Mode of Extrusion of Frenchman's Barn, Dunn Point Volcanic Formation, Arisaig, Antigonish County, Nova Scotia

by

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Work Time.

Field Work : 8 days

Microprobe : 8 hours

Thin Sections: 30 hours

Microphotos : 6 hours

Writting and Reasearch : 2 months.

Total Hours : 356.

Sources

- R. MacKay - Microprobe
- Boucot et'al. 1974. - Figure 2 and 4.

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Abstract

Frenchman's Barn, near Arisaig, Nova Scotia, is an enigma. It contains some of the textural characteristics of ash flows and lava flows and some which are not common to either. Part of the problem is that many of the original textures in the Barn have been destroyed by the later alteration and recrystallization textures now found in the Barn.

The Barn is one cooling unit consisting of three major rock types, a lower smooth-banded rock type containing elongated amygdules and sheets of devitrified glass, a massive rock type above, containing parallel, discontinuous, quartz-stringers and an upper contorted-banded rock type containing sporadic banding and occasional lithic inclusions.

It is thought that Frenchman's Barn was deposited as a lava flow because of such textural features as smooth, continuous banding at the base of the section, sporadic contorted banding at the top, and a lack of easily identifiable pumice fragments, glass shards and lapilli.

Frenchman's Barn was probably deposited as a very hot lava which was ponded soon after extrusion. The cooling effect of the ground and the force of the overlying magma resulted in smooth, continuous banding at the base. The cooling effect of the air and a limited

amount of movement resulted in sporadic contorted flow banding near the top of the flow. The central, massive portion was the last to freeze and as a result relatively coarse-grained quenched crystals with sutured boundaries developed.

The quartz stringers of the massive rock type are thought to have formed as a result of shear stresses causing weaknesses or fractures in the rock which were later filled by a quartz-rich vapour phase.

Alkali enrichment (metasomatism ?) has occurred in parts of the Barn, probably during regional metamorphism.

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Acknowledgements

I would like to thank Mr. H. D. MacGillivary for his hospitality and for his permission to work and camp on his property. I am deeply indebted to Mr. P. Mitchell and Mr. P. Thomas for their perseverance, hard work and astute observations while assisting me in the field. Thanks go to Mr. R. MacKay for his instruction and assistance with the microprobe analyses. I would like to express my gratitude to Mary Ann Annand for her professional typing job.

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Chapter 1: Introduction

Introductory Statement

Frenchman's Barn is a resistant body of siliceous igneous rock standing high above the sea shore, northeast of Arisaig Pier, Nova Scotia. It is a member of the Dunn Point Volcanic Formation which consists of rocks of andesitic and rhyolitic compositions. There are three textural rock types of rhyolitic composition which are readily recognizable. These are rhyolite lavas, tuffs of various degrees of welding and silicic lahars. Frenchman's Barn however, lacks easily identifiable textures which would distinguish it as an ash fall, ash flow or rhyolitic lava and because of this, its origin is obscure. The purpose of this study is to better understand the processes which led to the formation of Frenchman's Barn.

Size and Location

The Frenchman's Barn outcrop is 150 metres long in the east-west direction, 40 metres wide in the north-south direction and rises 20 metres above the sea at its highest point.

It is located, on the shore, 1.6 kilometres to the northeast of the Arisaig pier in Arisaig (Figure 1). Arisaig is a small village on the Northumberland Strait, 24 kilometres northeast of Antigonish, Nova Scotia (Figure 2). It can be reached from New Glasgow or Antigonish on the paved secondary road Nova Scotia Route 245. Direct

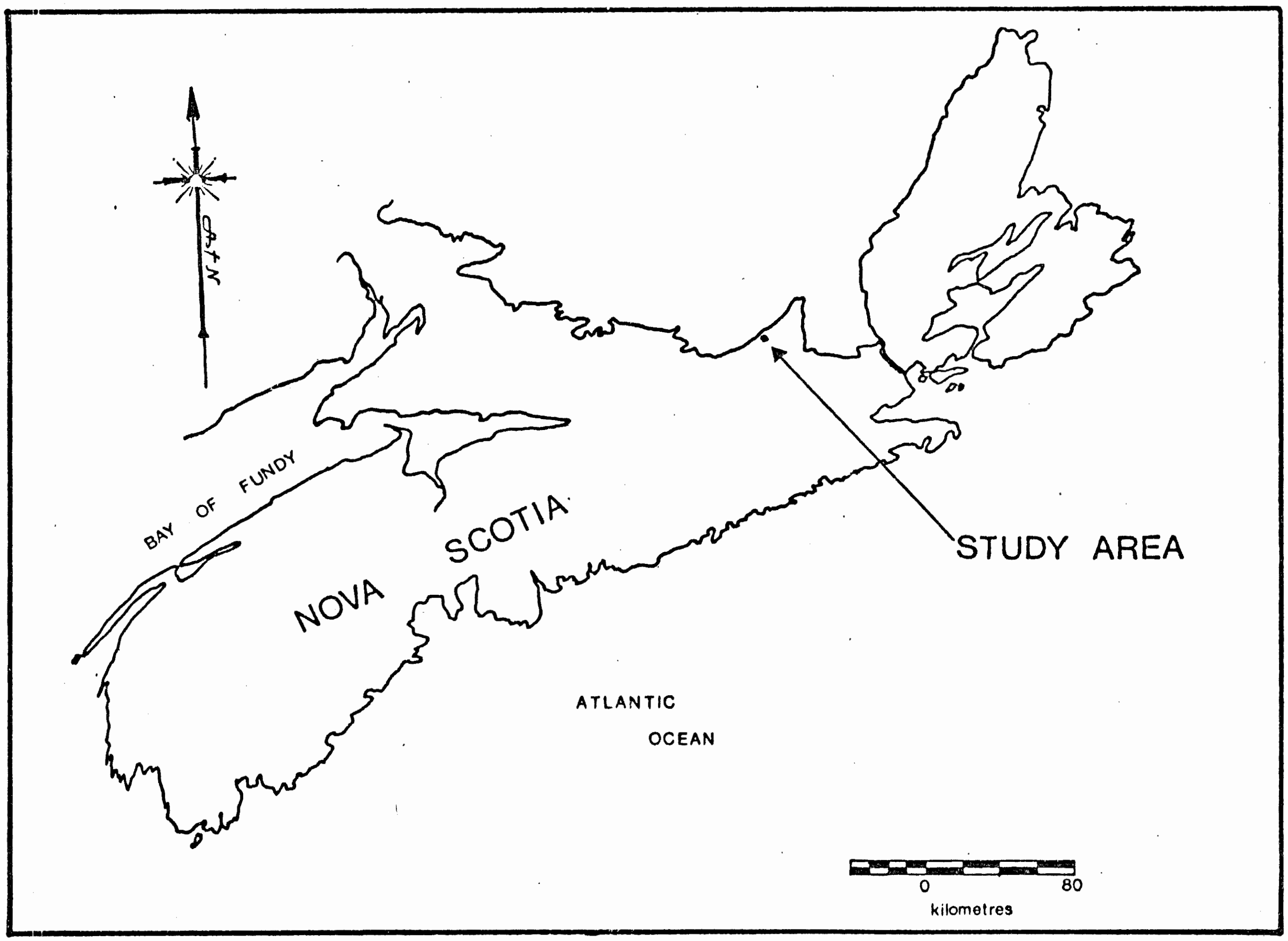

Figure 1. Location of Arisaig study area.

access to Frenchman's Barn can be made over a short, private road leading to the cottage of Mr. H. D. MacGillvary.

The Frenchman's Barn Problem

The object of this study is to determine the processes which led to the formation of the body of rock known as Frenchman's Barn. There are many cases in acid extrusive rocks in which the processes of formation are quite straightforward. For example, flow banding in siliceous rocks is characteristic of the deposition of rhyolite lava flows. The magma is low in volatiles and very viscous so that shear forces create flow laminae which are frozen into the rock when cooled. Ash flows and falls, conversely are derived from viscous magmas high in volatiles. Ash flows are erupted violently and are transported in a very hot, denser than air, mass of gases and liquid. As a result of this "clastic" deposition the rocks show elongated pumice and glass fragments, glass bubble-wall shards, euhedral but broken crystals and horizontal flow tops. Ash falls are erupted into the air where they have time to cool before falling to the ground. This produces good stratification, good sorting, a lack of welding and compaction and a continuous blanket deposit.

Not all rocks, however, have a clear cut mode of deposition. Frenchman's Barn exhibits textures, or at least the possible remains of textures, which are indicative of both ash flows and viscous lavas. It is important to note that the rocks of Frenchman's Barn have undergone abundant secondary quartz replacement, complete devitrification, recrystallization and metamorphism. These processes have combined to destroy a large amount of the original textures in the rock and have made it difficult to attach significance to the remaining textures observed.

Previous Work

The first author to discuss the geology of the Antigonish area was Gesner (1836). Williams (1914) compiled a report on the Arisaig-Antigonish District for the Geological Survey of Canada in which he described the rocks which are presently called the Bears Brook Volcanic Group. Some work was done on the area in the 1950's as a consequence of the Massachusetts Institute of Technology holding an annual field school at Crystal Cliffs. Two M.I.T. B.Sc. theses were completed on the igneous rocks of Arisaig by Foster *et al*. (1950) and Ziegler *et al*. (1950).

Benson (1974) published two geologic maps and an accompanying memoir entitled the Geology of the Antigonish Highlands. The maps are 1361A (11E/9) and 1360A (11E/8). Boucot *et al*. (1974) published the Geological Society of America Special Paper 139 entitled the Geology of the Arisaig Area. The work on the Bears Brook Volcanic Group in that report was done by Ziegler, Dewey and McKerrow. Eames (1978) wrote a B.Sc. thesis on the geochemistry of the ignimbrites of the Dunn Point Volcanic Formation.

Geologic History

The Dunn Point Volcanic Formation is contained within the Bears Brook Volcanic Group. They were formed under predominantly terrestrial conditions as indicated by the complete lateritic soil profiles and the welded tuffs. The Dunn Point Volcanic Formation is composed mainly of andesitic and rhyolitic lava flows, ignimbrites and lateritic soils (Boucot *et al.*, 1974).

The Bears Brook Volcanic Group is unconformably overlain by a fossiliferous Beechhill Cove Formation of Lower Silurian age (lower Llandovery) and is assumed to overlie unconformably the Browns Mountain Group, which was tentatively dated as Lower Ordovician (Figure 4), (Boucot *et al.*, 1974; Benson, 1974). Fullager and Bottino (1968) analyzed twelve whole rock samples from the Dunn Point Volcanics for rubidium, strontium and strontium isotopes and obtained an age of 430 ± 15 m.y. Thus the age is interpreted as the uppermost Ordovician.

The rocks of the Dunn Point Volcanics are interpreted as having extruded in a "non-orogenic environment, probably related to continental rifting", (Keppie *et al.*, 1978). Metamorphism to the greenschist facies has occurred probably as a consequence of the Acadian Orogeny (Eames, 1978).

