THE TWILLINGATE GRANITE AND ITS RELATIONSHIPS TO SURROUNDING COUNTRY ROCKS

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by

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ABSTRACT

The volcanic rocks of the Twillingate area are divided into two groups separated by the intrusion of the Twillingate Granite. The Sleepy Cove Group, comprising mixed mafic and silicic volcanic rocks, is intruded pre-tectonically by the Twillingate Granite, which is an unusual, homogeneous, trondhjemite pluton. These two units are cut post-tectonically by mafic dykes of the Herring Neck Group which is composed of mafic volcanic rocks. All three units are cut by a variety of mafic, acidic and alkaline dykes of different ages.

The one major deformation in the area produced a fabric in the Sleepy Cove Group and the Twillingate Granite that is very intense in the south of the area but generally becomes faint and absent to the north. The Herring Neck Group is post-tectonic with respect to this fabric. Earlier refolded fabrics are present in some mafic inclusions in the Twillingate Granite.

The distinctive chemistry of the Twillingate Granite when compared to other trondhjemites and experimental data suggests that it was produced by partial melting of oceanic lithosphere on a subduction zone. Both groups of volcanic rocks are considered to be island arc tholeiites having a consanguinous and nearly coeval origin with the granite.

A model is postulated of a late Cambrian to early Ordovician island arc developed on older ocean crust. The sequence of mafic and acidic magmatism and deformation is thought to be fairly continuous and occupy a short time span.

Frontispiece : Iceberg off Twillingate; photo J.C. Loveridge

"He either fears his fate too much,
or his deserts are small,
who does not put it to the touch,
to win or lose it all ...."

Duke of Montrose.

CHAPTER 1

INTRODUCTION

1.1 Location

The area studied for this thesis is on the north coast of Newfoundland at the east side of Notre Dame Bay (Figure 1). It comprises the Twillingate Islands, both north and south, the nearby Burnt Island, Duck Island and Black Island, and that part of New World Island lying north of a line drawn between Indian Cove and Ship Island. The limits of the area are approximately between latitude 49°35' north and 49°43' north and longitude 54°50' west and 54°35' west. The area is about 22 square miles in extent with approximately 70 miles of coastline.

1.2 Access

The area is easily reached by paved road from Gander. An hourly ferry operates between Indian Cove on New World Island and the southern tip of South Twillingate Island. These two islands are being joined by a causeway that is presently near completion.

A good paved road joins the five miles between the ferry landing at the southern tip of South Twillingate Island and the main settlement of Twillingate (population about 5,000). Elsewhere the Twillingate Islands have a reasonable network of dirt roads, footpaths and trails connecting the settlements but not extending inland to any extent. A fair quality dirt road connects Indian Cove to Herring Neck in that part of the study area on New World Island. Otherwise there are very few trails of any sort.

The coast of the area is readily accessible by boat, though landing is often difficult because of the strong prevailing winds and steep nature of many cliffs. Accessibility is limited to the period between May (when the ice breaks up) and the beginning of October (when the winds become too strong for coastal work).

1.3 Physiography

The Twillingate Islands are low and undulating, the highest point being about 1 mile east of Bluff Head at 304 feet elevation. Elsewhere the land rarely exceeds 150 feet elevation but terminates at the sea in steep cliffs with sheer faces 100 feet high in places. The part of the area on New World Island is hilly, being dominated by a ridge with elevations of 150 to 200 feet. Towards Salt Harbour Island and Herring Neck the land is lower. Much of the topography, particularly on New World Island, is characterised by prominent gullies and valleys that mark fault zones. Wave action has also eroded lines of structural weakness such as faults.

The whole area was extensively glaciated and erratics, striae and rounded outcrop outlines are a common occurrence. Till and outwash sand and gravel are present locally and quarried for road construction. Deep coastal embayments are the result of glacial scouring and drowning of a mature glaciated topography; according to Baird (1953), "... mature landforms, heavily modified by glaciation, extend well below sea-level." The movement of the ice is generally considered to have been towards the north (Williams, 1963).

The Twillingate Islands are bare with many ponds, much bog and scrub vegetation. In contrast New World Island is in most places heavily wooded.

1.4 Geological setting

The Twillingate study area lies at the northern end of the Appalachian Structural Province in Newfoundland. This was divided into three zones, the Western Platform, the Avalon Platform and the Central Mobile Belt (Williams, 1964; Kay and Colbert, 1965; Kay, 1967). The Twillingate area is located in the northern part of the Central Mobile Belt (Figure 2) and lies at the east end of a mafic, volcanic terrane that is referred to as the Lushs Bight Supergroup (Strong and Payne, 1973).

This group comprises Ordovician (and possibly older) volcanic and sedimentary rocks stretching as a discontinuous belt throughout Notre Dame Bay. It is intruded by plutons of gabbroic to granitic material ranging from Cambrian (?) to Devonian age. According to the recent tectonic-stratigraphic zonation of the Canadian Appalachian Region the Twillingate area lies at the northeastern extremity of Zone D (Williams, Kennedy and Neale, 1972). The thesis area is bounded to the south by the Luke Arm Fault, which also forms the southern boundary of Zone D.

In broad geological terms there are two major lithological units in the thesis area: (i) the Twillingate Granite of trondhjemitic composition and (ii) the surrounding country rocks divided into two groups and comprising mafic pillow lavas, mafic dykes, amphibolites, acidic flows and a few pyroclastics. Most lithologies show one regional fabric striking approximately northeast and generally decreasing in intensity from south to north. Metamorphism is generally within the

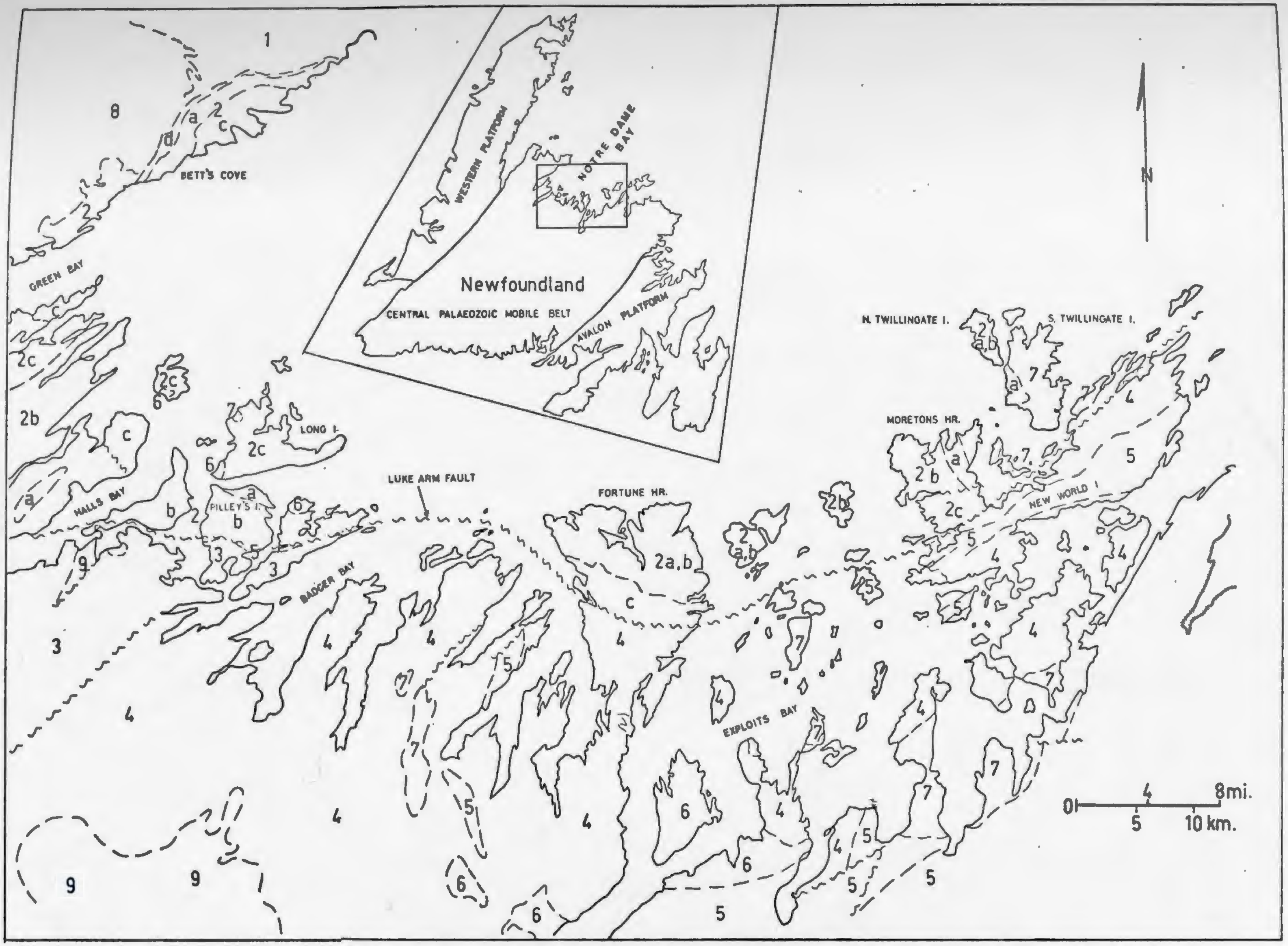


Figure 2 : Generalized geological map of Notre Dame Bay. 1. Precambrian-Cambrian undivided. 2. Lushs Bight Supergroup, a) mainly "sheeted" diabase, b) mainly pillow lava, c) mainly volcano-clastic sediments, d) peridotite. 3. Roberts Arm Group, mainly pillow lavas. 4. Wild Bight Group and Exploits Group, mainly Ordovician sediments. 5. Silurian sediments (possibly including some Ordovician). 6. Ordovician intermediate to basic intrusion. 7. Ordovician acidic intrusions. 8. Silurian quartz-feldspar porphyry. 9. Ordovician(?) dioritic intrusion. Modified after Strong and Payne (1973).

greenschist facies but locally it reaches amphibolite facies.

1.5 Previous work and present investigation (purpose and scope)

This specific map area has received little attention in the past. The present investigation is the only one to date that has concentrated on the geology north of the Luke Arm Fault.

The most comprehensive recent study was undertaken by Williams (1963) for the Geological Survey of Canada. This mainly deals with the Ordovician and Silurian stratigraphy and relationships south of the Luke Arm Fault on New World Island, although topics concerning the thesis area were touched upon. The volcanic rocks were considered to be the equivalents of the Lushs Bight Group and the Twillingate Granite to be intrusive into them.

Work in adjacent or nearby regions was carried out by Murray and Howley (1881), Heyl (1936), Twenhofel and Shrock (1937), Twenhofel (1947), Baird (1953, 1958) and Williams (1957). These works are almost solely devoted to the stratigraphy south of the Luke Arm Fault. A few other studies were concerned purely with economic aspects of the geology and references to these are given by Williams (1963, pp. 28-30) and McGee (1971, pp. 374 and 413).

Brief reference to the present study area was made by Horne and Helwig (1969), Helwig and Sarpi (1969), Horne (1970) and Kay (1972). They point to a possible correlation of the volcanic rocks to the north of the Luke Arm Fault with the Lower Ordovician ones to the south.

In the last two or three years the Twillingate Granite and the volcanic rocks of the Lushs Bight Supergroup have been mentioned in several papers. Dewey (1969), Bird and Dewey (1970) and Dewey and

Bird (1971) show the Twillingate (?) Granite to be intrusive into various different mafic (usually ophiolitic) terranes very approximately in the early Ordovician. Williams and Malpas (1972) and Williams, Malpas and Comeau (1972) stress the similarities in the relationships between the deformed variety of the Twillingate Granite and nearby relatively undeformed mafic dykes and pillow lavas, to similar relationships between deformed igneous rocks and neighbouring relatively undeformed mafic volcanic rocks in the Little Port Complex at Bay of Islands in western Newfoundland. As the Little Port Complex was interpreted to include both older deformed rocks and surrounding younger volcanic rocks (Comeau, 1972) then it was suggested that the deformed Twillingate Granite might be an "older crustal remnant" (Williams and Malpas, 1972) either "continental" or "quasi-ophiolite" (Williams, Kennedy and Neale, 1972) surrounded by younger mafic volcanic rocks. This view was also expressed by Kennedy and DeGrace (1972), and Williams, Kennedy and Neale (in press). It implies the existence of older and younger volcanic sequences in Notre Dame Bay, some of which might unconformably overlie the Twillingate Granite and volcanic block.

This new idea stimulated the present work in the area which was known to have volcanic rocks resembling parts of either island arc or ophiolite sequences and a granite of odd composition, plus seemingly complex structure and unusual cross-cutting relationships between the lithologies. The study was aimed at mapping out these lithologies specifically to determine the relationships of one rock group to another, particularly the granite and volcanics, and possibly deduce their origins and ages. Thus, it was hoped to establish clear and firm geological relationships in this area of Notre Dame Bay and so add to the geoevolutionary history of the Newfoundland Appalachians.

CHAPTER 2

GENERAL GEOLOGY AND RELATIONSHIPS

2.1 General statement

The Twillingate area is divisible into two broad geological units: (1) the Twillingate Granite, and (2) the surrounding country rocks. The country rocks have been further subdivided into two groups: the Sleepy Cove Group consisting of mixed mafic and silicic volcanic rocks that underlie North and part of South Twillingate Islands, part of New World Island and Black Island; and the Herring Neck Group that consists of mafic volcanic rocks, mafic dykes and sediments, and is restricted in the thesis area to a narrow strip parallel to, and immediately north of, the Luke Arm Fault on New World Island (Figure 1). Additionally the Twillingate Granite and the country rocks are cut by a variety of acidic, mafic and alkaline dykes of different ages.

All the volcanic rocks of both the Sleepy Cove Group and the Herring Neck Group were previously considered to be part of the Lushs Bight Group (Williams, 1963) or the Lushs Bight Terrane (Horne and Helwig, 1969) and interpreted to be of Lower Ordovician age. This is because of their lithological similarity to, and continuity with, dated Lushs Bight rocks elsewhere in Notre Dame Bay. More recently it has been shown that these volcanic rocks can be subdivided into local sequences and the name Lushs Bight Supergroup has been proposed (Strong and Payne, 1973). Sparse fossil evidence has been cited in Notre Dame Bay (Horne and Helwig, 1969) connecting the volcanic rocks north of the Luke Arm Fault at Fortune Peninsula and westward with Lower Ordovician sections to the south. However, no fossils were found in the thesis area.

The Sleepy Cove Group and the Herring Neck Group are for the most part lithologically similar and they may well be integral parts of one volcanic sequence. However, in the thesis area, they are faulted where in contact on New World Island, and an age distinction between the two groups is indicated by their structural relationships to the Twillingate Granite. The Sleepy Cove Group is cut pre-tectonically by the Twillingate Granite. Clear examples of granite dykes and apophyses are evident on North and South Twillingate Islands, Burnt Island, Black Island, and at Salt Harbour on New World Island. In contrast, the Herring Neck Group is nowhere cut by the Twillingate Granite, and at the contact on New World Island deformed Twillingate Granite is cut post-tectonically by mafic dykes that are considered to be an integral part of the Herring Neck Group. This latter relationship implies that the volcanic rocks of the Herring Neck Group post-date the deformation in the Twillingate Granite. The general relationships between the different lithologies are shown diagrammatically in Figure 3.

2.2 Sleepy Cove Group

2.2.1 Lithology and distribution

The Sleepy Cove Group comprises a mixed sequence of mafic and silicic volcanic rocks that are subdivided into five lithologies, (a) pillow lavas, (b) dykes, (c) pyroclastic rocks and acidic flows, (d) amphibolites, and (e) gabbro and diorite. This group is exposed over the whole of North Twillingate Island and a large part of South Twillingate Island as far south as Gillards Cove and about a mile inland, as well as a small part of Burnt Island. In the southern part of the area on New World Island it occurs at Salt Harbour and immediately north

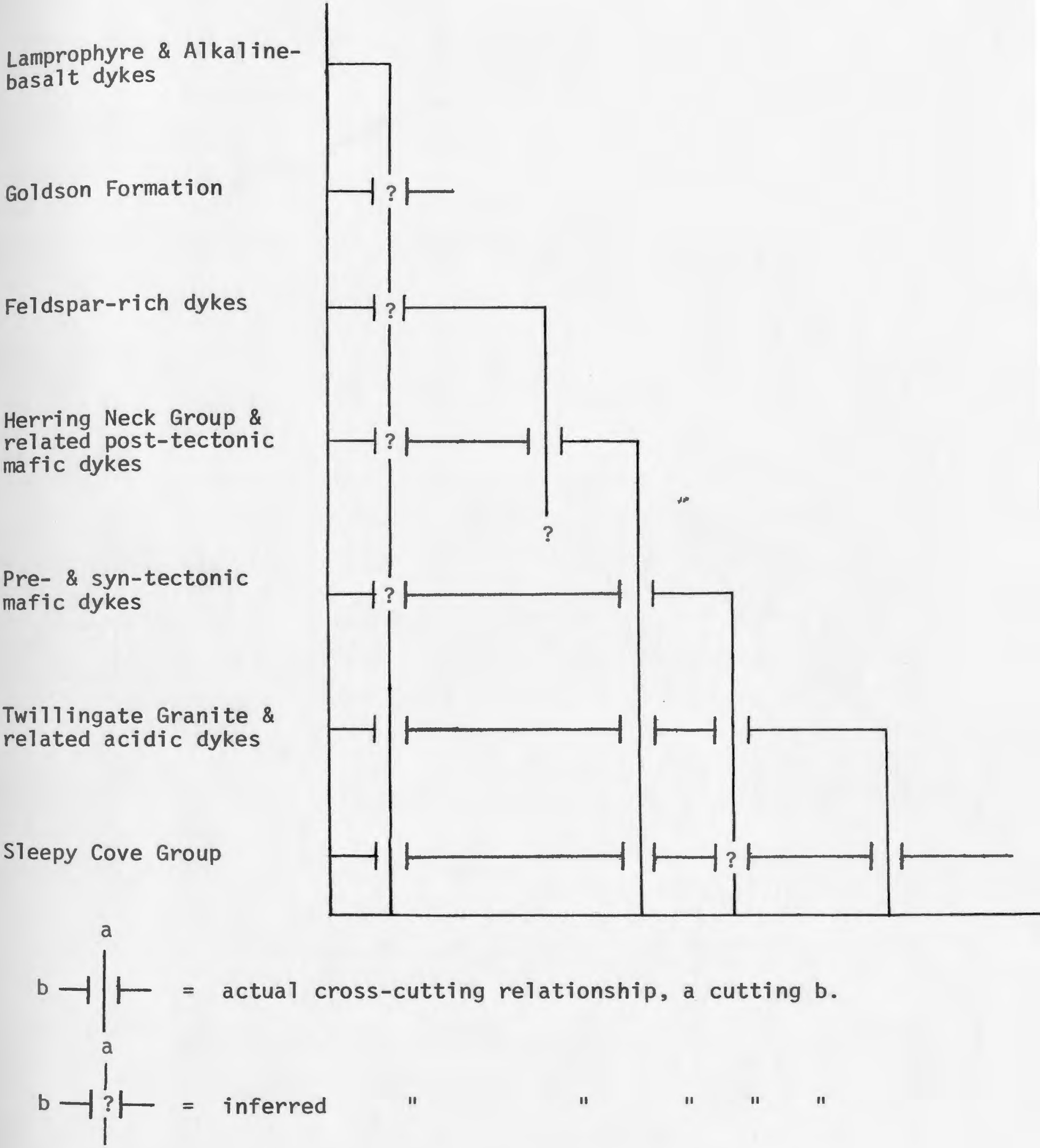


Figure 3 : Diagrammatic summary of the relationships between the lithologies in the Twillingate area.

of the Ferry Wharf, and as a narrow band through the middle of Black Island. The best section of pillow lavas and dykes occurs in and around the Sleepy Cove area and the amphibolites are best exposed on Salt Harbour Island.

Estimates of the thickness of the Sleepy Cove Group are difficult because the attitude and facing direction of the pillow lavas is not easy to determine. Lithological units within the group do not appear to be repeated by folding and faulting so that its thickness may be in the order of 6,000 - 10,000 feet. All of the lithologies (except the pyroclastic rocks and acidic flows) are basaltic in composition and most are more specifically island arc tholeiites as indicated by their chemical characteristics (see Chapter 4). In the field distinct mappable formations are almost impossible to separate. One possible division may be made between the less altered, metalliferous, pillow lavas (Figure 4) north of the Sleepy Cove Fault and the darker green, altered, non-porphyritic and commonly schistose ones to the south.

Pillow lavas (Figure 5) are the commonest lithology within the Sleepy Cove Group and make up about 60% of the exposure, particularly on North and South Twillingate Islands. The pillows are elongated in many places but some reasonably reliable attitudes were obtained using pillow form characteristics such as rounded tops, 'V'-shaped bottoms, and drooping edges. These indicate that the flows face north to northeast with local variations. The pillows are commonly well formed, about 1-3 feet in length, and generally vesiculated on their edges. The pillows are tightly compacted without interstitial sediments.

Dykes are abundant in small areas and they are associated with the pillow lavas. They usually occur in sets of two or three (each

Figure 4 : Little deformed pillow lavas of the Sleepy Cove Group near Sleepy Cove mine.

Figure 5 : Typical pillow lavas of the Sleepy Cove Group near Robins Cove.

about 3 - 10 feet wide) that cut some of the pillow lavas and act as feeders to others. Clear examples occur in the area around Horney Head (Figure 6), more extensive sections made up of 80 - 100% dykes (Figure 7) are exposed around Cuckold Point and on the coast between Lower Head and Crow Head. Successive dykes are recognized by chilled margins and subtle lithological differences. The overall strike of the dykes varies considerably from place to place.

The pyroclastic rocks are dominantly mafic and silicic tuffs and agglomerates. The tuffs are generally banded with layers a foot or so wide and mainly found on North Twillingate Island in small areas around Batrix Island and Bread and Butter Point. Examples of agglomerates occur locally along the west side of Twillingate Harbour, and between Bluff Head and Robins Cove (Figure 8). Nearly all the clasts are pink and felsitic and similar agglomerates are recognized in the amphibolites of the Sleepy Cove Group around Salt Harbour and New World Island (Figure 9). Thin acidic flows a few to several feet wide are common throughout the whole group, especially on North Twillingate Island.

The amphibolites are mainly found on New World Island particularly around Salt Harbour Island and north of the Ferry Wharf. Another section occurs on Black Island. On the Twillingate Islands there are only local patches of amphibolite among the predominantly greenschist volcanic rocks. A volcanic origin for the amphibolites is evident from sausage-shaped pillows (Figure 10) found at the southern end of Burnt Island, and from deformed agglomerates (Figure 9) at Salt Harbour, and metamorphosed pyroclastic rocks from Trump Island (Coish, 1973).

Amphibolite inclusions, several inches to several feet across (Figure 11), and larger rafts, several yards or more across, are abund-

Figure 6 : Pillow lavas and associated feeder dykes of the Sleepy Cove Group around Horney Head.

Figure 7 : Section of dykes in the Sleepy Cove Group near Cuckold Point.

Figure 8 : Deformed agglomerate in the Sleepy Cove Group at Bluff Head Cove. Note the elongated, lens-shaped clasts (compare Figure 9).

Figure 9 : Deformed agglomerate in the amphibolites of the Sleepy Cove Group at Salt Harbour Island.

Figure 10 : Sausage-shaped pillow relicts in the amphibolites of the Sleepy Cove Group at the southern end of Black Island.

Figure 11 : Mafic xenolith, probably from the Sleepy Cove Group, in the Twillingate Granite at Little Harbour.

ant in the Twillingate Granite particularly along the southern margin. They decrease in abundance towards the centre of the pluton. A dense area of inclusions is located on the west coast of Salt Harbour Island where the rocks resemble a volcanic breccia (Figure 12) and the inclusions show a variation in size, shape, lithology and intensity of fabric. All the amphibolite inclusions are interpreted as belonging to the Sleepy Cove Group (possibly its basal parts). Original structures are not preserved but locally there are suggestions of relicts of pillow forms, especially in a large inclusion on the 'H' shaped island west of Merritts Harbour.

Gabbro and diorite are found locally as small plugs. The largest is at Lower Head on North Twillingate Island.

2.2.2 Petrography

(a) Pillow lavas

In hand specimen these rocks are pale to dark green and weather buff or rusty brown. The majority are fine-grained and amygdaloidal with the amygdales containing pale green epidote. These give the rock a lumpy appearance on weathered surfaces, e.g. at Dumpling Cove. Economically significant amounts of disseminated chalcopyrite are found in the vesiculated edges of pillows and cracks. The mineralized area appears to be confined to the section between Sleepy Cove and Devils Head Cove north of the Sleepy Cove Fault. A mine was opened at Sleepy Cove in the early part of this century but was abandoned soon afterwards. The ore was apparently high grade but too deep to mine economically. Elsewhere in this lithology many pyrite showings occur (Figure 1) and at Wild Cove there is an abandoned shaft on the site of a sphalerite, chalcopyrite and galena showing.

In thin section the mineralogy of the rock is typical of the mid-greenschist facies and consists of about 50% plagioclase laths and about 50% disseminated chlorite and fibrous amphiboles. Accessory minerals include carbonate, epidote, iron ore and minor quartz. Some samples are brecciated and cut by quartz and epidote filled veins. The feldspar laths are generally small but locally they form micro-phenocrysts and in some places feldspar crystals appear to be relicts of larger phenocrysts. Alteration and replacement of feldspar by epidote is common and twinning is largely obliterated. A few optical determinations indicate albite and oligoclase with anorthite content of up to 30%. The feldspars form a felted, fine-grained matrix with chlorite and this together with the amygdales suggests a basaltic parental rock (Figure 13).

(b) Dykes

The dykes are of varied lithology with pale to dark green, fine-grained types being the most common. Some specimens are moderately coarse-grained and have small plagioclase phenocrysts.

In thin section the common fine-grained dykes have an equigranular texture with about 50% recrystallized plagioclase feldspar (probably oligoclase/andesine) and about 30-40% interstitial chlorite and fibrous tremolite and actinolite. Epidote and carbonate are extensive particularly as replacement products of the feldspars and a little accessory iron ore and quartz make up the rest of the rock.

A coarser, micro-gabbro variety has a similar mineralogy and texture. The feldspars are mainly untwinned but a few optical determinations on poor carlsbad/albite twins indicates an anorthite content of around 30%. A lot of the feldspars contain radiating, needle-like

Figure 12 : Dense area of mafic inclusions in the Twillingate Granite on the west coast of Salt Harbour Island.

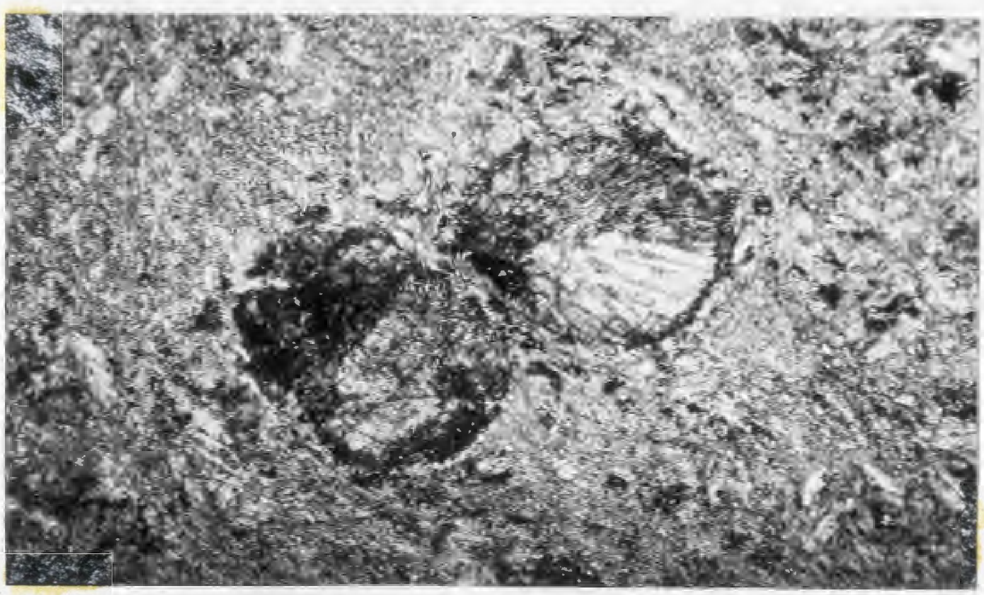


Figure 13 : Photomicrograph of a typical pillow lava of the Sleepy Cove Group, showing a fine-grained, felted mass of plagioclase laths and chlorite with well rounded vesicles. (Crossed nicols, x 30).

inclusions probably of natrolite crystals.

All the dykes are considerably altered and belong to the greenschist facies. However, the local presence of relicts of subhedral plagioclase phenocrysts and the suggestion of an igneous texture are still present in some sections.

(c) Pyroclastic rocks and acidic flows

The pyroclastic rocks are mafic and silicic tuffs and agglomerates. The tuffaceous rocks are pale green, fine-grained and in places slightly glassy. Black, aphanitic lenticles a 1/4 inch long or less are easily visible and have the appearance of shards. Locally, the tuffs are layered, with bands about a foot wide, but show no evidence of grading.

In thin section the tuffs are very fine-grained. Small crystals of quartz, chlorite, epidote and fibrous amphibole are barely visible and feldspar is minor or lacking. Larger particles, probably flattened shards, are replaced by chlorite or carbonate and other inclusions are patches of recrystallized mosaic quartz. The absence of welding and the overall glassy look to the rocks suggests they were originally vitric tuffs now altered to greenschist facies.

The agglomerates are composed of pink, fine-grained felsitic clasts varying from several inches to one or two feet long and contained in a basic matrix (Figure 8, p 14). These clasts are elongated in deformed specimens which produces a lenticular banded effect.

The acidic flows are usually light to mid green with a flow banded appearance. An aphanitic texture is common and they are probably rhyolitic in composition.

(d) Amphibolites

Amphibolites of the Sleepy Cove Group are composed of hornblende and plagioclase with a pronounced to poorly developed foliation (Figure 14) due to the alignment of amphibole prisms. In hand specimen the rocks are dark green to black and fine- to medium-grained, and a few have small plagioclase(?) phenocrysts about a 1/16 inch long. Discontinuous, thin, green and black mineral segregation bands are evident in some samples, especially those from the mylonite areas around Salt Harbour Island.

In thin section the rocks consist of amphibole (40-60%), plagioclase (albite/oligoclase, 40-50%), quartz (less than 5%) and accessory magnetite, ilmenite, sericite, epidote and sphene. Patches of later carbonate and cross-cutting epidote filled veins are common. The amphiboles are pleochroic from light to dark green and occur as aligned, prismatic crystals with ragged ends. They are mostly hornblende or actinolite with lesser amounts of tremolite and uralite, all probably resulting from the alteration of original pyroxene and subsequent retrogression. Further evidence of this are relict pyroxene (augite?) crystals occurring locally as colourless cores within green hornblende or actinolite, and the presence of chlorite pseudomorphs of hornblende. Augen-shaped clots of hornblende form in some places and these are surrounded by anhedral, recrystallized feldspar. Other samples display alternate bands enriched in hornblende and plagioclase.

The feldspars are subhedral, recrystallized and cloudy where replaced by sericite and epidote. A few show original albite twinning with fresher recrystallized outer portions. Some resemble corroded phenocrysts and others appear intergrown with adjacent areas of amphibole, thus portraying relicts of an intersertal or sub-ophitic igneous texture. This textural feature, combined with the presence of original pyroxene crystals and possibly some unaltered feldspar, together with the occurrence of the amphibolites among the mafic igneous rocks of the Sleepy Cove Group indicate an igneous parentage.

(e) Gabbro/diorite

In hand specimen the rock is mid green with pale green areas. In thin section it is medium-grained dominantly composed of altered plagioclase feldspar together with epidote and chlorite, and accessory skeletal leucoxene and carbonate. A few unaltered clinopyroxene crystals (probably augite) are also present.

2.2.3 Structure

Only one fabric is found in the Sleepy Cove Group and it is the same fabric as that in the Twillingate Granite (see 2.3.3). Within the lithologies of the Sleepy Cove Group it is expressed in various ways.

In the volcanic rocks this fabric is inhomogeneously developed, occurring in local zones generally steeply dipping, sub-parallel to bedding, and showing a general decrease in intensity from south to north on the two Twillingate Islands. Around Bluff Head there is a strongly developed local fabric (Figure 15) and these rocks are continuous with similar less deformed ones nearby. This very intense deformation is restricted to the west side of North and South Twillingate Islands other examples occur at Ragged Point, near Batrix Island, and Back Harbour Head. In contrast, no fabric at all is developed farther north around Long Point and north of the Sleepy Cove Fault. A progressive increase in the intensity of the fabric can also be traced eastwards from Lower Head, where moderately

Figure 14 : Amphibolite of the Sleepy Cove Group on Salt Harbour Island with a strongly developed, kinked fabric.

