EARLY PRECAMBRIAN BEDROCK GEOLOGY OF THE NORTHWEST ANGLE, LAKE OF THE WOODS COUNTY, MINNESOTA

A THESIS
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CRAIG EDWARD ZAMZOW

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ABSTRACT

The Northwest Angle is located in northwestern Minnesota, bounded by the Lake of the Woods, Manitoba, and Ontario. About 4 km^2 of outcrop scattered over 250 km^2 area was investigated, during ten weeks of field work.

The Northwest Angle contains four major rock units: a supracrustal unit; a tonalitic unit; a granitic unit; and a mafic dike unit. The supracrustal rocks show evidence of amphibolite prograde metamorphism; they are well foliated, and lineated. The foliation is given by compositional banding while the lineation is caused by the alignment of hornblende prisms in the plane of foliation. Tonalitic rocks show evidence of amphibolite grade metamorphism, the degree of foliation is variable. The granitic and mafic dike rocks show evidence of deuteric alteration; most outcrop areas contain massive rock, but two of the granite outcrop areas, both in the northwest part of the peninsula are foliated.

The supracrustal rocks appear to be composed of intermediate-mafic, calc-alkalic and tholeiitic volcanics mafic to ultra mafic hypabysal intrusions, and sediments which are mineralogically similar to the volcanics. The plutonic rocks of the area show varied metamorphic effects, but maintain an igneous texture overall.

The structure of the area is complex. The predominate structural grain is northeast - southwest and is

produced by foliations found in the supracrustal, and tonalitic units. The granite and supracrustal rocks which crop out in the northwest part of the peninsula have foliations trending northwest to southeast. It appears that northeast trending isoclinal folding of the supracrustal rocks is responsible for the northeast trending structural grain; northwest trending structural features are attributed to detachment, or rotation of large crustal blocks, during plutonic emplacement.

The apparent order of geologic events is: (1) deposition of supracrustal rocks; (2) isoclinal folding of supracrustal rocks along a northeast trend; (3) emplacement of tonalitic intrusives; (4) emplacement of granitic intrusives; (5) emplacement of large mafic dikes. Isoclinal folding of the supracrustal rocks may be comtemporaneous with tonalitic emplacement.

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INTRODUCTION

Location

The Northwest Angle is an area of approximately 518 km^2. It is bounded to the north, east, and south by the Lake of the Woods, and to the west by the Province of Manitoba (Fig. 1). This area lies within the southwestern part of the Superior Province of the Canadian Shield, and represents the northern most projection of the continental United States. The area investigated includes parts of eight 7.5 minute quadrangles (Fig. 2).

The Northwest Angle has only recently become accessible year around by road. Entry into the Northwest Angle is accomplished by taking Minnesota Highway 313 North from Warroad, Minnesota, then Manitoba Highway 12 North to Sprague, Manitoba, Provincial Road 308 northeast from Sprague, then east on Provincial Road 525 (Fig. 1). Boat launching is available at three fishing resorts all along Angle Inlet.

General Geology

The Northwest Angle is part of the Kenora Granite-Greenstone Block, an Early Precambrian terrane. A variety of rock types may be found including granitic and tonalitic intrusives as well as gneissic and amphibolitic supracrustal units. The supracrustal and tonalitic rocks show evidence of amphibolite prograde metamorphism.

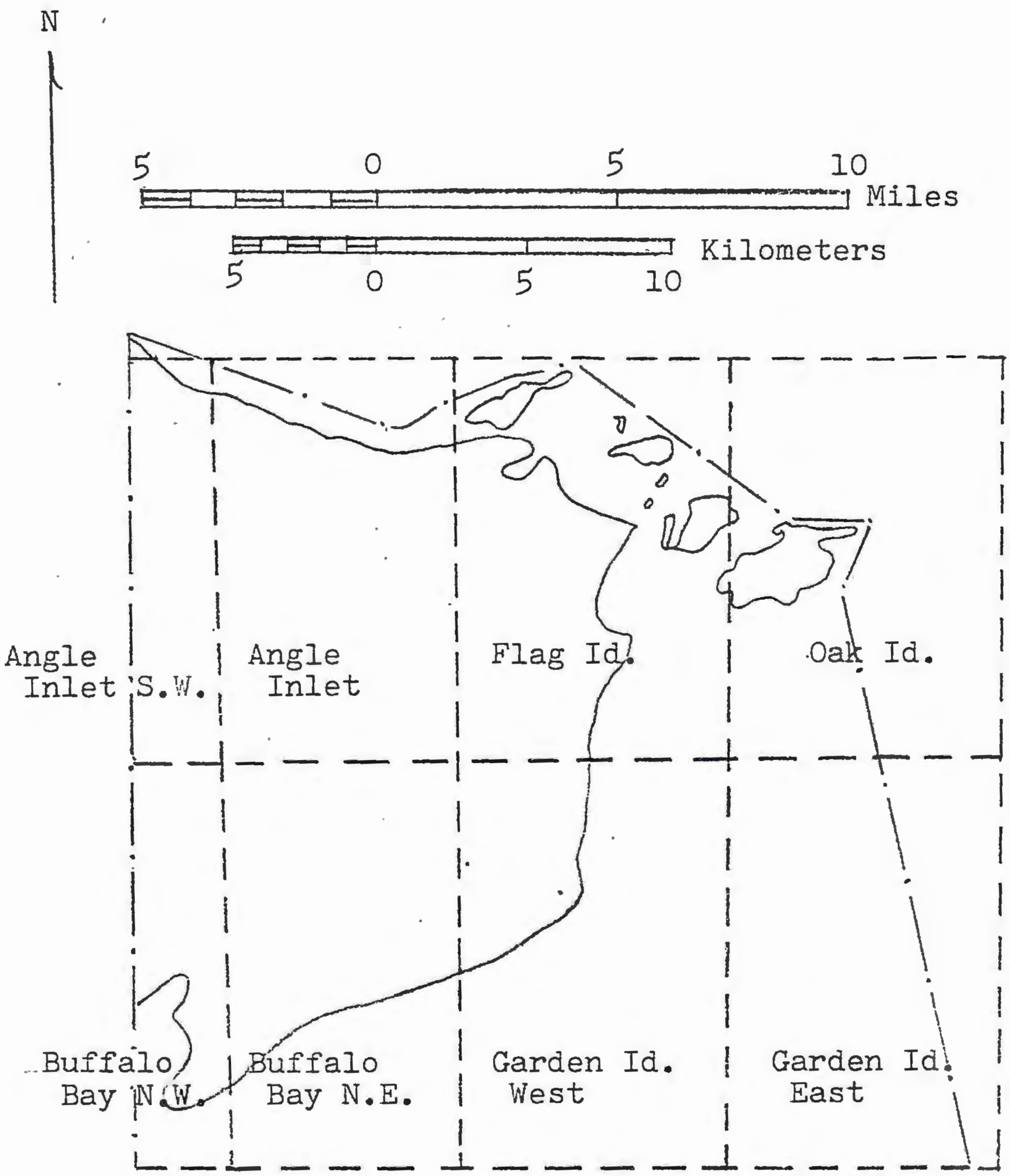


FIGURE 1 - INDEX MAP OF NORTHWEST ANGLE 1:250,000 SCALE

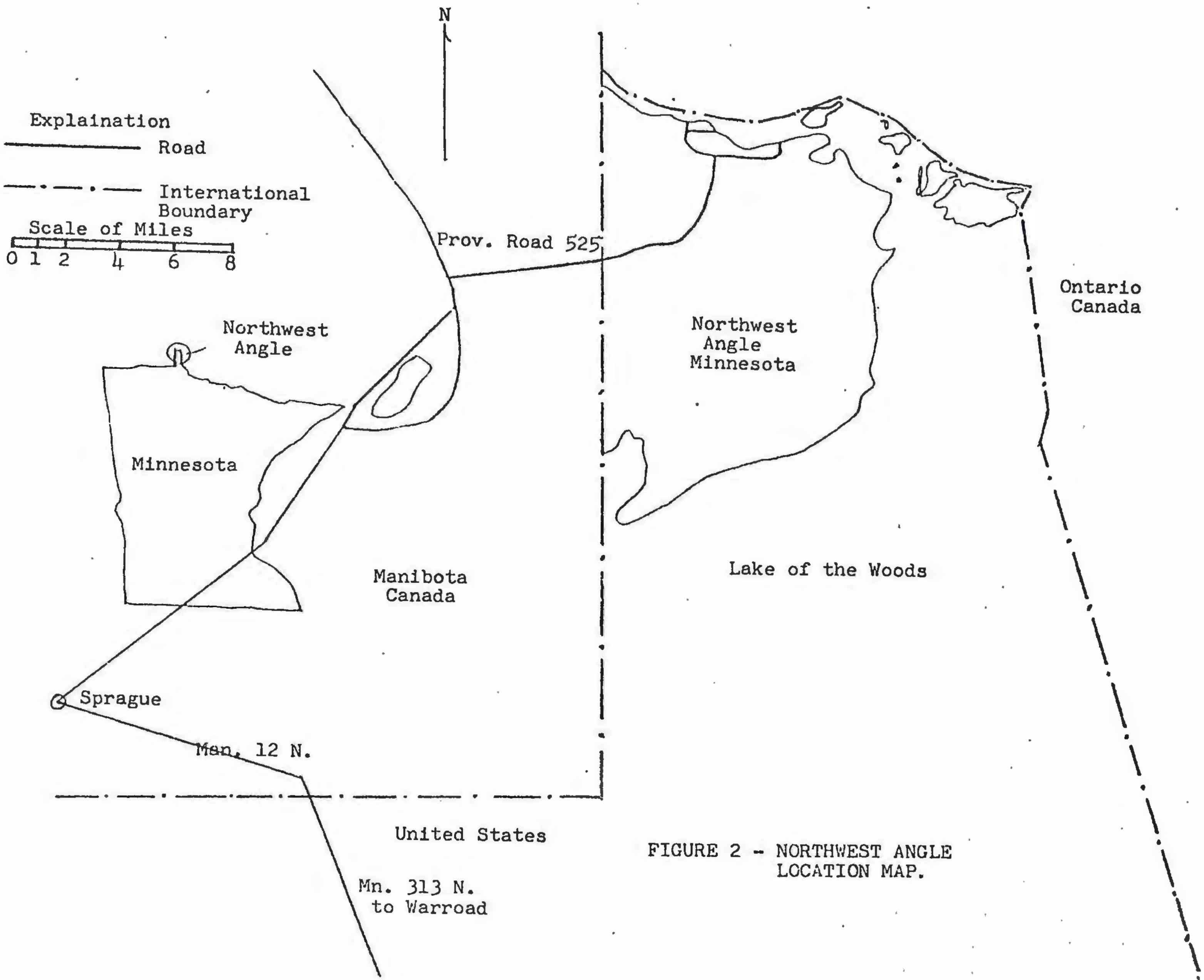


FIGURE 2 - NORTHWEST ANGLE LOCATION MAP.

Granitic plutonic rocks show evidence of deuteric alteration, and cataclasis.

Outcrops occur in the northern portion of the peninsula and on islands in the Lake of the Woods, however, exposures are limited because the terrain is swampy and has low relief (30 m total). Much of the area is a floating bog. A clayey soil was found on the islands, and along shorelines locally. The high ground in the northern part of the peninsula is sandy to the west of section 8, 167/34, and clayey north and east of section 8, 167/34.

Regional Geologic Setting

The Kenora Block is a granite-greenstone terrane. It is bounded by granite-gneiss terranes of the English River Block to the north, and the Quetico Block to the south (Fig. 3). Paleozoic cover is found 75 km to the west in Manitoba.

The western part of the Kenora Block contains large continuous expanses of greenstone, large multiphase tonalitic intrusions, and granitic intrusions which generally show little variation in composition. The greenstones of the area are composed of volcanics, related sediments, and mafic to ultramafic sills. The tonalitic intrusions are composed of tonalite and granodiorte. A well studied example of this type intrusive is the Aulneau Batholith. It is 1,250 km^2, oval shaped, and composed of multiple phases (granodiorite-trondhjemite) (Ziehlke 1974). The

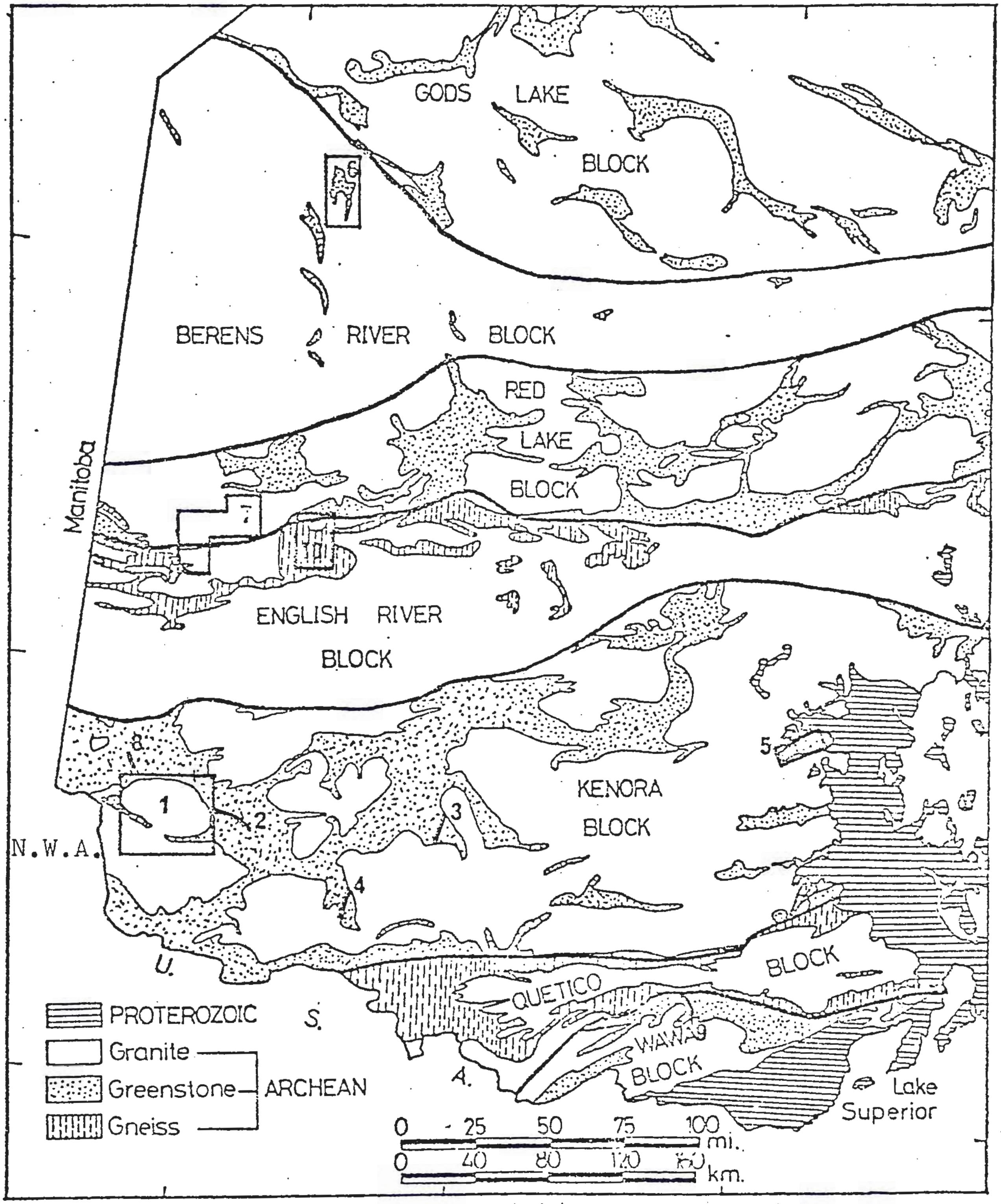


FIGURE 3 - GENERALIZED GEOLOGIC MAP AFTER BRISBIN AND WILSON, (1974).

granitic plutons of the region vary in size, but maintain a fairly consistant granitic composition. The tonalitic intrusions generally appear older than granitic intrusions in the same area (Ayres 1974) both intrude and metamorphose the greenstones.

The greenstones in the western part of the Kenora Block commonly show greenschist metamorphism elevation in grade occurs only within 350 m to 1 mi. from plutonic contacts (Ziehlke 1974) (Brown 1974). Alteration of the plutonic rocks is generally restricted to late deuteric alteration, however, cataclastic textures are common within 2 km of contacts. Sheared greenstones and mylonized plutonic rocks are found right along contacts.

The greenstones of the region generally have a strong east-west vertical, axial planar, foliation, as a result of isoclinal folding. Locally this trend is disrupted by intervening plutons. The plutonic rocks are generally foliated parallel to their contacts. This foliation is caused by the parallelism of platy mafic clots, and commonly varies from strong along the pluton's boundaries, to weak or nonexistant near the center of the pluton

Purpose of Study

This study was initiated for the purpose of assessing the bedrock geology of the Northwest Angle. It entails four major objectives; (1) to produce an outcrop map of the Northwest Angle on a 1:24,000 scale; (2) to study and describe the rock of the area megascopically, microscopically, and chemically to deciper the nature of the protoliths, and metamorphism; (2) to describe and interpret the structure of the area; and (4) to interpret the geologic history as it pertains to the bedrock.

Method of Study

Field work was accomplished in a six week period during the summer of 1977 and a three week period during the Fall of 1978. Mapping of outcrops was done on a 1:24,000 scale with 7.5 minute series topographic base maps. This was accomplished by field checking prominate highpoints over five feet in elevation. The only prominate high points not checked are in Sections 24, and 36, 166/35. Both of these areas are inaccessible by normal means. The more prominent high points were reinvestigated if no outcrop was found initially. Bedrock was found at two locations upon rechecking, but both were covered with 5 cm to 10 cm of soil. Bedrock with less than five feet of topographic expression would probably be covered with thick vegation.

Outcrops were sampled and photographed. Structural data were obtained with the aid of a Brunton Compass. Samples and structural data were obtained at over 500 sites.

Microscopic petrography was performed on 115 thin sections. Modal analysis was accomplished on 25 thin sections by grid counting at least 700 points on each thin section. Slabs were stained for potassium and calcium to aid in determining the feldspar composition. Ten samples of rock from the Northwest Angle were analyized by the Minnesota Department of Natural Resources, Hibbing, using a Perkin-Elmer Model 603 Atomic Absoption Sectrophotometer. Analyses were reported as weight percent oxides, for the common rock forming oxides.

Previous Work

Previous work concerning the geology of the Northwest Angle has generally been restricted to reconnaissance of the more accessible outcrops. The area was visited for a few days in 1927 by F. F. Grout. He submitted to the Minnesota Geological Survey a brief preliminary report (unpublished) on the accessible outcrops in the northern part of the area, particularly those outcrops near the Rader Feldspar Mine. This report included a reconnaissance map of the area (1:63,360 scale) denoting six major rock types. Also included was a map of the massive pegmatite around the Rader Feldspar (1:2133 scale). This report is on file at the Minnesota Geological Survey, however, Grout's 1927 notebook which presumably includes details and rock descriptions (Goldich and others 1961), is not available at this time.

Goldich and others (1961) dated the pegmatites of the area. Using muscovite from the "mine area" section 6

167/33 and biotite from section 32 168/34 a 2,480 m.y. (K-Ar age) was determined.

R. W. Ojakangas (1976) did the most recent work in the area. It included a scintillometer survey over outcrops of the various units, and interpretation concerning uranium potential for the area.

The Canadian portion of the Lake of the Woods region has been mapped by the Ontario Division of Mines, and is currently being studied in greater detail by personnel of the Centre for Precambrian Studies at the University of Manitoba. These data are included on O.D.M. map 2115, Kenora-Fort Francis Sheet, (Davies and Pryslak 1967) and the Centre for Precambrian Studies, University of Manitoba annual reports, part 2, research, (1974-1976).

Acknowledgements

The author would like to thank Dr. D. M. Davidson Jr., and Dr. R. W. Ojakangas both of the University of Minnesota, Duluth, who suggested the study and served as thesis advisors, their guidance, advice and encouragement greatly aided the study. Assistance given by Dr. J. A. Grant of the University of Minnesota, Duluth concerning petrology was greatly appreciated. The writer also gratefully acknowledges L. W. Gladen of the Minnesota Department of Natural Resources, Hibbing, for helpful discussions and suggestions during the study.

The Minnesota Geological Survey is gratefully acknowledged for financial support, to aid in payment of field and laboratory expenses. Whole rock analyses preformed by the Minnesota Department of Natural Resources, Hibbing, were very helpful concerning interpretation of the supracrustal rock, and are greatly appreciated. The writer wishes to acknowledge R. E. Leeach of Union Carbide for contributing a 1:24,000 scale base map of the area.

Ron Johnson and Steve Olson, both the University of Minnesota, Duluth graduates are gratefully acknowledged for serving as field assistants. Special thanks is extended to my mother, B. A. Zamzow, who aided in the preparation of the manuscript.

DESCRIPTION OF ROCKS FROM THE NORTHWEST ANGLE

Nomenclature and Classification

The rocks which exhibit intrusive igneous texture are classified on the basis of composition and texture. The nomenclature used is that recommended by the U.U.G.S. subcomission on the systematics of igneous rocks (Strecheisen 1973).

The supracrustal unit is classified on the basis of composition and structure. The amphibolites are banded and composed of predominately plagioclase and hornblende; they contain no potassium feldspar. The hornblende gneiss shows banding and is composed mainly of plagioclase, hornblende, biotite, and potassium feldspar. Both the amphibolite and gneiss display granoblastic texture, and exhibit both foliation and lineation. A minor phase within the supracrustal unit, soapstone is composed of talc, tremolite and quartz. Foliation due to alignment of talc aggregates was noted locally, however, the soapstone is generally isotropic

Northwest Angle Supracrustal Unit

The supracrustal unit of the Northwest Angle includes hornblende gneiss, amphibolite, and soapstone. The hornblende gneiss and amphibolite are similar in texture, composition, and outcrop morphology. Distinction between them is based on the presence of microcline and the percentage of mafic constituents. The soapstone differs from both the gneiss and amphibolite in texture, composition, and outcrop morphology.

Hornblende Gneiss

Outcrops of hornblende gneiss occur mainly on the islands in the northeast part of the Northwest Angle, although a few outcrops were also found on the mainland (Plate 1).

This unit is composed of fine-grained, granular, hornblende gneiss, which constitutes about 40% of the supracrustal outcrop area. It is light gray in color on both fresh and weathered surfaces. Banding is commonly present in the form of white or pink feldspar rich bands (0.5 mm - 2 cm), and dark mafic rich bands (0.5 - 2 cm) (Plate 2).

Locally, the hornblende gneiss appears agglomeratic. Plagioclase rich bombs and lapilli 2 cm to 20 cm long and 1 to 5 cm wide are more resistant to weathering than the matrix as illustrated in Plate 3. Because of incomplete exposure the exact thickness and extent of this unit are impossible to ascertain, however, agglomeratic beds range in thickness from 5 to 20 m and have been traced along strike for up to 1 km minimum. The agglomeratic beds make up about five percent of the hornblende gneiss unit. Contacts between banded gneiss and agglomeratic gneiss are sharp and coincident with foliation (Plate 4).