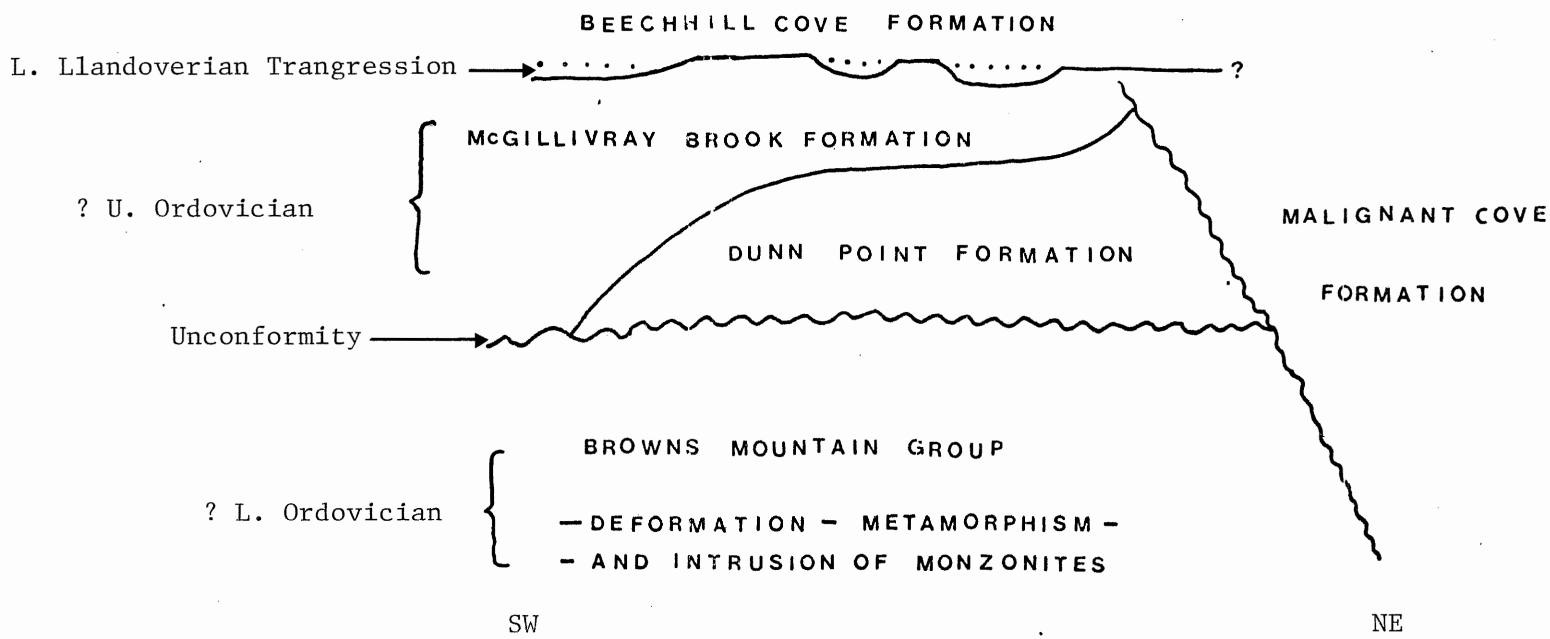

Figure 4. Stratigraphic relations of the Dunn Point Volcanic formation.

Chapter 2: Field Relations

Introduction

A total of eight days were needed in order to complete field work. These were the periods April 22-26 and October 7-9, 1978. An additional day (February 20, 1979) was spent checking field relations.

Field Methods

In order to produce an accurate and detailed picture of Frenchman's Barn and its geologic variations, all samples, pictures and descriptions were located on a map with the use of a plane table and stadia. Six base stations were used to complete the coverage of the outcrop. These were marked with piles of rubble and green fluorescent paint.

Geologic Relations

The rocks in the section are well exposed as a result of denuding by the sea. The section is right way up according to the stratigraphy of Boucot *et al*. (1974), parallel to the regional strike of approximately 060° and dipping steeply to the south at 74°. Three attitudes of joints were found 065°/S74, 167°/vertical and approximately 030°/W20. As indicated in Figure 3, all of the faults cutting through the outcrop strike in a NW-SE direction with the exception of one which strikes in a NE-SW direction. The dips of the faults were not easily discerned because of the extensive weathering along the fault which gives them a V-shape.

The rocks of Frenchman's Barn are underlain by green-black colored rocks defined as spilites by Eames (1978) and andesites by Boucot _et_ _al_. (1974) and Keppie _et_ _al_. (1978). These appear as islands in the sea 15 metres from the sea edge of the Barn. A laterite slump sheet directly overlies the Barn and is exposed in a small area on the southeast corner (Figure 3).

Major Rock Types

There are three major rock types of Frenchman's Barn which can be distinguished by general textural criteria in the field. These are designated (from lower to upper) as the smooth banded rock type, the massive rock type and the contorted-banded rock type.

Smooth-Banded Rock Type

The smooth-banded rock type can be properly studied only at low tide on a calm day or during the winter when the water has frozen.

The rock is a mottled purple and flesh color and exhibits well-developed banding which is parallel to the regional strike and dip. The bands are very sharp and planar, as can be distinguished by the three dimensional view (Plate 1). Some of these can be followed for over a metre and most for over 0.5 metres. Amygdules 1 to 3 cms long and filled with milky quartz are also characteristic of this rock type. They are elongated parallel to the direction of the banding (Plates 1 and 2). Bright red, irregular patches are found throughout the rock. These commonly follow fractures in the rock and often the center of the patch is vuggy, with some milky quartz filling. In addition, this rock type contains two or three dark brown, thin (2 to 5 cms) sheets, which weather recessively into the more resistant Barn rocks.

The sheets are parallel to the banding in the rock and continuous over a distance of at least one metre (Plate 1). The petrology of these sheets will be discussed in Chapter 3.

Massive Rock Type

The massive rock type overlies the smooth-banded rock type and comprises a significant amount of the Barn. Its color ranges from purple to flesh colored to a light green, where alteration to chlorite has taken place. The bright red, irregular patches described in the smooth-banded rock type are found scattered throughout the massive rocks as well (Plate 3).

The distinguishing textures of this rock type in the field are the numerous, discontinuous, stringers of milky quartz. These are parallel to the banding in the smooth-banded rock type, except in one case where they were observed to be deflected around an inclusion (Plate 3). The longest stringers are approximately 15 cms in length and 0.2 cms thick (Plate 4).

Contorted banding is occasionally found in this rock type, usually in isolated patches no larger than a square metre. The banding is usually strongest in the center of these patches, becoming progressively weaker away from the center until it is no longer visible. In one area where banding is developed, stringers are found amidst the banding and parallel to it (Plate 5).

Inclusions appear to be rare in this rock type. One small, dark green, fine-grained fragment was identified along with a few recognizable siliceous inclusions. There are, however, many more faint structures which may have been inclusions originally but are now not easily recognizable as such. One large siliceous inclusion is only recognizable as such because of the lack of quartz stringers inside the inclusion (as compared with outside) and by its relatively high concentration of red patches in comparison to the surrounding rock (Plate 3).

Contorted-Banded Rock Type

The contorted-banded rock type overlies the massive rock type and comprises most of the Barn. The rocks are cream-colored and completely free of the quartz stringers. Contorted banding of various orientations occurs as isolated patches. The banding becomes less distinct around the periphery of the patches until it fades out altogether (Plate 6).

Thin brown "streaks" averaging 4 cms in length and 0.1 cm in width were found in the area of point 21, (Figure 3). They form straight, discontinuous "streaks" parallel to each other and to the regional strike and dip (Plate 1).

Occasional inclusions were found in this rock type. Small, dark green, fine-grained inclusions are found concentrated in the area of point 60 (Figure 3, Plate 8). Dark red and purple, massive, siliceous inclusions show deflection of the banding, although it is hard to distinguish in the photo (Plate 9).

Other inclusions were found which are the same color as the body of the rock type. They contain well-developed, non-contorted flow banding, with their long axes oriented weakly in a direction parallel to the regional strike. The edges of the inclusions show a sharp contact with the matrix and the ends of the elongated pieces are frayed as if pulled apart (Plate 10).

The bright red patches described in the lower two rock types were also plentiful in the contorted-banded rock type.

Relations Among the Rock Types

The boundary between the lower smooth-banded rock type and the massive rock type above is gradational. The banding and elongated amygdules, that define the lower unit in the field, fade out and are gradually replaced by massive, stringer-rich rocks (Figure 3). No sharp, continuous contact was found.

The boundary between the massive rock type and the uppermost contorted-banded rock type usually occurs over a distance of 1 - 2 metres. This transition zone undulates between the two rock types at an approximate strike of 050° until it reaches the southwest corner of the knoll where it changes its strike to approximately 270°. The transition zone itself contains some small patches of stringers, some small patches of contorted-banding, and in one area pinhole vesicles (Plate 2). No sharp, continuous contact was found (Figure 3).

The transition zone undulates between the two rock types. These undulations however are not large enough to account for the large scale offset which is recorded at some of the faults. This offset is attributed to fault movements.

Chapter 3: Petrology

General Petrology

Approximately 50 thin sections were made from samples collected at Frenchman's Barn. In hand specimen the rocks are usually cream-colored, light green or light red to purple. In thin section and plane light the rocks vary from red-brown to brown to a light green in the northern altered portion of the Barn. They are composed primarily of quartz, orthoclase and plagioclase feldspar (An_{15}) with secondary minerals such as sericite, calcite, zircon, epidote and iron oxides.

The rocks are holocrystalline and the grain size is predominantly microcrystalline (< 0.1 mm but crystals are visible under a microscope). There may also be some areas in the slide which are cryptocrystalline (believed to be crystalline but crystals not visible to the naked eye) and other quartz-rich areas which are fine grained (> 0.1 mm and < 0.5 mm).

Primary phenocrysts have not been found in any of the thin sections examined, nor is there evidence for their existence from field and hand specimen examinations. Large crystals of quartz were found but they exhibit textures such as anhedral crystal shapes, cavity fillings and connections with adjacent quartz veins which suggest that they are of a secondary nature.

Devitrification textures occur in all the rock types of the Barn. The most common expression is that of spherulites scattered throughout the groundmass, or as bands alternating with microcrystalline material.

The recessive weathering sheets of the lower smooth-banded unit have a brown, to dark brown, cryptocrystalline groundmass (Slide 44c, Plate 12). It is probable that these sheets were originally glass and have since divitrified to a cryptocrystalline mass.

In addition, the recessive weathering sheets contain polygonal cracks with an average diameter of 2.0 mm, together with cracks which only produce part of a polygon. These are somewhat similar to perlitic cracks and are interpreted as having formed from contraction of the rock during cooling (Plate 12).

Another texture commonly seen in the thin sections consists of anhedral, equigranular quartz and feldspar minerals, the boundaries of which exhibit a sutured texture resulting from the interfingering growth of the minerals (hereafter referred to as a "sutured" texture.) The "sutured" minerals are substantially larger than the groundmass, are inclusion-rich and have an average diameter of 0.2 mm (Plate 13). This texture is most common in the massive rock type, although it is found, to some extent, in all the rock types. In one very interesting case this "suture" texture was found to form a continuous layer amidst layers of microcrystalline contorted banding. Because of the lack of well formed crystals, the abundance of inclusions in the minerals and because of the relatively large grain size, this texture is interpreted as resulting from quenching of a crystal poor liquid.

A texture which is common throughout the Barn is expressed as localized quartz-rich areas, usually elongated parallel to the foliation in the rock. The constituent minerals are coarse grained relative to the grain size of the groundmass, and they form equi-granular, spherical grains (Plate 14). This texture is found in the rhyolites of Arisaig pier and other rhyolites of the Dunn Point Volcanic Formation but it has not been found in any of the thin sections defined as ignimbrites by Eames (1978).

Rock-Type Descriptions

The following is a short summary of the textures of typical thin sections of each rock-type, condensed from Appendix A.

Smooth-Banded Rock-Type

Banding occurs in this rock type as alternating layers of spherulites and microcrystalline groundmass. The spherulitic texture averages 0.5 mm in thickness and forms a columnar pattern as a result of lateral interference of the spherulites (Plate 15).

Thin sections of Arisaig Pier rhyolites and of rhyolites collected by Eames (1978) from the Dunn Point Formation also show banding due to alternating spherulitic bands and microcrystalline groundmass (Plate 16).

Massive Rock Type

The most prevalent texture in this rock type is the microcrystalline groundmass. It is medium-brown in plane light and black in crossed nicols.

Distinct from the groundmass are relatively coarse-grained, quartz-rich patches (mentioned earlier in this Chapter) which are light brown in plane light and grey in cross-nicols. Minute grains of opaques often surround these patches. These are sometimes elongated and parallel so as to give the rock a slight foliation.

The sutured texture is common in this rock type, forming from 10 to 90 percent of the area in a slide.

In some slides the quartz-rich material makes up the bulk of the slide and the darker microcrystalline material forms distinct patches which give the slide a mottled appearance (Plate 14).

