain size, patchy and porphyritic texture he points out the inhomogeneity of the rock. Chemically the rock composition is relatively rich in SiO_2 and Na_2O, and relatively poor in Al_2O_3 and K_2O. These characteristics could fit either a rhyolite or an unusual sediment. He points out (p.14-15) the unusually high soda-potash ratio, varying from 1.05 to 10.25.

In contrast, the "quartz-eye granite" of the Elbow Lake area has characteristics of magmatic origin. This magmatic origin of the Elbow Lake stock is based upon the typical hypautomorphic granular igneous texture, homogeneity in mineral composition, the concentration of innumerable inclusions near the contact with the country rocks of the Wekusko group, discordant contact relationships with the country rocks, generally massive texture with some foliation, strongly developed joints, and both oscillatory and normal zoning in the large euhedral plagioclase crystals. The soda/potash ratio in the Elbow Lake stock is small in contrast to the quartz-eye gneiss of the Chisel Lake. It varies from 1.02 to 1.77 with an average of only 1.33. The chemical composition fits with other igneous rocks.

It appears that rocks of diverse origin in Northern Manitoba have been mapped as "quartz-eye granite". Quartz eyes may be striking in appearance, but they may have diverse origin. It is recommended that the use of the term "quartz-rye granite" be de-emphisized.

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APPENDIX I

DESCRIPTION OF THE MINERALS

PLAGIOCLASE FELDSPAR

Plagioclase is the most abundant mineral. Some of the plagioclase crystals are fresh and some are extremely altered (see description of alteration on p.43). The fresh plagioclase crystals are euhedral to subhedral, large and tabular (parallel to 010) in habit, but the altered ones are subhedral. Plagioclase is euhedral against quartz, potassium feldspars, hornblende and biotite.

They are usually polysynthetically twinned (albite and/or pericline). Carlsbad law twins also occur, but they are not common.

Zonal structure in plagioclase is very common. The zoning is regular oscillatory and the zones may be concentric and continuous or irregular and veining. In some plagioclase crystals, apart from the alteration products, rounded quartz grains are included in the outer rims of the plagioclase.

The effects of strain are seen in undulating extinction in some of the thin sections, breaking of crystals, and bent twinning lamellae.

There is evidence of a reaction between biotite and plagioclase. It appears that biotite replaces plagioclase, both in small irregular embayments and also in zones in the plagioclase (see Figure 27) in a manner similar to sericitization. Epidote crystals have grown at the boundaries.

ZONING IN PLAGIOCLASE

Zoned plagioclase crystals, both normal and oscillatory, are abundant. The oscillatory type of zoning is confined to the cores.

There are also, rarely, vein-like replacements of the core by sodic plagioclase of rim composition, and commonly the connection with the outer rim is visible.

LAMELLAR TWINNING IN PLAGIOCLASE

Twinning is abundant and lamellae are widest in the most calcic zones. Calcic plagioclases commonly have one set lamellae of hair-like fineness with broad interspaces whereas sodic plagioclases are commonly without twinning or have numerous fine lamellae of nearly equal width.

RELATIONSHIP BETWEEN LAMELLAR TWINNING AND ZONING

Emmons and Mann (1953) suggest, "...that the nature of the zoning in plagioclase reflects the condition under which the crystals grew, (2) that polysynthetic twinning replaces and is consequent on zoning, (3) that the spacing of twin lamellae may in turn reflect the nature of zoning in part and hence the condition under which the crystals grew, and

(4) that polysynthetic twinning and zoning in plagioclase feldspar may be used as a petrographic aid in determining the origin of granite.

The most important observation on the plagioclase crystals in the twin-zone relationship is that lamellar twinning tends to destroy zoning. Zoning in certain cases is present only in one set of lamellae, while in others it has been eliminated. More often the development of twin lamellae only decreases the range of zoning, and does not destroy it. In such cases the difference in extinction angle from the core to the rim may be as much as 10 degrees less in the new lamellae than in the remnant plagioclase.

Because twinning is commonly superimposed on zoned crystals, it was possible to trace the development of twinning through most of its stages. The process is outlined by Figures 41 to 46.

In Figure 41 twinning begins as very narrow streaks, development first in the rim of the plagioclase. Commonly they parallel 010, but sometimes they follow rarer twinning planes. The new twin lamellae taper and disappear towards the core of the crystal.

In Figure 42, a later stage, they have widened and their width is fairly uniform throughout. In these new lamellae the zoning has been either completely destroyed, or reduced in range. The original zoning remains sharp and clear throughout the rest of the crystal. The fact that zoning may be preserved

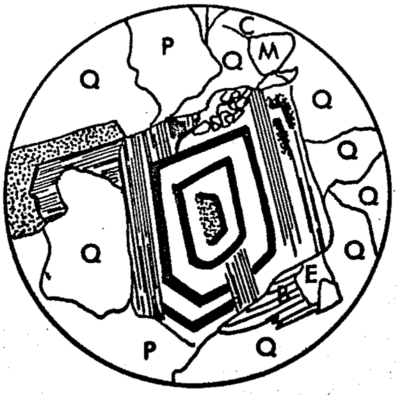


FIG. 41

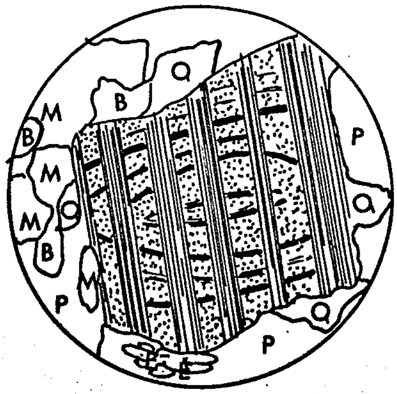


FIG. 42

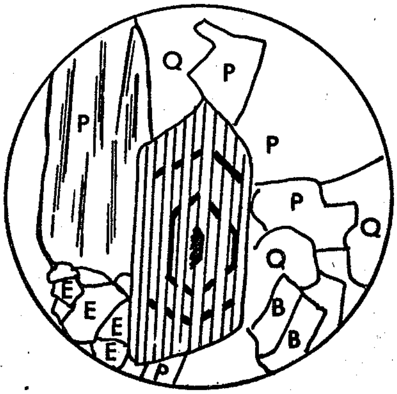


FIG. 43

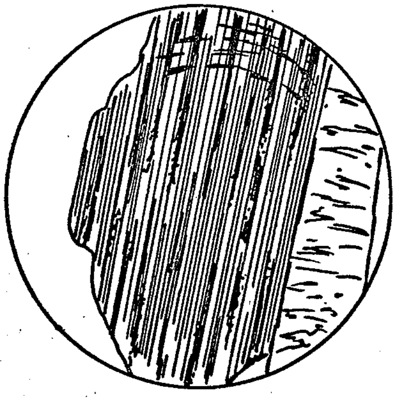


FIG. 44

6 mm.

in the new lamellae indicates that they have been formed by diffusion which acted most vigorously parallel with the composition plane.