Figure 15 : Well developed and kinked regional fabric in the Sleepy Cove Group north of Bluff Head.

deformed pillow lavas (Figure 16) become schistose rocks with very elongated pillows to the south of Sleepy Cove (Figure 17).

The strike of the fabric in the volcanic rocks varies locally. From Bluff Head to Twillingate Harbour it is north to south, and from there to the tip of North Twillingate Island it is approximately northwest. One exception is the area from Lower Head to Devils Cove where the strike is east to west.

The amphibolites, particularly on New World Island, have a very strong, steeply dipping fabric striking about north to northeast (Figure 14, p 22) parallel to the fabric in the Twillingate Granite and sub-parallel to the contact. A similar, steeply dipping fabric but generally striking north is developed in the small areas of amphibolite on North and South Twillingate Islands, for example around Bluff Head.

Direct evidence of folding in the Sleepy Cove Group is very slight. The fabric west of Gillards Cove and at Connert Head Cove is axial planar to folds of several feet amplitude. At Salt Harbour there are small folds about 1 inch in amplitude in the foliation in the mylonitic amphibolites and granitic dykes cutting them. No other folds were observed and the lack of many reliable attitudes on the pillow lavas makes folds difficult to map out. The Sleepy Cove Group appears to have a more or less continuous section but it may be repeated in places by isoclinal folding.

There is some evidence of an earlier deformation of rocks assigned to the Sleepy Cove Group. Around Little Harbour a pre-existing alignment of hornblende crystals within amphibolite inclusions in the Twillingate Granite is folded. The fabric in the granite is axial planar to these folds. However, most amphibolite inclusions in the Twillingate

Figure 16 : Moderately deformed pillow lavas of the Sleepy Cove Group near Lower Head.

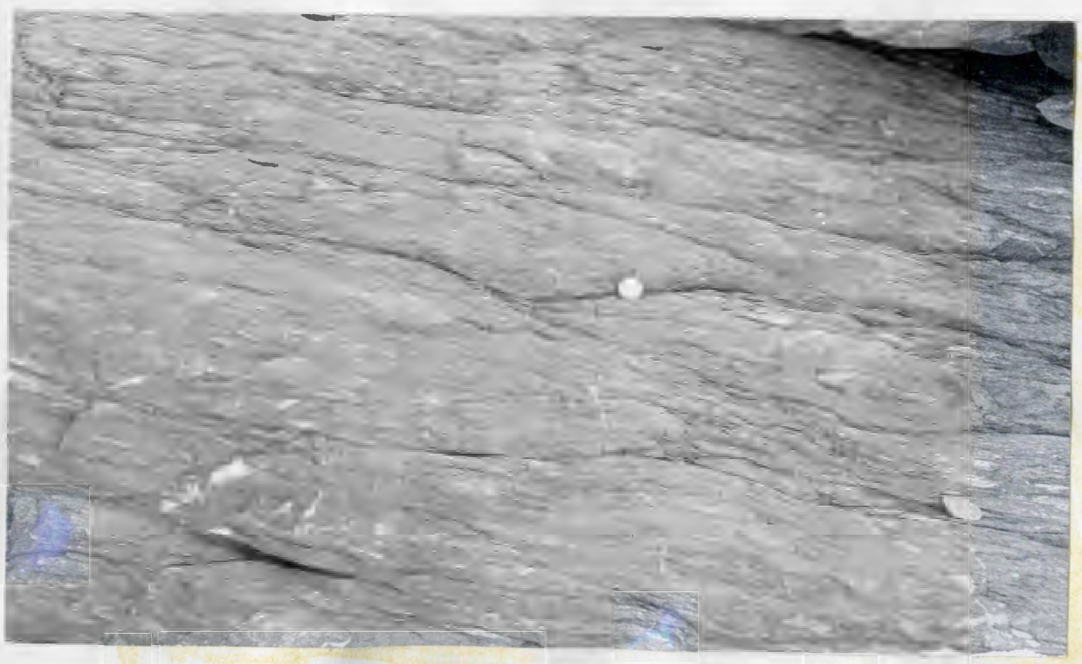


Figure 17 : Elongated and schistose pillow lavas of the Sleepy Cove Group south of Sleepy Cove.

Granite have a single foliation concordant to that in the granite, or at a small angle to it. They are considered to have been deformed contemporaneously with the granite.

A later, minor deformation in the area caused extensive kinking and crenulation of the fabric noticeably in the amphibolites and the more intensely deformed volcanic rocks (Figures 14, p 22 and 15, p 22). Box folds produced by conjugate sets of kinks are common. Columnar structures (mullions?) at Starve Head a foot or so in diameter and 10 feet or more long, may also belong to this later event.

2.2.4 Relationships

The Sleepy Cove Group is the oldest in the area. It is intruded pre-tectonically by the Twillingate Granite and both have the same regional fabric. Examples of foliated granitic dykes (see 2.5A) are common amongst the volcanic rocks between Twillingate Harbour and Wild Cove. The folded fabric in a few amphibolite inclusions within the Twillingate Granite implies that some amphibolites were deformed before granite intrusion. These may represent the bottom of the Sleepy Cove Group volcanic pile or possibly still older rocks unrelated to the Sleepy Cove Group.

The Sleepy Cove Group is cut post-tectonically on Salt Harbour Island by diabase dykes (see 2.6B) that are inseparable from, and interpreted as coeval with, volcanic rocks of the Herring Neck Group. Other mafic dykes of uncertain affinity (see 2.6C) cut the Sleepy Cove Group on the Twillingate Islands.

It is shown in Chapter 4 that the rocks of the Sleepy Cove Group are geochemically island arc tholeiites rather than ocean floor tholeiites. This is supported by the thickness of the section, the abundance of pillows, the profusion of dykes and the presence of acidic pyroclastics and flows.

2.3 Twillingate Granite

In this thesis, in accordance with the literature to date, the Twillingate pluton will be given the lithostratigraphic name of the Twillingate Granite. Whilst the mineralogy and petrology of the rock indicate that it is best included in the granite family, a more accurate description would be trondhjemite (see 2.3.2).

2.3.1 Lithology and distribution

The Twillingate Granite is exposed about 15 square miles on South Twillingate Island, Burnt Island, Black Island and northwest New World Island north of the Luke Arm Fault. Additionally it is recognized as numerous stocks and dykes intruding the Sleepy Arm Group. Outside the thesis area it also occurs at Trump Island (Coish, 1973), at Chanceport Harbour in the Moretons Harbour area (Strong and Payne, 1973), at Berry Island and Bacalhao Island (Williams, 1963). Geophysical evidence (Miller and Deutsch, 1973) confirms that the pluton is shallow with an oval shape and extends northwestwards under the sea between South Twillingate Island and New World Island.

The granite is remarkably homogeneous in both mineralogy and chemistry (see Chapter 4) and generally speaking the petrology is uniform throughout. It is strongly foliated in the south of the area but becomes more massive in its central and northern parts. Small faults and joints give it a blocky appearance. There is no apparent thermal metamorphism in the country rocks intruded by the granite. If once present, it has now been obliterated by post-intrusion deformation and accompanying regional metamorphism.

2.3.2 Petrography

In hand specimen the characteristic granite is greyish with a mottled look because of the distribution of the darker minerals. Areas of pink and orange granite are found in the northeast from French Head to Clam Rock Head and a darker green variety occurs in a few random places. Apart from their colour, these types are mineralogically and chemically similar to the rest of the pluton.

The rock comprises about 45% clear, vitreous quartz that shows a faint blue hue in places, about 45% soda plagioclase (albite and oligclase) and about 10% chlorite with very minor hornblende, pyrite and accessory minerals. The quartz typifies the rock and facilitates identification of the lithology in hand specimen.

The texture is usually medium to moderately coarse with quartz crystals up to 1/4 inch in diameter. Some types, for example at French Head and Burnt Island, are much coarser-grained with the quartz up to 1/2 inch in diameter. Other types are very fine-grained to aphanitic. The rock is commonly foliated, having one distinct fabric which is easily seen on weathered surfaces where the deformed quartz crystals stand out in relief (Figure 18). On the southern contact, around Merritts Harbour on New World Island, the rock is very strongly foliated and mylonitized. The mylonitic granite has elongated, lensoid-shaped quartz segregations up to 1 1/2 inches long. Massive granite occurs in the central and northern parts of the pluton.

In thin section the granite is typically holocrystalline with an equigranular, granitic texture (Figure 19). Extensive recrystallization is common. This produces a pseudoporphyritic effect where large

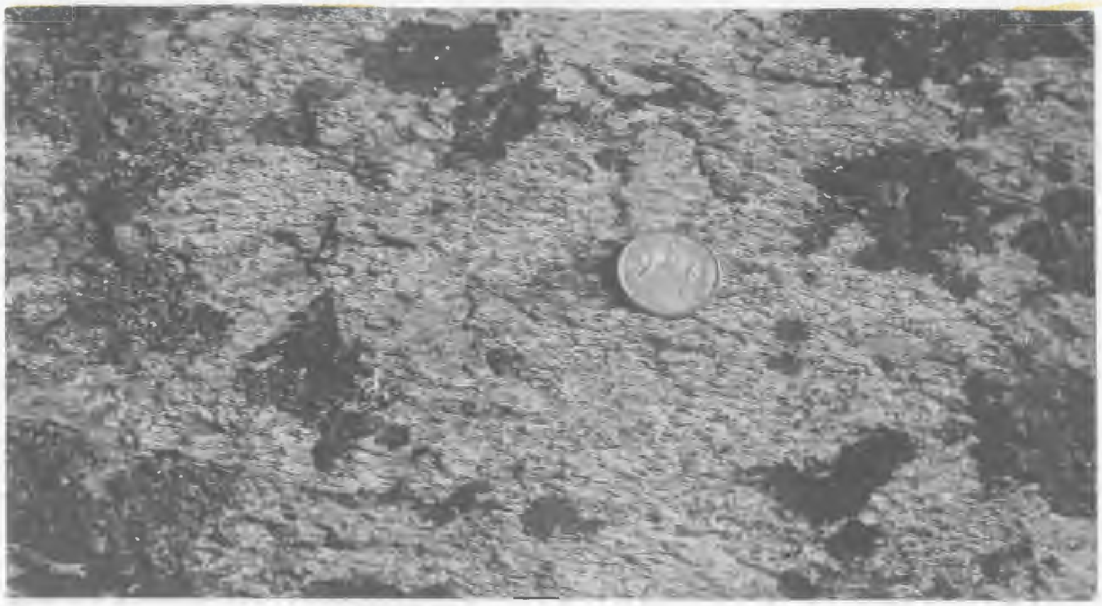


Figure 18 : Strongly developed foliation in the Twillingate Granite at Merritts Harbour.

Figure 19 : Photomicrograph of typical Twillingate Granite showing subhedral, twinned plagioclase and large quartz crystals with undulose extinction. (Crossed nicols, x 30).

single crystals or aggregates of quartz and plagioclase are surrounded by areas of finer grained, anhedral crystals of quartz, feldspar and chlorite forming the matrix and commonly displaying unequal angle triple point junctions (Figures 20 and 21). Some specimens are totally recrystallized and original large quartz crystals are represented by a mosaic of smaller, anhedral crystals (Figure 22). The deformation produces undulatory extinction in, and elongation of the quartz crystals which are extremely elongate in the mylonitic varieties. It also causes cracks and breaks in the plagioclase crystals. The mylonites (Figure 23) show a crude banding of quartz and feldspar and evidence of later cataclasis. Other textural varieties tend to occur near the edge of the pluton, for example on Burnt Island there is a gradation over a few hundred yards from a quartz-porphyry phase (Figure 24) near the contact with the Sleepy Cove Group to a coarse granite farther away.

Quartz is found commonly as large, anhedral crystals with undulose extinction giving a biaxial interference figure in some examples. These large crystals tend to recrystallize into aggregates of smaller crystals (Figure 22). Both large and small crystals have crenulated and sutured edges in places produced by small scale solution contacts between the grains. Plagioclase (being replaced by epidote), rare microline and anti-perthite (which are being reabsorbed), rutile, apatite and fluid-filled bubbles all occur as inclusions in the quartz.

The feldspar is almost all subhedral to euhedral albite and oligoclase though accurate determinations are hindered by the common, heavy alteration by sericite and epidote. This alteration gives the crystals a turbid yellow colour. Some crystals have fresher albite(?) rims, others appear to have antiperthitic ones. Twinning and zoning are

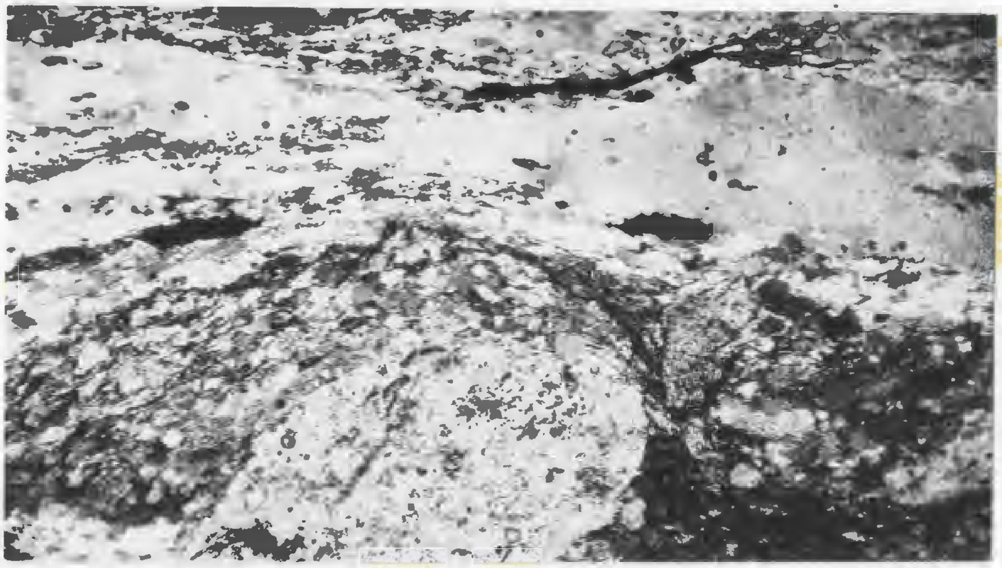


Figure 20 : Photomicrograph of a relict plagioclase crystal in recrystallized Twillingate Granite. (Crossed nicols, x 30).

Figure 21 : Photomicrograph of partly recrystallized Twillingate Granite showing large quartz crystals with undulose extinction and a recrystallized groundmass of quartz and feldspar crystals. (Crossed nicols, x 30).

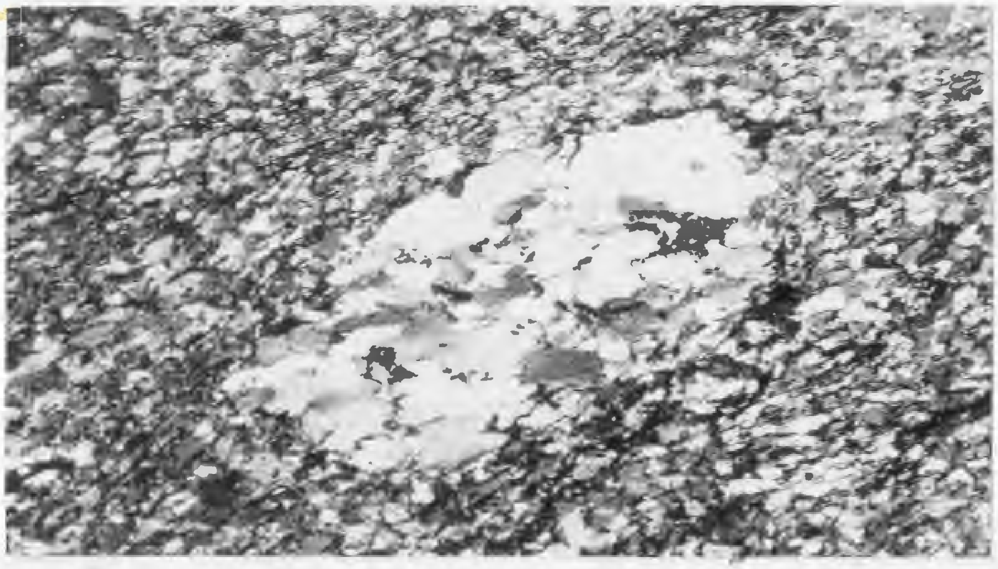


Figure 22 : Photomicrograph of almost totally recrystallized Twillingate Granite showing a mosaic texture of quartz and feldspar crystals. (Crossed nicols, x 48).

Figure 23 : Photomicrograph of the mylonitic variety of the Twillingate Granite. Note the crude banding and recrystallized texture, the feldspar augen and the extreme elongation of and undulose extinction in the quartz crystals. (Crossed nicols, x 30).

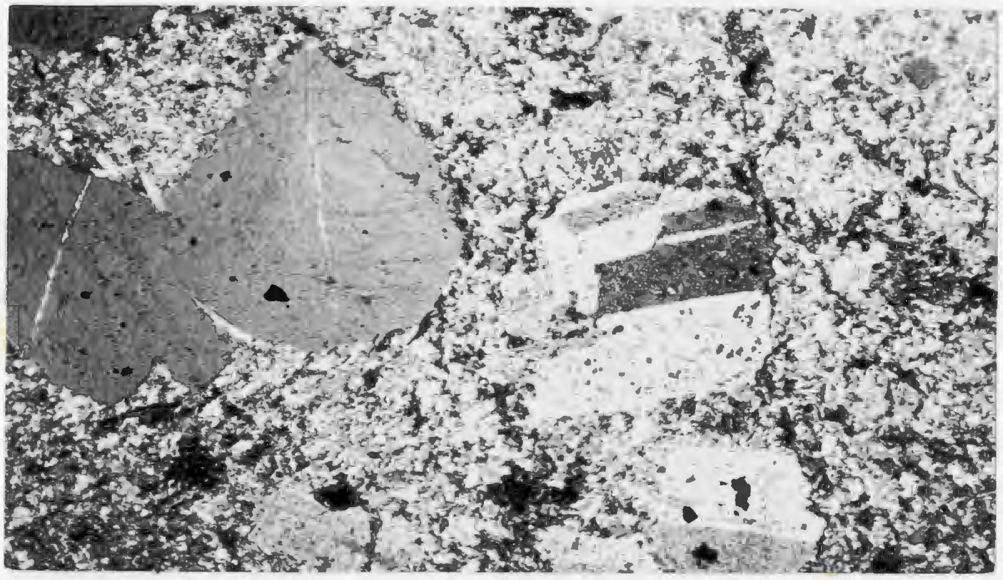


Figure 24 : Photomicrograph of the quartz-porphyry phase of the Twillingate Granite. (Crossed nicols, x 30).

not common and are usually masked by the alteration. Potash feldspar was identified only locally and its rarity is supported by the very low K_2O analyses (see Chapter 4). Microcline and antiperthite are found only in a very few sections and occur interstitially, on the edges of plagioclases, and as inclusions in quartz. The feldspar responds to the deformation by cracking and breaking unlike the quartz which tends to stretch and recrystallize. Twin planes are bent and dislocated in a few crystals.

Ferromagnesian minerals are very minor constituents of the rock. Green to colourless, secondary chlorite (penninite?) is the most common and probably replaces original biotite as a result of the greenschist facies metamorphism. It occurs in scaly masses, tabular-like crystals and is also elongated and strung out. Anomalous, very strong 'Berlin blue' interference colours are common. Hornblende is rare and where present it is subhedral, dark green, strongly pleochroic and has inclusions of quartz and feldspar.

Epidote (as clinozoizite, epidote, piedmontite and allanite) is the most common accessary mineral and extensively replaces the plagioclase but is also present in the groundmass and late stage veins. Subhedral to euhedral magnetite and ilmenite are associated with chlorite, and red, opaque haematite occurs with feldspar. Garnet (probably secondary) was recorded in a few samples and zircon in a few others.

Two types of narrow cross-cutting veins were observed in some thin sections. The first type is formed from a brecciation of preexisting crystals where thin linear zones contain similar minerals to the host granite. This feature resembles the brecciation effects reported in the Little Port Complex in the Bay of Islands on the west coast of Newfoundland (Williams and Malpas, 1972). They suggest an origin by gas action or fluidization similar to that thought to produce tuffisite textures in igneous rocks. The second type is a veining without brecciation and containing late stage minerals such as carbonate, epidote, muscovite and prehnite(?). These probably represent a minor, late, hydrothermal stage. The first type cuts the second and is therefore the younger.

The mineralogy and petrology of the Twillingate Granite indicate that it would best be called a trondhjemite. Johannsen (1939, p 387) quotes Goldschmidt (1916) who applied the term to quartz-rich tonalites and defines these rocks as "leucocratic, acid plutonic rocks, whose essential constituents are soda-rich plagioclase (oligoclase and andesine) and quartz. Potash feldspar is entirely wanting or is present only in subordinate amounts. Biotite is the most important of the mafic constituents, although it is present in small quantity." This definition aptly describes the Twillingate Granite, except that the biotite in the Twillingate Granite has been altered to secondary chlorite due to metamorphism in the greenschist and amphibolite facies.

Patches of quartz-hornblende-diorite are associated with the granite. They occur mainly on the west coast of New World Island and do not resemble inclusions, though they are cut by granite and aplite dykes. In places the rock resembles the more typical granite and both appear to grade into each other. Elsewhere the more mafic phase is in fault contact. A faint fabric is usually developed and this is the same as that in the granite.

The quartz-hornblende-diorite is coarse and equigranular but some samples are slightly porphyritic. It is generally green to black, weathering to a light buff brown, but a coarse-grained, probably pegmatitic phase, is black and white. In thin section the rock is fresh and comprises about 45% green, pleochroic hornblende; 40% altered, cloudy plagioclase; and 10-15% strained, but clear quartz. Recrystallized quartz and accessory iron ore are found interstitially and late epidote filled veins are present.

The rock is probably an early basic phase of the granite magma. It closely resembles sections of the granite containing hornblende.

2.3.3. Structure

The Twillingate Granite is moderately to strongly foliated in most places and has only one fabric. This fabric is concordant to, and the same as that in the Sleepy Cove Group. In the Twillingate Granite the fabric varies greatly in intensity. It is strongest in and around the mylonite zone along the southern margin of the pluton on New World Island near the contact with the Herring Neck Group. Strongly foliated granite is well exposed at Merritts Harbour (Figure 18, p 28). To the north the fabric progressively decreases in intensity and there are areas of massive granite around French Head, Clam Rock Head and Burnt Island.

The fabric is penetrative with a strong foliation of elongated quartz crystals. A planar element, usually with a steep dip, is also present. In the massive varieties the quartz crystals are equidimensional but in the deformed types they have become oblate.

The strike of the fabric varies considerably. It is generally east-northeast on New World Island but on South Twillingate Island it becomes west to east, and northwest striking. The overall impression is that the fabric generally runs sub-parallel to the edges of the pluton.

The mafic inclusions in the granite possess this same fabric. In most cases this is parallel to, and concordant with, that in the pluton, with the fabric passing through both lithologies. Some inclusions are flattened (Figure 25) and locally display an earlier fabric as discussed previously (see 2.2.3).

2.3.4 Relationships

The Twillingate Granite pre-tectonically intrudes the Sleepy Cove Group. Many granitic dykes and plugs cross-cut the volcanic rocks particularly on the Twillingate Islands (Figure 26) and the granite contains inclusions of these country rocks (Figure 11, p15 and 12, p18).

In contrast the Twillingate Granite is cut post-tectonically along its deformed southern margin by a zone of diabase dykes belonging to the Herring Neck Group (see 2.6B). Other mafic dykes, now largely amphibolite, intrude the granite pre- and syn-tectonically (Figure 27) with respect to its deformation (see 2.6A).

2.4 Herring Neck Group

2.4.1 Lithology and distribution

The Herring Neck Group comprises a sequence of mafic volcanic rocks and sediments that are subdivided into three lithologies (a) pillow lavas, (b) dykes and (c) sediments. The group is exposed on New World Island as a band of varying width between the Twillingate Granite or the Sleepy Cove Group to the northwest and the Luke Arm Fault to the south-east. Another narrow section, containing the best exposed sediments, occurs on the east side of Black Island. The sequence is extensively faulted and may be repeated, so its thickness is probably less than its maximum exposed width of 2,000 feet. All of the volcanic rocks in the

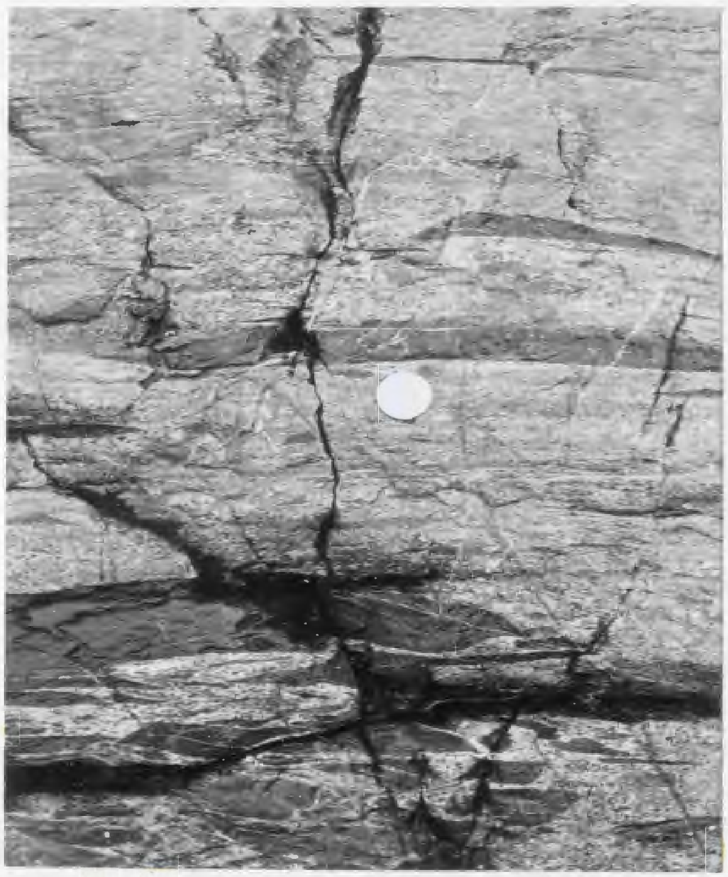


Figure 25 : Flattened mafic inclusions in the Twillingate Granite at Little Harbour.

Figure 26 : Dyke of Twillingate Granite intruding the Sleepy Cove Group near Connert Head Cove.

Figure 27 : Twillingate Granite cut by amphibolite dykes north of Merritts Harbour. Note the small scale faulting.

group are basaltic to andesitic in composition.

Distinct mappable formations are difficult to separate within the group at the present scale of mapping (Figure 1). It is hard to define the dyke zone accurately because it grades out into the coeval pillow lavas. More detailed work might also possibly distinguish two pillow lava lithologies separated by the Goshens Arm Fault. The sediments are easy to recognize but similarly hard to map out as they are interbedded with the volcanic rocks and are an integral part of the sequence.

The pillow lavas occur as a discontinuous, narrow zone parallel to, and between, the dyke zone and the Luke Arm Fault. The best exposures are along the west side of Goshens Arm where the pillows are relatively unaltered and little deformed (Figure 28). Their attitude varies but they generally face north to northwest.

The dykes form a continuous, fairly narrow zone from Ship Island in the northeast to Indian Cove in the southwest with the best sections in the Herring Neck area. They occur between the Twillingate Granite or the Sleepy Cove Group volcanic rocks, and the pillow lavas of the Herring Neck Group in the east to which they are directly related. The dykes are about 3-10 feet wide and generally strike north to northeast at the southern contact of the granite.

The sediments occur in two main regions. The biggest exposure is in a narrow strip on the east side of Black Island. Here red and green chert and siliceous argillite occur in beds 2-3 feet wide. The whole section is 200-300 feet wide as it extends inland to a fault which is probably a continuation of the Lobster Harbour Fault and the Chanceport Fault (Strong and Payne, 1973). The other exposures are

Figure 28 : Well formed pillow lava of the Herring Neck Group in Goshens Arm.

bands 2-6 feet wide of red chert and greywacke interbedded with the volcanics. The main occurrences of these are on the north side of Indian Cove, on the road immediately west of Indian Cove settlement, in the new road cutting for the Twillingate causeway, and at the south end of Goshens Arm.

2.4.2 Petrography

(a) Pillow lavas

The pillow lavas vary from pale to dark green and from grey to black, and are generally fine-grained. In thin section the rock is altered but still has a fine-grained, sub-ophitic texture of plagioclase laths and clinopyroxene with iron ore and minor quartz as accessory minerals. A microporphyritic variety from Upper Gut Arm contains plagioclase and augite microphenocrysts in a groundmass of similar composition altered to chlorite. Vesicles, infilled with carbonate, are present in some samples.

The plagioclase is generally oligoclase and some crystals have an anorthite content up to 30%. They are poorly twinned and show varying degrees of alteration. The clinopyroxene is probably augite, which is subhedral, and in most cases is extensively replaced by chlorite.

The pillow lithology is very similar to the dykes described below. This, together with their close spatial relations and general comingling indicates a common coeval origin.

(b) Dykes

In hand specimen the dykes are generally dark green and fine-grained though some are microporphyritic with plagioclase phenocrysts less than 1/16 inch long. In thin section some are moderately fresh rocks with an equigranular, fine-grained texture made up of about 50%

subhedral, poorly twinned, altered plagioclase and about 40% clinopyroxene (probably augite though some may be pigeonite) that has poor crystal forms and is commonly broken up. The remainder of the rock consists of secondary chlorite (replacing the clinopyroxene), ore minerals and possibly prehnite. Later cross-cutting veins infilled with chlorite are also present.

More altered dykes from around the Ferry Wharf and Indian Cove are palish green to black with a mottled look. In thin section they are heavily altered and have an overall brownish colour as a result. They show the remains of a sub-ophitic texture with subhedral to euhedral plagioclase surrounded by patches of penninite chlorite pseudomorphing relicts of clinopyroxene crystals. Tremolite, actinolite, skeletal magnetite and uralite(?) are accessory minerals.

(c) Sediments

Chert and greywacke are the two types of sediments in the Herring Neck Group. The cherts are dark red to brick red and green in hand specimen. They are very finely bedded with some beds only 1/16 inch or less thick.

In thin section they are so fine-grained that no minerals are discernible except rounded blebs of recrystallized quartz. A large (1/2 inch) cherty but paler coloured fragment was noted in one specimen. This forms an augen with the lamination bending around it. Another sample is made of small, angular fragments the result of micro-brecciation. It also contains recrystallized quartz blebs and inclusions of lighter coloured chert. The dark red areas in the cherts are rich in haematite but in some the red colour appears to be due to staining.

The greywackes are brownish, coarse, gritty rocks in hand specimen with clasts from less than 1/16 to 1 inch long. The clasts are poorly sorted and are mainly red and green chert, quartz and feldspar grains.

In thin section the rocks have an aphanitic, recrystallized quartz-feldspar groundmass with some sericite. The clasts are randomly distributed throughout. The quartz clasts are angular to sub-rounded and strained. The feldspar clasts generally preserve subhedral crystal shapes with twinning still visible though they are highly altered and brown coloured. Cherts are the largest fragments and are commonly sub-rounded.

2.4.3 Structure

The Herring Neck Group has a weak fabric only locally developed. This strikes about northeast on New World Island and is roughly parallel to the fabric in the Twillingate Granite and Sleepy Cove Group, though locally that fabric is truncated by essentially undeformed mafic dykes which are part of the Herring Neck Group. Additionally the sediments on Black Island have a good cleavage striking north to south and related to open folding. The amphibolites of the Sleepy Cove Group to the north of these sediments have a foliation striking northeast. The evidence indicates that the deformation in the Herring Neck Group post-dates that in the Twillingate Granite and Sleepy Cove Group and had little effect on them.

2.4.4 Relationships

The Herring Neck Group is the youngest group in the area. Mafic dykes that are coeval with, and part of, the group post-tectonically cut foliated Twillingate Granite and Sleepy Cove Group amphibolites along the southern contact of the Twillingate Granite on New World Island (see 2.6B). Some of these dykes contain inclusions of amphibolites, for example on the small island between Salt Harbour and Herring Neck and also inclusions of deformed Twillingate Granite as found in a dyke on the north side of the Ferry Wharf.