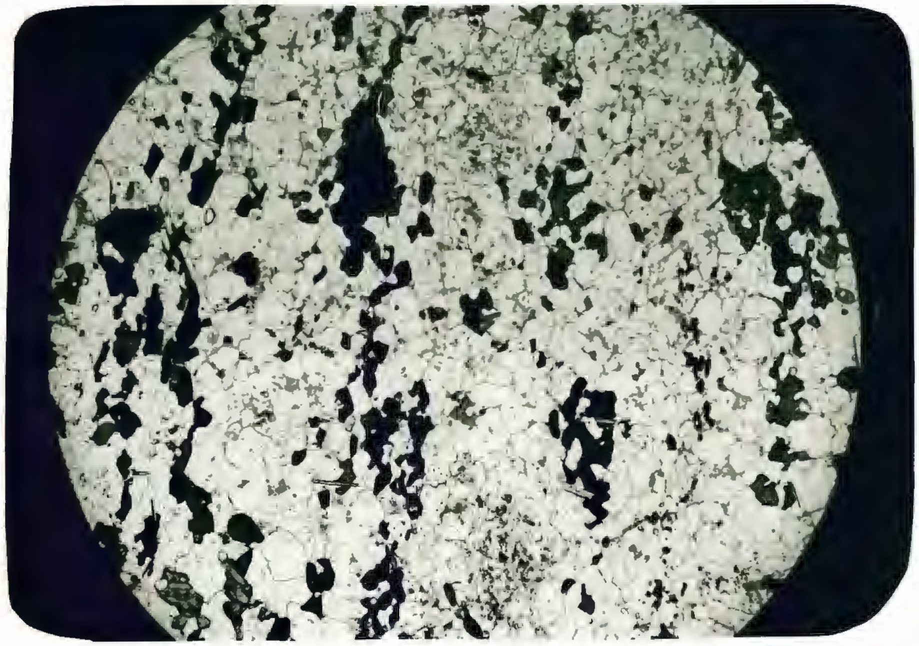


PLATE 2 - PHOTOMICROGRAPH SHOWING GNEISSIC BANDING IN GNEISS. MAJOR MINERALS INCLUDE, PLAGIOCLASE (LIGHT) AND HORNBLENDE (DARK). FIELD OF VIEW 6.2 mm LOCATION 157 (SEE PLATE 1), MAGNESON'S ISLAND.

PLATE 3 - CHARACTERISTIC AGGLOMERATIC GNEISS TEXTURE. LOCATION 114. (SEE PLATE 1), SOUTH SIDE OF BRUSH ISLAND.

PLATE 4 - TUFFACEOUS GNEISS OVERLYING GNEISS ALONG A CONTACT. LOCATION 213 (SEE PLATE 1), SMALL ISLAND TO SOUTH OF EBERHARD ISLAND. WHITE LINE IS APPROXIMATELY 1 cm WIDE.

The hornblende gneiss is generally well foliated. The foliation is caused by parallelism of feldspar, and hornblende rich bands, and lenses which range in width from 0.5 mm to 2 cm. Locally planar parallelism of biotite flakes provides a foliation which is coincident with the banding. Generally the foliation is pervassive in trend over the entire outcrop, however, certain outcrops on the mainland show variation in strike of up to 20°. In some cases this variation can be directly attributed to local deformation by intruding pegmatite dikes.

Lineation is a common feature of the hornblende gneiss. The lineation is caused by parallel to subparallel alignment of hornblende prisms. Local variations are difficult to detect because of the difficulty involved with obtaining a measurement on small grains, however, the orientation of the lineation does not appear to vary greatly within a single outcrop.

The hornblende gneiss is often found spatially associated with granite. In such cases, the granite appears to "hold up" the center portion of the outcrop with hornblende gneiss occurring as flanking exposures. The contacts between the granite and gneiss are sharp, but no chill margins were noted. Pegmatite dikes were found throughout the hornblende gneiss. They are 1 cm to 4 m wide, granitic in composition, and cross-cut foliation. Locally these dikes constitute up to ten percent of the outcrop. Gneiss-pegmatite contacts are sharp, but again the pegmatite does not exhibit chilled margins.

The hornblende gneiss unit is completely recrystallized consisting of a metamorphic assemblage of; plagioclase, microcline, quartz, hornblende, biotite, sphene, epidote, apatite, allanite, and opaques (Table 1). One sample contains less than one percent relict plagioclase crystals and four samples contain metamorphic augite. The hornblende gneiss shows very little alteration of the primary metamorphic assemblage. Minor sericitization of plagioclase or chloritization of biotite was noted locally.

TABLE 1 - MODES, IN VOLUME PERCENT, OF HORNBLENDE GNEISS

	Tuffaceous Gneiss				Banded Gneiss							
	Hb.	Bio. Hb.	Bio.	Cpx. Hb.	Bio.			Hb. Bio.		Hb.		
Sample No.#	213	190a	218a	308b	64	69	112d	265	170	65	106	168b
Plagioclase	38	76	63	36	58	80	70	59	75	70	70	65
Microcline	15	2	15	13	19	4	7	1	1	2	1	18
Quartz	2	5	18	2	11	6	16	2	13	11	10	5
Hornblende	44	16	-	25	-	-	-	10	1	15	15	15
Biotite	-	1	4	-	10	8	7	20	9	-	-	-
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-
Sphene	1	1	Tr.	Tr.	1	Tr.	Tr.	Tr.	0.5	1	Tr.	2
Epidote	Tr.	Tr.	Tr.	6	1	1	Tr.	8	Tr.	1	5	Tr.
Apatite	Tr.	-	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	0.5	Tr.	Tr.	Tr.
Allanite	-	-	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Opaques	Tr.	Tr.	Tr.	Tr.	Tr.	1	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Muscovite	-	-	Tr.	-	-	Tr.	-	-	Tr.	-	-	-
Garnet	-	-	-	-	-	-	-	-	-	-	-	-
Augite	-	-	-	18	-	-	-	-	-	-	-	-
Calcite	-	-	Tr.	-	-	-	-	-	-	-	-	-
Zircon	-	-	-	-	-	-	-	-	-	-	-	-
Total (Vol.%)	100	100	100	100	100	100	100	100	100	100	100	100
No. of Points*	V.E.	V.E.	839	887	936	779	V.E.	V.E.	V.E.	V.E.	V.E.	V.E.
An. Content of Plagioclase+	31	21	20	41	23	20	20	40	20	24	24	21

Sample numbers refer to Plate 1
* V.E. = Visual estimate using thin section.
+ N.D. = No determination.

TABLE 1 CONT.

	Banded Gneiss											
	Hornblende Gneiss				Biotite Hornblende Gneiss							
Sample No.	208a	178	268	302	192	110a	121	213b	308a	157a	164	211
Plagioclase	32	45	65	65	65	65	65	40	60	76	75	64
Microcline	30	9	7	18	1	15	10	20	1	2	4	10
Quartz	3	2	1	5	10	9	Tr.	5	2	5	5	10
Hornblende	35	40	23	15	15	10	23	35	37	12	12	13
Biotite	-	-	-	-	8	1	1	Tr.	Tr.	1	4	Tr.
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-
Sphene	Tr.	1	2	2	1	Tr.	Tr.	Tr.	Tr.	1	Tr.	Tr.
Epidote	Tr.	2	2	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	2	Tr.	2
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	1	Tr.	1
Allanite	-	Tr.	Tr.	Tr.	Tr.	-	-	-	-	Tr.	-	Tr.
Opaques	Tr.	1	Tr.	Tr.	Tr.	Tr.	1	Tr.	Tr.	Tr.	Tr.	Tr.
Muscovite	-	-	-	-	-	-	-	-	-	-	-	-
Garnet	-	-	-	-	-	-	-	-	-	-	-	-
Augite	-	-	-	-	-	-	-	-	-	-	-	-
Calcite	-	-	-	-	-	-	-	-	-	-	-	-
Zircon	-	-	-	-	-	-	-	-	-	-	-	-
Total (Vol.%)	100	100	100	100	100	100	100	100	100	100	100	100
No of Points	V.E.	784	V.E.	V.E.	V.E.	V.E.	V.E.	V.E.	V.E.	999	V.E.	V.E.
An. Content of Plagioclase	N.D.	41	23	21	21	17	24	39	25	25	25	20

TABLE 1 CONT.

	Banded Gneiss					
			Cpx. Hb. Gniess			
Sample No.	303	128a	97b	305	203a	169
Plagioclase	53	45	40	69	44	40
Microcline	15	5	10	4	1	1
Quartz	15	10	5	10	Tr.	Tr.
Hornblende	4	30	30	5	34	15
Biotite	7	10	-	-	-	-
Chlorite	-	-	-	-	-	-
Sphene	Tr.	Tr.	1	Tr.	1	Tr.
Epidote	6	Tr.	2	9	15	3
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Allanite	Tr.	Tr.	-	1	Tr.	-
Opaques	Tr.	-	1	Tr.	Tr.	Tr.
Muscovite	-	-	-	-	-	-
Garnet	-	-	-	-	-	-
Augite	-	-	11	2	5	35
Calcite	-	-	-	-	-	-
Zircon	-	-	-	-	-	-
Total (Vol.%)	100	100	100	100	100	100
No. of Points	V.E.	V.E.	V.E.	V.E.	V.E.	V.E.
An. Content of Plagioclase	N.D.	N.D.	40	30	39	38

The overall texture is granoblastic polygonal (Plate 5), idioblastic grains of hornblende biotite and epidote form rational boundaries against polygonal grains of plagioclase and quartz. The microcline appears interstitial.

Plagioclase is commonly the most abundant mineral constituent, composing 30 to 76% of the rock. It is granoblastic polygonal, and ranges in size from 0.2 mm - 0.5 mm) in most samples. Many crystals are untwinned.

PLATE 5 - PHOTOMICROGRAPH SHOWING GRANOBLASTIC TEXTURE IN HORNBLENDE GNEISS. MAJOR MINERALS INCLUDE PLAGIOCLASE (LIGHT) AND HORNBLENDE (DARK). FIELD OF VIEW 6.2 mm LOCATION 178 (SEE PLATE 1), NE CORNER OF SECTION 11, 167/34.

Some albite twins are generally present; carlsbad and pericline twins are uncommon. The a-normal method was used to determine plagioclase composition in 26 of the 29 samples. The composition ranged from oligoclase to andesine (An 17 - An 41) (Table 1). Many of the plagioclase crystals are discrete, but some are poikiloblastic. Intergrowths of quartz, epidote, apatite, biotite, sphene, sericite, muscovite, opaques and hornblende (minute - 0.1 mm) were noted. Secondary alteration of the plagioclase is absent or limited to minor sericitization. Kinked twin lamelli were noted in two of the samples, both from Brush Island.

Hornblende is the other major phase constituting a trace to 45% of the rock (Table 1). Idioblastic prisms (0.1 - 1.5 mm) are most common but larger poikloblasts (1.0 - 3.0 mm) are present locally. Intergrowths of quartz, plagioclase, epidote, biotite, and sphene were noted, but most grains are discrete or have only minor intergrowths of quartz and plagioclase. The hornblende, generally shows no strain or secondary alteration.

Quartz is a common phase making up a trace to 18% of the gniess. The crystals are xenoblastic (0.05 - 0.5 mm) larger grains are polygonal while smaller grains (0.1 mm) usually appear as rounded blebs intergrown in hornblende or plagioclase. Most of the larger polygonal grains are found in microcline-rich bands or as 1 mm to 2 mm wide veins. The quartz crystals are generally discrete but intergrowths of biotite, epidote, sphene and opaques were found in some of the larger grains. The quartz shows no secondary alteration, however, some of the larger grains do exhibit undulose extinction.

Microcline is another common phase constituting 1 to 30% of the rock. It is found as granoblastic polygonal, or interstitial crystals (0.1 - 1.0 mm). The microcline is concentrated in 0.5 mm to 1 cm wide bands where it makes up to 50% of the band. The microcline-rich bands tend to be enriched in quartz and biotite, and depleted in Hornblende. Most of the microcline crystals show cross-hatch twinning, and microperthite, or crytoperthite structure. Other intergrowths are uncommon but quartz, biotite, plagioclase, epidote, sphene, apatite, and hornblende (minute - 0.1 mm) were noted. Secondary alteration of the microcline is present in only a few samples, dusty koalinite is most common. Shadowy extinction was noted on one sample, from the south side of Eberhard Island.

Biotite was found in 17 of the 29 samples, constituting a trace to 20% of the rock. Elongate idioblastic plates (0.1 - 0.5 mm) are generally concentrated in 1 mm to 5 mm wide bands which tend to be depleted in hornblende and enriched in quartz and microcline. Most of the biotite crystals are discrete but some intergrowths of quartz, epidote and apatite (minute) were noted. The biotite is generally unaltered, but minor alteration to chlorite is present in a few samples.

Augite is present in 4 of the 29 samples ranging from 2 to 18% occurring as (0.1 - 1.0 mm) xenoblastic poikiloblasts with intergrowths of plagioclase, quartz, hornblende, epidote, apatite, microcline, and sphene (minute - 0.2 mm). Many of the grains have corroded boundaries and show alteration along cracks and cleavage to a reddish-brown opaque mineral. Augite is commonly found in association with hornblende, epidote, and sphene. No biotite is present in samples which contain augite.

Epidote is present in all the samples of hornblende gneiss, ranging from a trace to 15%. It varies from xenoblastic blebs to idioblastic prisms, and ranges from 0.1 mm to 1 mm in size. Common intergrowths include quartz, and mimetic crystals or allanite, less common are plagioclase and biotite. The epidote is generally evenly distributed throughout the sample, but a few samples with a greater abundance of epidote have 0.5 mm to 5 mm wide bands that are epidote enriched. Secondary alteration of the epidote was not noted.

Common accessory minerals include; sphene, apatite, allanite, and opaques. Sphene occurs as minute to 0.5 mm xenoblastic blebs which constitute a trace to two percent of the rock. Most crystals are discrete but a few minute intergrowths of quartz were noted. Apatite is present as discrete idioblastic prisms (minute - 0.1 mm) and makes up a trace to one percent. Opaques compose a trace to one percent of the rock. They occur as (0.5 mm) blocky crystals, or (0.1 mm) blebs. They were also found as lacy alterations of augite or sphene. Allanite occurs solely as minute intergrowths in epidote.

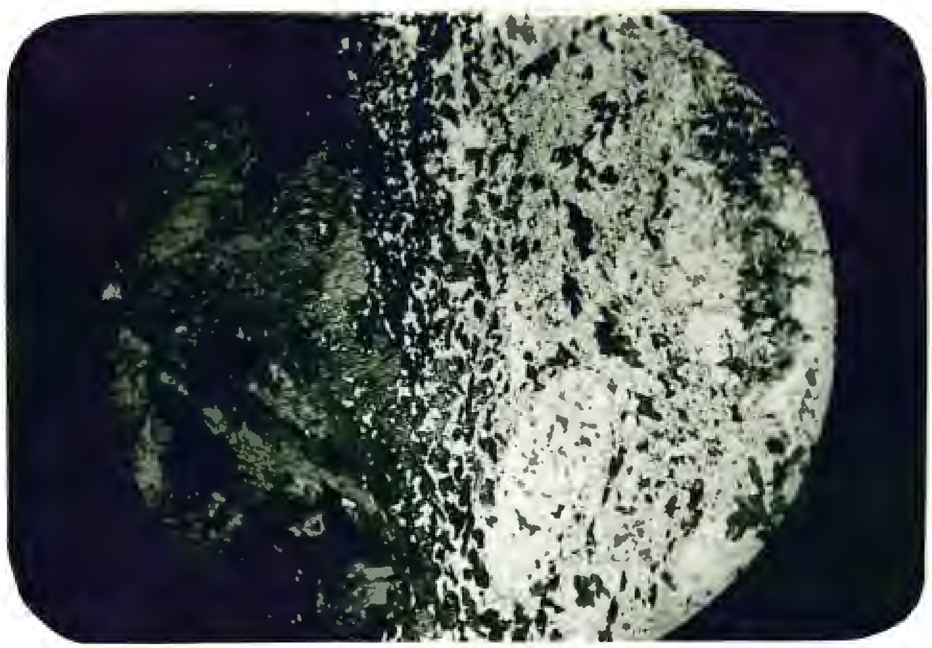
Amphibolite

Outcrops of the amphibolite occur mostly on a east-west trending ridge in the northeast part of the mainland. Amphibolite also crops out on islands in the Lake of the Woods (Plate 1).

This rock is composed of fine to medium-grained amphibolite, and constitutes about 60% of the supracrustal outcrop area. It is greenish-gray to black on fresh surfaces. Weathered surfaces generally maintain the same color but are locally stained a reddish-brown. Light gray plogioclase-rich bands (0.5 mm - 5.0 mm) wide give a laminated texture to many of the outcrops, however, about five percent of the amphibolite outcrop area is massive, and about three percent is agglomeratic. The massive beds of amphibolite range in thickness from 2 to 5 m and locally contain pillow structures (Plate 6). The agglomeratic amphibolite has plagioclase-rich bombs and lapitti 1 cm to 15 cm long and 0.5 cm to 2.0 cm wide in a hornblende-rich matrix (Plate 7). Because of limited exposure it is impossible to determine the exact thickness at all locations, but exposures up to 15 m thick and 300 m along strike have been noted. The amphibolite is generally well foliated, showing gneissic banding of light gray, plagioclase-rich band.

PLATE 6 - PILLOWS IN AMPHIBOLITE UNIT. LOCATION 128 (SEE PLATE 1), SEC. 32, 168/33.

A



B

PLATE 7 - CHARACTERISTIC AGGLOMERATIC AMPHIBOLITE TEXTURE, OUTCROP "A", PHOTOMICROGRAPH "B". MAJOR MINERALS INCLUDE PLAGIOCLASE (LIGHT) AND HORNBLENDE (DARK). FIELD OF VIEW 6.2 mm. LOCATION 186 (SEE PLATE 1), EAST-CENTRAL PART OF SEC. 7, 167/33.

(0.5 - 1.5 mm) and dark gray to black, hornblende- rich bands (0.5 - 1.5 mm) (Plate 8). Locally quartz veins (microscopic - 25 cm), or planar parallelism of biotite flakes provide a foliation coincident with the banding. The strike of this foliation is prevassive over an outcrop, however, variations in dip direction were found.

Hornblende lineation is generally present in the amphibolite. It is caused by the parallel to sub - parallel alignment of hornblende prisms. Local variations are difficult to detect, because of small grain size, but the orientation generally shows little local variation provided the dip direction remains constant.

The amphibolite which crops out on Oak Island is associated with the blastoporpyritic granodiorite. The contact is sharp, but there is no chilled margin on the granodiorite. Dikes of granodiorite (1 cm - 1 m) wide are found within the amphibolite (Plate 9). Most are concordant, but some of the smaller dikes cross-cut foliation. Locally the smaller dikes show ptymatic folds and at one location boudinage of a 1 m wide dike was noted.

Dikes and large pods of granitic pegmatite intrude the amphibolite. Contacts are sharp, but there are no chilled margins on the pegmatite. The dikes are (1 cm - 2 m) wide, the pods range from (50 - 15,000 m^2). The dikes are both concordant and discordant. Most of the pods are elongate along strike within the amphibolite unit.

PLATE 8 - PHOTOMICROGRAPH SHOWING GNEISS BANDING IN AMPHIBOLITE. MAJOR MINERALS INCLUDE PLAGIOCLASE (LIGHT) AND HORNBLENDE (DARK). FIELD OF VIEW 6.2 mm. LOCATION 126 (SEE PLATE 1), NORTH SHORE OF HONEYMOON ISLAND.

PLATE 9 - GRANODIORITE DIKE IN BANDED AMPHIBOLITE. LOCATION 233 (SEE PLATE 1), EAST END OF OAK ISLAND.

The pods are generally concordant, but cross-cut foliation locally.

Most of the amphibolite samples examined are completely recrystallized to a metamorphic assemblage of plagioclase, quartz, hornblende, sphene, epidote, apatite and opaques (Table 2). Biotite, augite, garnet and allanite are less common constituents.

Secondary alteration of the primary metamorphic assemblage is uncommon. Minor sericitization of plagioclase and chloritization of biolite was noted in a few samples. Augite is commonly altered along cracks and cleavage to a reddish-brown opaque mineral. The overall texture is granoblastic polygonal (Plate 10). Idioblastic grains of hornblende form rational boundries against polygonal grains of plagioclase and quartz.

Plagioclase is a major constituent composing 7 to 77% of the rock. It is xenoblastic polygonal (0.1 - 1.0 mm). Untwinned crystals are common but a few albite twins were noted in most thin sections. Carlsbad and pericline twins are uncommon. The a-normal method was used to determine the plagioclase composition in 26 of 39 samples (Table 2). It is andesine (An 30 - An 48), except for one sample (An 20) which has five percent relict plagioclase poikiloblasts (0.5 - 2 mm). The recrystallized polygonal grains in this same sample are An 32. Most of the plagioclase crystals are discrete but some are poikiloblastic. Common intergrowths are hornblende, quartz, apatite,

TABLE 2 - MODES, IN VOLUME PERCENT, OF AMPHIBOLITE.

	Tuffaceous Amph.					Massive Amph.				Banded Amph.		
	Amph.	Bio. Amph.			Ep. Amph.	Bio. Amph	Ep. Amph.			Amph.		
Sample No.#	183	258	259	88b	321	261	32	130	131	234b	126	314
Plagioclase	60	62	64	75	65	45	27	44	48	16	49	57
Microcline	-	-	-	-	-	-	-	-	-	-	-	-
Quartz	2	7	3	Tr.	1	Tr.	2	1	8	2	12	3
Hornblende	35	25	8	10	30	51	64	50	36	77	37	35
Biotite	-	3	23	15	Tr.	2	-	-	-	-	1	1
Chlorite	-	-	-	-	-	-	-	-	-	2	1	-
Sphene	1	-	2	Tr.	1	-	2	2	Tr.	-	Tr.	1
Epidote	1	Tr.	Tr.	-	2	-	3	2	8	1	Tr.	1
Apatite	Tr.	Tr.	1	1	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	1
Allanite	-	-	Tr.	-	Tr.	-	-	-	-	-	-	-
Opaques	Tr.	2	Tr.	1	1	2	-	1	Tr.	1	Tr.	Tr.
Muscovite	1	-	-	-	Tr.	-	-	-	-	Tr.	-	-
Garnet	-	-	-	-	-	-	-	-	-	-	-	-
Augite	-	-	-	-	-	-	-	-	-	-	-	-
Calcite	-	1	-	-	-	-	-	-	-	-	Tr.	1
Fe. Stain and saussurite	-	-	-	-	Tr.	-	2	-	-	1	-	-
Total (Vol.%)	100	100	100	100	100	100	100	100	100	100	100	100
No. of Points*	V.E.	V.E.	V.E.	V.E.	V.E.	V.E.	V.E.	880	V.E.	V.E.	V.E.	936
An. Content of Plagioclase+	41	32	35	29	44	35	40	40	39	39	38	35

Sample numbers refer to Plate 1
* V.E. = Visual estimate using thin section.
\+ N.D. = No determination.

TABLE 2 CONT.

	Banded Amphibolite												
	Amphibolite					Biotite Amphibolite							Bio. Garnet
Sample No.	125	184	200c	210	214	175	215b	147	181	266	317	322	264
Plagioclase	51	65	54	52	62	77	50	40	48	60	54	60	45
Microcline	-	-	-	-	-	-	-	-	-	-	-	-	-
Quartz	15	2	Tr.	Tr.	Tr.	1	13	11	1	1	2	Tr.	12
Hornblende	34	30	44	40	34	1	20	44	46	30	40	28	20
Biotite	Tr.	Tr.	-	Tr.	1	8	10	3	2	6	3	10	15
Chlorite	-	-	-	-	-	12	6	-	-	-	-	-	-
Sphene	Tr.	2	1	Tr.	Tr.	1	1	Tr.	2	1	Tr.	1	-
Epidote	Tr.	1	1	-	1	Tr.	Tr.	1	-	1	Tr.	1	-
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	1	Tr.	Tr.	Tr.
Allanite	-	-	Tr.	-	Tr.	-	-	Tr.	-	Tr.	-	Tr.	-
Opaques	Tr.	Tr.	Tr.	8	2	Tr.	Tr.	-	1	Tr.	2	Tr.	Tr.
Muscovite	-	-	-	-	-	-	-	-	-	Tr.	-	-	-
Garnet	-	-	-	-	-	-	-	-	-	-	-	-	8
Augite	-	-	-	-	-	-	-	-	-	-	-	-	-
Calcite	-	-	-	Tr.	-	-	-	-	-	Tr.	-	-	-
Fe Stain and Saussurite	Tr.	-	-	-	-	-	-	-	-	-	-	Tr.	-
Toval (Vol.%)	100	100	100	100	100	100	100	100	100	100	100	100	100
No. of Points	V.E.	V.E.	V.E.	V.E.	V.E.	V.E.	V.E.	943	734	V.E.	V.E.	V.E.	V.E.
An. Content of Plagioclase	37	38	37	35	N.D.	N.D.	N.D.	45	45	39	31	42	31

TABLE 2 CONT.