In Figure 43, the continuation of the process produces a crystal composed largely of broad new lamellae with a few narrow, old lamellae representing the former zoned crystal. As twinning continues to develop, it generally destroys itself by elimination of the interspaces (Figure 44). There is some indication, however, that the process begins to repeat itself when the new lamellae reach a certain width,but the process is then difficult to trace because little zoning remains to separate the first separation of lamellae from the second. Second generation of lamellae were recognised, however, in a number of crystals that showed good zoning in interspaces, faint zoning in broad lamellae, and none in the few second generation lamellae.

The available evidence suggests that the formation of twin lamellae is a gradual process, not an instantaneous snapping into place of the crystal lattice in response to exterior stress. Because zoning is actually destroyed by the process, it is assumed that some form of diffusion is operative. Yet diffusion in itself cannot be the whole explanation of twinning. An important factor is that the diffusion does not take place in a closed-system. If it did, the rims of new lamellae should become more calcic as the core becomes more sodic. But the rim does not become calcic in the process; it seems to remain the same and both twin and crystal become relatively more sodic. Thus, sodium that leaves the rim to diffuse towards the core must be replaced by sodium from the crystal, and the calcium that is displaced from the core is forced out of the crystal.

Although no reason is obvious why the closed-system should cause inversion of a crystal lattice, open-system diffusion involving displacement of calcium by sodium and change in total compensation of the lamellae might set up strain with respect to adjacent areas to effect inversion, the inverted position being one of less strain.

As previously mentioned, very thin lamellae separated by broad interspaces are characteristics in the more calcic zones. This is interpreted to be immediate stage of development, in which the narrower polsynthetic twins have not yet developed. As both interspaces and new lamellae are considered together in referring to average widths of lamellae, and because one grows narrower as the other becomes wider, the average lamellae width is progressively controlled by the number of lamellae initiated, and the temperature of the plagioclase during twin formation.

QUARTZ

Quartz occurs both interstitially to the plagioclase crystals and in oval pods or "eyes". Under the microscope each "quartz-eye" is seen to be an aggregate of small quartz grains with wavy irregular boundaries.

In general "quartz-eyes" are more abundant in the central part of the Elbow Lake stock. More precisely, it is more abundant in zone of high alteration, which is the central part of the stock. The "quartz-eyes" are less abundant in the medium zone of alteration and ultimately become scarce in the contact zones. Moreover they are more abundant in the biotite-rich rocks than in the hornblende-rich rocks.

Most quartz grains are strained, with wandering extinction. Coincident with these strain shadows, quartz usually show anomalous biaxial character. Large quartz crystals have been broken into smaller grains and their boundaries have a sutured appearance.

A feature of the "quartz-eyes" is the smoky blue color that can be seen in the hand specimens. The cause of the blue coloration could not be determined microscopically. Possibly it could be due to magnetite dust, or black carbonaceous materials. To explain the possible reason for this coloration of quartz grains, Roddick (1965, p.121) quoted work of the Pennsylvania State College in 1948 which suggested, "...it is due to slight distortion of the silicon lattice by certain foreign cations present in exceedingly small amounts". Most intense blue coloration is found where quartz is fairly abundant in the central (most altered) part of the stock.

POTASSIUM FELDSPARS

Much of the potash feldspar is microcline and perthite, although orthoclase is also present. It occurs interstitially between the plagioclase, and consequently it shows no crystal boundaries except against quartz.

The perthites consist of small blebs, films, stringers, rods, veinlets, and patches of albite in potash feldspar. The perthite intergrowths are fine grained and evenly distributed through the K-feldspar crystals, only in part patchy, and are, therefore, interpreted to be of exsolution origin.

A close association was noted between coarse grained perthite and grid twinning in the microcline.

In thin sections in which hornblende exceeds or equals biotite in amount, the potash feldspars contain no perthite, or only fine grained albite components. On the other hand, medium grained perthite, coarse grained perthite, and grid twinned potash feldspar are all restricted to sections in which biotite exceeds hornblende. When quartz is exceptionally abundant, the potash feldspar is commonly non-perthitic.

FERROMAGNESIAN MINERALS

BIOTITE

Biotite is the most common ferromagnesian constituent of the granitic body. In some areas north of the C.N.R. track, it is the only femic mineral. In most cases biotite is very uniformly distributed in no particular orientation, in some sections it has parallel orientation where weak foliation is developed in the rock.

In color it is brown or reddish brown and sometimes green, and strongly pleochroic. In some cases brown and green biotites are united in parallel intergrowth. The crystal shapes of biotite normally range from very irregular to regular six-sided euhedral crystals that are usually tabular or prismatic in habit. Another common habit of biotite is that of forming clots of small crystals, The crystals within the clots are generally arranged in a random pattern. The size of these individual biotite grains is much smaller than that of the average felsic crystals, although the dimensions of the clots themselves are about the same.

Biotite crystals appear to have lots of inclusions. Micro-inclusions of plagioclase are common. The minor accessories such as magnetitie, apatite, zircon and sphene are included in the biotite. Apatite is frequently very abundant, and may form rather long needles in no particular orientation with respect to other apatite crystals, or to the crystallographic directions of biotite. Magnetites usually occur as scattered grains throughout it. Zircons are also commonly found in biotite and are usually surrounded by the pleochroic halos.

Narrow projections of biotites commonly extend outward from the main crystal to fill interstices between plagioclase crystals, and in places filling fractures in that mineral. The larger biotite crystals commonly contain euhedral and partly replaced plagioclase crystals.

Biotite truncates the zoning of the plagioclase and replaces the sodic rim in preference to the core. The shape of the replacing biotite is controlled by plagioclase cleavage, resulting in many euhedral replacements remnants of plagioclase.

HORNBLENDE

Hornblende is the characteristic mineral in the south and southwestern part of the intrusive body. It is usually green or brownish green to brown in color. Hornblende crystals are usually large prismatic, with well-developed sides but no terminal faces. Twinning on (100) is seen in some sections. Zoning due to differences in color occurs in some thin sections.

In most of the sections hornblende appears more or less equivalent to the plagioclase in grain size and development of crystal form. However, hornblende also occurs interstitial among plagioclase crystals. Plagioclase crystals with angular corners jut into hornblende. In some thin sections interstitial hornblende is in the form of clots of fine grained crystals.

The hornblende-quartz relationship is that hornblende is embayed by quartz. It is evident that hornblende is older than quartz.

In the normal hornblende-biotite relationship, the minerals frequently lie in contact with each other. Intergrowths with biotite occur, the prism faces of hornblende usually being parallel to the cleavage of biotites. Some hornblende crystals are fringed by biotites.

From the above observations on the mafic minerals it could be summarised that (i) biotite is more abundant in the Elbow Lake stock than hornblende; (ii) hornblende is abundant only in the south and southwestern end of the intrusive body and at the contacts within the country rock; (iii)both mafic minerals are commonly irregular in shape and contain numerous plagioclase inclusions; (iv) in nearly all the thin sections examined the mafic minerals occupy a paragenetic position between plagioclase and quartz, and (v) the mafic minerals commonly replace plagioclase and are themselves replaced by quartz and potash feldspars.