Spherulites are common in this rock-type, often contained amidst the suture texture (Plate 13). The stringers, which are common only to this rock type, are composed of hypidiomorphic granular quartz.

Some of the rocks of the massive rock type do, in fact, show a preferred orientation such as in slide 22 where occasional elongated bodies filled with irregular quartz and surrounded by opaques are found in a fine-grained matrix showing spherulites (Plate 17). These textures have outlines similar to those of crushed pumice fragments. A similar texture is found in slide 45A. It also resembles crushed pumice fragments but it is much more elongated. It consists of irregular "veins" filled with anhedral quartz, opaques and a thin surrounding layer of sericite (Plate 18).

Slide 45A also contains bands of spherulites which when arranged in a linear fashion form a botryoidal-like texture (Plate 19). This texture is much like the banding found in slide 31A which was described as a rhyolite by Eames (1978) (Plate 16).

Contorted-Banded Rock Type

Banding is common in the contorted-banded rock type. The banding in the field is not continuous throughout the rock, but occurs as patches in which the banding gradually fades outward until none can be seen. Microscopic banding is found in the form of layers which are alternately rich and poor in minute opaques (Plate 20). "Suture" textures surround this banding and occur as layer within the banding (Plate 21).

Another type of banding is expressed as a compositional and grain size difference between two layers. This is typically in the form of a microcrystalline groundmass alternating with thin, slightly coarser-grained and more quartz-rich bands. These bands can be in the form of continuous layers, such as in slide 67A (Plate 21) and as discontinuous veinlets such as in slide 9A (Plate 22). These discontinuous veinlets are what were described as "brown streaks" in the previous chapter. The "streaks" are cut and offset by a perpendicular quartz vein. The vein appears to be a later event because of the offset of the streaks and because of the variable mineralogy of the streaks (i.e. streaks were not fed by the same fluids feeding the vein) (Plate 22).

Slide 9A also shows the deflection of these "streaks" around an inclusion of fine grained quartz crystals (Plate 23).

Inclusions in this rock type are in the form of fine-grained quartz crystals (discussed above), as fragments of siliceous rock (foliated and non-foliated) and as fragments of dark green, fine-grained rock. A polished thin section of the dark green inclusion was cut and the composition of the inclusion was analyzed using a microprobe. The results will be reported in the following section.

Chapter 4: Whole Rock Geochemistry

Introduction

Chemical analyses were made using the electron microprobe. A point analysis was used to determine the composition of individual crystals or of very small areas. A broad beam analysis (rastering the electron beam in order to cover a larger area) was used to determine the composition of interesting areas in the slides and as a quick and easy method of whole rock analysis. The raster area analyzed a large (hopefully representative) number of crystals because of the microcrystalline grain size of the rock.

Composition of Textural Areas

The microprobe was utilized to determine the composition of the dark green inclusions described in the previous chapters. These inclusions closely resemble the underlying dark green andesitic volcanics. An andesitic composition from the analyses would help to delineate the origin of these inclusions. Upon analysis it was found that the dark green inclusions (at least the ones analyzed) have a felsitic composition and lack such elements as Ca and Mg which would point to an andesitic origin (GM-1 Table 1).

The microprobe was also used to determine the composition of the light-colored, relatively coarse-grained, irregular patches described in the previous chapter. Analyses were made on slide 60A, which is part of the contorted-banded rock type and it was discovered that these patches are significantly richer in silica than the average

TABLE 1: Chemical Analyses (weight percent) and CIPW Normative Mineralogy.

	1	2	3	4	5	6	7
SiO_2	58.94	83.84	80.67	45.41	99.12	70.93	72.58
TiO_2	0.05	0.14	–	–	–	0.11	0.26
Al_2O_3	20.70	9.33	10.77	17.86	0.41	15.91	14.89
Cr_2O_3	–	–	0.07	–	0.08	–	–
Fe_2O_3	–	–	–	–	–	–	–
FeO	4.25	0.36	0.42	0.70	0.07	1.70	2.08
MnO	–	–	–	–	–	–	–
NiO	–	–	–	0.07	0.07	–	–
MgO	–	–	–	–	0.13	–	–
CaO	–	–	–	–	–	0.05	0.06
Na_2O	1.69	3.85	3.75	3.07	0.09	2.59	2.44
K_2O	11.37	2.41	3.46	10.86	0.17	6.50	5.66
P_2O_5	–	–	–	–	–	–	–
CO_2	–	–	–	–	–	–	–
H_2O	–	–	–	–	–	–	–
S	–	–	–	–	–	–	–
Total	97.01	99.93	99.15	97.91	100.22	97.04	97.97
Q			5.47			29.90	35.76
Or			65.61			39.48	34.17
Ab			26.53			22.50	21.07
An			–			0.25	0.30
Hy			1.31			3.02	3.46
Cr			–			–	–
Il			–			0.21	0.50
C			1.07			4.64	4.73
Total			100.00			100.00	100.00

1: GM-1, Point 60A
2: GM-3, Point 60A
3: P-6, Point 71
4: P-7, Point 71
5: P-8, Point 71
6: 66B-1, Point 66-B
7: 66B-3, Point 66-B

compositions of the microcrystalline groundmass of the Frenchman's Barn rocks. The area probed had a silica percentage of 83.83 as compared with the average silica composition of the groundmass of 69.17 percent (average of P-7, 66-B-1, 66-B-3, Table 1).

Small, parallel, rod-shaped patches with a coarse-grained inner core, a fine-grained outer core and a surrounding stain of black opaque material were examined chemically using the microprobe. It is possible that these textures represent the remains of fiammé (Figure 5). It was found that the inner core is composed almost entirely of quartz (99.12 percent silica (P-8, Table 1) and that the outer core is silica-rich (80.67 percent, P-6, Table 1). These values are significantly higher than the silica value for the groundmass which is 65.41 percent silica (P-7, Table 1). The high silica values found within the inner and outer cores of this texture are not comparable with those expected from pumice fragments of a normal rhyolite composition, such as that of the groundmass (P-7, Table 1).

Whole-Rock Geochemistry

A number of areas of microcrystalline groundmass (original rock ?), in the slides were analyzed as an approximation of the whole-rock compositions. The composition produced by this method is probably low in silica because of numerous (secondary ?) quartz-rich areas in the rocks which were not accounted for by the analyses. The compositions were run in a CIPW normative computer program. The results are shown in Table 1. Each analysis was

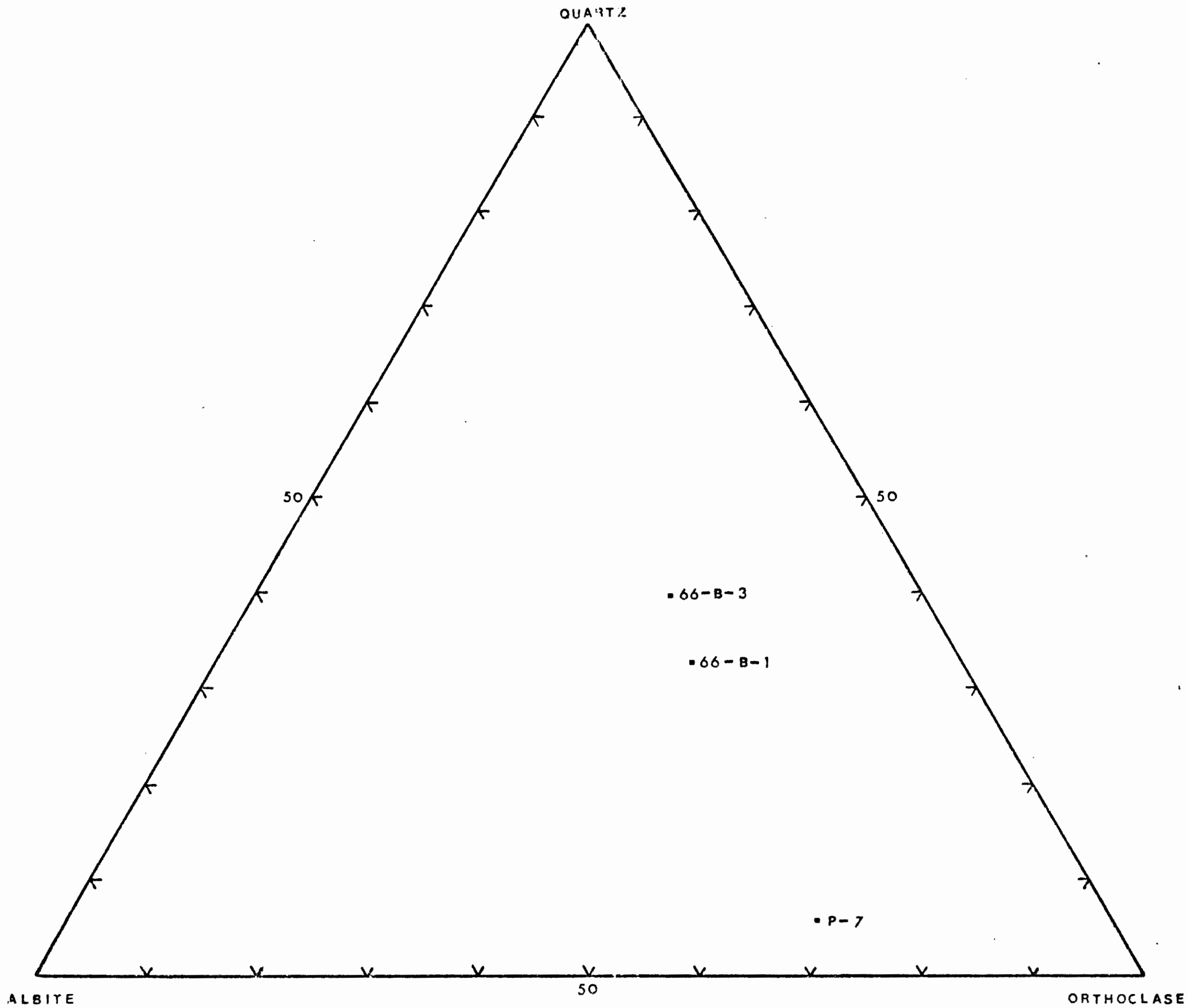

Figure 5. Distribution of normative Ab-Or-Q of three analyses from Frenchman's Barn (after Tuttle anb Bowen, 1958).

plotted on a quartz-albite-orthoclase normative graph (Figure 5).

The normative compositions of analyses 66-B-1 and 66-B-3 have plotted on an area of the graph which is common for rhyolite compositions (Tuttle and Bowen, 1958). Analysis P-7, however, had an unusually high content of K_2O (10.86 percent) and as a result plots near the orthoclase corner of the diagram. It should be noted that the chemical analysis which was made of the dark green inclusion (GM-1, Table 1) also showed an unusually high amount of K_2O, especially if it is correct to assume that the inclusion was originally basic in composition. If a second assumption is made that all the rocks of Frenchman's Barn had an originally rhyolitic composition somewhere near 66-B-3 and 66-B-1, it appears that preferential enrichment of K_2O has occurred in some parts of the Barn. Eames (1978) found abnormally low Na_2O/K_2O ratios, especially in the rhyolitic samples analyzed. She suggested three possibilities as explanations for this phenomenon: (1) a high K_2O percentage due to sericite; (2) K_2O concentration during differentiation and (3) diffusion of sodium into basalt during low grade metamorphism (spilitization ?).

The rocks of Frenchman's Barn are slightly different than those described by Eames (1978), in that the Na_2O/K_2O ratio is not as low in the Barn rocks. The K_2O percent is high but the Na_2O is over 3 percent for most Barn analyses as compared with less than one percent for many of the analyses of Eames (1978).

Chapter 5: Discussion

Introduction

This work is an attempt to delineate the process of deposition of Frenchman's Barn through the study of its texture. In order to present a concise summary of the textures found in each possible manner of deposition and compare them directly to Frenchman's Barn, a table of field and petrologic relationships was developed (Table 2).

Introduction to Table 2

There are a few field relations which will be deduced prior to the presentation of the table in order to make the table less complex.

The first is that the rocks of the Dunn Point Volcanics were deposited subaerially so that subaqueous deposition will not be discussed. The evidence for this is the development of lateritic soil horizons and the lack of pillow structures in the andesites.