The volcanic rocks of the Herring Neck Group, though less altered and deformed than those of the Sleepy Cove Group, are lithologically and petrologically similar. It is possible that they are integral parts of a more or less continuous volcanic sequence that was formed pre- and post-tectonically with respect to the main foliation in the Twillingate Granite and separated in time by a continual intrusion of consanguinous mafic dykes (see 2.6 and Chapter 5).

The sediments are poorly sorted and reworked indicating a moderately high energy regime such as that of an island arc. The probable plutonic quartz grains in the greywackes implies a source that may have been the Twillingate Granite. Helwig and Sarpi (1969) suggest a similar source for comparable lithologies in Upper Ordovician and Silurian rocks south of the Luke Arm Fault. These sediments have a strong similarity to the Chanceport Group (Strong and Payne, 1973) to the west and are correlated with them.

2.5 Acidic dykes

Acidic dykes are found throughout the area and fall into two categories: (A) granitic dykes related to the Twillingate Granite and confined to the pluton or the Sleepy Cove Group, and (B) younger, feldspar-rich dykes that mainly cut the Herring Neck Group and are unlike the Twillingate Granite.

2.5A Granitic dykes

2.5A.1 Lithology and distribution

These dykes are mainly quartz-porphyry and granite with a few aphanitic varieties and minor aplites. Their mineralogy and chemistry (see Chapter 4) is the same as the Twillingate Granite and their textures vary similarly. For instance some of the Twillingate Granite containing quartz phenocrysts is almost identical to the quartz-porphyry dykes on North Twillingate Island. On New World Island they are partially mylonitized and in general they exhibit the same structural features as nearby Twillingate Granite.

The dykes vary in width from about 2 inches for the aplites to 1-10 feet or more for the others and show no preferred regional orientation although many on North and South Twillingate Islands strike roughly northwest. They are most numerous on North Twillingate Island though they occur throughout most of the area where they cross-cut the Twillingate Granite and Sleepy Cove Group.

2.5A.2 Petrography

The quartz-porphyry dykes are pale to dark green and weather pink, whitish, rusty red and brown. They are medium to coarsely porphyritic containing quartz and feldspar phenocrysts in a fine-grained groundmass. The quartz phenocrysts are up to 1/4 inch long in undeformed samples and 3/4 inch where deformed. The feldspar phenocrysts are smaller and more euhedral measuring about 1/16 inch across.

In thin section the porphyritic texture is strongly developed (Figure 29) and very like parts of the Twillingate Granite (cf. Figure 24, p32). The phenocrysts tend to form augen. The quartz phenocrysts are generally large, anhedral and strained. In places they are

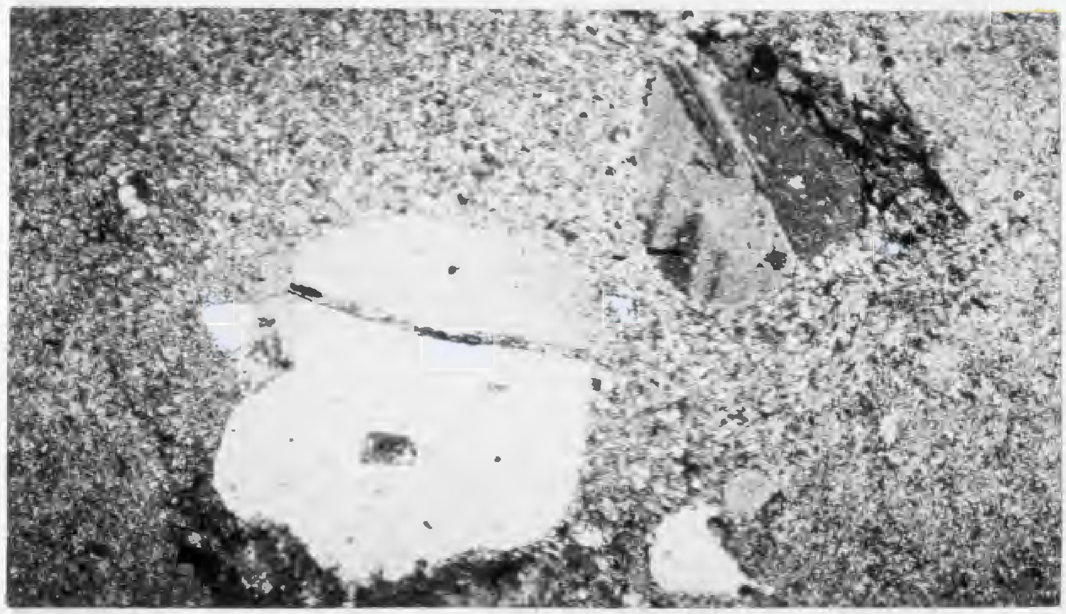


Figure 29 : Photomicrograph of a quartz-porphyry granitic dyke showing quartz and plagioclase phenocrysts. Compare with Figure 24 p 32 . (Crossed nicols, x 30).

recrystallized in a similar way e.g. mosaic patterns, to those in the Twillingate Granite. The feldspar phenocrysts are subhedral, commonly equidimensional, and partially altered by sericite and carbonate. They are rarely twinned but optical determinations of a few indicated an anorthite content of around 10%. The groundmass is a recrystallized quartzo-feldspathic mosaic with disseminated chlorite and carbonate and minor iron ore. Some of the specimens are brecciated internally by networks of carbonate filled veins.

The strongly deformed to mylonitic dykes are usually fine-grained and equigranular in thin section. They are composed of anhedral, recrystallized quartz and feldspar with secondary chlorite disseminated throughout. Locally faint outlines of former, larger crystals, which have been subsequently recrystallized, are visible. Cataclasis is also common.

The granite dykes tend to be slightly more recrystallized and altered than the granitic rock of the pluton which they so strongly resemble. The aplites are generally pink and aphanitic. In common with the other dykes they have a quartzo-feldspathic recrystallized texture but with less disseminated chlorite.

2.5A.3 Structure

The granitic dykes have the same single, penetrative fabric as the Twillingate Granite and that displayed in the nearby country rocks. Where these dykes cut the Sleepy Cove Group the fabric is concordant with that in the volcanic rocks (Figure 30).

In common with the rest of the area the intensity of the fabric in the granitic dykes varies greatly. For example many dykes in the southern part of the area on New World Island have a strongly developed fabric where-

Figure 30 : Fabric in a granitic dyke cutting the Sleepy Cove Group near Gillards Cove.

Figure 31 : Granitic dykes cutting a raft of Sleepy Cove Group rocks in the Twillingate Granite south of Purcells Harbour.

as some cutting the Sleepy Cove Group on North Twillingate Island have practically no fabric. This variation follows the overall one in the area showing a general decrease in structural intensity from south to north.

2.5A.4 Relationships

The granitic dykes are petrologically and chemically like the Twillingate Granite (see Chapter 4) and are interpreted to be intrusive offshoots of that pluton (Figure 31). Thus their relationships to other rock groups in the area is the same as the relationships of the Twillingate Granite, more specifically the granitic dykes are pre-tectonic and do not cut the Herring Neck Group.

2.5B Feldspar-rich dykes

2.5B.1 Lithology and distribution

The feldspar-rich dykes are usually brown, only a foot or two wide and have random orientations. They are characterised by an abundance of plagioclase in thin section. The dykes are scarce and generally found cutting the Herring Neck Group. The Twillingate Granite is cut by a feldspar-rich dyke near Merritts Harbour and there are similar (possibly related) dykes cutting the Sleepy Cove Group on North Twillingate Island.

2.5B.2 Petrography

The New World Island examples are light grey-green or brownish weathering pink to brown. They are medium-grained though locally some are porphyritic.

In thin section they are generally fresh looking and undeformed though one or two are considerably altered. They have an equigranular, igneous texture composed of about 80% plagioclase feldspar, less than 10% quartz and accessory chlorite, epidote and carbonate which are disseminated throughout. The feldspar is subhedral to euhedral and locally lath-shaped. It is partly altered to sericite, epidote and carbonate. Twinning is common and optical determinations indicate the feldspars have an anorthite content of about 30%. The quartz crystals are anhedral and unstrained and occur interstitially to feldspar.

Some feldspar-rich dykes that may be related to those on New World Island, occur on North Twillingate Island. A brown, prophyritic dyke containing small pink and white feldspar phenocrysts about 1/16 inch long set in an aphanitic groundmass was found north of Crow Head. In thin section it is a feldspar porphyry with subhedral plagioclase phenocrysts that are only slightly altered. Twinning is rare but a few crystals have an anorthite content of 30%. The groundmass is fine-grained feldspar with a little chlorite and iron ore. Another example east of Lower Head is brown and in thin section has a fine-grained trachytic texture of predominantly plagioclase laths. The accessories include much chlorite and carbonate and a little associated quartz and iron ore.

2.5B.3 Relationships

The feldspar-rich dykes are undeformed and sufficiently unlike the Twillingate Granite and related rocks to indicate a different origin. They are post-tectonic cutting all groups including the Herring Neck Group and thus probably represent one of the last events in the area.

2.6 Mafic dykes

Mafic dykes are very common throughout the whole area. They are divided into three categories based on their age of intrusion with respect to the deformation that produced the foliation in the Twillingate

Granite.

(A) The pre- and syn-tectonically intruded mafic dykes were either already in place (pre-tectonic) in the granite, or intruded during deformation (syn-tectonic) and both types were deformed at the same time as the granite.

Many pre- and syn-tectonic dykes are indistinguishable from each other as they have only a single foliation that is parallel to that in the granite. Some of the dykes have this single foliation inclined obliquely to the foliation in the granite and may also be either pre- or syn-tectonic (see Chapter 3).

The definite pre-tectonic dykes show evidence of two increments of deformation. A slightly earlier foliation in the dykes is crenulated by the foliation in the granite, both effects being part of the same episode of regional deformation (see Chapter 3).

(B) The post-tectonically intruded mafic dykes are undeformed and belong to the Herring Neck Group and therefore post-date the deformation of the Twillingate Granite. Thus they are younger than the pre- and syn-tectonic mafic dykes. They are included here as they occur separately cutting the pluton.

(C) The mafic dykes of unspecified age of intrusion, and therefore deformation, with respect to the foliation in the Twillingate Granite are apparently undeformed. However they could be pre-, syn- or post-tectonic because of their individual occurrences (see 2.6C.1).

2.6A Pre- and syn-tectonic mafic dykes

2.6A.1 Lithology and distribution

These dykes are either amphibolite or varieties of altered diabase and vary considerably in width from 3-20 feet. They are only found cutting the Twillingate Granite (Figure 32) and have a fairly dense distribution throughout the pluton. Their orientation is completely random except locally, where several may show a preferred trend as a result of exploiting joints and planes of weakness in the granite. Unrecognized examples (see 2.6C) may also intrude the Sleepy Cove Group.

2.6A.2 Petrography

The amphibolite dykes are dark green, grey and black in hand specimen and some have a sparkling appearance. The majority are fine-grained and equigranular but a few are slightly porphyritic. Thin sections consist of up to 50% very green and pleochroic hornblende in a recrystallized groundmass of quartz and feldspar with accessory magnetite and in some examples veins filled with quartz, feldspar and epidote. The hornblende is partly retrogressed to chlorite and the feldspar is moderately altered and generally untwinned. Patches of quartz and feldspar tend to form augen and in places faint banding is present.

The diabase dykes are mid to dark green in hand specimen. Most are fine-grained though a few are porphyritic. Thin sections reveal a fine-grained basaltic texture of altered plagioclase laths surrounded by subhedral augite which is commonly replaced by secondary chlorite. Fibrous amphiboles, such as tremolite and uralite, are found in places and locally there are remnant feldspar phenocrysts heavily altered by epidote and chlorite. Accessories include magnetite, haematite, quartz and carbonate and some sections are cut by carbonate and chlorite filled veins.

2.6A.3 Structure

These dykes are all foliated though the foliation is more strongly developed in some, particularly the amphibolites, than others.

Figure 32 : Pre- or syn-tectonic mafic dyke cutting the Twillingate Granite north of Purcells Harbour.

Figure 33 : Varieties of fabric in the pre- and syn-tectonic mafic dykes.

The intensity of the fabric in the dykes roughly follows that in the granite and generally decreases from south to north.

Three types of foliation occur (Figure 33). The most common is a single penetrative foliation generally parallel with the foliation in the Twillingate Granite. In some cases a single foliation, inclined at an angle to that in the granite, is found. The third type shows two effects, a foliation which is inclined to that in the granite and also crenulated on the edge of the dyke. The foliation in all these dykes is considered to be contemporaneous with that in the Twillingate Granite and is discussed below (see Chapter 3).

2.6A.4 Relationships

The pre- and syn-tectonic dykes cut the Twillingate Granite and are deformed with it. Also they probably intrude the Sleepy Cove Group but their lithological similarity to those volcanic rocks and the inhomogeneous deformation within the group makes their recognition difficult (see 2.6C). The dykes do not appear to feed any volcanic rocks and their intrusive relationship to the Twillingate Granite imply a younger age (if only slightly) than the Sleepy Cove Group. However, the lithological similarity between the dykes and the Sleepy Cove Group and their association in this geological environment suggest that they may be related and be part of the same period of magmatism. Along the southern contact of the pluton on New World Island these dykes are cut by post-tectonic mafic dykes (see 2.6B) of the Herring Neck Group (Figure 34).

2.6B Post-tectonic mafic dykes

2.6B.1 Lithology and distribution

These dykes belong to the Herring Neck Group and are restricted to New World Island where they intrude the Twillingate Granite and rocks of the Sleepy Cove Group. They are most numerous to the east near the Herring Neck Group and tend to decrease in number to the west. Their trend is roughly northeast and they are all broadly diabases and vary in width from one to two to several feet.

2.6B.2 Petrography

These dykes are very similar to those in the Herring Neck Group and are interpreted as being directly related (see 2.6B.4). In hand specimen they are fresh looking, pale green and fine-grained though a few are slightly porphyritic. Thin sections consist of mainly altered, subhedral plagioclase with twinning faintly visible and subhedral clinopyroxene (probably augite or diopside) together in a fine-grained, basaltic texture. Secondary chlorite, replacing the pyroxene, and iron ore are also present plus minor amounts of quartz and sphene.

2.6B.3 Relationships

The dykes are undeformed and post-tectonically cut both the foliated Twillingate Granite and the Sleepy Cove Group, plus the pre- and syn-tectonic dykes (Figure 34). On the grounds of lithological similarity and close spatial distribution they are considered to be consanguinous and coeval with the Herring Neck Group. Again the lithological resemblance of these dykes to the pre- and syn-tectonic ones and their common intrusive relationship to the granite lead to speculation on a possibly similar origin. The post-tectonic dykes might be a later stage to the earlier phase of dyke intrusion, finally leading to the formation of the Herring Neck Group. Furthermore it has been suggested above (see 2.4.4) that on the basis of lithology the Sleepy Cove Group and the Herring Neck Group are possibly part of one more or less continuous volcanic sequence separated in time by deformation. Thus the pre, syn- and post-tectonic mafic dykes may all be

Figure 34 : Post-tectonic mafic dyke of the Herring Neck Group cutting a pre- or syn-tectonic amphibolite dyke on Trump Island. Both are cutting the Twillingate Granite.

related and intruded during an interval of time, encompassing the period of deformation, of undetermined duration.

2.6C Mafic dykes of unspecified age of deformation

2.6C.1 Lithology and distribution

Mafic dykes of unspecified age of deformation cut the Sleepy Cove Group on North and South Twillingate Islands (Figure 35) and the Twillingate Granite on New World Island. They have random orientations and variable widths from a few to several feet. Most are diabases though there is some variation.

The age of deformation is uncertain in relation to the foliation in the Twillingate Granite because of the apparent absence of a foliation in the dykes and their various occurrences. For example in the Sleepy Cove Group the dykes cut undeformed country rocks, therefore because of the inhomogeneous nature of the deformation an undeformed dyke might be pre- or syn-tectonic and undeformed, or post-tectonic. Again on New World Island apparently undeformed mafic dykes occur a good distance away from the Herring Neck Group. These might be post-tectonic and belong to that group but they could also be very mildly deformed pre- or syn-tectonic ones that have a weak and indistinct fabric.

2.6C.2 Petrography

In general these dykes are altered diabases very like those of the other two categories. An unusual one containing primary hornblende occurs near Robins Cove and is probably unrelated to any of the others.

2.6C.3 Structure

The dykes are usually undeformed but some may have faint fabric depending on where they occur.

Figure 35 : Mafic dyke of unspecified age of deformation cutting the Sleepy Cove Group on South Twillingate Island.

2.6C.4 Relationships

These dykes are divisible into three sorts based on their relationships: (1) those cutting the Sleepy Cove Group on North and South Twillingate Islands are probably related to the pre- and syn-tectonic dykes: (2) the ones on New World Island are most likely the same as the post-tectonic dykes: (3) the one or two lithologically very different dykes, for example at Robins Cove, are clearly totally unrelated to any of the others and are much younger.

2.7 Alkaline dykes

Alkaline dykes are rare in the area but occur locally cross-cutting all lithologies except the Herring Neck Group. There are two types: (A) lamprophyres, and (B) alkaline-olivine-basalts. Both types are undeformed and easily recognized by their brown colour and unusual appearance.

2.7A Lamprophyre dykes

2.7A.1 Lithology and distribution

The lamprophyre dykes are characterized by large, biotite phenocrysts and a "knobby" texture (Figure 36). They are about 3-6 feet wide and usually long, sinuous and branching. The longest runs from the south side of Burnt Island (Figure 37) through South Twillingate Island to Bluff Head Cove. It cuts both the Twillingate Granite and the Sleepy Cove Group. Similar dykes are found on North Twillingate Island. However none is found in the main part of the pluton on South Twillingate Island or on New World Island.

2.7A.2 Petrography

The lamprophyres are very distinctive in hand specimen. They are brown and porphyritic with large biotite phenocrysts up to 1 1/2 inches

Figure 36 : Lamprophyre dyke near Devils Cove showing the characteristic "knobby" texture.

Figure 37 : Lamprophyre dyke cutting the Twillingate Granite near Carter Head.

across. Smaller augite phenocrysts about 1/8 inch across are also clearly visible. Additionally the dykes have a very characteristic "knobby" texture of leucocratic spherical globules about 1 inch radius in a melanocratic background. These globules coalesce in places and are mostly found in the centre of the dykes.

The rock is as distinctive in thin section as in hand specimen. It is very porphyritic with a medium-grained to aphanitic groundmass (Figure 38). The phenocrysts are clinopyroxene, biotite and some hornblende. Euhedral augite is very common and shows hourglass structures (Strong, 1969) and titanaugite and diopside also occur. Some of the crystals show signs of being corroded and reabsorbed as interreaction with the alkali magma is seen on their edges. Biotite is found as large, brown pleochroic crystals and some of them also show resorbtion phenomena.

The groundmass is either medium-grained with microphenocrysts or aphanitic and nondescript. The microphenocrysts are commonly long, acicular augites with hourglass structures and in common with the larger phenocrysts they have resorbtion edges. Biotite and magnetite are common and some sections contain nepheline. The remainder of the groundmass comprises microlites, alkali feldspar and/or feldspathoids. One specimen has veiscles infilled with stilbite.

Overall the rock has spherical ocelli forming leucocratic areas. These are the globules seen in hand specimen. They have the same mineralogy and composition (D.F. Strong, unpub. chemical analyses) as the rest of the rock but their lighter colour is due to a greater content of carbonate, zeolite and feldspathoidal material. It is likely that they are an immiscible part of the magma. The rock has strong alkaline affinities and is probably a type of minette.

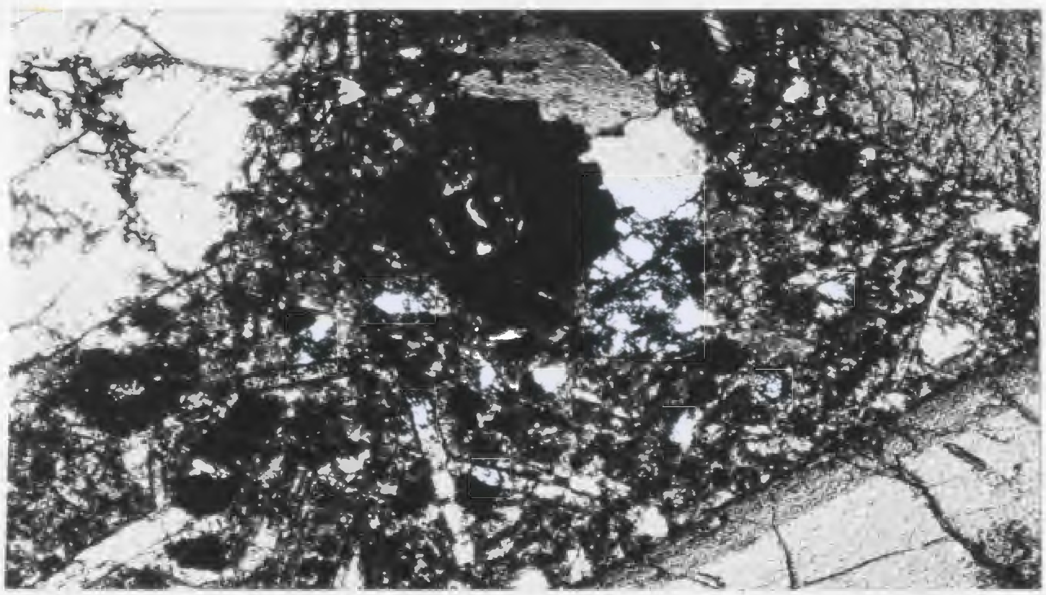


Figure 38 : Photomicrograph of lamprophyre dyke showing porphyritic texture of large augite phenocrysts (top left and bottom right with reaction rim), and large biotite phenocrysts (black in centre). The medium-grained microporphyritic groundmass is also visible. (Crossed nicols, x 30).

2.7A.3 Relationships

The lamprophyres are undeformed and cut both the Twillingate Granite and the Sleepy Cove Group though none were found cutting the Herring Neck Group. However the absence of fabric and their lack of alteration imply a young age. A Jurassic date was obtained from biotites of similar lamprophyres in nearby areas (Wanless, et al, 1965 and 1967).

2.7B Alkaline-olivine-basalt dykes

2.7B.1 Lithology and distribution

The alkaline-olivine-basalt dykes are brown, fine-grained and vesiculated. They occur only in a small area on the west coast of New World Island about 1/2 mile north of Lobster Harbour. Here they strike northwards, are no more than 3 feet wide and cut the Twillingate Granite.

2.7B.2 Petrography

In thin section the dykes are microporphyritic with a fine-grained and slightly glassy groundmass. The microphenocrysts are augite, found as zoned, lath shaped crystals; biotite, occuring as long, thin crystals; and olivine pseudomorphed by iddingsite rims with carbonate cores and locally serpentine.

The groundmass consists of small clinopyroxenes, biotite, feldspathoids, magnetite and microlites. The feldspathoids appear to have grid-iron patterns of magnetite which is probably a form of exsolution. Vesicles are present and infilled by chonchoidally formed carbonate.

The main differences from the lamprophyres are the presence of olivine and the absence of large phenocrysts, notably biotite. The groundmasses of the two are very similar.

2.7B.3 Relationships

The alkaline-olivine-basalt dykes are undeformed, slightly altered and cut the Twillingate Granite. No age dates have been carried out on them but chemical analyses (D.F. Strong, pers. comm.) suggest they are closely related to the lamprophyres and thus may belong to the same period of younger magmatism.

2.8 Goldson Formation

This formation is not included in the present study but outcrops along the length of the southern boundary of the thesis area just south of the Luke Arm Fault. The rocks are well exposed on the south side of Indian Cove and the east side of Ship Island where the beds strike approximately northeast, dip steeply and face northwest. They comprise coarse red and grey conglomerates and coarse, red and grey sandstone with minor fossiliferous interbeds. All are of Silurian age. Some of the pebbles in the conglomerates are volcanic and others are quartz and it is possible that they were derived from the Twillingate area. A more detailed description of the formation is given by Williams (1963).

CHAPTER 3

STRUCTURE AND TECTONIC INTERPRETATIONS

3.1 General statement

The most prominent structural feature of the Twillingate terrane is a single, generally steeply dipping, penetrative fabric found in the Twillingate Granite, the Sleepy Cove Group and the pre- and syn-tectonic dykes. This fabric strikes approximately northwest on North and South Twillingate Islands and northeast on New World Island but has considerable local variations and also tends to follow the contacts of the Twillingate Granite. It is inhomogeneously developed locally with some areas of very intense foliation and others where the fabric is absent. However over the whole area a general decrease in intensity is observed from the south, where the fabric is strongly developed with mylonite zones, to the north, where it is very faint to absent.

The Herring Neck Group, in contrast to this, is only mildly deformed. Its field relations, especially those of essentially undeformed mafic dykes of the Herring Neck Group cutting intensely deformed rocks of the Twillingate Granite and the Sleepy Cove Group, indicate that the deformation of the Herring Neck Group post-dates that of the other two units.

Evidence of a possibly earlier episode of deformation pre-dating that in the Twillingate Granite and Sleepy Cove Group is found in some amphibolite inclusions in the granite. These have a folded fabric and the foliation in the Twillingate Granite is axial planar to the folds.

A later event, post-dating the deformation in the Sleepy Cove Group (and the Twillingate Granite), is also inferred from the extensive kinking of the foliation in these volcanic rocks. Faulting is probably the youngest structural event in the area as individual faults displace both older deformed rocks and younger undeformed ones.

3.2 Interpretation

The structural history of the area is intimately connected with the relationships of the individual groups to one another and to the Twillingate Granite. These relationships indicate an order and timing of events with respect to the major deformation that produced the fabric in the Twillingate Granite. Thus the structural history of the area can be interpreted in terms of three episodes of deformation (Figure 39).

(a) Early event

It is clear that some of the amphibolite inclusions in the Twillingate Granite e.g. at Little Harbour must have been deformed prior to their inclusion into the pluton. They have a foliation that has been refolded by the regional fabric in the granite which is axial planar to the folds (see 2.2.3).

The majority of inclusions have a single fabric only which is concordant to that in the Twillingate Granite. They were probably undeformed prior to their inclusion into the granite and deformed with it later. In places their fabric is inclined to the fabric in the granite, this is probably a refraction through different lithologies or a shearing effect in the pluton. A few inclusions remain essentially undeformed.

Other inclusions at Little Harbour have a long linear shape and a fabric parallel to that in the granite. They are not obviously

Deformation	Twillingate Granite	Volcanic Rocks	Acidic Dykes	Mafic Dykes	Alkaline Dykes
d1 Early event		Partly deformed mafic terrane			
		Sleepy Cove Group			
	Start of intrusion inclusion of d1 xenoliths		Granitic dykes cutting Sleepy Cove Group		
Early shearing				Intrusion of pre- & syn-tectonic dykes	
				Early foliation	
d2 Main event	Foliation	Inhomogeneously developed foliation	Foliation	Foliation	
End	Mylonites ?				
		Herring Neck Group	Feldspar-rich dykes	Post-tectonic dykes	
d3 Later event(s)		weak foliation			
		kinking ?			
Faulting	Faulting and cataclasis ?	Faulting	Faulting	Faulting	
					Lamprophyres & alk-ol-basalts

Figure 39 : Diagrammatic summary of the structural history of the Twillingate area.

deformed with the granite because granitic dykes cross-cutting them are not boudinaged or folded. This might suggest that they had a pre-existing fabric and were included in the granite in their linear form with a preferred orientation.

The evidence indicates the Twillingate Granite intruded an earlier volcanic terrane that was deformed in places. This terrane might have been the bottom of the Sleepy Cove volcanic pile or possibly older mafic (oceanic?) crust. During the emplacement of the pluton pieces of both deformed and undeformed amphibolite and greenschist volcanic rocks were included in it.

(b) Main event

The main episode of deformation in the area is represented by the fabric in the Sleepy Cove Group, the Twillingate Granite and the pre- and syn-tectonic dykes. It therefore pre-dates the deformation of the Herring Neck Group.

The mechanism responsible for this fabric is a matter of debate particularly as the fabric is inhomogeneously developed in terms of both location and intensity and has local variations in strike. There are three broad possibilities that might account for some of these features (Figure 40).

The most likely occurrence was that the whole area was subjected to a regional stress, after and possibly during the intrusion of the granite, which would have continued until after the intrusion of the pre- and syn-tectonic mafic dykes. The granite would act as a fairly solid block forming an augen for the fabric around it. The stress was presumably more intense in the south of the area than the north.

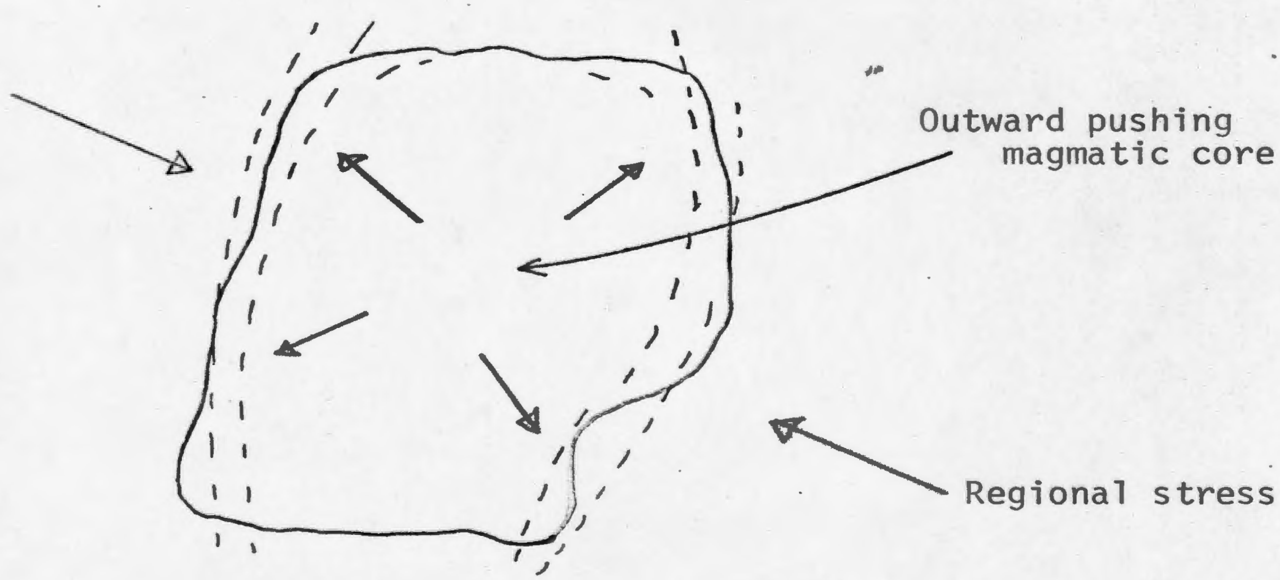


Figure 40 : Possible mechanisms for the production of the regional fabric in the Twillingate area.

Second there is the possibility that the granite itself produced most of the fabric. Compton (1955) cites the examples of the forceful intrusion of the trondhjemitic Bald Rock batholith in the Sierra Nevada Mountains. Here an upwelling core of magma was thought to have pushed country rocks aside and intensified pre-existing fabrics in them, particularly around the margin. However in the Twillingate area the country rocks did not have a pre-existing fabric, except possibly the basal part of the Sleepy Cove Group. So for this model to apply, the intrusion of the granite would have to produce all the fabric including that within the pluton and the pre- and syn-tectonic dykes. Also this mechanism would be expected to produce a similar development of fabric all the way round the margins of the pluton and this is not the case with the Twillingate Granite. Thus it is unlikely that this is an important mechanism in the area though it may have had some effect.

Possibly a combination of the above two ideas would allow the regional stress to work in opposition to the intruding magma forming an augen for the fabric. The mylonitic southern contact on New World Island may be explained as the result of a late outward forcing of the magmatic core on parts of the border still mobile enough to deform and recrystallize under stress, though it has been suggested (Williams, pers. comm.) that the mylonite zone and the deformation in this part of the area has nothing to do with the form of the Twillingate pluton. The local variations in the fabric's strike particularly in the centre of the pluton may also be partly explained by a central upwelling of magma.

The granite is cut by pre- and syn-tectonic mafic dykes (see 2.6A) so called on the basis of their inferred age of intrusion relative to the deformation of the Twillingate Granite. The dykes have variations in the orientation of their internal fabrics with respect to that in the host granite (Figure 33, p 53). Those with a parallel mineral alignment to the granite are interpreted as being either pre-tectonic and therefore in situ in the granite before deformation or intruded during deformation (syn-tectonic), both types being contemporaneously deformed with the granite.