ACCESSORY MINERALS

There are two groups of accessory minerals, those that are common accessories in igneous rocks, which are scattered throughout the Elbow Lake stock, and those which occur only as alteration products of the major minerals. The first group of accessories includes apatite, magnetite, ilmenite, sphene, zircon and garnet. The alteration products are sericite, muscovite, epidote, zoisite, chlorite and calcite.

APATITE

Apatite is widespread throughout the stock. It is usually found in minute six-sided prismatic euhedral crystals. They usually occur as inclusions in the ferromagnesian minerals, some are in plagioclase. In whatever mineral it is found, its orientation seems to bear no relation to any crystallographic direction of its host.

MAGNETITE

Magnetite occurs in the form of irregular grains. It occurs both as primary and alteration minerals. As alteration minerals, magnetite is derived from the ferromagnesian minerals and is then usually accompanied by chlorite.

SPHENE

As a primary mineral it occurs in euhedral crystals that have an acute rhombic cross-section, or in irregular grains and granular aggregates. Most commonly they are red-brown in color; pleochroism is weak to strong depending on the color of the mineral and thickness of the sections.

Usually they have a reaction rim of ilmenite, which forms as part of the deuteric alteration.

EPIDOTE

In thin sections primary epidote is found as olive-green to yellowish green, pleochroic, subhedral to aggregate crystals. It is interstitial between plagioclase and biotite. In some sections it is also seen as euhedral crystal with strong pleochroism. Twinning and zoning in epidote are also seen.

GARNET

Garnet is not a common mineral in the stock. It is not found in any of the thin sections. Euhedral crystals were seen in sample #A-17, which is located near the center of the stock.

SECONDARY MINERALS

SERICITE

Sericite is the most abundant product of the alteration of the plagioclase crystals. It is most conspicuous in the cores of the zoned crystals of plagioclase. Where the plagioclase is sharply zoned, sericite is largely restricted to the core or an intermediate zone. No example was found with sericitized outer zones of a plagioclase while the core remained unsericitized. The reaction possibly is as follows:

$$\underset{\text{anorthite}}{6CaAl_2Si_2O_8} + 7/3H_2O + 2/3K_2O \rightleftharpoons \underset{\text{zoisite}}{3Ca_2Al_3Si_3O_{12}(OH)}$$

$$+ \underset{\text{sericite}}{2KAl_3Si_3O_{10}(OH)_2}$$

when Al is replaced by Fe''' Epidote.

OR

$$\underset{\text{anorthite}}{2CaAl_2Si_2O_8} + \tfrac{1}{2}H_2O \rightleftharpoons \underset{\text{zoisite}}{Ca_2Al_3Si_3O_{10}(OH)} + AlSiO_{3.5}(OH)$$

$$\underset{\text{anorthite}}{3CaAl_2Si_2O_8} + K_2O + H_2O \qquad \underset{\text{sericite}}{2KAl_3Si_3O_{10}(OH)_2} + 3CaO$$

Numerous examples were noted of a sharply zoned plagioclase crystals with a relatively large core, in which only a part of the core was sericitized, although the core appeared to be of uniform composition. Such patches of sericite seemed to be independent of the boundaries of the cores, but many are shaped like a smaller core that no longer exists. These observations suggest that this particular type of sericite formed before the present crystal structure of the plagioclase and is, therefore, a relict mineral, remaining from the sericitization of a former plagioclase crystal.

In a few sections, the sericite is restricted to the very narrow lamellae of the crystals having lamellae of widely different widths. Where the twin lamellae are largely equal in width no relationship was noted. The distribution of sericite is probably independent of non-lamellar types of twinning.

Sericite is also found to occur in patches, trains and thin scattering. These occurrences of sericite are apparently unrelated to any zoning or to any structure now visible in the thin sections. The sericite patches are normally larger than the average grain size of the rock and cover all or part of several plagioclase crystals but do not overlap into other minerals. In places the concentrations of sericite in these patches is very high but rarely as high as sericitized cores. Trains of sericite may be confined within a single plagioclase crystal or cross several crystals. They are not controlled by any structure nor do they have any regular shape.

Except along fractures at crystal contacts, sericite was not seen in potassium feldspar, but the contacts between potash feldspar and chlorite are invariably sites of sericitization. No sericite forms in the contacts between plagioclase and quartz.

The conclusion is that where sericite is found in plagioclase, two possible sources of potassium were available, viz., a solution, and the plagioclase crystal itself. Calcic plagioclase is less capable of retaining potassium in solid solution than is sodic plagioclase. Consequently it is logical that sericite should be concentrated in cores and calcic intermediate zones where potassium might be provided by exsolution during a period of falling temperatures. This theory finds favour by the marked selectivity shown by sericite in replacing calcic parts of zoned crystals. However, water must be introduced regardless of the source of potassium.

EPIDOTE-ZOISITE

Epidote and zoisite are present as an alteration product of plagioclase. They occur in clusters of small grains, between grains of plagioclase feldspars, as a product of saussuritization. They are also found in fractures and joints in thin coatings of olive green, fine grained but also in irregular patches and spheroidal nodules.

In thin sections epidote is pleochroic, colorless to yellowish green. This is often zoned weakly, with the core stronger in pleochroism than the outer rim. This reflects a progressive alteration. Twinning in epidote is common.

Zoisite is rather colorless and occurs in columnar aggregates. Most of the zoisites and epidotes are produced from plagioclase as a result of saussuritization. Hydrothermal solutions in contact with anorthite will extract $Ca(OH)_2$. It is possible that in natural rocks the pore solutions will be alkaline. This reaction is as follows:

$$\underset{\text{anorthite (Xl)}}{3CaAl_2Si_2O_8} + Ca(OH)_2 \rightleftharpoons \underset{\text{zoisite (Xl)}}{2Ca_2Al_3Si_3O_{12}(OH)}$$

If ferric iron is present, epidote rather than zoisite will form. Water will act on plagioclase by transforming the anorthite end member into zoisite without affecting albite. The calcium is extracted and the remaining crystal becomes more sodic.

In most of the thin sections zoisite was also found to occur along cleavage planes of the plagioclase and very rarely in twinning planes.

Epidote in well developed crystals occurs at the contacts between biotite and plagioclase, and mixed in with chlorite which has replaced biotite.

CHLORITE

Chlorite occurs in clusters with the shapes of pyroxene pseudomorphs (see Figure 18). Some of the thin sections exhibit widespread chloritization. This is associated with epidotization and albitization. In some of the thin sections chloritization is so intense that the ferromagnesian minerals are completely altered to chlorite, epidote and magnetite.

Biotite is the most abundant ferromagnesian mineral which may be completely altered to chlorite plus dust particles of magnetite. Like biotite, hornblende is also susceptible to chloritization.

CALCITE

Calcite is a minor constituent,enriched in the central zone of the stock, which is the zone of most intense alteration.