The second deduction is that Frenchman's Barn represents only one depositional unit. There are three distinct rock types found on the Barn but at no point is a sharp contact found between them. The meeting of the lower smooth-banded rock type and the massive rock type above is clearly gradational, the lower banding being gradually replaced by stringers.

The massive rock type and the contorted-banded rock type above are separated by a transitional zone 1-3 metres wide. This zone undulates between the two rock types and at one point the zone strikes at nearly 90° to the regional strike. As a result the contorted-banded rock type cuts down deeply into the vertical section (Figure 3).

The argument against these rock types being separate units is that the top of the massive rock type does not resemble the expected surface of an ash flow (horizontal, smooth, non-welded), a lava flow (undulating and scoriaceous) or an ash fall (relatively smooth, non welded). Therefore, if they are separate units, substantial erosion of the massive rock type must have taken place. Erosion would explain the cutting of the contorted-banded rock type into the massive rock type but this erosion should be expressed in the rock by a weathered zone or at least by a sharp contact, neither of which is visible.

A discussion of important textures and structures related to the process of deposition is made in Table 2. The textures and structures are listed in the first column, the next three columns describe how these are expressed in ash flows, lava flows and ash falls respectively and the final column describes how they are expressed in Frenchman's Barn.

Summary Table

Table 3 is a summary of conclusions which were made by comparing the Frenchman's Barn column with the three columns describing the various structures and textures.

FIELD RELATIONSHIPS				
Textures & Structures	Ash Flow	Rhyolitic Lava Flow	Ash Fall	Frenchman's Barn
Thickness of unit	Generally thick - range 2 - 170 metres, average - 75-100 metres (Gorshkov, 1963; Ross and Smith, 1961)	Generally thick	Various	40 metres thick
Lateral extent	Extensive sheets to tongues in valley (Peterson, 1970)	Restricted	Extensive	Restricted in present outcrop area
Shape of unit surface	Smooth, horizontal (Ross and Smith, 1961)	Rough, scoriaceous (Ross and Smith, 1961)	Smooth, mirrors topography (Ross and Smith, 1961)	Smooth, probably eroded non scoriaceous, dense
Characteristics of unit base	Non-welded ash	Brecciated or linear flow banding (Christiansen and Lipman, 1966)	Non welded ash	Linear foliation but lower contact not seen (Plate 1)
Resistance to weathering	Resistant to non-resistant	Resistant	Non-resistant	Resistant. Note ignimbrites of Dunn Point Formation susceptible to weathering
Variability of unit thickness	Variable (Ross and Smith, 1961)	Variable	Constant thickness at local scale. Thins away from vent at regional scale (Ross & Smith, 1961)	Variable. May be due to erosion.
Lateral textural variation	Little	Little	Progressively finer grained	Some inclusions concentrated in one area

Textures & Structures	Ash Flow	Rhyolitic Lava Flow	Ash Fall	Frenchman's Barn
Vertical textural variation	Yes: different degrees of welding and compaction (Peterson, 1970)	Yes, variation in flow banding, degree of crystallinity, breccia- tion (Christiansen and Lipman, 1966)	No	Yes, type of banding, its abundance and the stringer zone
Bedding	Non-bedded (Fitch, 1967)	Non-bedded	Well-bedded (Ross and Smith, 1961)	Non-bedded
Sorting	Non-sorted (Fitch, 1967)	Non-applicable	Well-sorted (Ross and Smith, 1961)	Individual grains not possible to distinguish
Continuous Horizontal Banding	No, rarely 0.5 metres	Yes, at the base of the unit (Christiansen and Lipman, 1966) (Rutten 1963)	Yes, throughout the unit	Yes, at the base of the unit, greater than 1.0 metres (Plate 1)
Contorted Banding	No, rarely	Yes, middle and upper part of unit (Rutten, 1963). Extensive	No	Yes, in upper portion of unit (Plate 6). Not ex- tensive.
Pumice Fragments	Yes, compacted, elongated (Ross and Smith, 1961)	No	Yes, not compacted (Ross and Smith, 1961)	Possible elongated and compacted (Plates 4 & 17)
Pinhole Vesicles	Yes (Ratte and Steven, 1967)	Yes	No	Yes (Plate 11)
Elongated Amygdules	Yes, not often (Fitch, 1961)	Yes, common (Christiansen and Lipman, 1966)	No	Yes, base of unit. (Plates 1 & 2)
Foreign Inclusions	Yes, many - average 5% of rock. (Ross & Smith, 1961)	Yes, not common (Ross and Smith, 1961)	Yes, near vent	Yes, < 1% (Plates 8 & 9)

Textures & Structures	Ash Flow	Rhyolitic Lava Flow	Ash Fall	Frenchman's Barn
Density	Dense → light (Marshall, 1935)	Dense	Light	Dense, but metamorphism has resulted in the filling of voids.
PETROLOGIC RELATIONSHIPS				
1. Spherulitic Layers	Not common	Yes, common (Christiansen and Lipman, 1966) (Boyd, 1961)	Not common	Yes, found in massive and smooth banded rock types (Plates 13 & 14)
2. Banding due to concentrations of opaques	Yes, long thin crystallites (Eames, 1978)	Yes, bands of minute particles and long thin crystallites (Christiansen and Lipman, 1966)	Not common	Yes, bands of minute particles (Plates 20 & 21)
3. Banding due to grain size	Not common	Yes (Christiansen and Lipman, 1966)	Not common	Yes, but may be associated with recrystallization due to metamorphsim (Plates 15, 21 & 22)
Shards	Yes, stretched and flattened generally (Marshall, 1935)	No	Yes, non-compacted	Not recognized
Ash	Yes	No	Yes	Not recognized, devitrification can mask existance
Lapilli	Yes, flattened (Ross & Smith, 1961)	No	Yes, not flattened (Ross & Smith, 1961)	Possibly, structures seen which could be lapilli, identification not certain

Textures & Structures	Ash Flow	Rhyolitic Lava Flow	Ash Fall	Frenchman's Barn
Welding	Yes (Ross and Smith, 1961)	No	No (Ross and Smith, 1961)	Not recognized
Perlitic Structure	Yes (Mazzoulli and M. Pratesta, 1963)	Yes	No	Similar texture - polygonal cracks
Evidence of glass	Yes	Yes	Yes	Yes - devitrification textures (Plates 12, 16 & 19)
Phenocrysts	Broken (Mazzoulli and M. Pratesta, 1963)	Intact	Broken	Non-existant
Distortion around solid objects	Yes, shards or pumice Marshall, 1935)	Yes, flow laminae (Christiansen and Lipman, 1966)	No	Yes, brown "streaks", stringers (Plates 3 & 23)

Three terms were used to indicate the degree of similarity between Frenchman's Barn and features from deposits of known origin. A (+) sign is used to indicate that textural or structural evidence is found in the Barn rocks which supports this type of origin. A (o) sign is used when the evidence is neutral or not applicable, and a (-) sign is used to indicate that the evidence is unfavourable towards this mode of origin. An asterisk (*) sign means that the structure or texture is crucial because it is a characteristic of almost all rocks formed in that manner.

Examining the summary table it is possible to state with a great deal of confidence that Frenchman's Barn was not deposited as an ash fall. The ash fall column had a total of 2 positive (+), 14 negative (-) and 11 neutral (o) correlations with Frenchman's Barn. All the critical characteristics were negative. The ash flow column had a total of 9 positive, 5 negative and 13 neutral correlations as compared with 15 positive, 3 negative and 9 neutral correlations in the lava flow column. Therefore, the best correlation with the Frenchman's Barn rocks is the lava flow. Comparison of the critical characteristics of the ash flow and lava flow columns supports this conclusion. The ash flow column contains 2 positive, 4 negative and 2 neutral out of a total of 8. The lava flow column contains 6 positive, 2 negative and 2 neutral out of a total of 10. The conclusion reached is that Frenchman's Barn was deposited as a lava flow.

TABLE 3

Texture and Structures	Ash Flow	Rhyolitic Lava Flow	Ash Fall
Thickness of unit	o	o	o
Lateral extent	+	+	-
Shape of unit surface	+	-	+
Characteristics of unit base	o	+	o
Resistance to weathering	o	+	* -
Variability of unit thickness	o	o	-
Lateral textural variation	o	o	o
Bedding	o	+	* -
Sorting	+	+	* -
Continuous horizontal banding	* -	* +	-
Contorted banding	* -	* -	-
Pumice fragments	* +	* -	-
Pinhole vesicles	+	+	o
Elongated amygdules	o	+	-
Foreign inclusions	* o	o	o
Density	+	+	* o
Banding due to layering of spherulites	* -	* +	-
Banding due to concentrations of opaques	+	* +	o
Banding due to grain size differences	-	* +	+
Shards	* -	* +	-
Ash	* o	* o	o
Lapilli	* +	* o	o
Welding	o	o	* -
Perlitic structure	+	+	-
Evidence of glass	o	o	o
Phenocrysts	o	o	o
Distortion around solid Objects	o	* +	* -
Total +	9	15	2
Total -	5	3	14
Total o	13	9	11

Lateral Extent

The lateral extent of the rocks of Frenchman's Barn is not known. It is possible, however that the Frenchman's Barn rocks are not laterally extensive. The evidence is that the Barn rocks are unique because they are phenocryst-free and contain distinct bright red patches. All other rocks examined of the Dunn Point Volcanics contain phenocrysts and do not exhibit the bright-red patches. Figure 2 shows the equivalent rocks of Frenchman's Barn under the sea. However if these rocks were as recent as the Barn rock they would probably be exposed. The rock composing the Barn may have originally flowed into a depression or valley thus limiting their lateral extent.

Anomalous Textures

There are a number of textures found in the Barn which are not useful in defining the manner of deposition of the rock, essentially because the process producing the textures is not known. These will be discussed in the following pages.

Bright red, irregular patches with small, drusy vugs are described in Chapter 2 (Plates 3 and 4). These were found in all the rock types of the Barn but not in any of the other rocks in the Dunn Point Volcanics. This indicates that they are not a regional phenomenon. These textures can often be seen branching out from a central patch and moving vertically and horizontally, often along fractures in the rocks. This following of cracks suggests that the texture is secondary and the vugs filled with drusy quartz suggests that fluids were moving through the patches. Therefore the texture is probably a result of alteration by fluids travelling through the rock soon after deposition. The red coloration may be due to staining from iron transported by the fluids.

The dark brown, recessive weathering sheets are described in Chapters 2 and 3. They appear to be long thin sheets of divitrified glass, parallel to and in the center of well-developed, smooth banding. They are probably the result of quick-chilling of the base of the unit as it was cooled through contact with the ground.

The quartz-stringers are restricted to the massive rock type. If it is assumed that the rock originated as an ash flow these stringers might be explained as stretched pumice fragments of an intensely welded tuff, which were later replaced by quartz. This is supported by the evidence that these structures are parallel to the general lineation in the Barn. These structures may have been stretched due to secondary flowage from intense welding and compaction of an ash flow. If this was the case, however, the boundary between this rock type and the overlying stringer-free, contorted-banded rock type would likely be a contact between two cooling units. The evidence for this is poor, as was disucssed in the beginning of this chapter.

If it is assumed that the Barn originated as a lava flow, then the stringers are probably related to flowage. The evidence for this is that they are deflected around lithic fragments and in one case they follow the contortions of some banding. This, and the fact that the stringers gradually replace the lower smooth banding, suggests that the stringers may have originated in a manner similar to that of flow banding. These stringers are quartz-filled, however, which is usually a secondary feature. It is possible that fractures or at least weaknesses in the rock resulted from shear forces (perhaps the lava was too hot to develop flow banding) and that these were later filled by quartz, possibly a quartz-rich vapour phase due to some intra-flow differentiation.

As was mentioned previously, phenocrysts are absent in the Frenchman's Barn rock. This indicates that the magma was too hot to allow the formation of crystals before it was extruded.