The dykes with a fabric inclined to the one in the granite may be explained by a mechanism of lateral slip on the dyke walls to produce oblique internal foliations (Watterson, 1965 and 1968; Allaart 1967; Berger 1971). If the granite was hot for a fairly long time and behaved as a 'crystal mush' (Berger and Pitcher, 1970) then possibly it could respond to some deformation by local realignment along movement zones or junctions. The dykes would act as loci for such shear displacements. The angles between the internal foliation, the dyke wall and the foliation in the granite are related to the amount of movement and this looks to have been generally small. Again these dykes can be either pre- or syn-tectonic for the same reasons as above.

However some of the mafic dykes cutting the Twillingate Granite have two fabrics whereas the granite has only one. This paradoxical situation is resolved by the interpretation that these dykes were pre-tectonically emplaced and acted as early shear zones in the pluton. The resulting fabric inclined to the dyke walls would be crenulated by the closely following main period of deformation. Both increments of deformation are considered to be related and part of the same event.

(c) Later event(s)

Several milder effects of subsequent deformation post-dating the deformation of the Twillingate Granite occur in the area. The

Sleepy Cove Group, particularly the amphibolites, shows a well developed kinking of its fabric. The mylonite zone in the Twillingate Granite shows evidence of later cataclasis that may be associated with faulting which is probably the youngest structural feature in the area. The Herring Neck Group also has a weakly developed fabric post-dating that in the Twillingate Granite.

The relationships between all these features is not known. They might be part of one later event and closely related in time or totally unrelated. Finally all this is post-dated by faulting and the intrusion of the undeformed feldspar-rich and alkaline dykes.

3.3 Faulting

Faulting is the youngest structural feature of the area and very dominant especially on New World Island. Faults are clearly reflected in the topography and are more easily seen on aerial photographs than in the field. They tend to follow valleys and areas of lower relief. There is no concrete evidence of direction or amount of movement along any of the faults, apart from rare slickenslides and brecciation in places. One or two major faults dominate the geology especially on New World Island.

The Luke Arm Fault is the most significant fault in the area and forms the southern boundary to it. It was first recognized by Murray and Howley (1881) and described by Heyl (1936). In this area it strikes northeast and extends from Indian Cove, through Goshens Arm, across Ship Island and out into the Atlantic (Kay, 1973, pers. comm.). To the west of New World Island it is thought to extend about 100 miles (Heyl, 1936).

A distinct break in stratigraphy and structure occurs across the fault in the Twillingate area. To the north there are deformed and undeformed volcanic rocks of presumed Ordovician age and to the south is the Goldson Formation of Silurian age (Figure 41). Very little brecciation was noted along its length for such an apparent magnitude of faulting.

The movement along the fault is not positively known but Heyl (1936) and Kay (1969 and 1972) both suggest it was right lateral with a downthrow to the south. Kay (1972, p. 130, diagram 3) also suggested it was active in the Llandoverian period. Horne and Helwig (1969) think the fault may have a strike slip separation of tens of miles. The most recent publication to mention the fault (Williams et al., 1972) agrees with the previous interpretations of a dextral strike slip with a downthrow to the south.

The Lobster Harbour Fault is the only other important fault. Its significance lies in the fact that it separates the Sleepy Cove Group and the Twillingate Granite to the northwest, from the Herring Neck Group to the southeast. Mafic dykes belonging to the Herring Neck Group occur northwest of the fault indicating that the Herring Neck Group was in contact with the other groups before faulting. The fault strikes northeast and runs roughly sub-parallel to the Luke Arm Fault and extends the entire length of New World Island from Starve Harbour, through Upper Gut Arm and down to the Ferry Wharf. It probably continues on Black Island, separating Herring Neck Group sediments from Sleepy Cove Group amphibolites and finally becomes the Chanceport Fault (Strong and Payne, 1973) in the Moretons Harbour area.

Figure 41 : The Luke Arm Fault at the north end of Ship Island. Volcanic rocks of the Herring Neck Group to the left are separated from the Goldson Formation conglomerate to the right.

Figure 42 : The Sleepy Cove Fault at Sleepy Cove. Undeformed and metalliferous pillow lavas to the left are faulted against deformed pillow lavas to the right. Note the prominent fault scarp.

Other faults occur on New World Island such as the Goshens Arm Fault, the Merritts Harbour Fault and several smaller unnamed ones. They all tend to strike approximately northeast and are probably splays of the Luke Arm Fault.

No large faults were found on the Twillingate Islands except the Sleepy Cove Fault in the very north. This separates an area of deformed, unmetalliferous pillow lavas to the south from undeformed, pyrite and chalcopyrite bearing pillow lavas to the north (Figure 42).

Small scale faulting is evident throughout the area. Many dykes cutting the granite are slightly displaced and blocks of the granite are commonly faulted.

CHAPTER 4

GEOCHEMISTRY AND PETROGENESIS

The content of this chapter is concerned with the Twillingate Granite and its origin.

4.1 Methods

4.1.1 Sampling

One hundred and ten samples of granite were analysed for ten major elements and eleven trace elements. An idealised (1 square mile) grid was superimposed on the field area, so arranged that as many of the sampling stations as possible fell on or near the coast or in areas of easy access inland. Three of these square mile grids were divided into quarter square mile units to allow closer sampling. The three areas chosen were widely separated and generally had good coastal exposure. Two were on South Twillingate Island, in the Jenkins Cove - Carter Head - Durrells Arm area, and the Herring Cove - Kiddle Cove area. The third was on New World Island around and to the west of Merritts Harbour. Stations falling in the sea were either moved into the nearest coastal exposure or were considered too far out and ignored. Four sampled stations (numbers 4, 32, 35 and 69) fell outside the boundaries of the pluton, but were still used as they are offshoots of the pluton into the country rocks.

This allowed for 93 stations to which another 17 (numbers 94-110) randomly orientated but widely separated stations were added. Taking the exposed area as about 15 square miles there was an average of 7.3 samples taken per square mile (Figure 43).

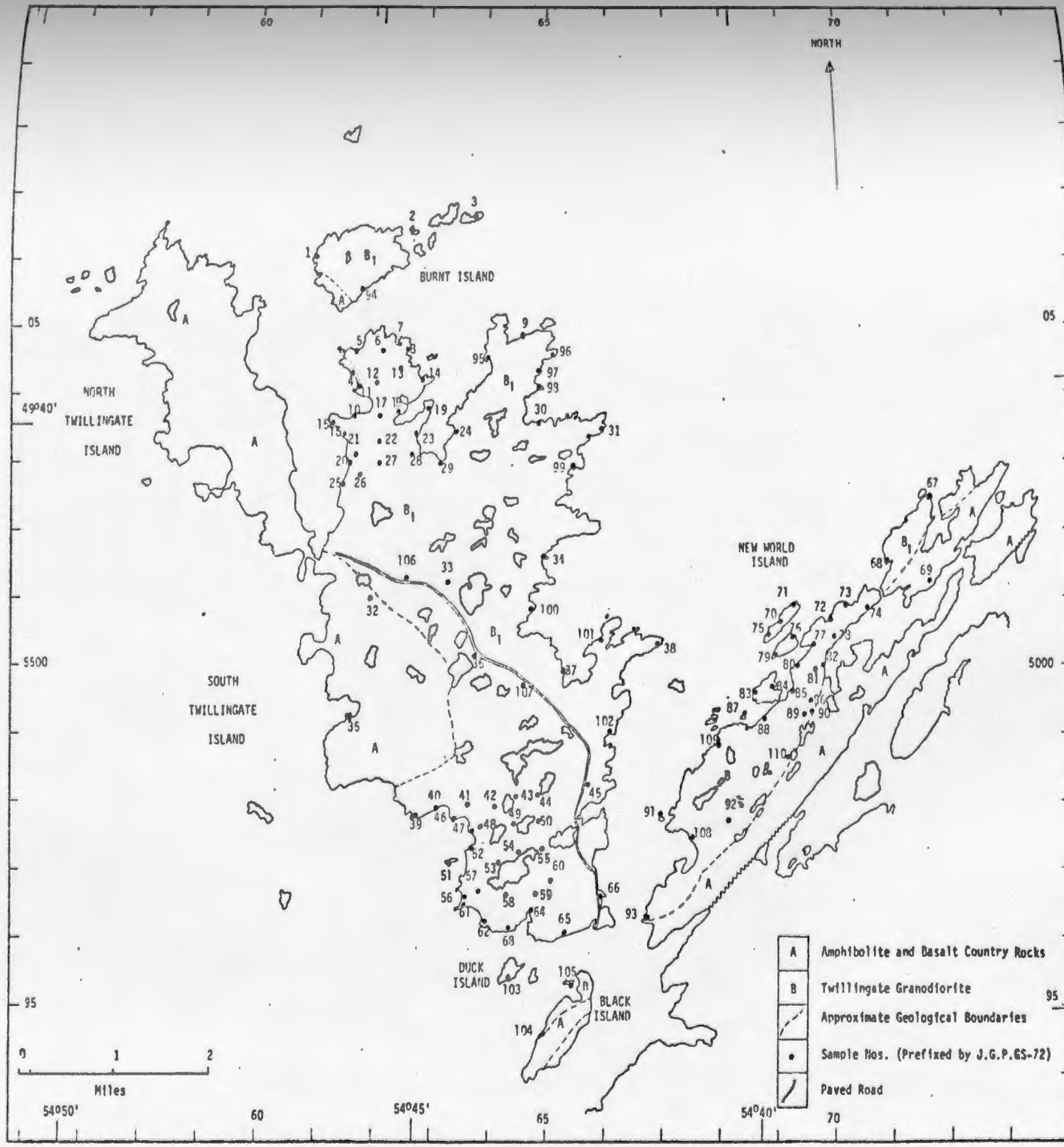


Figure 43 : Location map of geochemical samples.

Samples were taken using a ten pound sledge hammer, and fresh rocks were collected wherever possible. Each sample was at least fist-sized weighing approximately two to three pounds, and some were considerably larger if the rock was coarse-grained. No duplicate samples were taken.

4.1.2 Preparation

All the samples were crushed according to the following process.

1) Each sample was broken into chips using a small sledge hammer on a thick plywood board. A slab was saved for sectioning.

2) A fresh, representative sample of chips was crushed to half inch or smaller pieces in a steel jaw crusher.

3) A representative sample of these pieces was crushed in a tungston-carbide Seibtechnik swing mill for three to four minutes producing a rock powder of about -100 mesh, as determined by random sieving checks.

4) The powder was put into 4 oz jars and dried overnight in an oven at 110°F.

4.1.2A Trace element methods

Eleven trace elements (Zr, Sr, Rb, Zn, Cu, Ba, Mo, Nb, Bi, Pb) were determined by X-Ray Flourescence using a Phillips PW 1220C computerised spectrometer. The sample discs were prepared in the following manner.

1) 1.5 gm of rock powder was thoroughly mixed with 2 to 3 drops of N-30-88 Mowiol binding agent until the colour was uniform.

2) Using a Boric Acid base, this powder was pressed into a disc for 1 minute at 15 tons per square inch.

4.1.2B Major element methods

Eight major element oxides (Fe_2O_3, TiO_2, P_2O_5, SiO_2, CaO, K_2O, MgO, Al_2O_3) were determined using fused powders. The samples were prepared by the following method.

1) 0.7500 gm of rock powder + 0.7500 gm of La_2O_3 + 6.00 gm of $Li_2B_4O_7$ were carefully weighed out, mixed together, and put in a graphite crucible.

2) A dozen crucibles at a time were put in a muffle furnace pre-heated to 1,000°C and left to fuse for 30-35 minutes.

3) After fusion the resulting glass beads were allowed to cool for 5 minutes and put in clean glass jars.

4) The weight of each bead was readjusted to exactly 7.500 gm with dried $Li_2B_4O_7$, compensating for weight lost during fusion and thus giving an exact dilution.

5) Each bead plus the $Li_2B_4O_7$ was placed in a tungston-carbide ball mill vial, cracked with a steel cylinder, and then crushed in the ball mill to -100 mesh.

6) The powder was then put in bottles and dried overnight at 110°F.

7) The sample discs were then prepared as for the trace elements.

Two major elements (Na_2O, MnO) were analysed using a Perkin Elmer 303 Atomic Absorption Spectrometer. The solutions were prepared in the following way.

1) 0.2000 gm of powder was mixed with 5 ml of concentrated HF and heated for 20 minutes until completely dissolved.

2) Each sample was diluted with 50 cc of saturated boric acid and made up to 200 cc with distilled water.

4.1.2C Loss on ignition

This was done by measuring a known amount of powder into a porcelain crucible, heating at 1050°C for 2 hours, weighing again and expressing the difference in per cent. It is assumed that the loss on ignition represents predominantly H_2O and CO_2.

4.1.3 Precision and accuracy of results

The precision and accuracy of both the XRF and AA results can be seen from Table 1 which was taken directly from Strong, et al. (1973). The Twillingate Granite was analysed on the same programme and in the same way.

Samples 1, 79, 95 and 107 were analysed on both XRF and AA (Table 2). Na_2O and MnO were only done by atomic absorption. The results are very similar except for the variation in SiO_2 which is to be expected when dealing with such high levels; ±2% is not unusual (G. Andrews, pers. comm.).

4.1.4 Recording and processing of data

All the field data were entered on sheets similar to those used by Garrett (1972). The limitations of this are obvious and a lot of the classifications were rather subjective.

The analytical data were tabulated onto general coding forms for ease of reference, and then transferred to key-punch cards for computer processing. All major elements and loss on ignition were entered as percentages up to two decimal places. The trace elements were all in parts per million except Sn, Mo, Nb, Bi, and Pb which were peak counts against a standard to show any anomalously high values.

Computer programmes were used to calculate the weight and mole percentages of each sample and the ratios for plotting AFM and CNK diagrams.

Table 1. Precision and accuracy of analyses (Strong, et al., 1973)

A) Precision of analytical methods for major elements.

Element	Fused* Sample 371 CD			Unfused Sample LD 75		
	Range %	Mean	S. Dev.	Range %	Mean	S. Dev.
SiO_2	83.60-1.11	76.58	1.94	6.90	76.21	1.91
TiO_2	0.24-0.14	0.17	0.03	0.02	0.03	0.01
Al_2O_3	13.10-1.10	12.28	0.36	1.37	14.13	0.35
Fe_2O_3	1.36-1.02	1.15	0.08	0.57	1.45	0.20
MgO	5.80-0.10	0.30	0.94	1.66	0.91	0.45
CaO	1.09-0.33	0.87	0.10	0.24	1.11	0.08
K_2O	1.84-1.11	1.73	0.03	0.58	2.43	0.23
P_2O_5	0.01-0.00	0.005	0.002	0.10	0.04	0.09

Table 1 continued...

B) Precision of trace element analysis from nine independant discs of LD 75.

Element	Range (PPM)	Mean	S. Dev.
Zr	68	33	10
Sr	138	21	9
Rb	106	8	3
Zn	37	9	3
Cu	4	16	6
Ba	755	197	74

Table 1. continued...

C) Accuracy of major element analysis as determined by fit of standards to calibration curve.

Element	Fused Samples				Unfused Samples			
	Range %	Mean	S. Dev.	No. Stds.	Range %	Mean	S. Dev.	No. Stds.
SiO_2	75.5 -37.0	----	0.67	21	79.10-55.8	71.35	1.63	10
TiO_2	4.60- 0.01	----	0.03	23	1.09- 0.01	0.30	0.06	9
Al_2O_3	23.90- 0.55	----	0.37	23	16.30-12.10	14.05	0.67	11
Fe_2O_3	27.90- 0.07	----	0.16	20	7.90- 0.40	2.40	0.20	9
MgO	49.80- 0.10	----	0.89	18	3.35- 0.02	0.90	0.27	7
CaO	13.74- 0.11	----	0.10	21	7.70- 0.00	1.85	0.55	8
K_2O	11.80- 0.02	----	0.07	21	5.76- 1.24	3.95	0.14	9
P_2O_5	1.91- 0.01	----	0.09	18	----	----	----	--

Table 1. continued...

D) Accuracy of major element analysis as determined by comparison of 24 samples analysed by X-Ray flourescence and atomic absorption, and trace elements by fit of standards to calibration curve.

Major Elements

Element	Range %	St. Dev.
SiO_2	72.57-64.83	0.99
TiO_2	0.86- 0.15	0.02
Al_2O_3	20.31-12.91	0.30
Fe_2O_3	5.15- 0.09	0.10
MgO	1.05- 0.71	0.05
CaO	2.49- 1.94	0.05
K_2O	5.47- 0.47	0.04
P_2O_5	0.26- 0.03	0.04

Trace Elements

Element	Range(PPM)	St. Dev.	No. Stds.
Zr	540-50	13	16
Sr	850-66	18	19
Rb	250- 5	6	23
Zn	180-19	12	24
Cu	105- 5	5	23
Ba	1830-120	33	18

Table 2. Comparison of XRF and AA analyses for major elements on four selected samples.

	1		79		95		107	
	AA	XRF	AA	XRF	AA	XRF	AA	XRF
SiO_2	69.0	71.00	72.0	70.60	79.1	76.40	69.2	71.40
Al_2O_3	13.1	13.20	13.0	12.50	12.7	12.60	13.1	13.30
TiO_2	0.4	0.38	0.2	0.12	0.05	0.16	0.18	0.27
Fe_2O_3	3.83	3.81	2.81	2.01	1.37	1.61	3.28	3.50
MnO [1]	0.08	0.08	0.07	0.07	0.03	0.03	0.07	0.07
MgO	0.91	0.20	0.56	----	0.12	----	1.09	----
CaO	2.93	3.05	2.68	2.57	0.93	0.97	2.18	2.39
Na_2O [1]	4.21	4.21	3.71	3.71	4.33	4.33	4.73	4.73
K_2O	0.71	0.53	0.71	0.57	0.90	0.76	1.02	0.97
P_2O_5	----	0.01	----	----	----	----	----	----
TOTAL	95.17	96.47	95.74	92.15	99.53	96.86	94.85	96.63
L.O.I.	1.37	1.37	1.45	1.45	1.25	1.25	1.25	1.25
TOTAL	96.54	97.84	97.19	93.60	100.78	98.11	96.10	97.88

The means and standard deviations were calculated, and histograms plotted for most elements. Scatter diagrams of all major and trace elements against SiO_2 were also plotted. In the computer programmes only 109 analyses were used. Sample number 22 was not analysed for major elements in the XRF and was left out.

4.1.5 Effects of weathering and metamorphism

The granite is weathered a quarter inch deep or more in places. Nearly all the samples collected showed some effects of weathering, especially those from inland localities. However, large samples were taken and every effort was made to use the freshest parts and eliminate the remainder. Thus the effect of weathering on the results is probably negligable.

The effects of metamorphism are harder to evaluate. As stated earlier the pluton probably reached amphibolite facies conditions in places and generally greenschist facies overall. Granites generally do not react to metamorphism as strongly as other rocks. Even basalts have been shown to react only by internal chemical reconstruction in a closed system with little or no addition or subtraction of elements (Van de Kamp, 1970; Jolly and Smith, 1972; Wilson and Leake, 1972). The only observable metamorphic changes in the Twillingate Granite are sericitization of feldspar, the production of some epidote, and the alteration of hornblende and biotite to secondary chlorite. There are physical responses to the deformation, such as the recrystallisation of quartz and feldspar to a mosaic and a few cataclastic effects. These features do not require any changes in bulk chemistry, except perhaps for the addition of water. Thus it appears unnecessary to suggest any important chemical changes, for example that all the Na was metasomatically introduced. In this case the amounts are too high and the distribution is too uniform over the whole area of the pluton.

4.1.6 Treatment of data and preliminary observations

All the basic analytical data for the granite are shown in the appendix. The means, ranges, standard deviations and some selected ratios can be seen in Table 3. Average Twillingate values are compared with the average results from other granites and recent published analyses of trondhjemites in Table 4. Differences in major element chemistry can be seen in these results compared to normal granites.

[redacted]erally higher values

SiO_2 in the Twillingate Granite is about the same as other granites but tends to be high. Glikson and Sheraton (1972) show a higher value for their trondhjemite while Larsen and Poldervaart (1961), and Hotz (1971) show lower values. Na_2O is consistently at least 1% higher than normal granites and in some cases more. This agrees with Larsen and Poldervaart and Hotz, while Glikson and Sheraton have a much higher figure. Loss on ignition (H_2O and CO_2) is over 1% like Glikson and Sheraton's value (H_2O only). Other granites and Hotz's figures for trondhjemites are about half this as only H_2O is given. Larsen and Poldervaart quote only H_2O+.

[redacted]rally similar values

TiO_2 and MnO are fairly consistent throughout all the granites. MgO is similarly consistent except for the more calcic rocks which have higher contents and Larsen and Poldervaart's leucotrondhjemite which is lower.

Table 3. Summary of analytical results from the Twillingate Granite.

Major Elements	Average	High Range	Low Range	St. Dev.	No. of Samples
SiO_2	72.69	80.00	55.10[2] (66.5)	3.82	109
TiO_2	0.24	0.93[2] (0.54)	0.05	0.1	
Al_2O_3	12.84	16.8[2] (15.3)	10.00	1.1	
Fe_2O_3[1]	2.75	8.7[2] (4.73)	0.83	1.06	
MnO	0.06	0.57	0.01	0.06	
MgO	0.51	15.6[2] (1.6)	0.0	1.69	
CaO	1.89	7.81[2] (4.61)	0.16	1.14	
Na_2O	4.80	6.42	2.43[2] (2.69)	0.83	
K_2O	0.57	3.88[2] (2.51)	0.03	0.56	
H_2O	1.27	5.24[3]	0.0	0.65	
P_2O_5	0.02	1.17[3]	0.0	0.12	

Table 3. continued...

Trace Elements	Average	High Range	Low Range	St. Dev.	No. of Samples
Zr	102	352	7	---	110
Sr	87	200	0	---	
Rb	18	39	2	---	
Zn	39	91	9	---	
Cu	8	160	0	---	
Ba	63	194	0	---	
Sn, Mo, Nb, Bi, Pb; comparison with standard counts only					
Ratios					
K/Rb	268	1908[3]. (771)	27	---	109
Rb/Sr	0.33	3.57	0.036	---	97
Ba/Rb	4.	20.5	0	---	110

---

1. Total Fe as Fe_2O_3.

2. Anomalously high or low value from a basic phase. Value in brackets is highest or lowest normal value.

3. One very high value, due to other factors, possibly contamination.

[redacted]ally lower values

Al_2O_3 is about 1% less than average granites and Glikson and Sheraton's trondhjemite value. However it is approximately 3% less than those of Larsen and Poldervaart and 4-5% less than those of Hotz. CaO is similar to Glikson and Sheraton's value. This is similar to average calc-alkaline granite and between high and low Ca granite. Hotz and Larsen and Poldervaart show almost twice as much in their results. K_2O in all the trondhjemites is characteristically much lower (4-5% less) than in the granites. Larsen and Poldervaart's results have the highest content. P_2O_5 is usually somewhat depleted with respect to the more normal granites.

The trondhjemites are broadly similar in all major elements, apart from the inconsistency in Al_2O_3 between Twillingate and the rest. The leucotrondhjemite of Larsen and Poldervaart and the calcic trondhjemite of Hotz stand out as slightly different. All the trondhjemites are typified by very high Na_2O values and very low K_2O ones compared with normal granitic rocks.

Comparison of trace elements is difficult because of lack of published analyses. Nearly all the trace elements analysed from Twillingate are depleted compared with other trondhjemites and these are depleted with respect to more typical granites. In the Twillingate Granite Ba and Sr are strongly depleted: Zr and Rb compare with other trondhjemites but all are less than the granites. Zn and Cu are similar to the granites. Some unpublished results of samples collected from Twillingate in 1971 for Ni, Cr and V again have similarities to the other trondhjemites and are depleted relative to the granites.

Table 4. Comparison of analyses from the Twillingate Granite with other trondhjemites and average granites.

1. Twillingate Granite, 1973; Ni, Cr and V from 12 analyses, 1972.
2. Bald Rock batholith, average of nine trondhjemite samples (Larsen and Poldervaart, 1961).
3. Bald Rock batholith, average of three leucotrondhjemite samples (Larsen and Poldervaart, 1961).
4. Average of seven trondhjemite pebbles from the Kurrawang Conglomerate, Western Australia (Glikson and Sheraton, 1972).
5. Trondhjemite, Craggy Peak (Hotz, 1971).
6. Trondhjemite, White Rock no. 54 (Hotz, 1971).
7. Trondhjemite, White Rock no. 55 (Hotz, 1971).
8. Calcic trondhjemite, Caribou Mountain (Hotz, 1971).
9. Average calc-alkaline granite (Nockolds, 1954): trace elements (Taylor, 1965).
10. Average alkaline granite (Nockolds, 1954): trace elements (Taylor, 1965).
11. Average high calcium granite (Turekian and Wedepohl, 1961).
12. Average low calcium granite (Turekian and Wedepohl, 1961).

a. Total Fe as Fe_2O_3.

b. Total Fe as FeO.

c. H_2O and CO_2.

d. H_2O+ only.

Table 4. continued...

Major Elements	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	72.69	70.8	72.8	74.60	70.5	69.2	70.8	68.58	72.08	73.86	67.19	74.25
TiO_2	0.24	0.18	0.1	0.15	0.28	0.24	0.13	0.29	0.37	0.20	0.56	0.20
Al_2O_3	12.84	15.8	15.5	13.96	16.4	17.6	17.5	17.10	13.86	13.75	15.41	13.53
Fe_2O_3	2.75[a]	0.9	0.4	1.02[a]	0.79	1.0	0.33	0.76	0.86	0.78	---	---
FeO	---	1.3	0.6	---	1.1	1.1	0.88	1.44	1.87	1.13	3.79[b]	1.82[b]
MnO	0.06	---	---	0.03	0.06	0.06	0.05	0.23	0.06	0.05	0.07	0.05
MgO	0.51	0.8	0.2	0.31	0.87	0.69	0.41	1.18	0.52	0.26	1.56	0.26
CaO	1.89	3.1	2.5	1.20	3.4	3.6	3.4	4.40	1.33	0.72	3.54	0.71
Na_2O	4.80	4.8	5.4	7.40	4.7	4.8	4.7	4.69	3.08	3.51	3.83	3.48
K_2O	0.57	1.8	2.0	0.49	0.95	0.84	0.95	0.96	5.46	5.13	3.02	5.04
H_2O	1.27[c]	0.4[d]	0.2[d]	1.19	0.5	0.76	0.59	0.58	0.53	0.47	---	---
P_2O_5	0.02	0.1	0.2	0.03	0.02	0.09	0.04	0.32	0.18	0.14	---	---
Total	97.64	99.98	99.9	100.58	99.57	99.98	99.78	100.53	100.2	100.0	98.97	99.34

Table 4. continued...

Trace Elements	1	2	3	4	5	6	7	8	9	10	11	12
Zr	102	---	---	100	---	100	70	---	180		140	175
Sr	87	---	---	298	---	1000	1000	---	285		440	110
Rb	18	---	---	10-30	---	---	---	---	150		110	170
Zn	39	---	---	---	---	---	---	---	40		---	---
Cu	8	---	---	7	---	15	10	---	10		30	10
Ba	63	---	---	371	---	300	300	---	600		420	840
Sn	comparison	---	---	---	---	---	---	---	---		---	---
Mo	with	---	---	---	---	---	---	---	---		---	---
Nb	standard	---	---	---	---	0	0	---	---		---	---
Bi	counts	---	---	---	---	---	---	---	---		---	---
Pb	only	---	---	---	---	7	10	---	---		15	19
Ni	0	---	---	9	---	5	1	---	0.5		15	4.5
Cr	11	---	---	6	---	19	5	---	4		22	4.1
V	65	---	---	18	---	50	15	---	20		88	44
K/Rb	268	---	---	333	---	---	---	---	302		229	247
Rb/Sr	0.33	---	---	0.047	---	---	---	---	0.5		0.25	1.7
Ba/Rb	4	---	---	31	---	---	---	---	4		3.8	4.9

The K/Rb, Rb/Sr and Ba/Rb ratios are all fairly similar. This implies that though Twillingate is depleted in trace elements this depletion is uniform for each element.

Overall results from Twillingate indicate a uniform chemistry across the pluton. More detailed work might reveal some subtle variations. One or two major variations are seen in the ranges of some elements. This is because some basic parts (quartz-hornblende-diorite) of the granite were analysed and included (samples 68, 73 and 87). These usually have lower SiO_2 and higher Fe_2O_3, CaO, K_2O, MgO and Al_2O_3 values, as would be expected in a basic phase. It is also noticed that samples 4, 32, 35 and 69 which are thought to be apophyses of the pluton have an identical chemistry to it. Table 5 shows similar results from the Trump Island area (Coish, 1973).

Four selected scatter diagrams (CaO, K_2O, Al_2O_3 and Na_2O against SiO_2) are shown in Figure 44. These confirm the lack of systematic variation in the chemistry as the majority of the plots fall close together. Scatter diagrams for all the other major and trace elements show the same thing. Values falling outside the main groupings are the basic phases.

Histograms were also plotted for each major and trace element. They are not included here as all had normal distributions, and the means are given in Table 3.

The qtz-or-ab normative diagram (Figure 45a) clearly reflects the lack of potassium feldspar in the Twillingate Granite (as seen in the low K_2O values) and the approximate 1:1 ratio of quartz to albite (as noted in thin sections). The AFM diagram (Figure 45b) is not as clear because so many samples have no MgO and consequently plot on the

Table 5. Major and trace element analyses for Twillingate Granite and acidic dykes from Trump Island (Coish, 1973).