Calcite is found in many of the thin sections as alteration products of plagioclase. They are mostly found in the large euhedral crystals of plagioclase, especially in the core, but also in the intermediate zones. Possible reactions are:

$$CaAl_2Si_2O_8 + K_2O + CO_2 \rightleftharpoons \text{Sericite} + \text{Calcite}$$

APPENDIX II

SELECTIVE STAINING OF POTASH FELDSPAR

- A preliminary microscoping examination of the thin section was made, and the minerals identified.
- Stains were applied to thin sections which have been prepared without cover glasses.
- The exposed glass of the slide was covered with a thin coating of celluloid. The celluloid solution protects the glass from the effects of the hydrofluoric acid during the subsequent fuming. It was applied with a camel's hair brush. Any laxity during this part of the method was rewarded by thin sections whose backs were deeply etched.
- The thin sections were carefully dried, and then placed with their faces down over the plastic beaker containing 52% hydrofluoric acid to about ¼" of the top, and etch them for 30 to 40 seconds.
- The slides were immersed in the saturated solutions of sodium cobaltinitrite for 15 to 20 seconds. The saturated solution of sodium cobaltinitrite was made by adding 15 cc of water to 12.5 grams of $Co(NO_3)_2$ and 20 grams of $NaNO_2$. Upon standing a yellow precipitate is developed in this solution. The solution was apparently stable in contact with this precipitate and should not be filtered.
- The section was washed very gently, rinsing in a beaker of water, as the stain might flake away easily.

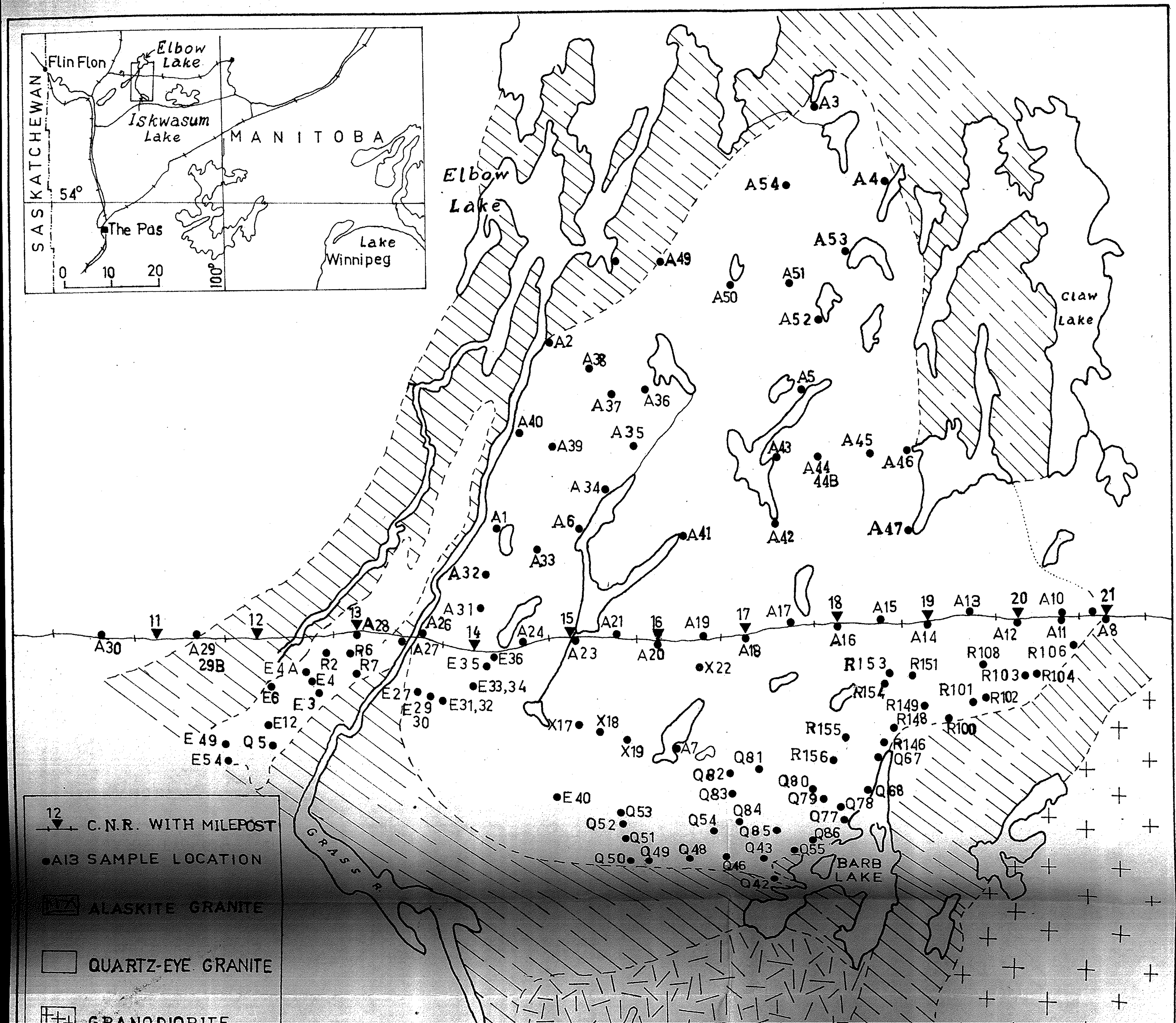
- It seemed apparent that etch residues left after the hydrofluoric acid treatment are stained and not the feldspars themselves. Unetched feldspars were not visibly stained. In etching with the hydrofluoric acid vapour, silicon was removed as the volatile fluoride, leaving the other elements on the feldspar surface.

Residual potassium from the potash feldspar reacts with sodium cobaltinitrite and the potassium feldspars were evenly stained light yellow.

FIGURE 1

"Map showing the location of samples taken from the Elbow Lake Stock"

To accompany (in pocket at back)
the thesis of A. A. Quaraishi


Flin Flon
Elbow Lake
SASKATCHEWAN
Iskwasum Lake
MANITOBA
54°
The Pas
Lake Winnipeg
0 10 20
100°
Elbow Lake
Claw Lake
GRASS R.
BARB LAKE
A2 A3 A4 A5 A6 A7 A8 A10 A11 A12 A13 A14 A15 A16 A17 A18 A19 A20 A21 A23 A24 A26 A27 A28 A29 29B A30 A31 A32 A33 A34 A35 A36 A37 A38 A39 A40 A41 A42 A43 A44 44B A45 A46 A47 A49 A50 A51 A52 A53 A54 A1
11 12 13 14 15 16 17 18 19 20 21
E3 E4 E4A E6 E12 E27 E29 30 E31,32 E33,34 E35 E36 E40 E49 E54
R2 R6 R7 R100 R101 R102 R103 R104 R106 R108 R146 R148 R149 R151 R153 R154 R155 R156
X17 X18 X19 X22
Q5 Q42 Q43 Q46 Q48 Q49 Q50 Q51 Q52 Q53 Q54 Q55 Q67 Q68 Q77 Q78 Q79 Q80 Q81 Q82 Q83 Q84 Q85 Q86
12 C.N.R. WITH MILEPOST
A13 SAMPLE LOCATION
ALASKITE GRANITE
QUARTZ-EYE GRANITE
GRANODIORITE