	Banded Amphibolite												
	Chl.	Epidote Amphibolite							Augite Epidote Amphibolite				
Sample No.	189	234a	297	88a	94	97a	171	325	129	202	42	317	323
Plagioclase	3	10	10	20	7	37	48	35	10	31	45	25	46
Microcline	-	-	-	-	-	-	-	-	-	-	-	-	-
Quartz	Tr.	8	10	Tr.	10	Tr.	6	8	Tr.	1	2	3	5
Hornblende	68	70	60	73	70	49	36	50	25	12	40	48	40
Biotite	-	-	-	-	-	Tr.	-	-	-	-	-	-	1
Chlorite	28	-	Tr.	-	3	9	-	-	-	-	-	-	-
Sphene	1	Tr.	-	-	Tr.	Tr.	Tr.	2	Tr.	3	Tr.	2	1
Epidote	-	12	15	3	10	3	10	4	55	17	8	20	5
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.	1	Tr.	Tr.	Tr.	Tr.	Tr.	-	Tr.
Allanite	-	-	Tr.	Tr.	Tr.	-	-	Tr.	-	-	-	-	Tr.
Opaques	Tr.	Tr.	Tr.	1	-	Tr.	Tr.	Tr.	Tr.	1	Tr.	Tr.	Tr.
Muscovite	-	-	-	Tr.	-	-	-	-	-	-	-	-	-
Granet	-	-	-	-	-	-	-	-	-	-	-	-	-
Augite	-	-	-	-	-	-	-	-	10	35	5	2	2
Calcite	-	-	-	-	-	-	-	-	Tr.	-	-	-	-
Fe Stain and Saussurite	Tr.	-	5	3	-	1	-	-	-	-	-	-	-
Total (Vol.%)	100	100	100	100	100	100	100	100	100	100	100	100	100
No. of Points	V.E.	V.E.	V.E.	V.E.	V.E.	878	V.E.	V.E.	V.E.	839	V.E.	V.E.	V.E.
An. Content of Plagioclase	N.D.	N.D.	N.D.	40	N.D.	45	40	N.D.	N.D.	45	N.D.	N.D.	N.D.

PLATE 10 - PHOTOMICROGRAPH SHOWING GRANOBLASTIC TEXTURE IN AMPHIBOLITE. MAJOR MINERALS INCLUDE PLAGIOCLASE (LIGHT) AND HORNBLENDE (DARK). FIELD OF VIEW 6.2 mm. LOCATION 130 (SEE PLATE 1), NW $\frac{1}{4}$, SEC. 5, 167/33.

epidote, and opaques. Secondary alteration is variable, but generally limited to minor sericitization. The plagioclase in samples from the North Shore of Oak Island is partially altered to an unidentified sub-opaque substance that appears to be a mixture of cryptocrystalline epidote, sericite, and limonite.

Hornblende is the other major phase constituting 30 to 77% of the rock. It occurs as idioblastic prisms (0.1 - 1 mm) which form rational boundaries against plagioclase and quartz. Locally subidioblastic poikiloblasts (1.0 - 5.0 mm) are present. The poikiloblasts contain intergrowths similar to those in the larger subidioblastic grains. No secondary alteration of hornblende was noted.

Quartz was found in every amphibolite, ranging from a trace to 15%. Its major occurrence is as 0.05 mm to 20 cm wide veins, where it is polygonal (0.05 - 1.5 mm). It is also found as xenoblastic blebs (minute - 0.5 mm) which commonly occur as intergrowths in plagioclase hornblende and epidote. The quartz is generally discrete and shows no secondary alteration. Most grains are clear and unstained, but slightly undulose extinction was noted in a few samples.

Epidote is present in most of the samples in amounts ranging from a trace to 55%. It is generally disseminated throughout the sample, however, compositional segregation into 5 mm to 2 cm wide bands is fairly common. Idioblastic to subidioblastic blocky prisms (0.1 - 0.3 mm) are most common, but some xenoblastic blebs (minute - 0.1 mm) were found. One sample contained epidote as psudomorphs after hornblende. Discrete crystals are fairly common but intergrowths of allanite, plagioclase, and quartz are present. The allanite occurs as mimetic intergrowths (minute - 0.1 mm). The plagioclase and quartz generally occur as minute blebs, but vermicular intergrowths with quartz were noted. Most of the epidote shows no secondary alteration,however, some samples have an unidentified subopaque rim around the epidote crystals.

Biotite was found in about 50% of the samples constituting a trace to 23% of the rock. It occurs as idioblastic plates (0.1 - 0.3 mm) which form rational boundaries against plagioclase and quartz. The biotite is generally concentrated in 1.0 mm to 1.0 cm wide bands, but is evenly distributed in a few samples. As in the case of the gniess unit, biotite bands result in a spaced schistosity which often gives hand specimens the appearance of a biotite schist. Most of the biotite grains are discrete, however, minute intergrowths of quartz were also noted. Unaltered crystals of biotite are most prevalent, but partial alteration to chlorite was observed.

Augite is present in 5 of the 35 samples, making up up 2 to 35% of the rock. Subidioblastic poikiloblasts (0.2 - 0.8 mm) are most common, but one sample contains crystals to 3 mm. The augite is concentrated in 0.5 mm to 1 cm wide bands where it constitutes 6 - 95% of the band. Plagioclase, hornblende, epidote, apatite, and opaques were noted as intergrowths. Alteration along cracks and cleavage to a reddish-brown, opaque, mineral is common.

Garnet was found in only one sample, where it constitutes eight percent of the rock. It occurs as (0.5 - 3 mm) corroded poikiloblasts which contain intergrowths of quartz, plagioclase, hornblende, biotite, and opaques, (minute - 0.1 mm). The biotite foliation is bent around the garnet crystals. No secondary alteration was noted.

Common accessory minerals include; sphene, apatite, allanite, and opaques. Less prevalent are muscovite and calcite. The sphene constitutes a trace to two percent of the rock. It generally occurs as xenoblastic blebs (0.1 - 0.2 mm), but was also found as (minute - 0.1 mm) idioblastic diamonds. Apatite occurs as (minute - 0.1 mm) idioblastic prisms. Allanite occurs only as (minute - 0.1 mm) mimetic intergrowths in epidote. Opaques were found as (0.05 - 0.5 mm) blocky crystals or as (minute - 0.1 mm) blebs. Muscovite occurs as (0.1 - 0.3 mm) idioblastic crystals which are generally associated with sericite. Calcite was found as (0.1 - 0.4 mm) xenoblastic grains that are interstitial.

Soapstone

Outcrops of soapstone were found only on the north shore of Oak Island, just west of Soldiers Point. It occurs as 3 to 10 m thick bands in the amphibolite. The soapstone-amphibolite contacts are sharp and coincident with the trend of foliation in both phases.

This phase is composed of fine-grained soapstone, and constitutes less than one percent of the supracrustal outcrop area. It is white on both fresh and weathered surfaces, and commonly shows a weak foliation. The foliation is given by the planar parallelism of (0.2 - 1.0 mm) aggregates of talc.

Minerallogically the soapstone is composed of 37 to 75% fibrous white talc. White prisms of tremolite (0.5 - 1.5 mm) make up to 5 to 40%. Clear veins of quartz (0.5 - 1 mm) wide, and blocky (0.5 - 1.0 mm) patches of opaques are conspicuous components.

Northwest Angle Tonalitic Unit

The tonalite unit is generally found in small rounded outcrops on Oak Island, Sugar Point, and the small islands to the south. Larger outcrops may be found along the shoreline, but most of these are low lying and usually submerged. A notable exception to this is Bridges Island which rises 5 m from the water and has continuous outcrop over its entire 0.25 km^2. Most of the outcrops have only a thin weathering veneer (0 - 2 cm) where formation of clay minerals has made the rock crumbly, however, in areas where weathering is not active, such as depressions in larger outcrops, a thicker weathered surface (5 - 10 cm) is present.

The tonalite displays a foliation which is developed to varying degrees. The foliation is the result of planar parallelism of micas. When it is present the foliation conforms to a consistant east-west trend with vertical, to steep northerly dip.

Quartz veins are found throughout the unit; they range in width from microscopic to 25 cm, and crosscut foliation. Vein quartz constitutes only a trace of the entire tonalite outcrop area. Aphanitic to medium-grained mafic dikes are found in association with many of the tonalite outcrops. These dikes vary in width from 1 cm to 200 m. Several mafic and quartzo-feldspathic inclusions are also present within the tonalite unit (Plate 11). These inclusions are generally 1 m to 2 m wide and 5 m to 50 m long. They are normally concordant with the tonalite foliation. Although the inclusions are very noticeable they constitute only trace amounts of the tonalite outcrop area. Another minor, though rather conspicuous feature within the tonalite unit is granitic pegmatite dikes. These dikes were noted only on Knight Island, they range in width from 1 cm to 1 m, and crosscut the tonalite foliation.

Blastoporphyritic Granodiorite

Medium-grained blastoporphyritic granodiorite constitutes this phase of the Northwest Angle tonalite unit. Blastophenocrysts of plagioclase, quartz, and hornblende

PLATE 11 - MAFIC INCLUSION IN GRANODIORITE. LOCATION 75 (SEE PLATE 1), SOUTH SHORE OF OAK ISLAND. FIELD NOTEBOOK INDICATES SCALE.

are surrounded by a fine-grained, porphyroclastic, metamorphic assemblage of plagioclase, microcline, quartz, epidote, and biotite (Table 3). Minor secondary alteration in the form of sericitization of plagioclase and chloritization of biotite was noted.

The overall texture is cataclastic. Fractured, strained and corroded igneous phenocrysts (50%) are surrounded by finer recrystallized minerals (50%). A minor preferred orientation of mineral grains is not apparent in thin section.

Plagioclase is the main mineral constituent, composing 30% of the rock. The phenocrysts are fractured and strained and bent albite twins and optically discontinuous grains are common. Recrystallization has taken place along the old grain boundaries with granoblastic crystals of quartz, microcline, and plagioclase producing ragged edges on the plagioclase phenocrysts (Plate 12). Although albite, carlsbad, and pericline twins are present, many of the phenocrysts show no twinning. The composition of the phenocrysts was determined by the a-normal method to be oligoclase (An 20 - An 22) with minor normal zoning in a few crystals. Many of the phenocrysts are poikloblastic with minute intergrowths of quartz, microcline, biotite, and epidote. Minor secondary alteration to sericite was noted.

Granoblastic plagioclase makes up 10 to 15% of the rock. It is polygonal and ranges in size from 0.1 to

TABLE 3 - MODES, IN VOLUME PERCENT, OF TONALITIC ROCKS.

	Porphyritic Granodiorite			Phaneritic Tonalite						
Sample No.#	36	295	55	248b	277	249a	250	247b	289b	244
Plagioclase	40	38	44	58	63	60	60	70	71	57
Microcline	13	11	13	6	2	2	2	Tr.	Tr.	1
Quartz	34	35	30	23	31	30	35	25	25	27
Hornblende	6	7	8	6	-	-	-	-	-	3
Biotite	3	5	2	1	2	5	1	-	-	6
Chlorite	-	1	1	4	-	-	Tr.	3	2	3
Sphene	1	Tr.	Tr.	-	Tr.	-	Tr.	Tr.	Tr.	-
Epidote	1	3	2	1	2	2	Tr.	2	1	3
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	-
Opaques	Tr.	Tr.	Tr.	0.5	-	Tr.	Tr.	-	1	-
Muscovite	-	-	-	-	Tr.	1	2	Tr.	-	-
Zircon	Tr.	-	-	-	Tr.	-	-	-	Tr.	-
Saussurite	2	-	-	0.5	-	Tr.	-	Tr.	Tr.	-
Calcite	-	-	-	-	-	-	-	-	-	-
Total (Vol.%)	100	100	100	100	100	100	100	100	100	100
No. of Points*	V.E.	1265	1012	1127	1019	V.E.	V.E.	V.E.	V.E.	1015
An. Content of Plagioclase+	20	20	20	23	18	20	20	20	20	27

Sample numbers refer to Plate 1
* V.E. = Visual estimate using thin section.
+ N.D. = No determination.

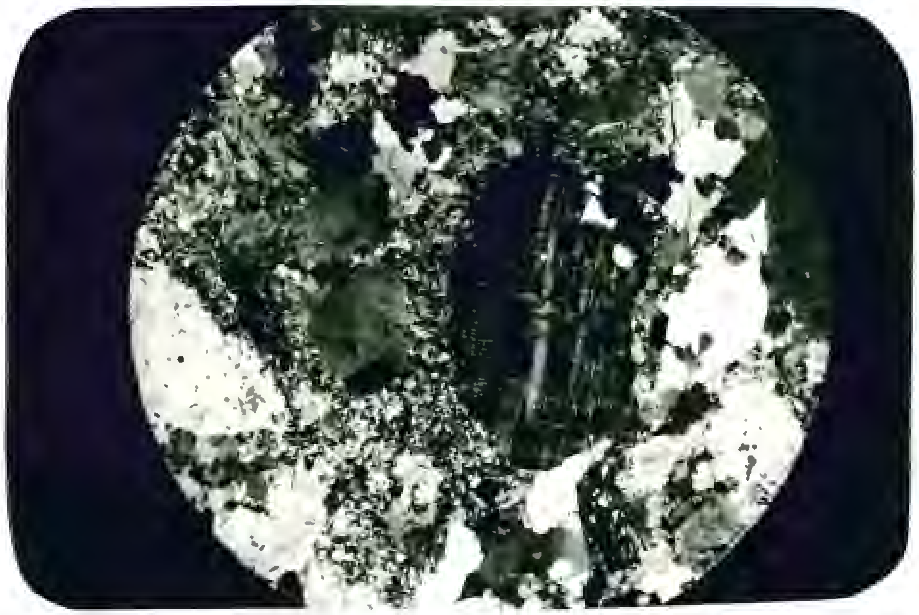


PLATE 12 - PHOTOMICROGRAPH SHOWING POLYGANIZED GRAIN BOUNDARIES IN GRANODIORITE. FIELD OF VIEW 6.2 mm. LOCATION 36 (SEE PLATE 1), NORTH SIDE OF OAK ISLAND.

0.3 mm. Composition as determined by the a-normal method, and found to be albite or oligoclase (An 6 - An 15). Pericline, carlsbad, and albite twins are uncommon. A few grains contained vermicular intergrowths of quartz, but most are discrete and show no secondary alteration. Strain in the form of bent twin laminae and optical discontinuity was noted in a few grains.

Quartz makes up 30 to 35% of the blastoporphyritic granodiorite. Most of it, (20 - 30%) is in the form of (0.1 - 0.5 mm) metamorphic crystals, but some (5 - 10%) is 1 to 3 mm igneous crystals. The remnant grains are interstitial and often have polygonized boundaries. They are strained as shown by small cracks and undulose extinction. Intergrowths of biotite as well as inclusions of sphene, hornblende, apatite, and zircon are present, but most grains are distinct.

The metamorphic quartz is mostly granoblastic, but lobate, or scalloped boundaries were also noted. Most of the metamorphic quartz occurs as discrete grains, although vermicular intergrowths with plagioclase and microcline were found.

Microcline constitutes 10 to 13% of the rock. Granular crystals (0.1 - 0.3 mm) make up the majority, however, relict grains (0.5 - 3 mm) are present in trace amounts. Both medium-grained and fine-grained microcline show cross-hatch twinning.

The relict crystals are often strained. Fractures, and bent twins are common. The boundaries are polygonized and, thus, have a ragged appearance. Intergrowths of quartz and biotite are present in all of the phenocrysts. Most of the fine-grained microcline is granoblastic, but some is interstitial. These crystals occur as discrete grains and show no signs of strain or alteration. Hornblende is the only major constituent which occurs only as relict crystals. It comprises 6 to 8% of the rock, as 0.5 to 2 mm subhedral grains. The hornblende is often partially altered to epidote and biotite. Intergrowths of quartz (minute - 0.1 mm) are commonly present.

Epidote was found as subhedral prisms (0.2 - 1 mm) which comprise one to three percent of the granodiorite. It occurs in association with the other mafic constituents and as intergrowths within relict plagioclase. Minute crystals of quartz and biotite are present as intergrowths within epidote.

Biotite makes up two to five percent of the granodiorite. It is subhedral and varies in size from 0.3 to 1 mm. It commonly occurs as discrete grains associated with the other mafic minerals, but is also found as intergrowths within plagioclase, microcline, quartz, hornblende and epidote. Some secondary alteration to chlorite has occurred, but this is minor and is commonly restricted to partial alteration along cleavage planes.

Accessory minerals include; sphene, apatite, magnetite, and ziron. Together they make up a trace to one percent of the rock. Sphene is the most abundant; euhedral diamond shaped crystals (0.2 - 1 mm) constitute a trace to 0.5%. These crystals are commonly associated with the mafic minerals where they were often found as inclusions within hornblende. Apatite was found as minute needle-like inclusions within relict grains of plagioclase, quartz, and hornblende. Magnetite occurs as (0.1 - 0.2 mm) blebs associated with the mafic minerals. Zircon is a minor assessory occurring as minute prismatic inclusions within relict grains of plagioclase, quartz, and hornblende.

Phaneritic Tonalite

This phase is composed mostly of phaneritic tonalite, however, one sample contains slightly more microcline and is a granodiorite. Although a metamorphic assemblage of plagioclase, microcline, quartz, biotite, and epidote was noted, the majority of crystals are igneous (Table 3).

Cataclastic texture is exhibited by strained and fractured grains, although the overall texture appears igneous (Plate 13). No fluxion structure was noted and preferred orientation of mineral grains is not apparent in thin section. Secondary alteration is minor, limited to sericitization of plagioclase, and chloritization of biotite.

Plagioclase is the dominate phase in all samples. It composes from 50 to 70% of the rock. Crystals range

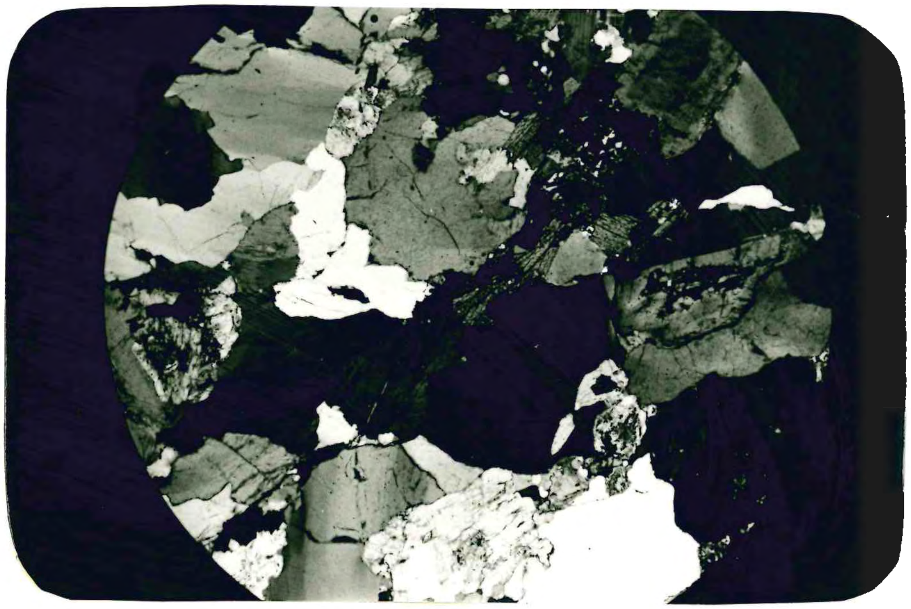


PLATE 13 - PHOTOMICROGRAPH SHOWING IGNEOUS TEXTURE IN TONALITE. MAJOR MINERALS INCLUDE PLAGIOCLASE AND QUARTZ. FIELD OF VIEW 6.2 mm. LOCATION NORTHEAST POINT OF NORMAN ISLAND.

in size (0.5 - 5 mm) but 1 - 2 mm is most typical. The plagioclase is blocky, subhedral, and commonly shows albite twins, while pericline and carlsbad twins are less common. Many of the larger crystals are poiklioblastic. Minute crystals of quartz, microcline, biotite, and epidote were found as intergrowths. Plagioclase grains are commonly fractured and bent albite twins and optically discontinuous grains were frequently observed. Composition was determined by either the a-normal, or Michel-Levy, method, and found to be oligoclase (An 18 - An 27). Secondary alteration to sericite is present in all samples, but most prevalent in those samples collected near large mafic dikes (Plate 1).

Quartz is the other major constituent of the phaneritic tonalite. It is interstitial (0.2 - 3 mm) and constitutes 25 to 45% of the rock. The quartz crystals have small cracks, and undulose extinction. Inclusions of biotite, apatite, and zircon (minute - 0.1 mm) are present in minor amounts. Quartz is also commonly found as (0.05 - 0.2 mm) polygonal intergrowths within plagioclase, hornblende, and microcline; these intergrowths constitute up to one percent of the rock.

Microcline generally occurs as interstitial (0.2 - 0.5 mm) crystals. It is the only potassium feldspar present ranging from a trace to six percent in abundance. Cross-hatch twinning is common. The microcline generally occurs as discrete grains, but a few intergrowths of quartz were noted. Microcline blebs (minute) are found in trace amounts as intergrowths within larger plagioclase crystals. The minute crystals are unstrained, but the larger interstitial microcline crystals show strain in the form of fractures, offset and bent twin lines, and lack of optical continuity.

Hornblende is the only mafic constituent which does not appear to be metamorphic. It is present in only 29% of the samples examined constituting three to six percent. The hornblende is anhedral (0.5 - 2 mm), and extensively altered to epidote, and biotite. Blebs of quartz (minute-0.1 mm) are common as intergrowths. The hornblende is typically associated with the other mafic constituents.

Epidote occurs as subhedral (0.2 - 2 mm) crystals which compose a trace to three percent of the rock. It was generally found in the mafic-rich clots, but, was also found as intergrowths within plagioclase crystals. Minute intergrowths of quartz, biotite, magnetite and sphene are fairly common.

Biotite is present in all samples varying from a trace to six percent. It occurs as subhedral (0.5 - 1 mm) grains, which are commonly partially altered to chlorite. Intergrowths of biotite in plagioclase and quartz were noted, but the most common occurrance is in (1 - 5 mm) mafic clots.

Chlorite makes up a trace to four percent of the phaneritic tonalite. Its sole occurrance is a pseudomorph after biotite, where it was commonly found in a lacy intergrowth with magnetite.

Muscovite is present in 43% of the samples, constituting one to two percent of the rock. It occurs as subhedral (0.5 - 1 mm) grains. Intergrowths with plagioclase are common, but most crystals were found in the mafic-rich clots.

Accessory minerals such as sphene, magnetite, apatite, and zircon, generally make up a trace to one percent of the rock. Sphene is the most abundant, making up to 0.5%. It occurs as diamond-shaped, euhedral (0.2 - 1 mm) crystals which are commonly associated with the mafic clots. Apatite is another common accessory. It was found as minute euhedral needles within quartz and plagioclase crystals. Magnetite was found as blebs (0.1 mm) associated with sericitized plagioclase, and as lacy intergrowths with chlorite. Zircon is a minor accessory which occurs as minute euhedral prismatic inclusions within quartz and plagioclase.

Northwest Angle Granitic Unit

Phaneritic Granite

Outcrops of the granites are widespread occurring throughout the northern part of the area (Plate 1). This phase is composed of phaneritic medium-grained granite, which is pink on both weathered and fresh surfaces.