Major Oxide	Acidic Dikes					Twillingate Granite		
	758	750	502	527	500	535	737	741
SiO_2	74.86	76.64	82.39	74.64	76.73	80.70	72.75	72.63
TiO_2	0.21	0.20	0.10	0.21	0.20	0.10	0.21	0.21
Al_2O_3	13.55	12.01	8.86	13.80	12.33	11.22	13.88	14.36
Fe*	2.40	1.80	2.23	2.59	2.97	1.55	4.06	3.36
MnO	0.03	0.02	0.04	0.04	0.03	0.04	0.09	0.06
MgO	0.99	0.60	1.06	1.12	1.04	0.16	0.93	0.92
CaO	1.78	1.76	1.46	1.61	0.48	1.10	2.39	3.24
Na_2O	5.78	3.16	3.36	5.71	6.17	4.70	4.91	4.47
K_2O	0.41	3.81	0.51	0.29	0.06	0.44	0.78	0.76
P_2O_5	----	----	----	----	----	----	----	----

Trace Element	Acidic Dikes					Twillingate Granite		
	758	750	502	527	500	535	737	741
Rb	16	----	14	14	12	----	24	18
Cu	5	----	----	93	34	----	----	35
Sr	207	----	8	134	----	----	114	151
Ba	121	----	----	----	----	----	----	580
Zn	17	----	28	----	24	----	54	52
Zr	144	----	55	138	130	----	91	4
Cr	35	----	33	37	33	----	33	39
Ni	7	----	17	15	17	----	7	45
Rb/Sr	.08	----	1.75	.10	----	----	0.21	0.12
K/Rb	200	----	300	160	40	----	270	330
Ba/Rb	----	----	----	----	----	----	----	----
Ba/Sr	----	----	----	----	----	----	----	----

*Total Fe as Fe_2O_3

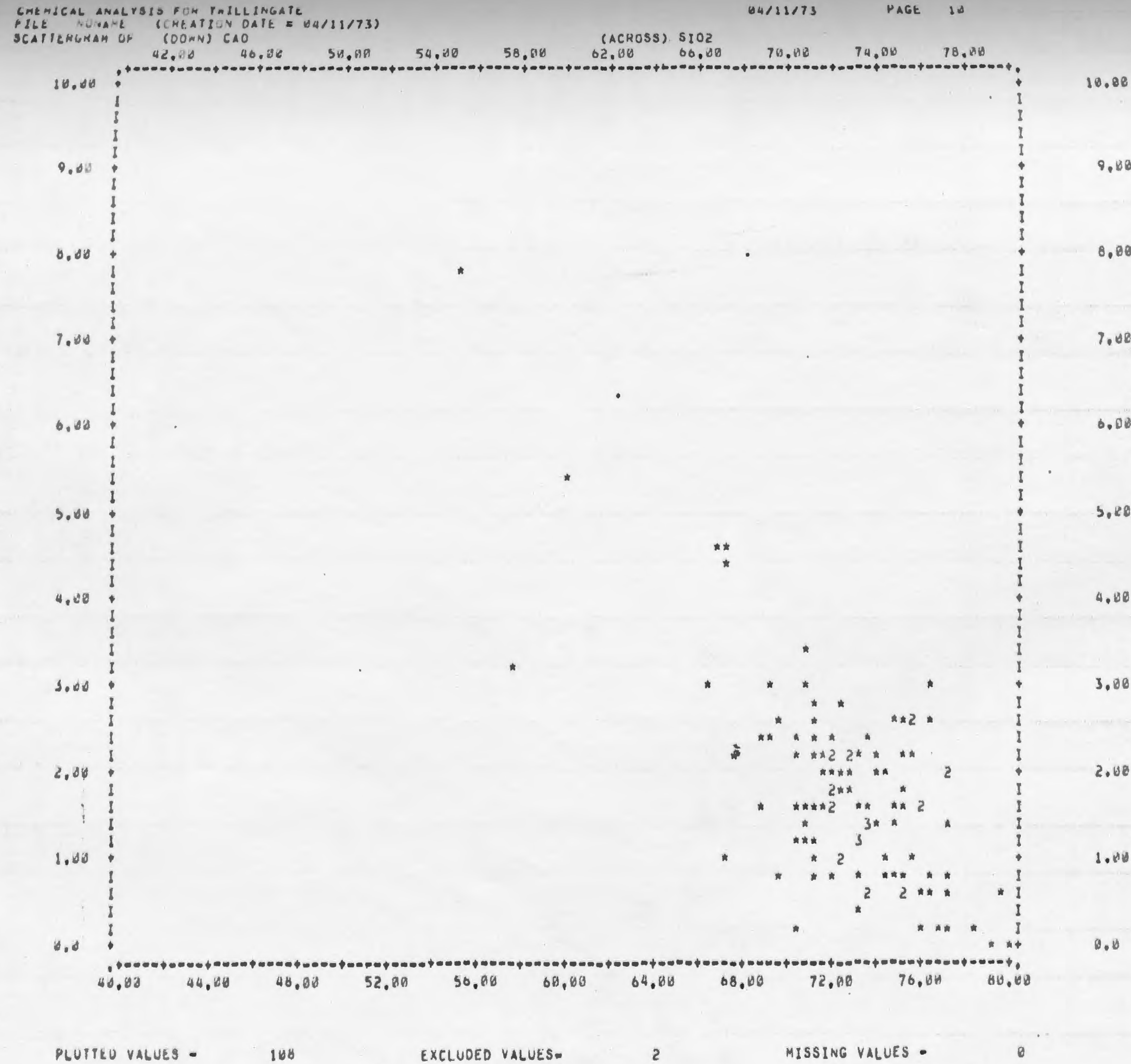
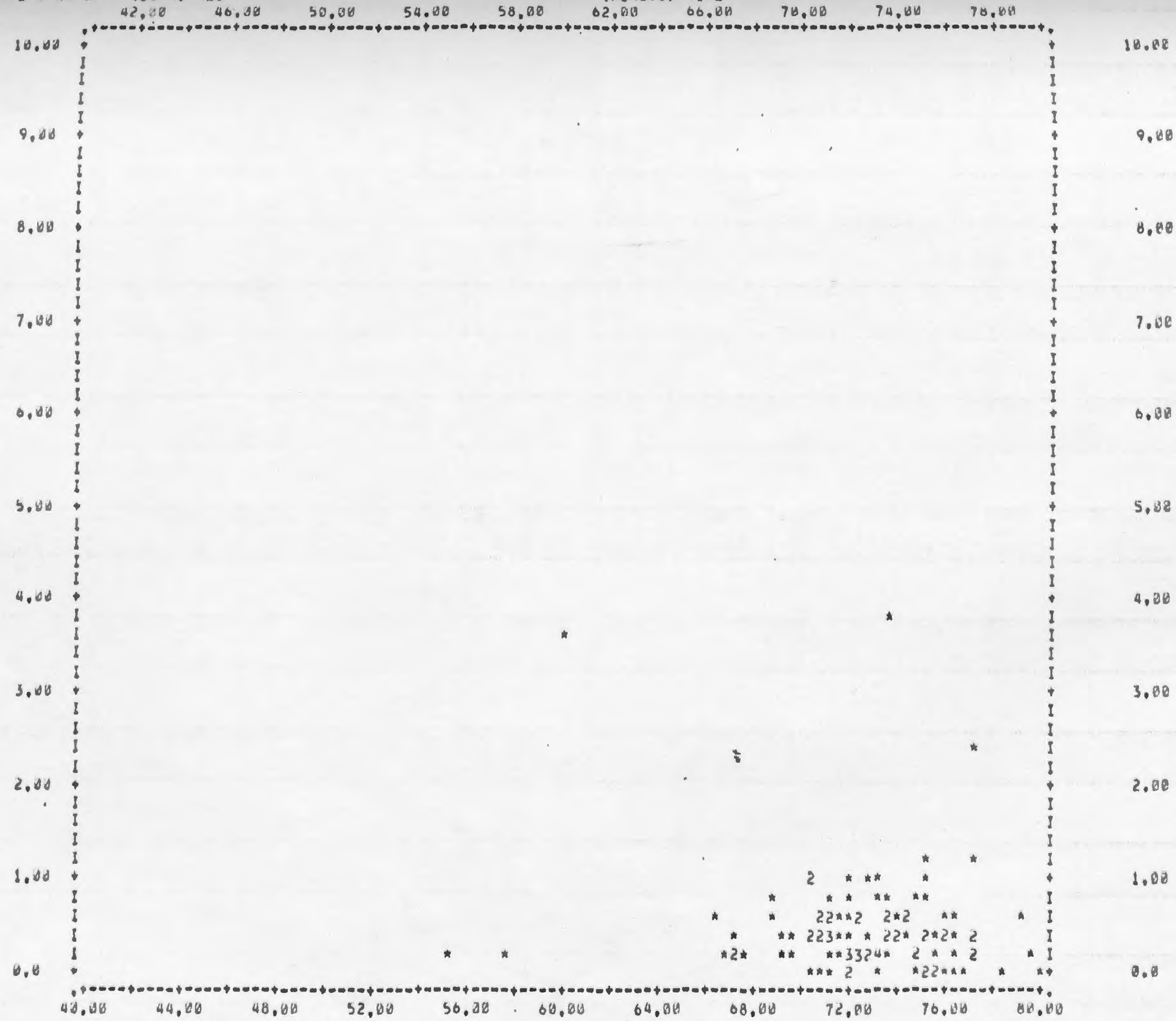


Figure 44a : Scatter diagram of CaO against SiO_2.

CHEMICAL ANALYSIS FOR THILLINGATE 04/11/73 PAGE 12
FILE NONAME (CREATION DATE = 04/11/73)
SCATTERGRAM OF (DOWN) K2O (ACROSS) SIO2



PLOTTED VALUES - 108 EXCLUDED VALUES- 2 MISSING VALUES - 0

Figure 44b : Scatter diagram of K_2O against SiO_2.

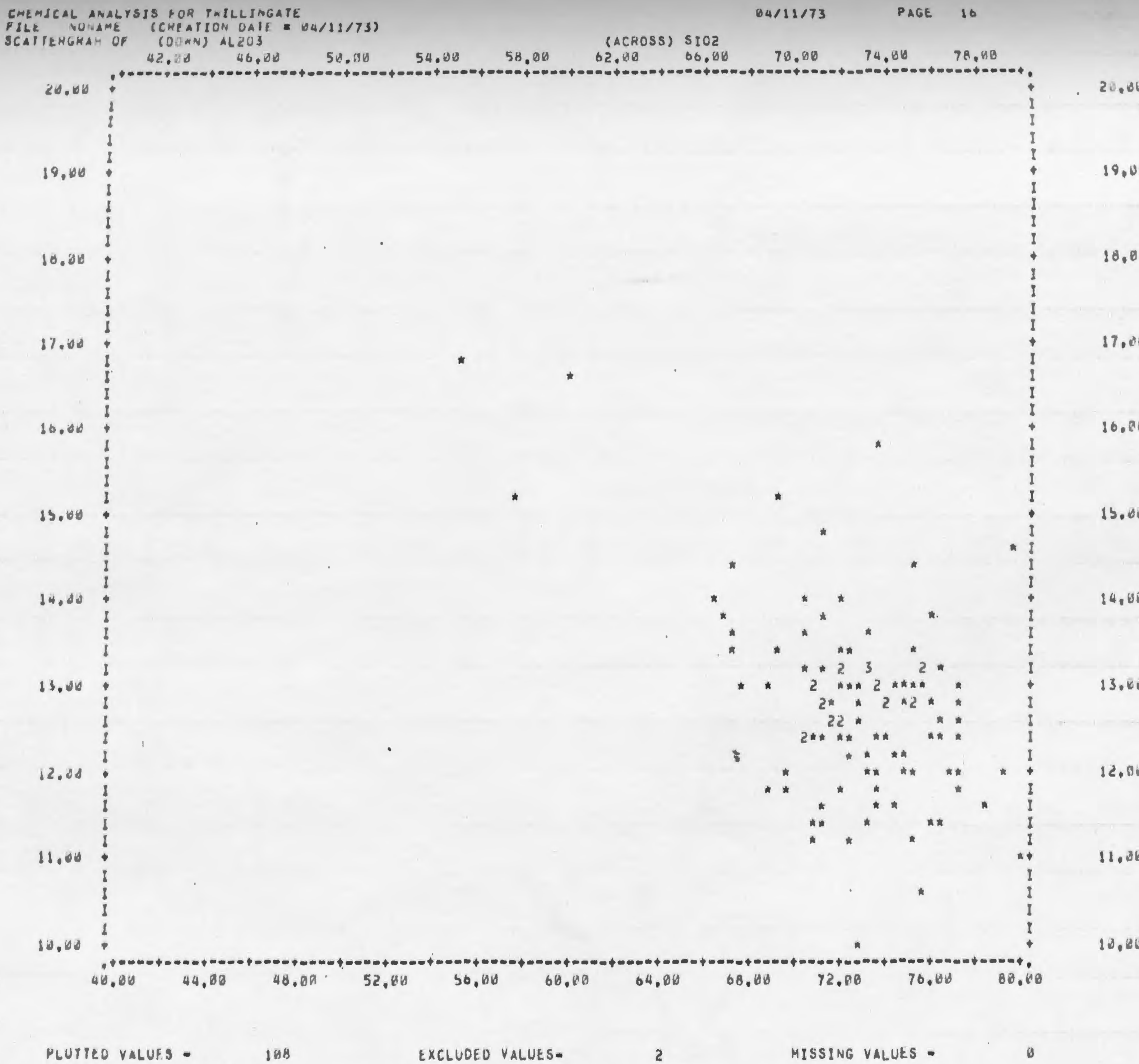
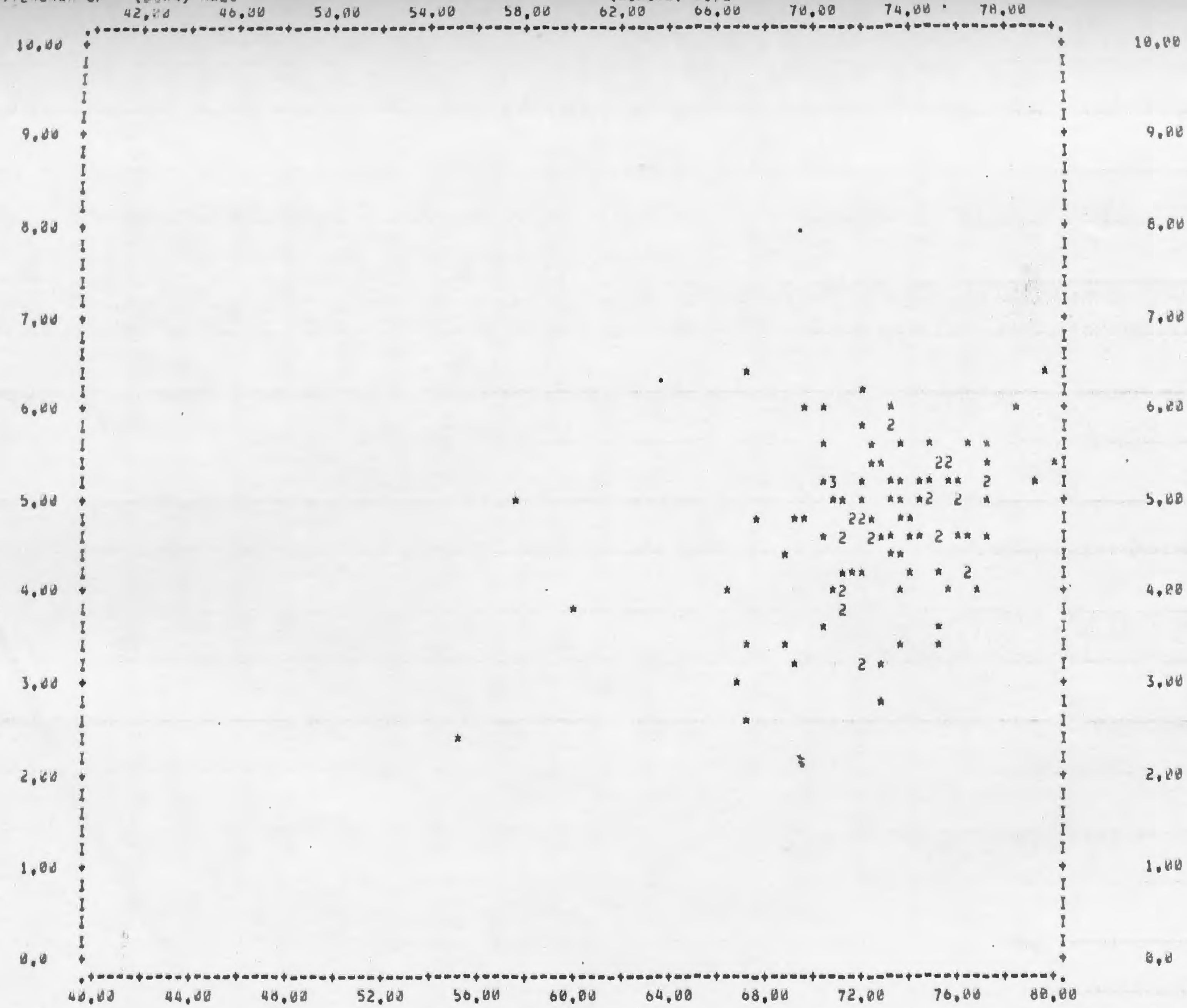


Figure 44c : Scatter diagram of Al_2O_3 against SiO_2.

CHEMICAL ANALYSIS FOR THILLINGATE 04/11/73 PAGE 20
FILE NUNAME (CREATION DATE = 04/11/73)
SCATTERGRAM OF (DOWN) NA2O (ACROSS) SIO2



PLOTTED VALUES - 108 EXCLUDED VALUES- 2 MISSING VALUES - 0

Figure 44d : Scatter diagram of Na_2O against SiO_2.

A-F line. The close grouping of results is again obvious except for the basic phases. The CNK diagram (Figure 45c) shows the widest spread reflecting the varying composition of the plagioclase feldspar.

4.2 Interpretation

4.2.1 Previous and current views on the origin of trondhjemites

Trondhjemites and sodic granites are not common rocks and have been the subject of many diverse interpretations. Goldschmidt (1922), cited in Gustavson (1969), suggested the possibility that sodic differentiates were produced by the fractional crystallization of basaltic magma. Battey (1956) and Kuno (1968) both stressed the importance of water in the development of soda-dominant acid rocks. Battey suggested this process was in the post-magmatic stage, as albitization of feldspars was thought to be due to a redistribution of alkalies during the subsequent burial of rhyolites. Kuno thought the enrichment of water may occur in connection with the assimilation of granitic or siliceous sedimentary rocks by basalt magma, or even independently. Foslie (1922) considered amphibolites, serpentinites, trondhjemites and granites from Norway as comagmatic and formed by differentiation due to differential squeezing during crystallization. Oftedahl (1959), cited in Gustavson (1969), stated that the extreme soda dominance of keratophyres was not magmatic in origin but more likely metasomatic resulting from the action of sea water on rhyolitic ashes or the passage of granitic magma through wet geosynclinal sediments. Barth (1962) suggested the formation of trondhjemitic magmas by the melting of greywackes during metamorphism and deep burial, assuming anatexis rather than fractional crystallization.

Recent papers (e.g. Coleman, 1971) stressed the relationship of small pods of trondhjemite to ophiolite suites and suggested they are the

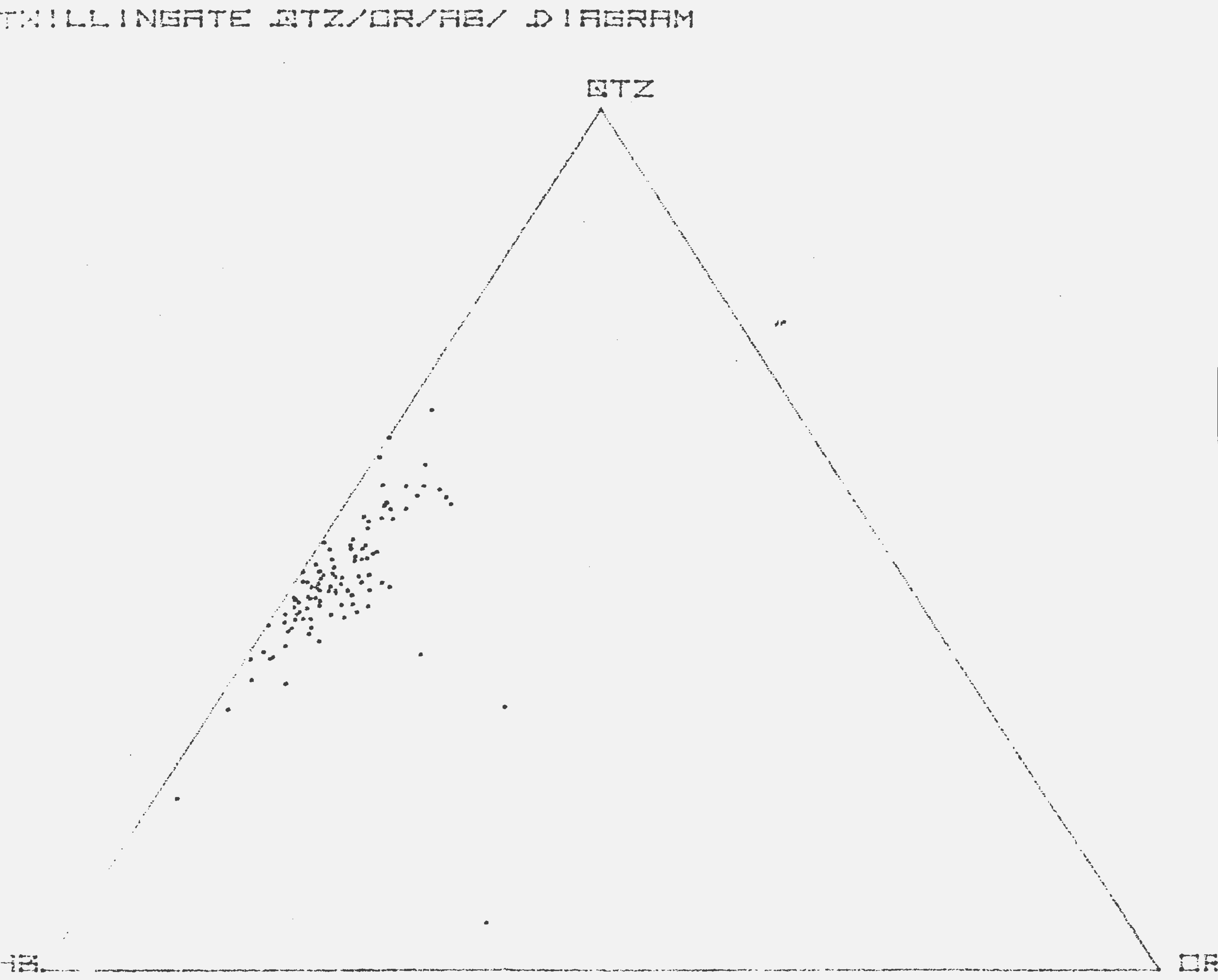


Figure 45a : Qtz-Or-Ab normative diagram (weight %) for the Twillingate Granite.

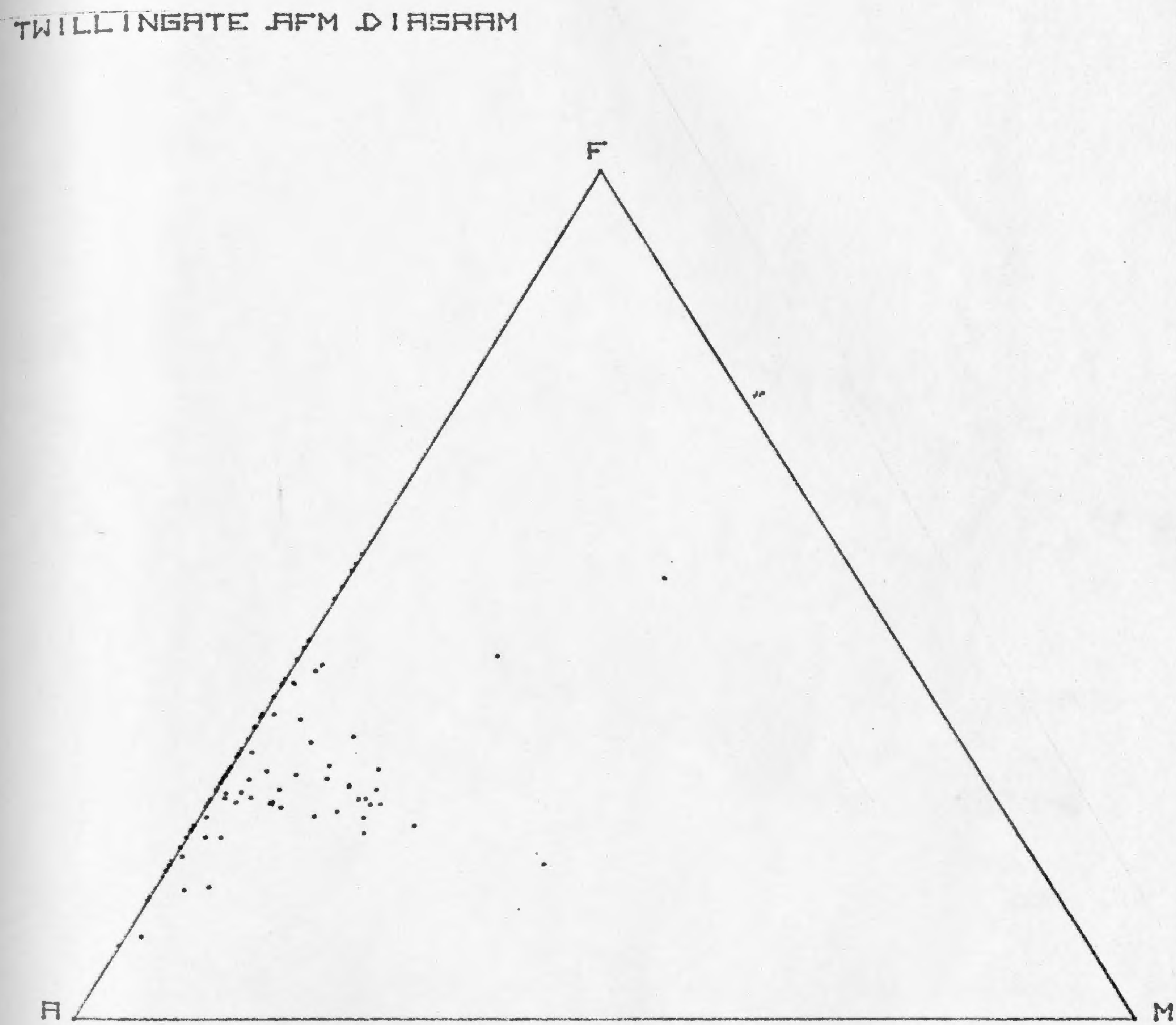


Figure 45b : AFM diagram (weight %) for the Twillingate Granite.

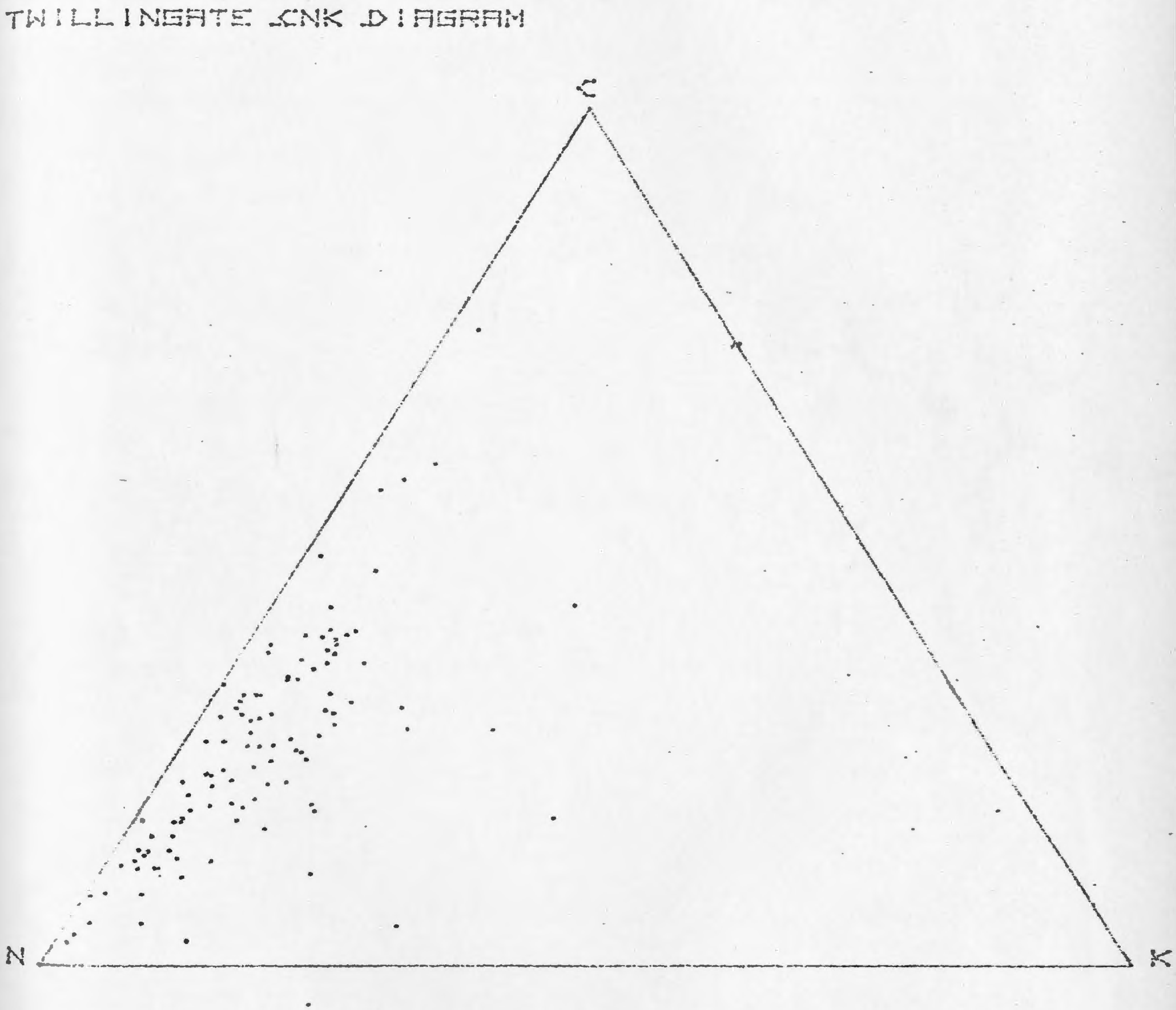


Figure 45c : CNK diagram (weight %) for the Twillingate Granite.

residue of the fractional crystallization of basaltic magma. Trondhjemites are commonly compared to the Norwegian examples which are small bodies probably associated with old ophiolites (Gustavsen, 1969). However, Glikson (1972) suggested that large bodies of sodic granite and trondhjemite intrude primitive Archaen ocean crust at an early stage followed by later stage potassic granite. He proposed a model involving a primordial crust of stratiform, oceanic-type ultra-basic and basic assemblages that were subjected to 'mega-rippling' producing linear zones of subsidence. Below these troughs partial melting of eclogite under wet conditions at about 100-150 km, or of amphibolites at around 30 km, took place to produce sodic granites. Basic xenoliths in many of the sodic granites also point to an origin of the melts below the basic crust. The sodic granites were thought to represent large volumes of little differentiated, low volatile, acid melts diapirically emplaced under a steep geothermal gradient.

Hotz (1971) suggested that the trondhjemites in the Sierra Nevada arose from an eastward dipping subduction zone. There the batholiths farther to the east are more potassic and this agrees with similar models proposed by Dickinson (1970), Bateman and Dodge (1970), and Strong et al. (1973). Fractional separation of plagioclase under crustal conditions could subsequently lead to this K enrichment. Late kinematic K granites also may have been derived through anatexis of earlier sodic granites (Glikson and Sheraton, 1972).

In summary, four main processes have been proposed for the origin of trondhjemites: (1) fractional crystallization of basaltic magma, (2) metasomatic introduction of Na, usually by water, (3) anatexis of sediments during burial and metamorphism, and (4) partial melting of eclogite or amphibolite. In attempting to outline the possible origin of the Twillingate Granite it is necessary to evaluate the characteristics of the geochemical data, plus their relationship to experimental work and the general geological setting, in terms of the above processes.

4.2.2 Trace elements in the Twillingate Granite

The depletion in the trace element content of the Twillingate Granite is a striking feature which is useful in generalizing about the origin of the pluton. For example, the trace element abundances show little indication of a sedimentary parent or metasomatic origin (Taylor, 1965), leaving the two other alternatives, crystal fractionation or partial melting.

If crystal fractionation is the dominant mechanism there should be a trend from basic to residual acidic rocks but there is no evidence for this in the area (see comments below on Yoder, 1973). This process would also tend to produce a segregation of trace elements, possibly on a large scale, and again there is no evidence of this.

The Twillingate Granite could not be an early fractionation product because they are basic in composition and enriched in trace elements such as Zr, V, Cr, Cu, Ni and Zn which are associated with Mg and Fe, and the granite is acidic and depleted in all these elements. The granite is also not a late fraction because of the lack of enrichment in some trace elements (Taylor, 1965). For example, in late fractions Rb is usually around 550 ppm with a K/Rb ratio of less than 100, the same values for the Twillingate Granite are 18 ppm and 268 respectively. The evidence, therefore, indicates the alternative origin of partial melting. Furthermore, Glikson and Sheraton (1972) suggest that high Ba/Rb and K/Rb ratios, such as those in the Twillingate Granite, indicate little or no fractional crystallization of sodic melts.

The low water content and lack of hydrous minerals such as amphibole and biotite show that the Twillingate Granite was a dry magma. This is supported by the absence of pegmatites and features resulting from hydrothermal activity. If crystal fractionation of a dry magma is proposed, pegmatites may not separate out but then the trace elements would be enriched and dispersed throughout the whole rock. The evidence in the Twillingate Granite is opposed to this and again points to an alternative mechanism such as partial melting.

4.2.3 Major elements in the Twillingate Granite

The major element chemistry of the Twillingate Granite was plotted into the "granite system" (Tuttle and Bowen, 1958; Luth, 1969; Luth et al., 1964; Luth and Tuttle, 1969) to try to determine the temperature and pressure conditions of its formation (Figure 46). The data show a distinct grouping almost on the qtz-ab line with their centre about $qtz_{45}:ab_{55}$ and a range from qtz_{60} to qtz_{40}, with an orthoclase content around 1-5. For granites of this composition the cotectic line at P_{H_2O} = 0.5 kb falls in the centre of the spread and the P_{H_2O} = 1 kb line is immediately below this. Temperatures are around 800-850°C.

