GEOLOGY OF THE MORETON'S HARBOUR AREA, NEWFOUNDLAND WITH EMPHASIS ON THE ENVIRONMENT AND MODE OF FORMATION OF THE ARSENOPYRITE VEINS

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Geology of the Moreton's Harbour area, Newfoundland with emphasis on the environment and mode of formation of the arsenopyrite veins

by

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ABSTRACT

Basic volcanic rocks of Ordovician age near Moreton's Harbour, Newfoundland (pillow lavas, massive flows, and pyroclastic rocks) are intruded by numerous basic and acidic dykes. The rocks are cut by a network of thin veins containing abundant arsenopyrite and some stibnite, associated with pyrite, pyrrhotite, and minor sphalerite, galena, and chalcopyrite. In a few veins, stibnite predominates. Both arsenopyrite and stibnite veins have been mined on a small scale for their associated gold content. The widespread arsenopyrite has been used to determine P-T conditions of formations of the veins, applying the methods of L.A. Clark and A.H. Clark.

X-ray diffraction analysis of 30 specimens shows that the arsenic content of the arsenopyrite varies between 30 and 34 atomic per cent ($^{d}131$ spacing from 1.6301 to 1.6338 Å.), indicating that the probable temperature range of crystallization extended from about 610°C to 390°C under confining pressures of 1500 bars.

The hydrothermal veins are related structurally to the acidic dykes (the most competent rock in the area) and genetically to granodioritic intrusive rocks of Devonian age outcropping about five miles east of Moreton's Harbour.

FRONTISPIECE. View from the southwest of Moreton's Harbour Head (left) and Wild Cove Head.

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CHAPTER I

INTRODUCTION

Location and Area.

Moreton's Harbour map-area is located on the northwestern portion of New World Island, Notre Dame Bay, Newfoundland; its location is shown on the accompanying index maps (figs. 1, 2). It is bounded by longitudes 54°50'30" and 54°52'48" and by latitude 49°33'40" and 49°36'00".

The map-area includes the communities of Moreton's Harbour and Bridgeport; it has a length of 3½ miles from north to south and a width of 1 3/4 miles. Its area is 4.5 square miles, of which approximately one third is covered by the sea.

Access and Resources.

The community of Moreton's Harbour (population 200) lies around the harbour in the center of the map-area. It is about six miles southwest of Twillingate Island by sea and about 50 miles northeast of Lewisporte by road along Route 41, which passes through the central and southern parts of the map-area. Bridgeport (population 200) is two miles south of Moreton's Harbour. Both of these communities are typical Newfoundland outports; lobster fishing and inshore cod and turbot fishing are

Figure 1. Island of Newfoundland. Moreton's Harbour map-area is indicated by the arrow in Notre Dame Bay. (Geology Survey of Canada, Map 1231A, 1967).

Figure 2. The southern part of National Topographical map, Twillingate, Newfoundland, 2 E/10 west half showing the areal extent of the map-area.

Figure 1

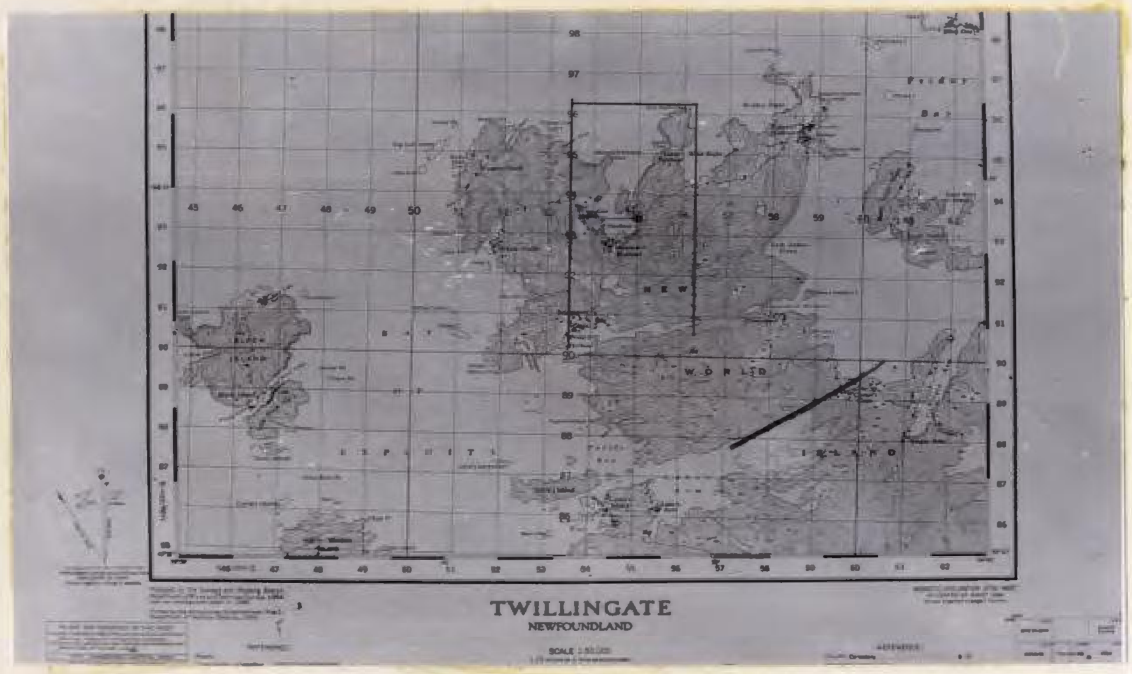


Figure 2

the only industries and both are very rapidly declining.

Previous geological work.