The quartz-rich patches are described in Chapter 3. The high percentage of silica, the irregular crystal shapes, and the lack of rhyolitic or ignimbritic textures suggests that they are of a secondary nature, possibly resulting from metamorphism.

These textures might be related to the elongated patches with the quartz inner core, silica-rich outer core and surrounding stain of opaques (Chapter 3 and 4). If these structures were originally pumice fragments, they have since undergone metasomatism and recrystallization, again, possibly due to metamorphism.

The "sutured" texture is described in Chapter 3. It is most abundant in the massive rock type but can occur in all the rocks.

The grains have sutured boundaries and inclusions which implies that they grew rapidly compared to deep plutonic minerals. The "sutured" minerals, however, are substantially larger than the other grains in the barn which implies that they cooled relatively slower. These areas may represent the hot, central portion of the flow which was the last to solidify.

Geochemical Relations

Dark-green, fine-grained inclusions were discussed in Chapter 2 and 4. Chemical analyses of the inclusions showed that they are alkali-rich (slide 60A, GM-1, Table 1). This was surprising because it was thought that the inclusions were derived from the underlying andesites. It is possible, however, that the original elements were replaced by metasomatism. Supporting evidence for this idea is the groundmass analysis of slide 71 (p. 7, Table 1). This analysis showed an enrichment in the alkalis which was substantially greater than the normal for rhyolites (Figure 4). It is apparent that parts of the Barn have undergone enrichment in the alkalis, probably during metamorphism. Sericite alteration may account for the enrichment of K_2O in some areas.

Model of Deposition

The model proposed for the deposition of the Frenchman's Barn is based on the conclusion from the summary (Table 3) that the unit was deposited as a lava flow. The rocks of the Barn were extruded at a very high temperature (as shown by the lack of phenocrysts).

Being very hot the lava flowed freely and did not develop enough shear stresses to cause flow banding, except where it was cooled at the base and near the top. By the time the magma had cooled enough to develop shear stresses in the central portion, the lava had all but stopped flowing. Perhaps it was ponded in a depression, (possible limited lateral extent favours this) and only weak flow banding was developed in isolated areas.

The quartz-stringers in the massive rock-type are thought to have formed as a result of shear stresses causing subhorizontal weaknesses or fractures in the rock. These were later filled by a quartz-rich vapour phase, developed during crystallization.

Chapter 6: Conclusions

The conclusions reached from this study are:

(1) From the consideration of all the geometrical, sructural and textural features that could be observed, it is concluded the Frenchman's Barn represents a single rhyolite lava flow which is characterized by the three distinct textural parts, the lower, smooth-banded rock type, the massive rock type and the upper, contorted-banded rock type.

(2) Textures, not seen in any Dunn Point Volcanic except the rocks at Frenchman's Barn, such as red patches, the lack of phenocrysts and quartz-stringers, suggests that the Barn was deposited with a limited lateral extent.

(3) The magma was extruded at a very high temperature as is shown by the lack of phenocrysts.

(4) Many textures such as the quartz-rich areas, the brown "streaks", and the mottled areas resulted from deuteric alteration and/or regional metamorphism (hydrothermal alteration). The red patches are local and therefore are related to deposition.

(5) Lack of flow banding in the Barn is probably a result of early ponding of a hot liquid and from shear forces being expressed in quartz stringers instead of flow bands.

(6) Alkali enrichment (metasomatism ?) has occurred in parts of the Barn, probably during regional metamorphism.

(7) The massive portion of the Barn was cooled relatively slower than the lower smooth-banded portion. This is expressed by the relatively coarser grained "sutured" texture of the massive portion and by the evidence of glass in the smooth-banded portion. The upper contorted-banded portion was cooled at a rate part way between the other two.

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Appendix A

Thin Section Descriptions

Appendix A contains descriptions of typical thin sections from each rock type, in addition to those thin sections which contained a particular feature which was discussed in the text.

Rock Type: Smooth banded

Thin Section No.: 25

Plate No.: 15

Composition: Quartzo-feldsphathic

Color (plane light): Light brown

Crystallinity: Holocrystalline

Grain Size (Groundmass): Microcrystalline

Phenocrysts: Absent

Banding: Present as alternating layers of microcrystalline groundmass and layers of spherulites, 0.5 mm in diameter.

Other Textures: Small veinlets of quartz or felsitic composition cut perpendicular to Banding.

Rock Type: Smooth-banded

Thin Section No.: 44c

Plate No.: 12

Composition: Quartzo-feldspathic

Color (plane light): Medium to dark brown

Crystallinity: Holocrystalline

Grain Size (Groundmass): Cryptocrystalline

Phenocrysts: Absent

Banding: Present as very small, aligned, red-brown acircular crystals.

Other Textures: Scattered randomly among the groundmass are small, circular concentrations of minerals, 0.2 mm in diameter, which appear to be composed predominantly of quartz. There are a number of dark brown to black patches, 1-2 mm in diameter, resulting from high concentrations of opaques. The section contains polygonal microfractures, many of which show a high concentration of opaques.

Rock Type: Massive

Thin Section No.: 41B

Composition: Quartzo-feldspathic

Color (plane light): Light brown

Crystallinity: Holocrystalline

Grain Size (Groundmass): Fine grained

Phenocrysts: Absent

Banding: Absent

Other Textures: "Sutured" textures compose approximately 40 percent of the slide. Spherulites with an average diameter of 0.5 mm make up less than 3 percent of the slide. Circular areas, high in opaques, with an average diameter of 0.5 mm are restricted to one portion of the slide. Quartz-rich areas are scattered unevenly throughout the slide.

Rock Type: Massive

Thin Section No.: 45A

Plate No.: 18 and 19

Composition: Quartzo-feldspathic

Color (plane light): Light brown

Crystallinity: Holocrystalline

Grain Size (Groundmass): Microcrystalline

Phenocrysts: Absent

Banding: Banding is expressed as slight color differences in the groundmass, parallel quartz veinlets, and as veinlets filled with felsic minerals and opaques and lined with discontinuous sericite. The opaques are short, thin and aligned parallel to the vein. They may represent pieces of a crushed pumice fragment. Other banding results from the layering of spherulites approximately 1.0 mm in diameter. The spherulites form a botryoidal like texture, when grown together, occasionally with cavities forming between the layers.

Rock Type: Massive

Thin Section Nol: 22

Plate Nos.: 13 and 17

Composition: Quartzo-feldspathic

Color (plane light): Light Brown

Crystallinity: Holocrystalline

Grain Size (Groundmass): Fine grained

Phenocrysts: Absent

Banding: Small, elongated, parallel patches with a coarse grained outer core, a fine grained inner core and a surrounding concentration of minute opaques give the slide a slight foliation. More than 80 percent of the slide area shows the "sutured" texture. Spherulites, with an average diameter of 0.5 mm compose less than 3 percent of the slide.

Rock Type: Contorted-banded

Thin Section No.: 42

Plate No.: 14

Composition: Quartzo-feldspathic

Color (plane light): Light brown

Crystallinity: Holocrystalline

Grain Size (Groundmass): Microcrystalline

Phenocrysts: Absent

Banding: Small quartz-rich patches and darker, microcrystalline patches visible only in cross nichols are oriented in a prefered direction. The microcrystalline patches have a higher concentration of opaques than the surrounding areas.

Rock Type: Contorted-banded

Thin Section No.: 25A

Composition: Quartzo-feldspathic

Color (plane light): Light brown

Crystallinity: Holocrystalline

Grain Size (Groundmass): Microcrystalline

Phenocrysts: Absent

Banding: Banding is expressed as small, parallel veinlets which are filled with quartz. The grain size ranges from microcrystalline to 0.5 mm.

Rock Type: Contorted-banded

Thin Section No.: 67A

Plate Nos. 20 and 21

Composition: Quartzo-feldspathic

Color (plane light): Light brown

Crystallinity: Holocrystalline

Grain Size (Groundmass): Microcrystalline to fine grained

Phenocrysts: Absent

Banding: Banding is expressed as alternating, microcrystalline, opaque rich and opaque poor layers. Layers with "sutured" texture are also found amidst the banding.

Other Textures: The "sutured" texture occurs in approximately 40 percent of the slide.

Rock Type: Contorted-banded

Thin Section No.: 9A

Plate Nos.: 22 and 23

Composition: Quartzo-feldspathic

Color (plane light): Light brown

Crystallinity: Holocrystalline

Grain Size (Groundmass): Microcrystalline

Phenocrysts: Absent

Banding: Banding is due to parallel, quartz-rich, fine grained veinlets alternating with the groundmass. These are discontinuous, some only a few centimeters in length. Plate 23 shows the veinlets being deflected above and below an inclusion of fine grained quartz crystals.

Other Textures: A perpendicular vein cuts and offsets the veinlets, it is believed to have followed after the veinlets.

Plate 1, point 44. Parallel, continuous banding (1), elongated amygdules (2), red patches (3), and recessive weathering sheets (4) from the lower smooth banded rock type. The black line represents approximately one metre.

Plate 2, point 15. Parallel banding, elongated amygdules and a recessive weathering sheet from the smooth-banded rock type. The scale represents approximately 36 cm.

Plate 1

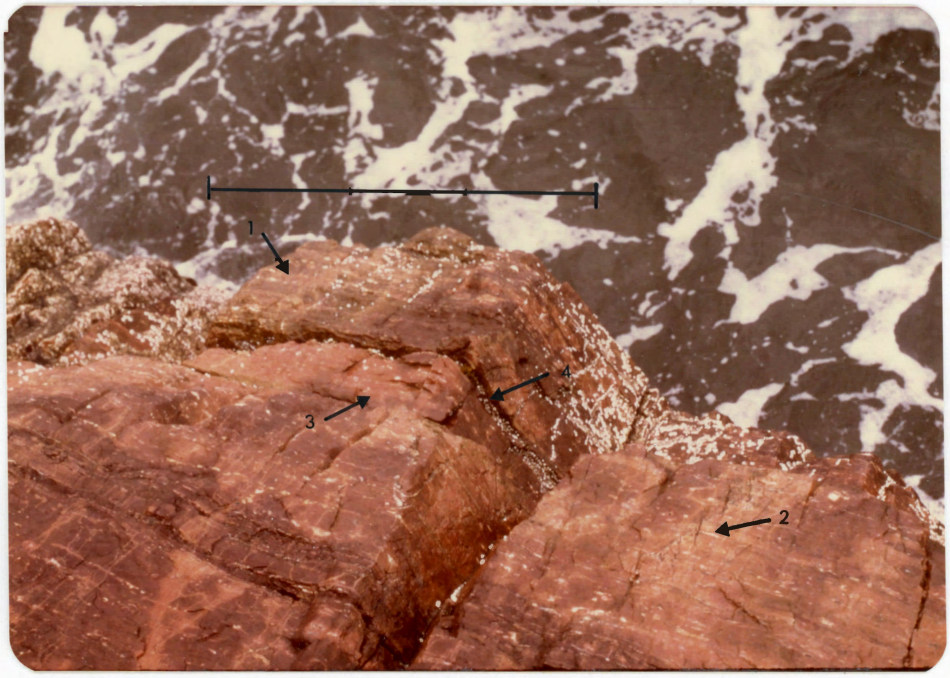


Plate 2

Plate 3, point P-6, 7. Large inclusion (outlined) shows deflection of the surrounding quartz stringers from the massive rock type. Red patches in the middle of the inclusion contain vugs partially filled with milky-quartz. Lens cap is 5.4 cm in diameter.

Plate 4, point P-4. Parallel, discontinuous, quartz-stringers from the massive rock type. Note the red patch on the cliff following a fracture. The distance is 32 cm between the 9 and 10 on the pole.