This does not adequately encompass the overall range in data especially those above the 0.5 kb cotectic line. As quartz is a primary crystallization product this indicates pressures greater than 0.5 kb. A possible answer to these inconsistencies lies in the work of von Platten (1965), cited in Krauskopf (1967), who investigated the effects of adding small amounts of calcium to the granite system. Three main points arose from this work. First, the range of compositions in which feldspar is the first mineral to crystallize expands at the expense of

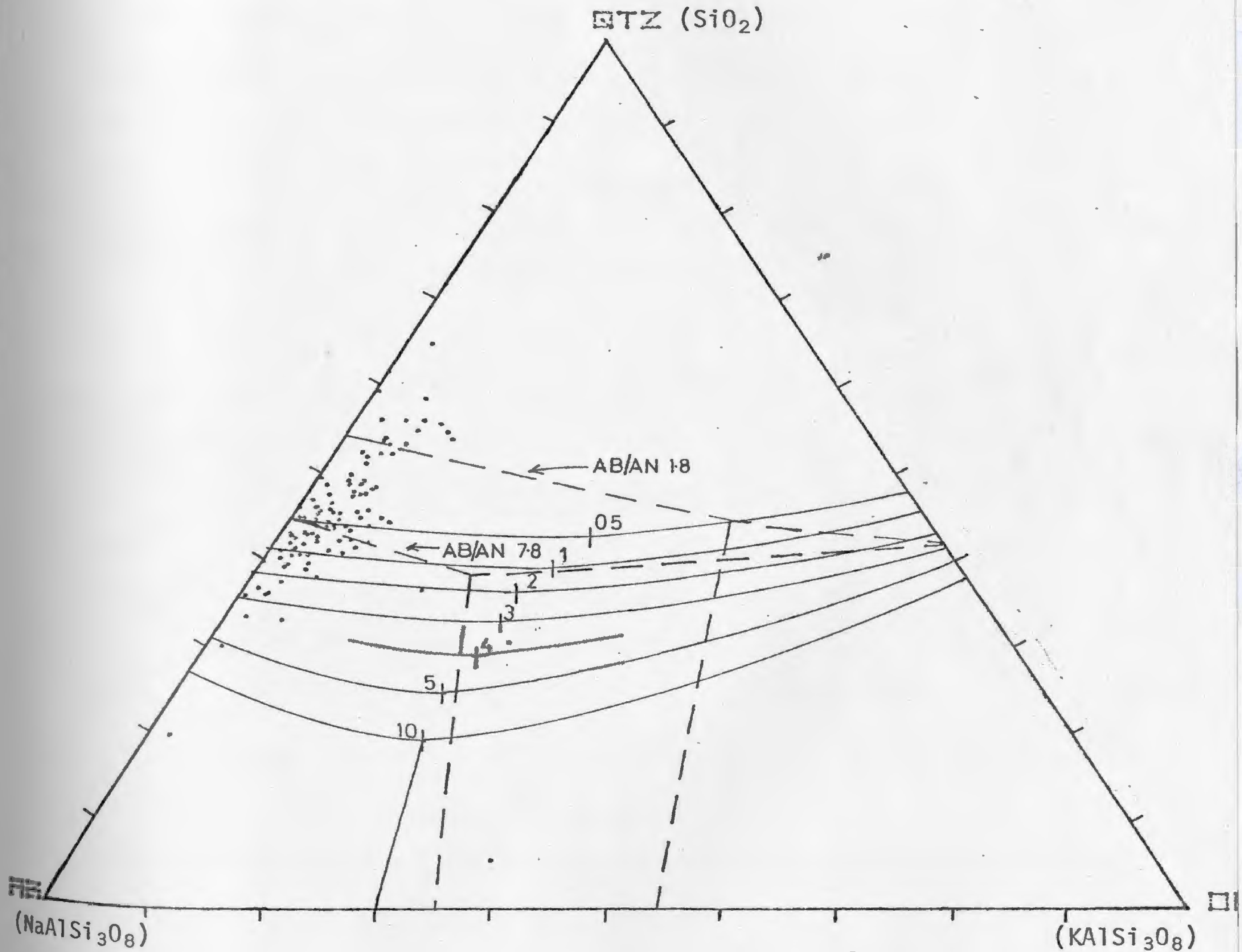


Figure 46 : Phase diagram for the granite system (SiO_2 - $NaAlSi_3O_8$ - $KAlSi_3O_8$) showing the position (solid lines) of the isobaric minimum at P_{H_2O} 0.5 - 3 kb and the "ternary eutectic" at P_{H_2O} 4 - 10 kb (Tuttle and Bowen, 1958). Dots are the values for the Twillingate Granite (weight %). Dashed lines show different quartz-feldspar boundaries for various Ab/An ratios at P_{H_2O} = 2 kb. The Ab/An = ∞ is the same as the 2 kb isobaric minimum line (Von Platten, 1965).

quartz. Second, the single feldspar field is split into two parts, one with the initial crystallization of plagioclase, and the other with the initial crystallization of orthoclase. Third, as the proportion of anorthite in the melt becomes larger there is a shift in the eutectic to increasing silica and potash feldspar. Therefore, with more Ca in the melt plagioclase crystallizes over a wide range of compositions. The ultimate residual liquid becomes rich in the constituents of quartz and orthoclase. As the Twillingate values range between Ab/An ratios of greater than 1.8 to around 7.8, for a pressure of 2 kb (Figure 46), it must be assumed that the Ca content varied slightly in the initial melt. This could be accompanied by small fluctuations in temperature and pressure.

It is also possible to consider the Twillingate Granite in the binary system silica - albite as the data are concentrated to one side of the qtz-ab-or triangle. In this system (Tuttle and Bowen, 1958, Figure 20, p. 52) at the $Si_{40}:Ab_{60}$ end of the range of Twillingate values, there is a eutectic point at approximately P_{H_2O} = 1 kb at just over 800°C. At the $Si_{40}:Ab_{60}$ end for the same pressure the temperature is around 950°C.

The evidence from both systems indicates that the melting relations of the Twillingate Granite reflect low pressures about P_{H_2O} = 2 kb or less at around 850°C with varying amounts of anorthite. One other variable could be P_{H_2O} which might not be equal to total pressure as there is evidence above showing the granite is undersaturated with respect to water. Either crystal fractionation or partial melting could achieve these conditions. If crystal fractionation is assumed any primary magma must have been very sodic (which is unlikely) and crystallized albite and quartz which would have to be removed before the liquid moved towards the granite eutectic. Albite cumulates and physical evidence of banding would also be expected. Neither of these are found in the Twillingate Granite; conversely the homogeneity of the mineralogy and chemistry is more favourable to a partial melting process.

Partial melting could happen in two ways. In the "granite system" with a little potassium the initial melt would be at the granite eutectic. Subsequent melts would follow the cotectic line and eventually depart from it as temperatures became higher. The last liquid produced would be an advanced stage of melting rich in albite and quartz (Figure 47a).

In the silica-albite binary system there would be no potassium so an albite and quartz rich liquid would represent an initial melt at the eutectic point. As the temperature increases the range of Si:Ab in the Twillingate Granite would be covered at P_{H_2O} = 1 kb (Figure 47b).

4.2.4 Petrogenesis of the Twillingate Granite

Bowen (1928), Yoder and Tilley (1962), Green and Ringwood (1968), and Brown and Fyfe (1970) suggest that partial melting of amphibolites (and eclogites) can produce fractions in the granite family. The least differentiated acid liquids arising from low degrees of melting of hydrated amphibolite or eclogite are typically sodic. Fractional melting of wet peridotite is also possible, but less likely as only small volumes of granite could be produced in this way. In addition the granite-H_2O solidus and the minimum melting curve of the qtz-or-ab system also fall in the amphibolite facies conditions of metamorphism (Figure 48).

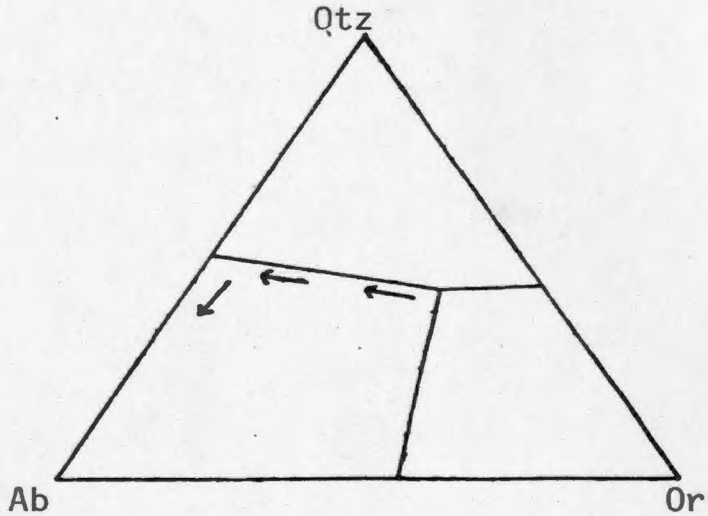


Figure 47a : Advanced melt, sodic parental material with some K_2O.

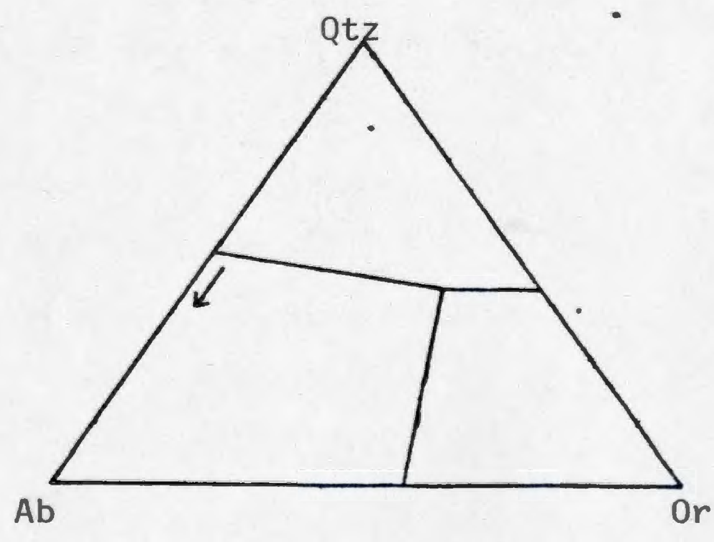


Figure 47b : Initial Melt, very sodic parental material with no K_2O.

There are two possible regions to produce the partial melting of amphibolites: (i) at the temperature and pressure of the Twillingate Granite equilibrium established above, i.e. around crustal levels, (ii) at much higher temperatures and pressures and therefore presumably deeper levels.

The Twillingate Granite's minimum melting conditions (see above) are about P_{H_2O} = 2 kb at around 800°C. To melt amphibolite at this pressure a slightly higher temperature of around 900°C (Figure 49) is needed to satisfy hypothesis(i) above. However, the crust at these relatively shallow levels does not have temperatures in the range of 900°C (Toksöz et al., 1971). Also as the conditions are only just above those of amphibolite melting it is questionable if a large enough granite melt would be produced to account for the size of Twillingate.

The second hypothesis is more practical. If a slab of lithosphere (which would comprise mainly amphibolite and basalt) was on a descending plate the required temperature and pressure conditions for partial melting would be easily attained. If the descent was slow the depth required may not be exceptionally great, possibly 50 km according to Toksöz et al., (1971, Figure 9, p 1126), Stern and Wyllie (1973) have shown that granite liquids depart from a eutectic composition at depths greater than 40-50 km. This tends to put a lower limit of depth on the production of granite. They further suggest that crystal-liquid equilibria are not likely to yield a primary granite magma by partial fusion of ocean crust in subduction zones. However, Twillingate is not a true granite composition and other factors may be important, such as the degree of water-saturation and differences between water pressure and total pressure (as mentioned above). For comparison Larsen and Poldervaart (1961) suggest the partial melting of basalt at 30-40 km around 900°C produced the trondhjemitic Bald Rock Batholith.

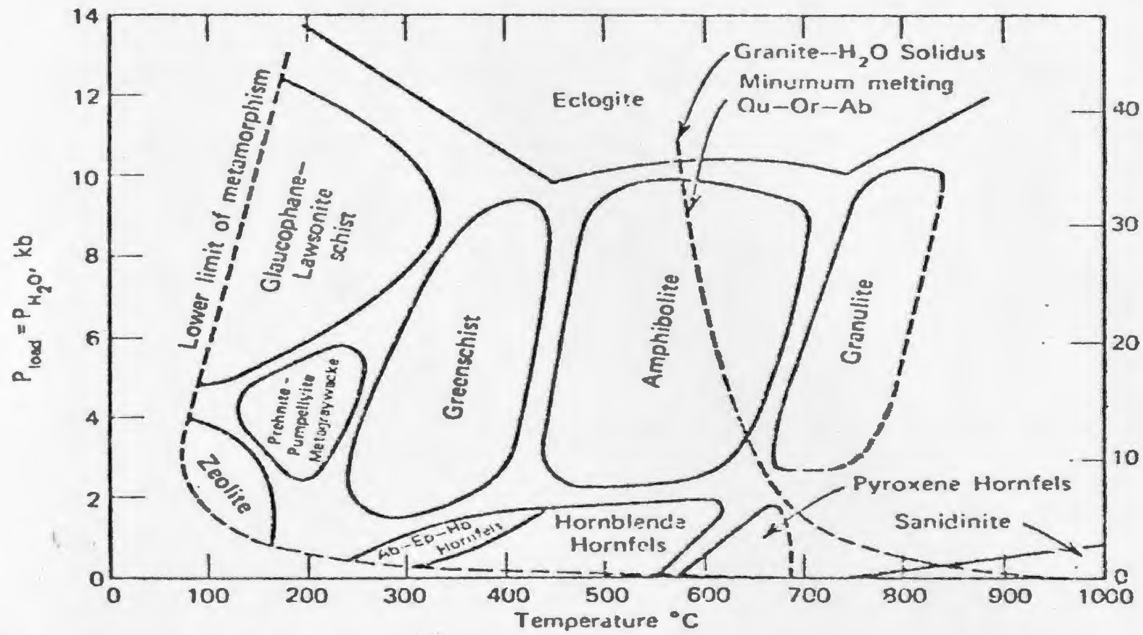


Figure 48 : "Tentative scheme of metamorphic facies in relation to total pressure (assumed equal to P_{H_2O}) and temperature; all boundaries are gradational (after Turner, 1968)." (From Wyllie, 1971, Figure 9.9, p. 230).

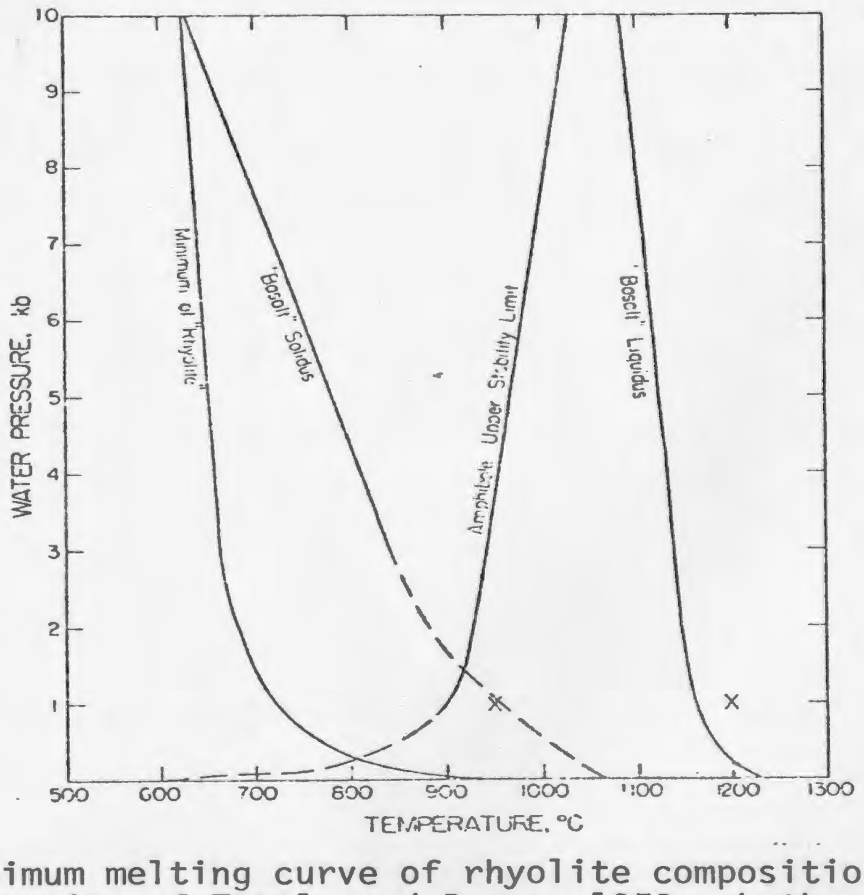


Figure 49 : "Minimum melting curve of rhyolite composition (= granite of Tuttle and Bowen, 1958; Luth et al. 1964) and the liquidus, solidus and upper stability curve of amphibole for the olivine tholeiite composition (Yoder and Tilley, 1962) in the presence of excess H_2O." (From Yoder, 1973, Figure 6, p. 157).

At these greater pressures the higher aluminous-magnesian-calcic amphiboles are more stable than their Fe^{2+} analogues (Ernst, 1968). This could account for the low Al_2O_3 values in the Twillingate Granite particularly as amphiboles show great flexibility of ionic replacement especially Si for Al. This would also mean an enrichment in silica, another characteristic of the Twillingate Granite. Furthermore, the amphiboles would be enriched in Na which would go into early melts leaving K until later ones.

This origin for the Twillingate Granite is further supported by the chemistry of the country rocks around the pluton which may have been derived from a similar source. The results quoted here (Table 6) are from Coish (1973) who analysed the volcanic rocks from Trump Island at the southwest corner of the Twillingate pluton. These rocks are part of the Sleepy Cover Group and they are cut by the granite. The bulk of the geochemical evidence (Table 7) shows that they are island arc tholeiites (Jakes and Smith, 1970; Jakes and White, 1970 and 1972), now metamorphosed to greenschist and amphibolite facies. The chemistry of the pluton with high Na/K values and moderate Ca/Al values bears strong similarities to Coish's analyses. Glikson and Sheraton (1972) suggest that similar values in Archaen terranes reflect original mantle concentrations and not fractional crystallization.

This hypothesis is additionally supported by Yoder (1973) who showed that fractional melting can produce two magmas of highly contrasting compositions with no intermediate rocks (the Daly Gap) from the same parental material). If the hydrous minerals are retained in the parental material the two magmas will be andesite and rhyolite.

Table 6. Major and trace element analyses for mafic and volcanic rocks from Trump Island (Coish, 1973)

	Pillow Lavas-----			Diabase Dikes-----------				Amphibolite Dikes		Amphibolite Metasediments	
Major Oxide	766	513	526	537	546	737	762	734	536	745	744
SiO_2	50.60	48.40	50.42	50.31	48.99	50.21	49.21	57.02	56.47	51.45	49.26
TiO_2	0.71	0.33	0.31	0.93	1.14	1.14	0.84	0.14	1.21	0.61	1.32
Al_2O_3	15.42	12.84	15.22	15.46	15.78	17.33	18.56	16.34	14.87	13.25	13.96
*Fe	10.73	8.89	9.16	11.88	10.39	10.60	9.25	8.35	12.51	9.04	13.55
MnO	0.26	0.14	0.20	0.22	0.19	0.19	0.15	0.17	0.24	0.14	0.30
MgO	8.92	6.34	11.99	7.19	9.42	7.46	6.59	5.61	3.73	9.04	6.81
CaO	9.11	17.76	9.32	9.74	10.25	10.29	11.45	6.58	5.54	12.07	11.41
Na_2O	3.91	4.67	3.07	2.40	2.52	2.23	2.73	3.81	4.89	3.48	3.17
K_2O	0.34	0.64	0.32	1.88	1.06	0.43	1.12	1.73	0.47	0.93	0.23
P_2O_5	N.D.	Trace	N.D.	Trace	0.27	0.21	0.31	N.D.	0.08	N.D.	Trace
Trace Element	766	513	526	537	546	737	762	734	536	745	744
Rb	11	21	15	46	38	19	18	31	21	---	14
Cu	14	46	---	61	50	274	35	77	55	---	2
Sr	187	166	186	217	248	---	151	197	129	---	201
Ba	561	520	464	348	285	114	580	639	115	---	---
Zn	81	77	83	82	77	---	52	76	96	---	99
Zr	37	56	48	64	123	---	71	57	70	---	81
Cr	41	454	53	108	253	---	39	64	64	---	57
Ni	123	273	236	61	165	---	45	63	18	---	61
Rb/Sr	.06	0.11	0.08	0.21	0.15	---	0.12	0.16	0.16	---	0.07
K/Rb	260	240	185	330	220	140	500	450	190	---	130
Ba/Rb	51	25	31	7.6	7.5	---	32	21	5.5	---	---
Ba/Sr	3.0	2.8	2.5	1.6	1.1	---	3.8	3.2	0.9	---	---

*Total Fe as Fe_2O_3.

Table 7. Comparison of Trump Island mafic rocks with values from known basalt types (Coish, 1973).

	SAMPLE						
Major Oxide	1	2	3	4	5	6	7
SiO_2	51.57	50.59	49.34	50.3	49.80	49.65	49.5
TiO_2	.80	1.05	1.49	1.6	0.45	1.06	0.97
Al_2O_3	15.91	16.29	17.04	15.7	14.47	16.89	13.6
Fe	9.78	8.68	8.81	11.4	9.60	10.53	11.79
MnO	0.17	0.17	0.17	0.2	0.2	0.16	0.22
MgO	6.73	8.96	7.19	7.0	9.10	8.02	7.92
CaO	11.74	9.50	11.72	9.5	12.06	10.81	11.81
Na_2O	2.41	2.89	2.73	2.9	3.8	2.95	3.32
K_2O	0.44	1.07	.16	1.1	0.43	1.12	0.58
P_2O_5	.11	.21	.16	.3	-----	-----	-----

1. Island arc tholeiitic basalt, Lake Dakatra, Talesea, New Britain (Lowder and Carmichael, 1970).
2. High-alumina basalt, Cape Nelson, East Papua (Jakes and Smith, 1970).
3. Abyssal theleiite (Engel et al., 1965).
4. Average of 200 amphibolites computed by Poldervaart (1955).
5. Average values of pillow lavas from Trump Island.
6. Average values of basic dikes, Trump Island.
7. Average of amphibolite, Trump Island.

Trace Element*	Ocean Floor Basalts	Island Arc Andesites	Japan Arc Tholeiites	Alkali Basalts	Trump Island
Mean Ti ppm	7760	4050	6430	20300	5200
Mean Zr ppm	80	106	47	227	48

* (Pearce and Cann, 1971)

Figure 50 : Partial melting textures in amphibolites from around Sam Jeans Cove, Moretons Harbour.

If the H_2O of the parent is consumed in the first stage of fractional melting the products are rhyolite and tholeiite. The parental material is assumed to by hydrous and olivine rich, capable of producing quartz-normative liquids. This could be oceanic crust or its metamorphic equivalent.

This presents a hypothesis for the origin of the Twillingate Granite as it is surrounded by island arc tholeiites and mafic inclusions in it provide some evidence for the existence, at lower levels, of older ocean crust (see 2.2.4). Also possible partial melting textures are found in the amphibolites of the Moretons Harbour area nearby. Here small veins of granitic material that are not obviously intrusive appear to be melted out of amphibolites (Figure 50).

Contemporaneity of the magmatism is an integral part of Yoder's theory. He suggests the basalt liquid would have to be removed continuously but the rhyolitic liquid could depart in one batch. This again accords well with the evidence from Twillingate where a more or less continuous production of basic magma is inferred by the relationships of the volcanic rocks and dykes to the granite (see earlier chapters and Strong and Payne, 1973), and the granite is intruded at one time during this process.

In summary, all the evidence points strongly to the contemporaneous production of island arc tholeiites and the Twillingate Granite magma from the partial melting of oceanic lithosphere (amphibolites) along a subduction zone (Payne and Strong, in prep).

CHAPTER 5

THE SIGNIFICANCE OF TWILLINGATE GEOLOGY

To approach a regional problem is to tackle it from as many sides as possible. This has been applied here in trying to evaluate the relationships of the unusual Twillingate trondhjemitic Granite to the complex surrounding country rocks. The ultimate aim being to try to ascertain the origin and significance of the rocks and to produce a geological evolutionary history of the area in terms of the recent ideas of plate tectonics (Dewey and Bird, 1970; Bird and Isacks, 1972).

5.1 Previous regional interpretations

Several broad plate tectonic models have been produced to explain in very general terms the development of the Newfoundland Appalachians. All have referred verbally or visually to the thesis area as it lies in a very significant position. This is in the north of the Central Mobile Belt which is part of the threefold division of the island (Figure 2, p 4) made by Williams (1964). Each division is characterized by a different depositional and structural history in the early Palaeozoic (Williams, 1969). The thesis area lies in an axial region of Ordovician and Silurian sedimentary and volcanic rocks in this central division which is bounded by two stable platformal areas, the Western and Avalon Platform (Kay and Colbert, 1965; Kay 1967).

The models produced to date have all relied very heavily on this threefold division. Dewey (1969) published the first model to encompass the whole Appalachian-Caledonian orogen. He proposed to open a 'proto-Atlantic ocean' similar to Wilson's (1966) in the late Precambrian to early Cambrian producing the two stable platform areas and the incipient mobile belt of Williams. All succeeding models agree with this initial point but it is in the subsequent history and closing of this 'ocean' that they differ. Figuratively and literally the thesis area is in the middle of this controversy.

Dewey (1969) deals only with the west side of the system, a shortcoming common to many of the other models. He suggests that a continental shelf and rise sequence was deposited in the mid-Cambrian upon a Grenville basement. The Lushs Bight, neglecting mid-Ordovician fossil evidence, is given an Upper Cambrian age and is interpreted to lay to the east of the continental margin, though not specifically interpreted as oceanic crust. Around the Arenigian a westward dipping subduction zone leads to the formation of the Twillingate Granite which intrudes the Lushs Bight. The Dunnage mélange is interpreted as a molasse deposit not a trench one. Later on in the Llanvirnian and Caradocian the whole continental margin is deformed and metamorphosed and the West Newfoundland klippen (as far as they were understood then) were transported.

Bird and Dewey's (1970) model begins in the same way but the history is modified by the introduction of a grabensuture to account for the Baie Verte ophiolites. The ages of the units are hazy. The Lushs Bight is given a pre-Humerian age. A pluton, not specifically named, but in the right place for Twillingate, is shown to intrude already deformed Lushs Bight in the early Humerian. Other volcanic rocks in the same area appear in their figures to be obducted ocean floor structurally emplaced by the early Humberian but not shown being cut by the pluton. Some island arc activity was mentioned in the text but not shown on the diagrams. The Dunnage mélange was reinterpreted as a pre-early Humberian trench deposit on a westward dipping subduction zone. The model is completed in the late Humberian with the transport of klippen and the Bay of Islands complex is shown as an intrusion rather than ophiolitic oceanic crust and mantle.

The most recent Dewey and Bird (1971) model is quite similar to the 1970 version. The Lushs Bight is not named on the diagrams but it is stated elsewhere that there is good evidence for older ocean floor, such as the Little Bay Head Group. Presumably the Lushs Bight may be a slightly younger equivalent to the material that is obducted by the late Cambrian to the early Ordovician (see Dewey and Bird, 1971, Figure 11, d and e). The Dunnage mélange is interpreted as a trench deposit again. The Long Island pluton and a similar, unnamed body (suspiciously like Twillingate) to the east are intruded in a short space of time in the early mid-Ordovician as they are shown to be sub-aerial by the late mid-Ordovician. Some andesitic volcanic activity is shown to be about the same age. The Luke Arm Fault is interpreted to be active before the late mid-Ordovician. The model finishes with transport of klippen during the early to late mid-Ordovician. The Bay of Islands complex is now interpreted as ophiolitic being derived from a small ocean basin west of the main subduction zone. This avoids having to transport it the larger distance from the main ocean and across the already deformed Fleur de Lys terrane.

Similar models but focussed more on the eastern Notre Dame Bay area have been proposed. Horne (1970, Figure 11, p 1782) modifies his model from Dewey (1969). He suggested the development of an island arc in the New World Island area in the late Cambrian to early Ordovician as the result of a westward dipping subduction zone. Again the unnamed (presumably Twillingate) pluton intrudes in the early Ordovician. Deformation was apparently contemporaneous and associated with the under-thrusting of an oceanic plate.

Kay (1972) suggests that the Dunnage mélange marks an oceanic trench above a northwest dipping subduction zone that evolved in the Cambrian. The subduction zone had an associated island arc which was intruded by the Twillingate pluton between the Llandeillian and the Caradocian. The major deformation is thought to be early Ordovician.

A differing viewpoint has been put forward by Church and Stevens (1971) and Strong et al. (in press). They contend that any subduction zone in Notre Dame Bay was eastward dipping. Church and Stevens cite indirect stratigraphic and structural evidence; Strong et al. use geochemical evidence and point out an increasing K_2O content in the granite rocks eastward across the Gander Lake belt.

More recently it has been suggested that the whole Twillingate block might represent an older crustal area, either a 'quasi-ophiolite' (oceanic) or even a continental remnant (Williams and Malpas, 1972; Williams, Malpas and Comeau, 1972; Williams, Kennedy and Neale, 1973; Williams, Kennedy and Neale, in press). This was proposed mainly because of strong analogies in relationships and deformational style within the transported Little Port Complex in the Bay of Islands area of western Newfoundland compared to the Twillingate area in central Newfoundland. In the Little Port Complex a sodic granite of similar petrology and chemistry to the Twillingate Granite (J.G. Payne, unpub. results) cuts amphibolites and both are locally well foliated. The granite and amphib-olite are cut post-tectonically by poorly developed sheeted dykes which grade into relatively undeformed mafic volcanics. These dykes and volcanics of the Little Port Complex are considered to be the same as those in the main transported ophiolite sequences in the Bay of Islands Complex. As mafic dykes like those of the Bay of Islands Complex cut already deformed gabbros and granites of the Little Port Complex, then the granite and gabbro were interpreted as the older. Similar reasoning in the Twillingate area, where deformed granite is cut by mafic dykes on New World Island, led to the same conclusion.

An alternative interpretation of the Moretons Harbour - Twillingate area was proposed by Strong and Payne (1973). It is suggested that, although Twillingate Granite intrudes volcanic rocks of the Moretons Harbour Group at Trump Island and both are deformed and metamorphosed, it is not an older crustal remnant because the volcanic rocks become progressively less deformed and metamorphosed to the west and all are thought to be island arc tholeiites and part of the Lushs Bight Supergroup. In addition the 'conflicting' intrusive relationships between mafic and acidic rocks plus the range in mafic dykes cutting the Twillingate Granite from deformed to essentially undeformed "are taken as evidence that mafic and felsic magmatism continued during and after deformation and metamorphism."

5.2 Present evidence and interpretations

To propose any model for the Twillingate area the following points arising out of this study must be included.

Relationships

The Twillingate Granite pre-tectonically intrudes the Sleepy Cove Group and both are cut by pre- and syn-tectonic mafic dykes and by later post-tectonic mafic dykes belonging to the Herring Neck Group. This is in general agreement with all the Dewey models, Horne (1970) and Kay (1972), though some details, such as the pre-, syn- and post-tectonic dykes are omitted. It also concurs with the older crustal remnant theories except that in the Twillingate area the granite cuts both amphibolites and fresher, less deformed volcanic rocks all belonging to the Sleepy Cove Group, whereas at Little Port only amphibolites are intruded and there are no pre- and syn-tectonic dykes cutting the granite. Both areas have post-tectonic dykes with associated less deformed volcanic rocks.

Lithology

The Sleepy Cove Group is comprised of island arc tholeiites which are lithologically and petrographically similar to the Herring Neck Group.

The best correlation to date of both the Sleepy Cove Group and the Herring Neck Group is with the Lushs Bight Supergroup (Strong and Payne, 1973). This is because of their lithological similarity to and continuity with Lushs Bight rocks elsewhere in Notre Dame Bay (Strong, 1972; Smitheringale, 1972; Strong and Payne, 1973).

Previous models show disagreement and contradiction over the age and interpretation of the Lushs Bight rocks. There is great difficulty experienced in separating the volcanic units in the field. One looks very like another and those associated with oceanic environments have essentially lateral time divisions, juxtaposing older rocks with younger ones.

Dewey (1969) suggested an Upper Cambrian age for the Lushs Bight Group but Bird and Dewey (1970) have a pre-Humberian age and hint at an ocean floor origin for the group. Dewey and Bird (1971) postulate an older ocean floor terrane (Little Bay Head Group) in Notre Dame Bay but the rocks referred to the Lushs Bight Group are inferred to be younger than this. Horne and Helwig (1969) suggest that there are Ordovician volcanic rocks both north and south of the Luke Arm Fault zone, based on the lithological similarity of interbedded sedimentary rocks in the volcanic sequence on either side of the fault. Horne (1970) cites sparse fossil evidence from the Lushs Bight Group in western Notre Dame Bay suggesting that these volcanic rocks are, at least in part, contemporaneous with Lower Ordovician ones to the south. An island arc was proposed by Horne (1970) and Kay (1972) and both suggest a late Cambrian to early Ordovician age for it. As a whole the Lushs Bight Supergroup could not be younger than mid-Ordovician because of evidence from the transported klippen on the west coast of Newfoundland. A lower age limit is much harder to define but it could be in the early Cambrian.

Consequently the Lushs Bight Supergroup as presently understood in Notre Dame Bay probably spans a long period of time and includes many igneous and volcanic rocks of different origins (ophiolite and island arc), ages, and deformational and metamorphic histories that are as yet undifferentiated, except in theory. So the inclusion of the lithologically similar but structurally separate Sleepy Cove and Herring Neck Groups in the Lushs Bight Supergroup is not at variance with present knowledge and definitions.