Most of the granites are not well foliated. A weak foliation was measured at a few locations (Plate 1). The foliation is defined by the planar parallelism of micas, and mafic clots. Where present the foliation generally trends northwest to southeast with a steep to vertical dip.

The granites which crop out on the mainland are commonly associated with migmatized hornblende gneiss. These granite bodies often contain (1 - 30 m) inclusions of hornblende gneiss. Locally these inclusions make up to ten percent of the outcrop. The granites which occur on the islands are generally free of inclusions.

Granitic pegmatite dikes are found throughout the granites; they are 1 cm to 3 m wide, and crosscut foliation. Locally these dikes constitute up to ten percent of the outcrop.

The foliated granites exhibit a metamorphic assemblage of plagioclase, microcline, quartz, biotite, epidote, and calcite, but maintain an overall igneous texture and mineralogy similar to the relatively unmetamorphosed granite samples (Table 4).

Although the overall texture is igneous, strain in the form of undulose extinction, bent and kinked twin lamelae, and fractured grains was found throughout the unit (Plate 14). The foliated granites exhibit this strain to a greater extent. Large fractures, stretched grains, and even detached fragments of crystals are common (Plate 15). Fluxion structure produced by quartz was found in a few samples, but recrystallization and neomineralization are not pronounced.

TABLE 4 - MODES, IN VOLUME PERCENT, OF GRANITIC ROCKS

	Biotite Granite					Muscovite Biotite Granite					Hb. Bio. Granite	
Sample No.#	228	227a	98	104a	166b	100a	316	80	315	306	301	310
Plagioclase	32	43	34	34	34	31	35	33	33	35	32	38
Microcline	33	37	30	27	36	32	30	28	32	28	33	30
Quartz	33	18	32	33	29	35	32	35	33	35	26	20
Hornblende	-	-	-	-	-	-	-	-	-	-	3	5
Biotite	2	2	4	6	1	0.5	1	1	1	1	6	3
Chlorite	Tr.	Tr.	-	-	-	-	Tr.	Tr.	Tr.	Tr.	-	-
Sphene	-	-	-	Tr.	-	-	-	-	-	-	Tr.	1
Epidote	-	Tr.	-	-	-	Tr.	Tr.	Tr.	-	-	Tr.	1
Apatite	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Allanite	-	-	-	-	-	-	-	-	-	-	-	-
Opaques	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Muscovite	Tr.	-	-	Tr.	Tr.	-	2	2	1	1	-	Tr.
Zircon	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Augite	-	-	-	-	-	-	-	-	-	-	-	-
Calcite	-	-	-	-	-	-	-	-	-	-	-	Tr.
Fe. Stain and Saussurite	-	-	-	-	-	0.5	-	-	-	-	-	-
Total (Vol.%)	100	100	100	100	100	100	100	100	100	100	100	100
No. of Points*	1020	V.E.	872	V.E.	V.E.	928	V.E.	973	V.E.	V.E.	V.E.	V.E.
An. Contant of Plagioclase+	17	17	18	17	10	17	18	16	17	16	17	18

Sample numbers refer to Plate 1
* V.E. = Visual estimate using thin section.
\+ N.D. = No determination.

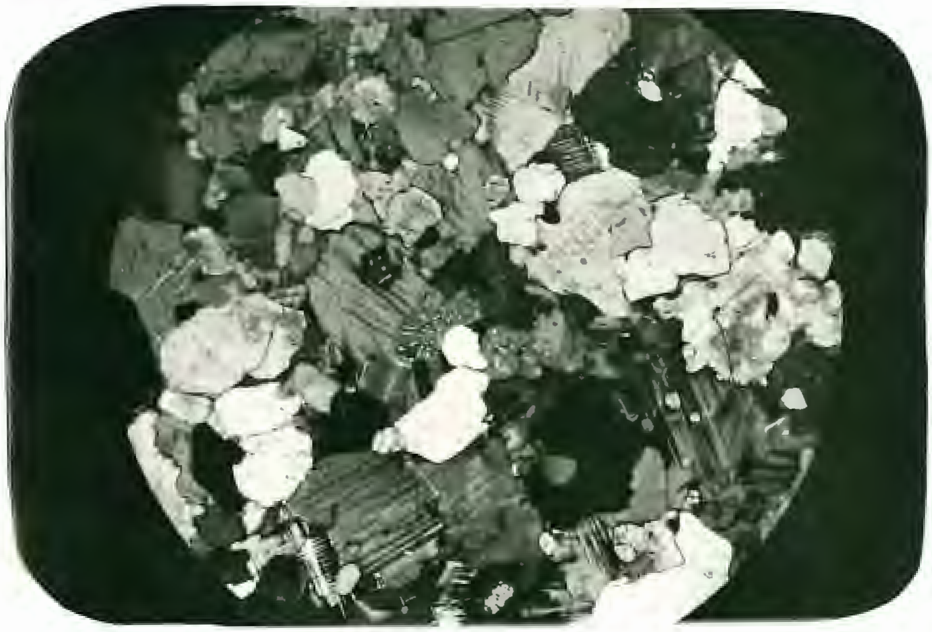


PLATE 14 - PHOTOMICROGRAPH SHOWING IGNEOUS TEXTURE IN GRANITE. MAJOR MINERALS INCLUDE PLAGIOCLASE, MICROCLINE, AND QUARTZ. FIELD OF VIEW 6.2 mm. LOCATION 100b (SEE PLATE 1), SECTION 31, 168/34.

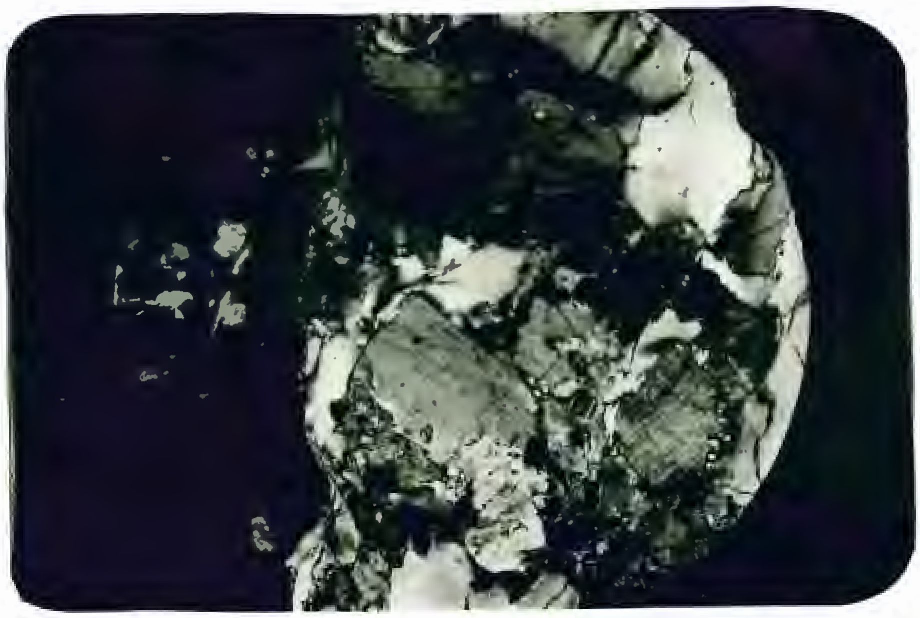


PLATE 15 - PHOTOMICROGRAPH SHOWING CATACLASTIC TEXTURE IN GRANITE. MAJOR MINERALS INCLUDE PLAGIOCLASE, MICROCLINE, AND QUARTZ. FIELD OF VIEW 6.2 mm. LOCATION 228 (SEE PLATE 1), SECTION 10, 167/35.

Plagioclase is generally the main mineral constituent, composing 30 to 43% of the rock. Blocky anhedral crystals (0.2 - 4 mm) constitute most of the plagioclase, but trace amounts of polygonal crystals (0.2 - 0.4 mm) were found locally. Albite twins are common, while pericline and carlsbad twins are less so. Composition was determined in all samples by the a-normal method, and was found to be oligoclase (An 16 - An 18). Many of the plagioclase crystals are poikiloblastic, with intergrowths of microcline, quartz, biotite, muscovite, epidote, magnetite, and calcite. Most of the intergrowths occur as minute blebs but some vermicular intergrowths with quartz were noted. Minute needles of apatite are common inclusions. Secondary alteration to sericite is common but generally minor.

Microcline is also a major phase, constituting 29 to 37% of the rock. It is anhedral, and commonly interstitial (0.1 - 4 mm). Trace amounts of (0.1 mm) polygonal grains are also present. Cross-hatch twins and microperthites were commonly observed as were bent twin lines, fractures and optically discontinuous grains. Many of the crystals are poikiloblastic with intergrowths of quartz, plagioclase, biotite, and muscovite. The intergrowths generally occur as minute blebs, but some with quartz is vermicular. Minute prisms of apatite, and zircon, were found as inclusions.

Quartz is another major constituent making up 18 to

36% of the granite. Although interstitial grains (0.1 - 4 mm) are most common, and generally the only type present polygonal grains (0.1 - 0.3 mm) were also found.

The polygonal grains are generally restricted to the foliated samples where they make up a trace to three percent of the rock. They generally occur as polygonized borders around the larger relict quartz, but are also found as interstitial aggregates which exhibit fluxion structure locally.

The larger interstitial quartz is usually strained and fractured; locally it appears stretched. A few of the stretched grains are completely polygonized. Most of the quartz occurs as discrete grains but minute inclusions of microcline, plagioclase, biotite, apatite, and zircon are present.

Biotite is a relatively minor constituent. Elongate subhedral crystals (0.1 - 1 mm) make up 0.5 to 6% of the rock. Partial alteration to chlorite and magnetite is present locally. This is the only occurrence of chlorite in the granite unit. Most of the biotite occurs as discrete grains, however, minute inclusions of quartz, muscovite, apatite, and zircon were found.

Muscovite is found in many of the granitic samples. Where present it occurs as subhedral (0.1 - 1 mm) crystals which constitute a trace to two percent of the rock. It is often found in association with biotite or as inclusions within plagioclase. Most grains are discrete but some contain minor inclusions of quartz.

Epidote occurs as subhedral (0.1 - 0.8 mm) crystals. Where present it constitutes a trace to one percent of the rock. It is found in association with the mafic constituents or as intergrowths in plagioclase, and hornblende where it appears to be an alteration product of the hosts. Although some grains have intergrowth of quartz, most are discrete.

Hornblende is present in a few of the granite samples being most abundant in those from Brush Island. It occurs as subhedral (0.5 - 1.5 mm) grains which constitute three to five percent of the rock. It is associated with the other mafic minerals and partially altered to epidote and biotite. Locally the hornblende crystals are elongate and show subparellel orientation. These elongate crystals are commonly twinned some polysynthetically. Quartz is commonly present as an intergrowth.

Accessory minerals include sphene, apatite, zircon, magnetite, and calcite. Minor amounts of saussurite and iron stain are present as crack fillings. Together these accessories constitute a trace to two percent of the rock. Magnetite is generally the most abundant. It occurs as blocky subhedral crystals and as interstitial, blebs (0.1 - 0.5 mm) which are commonly associated with the mafic minerals. It also occurs as lacy intergrowths with chlorite or sericite. In these associations it is found as intergrowths within biotite and plagioclase respectively. Sphene is another common accessory, occurring as euhedral diamonds (0.1 - 0.8 mm). It is commonly found in association with the other mafic minerals. Apatite and zircon are found as minute prismatic inclusions within plagioclase, quartz, microcline, and biotite. Calcite was noted in only one sample, where it occurred as (0.1 - 0.8 mm) intergrowths within plagioclase crystals.

Granitic Pegmatite

Outcrops of pegmatite are found throughout the area. They occur either as dikes 1 mm to 4 m wide or as large (10 - 100,000 m^2) ovid lenses. The dikes were noted to intrude all the units in the Northwest Angle except the blastoporphyritic granodiorite (Plate 16). Contacts are sharp, but there is no chill margin on the dikes. The large lenses are found within the supracrustal units. The contacts between the supracrustal rocks and the pegmatite are sharp, but there is no chill margin on the pegmatite. The contacts are coincident with the foliation in the supracrustal rocks along the long axis of the pegmatite lenses, but the ends of the lenses crosscut foliation. Pegmatitic granite is also found within the Northwest Angle granites but contacts are not defined. The pegmatite occurs as (0.001 m^2 - 1,000 m^2) clots which grade into finer grained granite.

The granitic pegmatite phase is made up entirely of

PLATE 16 - PEGMATITE DIKE IN BANDED GNEISS. LOCATION 109 (SEE PLATE 1), WEST POINT OF BRUSH ISLAND

granitic pegmatite. It is pink on fresh and weathered surfaces, but locally bleached white. No foliation or lineation was noted. Mineralogically the rock consists of 30 to 40% pink microcline,(0.5 mm - 0.6 m) which is generally perthitic. Clear to white plagioclase (0.5 mm - 0.3 m) makes up 20 to 30%, while clear quartz (0.5 mm - 0.3 m) constitutes 25 to 35%. Locally the quartz is graphically intergrown with plagioclase or microcline. Biotite or muscovite are present locally in amounts up to ten percent. Minor but notable phases include reddish-brown garnet to 0.5 cm and black opaques, to 1.0 cm. Because of the coarse nature of this phase it is difficult to study in thin section. Three samples of finer grained portions of the granitic pegmatite were chosen for study. The composition of the samples was assumed to approximate that of the coarser grained counterparts, however, descriptions of grain size, texture and composition were developed using pegmatitic hand specimens as well as the finer grained thin sections.

Plagioclase makes up 15 to 30% of the rock. It occurs as blocky subhedral crystals (0.5 mm - 0.3 m). Carlsbad, pericline, and albite twins are common. Composition was determined in three samples by the a-normal method, and found to be cligoclase (An 15 - An 18). Graphic intergrowths of quartz (0.5 mm - 5 cm) are common; as are exsolution blebs (0.5 mm - 1 cm)of microcline. Other notable intergrowths are muscovite, opaques, and garnet. Most of the plagioclase crystals show no secondary alteration, however, minor alteration to sericite was found in one sample. In thin section the plagioclase exhibited strain in the form of bent, kinked, and broken twin lamelae, and slight polygonization along boundaries.

Microcline constitutes 30 to 40% of the granitic pegmatite. Blocky subhedral crystals (0.5 mm - 0.6 m) are generally pink, but are locally bleached white. The color is imparted by red iron stain covering the crystal surface. Most crystals show cross-hatch twinning. Marco-perthites are common, exsolution blebs of plagioclase (0.5 mm - 1 cm) are less so. Graphic intergrowths with quartz are a conspicuous feature, intergrowths with muscovite, and garnet were also found. Secondary alteration was not noted, however, strain in the form of cracked crystals, bent twins, and minor polygonization along boundaries was found in all thin sections.

Quartz is also a major phase, constituting 25 to 35 percent of the rock. Clear interstitial crystals (0.5 mm - 0.3 m) are most common, but graphic intergrowths with plagioclase or microcline, and rounded blebs, are also present. Most grains are discrete but intergrowths of plagioclase, microcline, garnet and micas (0.5 mm - 10 cm) were noted. Undulose extinction, cracks, and minor polygonization of boundaries are prominent features of the quartz.

Locally muscovite, or biotite is present in amounts up to ten percent. Large books to 0.1 m were noted, but most common are aggregates to 0.2 cm.

Accessory minerals are garnet and opaques. The garnet occurs as reddish-brown, euhedral, crystals to 0.5 cm. The opaques were found as black interstitial crystals to 1 cm.

<u>Northwest Angle Mafic Dike Unit</u>

Outcrops of mafic dike occur mostly on islands in the Lake of the Woods associated with outcrops of tonalite, but mafic dike rocks are also found on the mainland where they are associated with outcrops of supracrustal rocks. (Plate 1).

The mafic dikes are composed of fine to medium-grained hornblende gabbro (Plate 17). It is dark gray on fresh surfaces, but weathered surfaces are light gray and pitted. The pitted texture is due to the more rapid weathering of plagioclase, while pyroxene and opaques protrude from the surface. Secondary alteration is variable, but generally restricted to sericitization of plagioclase.

Mafic dike contacts are sharp, with chill margins within the dike. Grain size ranges from diabasic along contacts to medium-grained in the center of the dike. No penetrative foliations or lineations were noted, however, a prominent joint set, normal to the contact trend was noted at several locations.

Plagioclase is the most abundant mineral. Lathy

PLATE 17 - PHOTOMICROGRAPH SHOWING LATHY IGNEOUS TEXTURE IN HORNBLENDE GABBRO. MAJOR MINERALS INCLUDE PLAGIOCLASE AND AUGITE. LOCATION 281 (SEE PLATE 1), SMALL ISLAND IN SEC. 20, 167/33.

crystals (0.3 - 2.5 mm) constitute 41 to 56% of the rock. Albite, pericline, and carlsbad twins are common. The composition was determined in all samples by the a-normal method, and was found to be labradorite, with normal zoning (Table 5). Most of the plagioclase crystals are discrete. Secondary alteration to sericite or saussurite is common.

Augite is another dominate phase, making up 5 to 39% of the rock. It occurs as blocky, subhedral, crystals (0.5 - 2.5 mm), which commonly show simple twins. Some crystals contain intergrowths of plagioclase, apatite, and opaques, but most do not. Partial or complete alteration to hornblende is ubiqutous.

Hornblende was found solely as a pseudomorph after augite. It constitutes 12 to 28% of the rock. Partial replacement of the augite along cleavage, and boundaries is most common, but complete replacement was also noted.

Quartz forms (0.5 - 2 mm) interstitial grains which are commonly subpoikilitic. It constitutes two to seven percent of the rock. The crystals are clear and show little alteration. No grains showing undulose extinction were noted.

The opaques occur as blocky subhedral or interstitial crystals (0.5 - 2 mm) which constitute two to four percent of the rock. Minor amounts of opaques are also found as crack fillings in augite and plagioclase. Most of the grains are discrete, but intergrowths of plagio-

TABLE 5 - MODES, IN VOLUME PERCENT OF MAFIC DIKES

	Hornblende Gabbro			
Sample No.#	137b	289a	248a	281
Plagioclase	56	50	52	41
Augite	5	28	32	39
Hornblende	28	16	2	4
Quartz	7	3	12	12
Biotite	1	-	Tr.	Tr.
Opaques	2	3	2	4
Sphene	-	Tr.	Tr.	Tr.
Apatite	Tr.	Tr.	Tr.	Tr.
Epidote	Tr.	-	-	-
Saussurite	Tr.	Tr.	Tr.	Tr.
Total(Vol.%)	100	100	100	100
No. of Points*	1014	1166	V.E.	V.E.
An. Content of Plagioclase	58-65	55-64	54-63	55-63

Sample numbers refer to Plate 1
* V.E. = Visual Estimate using thin section.

clase and augite were noted. In one thin section blocky opaques are closely associated and intergrown with biotite.

Accessory minerals are biotite, apatite, suassurite, sphene, and sericite. Biotite occurs as (0.1 - 0.3 mm) subhedral plates which constitute zero to one percent. Prisms of apatite (minute - 0.2 mm) were found in trace amounts. Blebs of sphene to 0.1 mm were noted. Sericite occurs as a dusty alteration of plagioclase, while saussurite was found as crack fillings.

STRUCTURE

General Statement

Four major rock units were found in the Northwest Angle: supracrustal rocks, tonalitic intrusive rocks, granitic intrusive rocks, and large mafic dikes. The supracrustal rocks have a northeast trending structural grain throughout most of the area, however, in the north central part of the peninsula (sections 4 & 5, 167/34 sections 32 & 33, 168/34) the structural grain trends northwest. The tonalitic rocks fround on Oak Island have a northeast trend with vertical foliation. The orientation of the foliation found within tonalitic rocks from Sugar Point, and the islands to the south is variable, but is generally vertical, and trends east-west. Most of the granitic rocks are massive, however, two outcrop areas, both in the northwest part of the peninsula are foliated. This foliation is generally vertical and trends northwest. The large mafic dikes trend northwest to southeast, but they display an isotropic fabric internally.

Primary Structures

The supracrustal rocks are completely recrystallized thus obliterating most primary structures, although stretched pillows, a faint but distinguishable crossbed and a graded bed were noted.

The crossbed and graded bed were found in the same outcrop at the northwest point of Eberhard Island. Here the granular hornblende gneiss unit shows a gradual transition from medium-grained to fine-grained in the first 25 cm above a contact with a tuffaceous augite-hornblende gneiss. The crossbed was found about 5 m up section from this contact.

Pillow structures were observed in the amphibolite phase of the supracrustal unit. They range in length from 0.3 to 1.0 m and are 0.1 to 0.3 m wide (Plate 18). The rinds are 0.5 to 1 cm thick. The down plunge dimension is difficult to measure, but at the southeast point of Honeymoon Island it was measured at 1.0 m (Plate 19). The ratio of down plunge height to length and width measured normal to plunge is 4:2:1 at this location. The plunge of all pillows observed lies within the plane of foliation.

Although the crossbed and some of the pillow structures are faint and difficult to distinguish, the validity of the primary structures can generally be established. Top directions are generally simple to determine from the primary structures because characteristic top indicators are commonly present. The locations and top directions of primary structures are shown on (Plate 20). Tops are generally northward in the supracrustal unit.

PLATE 18 - CHARACTERISTIC PILLOW STRUCTURE. LOCATION 128 (SEE PLATE 1), SEC. 6, 167/33.

PLATE 19 - PHOTOGRAPH SHOWING DOWN-PLUNGE DIMENSION OF PILLOW STRUCTURE. LOCATION 314 (SEE PLATE 1), HONEYMOON ISLAND.

Secondary Structures

Penetrative Structures

The supracrustal rocks of the area are generally well foliated. This foliation is mainly the result of compositional variations. Feldspar or mafic-rich bands, lenses, or elongate clots are most common. Where present, mineral constituents such as biotite, add to the compositional foliation by planar parallelism of grains.

The granitic rocks generally display a massive texture, however, all of the tonalitic rocks and the granitic rocks in the northwest part of the peninsula are foliated. This foliation is due to the segregation and alignment of mafic clots, or bands, and planar parallelism of micaceous minerals within the mafic concentrations.

Figures 4 & 5 are equal area projections of poles to foliation in the supracrustal and plutonic rocks respectively. Two well defined maxima appear in Figure 4, and planes designated S_1 and S_2 are plotted corresponding to these maxima. The east-west trending supracrustal foliation shows a "tail" (Fig. 4), which may indicate local folding of the foliation. The data shown in Figurs 5 is diverse, but three maxima are present and planes are ploted corresponding to these maxima. The general trend of two of the foliations in the plutonic rocks are coincident with those found in the supracrustals.