Plate 3

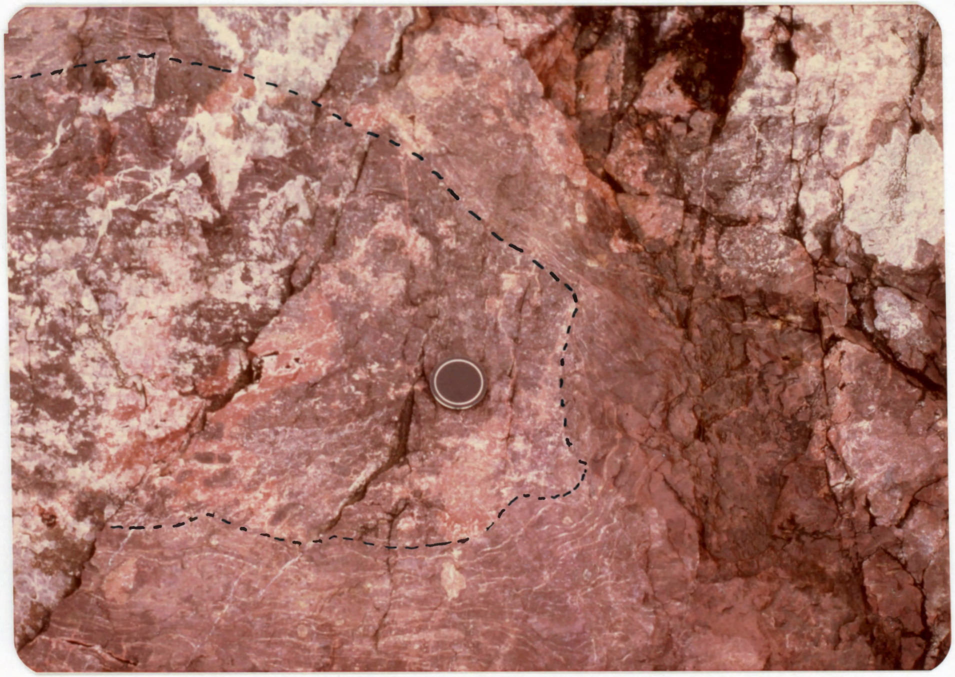


Plate 4

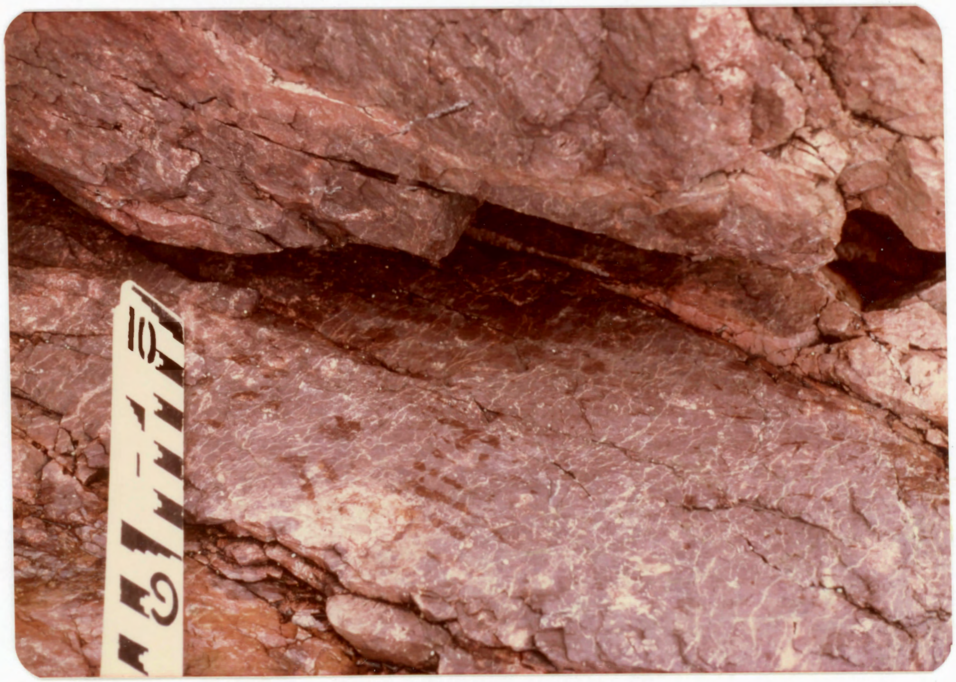


Plate 5, point P-3. Quartz-stringers contained within, and parallel to banding from the massive rock type. Lens cap is 5.4 cm in diameter.

Plate 6, point 65. Contorted-banding gradually fading out to the left of the plate, from the contorted-banded rock type. Lens cap is 5.4 cm in diameter.

Plate 5

Plate 6

Plate 7, point 21. Thin discontinuous brown "streaks" from the contorted-banded rock type. Lens cap is 5.4 cm in diameter.

Plate 8, point 61. Two dark-green, fine-grained inclusions from the contorted-banded rock type. Lens cap is 5.4 cm in diameter.

Plate 7

Plate 8

Plate 9, point 69. Silicic inclusions amidst banding (banding not easily distinguishable) from the contorted-banded rock type. Lens cap is 5.4 cm in diameter.

Plate 10, point 61. An inclusion of flow banding exhibiting a sharp contact with the country rock from the contorted-banded rock type. Lens cap is 4.5 cm in diameter.

Plate 9

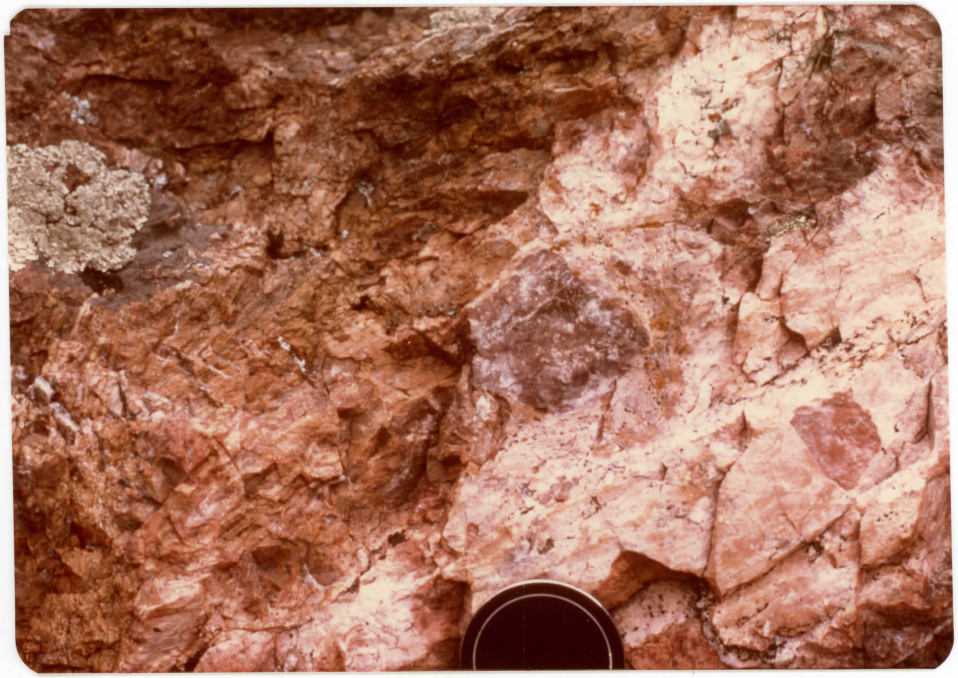


Plate 10

Plate 11, point 67. Pinpoint vesicles (to right of lens cap) filled or partially filled with quartz. Lens cap is 4.5 cm in diameter.

Plate 11

Plate 12, point 44c, (x16, plane light). Section of recessive weathering sheets showing cryptocrystalline groundmass, polygonal cracks with staining and small blebs of anhedral quartz grains. From the smooth-banded rock type.

Plate 13, point 22, (x16, crossed polars). Massive rock type showing "sutured" texture. Spherulites are indicated by the arrows.

Plate 12

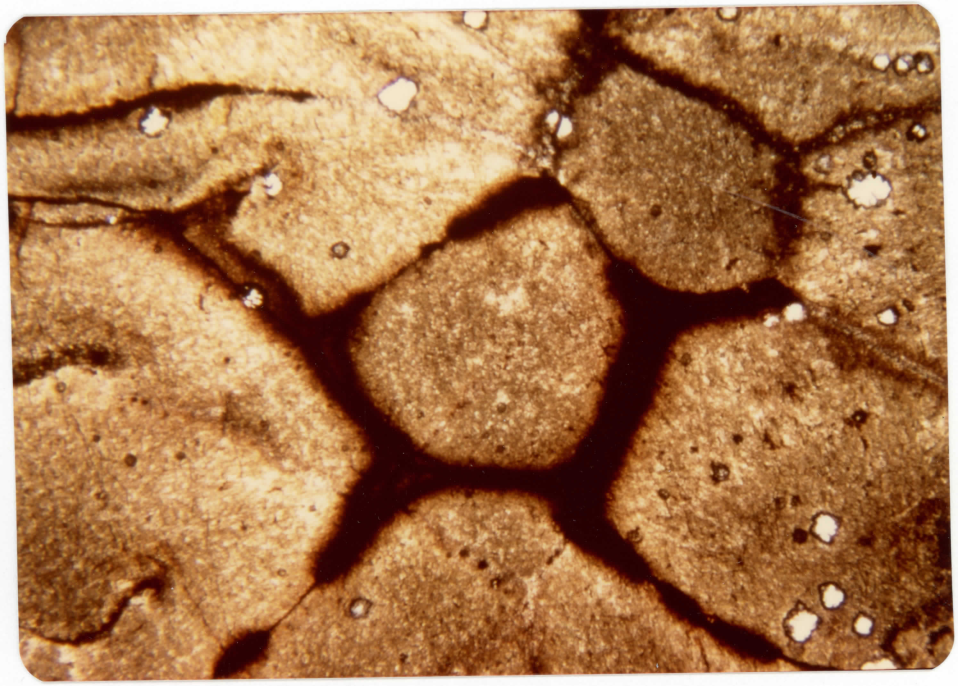


Plate 13

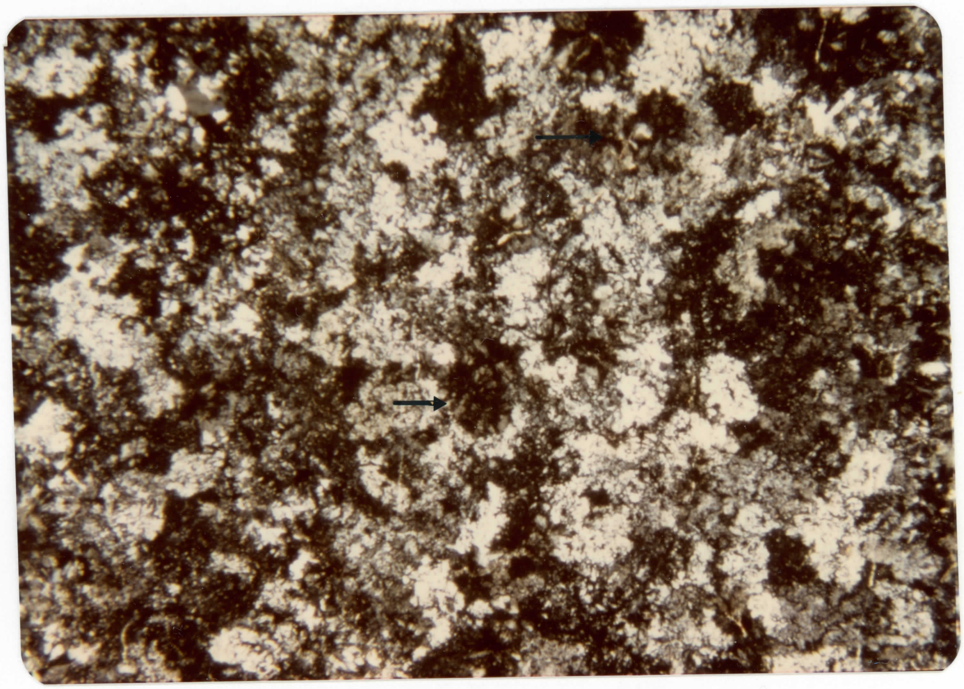


Plate 14, point 42 (x16, crossed polars). Mottling due to quartz-rich areas surrounding microcrystalline groundmass from the contorted-banded rock type.