The Sleepy Cove Group and the Herring Neck Group are separated in time by the intrusion of the Twillingate Granite and the deformation of it and the Sleepy Cove Group. Thus there is evidence for relatively older and younger volcanic rocks in the area. The difference in age between the two is open to debate as the rocks are undated.

A substantial time gap between the two groups could be inferred, as with the Little Port Complex, based on the difference in deformation between the two groups and their relationships to the Twillingate Granite. Also there is some evidence for older deformed and younger less deformed volcanic sequences in Notre Dame Bay (e.g. Dewey and Bird, 1971).

A short time interval can also be inferred as the Sleepy Cove Group and the Herring Neck Group are lithologically and petrologically similar and may be integral parts of a more or less continuous volcanic sequence. This sequence is linked together by a continual intrusion of consanguinous mafic dykes. The pre- and syn-tectonic mafic dykes are similar to the Sleepy Cove Group, the post-tectonic dykes are part of the Herring Neck Group and both types of dykes resemble each other and have an intrusive relationship to the Twillingate Granite. Thus all the mafic dykes could be related and be part of the same general period of magmatism. Similarly the granite and volcanic rocks are part of this period. All the lithologies are associated in an island arc environment and Mitchell and Reading (1971) suggest island arcs evolve over a fairly short time span.

This is not to suggest a completely continuous evolution of the Twillingate area with acid and mafic magmatism occurring in an uninterrupted sequence. A more continual evolution is proposed over a short period of time (possibly only a few tens of millions of years) encompassing frequent mafic magmatism and the production of the Twillingate Granite.

As the rocks in the Twillingate area are not satisfactorily dated no definite conclusions can be stated to the above possibilities. The only age date at present that bears upon the age of the volcanic rocks and the Twillingate Granite is 515 million years on amphiboles from the Little Port Complex (Archibald, pers. comm.). If comparisons are in order this implies a similar age for similar rocks in the Twillingate area. Much depends on a reliable date from the Twillingate Granite. However, the bulk of the previous work and interpretations, combined with circumstantial evidence from the area, suggests that the two volcanic groups (and therefore the Twillingate Granite) are all closely related, evolved in an island arc covering a relatively short time span and have a late Cambrian to early Ordovician age, though there remains a possibility that one or both groups and the Twillingate Granite could be much older.

Structure

The structure of the area is not as complex as previously suggested (Williams and Malpas, 1972) and only one main deformational episode is indicated, pre- and post-dated by apparently minor events. The intensely developed fabric in the amphibolites and granite of the Little Port Complex compared with the volcanic rocks was one fact which led to the suggestion that the deformed part of the complex was older crustal material. If most of the Twillingate area was a complex, multi-deformed terrane an old age would be a distinct possibility. However the single fabric is only strongly developed in places in the Sleepy Cove Group and the Twillingate Granite, in contrast relatively undeformed pillow lavas at Sleepy Cove are almost indistinguishable from pillow lavas in the Herring Neck Group. Thus although the deformation in the Twillingate area separates relatively older, deformed rocks from relatively younger, undeformed rocks, both are considered to be part of the same sequence: absolute time divisions cannot be made. The volcanic rocks are interpreted as being possibly late Cambrian or early Ordovician, the main deformation of the area was probably mid-Ordovician as proposed in many of the previous models.

This interpretation does not favour the hypothesis, based on evidence from the Little Port Complex, that a much older volcanic sequence and granite were deformed and overlain by a younger sequence of mafic volcanic rocks. However the strong similarity of the geology in the Twillingate and Little Port areas suggests they are to be correlated in some way. For instance, a transported slice resembling the New World Island section, and omitting some of the relationships seen elsewhere in the area, could have been preferentially moved. However the Twillingate area appears to be a very small source compared with the large size of some of the transported slices and the distance of transport is considerable, yet it is not unreasonable that a similar chain of events could have occurred farther west. There are many possibilities and their solutions await further investigation.

Chemistry

The trondhjemitic composition of the Twillingate Granite indicates that it is associated with an oceanic environment and not a continental one where such rocks are rare. The volcanic rocks are island arc tholeiites and this indicates a special environment of formation. The granite and the volcanic rocks are thought to be consanguinous and nearly coeval, both probably being produced by partial melting of oceanic lithosphere along a subduction zone (under an island arc) where a continuous production of basic magma is to be expected with some contemporaneous acid magma. This reasoning further suggests a temporal link between both volcanic groups and the Twillingate Granite.

5.3 Twillingate geology and its regional interpretation - a model

The evidence most reasonably points to the Twillingate Granite intruding a late Cambrian to early Ordovician island arc before the mid-Ordovician. All previous models gave an early Ordovician date for intrusion and a mid-Ordovician date for deformation. This is consistent with the evidence here and with the proposal that the intrusion was probably contemporaneous with the formation of an island arc. This most satisfactorily accounts for the cross-cutting relationships and the range of acid and basic magmatism. The short time span proposed for the evolution of this island arc is consistent with present knowledge: Mitchell and Reading (1971) suggest that a cycle of evolution could be as short as 20 million years. The island arc was probably underlain by older ocean crust and the two are now included in the Lushs Bight Supergroup.

The model proposed follows a sequence of events similar to those put forward for island arcs by Mitchell and Reading (1971). The following outlines its development and sequence of events as summarized in Figure 51.

1) A late Precambrian to early Cambrian opening of a 'proto-Atlantic' ocean. This formed the oldest of the Lushs Bight rocks.

2) Subsequent contraction and the formation of a subduction zone in the late Cambrian and early Ordovician. The older Lushs Bight is undergoing subduction while young Lushs Bight is still being produced. The older Lushs Bight rocks may be the early, locally deformed terrane (possibly the base of the Sleepy Cove Group) postulated from the deformed mafic inclusions in the Twillingate Granite.

The position of the subduction zone is speculative. It may be indicated by the Dunnage mélange which is interpreted as a trench deposit. A westward dip is generally favoured for the subduction zone though there are arguments for an eastward dipping one (see 5.1). A 'flip' of the subduction zone might explain both hypothesis but there are many possibilities, few geological constants, and all are highly speculative.

3) Activity along the subduction zone resulted in the build up of an island arc (Sleepy Cove Group) in the late Cambrian to early Ordovician on top of the older ocean floor. Mitchell and Reading (1971) suggest that most island arcs are developed on normal ocean crust.

4) This was followed closely by the intrusion of the consanguinous Twillingate trondhjemite Granite produced by partial melting of older mafic rocks on the zone of subduction.

5) Mafic magmatism continued as witnessed by the pre- and syn-tectonic mafic dykes cutting the pluton. At this stage the granite was probably still fairly hot, possibly in a 'crystal mush' state, so that it could fracture and allow the easier intrusion of dykes and at the same time respond to deformation.

6) Deformation began incrementally producing some earlier fabrics in the mafic dykes in situ in the pluton. The deformation became stronger developing the main fabric, possibly modified in places by the last of the

granite intrusion working in opposition to the regional stress regime. It also folded some pre-existing fabrics in mafic inclusions, and foliated the mafic dykes that were intruded pre- and syn-tectonically. Metamorphism probably accompanied all this on a regional scale, generally to greenschist facies but locally to amphibolite facies.

7) Mafic magmatism continued post-dating the deformation and leading to the production of additional island arc material (Herring Neck Group) which is probably at the top of the volcanic pile. The overall evidence from the Twillingate area indicates this later mafic magmatism was more or less continuous with the earlier episodes.

8) The development of a weak fabric in the Herring Neck Group (this could post-date stage 10). Later kinking of the main fabric in the Sleepy Cove Group (this could pre-date stage 7). Cataclasis in the mylonite zone. These three events post-date the deformation and are probably unrelated to one aother.

9) The intrusion of the undeformed feldspar-rich dykes.

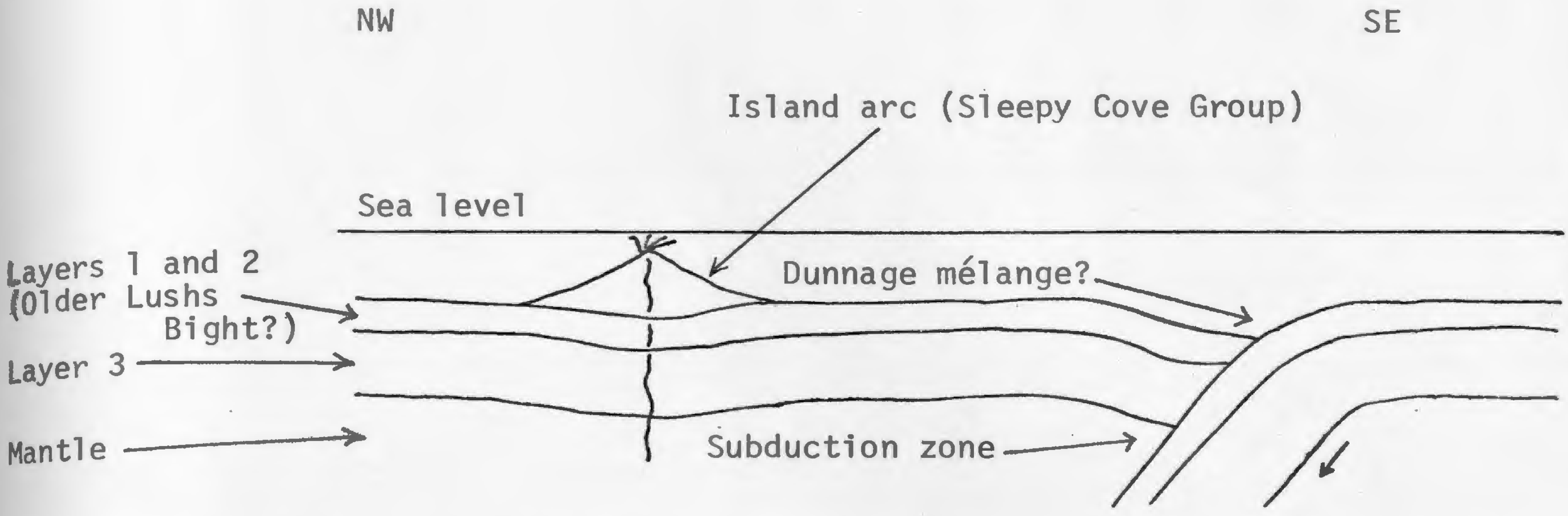
10) Considerable uplift must have occurred before the end of the Ordovician as the area is thought to have been the source of detritus for late Ordovician and Silurian sediments (Helwig and Sarpi,1969). Stages 1-9 were probably over before the mid-Ordovician as this is the date by which the transported klippen (containing mafic rocks similar to those in Notre Dame Bay) in the west of Newfoundland are thought to have been emplaced (Church and Stevens, 1971).

11) Faulting appears to have been active throughout. The Luke Arm Fault truncates all the main faults in the area. It is thought to have been active and possibly a topographic feature, in the Silurian (Kay, 1972). Thus allowing for the formation of conglomerates containing volcanic and granitic detritus (possibly from Twillingate). Other faults are probably of the same age, if they are splays off the Luke Arm Fault

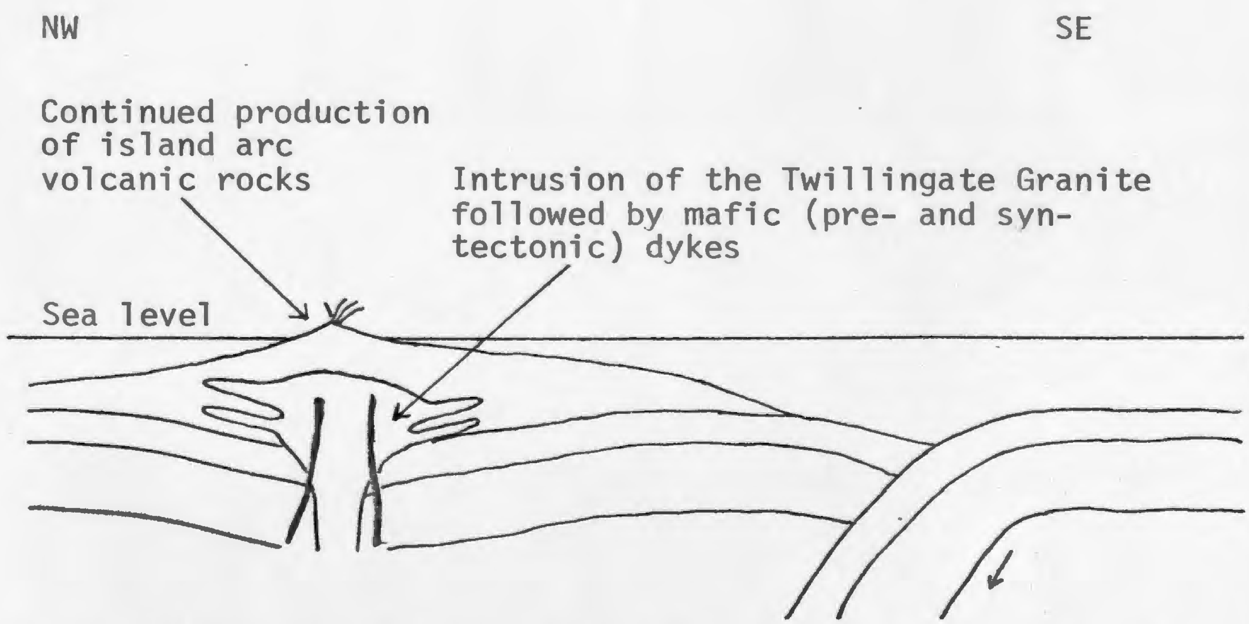
as their angles to it suggest. This zone on New World Island may be quite significant with a long involved history because it seems to follow a general line of weakness that is marked by intense deformation in the Twillingate terrane, intrusion of mafic dykes and volcanic rocks of the Herring Neck Group and repeated faulting.

12) The last event represented in the area is the intrusion of lamprophyre and alkaline basalt dykes in the Jurassic.

The weight of evidence from this study and previous work and interpretations therefore leads to the present interpretation that the Twillingate Island arc episode was of short duration occuring around the late Cambrian or early Ordovician.

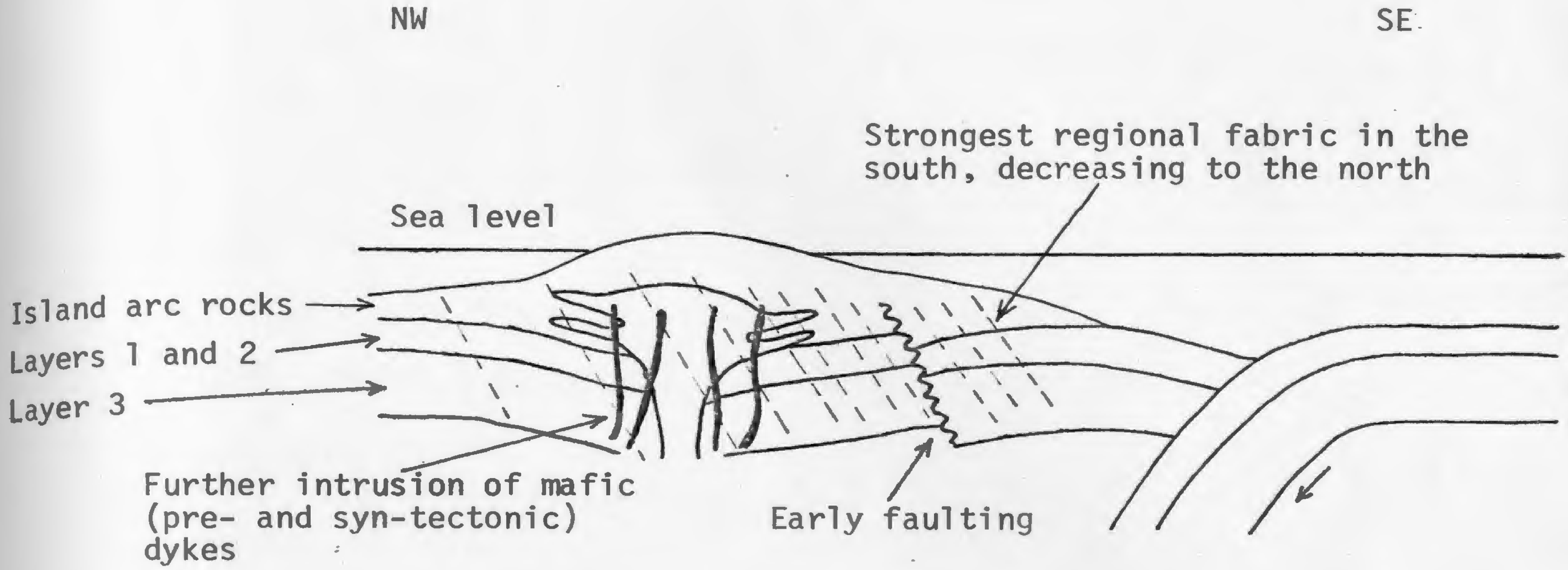


Stages 1 - 3 : Descent of lithosphere beneath earlier ocean crust (older Lushs Bight?); development of subduction zone, submarine trench and mélange; formation of island arc (Sleepy Cove Group) on top of ocean crust.

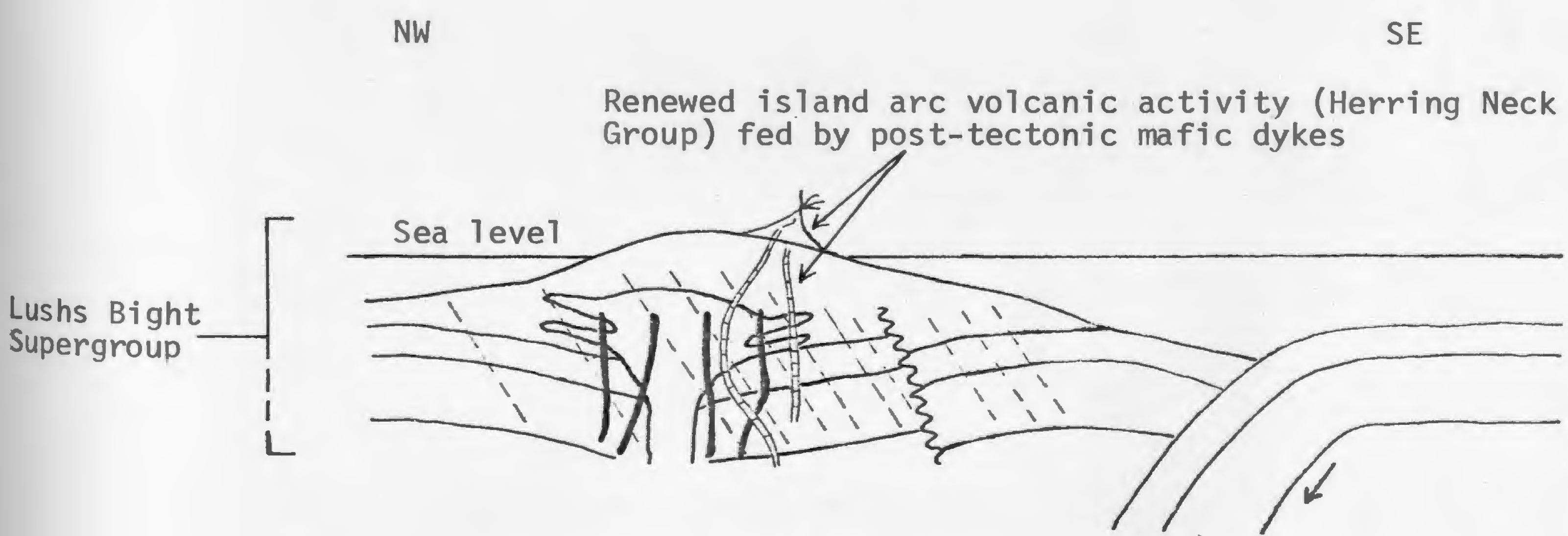


Stages 4 and 5 : Continued descent of lithosphere along Benioff zone; partial melting leading to the intrusion of the Twillingate Granite; followed by the cross-cutting pre- and syn-tectonic mafic dykes.

Figure 51 : Diagrammatic cross-sections through the Twillingate area showing a model for its geological evolution.



Stage 6 : Main deformation producing a strong regional fabric in the south of the area that decreases to the north; accompanied by further intrusion of mafic dykes.



Stage 7 : Post-tectonic mafic magmatism forming the Herring Neck Group

Figure 51 : continued ....

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APPENDIX

Analyses of the Twillingate Granite

SAMPLE NO.	JP 1	JP 2	JP 3	JP 4	JP 5	JP 6	JP 7
COORDINATES	2E10 W61 106	2E10 E62 606	2E10 E63 706	2E10 W61 604	2E10 W61 704	2E10 W62 304	2E10 E62 504
ROCK TYPE	GRANODIORITE	GRANITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	XXXXXXXXXXX	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	XXXXX	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	WT-BLK	XXXXXX	WT-BLK	GREEN	WT-BLK	WT-BLK	WT-BLK
GRAIN SIZE	MED	XXXXXX	MED	MED	MED	MED	MED
TEXTURE	UNIFORM	XXXXXXXXXX	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	XXXXXXXXX	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE
ALTERATION	FRESH	XXXXXX	FRESH	WEATH	FRESH	WEATH	WEATH
FELDSPARS	CLOUDY	XXXXXX	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	XXXXXX	NO MEG	Q-MEG	QFMEG	QFMEG	QFMEG
MAFMI							
SULP.	ABSENT	XXXXXX	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
SU,MI	00035		00035	00035	00035	00035	00035
MGMT	00010		00010	00005	00005	00050	00050
SIO2	71,00	68,90	74,90	75,60	72,00	72,30	73,00
TIO2	0,38	0,51	0,19	0,15	0,24	0,22	0,20
AL2O3	13,20	13,00	12,10	10,70	13,50	12,50	12,30
FE2O3	3,01	3,42	1,94	1,44	2,79	2,36	2,08
FEO	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MNO	0,08	0,07	0,04	0,02	0,06	0,05	0,05
MGO	0,20	0,90	0,05	0,05	1,60	1,10	1,40
CAO	3,05	2,44	1,58	2,63	1,91	1,95	2,23
NA2O	4,21	4,42	5,19	5,37	4,86	4,72	4,42
K2O	0,55	0,81	0,32	0,03	0,86	0,72	0,83
P2O5	0,01	0,01	0,01	0,01	0,01	0,01	0,01
H2O	1,37	1,21	0,73	1,89	1,41	1,13	0,90
TOTAL	97,64	95,49	97,05	97,89	99,24	97,06	97,42
RB	0016	0022	0013	0005	0021	0016	0020
BA	0061	0130	0073	0000	0071	0099	0112
SR	0085	0058	0070	0034	0075	0073	0047
PB	0388	0385	0367	0372	0372	0376	0399
CU	0003	0009	0004	0037	0013	0005	0000
ZN	0049	0053	0025	0018	0035	0034	0036
CO							
CR							
NI					0		
V							
ZR	0067	0083	0148	0352	0115	0119	0106
SN	1023	0997	0977	1035	1035	1075	1165
MO	0168	0162	0165	0170	0172	0170	0162
BI	0419	0397	0392	0415	0411	0410	0430
NE	0147	0141	0144	0152	0151	0149	0160
F							
HG							
B							

SAMPLE NO.	JP 8	JP 9	JP 10	JP 11	JP 12	JP 13	JP 14
COORDINATES	2E10 E62 704	2E10 E64 504	2E10 W61 703	2E10 W61 804	2E10 W62 104	2E10 E62 504	2E10 E62 904
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	BLK&WT	WT-BLK	WT-BLK	BUFF	GREEN	WT-BLK	WT-BLK
GRAIN SIZE	MED	CORS	MED	MED	MED	MED	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	VARIABLE	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE
ALTERATION	WEATH	FRESH	FRESH	WEATH	WEATH	FRESH	FRESH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
MOBIL							
SULF.	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
SQ.MI	00035	00035	00035	00035	00035	00035	00035
HGHT	00010	00010	00010	00010	00050	00075	00010
SIO2	73,00	71,10	72,20	72,40	78,40	77,20	74,00
TIO2	0,22	0,31	0,22	0,21	0,16	0,19	0,20
AL2O3	13,30	12,50	12,40	13,00	11,70	13,10	12,50
FE2O3	2,36	3,11	2,52	2,39	2,07	2,29	2,16
FEO	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MNO	0,04	0,05	0,02	0,04	0,02	0,05	0,05
MGO	0,00	0,30	0,20	0,00	0,00	0,00	0,20
CAO	1,27	2,76	1,65	2,19	0,33	2,06	2,19
NA2O3	4,62	4,17	5,17	4,90	6,12	4,70	4,70
K2O	1,12	0,66	0,38	0,21	0,14	0,40	0,76
P2O5	0,00	0,00	0,00	0,00	0,00	0,00	0,00
H2O	1,31	1,11	0,83	0,95	0,68	0,76	0,92
TOTAL	97,24	96,07	95,59	96,29	99,62	100,75	97,68
RB	0025	0015	0014	0011	0011	0016	0026
BA	0113	0121	0045	0038	0000	0084	0118
SR	0007	0016	0114	0114	0000	0059	0078
PB	0401	0384	0353	0375	0374	0394	0386
CU	0041	0003	0000	0000	0000	0000	0000
ZN	0049	0046	0029	0039	0047	0038	0043
CO							
CR							
NI							
V							
ZR	0097	0061	0114	0129	0062	0142	0094
SN	1089	1047	1041	1118	1150	1246	1053
MO	0177	0168	0154	0164	0172	0175	0161
BI	0433	0419	0385	0410	0411	0424	0421
NE	0154	0147	0136	0143	0151	0155	0143
F							
HG							
S							

SAMPLE NO.	JP 15	JP 16	JP 17	JP 18	JP 19	JP 20	JP 21
COORDINATES	2E10 W61 503	2E10 W61 503	2E10 W62 103	2E10 F62 503	2E10 E63 003	2E10 W61 602	2E10 W61 803
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	BLK&WT	GREEN	BUFF	BUFF	WT-BLK	BUFF	WT-BLK
GRAIN SIZE	MED	MED	MED	MFD	MED.	MED	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE
ALTERATION	FRESH	WEATH	WEATH	WEATH	FRESH	WEATH	WEATH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
HB,BI							
SULF.	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
SU,MI	00035	00035	00035	00035	00035	00035	00035
MGNT	00010	00010	00020	00005	00005	00025	00075
SIO2	77,00	71,90	75,90	70,80	73,50	73,60	75,30
TIO2	0,13	0,22	0,16	0.21	0,19	0.22	0.19
AL2O3	12,00	13,10	11,40	11,50	11,80	12,50	12,00
FE2O3	1,53	2,50	2,55	2,37	1,92	2,40	1,03
FEO	0,00	0,00	0,00	0.00	0,00	0,00	0,00
MNO	0,01	0,05	0,05	0,05	0,03	0,02	0,02
MGO	0,00	0,00	0,00	0,00	0,00	0,20	0,30
CAO	0,93	0,89	0,24	1,61	0,77	0,66	2,62
NA2O3	5,62	6,20	5,27	5.33	5,75	5,23	4,28
K2O	0,35	0,19	0,41	0.50	0,22	0,50	0,44
P2O5	0,00	0,00	0,00	0,00	0,00	0,00	0,00
H2O	0,80	0,90	1,54	3,37	1,00	1,21	0,98
TOTAL	98,85	95,95	97,55	95,74	95,18	96,54	97,16
RB	11	0003	0011	0014	0012	0020	0018
BA	60	0004	0000	0037	0024	0057	0044
SR	8	0000	0000	0007	0029	0034	0191
PB	395	0368	0373	0371	0373	0371	0371
CU		0000	0000	0000	0000	0000	0200
ZN	22	0036	0035	0033	0065	0025	0012
CO							
CR							
NI							
V							
ZR	226	0104	0133	0065	0164	0117	0129
SN	1012	1130	1145	1145	1147	1017	1016
MO	171	0165	0170	0168	0170	0157	0160
BI	429	0399	0401	0399	0399	0394	0390
NE	151	0145	0149	0148	0150	0138	0141
F							
HG							
S							

SAMPLE NO.	JP 22	JP 23	JP 24	JP 25	JP 26	JP 27	JP 28
COORDINATES	2E10 W62 203	2E10 E62 703	2E10 E63 403	2E10 W61 502	2E10 W61 802	2E10 W62 202	2E10 E62 703
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	BUFF	GREY	BLK&WT	WT-BLK	BUFF	BUFF	BUFF
GRAIN SIZE	MED	FINE	MED	MED	MED	MED	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	OR MEGA
ALTERATION	WEATH	WEATH	FRESH	FRESH	WEATH	WEATH	WEATH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
MBIBI							
SULF.	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
SQ,MI	00035	00035	00035	00035	00035	00035	00035
MGMT	00100	00005	00005	00005	00100	00150	00050
SIO2	NOT ANALYSED	70.90	75.90	77.00	71.90	77.40	77.30
TIO2		0.13	0.17	0.21	0.33	0.18	0.05
AL2O3		11.20	12.50	12.80	13.30	11.80	12.40
FE2O3		2.15	2.28	2.35	3.64	1.42	0.83
FEO		0.00	0.00	0.00	0.00	0.00	0.00
MNO		0.05	0.06	0.02	0.05	0.02	0.02
MGO		0.10	0.00	0.60	0.00	0.00	0.00
CAO		1.50	0.70	2.15	2.21	1.43	0.38
NA2O3		5.31	5.09	5.31	5.91	5.47	5.38
K2O		0.16	0.19	0.44	0.32	0.26	2.51
P2O5		0.00	0.00	1.17	0.00	0.26	0.00
H2O		3.20	1.82	1.05	0.87	0.86	0.87
TOTAL		94.70	98.79	103.10	98.53	99.10	99.74
RB	0010	0006	0009	0011	0011	0010	0027
BA	0020	0003	0053	0063	0016	0020	0039
SR	0030	0117	0072	0053	0008	0000	0000
PB	0382	0391	0266	0385	0393	0432	0403
CU	0101	0000	0000	0000	0018	0000	0020
ZN	0019	0024	0045	0014	0053	0018	0025
CO							
CR							
NI							
V							
ZR	0110	0140	0122	0202	0121	0294	0109
SN	1104	1099	1073	1085	1102	1461	1071
MO	0170	0168	0150	0164	0170	0219	0173
BI	0405	0425	0293	0413	0422	0468	0440
NB	0151	0150	0131	0146	0151	0194	0153
F							
HG							
S							

SAMPLE NO.	JP 29	JP 30	JP 31	JP 32	JP 33	JP 34	JP 35
COORDINATES	2E10 E63 203	2E10 E64 903	2E10 E65 903	2E10 W62 001	2E10 E63 301	2E10 E65 001	2E10 W61 699
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	YELLOW	YELLOW	WT-BLK	GREY	BLK&WT	WT-BLK	BUFF
GRAIN SIZE	MED	FINE	MED	MED	MED	MED	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE
ALTERATION	FRESH	FRESH	WEATH	FRESH	FRESH	FRESH	WEATH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
HB:BI							
SULF.	ABSENT	ABSENT	ABSENT	ABSENT	PRESEN	ABSENT	ABSENT
SU,MI	00035	00035	00035	00035	00035	00035	00035
MGMT	00005	00005	00005	00075	00005	00005	00005
SIO2	69.50	79.10	70.30	80.00	69.80	73.80	70.30
TIO2	0.15	0.10	0.19	0.15	0.18	0.22	0.20
AL2O3	11.80	12.00	14.00	11.00	12.00	13.10	12.40
FE2O3	2.21	1.13	2.88	1.60	2.36	2.71	2.95
FEO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MNO	0.06	0.02	0.06	0.02	0.02	0.09	0.03
MGO	2.08	0.00	0.00	0.00	0.00	0.00	1.60
CAO	2.69	0.18	2.36	0.16	0.81	2.40	0.23
NA2O3	4.92	5.25	5.38	5.59	6.00	3.59	6.10
K2O	0.48	0.74	1.06	0.07	0.34	0.81	0.09
P2O5	0.00	0.00	0.00	0.00	0.00	0.10	0.03
H2O	5.24	0.66	1.63	1.00	1.14	1.36	1.35
TOTAL	97.13	99.20	97.86	99.59	92.65	98.18	95.25
RB	0014	0039	0027	0011	0014	0020	0014
BA	0037	0160	0105	0024	0074	0121	0000
SR	0026	0000	0139	0000	0055	0093	0000
PB	0400	0423	0381	0411	0420	0403	0409
CU	0000	0000	0000	0017	0151	0003	0000
ZN	0032	0024	0045	0018	0023	0050	0042
CO							
CR							
NI							
V							
ZR	0116	0088	0119	0098	0111	0096	0154
SN	1261	1202	1456	1180	1233	1121	1194
MO	0187	0183	0166	0184	0187	0179	0172
BI	0433	0442	0407	0447	0451	0434	0443
NB	0166	0161	0146	0163	0167	0160	0152
F							
HG							
S							