No lineations were noted in the plutonic rocks,

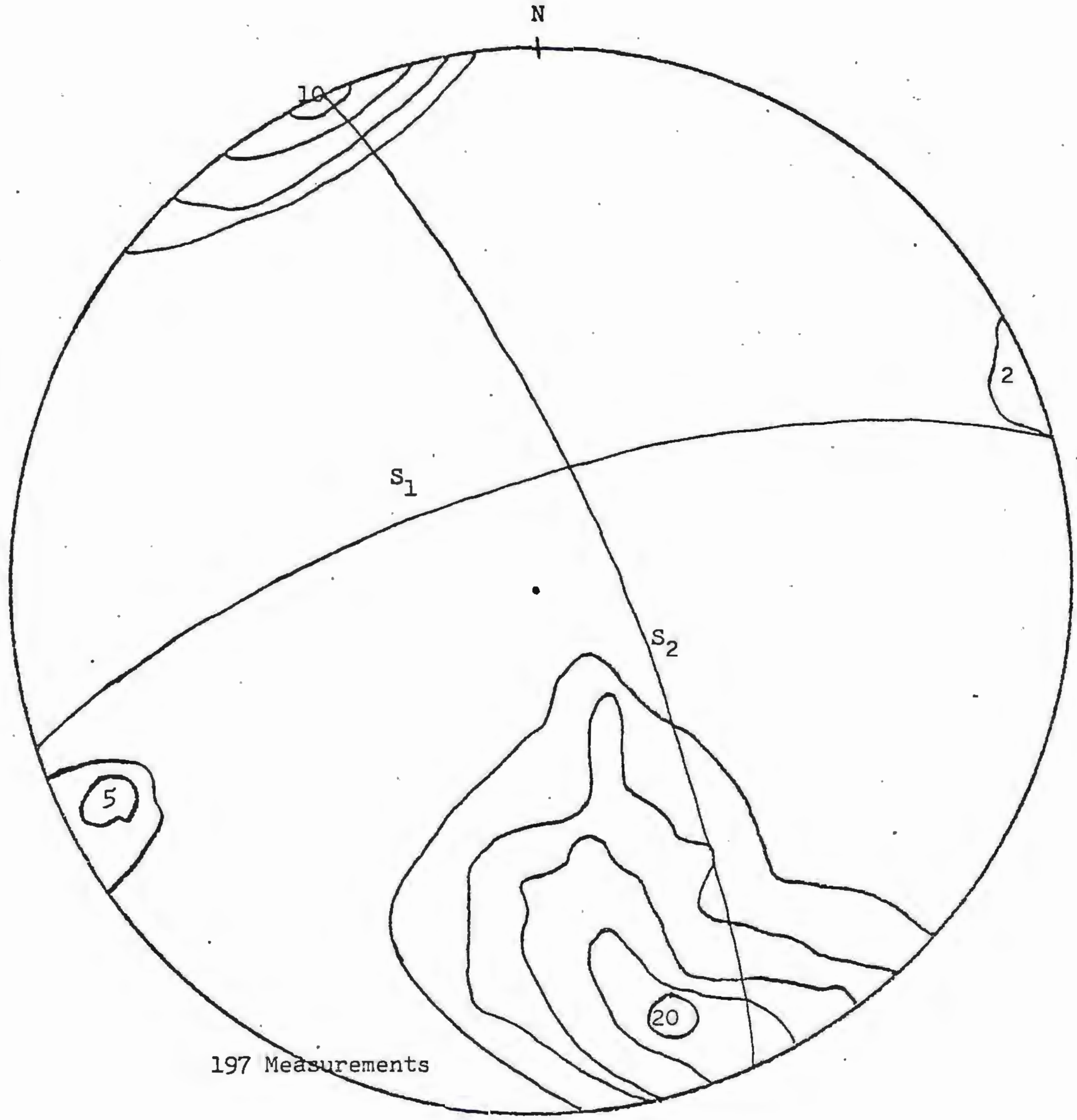


FIGURE 4 - EQUAL AREA CONTOUR OF POLES TO FOLIATION IN SUPRACRUSTAL ROCKS. COUNTOURS AT 2, 5, 10, 15, AND 20 PERCENT. CORRESPONDING PLANES ARE ORIENTED N.68°E. 74°N, AND N.24°W. 80°E.

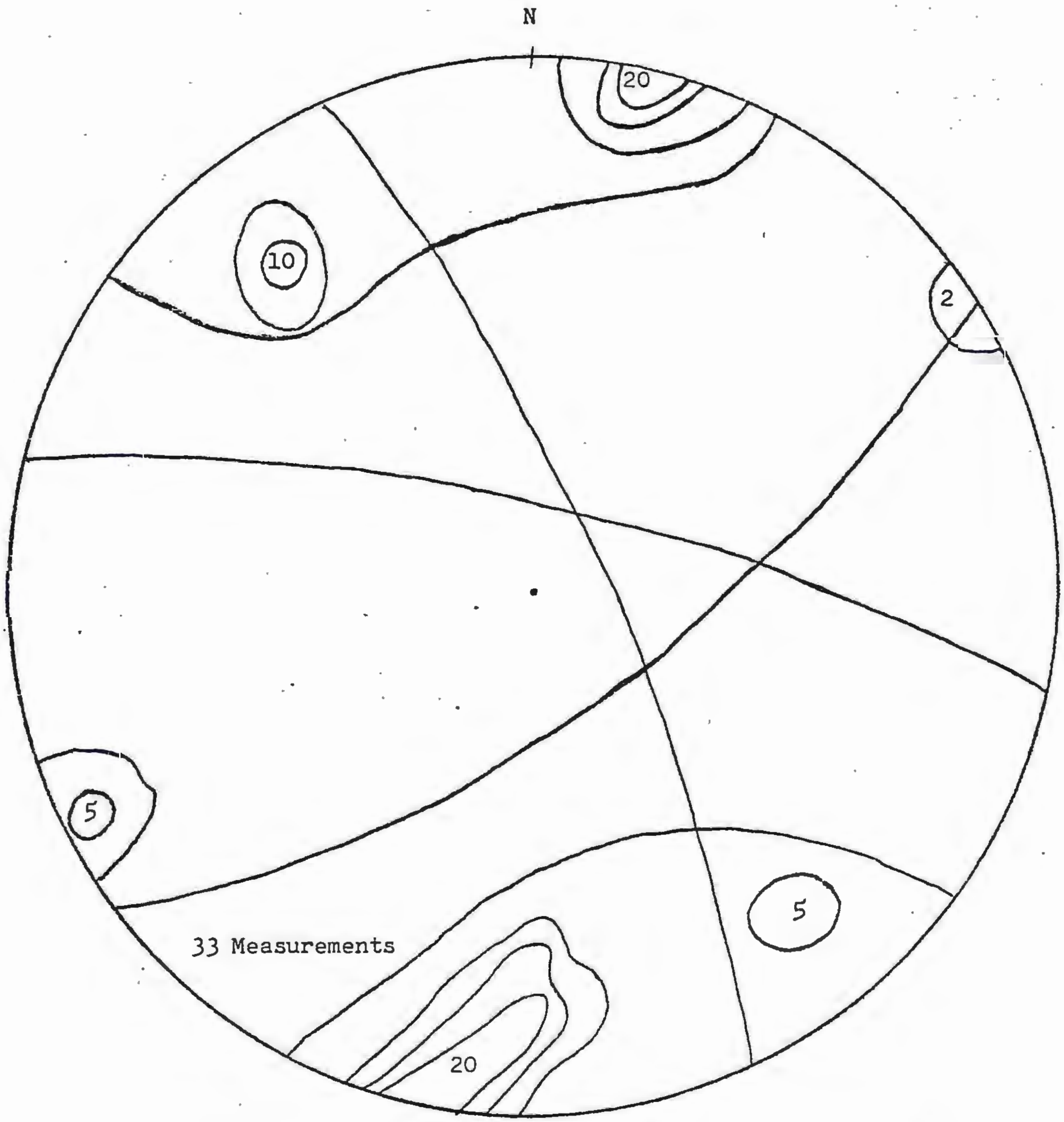


FIGURE 5 - EQUAL AREA CONTOUR OF POLES TO FOLIATION IN PLUTONIC ROCKS. CONTOURS AT 2, 5, 10, 15, AND 20 PERCENT. CORRESPONDING PLANES ARE ORIENTED N.27°W. 80°E. N.78°W. 80°N. AND N.56°E. 18°S.

however, the supracrustal rocks do contain lineations as well as linear structures. Mineral lineations are most common, but pytgmatic and small scale fold axes were also found. Lineations due to cleavage-bedding intersection were not noted. Mineral lineations are the result of parallel to subparallel alignment of hornblende prisms within the plane of foliation. Degree of development and orientation of these mineral lineations varies throughout the map area, but the orientation of such structures is fairly consistant within a single outcrop.

Ptygmatially folded veins, and dikes were found throughout the supracrustal unit, and are most prevalent in the hornblende gneiss phase. The folded veins and dikes range in width from 0.5 mm to 10 cm. The veins are composed of quartz, and the dikes are composed of medium to coarse-grained granite, or tonalite (plate 21).

Small scale folds were found along the northeast end of Oak Island. They occur in the amphibolite, and soapstone phases of the supracrustal unit. The folds are about 3 to 30 m in wave length and 3 to 20 m in amplitude. They are open, have vertical axial planes, and the dip on the limbs varies from 13° to 34° to the northeast (Plate 22).

Figures 6 and 7 are equal area projections of mineral lineations. These figures also include plots of ptygmatic and small scale fold axes. Figure 6 depicts data collected from supracrustal rocks which are fol-

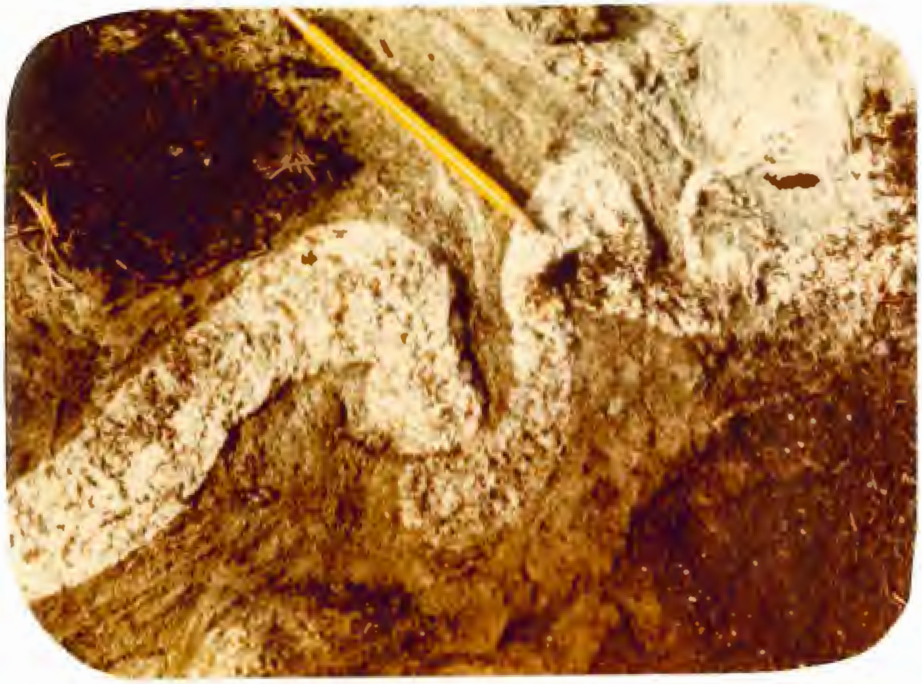


PLATE 21 - MEDIUM-GRAINED TONALITE DIKE IS PTYGMATICALLY FOLDED WITHIN AMPHIBOLITE HOST. LOCATION 400 (SEE PLATE 1), EAST END OF OAK ISLAND.

PLATE 22 - PHOTOGRAPH OF SMALL SCALE FOLD IN AUGITE EPIDOTE AMPHIBOLITE. LOCATION 42 (SEE PLATE 1), EAST END OF OAK ISLAND.

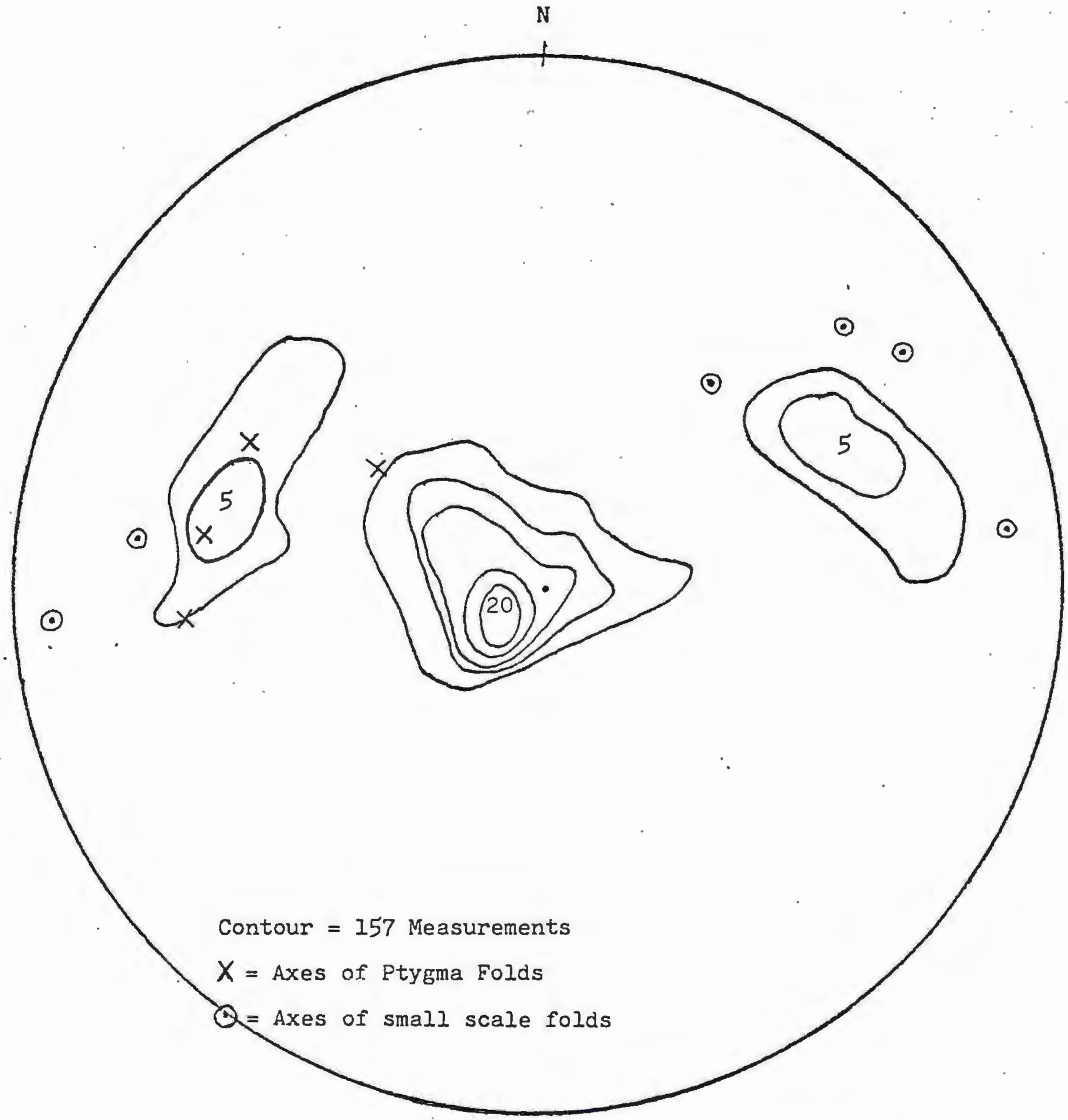


FIGURE 6 - EQUAL AREA CONTOUR OF HORNBLENDE MINERAL LINEATIONS, AND PLOT OF SMALL SCALE FOLD AND PTYGMA AXES IN SUPRACRUSTAL TRENDING NORTH-EAST - SOUTHWEST COUNTOURS 2, 5, 10, 15, AND 20 PERCENT.

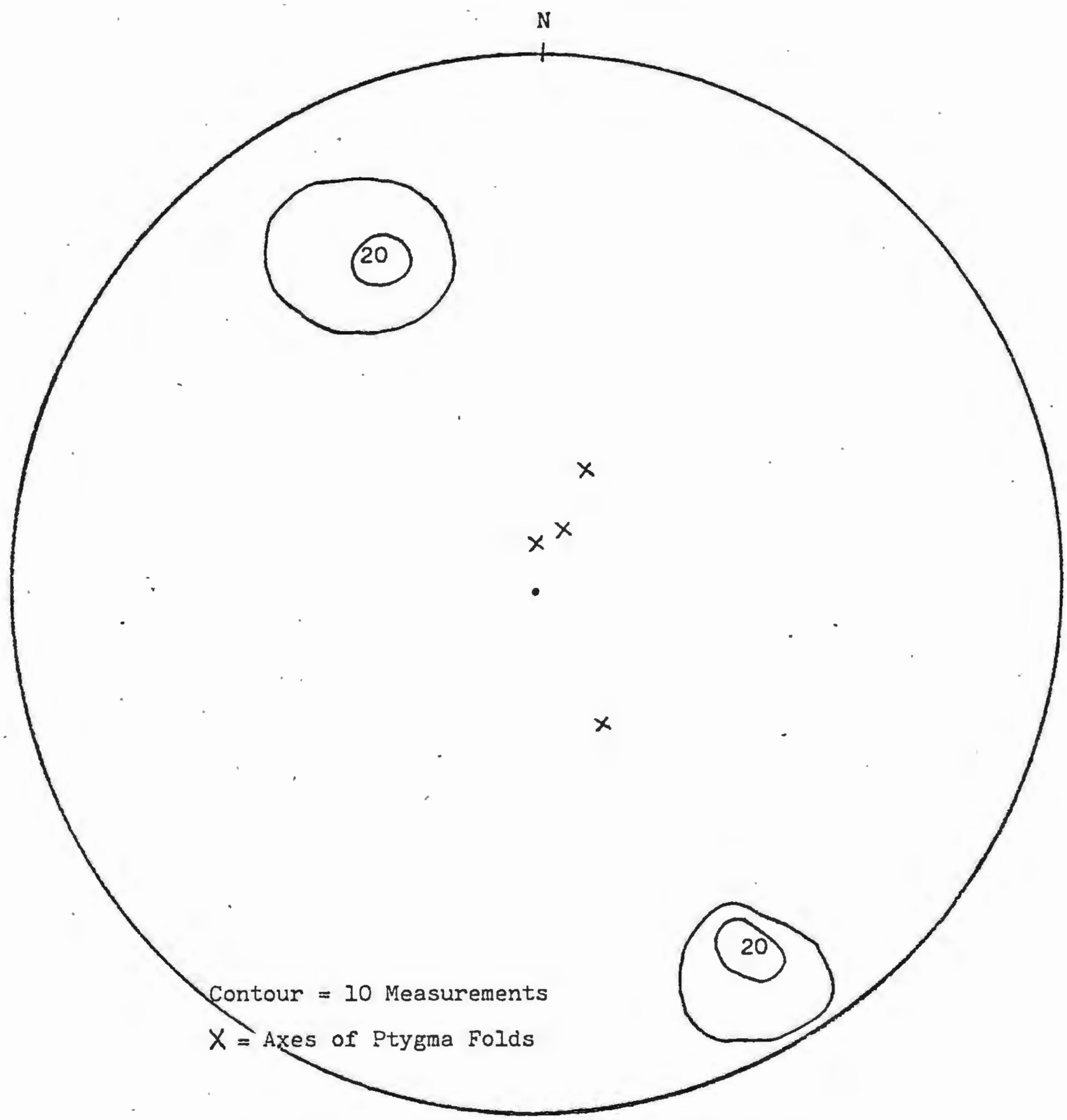


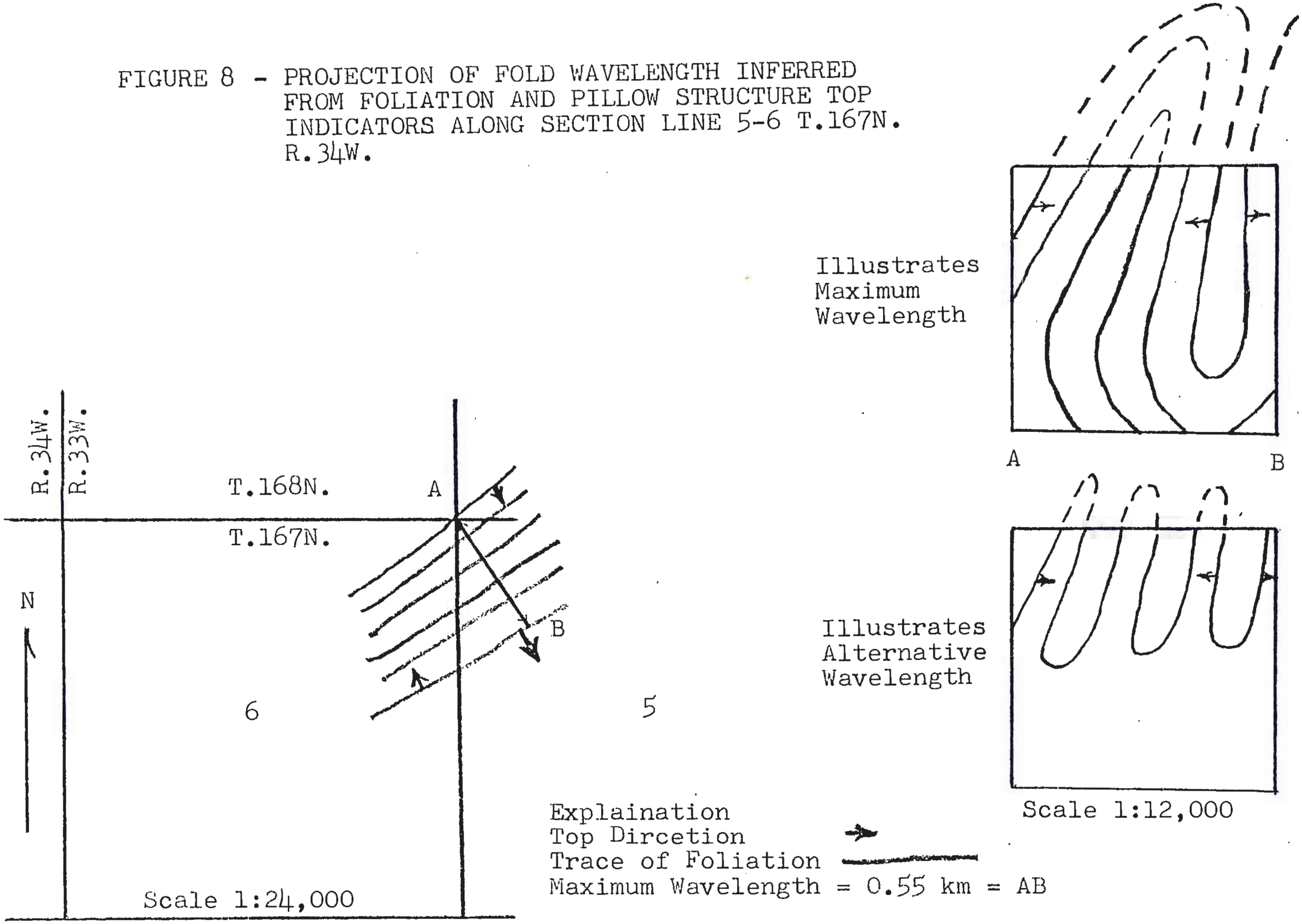
FIGURE 7 - EQUAL AREA CONTOUR OF HORNBLENDE MINERAL LINEATIONS, AND PLOT OF PTYGMA AXES IN SUPRACRUSTALS TRENDING NORTHWEST TO SOUTH-EAST. CONTOURS AT 10 AND 20 PERCENT.

iated subparallel to S_1, while figure 7 dipicts data collected from rocks which are foliated subparallel to S_2. The plot of mineral lineations associated with the supracrustal, S_2 trend (Fig. 4) appear as a line. Thus folding of S_2 features is not implied. The plot of mineral lineations associated with the supracrustal S_1 trend (Fig. 4) do not appear as a line, this may indicate folding subsequent to the development of this lineation.

Most areas of concentrated outcrop are less than 1 km_2 in area, and isolated. Thus while structural data is fairly consistant within outcrop areas, it is not necessarily consistant between outcrop areas. As few top indicators have been observed, specific definition of folding is not possible. The only outcrop area where top indicators show reversal in top direction is that in sections 1 and 12, 167/34, sections 6 and 7, 167/33. Determination of the precise nature of folds in this area is not possible, however, inference has been made concerning their general nature. The folds appear to be isoclinal. Evidence for this is the reversals of top direction in an area which has a consistant near vertical foliation. Assuming the fold model is correct these folds in section 7, 167/33 appear to be overturned, with axial planes dipping northward 80°. The folds in section 1 and 12, 167/34, and section 6, 167/33 appear to have nearly vertical axial planes. Since no marker beds have been noted in this area, it is impossible to infer the wave length or amplitude of these folds, however, a maximum possible wave length can be ascertained by measuring the distance normal to strike, between two consistent top indicators which have a reversal in tops between them (Fig. 8). The area along the north half of section lines 5 and 6, 167/33 is the only area which provides this opportunity. It should be noted that this calculated maximum wavelength (550 m) probably represents many fold wavelengths which are not recognized (Fig. 8).