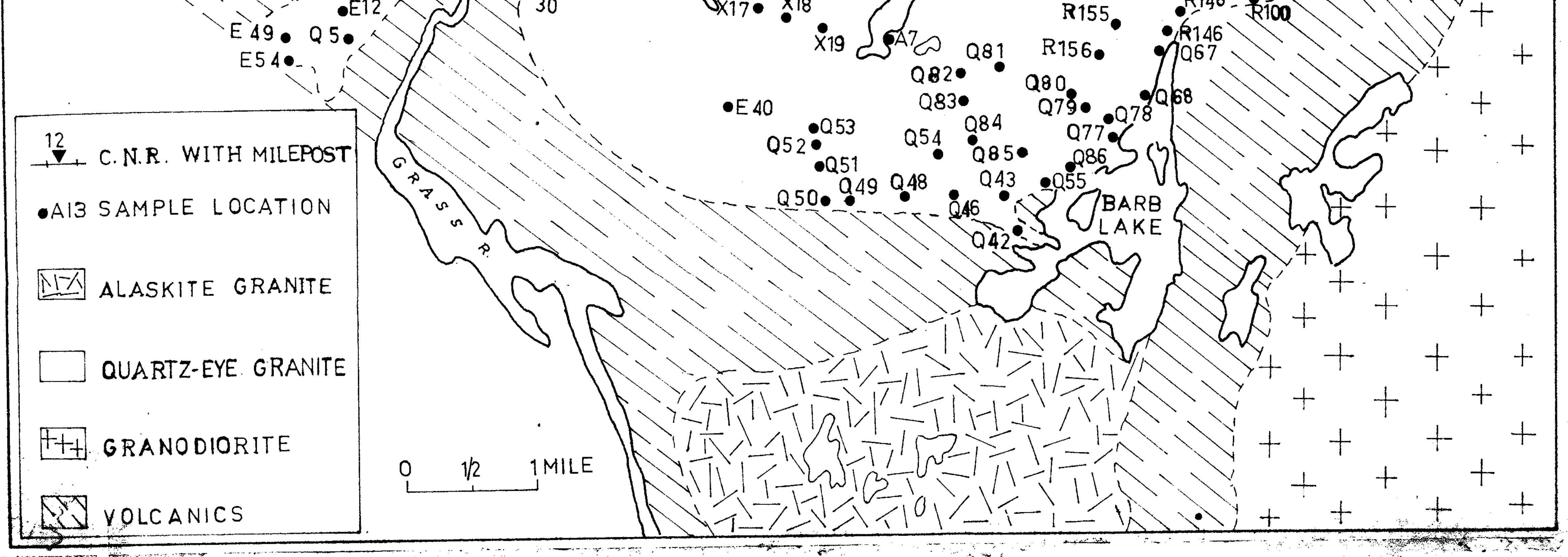


FIGURE-1. GEOLOGICAL MAP OF THE ELBOW LAKE - GRASS RIVER AREA, NORTHERN MANITOBA, SHOWING LOCATION OF SAMPLES, RAILROAD MILE POST AND POSITION INDEX (INSET).