SAMPLE NO.	* JP 36	* JP 37	* JP 38	* JP 39	* JP 40	* JP 41	* JP 42	*
COORDINATES	* 2E10 E63 000	* 2E10 E65 399	* 2E10 E66 900	* 2E10 E62 897	* 2E10 E63 197	* 2E10 E63 797	* 2E10 E64 297	*
ROCK TYPE	* GRANODIORITE	* GRANODIORITE	* GRANODIORITE	* GRANODIORITE	* GRANODIORITE	* GRANODIORITE	* GRANODIORITE	*
AGE	* ORDOVICIAN	* ORDOVICIAN	* ORDOVICIAN	* ORDOVICIAN	* ORDOVICIAN	* ORDOVICIAN	* ORDOVICIAN	*
SAMPLE TYPE	* GRAB	* GRAB	* GRAB	* GRAB	* GRAB	* GRAB	* GRAB	*
COLOUR	* WT&BLK	* BLK&WT	* WT-BLK	* WT-BLK	* YELLOW	* BUFF	* WT&BLK	*
GRAIN SIZE	* MED	* MED	* MED	* MED	* MED	* MED	* MED	*
TEXTURE	* UNIFORM	* UNIFORM	* UNIFORM	* UNIFORM	* UNIFORM	* UNIFORM	* UNIFORM	*
STRUCTURE	* MASSIVE	* MASSIVE	* MASSIVE	* MASSIVE	* MASSIVE	* MASSIVE	* MASSIVE	*
ALTERATION	* WEATH	* FRESH	* FRESH	* WEATH	* WEATH	* WEATH	* WEATH	*
FELDSPARS	* CLOUDY	* CLOUDY	* CLOUDY	* CLOUDY	* CLOUDY	* CLOUDY	* CLOUDY	*
CRYSTALS	* QFMEG	* QFMEG	* QFMEG	* QFMEG	* QFMEG	* QFMEG	* QFMEG	*
HBBIOT	*	*	*	*	*	*	*	*
SULF.	* ABSENT	* ABSENT	* ABSENT	* ABSENT	* ABSENT	* ABSENT	* ABSENT	*
SG,MI	* 00035	* 00035	* 00035	* 00035	* 00035	* 00035	* 00035	*
HGMT	* 00100	* 00005	* 00010	* 00005	* 00005	* 00020	* 00050	*
SIO2	* 74,80	* 70,90	* 70,90	* 72,00	* 76,60	* 74,40	* 73,80	*
TIO2	* 0,23	* 0,25	* 0,23	* 0,21	* 0,12	* 0,19	* 0,19	*
AL2O3	* 13,00	* 13,00	* 13,00	* 14,10	* 11,50	* 12,30	* 12,10	*
FE2O3	* 1,10	* 4,32	* 2,92	* 3,00	* 1,81	* 2,44	* 2,37	*
FEO	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	*
MNO	* 0,02	* 0,06	* 0,07	* 0,02	* 0,03	* 0,06	* 0,05	*
MGO	* 0,20	* 0,10	* 0,00	* 0,50	* 0,00	* 0,00	* 0,30	*
CAO	* 2,63	* 3,56	* 3,04	* 2,39	* 0,77	* 1,07	* 1,47	*
NA2O3	* 5,39	* 5,07	* 4,03	* 4,90	* 5,62	* 4,66	* 5,10	*
K2O	* 0,33	* 0,74	* 0,72	* 0,16	* 0,34	* 0,60	* 0,62	*
P2O5	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	*
H2O	* 1,08	* 1,28	* 1,18	* 0,81	* 1,86	* 1,33	* 0,99	*
TOTAL	* 98,86	* 99,28	* 96,09	* 98,09	* 98,65	* 97,05	* 96,99	*
RB	* 0015	* 0025	* 0025	* 0015	* 0014	* 0023	* 0021	*
BA	* 0054	* 0086	* 0146	* 0071	* 0013	* 0057	* 0157	*
SR	* 0200	* 0150	* 0136	* 0150	* 0000	* 0084	* 0132	*
PB	* 0410	* 0375	* 0379	* 0401	* 0422	* 0398	* 0397	*
CU	* 0000	* 0000	* 0002	* 0000	* 0002	* 0000	* 0000	*
ZN	* 0015	* 0060	* 0052	* 0018	* 0043	* 0042	* 0036	*
CO	*	*	*	*	*	*	*	*
CR	*	*	*	*	*	*	*	*
NI	*	*	*	*	*	*	*	*
V	*	*	*	*	*	*	*	*
ZR	* 0071	* 0060	* 0091	* 0121	* 0106	* 0100	* 0078	*
SN	* 1150	* 1994	* 1018	* 1090	* 1202	* 1104	* 1002	*
MO	* 0175	* 0149	* 0156	* 0164	* 0187	* 0174	* 0165	*
BI	* 0450	* 0404	* 0426	* 0425	* 0450	* 0428	* 0420	*
NE	* 0154	* 0130	* 0138	* 0143	* 0164	* 0154	* 0146	*
F	*	*	*	*	*	*	*	*
MG	*	*	*	*	*	*	*	*
S	*	*	*	*	*	*	*	*

SAMPLE NO.	JP 43	JP 44	JP 45	JP 46	JP 47	JP 48	JP 49
COORDINATES	2E10 E64 598	2E10 E64 998	2E10 E65 798	2E10 E63 497	2E10 E63 797	2E10 E63 997	2E10 E64 497
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	XXXXXXXXXXX
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB	CORE
COLOUR	WT-BLK	WT-BLK	WT&BLK	WT-BLK	WT-BLK	WT&BLK	WT-BLK
GRAIN SIZE	MED	MED	MED	MED	MED	MED	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE
ALTERATION	WEATH	FRESH	FRESH	FRESH	FRESH	WEATH	FRESH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
MOBIL							
SULP.	ABSENT	ABSENT	ABSENT	ABSENT	PRESEN	ABSENT	ABSENT
SG,MI	00035	00035	00035	00035	00035	00035	00035
MGNT	00050	00030	00075	00005	00005	00020	00030
SIO2	74,20	74,20	75,50	74,30	74,80	76,40	75,00
TIO2	2,24	0,22	0,22	0,22	0,16	0,23	0,19
AL2O3	12,90	12,90	13,20	13,00	12,20	13,30	12,90
FE2O3	2,75	2,65	2,12	2,30	2,56	1,92	2,36
FEO	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MNO	0,26	0,06	0,02	0,03	0,04	0,03	0,06
MGO	0,00	0,30	0,00	0,10	1,50	0,00	1,40
CAO	2,37	1,51	2,34	2,00	0,92	3,14	2,22
NA2O3	4,24	4,97	5,58	5,30	5,73	4,61	4,64
K2O	0,48	0,48	0,16	0,47	0,16	0,40	1,01
P2O5	0,00	0,00	0,00	0,00	0,00	0,00	0,00
H2O	0,08	1,07	0,39	0,98	0,82	0,51	0,58
TOTAL	98,12	98,36	99,53	98,70	98,89	100,54	100,36
RB	0018	0020	0009	0016	0014	0016	0030
BA	0104	0121	0042	0047	0012	0085	0126
SR	0123	0097	0162	0119	0081	0183	0061
PB	0399	0373	0393	0394	0378	0362	0371
CU	0000	0043	0000	0000	0000	0000	0000
ZN	0042	0047	0023	0021	0028	0027	0042
CO							
CR							
NI							
V							
ZR	0070	0069	0090	0109	0082	0102	0072
SN	1124	1055	1218	1132	1300	1063	1189
MO	0175	0166	0178	0167	0180	0159	0168
BI	0417	0410	0434	0419	0418	0392	0398
NE	0153	0147	0156	0146	0159	0140	0147
F							
HG							
S							

SAMPLE NO.	JP 50	JP 51	JP 52	JP 53	JP 54	JP 55	JP 56
COORDINATES	2E10 E64 897	2E10 E63 397	2E10 E63 797	2E10 E64 297	2E10 E64 597	2E10 E64 997	2E10 E63 096
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	XXXXXXXXXXX	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	CORF	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	BLKRWT	WT-BLK	WT-BLK	GREY	WT-BLK	WT-BLK	WT-BLK
GRAIN SIZE	MED	MED	MED	FINE	MED	FINE	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE
ALTERATION	WEATH	FRESH	FRESH	WEATH	FRESH	WEATH	FRESH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
HBIBI							
SULF.	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
SQ.MI	00035	00035	00035	00035	00035	00035	00035
HGHT	00005	00005	00005	00030	00030	00030	00005
SIO2	76,00	73,10	72,30	79,50	73,40	71,50	70,90
TIO2	0,12	0,22	0.21	0,23	0,20	0,25	0,25
AL2O3	13,90	13,60	13,40	14,60	12,00	12,70	12,50
FE2O3	2,85	2,89	2,80	2,15	2,82	2,88	2.99
FEO	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MNO	0,08	0,08	0,08	0,02	0,07	0,07	0,07
MGO	0,60	0,90	1,40	0,30	0,10	0,80	1,20
CAO	1,75	1,65	2,93	0,62	1,20	2,12	1,38
NA2O3	5,16	5,38	4,67	6,42	5,13	4,92	5,30
K2O	0,59	0,30	0,71	0,39	0,31	0,36	0,58
P2O5	0,00	0,00	0,00	0,00	0,00	0,00	0,00
H2O	1,04	0,95	1,36	1,36	1,35	0,87	0,81
TOTAL	102,89	99,05	99,86	105,59	96,58	96,47	95,98
RB	0014	0012	0017	0015	0021	0016	0014
BA	0108	0096	0078	0046	0069	0088	0045
SR	0153	0092	0087	0066	0165	0121	0086
PB	0374	0397	0365	0388	0378	0383	0421
CU	0019	0014	0011	0000	0000	0000	0009
ZN	0057	0050	0036	0031	0044	0035	0056
CO							
CR							
NI							
V							
ZR	0115	0126	0077	0129	0135	0129	0145
SN	1166	1250	1156	1140	1157	1213	1107
MO	0167	0178	0168	0180	0165	0170	0165
BI	0427	0435	0416	0419	0411	0400	0446
NB	0146	0157	0148	0159	0145	0150	0146
F							
HG							
S							

SAMPLE NO.	JP 57	JP 58	JP 59	JP 60	JP 61	JP 62	JP 63
COORDINATES	2E10 E63 896	2E10 E64 396	2E10 E64 896	2E10 E65 196	2E10 E63 696	2E10 E63 996	2E10 E64 496
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	XXXXXXXXXXX	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	CORE	GRAB	GRAB
COLOUR	WT-BLK	WT-BLK	WT-BLK	WT-BLK	BLK&WT	WT-BLK	WT-BLK
GRAIN SIZE	MED	MED	MED	MED	MED	MED	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE
ALTERATION	FRESH	FRESH	FRESH	FRESH	FRESH	FRESH	FRESH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
MBIBI							
SULF.	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	PRESEN
SU,MI	00035	00035	00035	00035	00035	00035	00035
MGMT	00020	00020	33320	00050	00005	00005	00005
SIO2	75,30	72,90	71,20	69,40	70,50	72,20	73.30
TIO2	0,20	0,22	0,31	0.31	0,29	0,25	0,24
AL2O3	13,00	12,70	12,90	13,40	13,20	12,60	11,50
FE2O3	2,52	2,63	3,62	3,84	3,07	2,70	2,47
FEO	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MNO	0,05	0,07	0,04	0,09	0,06	0,07	0.05
MGO	0,50	0,00	0,10	0,00	0,00	1,30	1,20
CAO	0,75	2,08	1,74	2,41	1,61	1,62	0,53
NA2O3	5,50	5,47	4,76	4,92	5,67	5,33	6,00
K2O	0,10	0,59	0,14	0,33	0,40	0,29	0,04
P2O5	0,00	0,00	0,00	0,00	0,00	0,04	0,00
H2O	1,20	1,69	1,23	1,07	1,70	0,85	1,01
TOTAL	99,18	98,35	96,04	95.77	96,50	97,25	96,14
RB	0008	0016	0012	0017	0021	0015	0012
BA	0016	0062	0062	0088	0052	0070	0033
SR	0059	0010	0125	0144	0150	0116	0008
PB	0386	0374	0372	0394	0411	0418	0402
CU	0000	0000	0010	0000	0011	0005	0008
ZN	0038	0040	0047	0048	0045	0042	0039
CO							
CR							
NI							
V							
ZR	0095	0065	0119	0127	0143	0130	0130
SN	1224	1224	1146	1066	1111	1199	1158
MO	0171	0174	0163	0160	0170	0175	0176
BI	0406	0404	0394	0421	0436	0446	0423
NE	0150	0153	0143	0141	0151	0155	0155
F							
HG							
S							

SAMPLE NO.	JP 64	JP 65	JP 66	JP 67	JP 68	JP 69	JP 70
COORDINATES	2E10 E64 896	2E10 E65 396	2E10 E65 996	2E10 E71 502	2E10 E70 801	2E10 E71 501	2E10 E69 000
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	WT-BLK	WT-BLK	WT-BLK	WT-BLK	WT-BLK	GREY	WT-BLK
GRAIN SIZE	MED	MED	MED	MED	MED	FINE	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	VARIABLE	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	OR MEGA	MASSIVE
ALTERATION	FRESH	FRESH	FRESH	FRESH	FRESH	FRESH	FRESH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
MBIMI							
SULF.	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
SO,MI	00035	00035	00035	00035	00035	00035	00035
MGMT	00005	00005	00005	00005	00005	00050	00005
SIO2	67,50	74,50	74,90	71,00	60,10	70,50	67,10
TIO2	0,20	0,22	0,25	0,30	0,93	0,28	0,31
AL2O3	13,00	11,70	12,90	13.90	16,70	13,60	14,40
FE2O3	5,43	2,49	2,96	4,06	3,36	3,64	4,13
FEO	0,00	0,00	0,00	0.00	0,00	0,00	0,00
MNO	0,04	0,06	0,08	0,09	0,08	0,07	0,06
MGO	0,00	0,00	0,00	0,00	5,80	0,10	0,00
CAO	2,32	0,81	1,60	2,92	5,59	1,34	4,54
NA2O3	4,83	5,17	5,00	4,20	3,98	4,67	2,69
K2O	0,20	0,63	0,88	0,50	3,68	1,09	0,53
P2O5	0,00	0,00	0,00	0.00	0,38	0,00	0,03
H2O	1,84	1,10	1,02	1,37	1,40	1,93	1,24
TOTAL	95,44	96,68	99,59	98,34	102,00	97,22	95,03
RB	0014	0019	0026	0017	0016	0023	0016
BA	0136	0086	0167	0089	0045	0113	0038
SR	0136	0091	0138	0145	0169	0168	0178
PB	0388	0388	0384	0390	0389	0278	0251
CU	0002	0000	0000	0000	0000	0003	000P
ZN	0034	0041	0052	0066	0049	0046	0042
CO							
CR							
NI							
V							
ZR	0136	0138	0120	0077	0159	0099	0013
SN	1186	1135	1149	1044	1068	1137	0921
MO	0170	0172	0158	0153	0159	0162	0134
BI	0416	0431	0412	0411	0421	0308	0280
NE	0150	0152	0141	0135	0138	0142	0117
F							
HG							
S							

SAMPLE NO.	JP 71	JP 72	JP 73	JP 74	JP 75	JP 76	JP 77
COORDINATES	2E10 E69 300	2E10 F69 900	2F10 E70 200	2E10 E70 500	2E10 E68 800	2E10 E69 300	2F10 F69 600
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	BLK&WT	WT-BLK	BLK&WT	WT-BLK	BLK&WT	BLK&WT	BLK&WT
GRAIN SIZE	MED	MED	MED	MED	MED	MED	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	OR MEGA	MASSIVE	OR MEGA	MASSIVE	MASSIVE
ALTERATION	FRESH	FRESH	FRESH	FRESH	FRESH	FRESH	WEATH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
MOBOI							
SULP.	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
SQ.MI	00035	00035	00035	00035	00035	00035	00035
WGHT	00025	00005	00005	00005	00005	00005	0000K
SIO2	66,90	67,10	55,10	72,20	66,50	69,40	71,80
TIO2	0,36	0,50	0,37	0,19	0,33	0,35	0,17
AL2O3	15,90	15,40	16,80	11,90	14,00	15,30	12,80
FE2O3	4,73	4,04	8,70	1,81	4,55	4,65	2,11
FEO	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MNO	0,29	0,08	0,15	0,03	0,07	0,06	0,06
MGO	0,00	0,00	4,50	0,00	0,00	0,00	0,00
CAO	4,61	4,61	7,81	2,87	5,06	3,19	2,25
NA2O3	5,12	3,42	2,43	3,35	4,17	3,21	4,91
K2O	0,39	0,27	0,29	1,01	0,69	0,53	0,49
P2O5	0,03	0,01	0,05	0,00	0,02	0,06	0,00
H2O	1,15	1,51	1,36	3,49	1,67	1,84	1,16
TOTAL	95,28	94,54	97,52	96,05	94,86	98,59	95,75
RB	0017	0014	0014	0020	0017	0019	0016
BA	0020	0024	0013	0161	0084	0089	0057
SR	0154	0192	0175	0033	0199	0123	0051
PB	0268	0309	0287	0537	0381	0398	0392
CU	0000	0000	0010	0021	0000	0015	0008
ZN	0047	0052	0081	0020	0060	0054	0037
CO							
CR							
NI							
V							
ZR	0007	0026	0041	0073	0060	0105	0038
SN	0946	1038	0886	1198	1080	1086	1183
MO	0133	0142	0118	0172	0153	0155	0172
BI	0286	0340	0312	0375	0409	0418	0432
NE	0116	0125	0102	0149	0135	0137	0152
F							
HG							
S							

SAMPLE NO.	JP 78	JP 79	JP 80	JP 81	JP 82	JP 83	JP 84
COORDINATES	2E10 E69 900	2E10 E68 900	2E10 E69 400	2E10 E69 699	2E10 E69 700	2E10 E68 699	2E10 F68 999
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	BLK&WT	WT-BLK	WT-BLK	BLK&WT	GREEN	WT-BLK	WT-BLK
GRAIN SIZE	MED	MED	MED	MED	MED	MED	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE
ALTERATION	WEATH	FRESH	FRESH	WEATH	FRESH	FRESH	FRESH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
MOBIL							
SULF.	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
SU,MI	00035	00035	00035	00035	00035	00035	00035
HGHT	00025	00035	00005	00050	00005	00005	00005
SIO2	75,00	70,60	72,90	72,10	76,80	71,50	71,40
TIO2	0,20	0,12	0,20	0,24	0,18	0,21	0,25
AL2O3	13,40	12,50	13,10	13,20	12,00	12,60	12,80
FE2O3	2,40	2,01	2,57	3,48	1,37	2,53	2,77
FEO	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MNO	0,05	0,07	0,07	0,07	0,02	0,08	0,07
MGO	0,00	0,00	0,00	0,20	0,00	1,00	1,40
CAO	1,85	2,57	2,31	1,85	0,38	1,65	1,38
NA2O3	3,50	3,71	4,69	3,39	4,06	4,22	5,00
K2O	1,32	0,57	0,28	0,78	0,08	0,71	0,70
P2O5	0,00	0,00	0,00	0,00	0,00	0,00	0,00
H2O	2,26	1,45	1,17	1,38	1,05	1,31	1,50
TOTAL	99,96	93,60	97,29	96,69	95,94	95,81	97,27
NB	0027	0020	0013	0021	0002	0021	0010
BA	0166	0072	0015	0107	0041	0107	0007
SR	0019	0077	0087	0169	0010	0140	0110
PB	0397	0401	0402	0397	0415	0370	0401
CU	0000	0000	0000	0000	0002	0005	0011
ZN	0058	0045	0054	0055	0013	0051	0050
CO							
CR							
NI							
V							
ZR	0070	0076	0062	0094	0087	0106	0085
SN	1191	1152	1047	0995	1121	0987	0982
MO	0172	0170	0160	0154	0185	0158	0161
BI	0424	0434	0428	0426	0452	0406	0430
NE	0152	0153	0141	0136	0166	0141	0142
F							
HG							
S							

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SAMPLE NO.	JP 85	JP 86	JP 87	JP 88	JP 89	JP 90	JP 91
COORDINATES	2E10 E69 399	2E10 E69 599	2E10 E68 499	2E10 E68 899	2E10 E69 499	2E10 E69 599	2E10 E67 097
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	BLK&WT	BLK&WT	BLK&WT	BLK&WT	WT-BLK	GREEN	WT-BLK
GRAIN SIZE	MED	MED	MED	MED	MED	FINE	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE
ALTERATION	FRESH	FRESH	WEATH	WEATH	FRESH	WEATH	FRESH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
MBTHI							
SULF.	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
SO,4I	00035	00035	00035	00035	00035	00035	00035
HGMT	00005	00050	00005	00005	00050	00050	00005
SIO2	68,70	71,00	57,70	71,20	72,70	72,30	72,80
TIO2	0,22	0,24	0,34	0,22	0,22	0,15	0,29
AL2O3	11,80	11,50	15,30	11,70	10,00	11,20	12,80
FE2O3	2,67	1,50	6,60	2,77	3,59	1,34	2,83
FEO	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MNO	0,04	0,01	0,17	0,06	0,09	0,02	0,05
MGO	0,00	0,10	2,60	0,00	0,00	0,00	0,00
CAO	1,79	0,96	3,21	1,01	2,24	1,19	1,95
NA2O3	3,55	3,85	5,18	3,94	2,82	5,40	3,55
K2O	0,73	0,32	0,20	0,50	0,30	0,30	1,16
P2O5	0,00	0,00	0,00	0,00	0,00	0,00	0,00
H2O	2,72	1,49	1,35	1,31	1,09	1,49	1,19
TOTAL	92,22	9[illegible],77	92,65	92,71	93,05	93,39	96,42
RB	0025	0015	0014	0022	0012	0011	0032
BA	0081	0054	0015	0056	0093	0038	0194
SR	0073	0061	0187	0071	0167	0098	0145
PB	0383	0391	0342	0394	0366	0408	0334
CU	0013	0000	0001	0000	0002	0000	0002
ZN	0045	0015	0091	0041	0045	0014	0033
CO							
CR							
NI							
V							
ZR	0089	0072	0057	0030	0028	0158	0061
SN	1244	1157	0926	1185	0989	1202	1122
MO	0176	0187	0138	0170	0153	0179	0159
BI	0400	0419	0372	0414	0392	0433	0356
NB	0155	0169	0122	0150	0134	0158	0138
F							
HG							
S							

SAMPLE NO.	JP 92	JP 93	JP 94	JP 95	JP 96	JP 97	JP 98
COORDINATES	2E10 E68 297	2E10 E66 896	2E10 W61 805	2E10 E64 004	2E10 E65 104	2E10 E64 804	2E10 E64 804
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	GREY	WT-BLK	GREY	YELLOW	YELLOW	YELLOW	BLKWT
GRAIN SIZE	FINE	MED	V.F.	MED	MED	MED	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE
ALTERATION	WEATH	FRESH	WEATH	FRESH	FRESH	FRESH	FRESH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG	QFMEG
MB+MI							
SULF.	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT
SQ.MI	00035	00035	00035	00035	00035	00035	00035
MGMT	00150	00005	00005	00005	00005	00005	00005
SIO2	75,40	73,70	76,40	76,40	72,00	73,50	75,80
TIO2	0,27	0,25	0,23	0,16	0,41	0,54	0,56
AL2O3	11,70	11,60	12,40	12,60	12,70	15,90	13,10
FE2O3	2,68	2,02	3,05	1,61	4,24	3,71	3,79
FEO	0,00	0,00	0,00	0,00	0,00	0,00	0,00
MNO	0,03	0,02	0,08	0,03	0,03	0,06	0,10
MGO	2,00	0,00	15,60 ? 5.6	0,00	0,00	0,00	0,00
CAO	0,76	1,56	2,61	0,97	2,40	1,75	2,70
NA2O3	3,67	4,00	4,36	4,33	4,31	4,48	4,06
K2O	0,04	0,51	0,18	0,76	0,41	3,88	0,57
P2O5	0,00	0,00	0,00	0,00	0,00	0,16	0,00
H2O	0,99	1,60	0,67	1,25	0,00	1,44	0,89
TOTAL	95,04	95,26	115,58 ?	98,11	96,50	105,42	101,37
RB	0011	0019	0012	0018	14	0031	0012
BA	0018	0071	0045	0087	67	0125	0076
SR	0014	0100	0130	0000	33	0000	0075
PB	0344	0350	0342	0360	347	0369	0334
CU	0007	0000	0000	0000	0	0000	0000
ZN	0010	0009	0052	0023	58	0013	0072
CO							
CR							
NI							
V							
ZR	0067	0092	0140	0096	81	0079	0054
SN	1111	1134	1027	1044	1083	1145	1019
MO	0166	0167	0152	0169	155	0179	0151
BI	0374	0374	0389	0411	381	0384	0358
NE	0144	0146	0134	0150	136	0158	0133
F							
MG							
B							

SAMPLE NO.	* JP 99	* JP 100	* JP 101	* JP 102	* JP 103	* JP 104	* JP 105	*
COORDINATES	* 2E10 E65 502	* 2E10 E64 700	* 2E10 E65 900	* 2E10 E66 199	* 2E10 E64 495	* 2E10 E64 994	* 2E10 E64 595	*
ROCK TYPE	* GRANODIORITE	* GRANODIORITE	* GRANODIORITE	* GRANODIORITE	* GRANODIORITE	* GRANODIORITE	* GRANODIORITE	*
AGE	* ORDOVICIAN	* ORDOVICIAN	* ORDOVICIAN	* ORDOVICIAN	* ORDOVICIAN	* ORDOVICIAN	* ORDOVICIAN	*
SAMPLE TYPE	* GRAB	* GRAB	* GRAB	* GRAB	* GRAB	* GRAB	* GRAB	*
COLOUR	* YELLOW	* BLK&WT	* WT-BLK	* GREEN	* WT-BLK	* GREY	* GREEN	*
GRAIN SIZE	* MED	* MED	* MED	* MED	* MED	* MED	* MED	*
TEXTURE	* UNIFORM	* UNIFORM	* UNIFORM	* UNIFORM	* UNIFORM	* UNIFORM	* UNIFORM	*
STRUCTURE	* MASSIVE	* MASSIVE	* MASSIVE	* MASSIVE	* MASSIVE	* MASSIVE	* MASSIVE	*
ALTERATION	* FRESH	* WEATH	* FRESH	* FRESH	* FRESH	* WEATH	* WEATH	*
FELDSPARS	* CLOUDY	* CLOUDY	* CLOUDY	* CLOUDY	* CLOUDY	* CLOUDY	* CLOUDY	*
CRYSTALS	* QFMEG	* QFMEG	* QFMEG	* QFMEG	* QFMEG	* QFMEG	* QFMEG	*
MS:MI	*	*	*	*	*	*	*	*
SULF.	* ABSENT	* ABSENT	* ABSENT	* ABSENT	* ABSENT	* ABSENT	* ABSENT	*
SG,MI	* 00035	* 00035	* 00035	* 00035	* 00035	* 00035	* 00035	*
MGMT	* 00005	* 00005	* 00005	* 00005	* 00005	* 00005	* 00005	*
SIO2	* 77,30	* 67,20	* 71,40	* 75,30	* 73,50	* 72,40	* 73,20	*
TIO2	* 0,14	* 0,34	* 0,29	* 0,25	* 0,22	* 0,25	* 0,26	*
AL2O3	* 12,70	* 13,60	* 14,80	* 12,80	* 13,10	* 12,30	* 13,30	*
FE2O3	* 1,15	* 3,62	* 3,51	* 2,60	* 2,39	* 2,81	* 2,72	*
FEO	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	*
MNO	* 0,02	* 0,05	* 0,07	* 0,05	* 0,05	* 0,04	* 0,05	*
MGO	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	*
CAO	* 0,77	* 1,18	* 2,49	* 1,79	* 1,54	* 1,07	* 1,24	*
NA2O	* 5,00	* 6,40	* 4,16	* 4,73	* 4,98	* 5,64	* 5,84	*
K2O	* 1,38	* 0,21	* 0,55	* 0,91	* 0,74	* 0,32	* 0,33	*
P2O5	* 0,00	* 0,00	* 0,00	* 0,00	* 0,00	* 2,00	* 0,00	*
H2O	* 1,17	* 1,53	* 0,94	* 0,82	* 0,96	* 1,42	* 0,51	*
TOTAL	* 99,63	* 94,13	* 98,17	* 99,25	* 97,48	* 96,25	* 97,45	*
RB	* 0022	* 0011	* 0015	* 0025	* 0020	* 0012	* 0013	*
BA	* 0051	* 0017	* 0072	* 0137	* 0094	* 0026	* 0051	*
SR	* 0000	* 0096	* 0145	* 0095	* 0169	* 0045	* 0125	*
PB	* 0384	* 0369	* 0371	* 0380	* 0376	* 0392	* 0397	*
CU	* 0000	* 0000	* 0000	* 0013	* 0000	* 0000	* 0006	*
ZN	* 0017	* 0050	* 0053	* 0045	* 0034	* 0044	* 0039	*
CO	*	*	*	*	*	*	*	*
CR	*	*	*	*	*	*	*	*
NI	*	*	*	*	*	*	*	*
V	*	*	*	*	*	*	*	*
ZR	* 0113	* 0017	* 0059	* 0044	* 0126	* 0104	* 0129	*
SN	* 1187	* 1092	* 1143	* 1173	* 1065	* 1106	* 1165	*
MO	* 0176	* 0157	* 0156	* 0164	* 0162	* 0164	* 0172	*
BI	* 0405	* 0393	* 0390	* 0393	* 0400	* 0416	* 0423	*
NE	* 0155	* 0140	* 0137	* 0145	* 0142	* 0145	* 0152	*
F	*	*	*	*	*	*	*	*
HG	*	*	*	*	*	*	*	*
S	*	*	*	*	*	*	*	*

SAMPLE NO.	JP 106	JP 107	JP 108	JP 109	JP 110
COORDINATES	2E10 E62 601	2E10 E64 799	2E10 E67 597	2E10 E67 098	2E10 E69 298
ROCK TYPE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE	GRANODIORITE
AGE	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	ORDOVICIAN
SAMPLE TYPE	GRAB	GRAB	GRAB	GRAB	GRAB
COLOUR	GREEN	BLK-WT	WT-BLK	WT-BLK	GREEN
GRAIN SIZE	MED	MED	MED	MED	MED
TEXTURE	UNIFORM	UNIFORM	UNIFORM	UNIFORM	UNIFORM
STRUCTURE	MASSIVE	MASSIVE	MASSIVE	MASSIVE	MASSIVE
ALTERATION	WEATH	WEATH	WEATH	FRESH	WEATH
FELDSPARS	CLOUDY	CLOUDY	CLOUDY	CLOUDY	CLOUDY
CRYSTALS	UFMEG	UFMEG	UFMEG	UFMEG	UFMEG
MOBIOI					
SULF.	PRESEN	ABSENT	ABSENT	ABSENT	ABSENT
SG,MI	00035	00035	00035	00035	00035
HGHT	00050	00005	00005	00005	00075
SIO2	73.10	71.40	75.30	76.10	75.70
TIO2	0.27	0.27	0.30	0.23	0.28
AL2O3	13.20	13.30	14.50	12.90	13.30
FE2O3	3.52	3.50	2.71	2.47	2.35
FEO	0.00	0.00	0.00	0.00	0.00
MNO	0.05	0.07	0.04	0.57	0.25
MGO	0.20	0.00	2.20	0.00	0.50
CAO	0.73	2.39	0.87	1.69	1.15
NA2O3	5.80	4.73	5.58	4.73	5.42
K2O	0.22	0.97	0.43	0.64	0.27
P2O5	0.00	0.00	0.00	0.00	0.00
H2O	1.61	1.25	0.97	0.83	0.92
TOTAL	98.70	97.88	102.90	102.16	100.14
NB	10	0023	0013	0016	0004
BA	26	0169	0055	0092	0081
SR	12	0099	0038	0117	0111
PB	377	0373	0385	0290	0295
CU	160	0000	0000	0000	0000
ZN	42	0052	0043	0048	0021
CO					
CR					
NI					
V					
ZR	124	0066	0086	0115	0325
SN	1129	1079	1142	1210	1253
MO	162	0157	0170	0165	0170
BI	402	0395	0417	0320	0323
NE	143	0139	0150	0143	0149
F					
HG					
S					

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