The singularity of foliation trend within outcrop areas points toward two possible alternatives to explain the structural nature of individual outcrop areas other than the north shore of Oak Island, and sections 1 and 12 167/34, sections 5 and 6, 167/33. These areas appear to be (1) monoclines; or (2) isoclinally folded. The outcrop areas on the islands in the northeast part of the Northwest Angle and those in sections 3, 8, 10, 11, 14, 167/33 are difficult to interpret because they contain foliations which vary no more than 25° in dip, 5° in strike and dip consistantly in one direction. The outcrop areas in sections 10, 11 and 12, 167/34 may be isoclinally folded because they lie along strike from the outcrop area in sections 1 and 12, 167/34, sections 5 and 6, 167/33 which appears to be isoclinally folded. There is no apparent evidence favoring either of the two structural alternatives concerning those outcrop areas on the islands, and in sections 3 and 8, 167/34, however, reversal of dip direction would favor isoclinal folding

FIGURE 8 - PROJECTION OF FOLD WAVELENGTH INFERRED FROM FOLIATION AND PILLOW STRUCTURE TOP INDICATORS ALONG SECTION LINE 5-6 T.167N. R.34W.



as a explaination for the structural nature of outcrop areas found in sections 4 and 5, 167/34, and sections 32 and 33, 168/34.

The supracrustal rocks of the Northwest Angle generally appear to be isoclinally folded with axes trending northeast, subparallel to S_1 foliation. These isoclinal folds are designated F_1. The supracrustal rocks in the northwest part of the peninsula (sections 4 and 5, 167/34 and sections 32 and 33, 168/34) also appear to be isoclinally folded, with axes trending northwest, subparallel to S_2 foliation. Possible explanations for this structural pattern are: (1) F_1, isoclinal folding was refolded along F_2 northwest trend or (2) F_1 isoclinal folding was disrupted by emplacement of granitic plutons, causing S_2 trend by rotation of isolated detached blocks.

Non-Penetrative Structures

Observable contacts between the major rock units are generally absent, however, isolated areas with visible contacts were noted. Details regarding the macroscopic nature of these contacts appear in chapter 2, above. Interpretation of the megascopic nature of contacts appears below.

Preceptible contacts between the supracrustal units and the tonalite involve dikes of tonalite, which cut the foliation in the supracrustal units. Inferred contacts were projected from the location of outcrops, local topographic lows, the location of zones showing cataclastic textures, and the orientation of foliation within the units. The contact appears to trend east-west across the area and is curvilinear in shape.

Observable contacts between the supracrustal units and the granite involve massive granite intruding the supracrustals both parallel to and cross-cutting foliation. These contacts are sharp, but have no distinctly consistent trend. Contacts projected between outcrops have little basis for control, however, where sufficient outcrop is present to make a reasonable inferrence the contacts appear to be irregular in shape.

No visible granite-tonalite contacts were noted in the Northwest Angle, consequently little is known of their nature.

Contacts between the large mafic dikes and the other Northwest Angle units are sharp, vertical, and have a linear, northwest - southeast trend even where inferred.

Evidence of faulting was noted at only two outcrops. A linear pod of pegmatite in the southwest corner, SE $\frac{1}{4}$, NE $\frac{1}{4}$, section 6, 167/33, appears to be offset (Plate 1). The trend of the fault plane is inferred from the linear trend of covered contacts. No macroscopic evidence of shear was noted, thus the inferrance is highly conjectural. The trend of the inferred fault plane is N. 30 W. and vertical. If this relationship is valid, left lateral separation is the apparent movement along the fault plane. In the NE$\frac{1}{4}$, section 8, 167/34 warping of foliation within supracrustal rocks was noted along a pegmatite dike-supracrustal contact (plate 23). The dike is one foot wide and trends N. 40 W. with apparent left lateral separation.

Macroscopic evidence of shear was noted at two outcrop areas: the south shore of Honeymoon Island; and the north shore of Oak Island. Evidence of shear at these locations includes: (1) tendency of the rock to split parallel to foliation, without having a noticable penetrative schictosity; (2) strong non-penetrative lineation of minerals along the planes of separation; (3) stretched pillows, mentioned above, and boudins of tonalite dike, which have long axes parallel to the trend of non-penetrative mineral lineations. The best indicator of shear orientation on the south shore of Honeymoon Island is the plunge of the stretched pillows in a direction N. 58° W. 57°. This orientation is quite different than the orientation of penetrative mineral lineations found at this location (Plate 20). Because of the very fine grain size of the supracrustal rocks found on the north shore of Oak Island penetrative mineral lineations could not be measured, however, non-penetrative linear structures consisting of alignment of larger hornblende prisms along the parting planes were measured. Therefore the best indicator of shear orientation at this location are the mineral lineations. Orientation of these lineations is highly variable due to small scale folding, but the

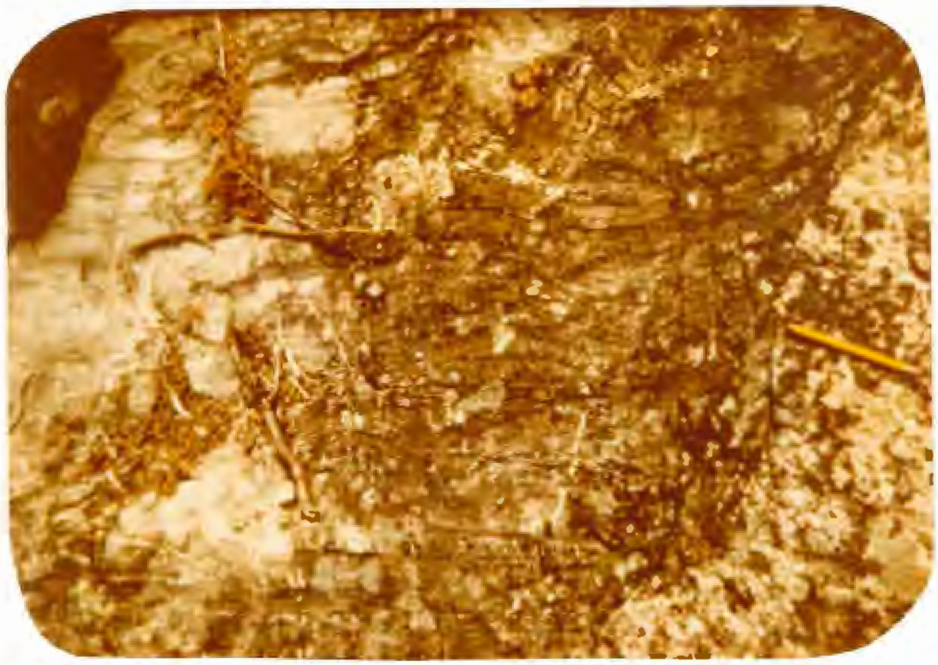


PLATE 23 - PHOTOGRAPH OF WARPED SUPRACRUSTAL FOLIATION. LOCATION 191 (SEE PLATE 1), SECTION 8, 167/34.

orientations appear to be consistant with the trend of fold axes at this location (Plate 20).

Microscopic cataclastic features were noted in many thin sections of rocks from the Northwest Angle. In general the plutonic rocks are deformed in a more ductile manner, while the supracrustal rocks show brittle fracture. For the purpose of classification I have divided the plutonic rocks into three groups non-cataclasized, cataclasized and moderately cataclasized (Appendix 1). The cataclasized plutonic rocks contain cracked, broken, and bent feldspar and quartz crystals. Neomineralliza- tion is also present in the form of polyganized boundaries on feldspar and quartz, and minor fluxtion structure of quartz and micas (Plate 24). Moderately cataclasized plutonic rocks have cracked, bent, and broken feldspar, and quartz crystals, but no neomineralization. Non-cataclasized rocks are characterized by only slightly undulose extinction in quartz, a few or no bent twin lamine, and few broken crystals.

The supracrustal rocks were divided into two groups: sheared and non-sheared (Appendix 2). The sheared samples show fractures along which shear has occurred (Plate 25). Non-sheared samples do not.

Most of the cataclasized rocks occur in isolated outcrops, however, one prevassive zone of cataclasis is apparent (Fig. 9). The shear zone appears to be about 0.5 km wide, and trends east-west along the inferred

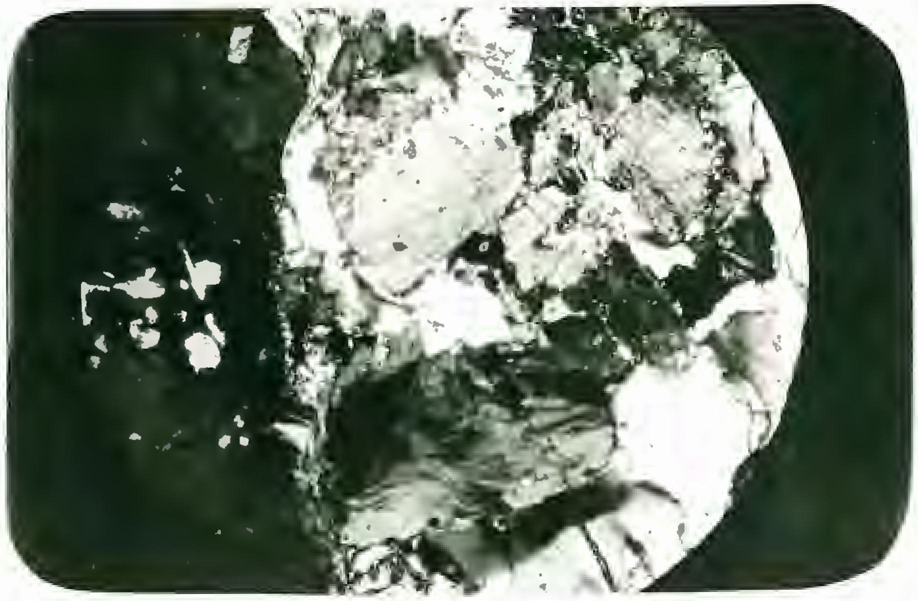


PLATE 24 - PHOTOMICROGRAPH SHOWING MINOR FLUXION STRUCTURE IN GRANITIC ROCK. MAJOR MINERALS INCLUDE PLAGIOCLASE, MICROCLINE, AND QUARTZ. FIELD OF VIEW 6.2 mm. LOCATION 228 (SEE PLATE 1), SECTION 10, 167/35.

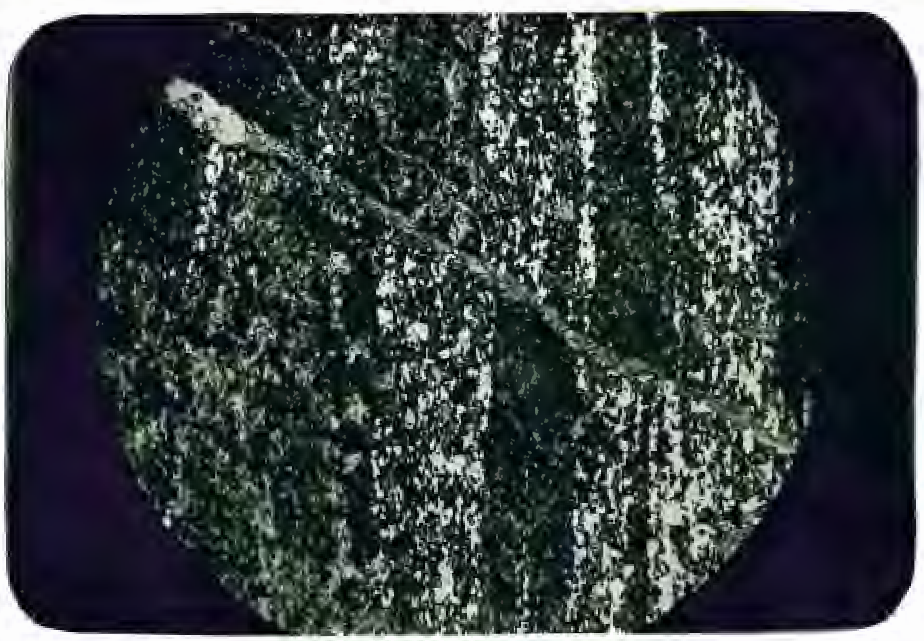


PLATE 25 - PHOTOMICROGRAPH SHOWING SHEAR IN AMPHIBOLITE. MAJOR MINERALS INCLUDE PLAGIOCLASE (LIGHT) AND HORNBLENDE (DARK). FIELD OF VIEW 6.2 mm. LOCATION 94 (SEE PLATE 1), SOUTH SIDE OF FLAG ISLAND.

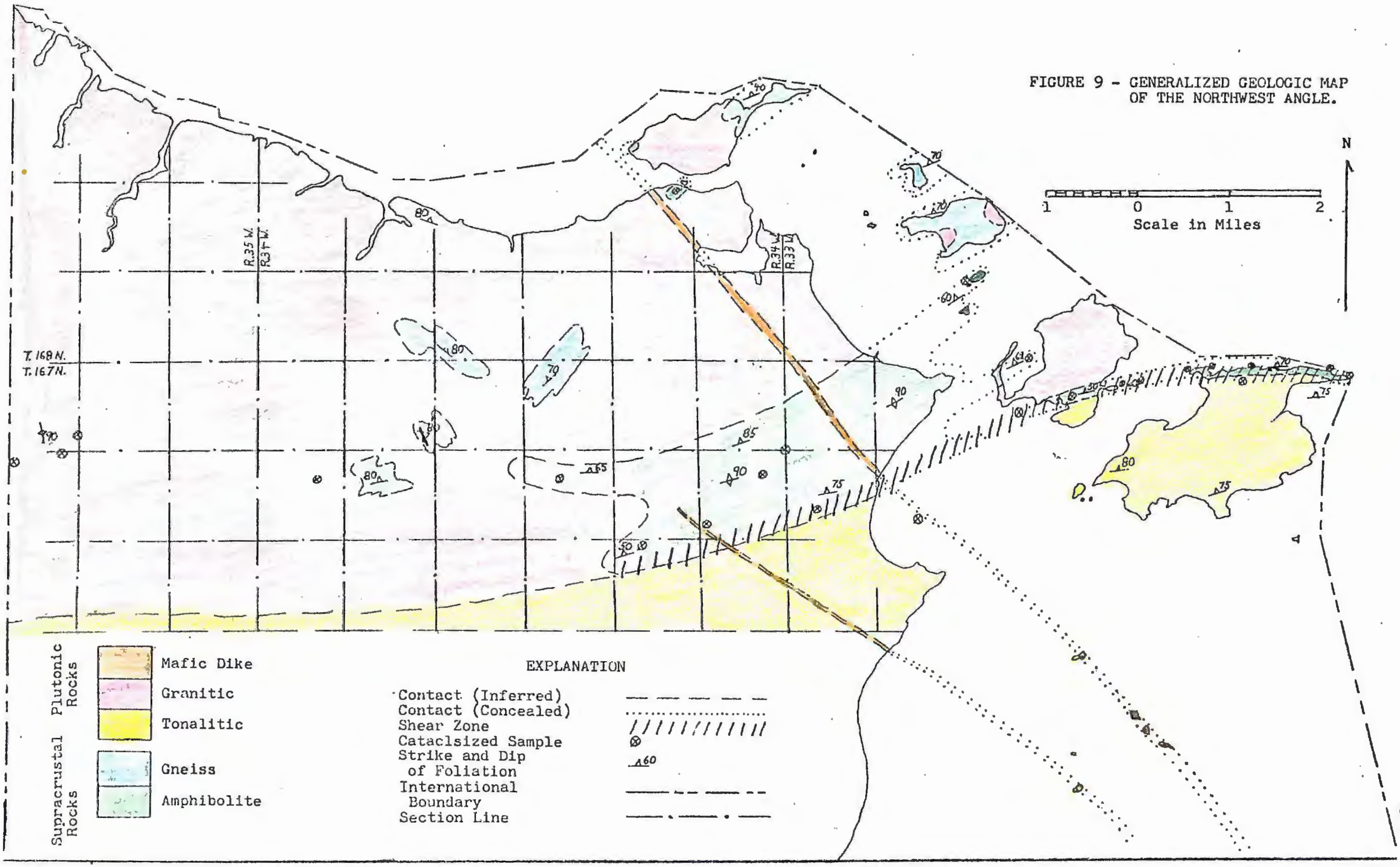


FIGURE 9 - GENERALIZED GEOLOGIC MAP OF THE NORTHWEST ANGLE.

Tonalite-amphibolite contact, in the central part of the map area.

Data concerning the orientation of shear is very limited, however, two general trends have been outlined: a vertical east-west trend, which appears to be subparallel to S_1; and a vertical north-south trend, which appears to be subparallel to S_2. The east-west shear is indicated by evidence of shear along the foliation plane of the supracrustals, and the large east-west trending shear zone found in the east-central part of the map area. Shear in the plane of foliation appears to have formed after folding. This is particularly evident in rocks from the south shore of Honeymoon Island, where the penetrative lineation trends differently than the non-penetrative lineation which appears to be related to shear. Cataclasis is noted in the tonalitic, and granitic rocks along the major east-west shear zone, thus shear continued to occur subsequent to granitic emplacement at this location. The trend of the large mafic dikes does not appear to be disrupted as they cross the projected east-west shear zone therefore no major strike slip movement occurred along this shear zone subsequent to dike emplacement.

The north-south shear evidenced by the inferred fault in section 6, 167/33 occurred after the formation of the granitic pegmatite found at this location. The north-south movement evidenced by the warped foliation within supracrustals in section 8, 167/34 appears to have occurred during the emplacement of the granitic pegmatite at this location. It should be noted that this trend is parallel to the trend of large mafic dikes. This may indicate the dikes were emplaced along an earlier formed fracture system. The internal isotropy of the large mafic dikes indicates little or no structural deformation occurred during or subsequent to their emplacement.

Structural Interpretation

Foliations in the supracrustal rocks appear to be the result of folded bedding, accentuated by dynamothermal metamorphism. Evidence for this is four fold; (1) compositional variation is the major cause of foliation (Plates 3, 4, 7); (2) contacts within the supracrustal are coincident with foliation (Plate 26); (3) the orientation of top indicators, and foliation describes folding; and (4) recrystallized mineral phases have long axes parallel to the compositional foliation.

Foliations within the plutonic rocks of the area appear to be due to flow structure. Mafic mineral constituents have parallel long axes which are coincident with the long axes of elongate clots of mafic minerals and mafic xenoliths.

Two general orientations of the foliation are dominant in the supracrustals; an east-west trend, S_1, and a north-south trend, S_2. These are coincident with the general orientation of foliations in the plutonic rocks. The S_1 trend represents data gathered from the tonalitic

PLATE 26 - BANDED HORNBLENDE GNEISS OVERLYING TUFFACEOUS AUGITE HORNBLENDE GNEISS ALONG A CONTACT. LOCATION 308 (SEE PLATE 1), NORTH SHORE OF EBERHARD ISLAND.

plutonic rocks, and most of the supracrustal rocks, The S_2 trend represents data gathered from granitic plutonic, and supracrustal rocks in the northwest part of the map area (Fig. 9).

Mineral lineations are the result of dynamothermal metamorphism. Presumably their orientation was controlled by stress during plutonic emplacement. There are two general trends of orientation seen in mineral lineations; steep, and fairly shallow plunging (Figs. 6 & 7). The steeper lineations represent data gathered near the tonalite-supracrustal contact, while the more shallow lineations represent data gathered to the north, where the plutonic rocks are granitic in composition. (Plate 20).

Other conclusions which relate to the structural interpretation are: (1) the supracrustal rocks of the area were at one time a continuous structural block, but at the present level of erosion are restricted in area to that which is outlined by the outcrops; and (2) the plutonic rocks of the area represent multiple intrusions over a period of time.

The first of these conclusions encompasses two points. I believe the supracrustals once formed a continuous block, because of the general continuity of foliation trend shown by the rocks, and compositional similarity throughout the supracrustal unit. The reason for believing the supracrustals are not a continuous block at the present level of erosion is that discrete individual beds cannot be traced along strike beyond the boundary of the particular outcrop area in which they are found. Also, Ziehlke (1974), and Brown (1975), note that the common metamorphic grade in the area is greenschist, with elevation in grade no further than 350 m to 1 mile away from plutonic contacts, therefore the supracrustal rocks of the Northwest Angle, which show amphibolite prograde metamorphism are presumed to be close to plutonic contacts. If the supracrustals formed one continuous block, this could not be true in all instances.

The second conclusion is based on the fact that there are at least five compositionally different types of plutonic rock. These rocks show varied metamorphic and cataclastic features, but the more basic types generally show greater evidence of metamorphism, and cataclasis.

Considering these conclusions a feasible structural history would be: (1) deposition of supracrustals, formation of bedding, and primary structures; (2) structural deformation, causing isoclinal F_1 folding of bedding in supracrustals; (3) emplacement of large tonalitic intrusions, contact metamorphism of supracrustals, formation of foliation in tonalite, formation of S_1 foliation in supracrustals; (4) emplacement of smaller granitic intrusions, regional metamorphism of supracrustals, and tonalite, further development of compositional foliation and lineation in supracrustals, local disruption of S_1 producing S_2 north-south trend, emplacement of the younger granitic intrusions caused shear, particularly along the rigid boundaries between earlier instrusives, and the supracrustals.

No clear cut evidence has been noted that would indicate whether the major F_1folding occurred before, or during the emplacement of the tonalite. The orientation of the tonalite-supracrustal contact may have been controlled by the F_1 trend in the supracrustals at the time of emplacement, or the F_1 trend in the supracrustal may have developed at the time of tonalitic emplacement, caused by the same tectonic regime which produced the orientation of the foliation within the tonalite, and the trend of the tonalite-supracrustal contact.

It is apparent that the tectonic regime which produced F_1 folding in the supracrustals had dissappeared before the onset of granitic emplacement.

PETROCHEMISTRY

Ten rock samples from the Northwest Angle area were analyzed for weight percent of common rock forming oxides using atomic absorption methods. Table 6 shows the results of these analyses on seven samples from the supracrustal unit and one sample from each of the three major intrusive units. The samples were chosen for analysis after microscopic examination, and only samples which showed little visible evidence of secondary alteration were considered for analysis. The intrusive samples were chosen because they represent an average model composition for that particular unit (Figs 10 -13). The supracrustal samples were selected on the basis of several criteria with the goal of obtaining a suite that is representative of the entire supracrustal unit (geographically, mineralogically, and texurally). Color, mineralogy and location were used as criteria for the selection, but the over-riding factor was texture. Two samples appear tuffaceous, two samples appear agglomeratic one sample contains evidence of pillow structure, and two samples are banded.

The supracrustal rocks were classified using the schemes of Irving and Baragar (1971), and Jensen (1976). Table 7 indicates rock names classified according to Irving and Baragar (Fig. 14), Jensen (Fig. 15) as well as a descriptive name and location for all the supracrustal samples analyized. A list of norm symbols used in the

TABLE 6-ANALYSES OF SAMPLES FROM THE NORTHWEST ANGLE.