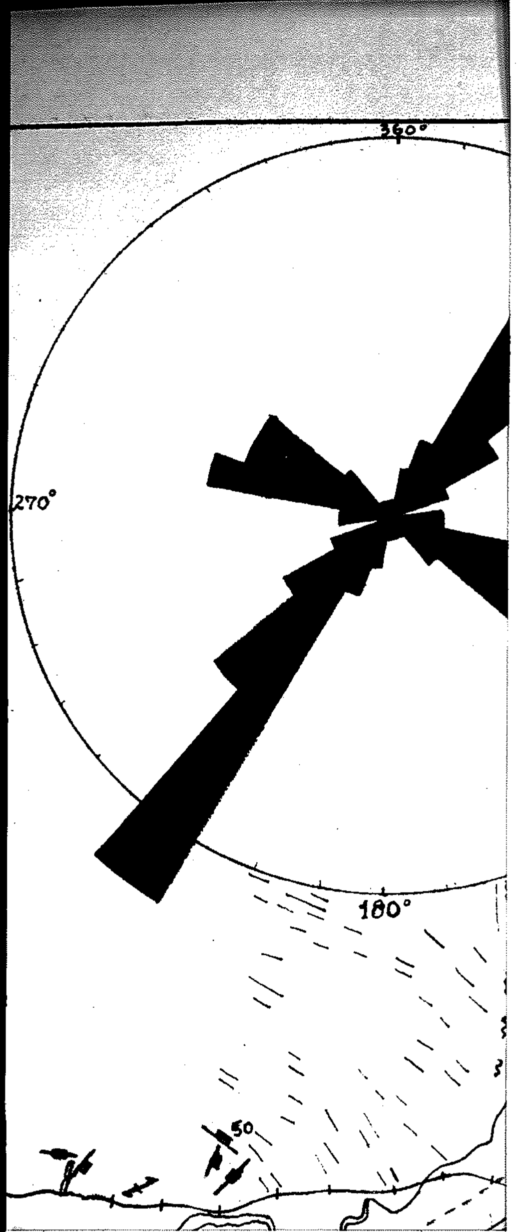
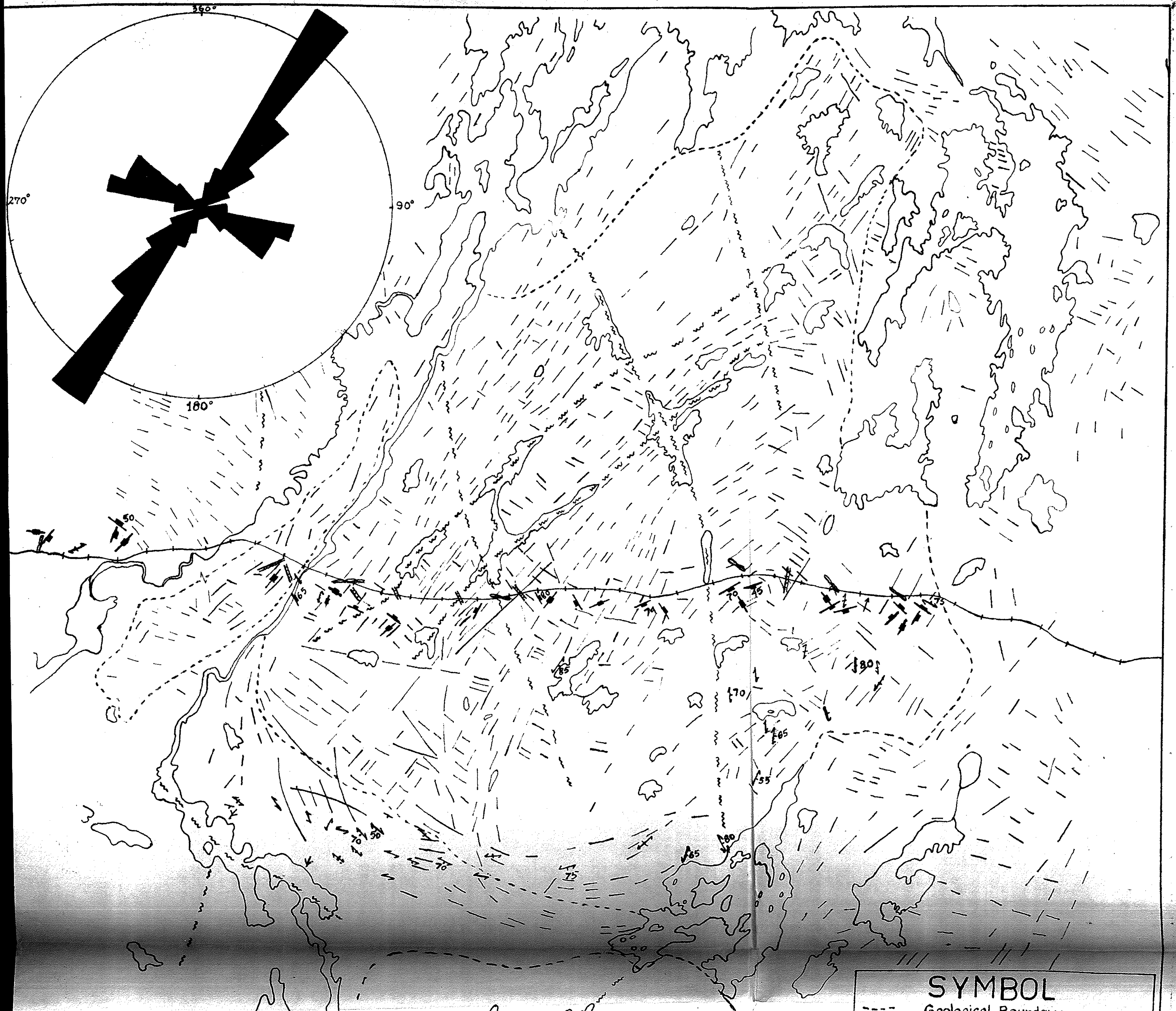
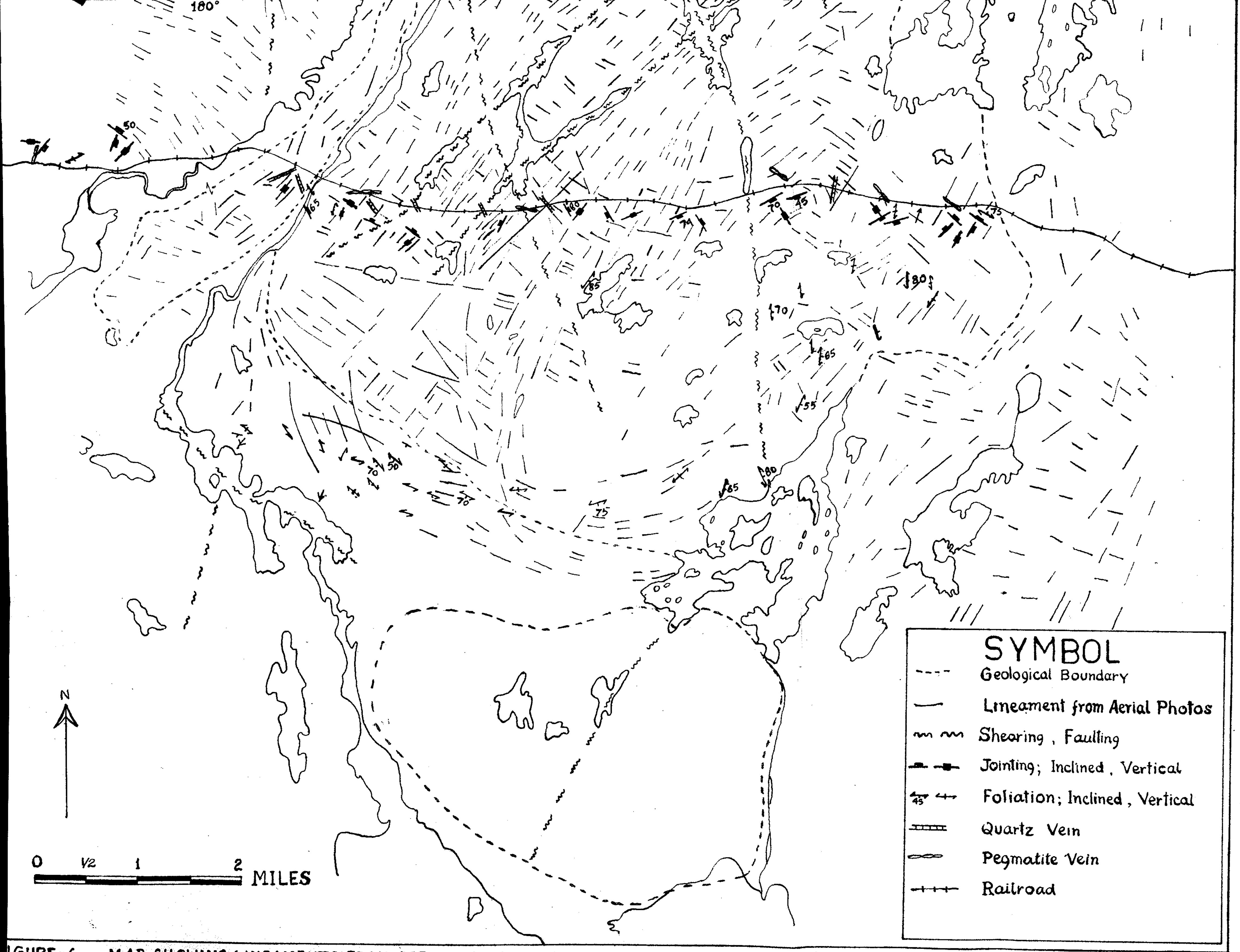


FIGURE 6

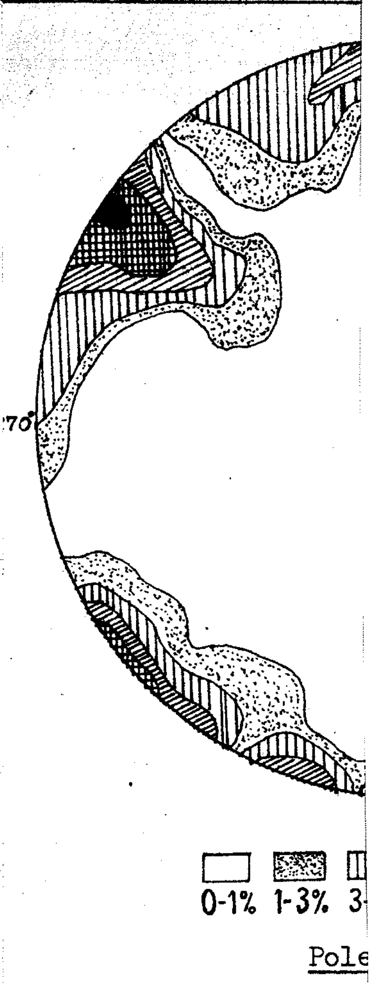
"Map of Lineaments which can be seen
in aerial photographs of the
Elbow Lake Stock"

To accompany (in pocket at back)
the thesis of A. A. Quaraishi


360°
90°
180°
270°
50
65
60
74
70
45
75
80
85
70
65
55
80
85
70
50
70
75
SYMBOL
Geological Boundary



IGURE-6 MAP SHOWING LINEAMENTS FROM AERIAL PHOTOGRAPHS, AND STATISCAL ANALYSIS OF LINEAMENTS PLOTTED IN A ROSE DIAGRAM. ALSO SHOWS PEGMATITE DIKES AND QUARTZ VEINS, FOLIATION, AND JOINTS OBSERVED IN THE FIELD.