Plate 15, point 25 (x18, crossed polars). Spherulites arranged in parallel bands alternating with microcrystalline groundmass and relatively coarser grained, quartz-rich layers from the smooth-banded rock type.

Plate 14

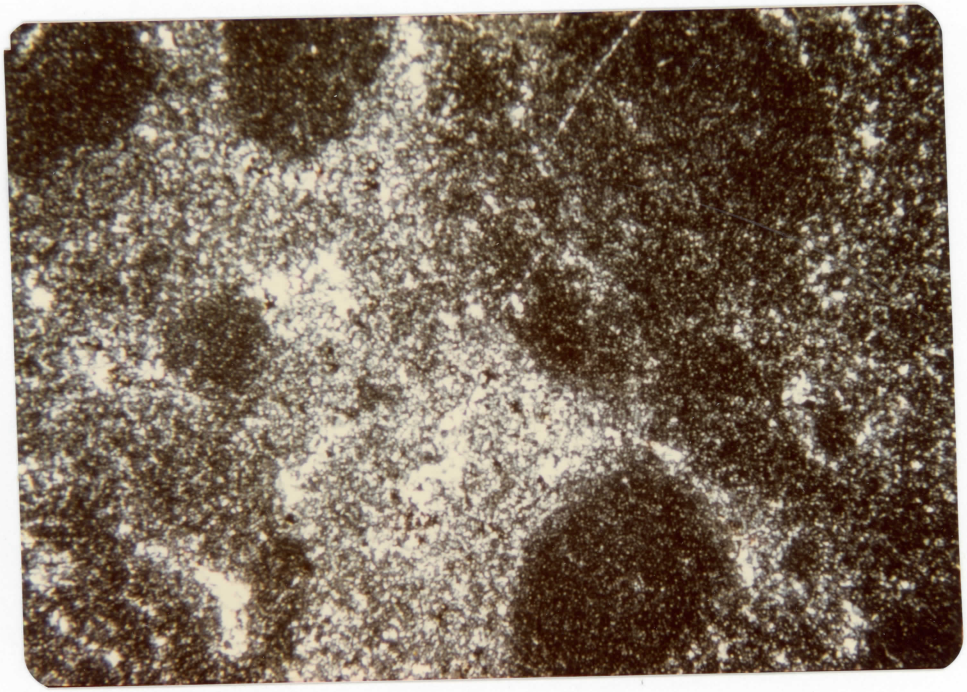


Plate 15

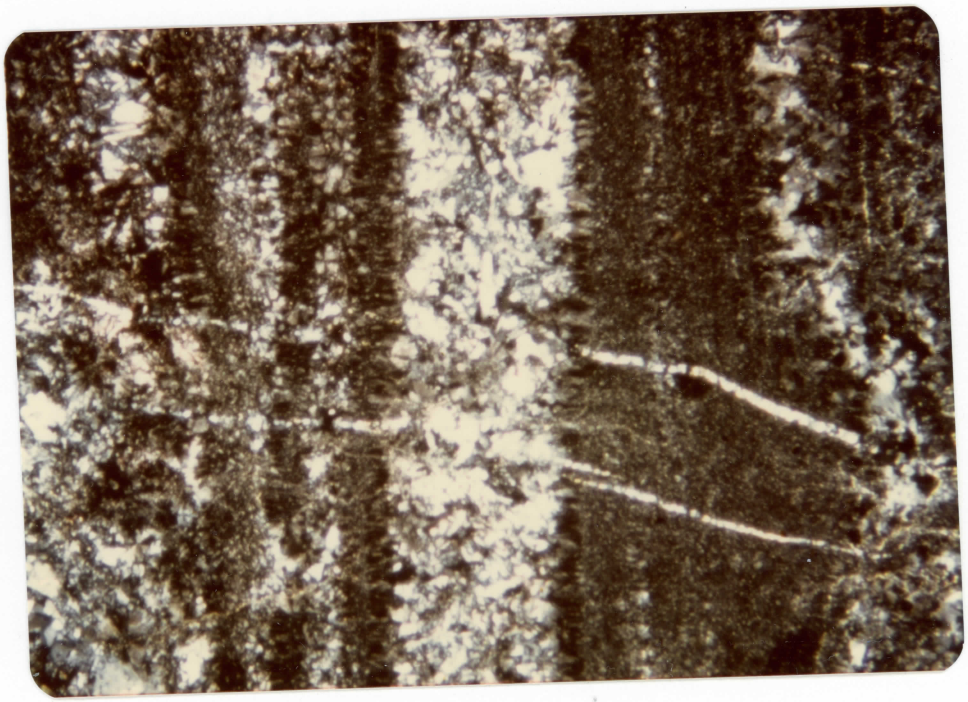


Plate 16, slide 31A (rhyolite collected by Eames (1978), not on map), (x16, crossed polars). Rhyolite showing flow banding expressed as bands of spherulites alternating with microcrystalline groundmass and layers of opaques (left edge of plate).

Plate 17, point 22, (x16, plane light). Elongated, quartz-rich patch surrounded by opaques from the massive rock type. Light brown spherulites are scattered amidst the grey, microcrystalline groundmass.

Plate 16

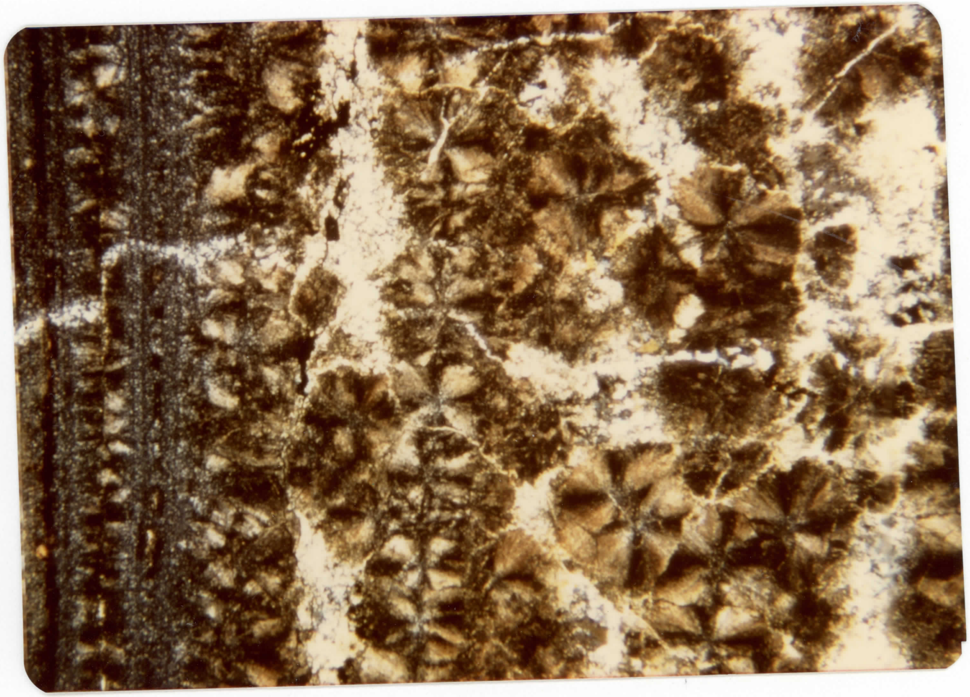


Plate 17

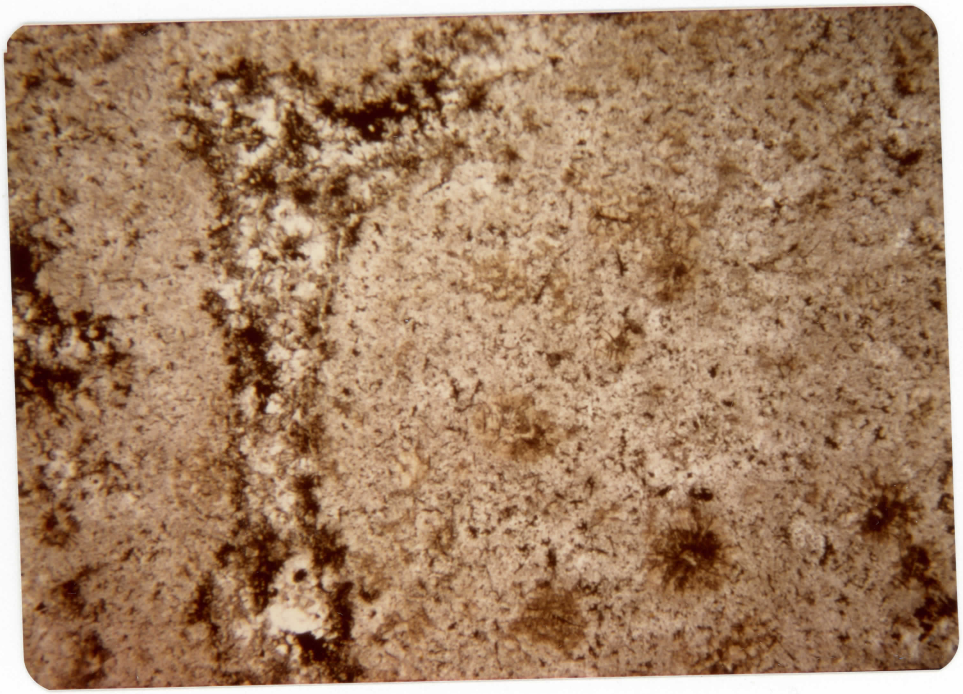


Plate 18, point 45A, (x16, plane light). Possible stretched pumice fragments containing quartz, opaques and a surrounding discontinuous layer of sericite from the massive rock type.

Plate 19, point 45A, (x16, crossed polars). Bands of spherulites forming botryoidal-like texture from the massive rock type.