	Supracrustal							Plutonic		
Sample	64	211	128a	264	183	308b	297	80	277	289a
SiO_2	67.45	65.43	57.76	57.76	52.48	52.41	51.34	73.94	71.66	51.34
Al_2O_3	18.15	16.52	16.00	16.09	19.27	17.02	15.13	15.48	17.45	15.38
FeO*	3.26	4.06	9.40	13.83	9.33	7.86	10.85	1.59	1.69	6.30
MgO	0.76	1.81	2.24	1.98	4.01	4.34	7.05	0.17	0.31	11.92
CaO	3.37	5.47	8.95	5.68	11.33	12.31	12.80	0.88	2.53	11.53
Na_2O	5.36	6.39	2.80	2.88	3.44	2.67	0.91	4.41	6.60	1.68
K_2O	3.32	1.66	2.14	1.84	0.29	2.68	1.21	5.02	2.84	0.30
TiO_2	0.58	0.42	1.62	0.83	1.37	0.88	0.88	0.35	0.17	1.47
MnO	0.05	0.11	0.18	0.42	0.17	0.13	0.19	0.07	0.06	0.20
L.O.I.	0.30	0.25	0.34	0.45	0.37	0.33	0.79	0.33	0.30	0.49
Total	102.96	102.10	101.43	101.76	102.06	100.63	101.15	102.24	103.61	100.61

L.O.I. = Loss on ignition.

FeO* = Atomic Fe x 1.29.

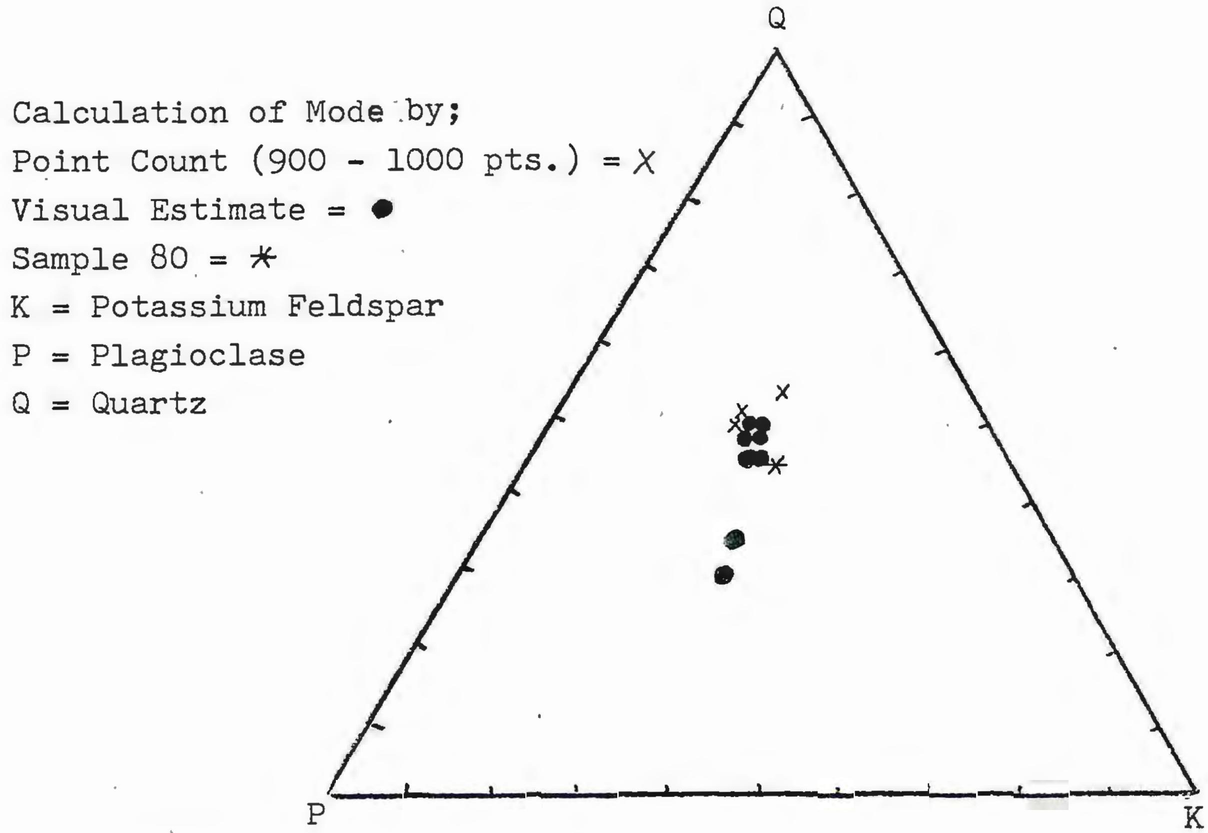


FIGURE 10 - Q-P-K TERNARY DIAGRAM OF GRANITIC ROCKS.

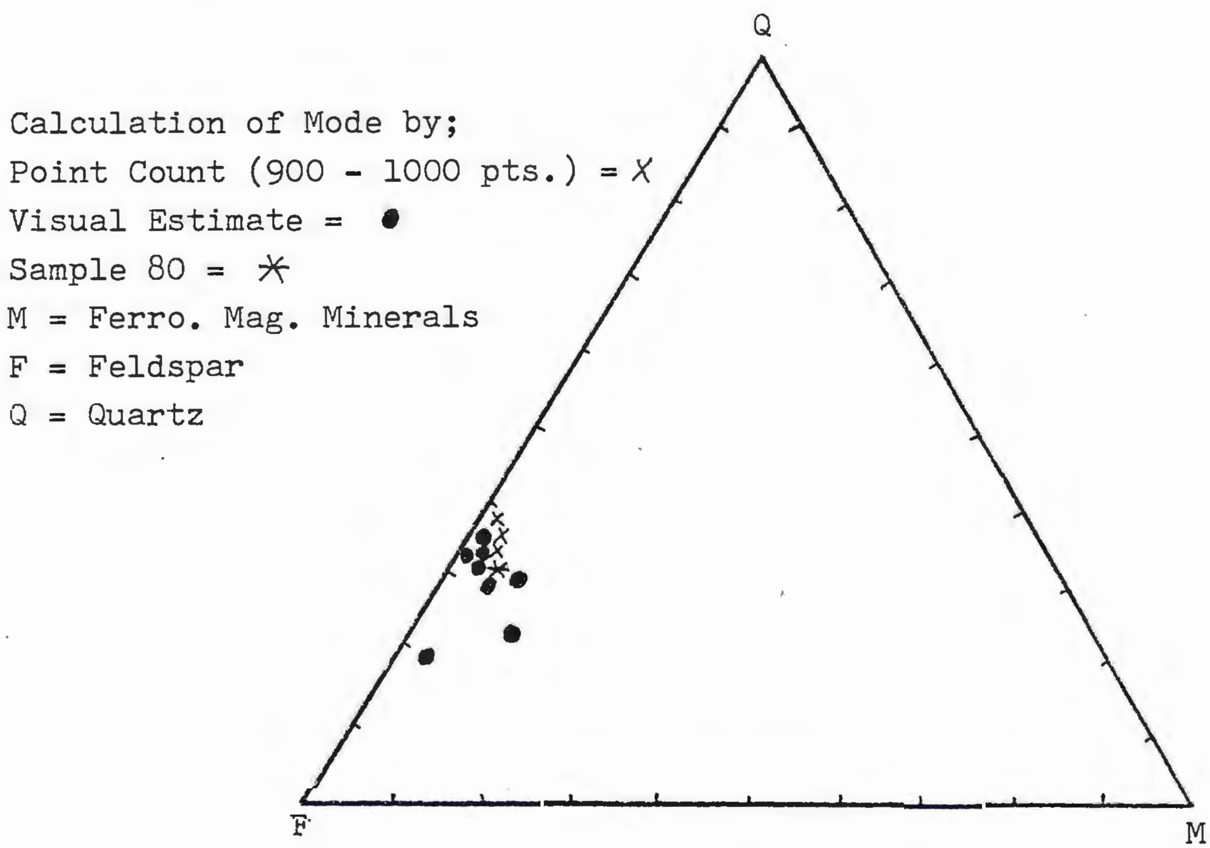


FIGURE 11 - Q-F-M TERNARY DIAGRAM OF GRANITIC ROCKS.

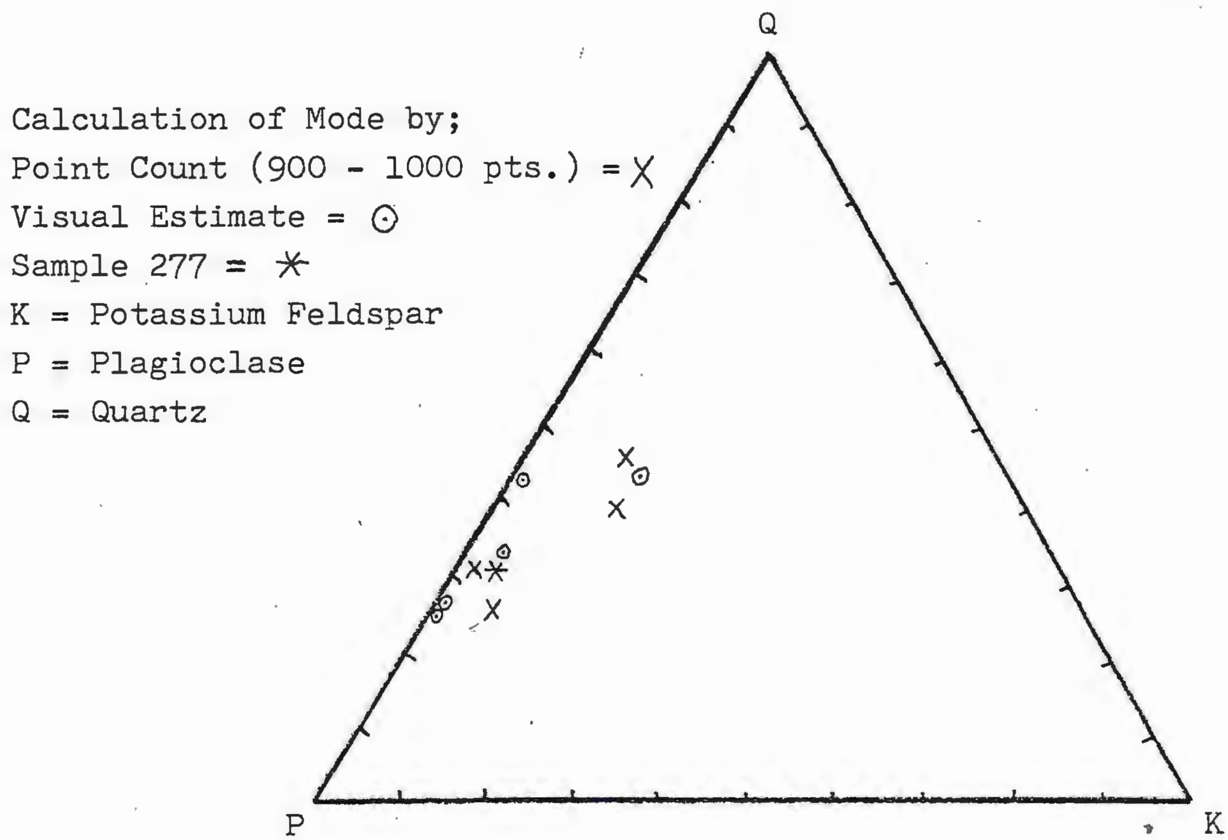


FIGURE 12 - Q-P-K TERNARY DIAGRAM OF TONALITIC ROCKS.

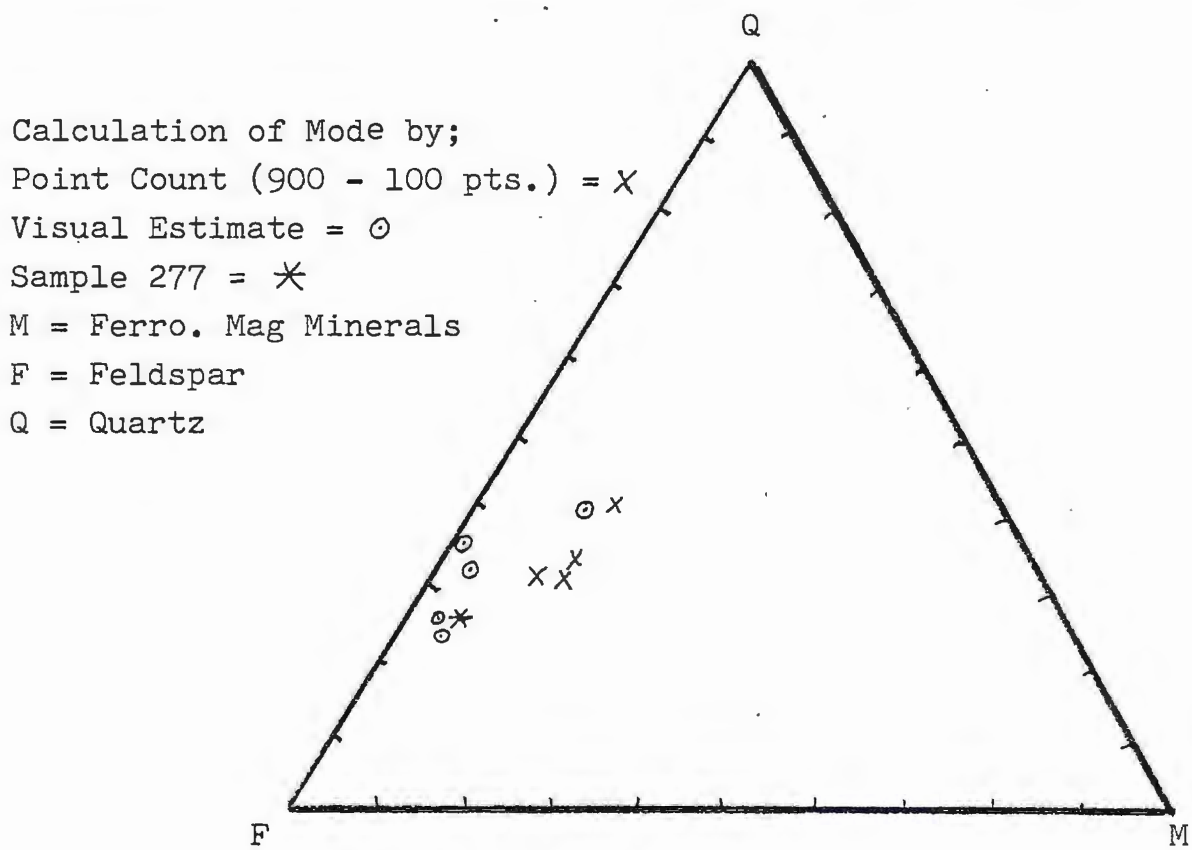


FIGURE 13 - Q-M-F TERNARY DIAGRAM OF TONALITIC ROCKS.

TABLE 7 - CHEMICAL, AND DESCRIPTIVE CLASSIFICATION OF SUPRACRUSTAL ROCKS

Sample	Chemical name after Irving and Baragar (1971)	Chemical Name after Jensen	Descriptive Name
64	Dacite	Calc-alkalic Rhyolite	Lensoid Biotite Gneiss
211	Dacite	Calc-alkalic Dacite	Banded Biotite-Hornblende Gneiss
128 a	High Alumina Basalt	Tholeiitic Andesite	Pillowed Biotite Hornblende Gneiss
264	High Alumina Basalt	Thoeliitic Andesite	Banded Biolite Garnet Amphibolite
183	High Alumina Basalt	Calc-alkalic Andesite	Tuffaceous Amphibolite
308a	High Alumina Basalt	Calc-alkalic Basalt	Agglomeratic Augite Hornblende Gneiss
297	Tholeiitic Basalt	High Iron Tholeiitic Basalt	Schistose Amphibolite

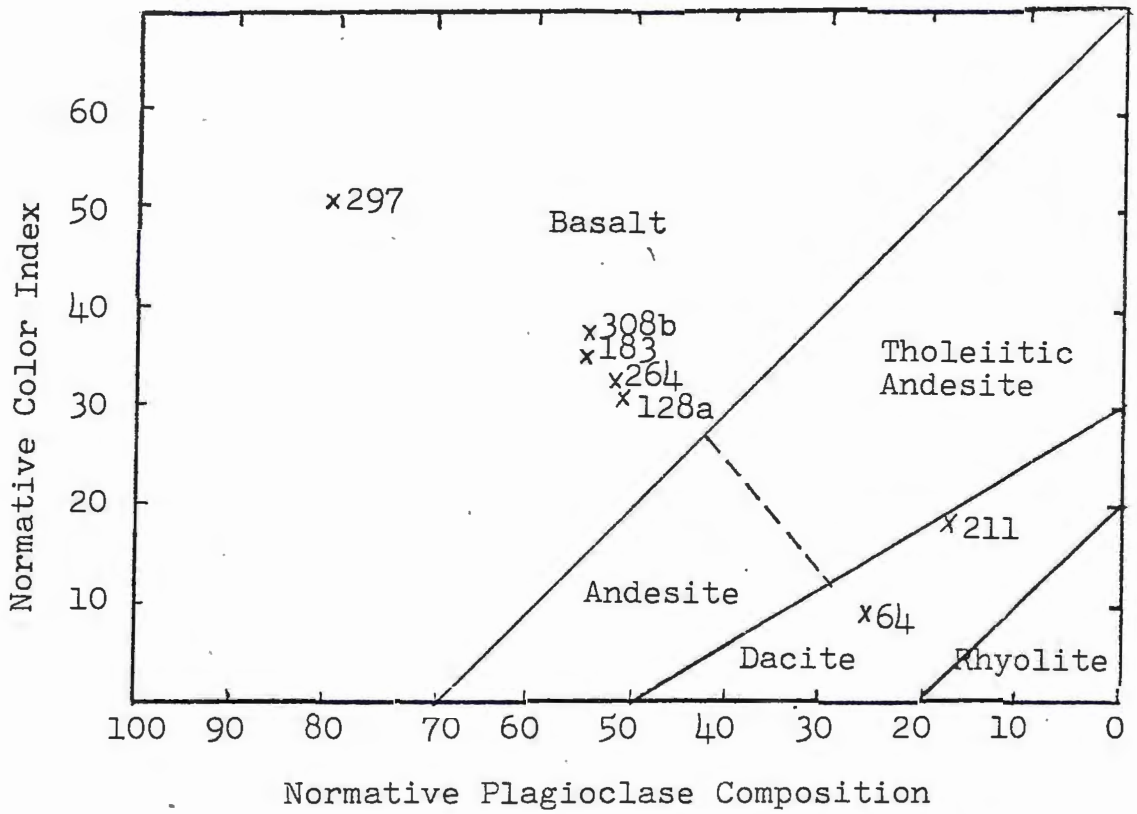


FIGURE 14 - A PLOT OF NORMATIVE COLOR INDEX VS. NORMATIVE PLAGIOCLASE COMPOSITION, AFTER IRVING AND BARAGAR, (1971).

Normative Color Index = Ol+Cpx+Opx+Il

Normative Plagioclase Composition = 100An/(An+Ab+5/3Ne)

X = Northwest Angle Sample

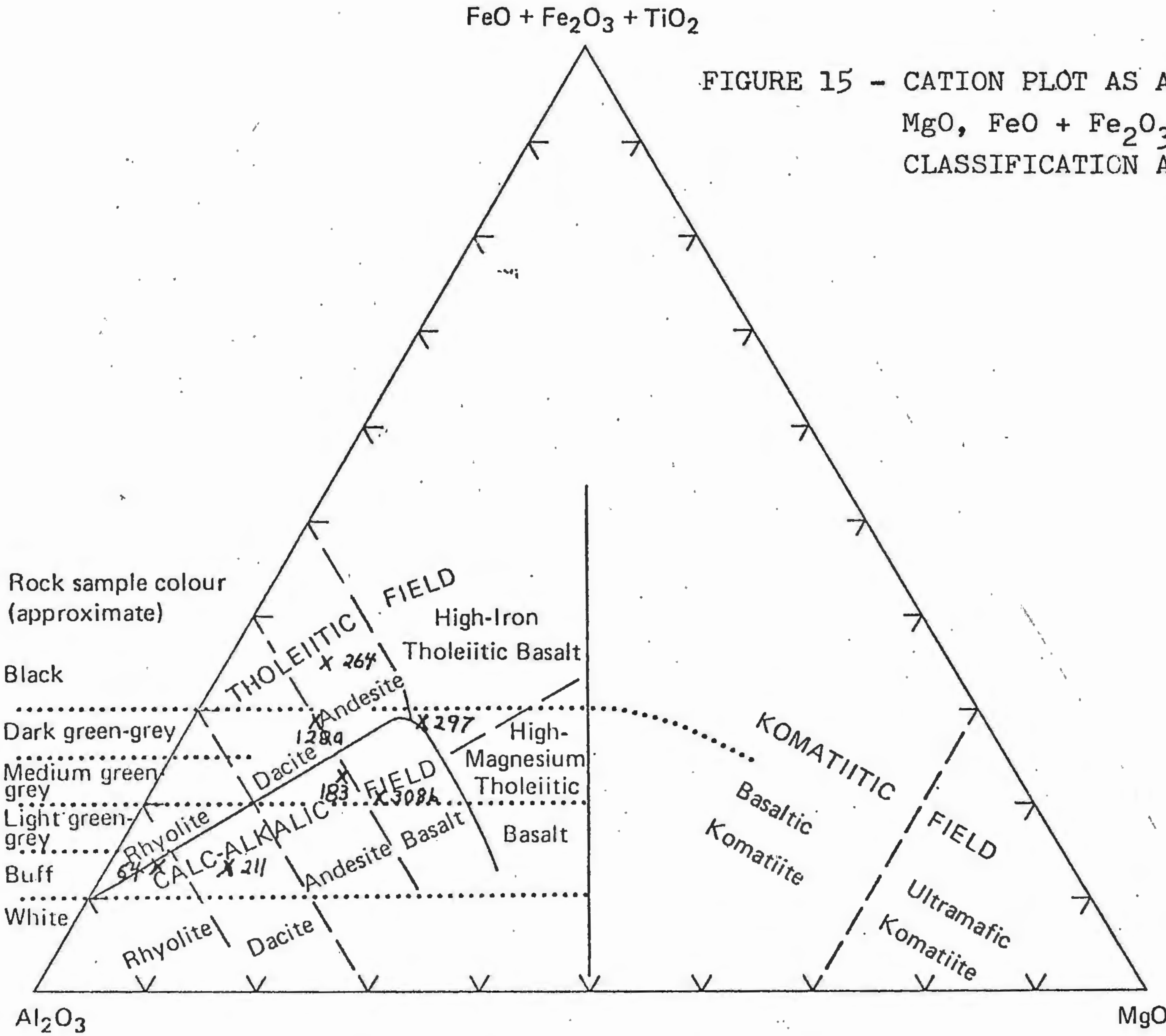


FIGURE 15 - CATION PLOT AS A FUNCTION OF Al_2O_3, MgO, $FeO + Fe_2O_3 + TiO_2$ SHOWING ROCK CLASSIFICATION AFTER JENSEN, (1976).

text appears in Table 8.

According to criteria used by Irvine and Baragar (1971) the supracrustal rocks of the Northwest Angle represent a subalkaline suite as indicated in Figures 16 and 17.

The determination of whether the Northwest Angle supracrustal samples belong to the calc-alkalic series or the tholeiitic series of subalkaline volcanic rocks is not clear cut. Table 9 indicates this determination according to the criteria of (Irving and Baragar, 1971; Figs. 18, 19 and of Jensen, 1978; Fig. 15). By noting which samples were not clearly classified by a particular method (plots on or near lines proposed to distinguish between the two series), and disregarding these determinations a logical classification results. Samples 64, 211, 183, and 308b are calc-alkalic and thus chemically similar to the volcanic rock found in the Paricutin Region, Mexico (Williams 1950, Wilcox 1954), the Aleutions (Irving and Baragar, 1971), or the Cascades (Irving and Baragar, 1971). Samples 128a, 264, and 297 are tholeiitic, and thus chemically similar to the volcanic rock found in the Snake River Plane, Idaho (Stowe, 1967), the Columbia River Basalts, (Irving and Baragar, 1971), and the Hawaiian tholeiitic rocks (Irving and Baragar, 1971). It is notable that all of the samples classified as calc-alkalic appear tuffaceous, while the tholeiitic samples are pillowed or banded.

TABLE 8 - C.I.P.W. NORM SYMBOLS IN TEXT.