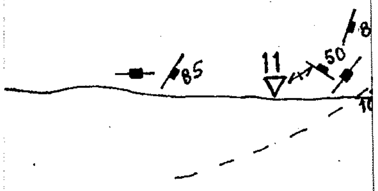


FIGURE 7

"Map of observed joints

in the Elbow Lake Stock"

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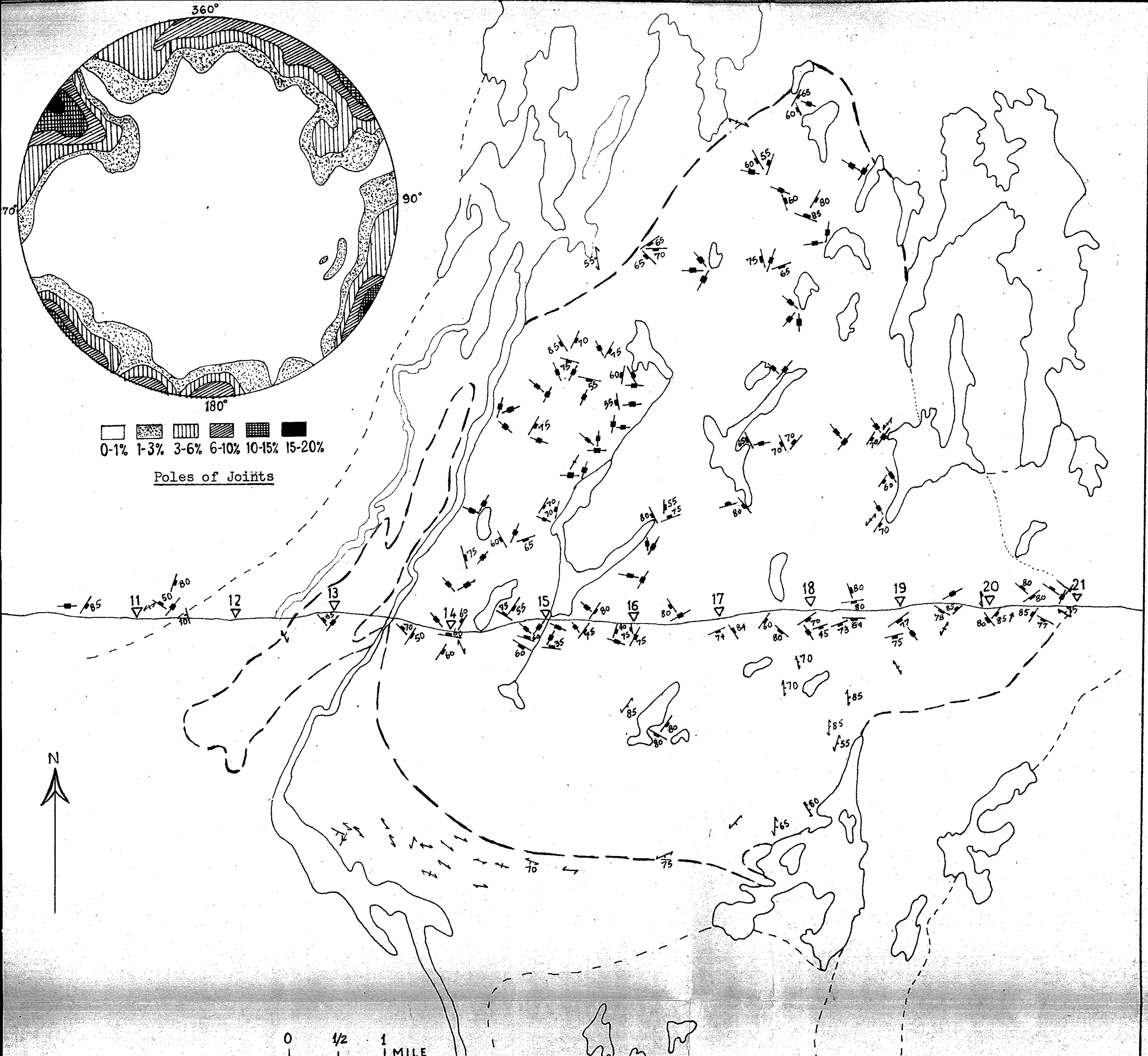
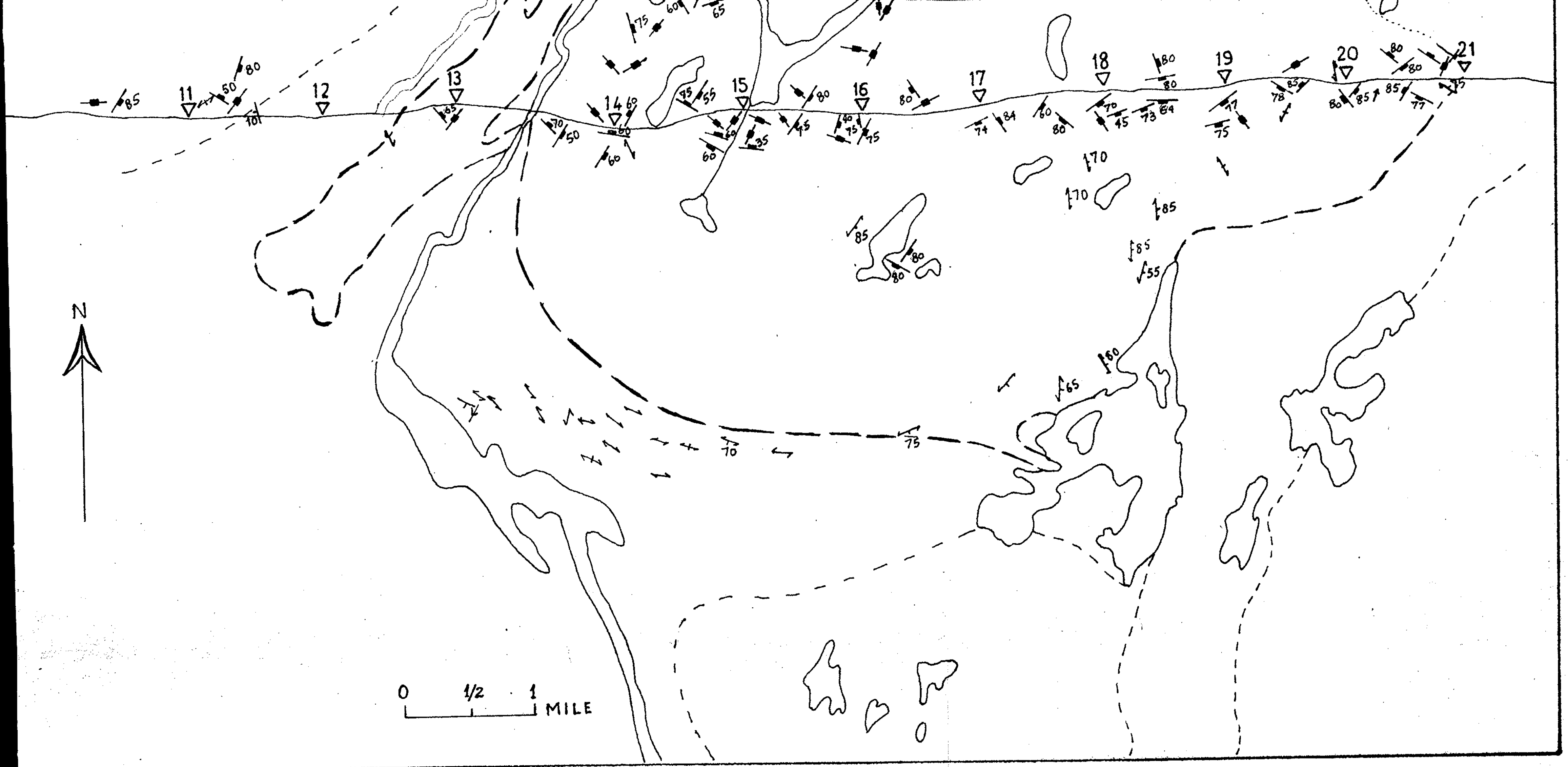