Plate 18

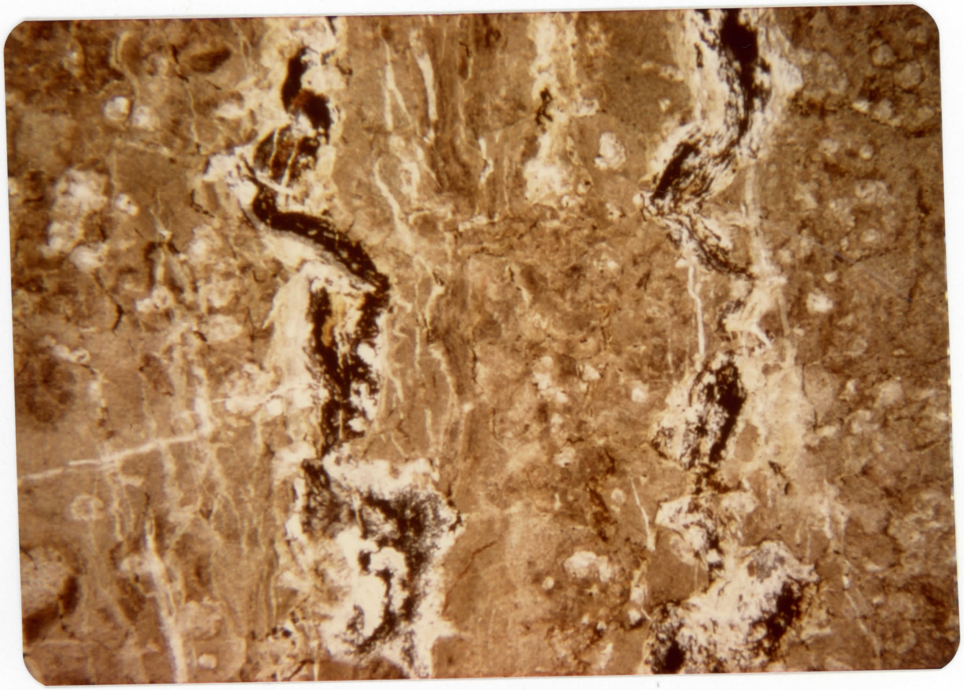


Plate 19

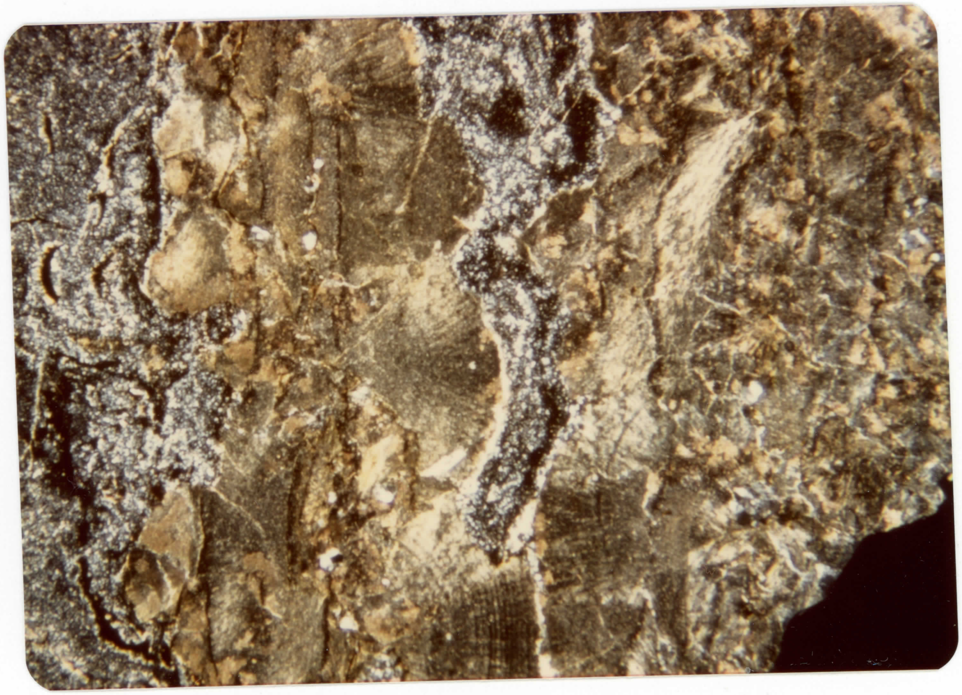


Plate 20, point 67A, (x25, plane light). Banding due to alternating opaque-rich and opaque-poor layers from the contorted-banded rock type.

Plate 21, point 67A, (x16, crossed polars). Contorted banding resulting from alternating opaque-rich and opaque-poor layers from the contorted-banded rock type. Note bands of quartz and sutured texture within banding and surrounding banding.

Plate 20

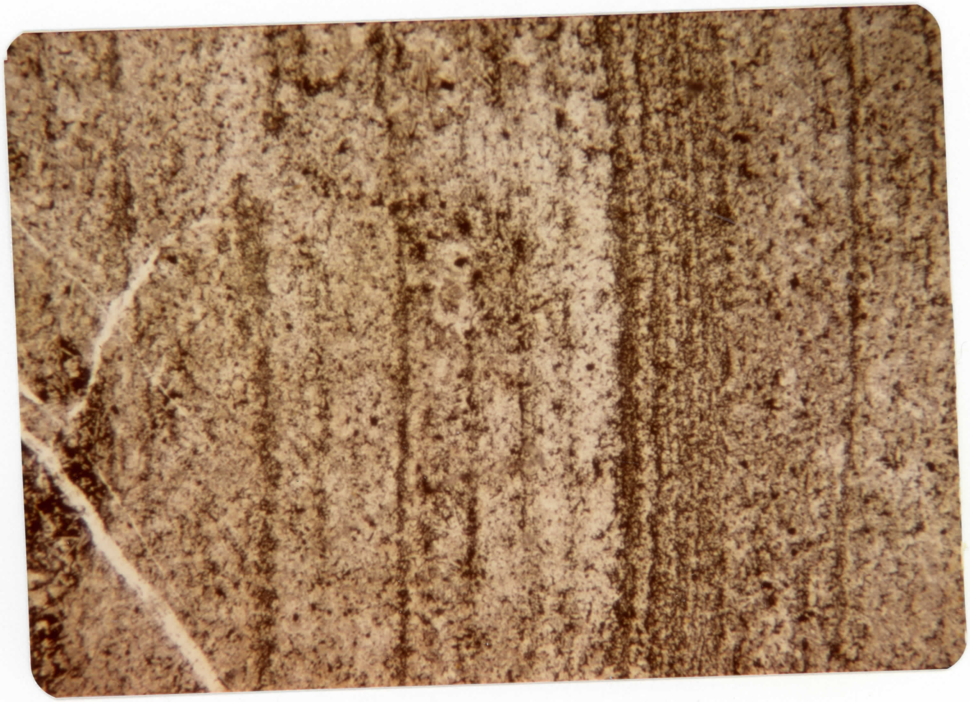


Plate 21

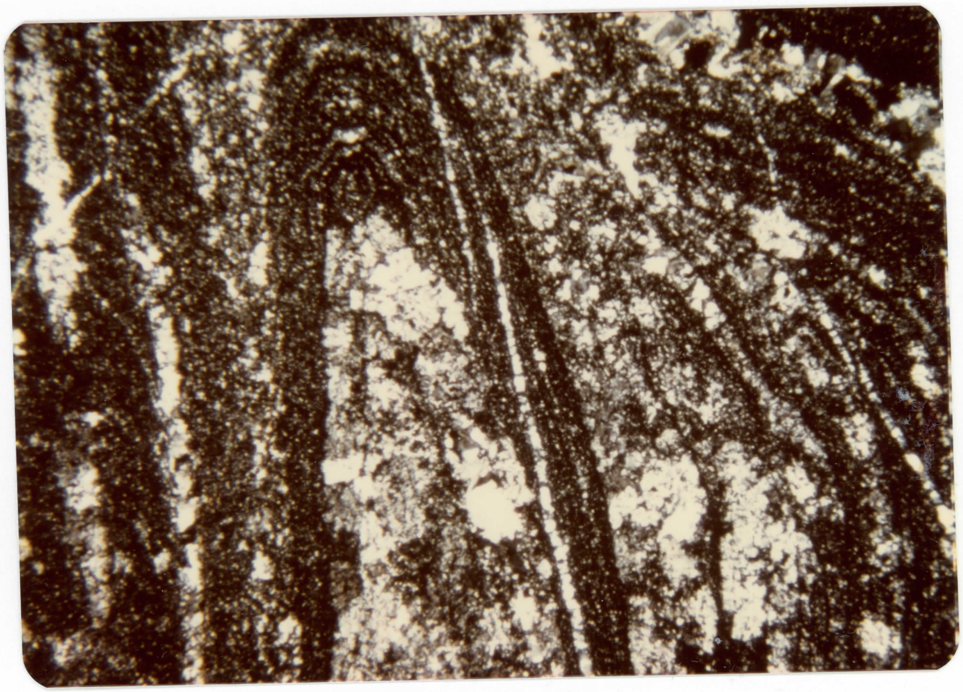


Plate 22, point 9A (x16, crossed polars). Parallel quartz-rich veinlets of varying grain sizes from the contorted-banded rock type. Note the pinching out of the veinlet in the middle of the plate and the small offset from the cutting vein.

Plate 23, point 9A, (x16, crossed polars). Quartz-rich veinlets shown deflected around an inclusion composed predominantly of quartz from the contorted-banded rock type.

Plate 22

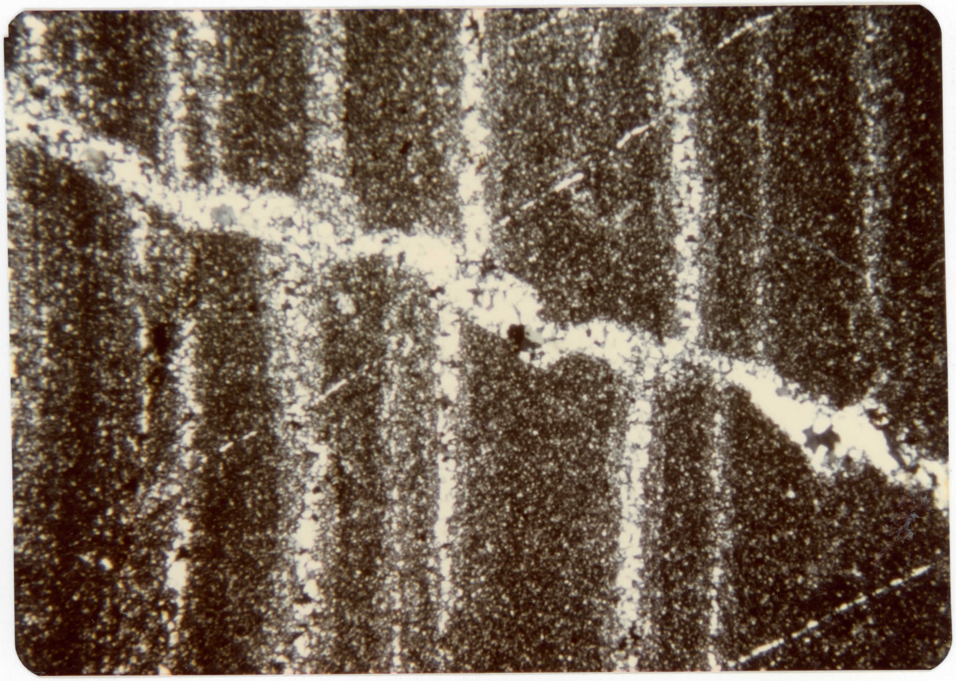
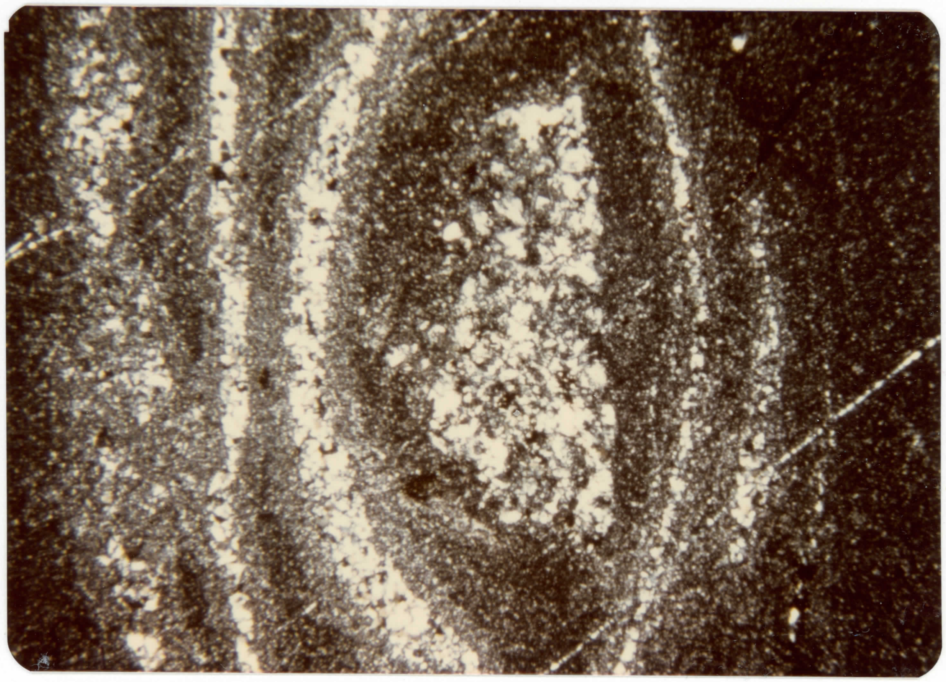


Plate 23



Appendix C

Analytical Methods

Chemical analysis were made on the Cambridge Mark V Microprobe. The operating conditions were at 15 KV EHT and 15 na probe current. An Ortec Energy Dispersive System was employed together with the Software Program EDATA from Smith and Gold of the University of Alberta.

The Energy Dispersive System has an accuracy of ± 1.5 - 2% for the Major elements. The detection limit is 0.1 percent for most elements, 0.3 percent for Na and 0.2 percent for Mg.

The standards utilized were manganese and kaersutite.

Figure 2. Shore Section from Arisaig Pier to Frenchman's Barn (from Boucot *et al.*, 1974).

Figure 3. Frenchman's Barn Sample Locations and Geologic Relations