Q	Quartz
Or	Orthoclase
Ab	Albite
An	Anorthite
Ne	Nepheline
Ol	Olivine
Opx	Hypersthene
Cpx	Diopside
Il	Ilmenite

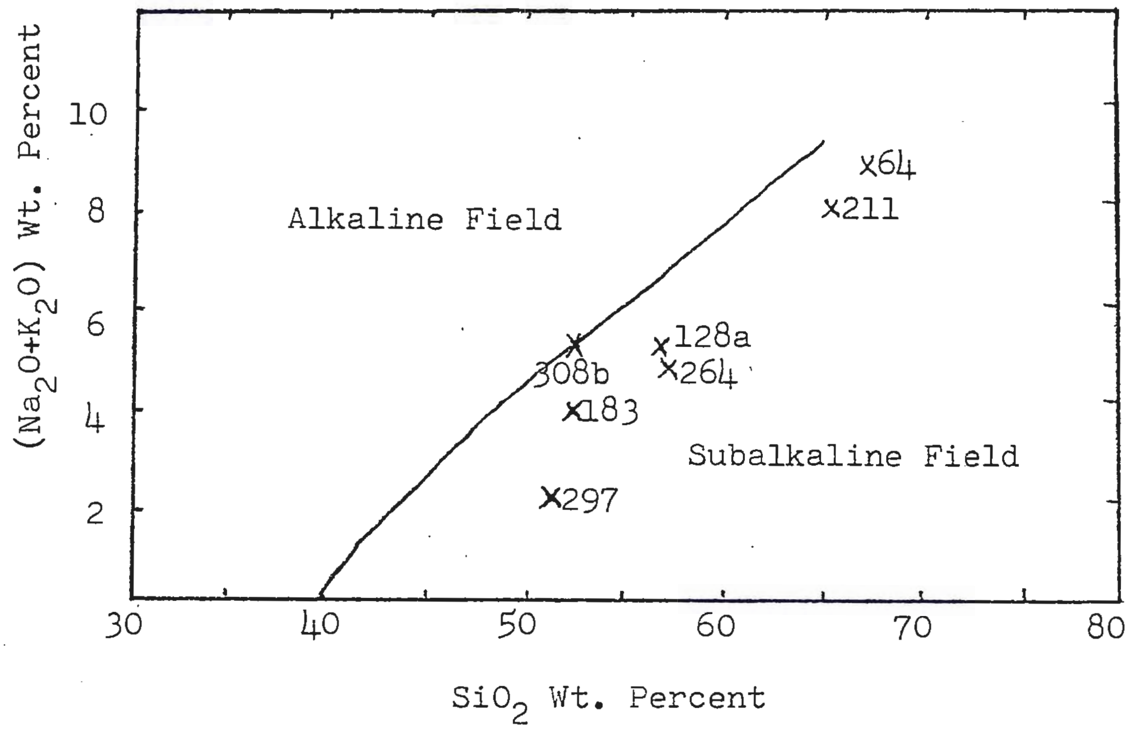


FIGURE 16 - WEIGHT PERCENT (Na_2O+K_2O) VS. WEIGHT PERCENT SiO_2, AFTER IRVING AND BARAGAR, (1971).

X = Northwest Angle Sample

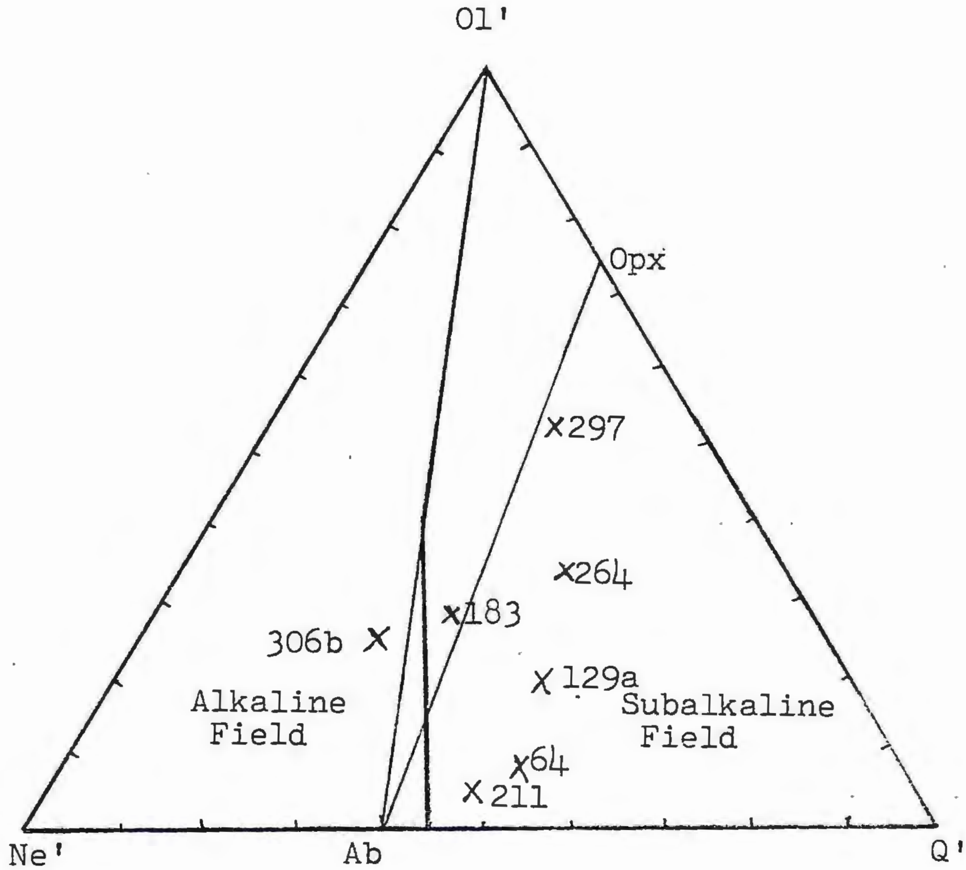


FIGURE 17 - A PROJECTION OF THE Cpx-Ol-Ne-Q TETRAHEDRON FROM Cpx APEX TO THE Ol-Ne-Q PLANE. AFTER IRVING AND BARAGAR, (1971).

Ne' = Ne+3/5Ab

Ol' = Ol+3/4Opx

Q' = Q+2/5Ab+1/4Opx

X = Northwest Angle Sample

TABLE 9 - RESULTS OF CALC-ALKALIC VS. THOLEIITIC CHEMICAL CLASSIFICATIONS.

Criteria	64	211	128a	264	183	308b	297
A-M-F	C.A.	C.A.	T.	T.	T.*	C.A.	T.
Wt.% Al_2O_3 Vs. Norm. Plag. Comp.	C.A.	C.A.	C.A.*	C.A.*	C.A.	C.A.	T.
Cation Plot (Jensen)	C.A.	C.A.	T.	T.	C.A.	C.A.	T.

C.A.* Calc-alkalic, near diving line.

T.* Tholeiitic, near dividing line.

C.A. Calc-alkalic, in field.

T. Tholeiitic, in field.

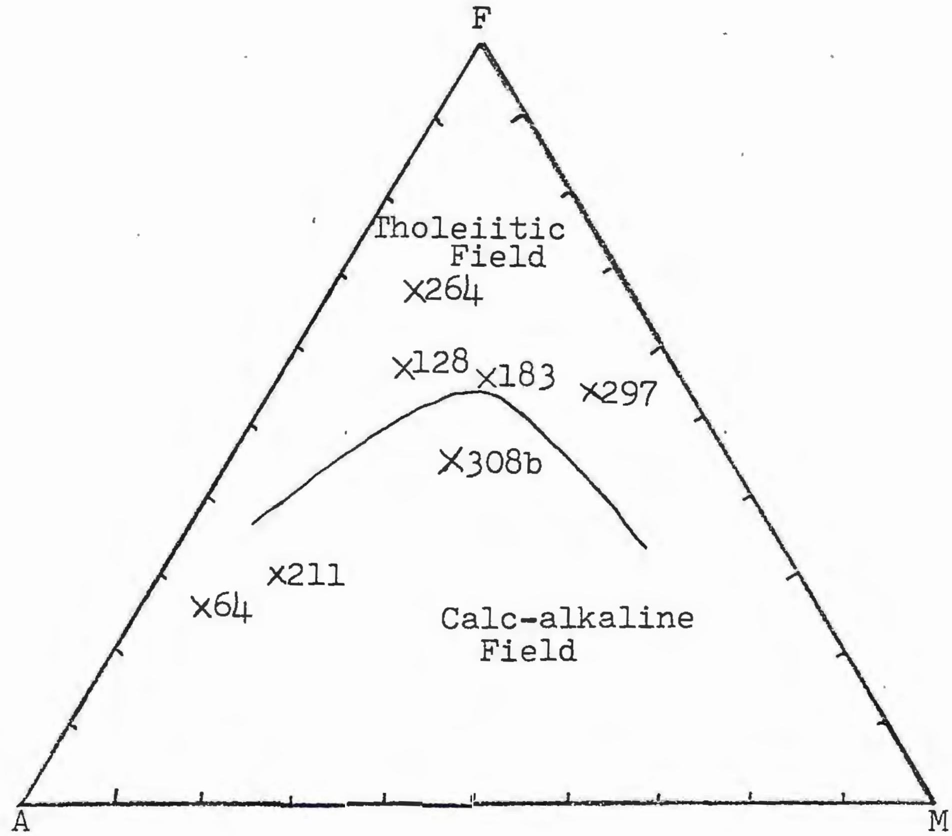


FIGURE 18 - AN A-F-M TERNARY DIAGRAM, AFTER IRVING AND BARAGAR, (1971).

A = (K_2O+Na_2O) Wt. Percent
F = FeO* Wt. Percent
M = MgO Wt. Percent
X = Northwest Angle Sample

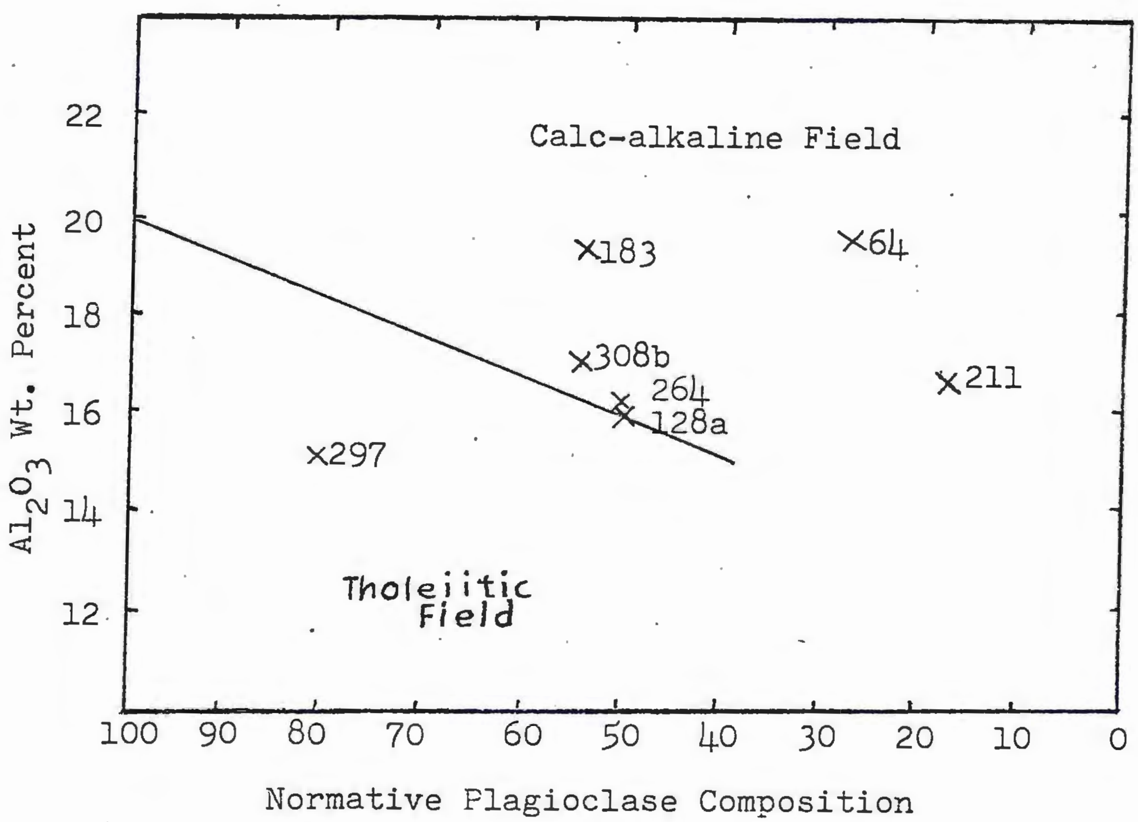


FIGURE 19 - A PLOT OF WEIGHT PERCENT Al_2O_3 NORMATIVE PLAGIOCLASE COMPOSITION. AFTER IRVING AND BARAGAR, (1971).

Normative Plagioclase Composition = 100An/An +Ab+5/3Ne

X = Northwest Angle Sample

A plot of the Niggle Alkaline Index versus Si values (Fig. 20) indicates the Northwest Angle supracrustal samples lie near or within the orogenic calc-alkaline field (Wilson, et al., 1965).

The analyses of the Northwest Angle supracrustal samples indicates they are calc-alkalic and tholeiitic volcanic rocks, chemically similar to the subalkaline Archean volcanic rocks from the Indus Area of northern Minnesota (Gladen, 1978), the Vermilion District (Green, 1971). and the Superior Province (Wilson et al., 1965). Although calc-alkalic and tholeiitic volcanic rocks are not commonly associated in modern volcanic terranes, this association is common in Archean volcanic terranes where it is thought to be the product of contemporaneous extrusion from separate magma sources.

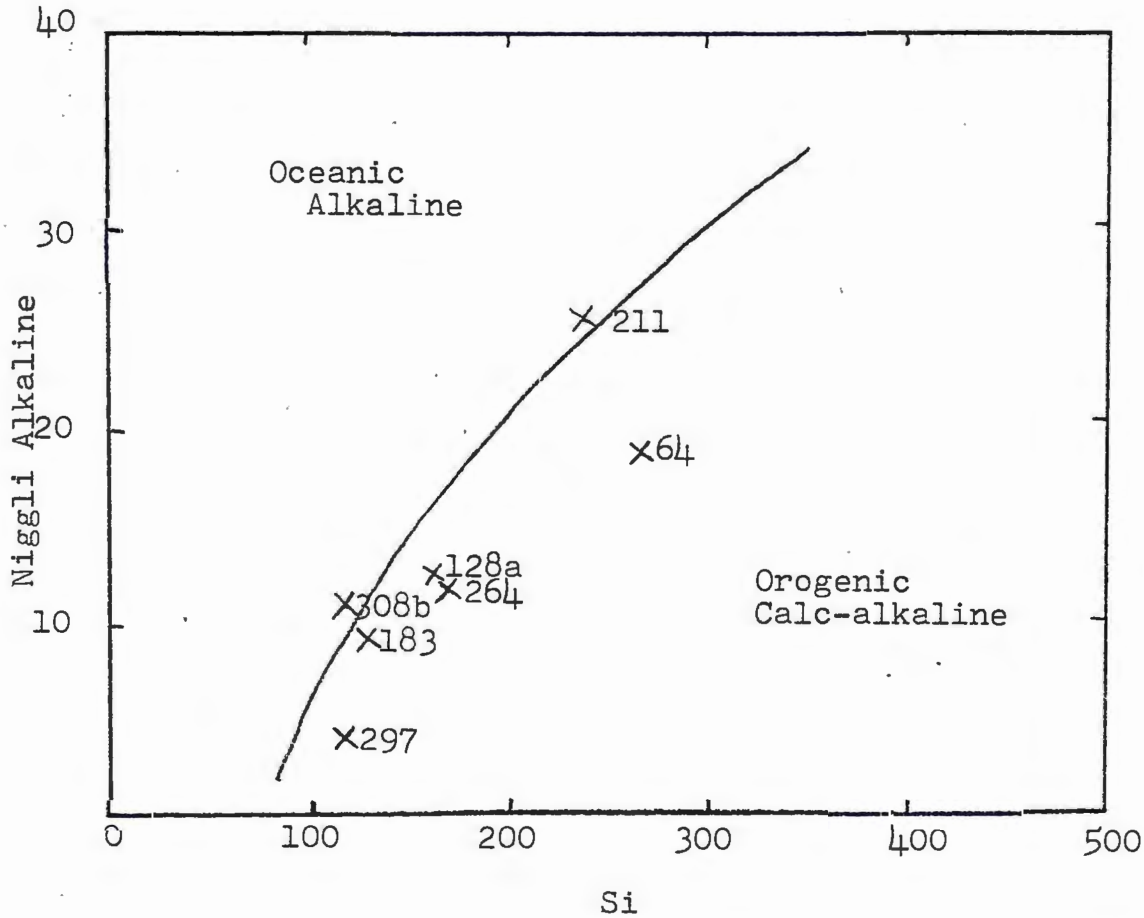


FIGURE 20 - NIGGLI ALKALINE INDEX VERSUS Si VALUES, AFTER WILSON (1965).

X = Northwest Angle Sample

SUMMARY AND CONCLUSIONS

Four major rock units are found in the Northwest Angle; a supracrustal unit, a tonalitic unit, a granitic unit, and large mafic dikes.

No evidence was noted, concerning the nature of the platform on which the supracrustal rocks were deposited.

The Northwest Angle supracrustals appear to be intermediate to mafic subalkaline volcanics, chemically similar to orogenic calc-alkalic volcanic rocks which are characteristic of modern island arc enviroments. The supracrustal unit exhibits prograde metamorphic assemblages indicative of amphibolite grade regional metamorphism. Probable protoliths inferred from chemical, mineralogical, textural and outcrop relations include intermediate crystal and lapilli tuffs; intermediate to mafic flows; agglomerates; and lapilli tuffs; mafic to ultramafic hypabysal intrusions; and sediments which are minerallogically similar to the interbedded volcanic rocks.

The supracrustal rocks of the Northwest Angle are the oldest rocks found in the area. Contacts between supracrustal and plutonic rocks are sharp; only the mafic dike unit shows chilled margins. Age relations along supracrustal-granitoid contacts were inferred from cross cutting relationships; the granitic and tonalitic plutonic rocks cut the foliation within the supracrustal rocks at all visible contacts noted. Chilled margins are absent along the supracrustal-granitoid contacts. Reasons for this include: (1) supracrustal rocks were near magmatic temperature at the time of granitoid emplacement, thus chilled margins would not occur; (2) the area was metamorphosed subsequent to granitoid emplacement, thus obliterating chilled margins by recrystallization.

The presence of pillows in the supracrustal unit indicate subaqueous extrusion during volcanic deposition. The presence of primary structures indicate contemporaneous deposition of volcanically-derived clastic sediments. The hypabysal intrusions are obviously younger than the supracrustal rocks which they intrude, and primary top indicators make age relationships possible at a few isolated outcrops, however, age relationships within supracrustal units can only generally be inferred.

The tonalitic unit appears to be part of a large multi-phase intermediate intrusion. This unit contains a metamorphic mineral assemblage indicative of amphibolite grade, regional metamorphism.

The tonalitic rocks are clearly younger than the supracrustal unit, and clearly older than the mafic dikes, but no clear cut age relationship exists concerning the tonalitic and granitic units. Perceptible supracrustal-tonalite contacts involve dikes of tonalite which cross-cut the supracrustal foliation. No chilled margin is present along the contact; microscopic petrography indicates the supracrustal-tonalite contact is highly cataclasized thus recrystallization probably destroyed visible traces of chilled margins. Tonalite-mafic dike contacts are sharp and vertical; the mafic dikes cut the foliation within the tonalite and show chilled margins against the contact.

The granitic unit appears to consist of smaller granite intrusions, which show deueric alteration; cataclastic features were noted locally.

The granitic rocks are clearly younger than the supracrustal rocks, and older than the mafic dikes. Visible granite-supracrustal contacts involve massive granite, and granitic dikes inturding and cutting the foliation in the supracrustals. Chilled margins were not noted along the contacts. Microscopic petrography indicates no evidence of cataclasis or metamorphism along these contacts. This may indicate the supracrustals were hot at the time of granitic emplacement, thus eliminating the cause of chilled margins. Perceptible contacts between massive granite and mafic dikes were not noted, however, contacts were noted between granitic dikes in the supracrustals and the mafic dikes which are sharp and the mafic dikes show chilled margins against the granitic dikes.

Direct age relationship between the tonalitic and granitic rocks cannot be established, however, an age relationship has been inferred on the basis of metamorphic features. The tonalitic rocks of the area show evidence of amphibolite grade metamorphism. The granitic rocks show metamorphic features indicative of deuteric alteration, or cataclasis, but no evidence of amphibolite grade metamorphism. This points out two possible conclusions: (1) the tonalitic rocks were metamorphosed prior to cooling of the granitic magma; or (2) the granitic rocks were present, but not affected during the regional metamorphism which altered the tonalite. The first interpretation is greatly favored because granite and tonalitic outcrops are found close to each other (less than 0.5 km apart along the south shore of Flag Island), thus, it appears highly unlikely that metamorphism could have affected the tonalite and not the granite if both were in place at the time of metamorphism.

The granitic plutonic rocks richer in mafics and plagioclase generally show greater evidence of cataclasis, thus, an intermediate to acid trend can be inferred concerning the age of various granitic plutons.

The size and general nature of the tonalitic and granitic instrusions mentioned above is highly conjectural. The nature of petrographically similar intrusives found to the east (Ziehlke, 1974 and Brown 1975) where they are well exposed on the Aulneau pennisula is the major foundation of this interpretation.

The mafic dikes of the Northwest Angle appear to be large homogeneous-dikes. Deuteric alteration is prevalent, but cataclastic features were not noted.

Contacts between mafic dikes and the other Northwest Angle units are sharp, with chilled margins in the mafic dikes.

The isotropic fabric found in the mafic dikes indicates little metamorphic or tectonic activity has taken place in the area subsequent to their emplacement.

Table 10 models the major geologic events recorded in the bedrock of the Northwest Angle and indicates possible effects related to these events.

TABLE 10 - GEOLOGIC MODEL PERTAINING TO BEDROCK OF NORTHWEST ANGLE

Events	Effects
(1) Supracrustals deposited in environment comparable to modern island arc.	Development of primary structures, and bedding in supracrustals
(2) Folding and metamorphism of supracrustals	Development of isoclinal folding along northeast trend, Axial planar cleavage parallel to the folding, and greenschist metamorphic assemblages, in the supracrustals.
(3) Emplacement of tonalitic intrusions, and metamorphism of supracrustals.	Development of compositional foliation parallel to folded bedding, and hornblende hornfels metamorphic assemblages, in the supracrustal, also, flow banding in the tonalite. Elimination of axial planar cleavage and greenschist metamorphic assemblages in the supracrustals.
(4) Emplacement of granitic intrusions, as well as metamorphism and cataclasis of supracrustals, tonalites, and earlier fromer granites.	Development of amphibolite metamorphic assemblages, and enhancement of compositional foliation noted in (3) in the supracrustals. Development of amphobolite metamorphic assemblages in the tonalite, and cataclastic features, particularly along previously formed contacts. Detachment, or highly ductile rotation of large crustal blocks, producing northwest trending structural features, and eliminating structural continuity of northeast trending isoclinal folds
(5) Emplacement of large mafic dikes	Development of retrograde metamorphic assemblases near dike contacts.

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APPENDIX 1 - CATACLASIZED SAMPLES

Non-cataclasized	Moderate Cataclasis	Cataclasized
100b	55	33a
104a	80	36
137b	98	196
166b	100a	221
203b	190b	227a
244	199	228
248	247b	316
289a	248b	
281	249a	
310	250	
	205	
	277	
	295	
	289b	
	315	

APPENDIX 2 - CATACLASIZED SUPRACRUSTAL SAMPLES

Sheared

32
42
88a
94
97b
147
171
175
187
189
202
215a
215b
234a, b, c, d
204
270
297