360°
90°
180°
70°
0-1%
1-3%
3-6%
6-10%
10-15%
15-20%
Poles of Joints
N
11
12
13
14
15
16
17
18
19
20
21
0
1/2
1
MILE



IGURE-7 MAP SHOWING OBSERVED JOINTS OF ELBOW LAKE STOCK. CONTOUR DIAGRAM OF JOINTS IS PLOTTED IN AN EQUAL AREA STEREOGRAM ON LOWER HEMISPHERE (INSET).

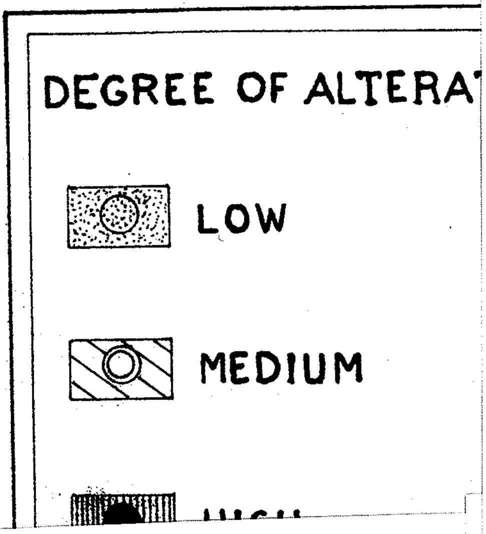


FIGURE 29

"Map of Intensity of Deuteric Alteration

To accompany (in pocket at back)

the thesis of A. A. Quaraishi

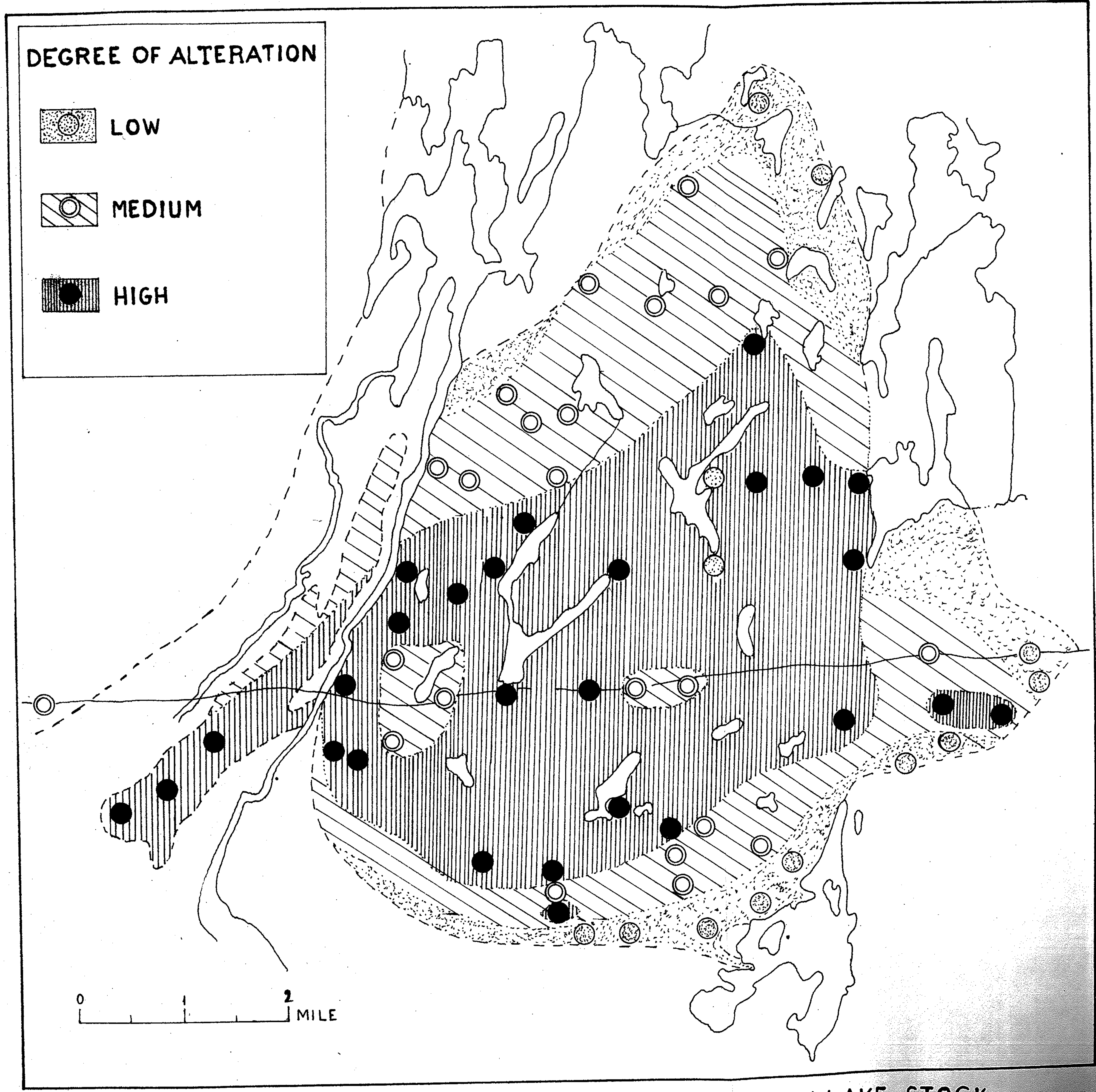


FIGURE-29. MAP SHOWING DEUTERIC ALTERATION OF ELBOW LAKE STOCK