The area was first mapped by Heyl during his survey of the Bay of Exploits in the summer of 1934 and 1935 (Heyl, 1936). More recently it was mapped by Williams as part of Twillingate Map-area in 1962 (Williams, 1963). Other work was carried out on the Newmont Concessions in and around Moreton's Harbour by Newfoundland and Labrador Corporation in 1965 and 1967 (unpublished confidential maps and reports). Four boreholes totalling about 800 feet were drilled by that company within the map-area in 1965.

Present field work.

The field work for this project was carried out between May and September, 1967 and in July, 1968 under the auspices of Memorial University of Newfoundland. The work was supported partly by NRC Grant A-2131 and partly by a supplementary grant given by the Newfoundland and Labrador Corporation. This financial support is gratefully acknowledged.

CHAPTER II

PHYSIOGRAPHY AND GLACIATION

Physiography.

The most conspicuous physical feature of the area is the highly dissected topography, which lends the area a moderately rugged appearance. The land surface is very irregular and moderately high; the hills range in altitude from 200 to 400 feet above sea level. The highest hills are located on the eastern side of Moreton's Harbour, to the west of Church Hill Pond. Church Hill, the highest one, reaches approximately 400 feet above sea level. To the west of Moreton's Harbour the topography is characterised by slightly lower and broader ridges. Aerial photographs of the area show that roughly parallel ridges and narrow valleys are characteristic of this irregular surface. The majority of those ridges and valleys are elongated in a northerly direction but some conspicuous linear features strike in various other directions.

In many places the coast is bordered by steep cliffs and hills that rise directly from the shoreline, with deep water close to shore. The nearly vertical cliffs 150 - 200 feet high around Moreton's Harbour Head and Wild Cove Head are characteristic of this abruptly emerging coast line. Intermittent short stretches of small cobble, gravel, and coarse sand beaches have developed in some of the more protected parts of this rugged shoreline. These beaches usually have a steep seaward gradient. Emergence of the shoreline is indicated by the presence of wave-cut benches above the shore and the occurrence of small waterfalls in some of the streams near the shore.

Twelve small ponds are present in the area at elevations varying from fifty feet to 150 feet. Eight of these are swampy and partially surrounded by bogs. These bogs are present throughout the map-area as undulating treeless surfaces at all levels. The other ponds, including Moreton's Harbour Pond and Church Hill Pond, appear to be of the rock basin type. Streams flowing from these ponds are very small and become dry in summer.

Many of the hills and valleys are fairly heavily wooded with a thick growth of spruce and fir. Except for a couple of small isolated patches there is no virgin timber, the original forest having been either destroyed by fire or removed by logging; the trees are generally small in size. Birch and aspen are abundant in some localities that have been logged; dense thickets of low-growing alders are found in the valleys and beside the streams and ponds.

Glaciation:

The area has been thoroughly glaciated; many features of the topography owe their origin to glaciation. In spite of the relatively rugged topography, the hills have been rounded and smoothed off by the ice; roches moutonées have been formed so that some of the hills demonstrate fairly good stoss and lee topography. Rock-basin ponds were also developed and the drainage controlled so that small streams now appear to follow irregularities of the post-glacial surface. Glacial erosion appears to have been strong over the whole area, and much more significant than glacial deposition.

The material deposited during glaciation includes erratic boulders and patches of glacial drift. The glacial drift, when present, is generally less than five feet thick, according to thicknesses observed in road cuts and prospect pits. Glacial erratics are numerous and vary greatly in size. The largest boulder, on the top of Middle Mountain south of Moreton's Harbour, is about 10 - 12 feet in diameter; most are from 1 - 3 feet in size. Many of the boulders of basic volcanic rock are probably locally derived, but they could just as well have been brought from fifty miles to the south where volcanic rocks of the Headlands Group are exposed. The boulders also include pyroxenite, granodiorite, and granitic gneiss which must have been transported considerable distances in view of the present geology of the region.

No striae were observed in the map-area, but in the Bay of Exploits area Heyl (1936) found striae directions which vary from N30°W to N20°E. Therefore, the direction of ice movement over the area was probably northwards. Such movement from the south is also indicated by the stoss and lee slopes of some roches moutonées and by the character of some of the erratics, which must have had their source south of Moreton's Harbour. Notably to the east of Moreton's Harbour, the topographic "grain" of the country has also been accentuated by a northerly direction of glaciation. One need only make a traverse across the grain and then one with it to be forcibly impressed by the marked manner in which such glaciation has moulded this topography. Heyl (1936) and Espenshade (1937) have written that this glaciation in Notre Dame Bay was of Wisconsin age, with the ice spreading northwards from the interior.

CHAPTER III

GENERAL GEOLOGY

General Statement.

The map-area is at the northeast end of the Appalachian Orogen, where the mountain system plunges beneath the waters of the North Atlantic. It is underlain by volcanic rocks which include basaltic pillow lavas, massive and amygdaloidal andesitic lavas, and basic volcanic clastic rocks. These lavas and volcanic clastic rocks are cut by several types of later intrusive rocks. Most of the intrusive rocks are dykes; the others are small, stock-like bodies of gabbro, diorite, and granite. The dykes include diabase, latite, rhyolite, granite, and lamprophyre.

These consolidated rocks of the map-area are all of the Paleozoic age, except a single lamprophyre dyke which is believed to be of Mesozoic age on the basis of potassium-argon dates determined on similar dykes from elsewhere in the Bay of Exploits region (Wanless, 1965 and 1967).

The volcanic and basic intrusive rocks are Middle Ordovician in age while the acidic intrusive rocks are believed to be of Devonian age (Heyl, 1936; Faul,1963).

The volcanic rocks and dykes are cut by numerous thin quartz veins containing abundant arsenopyrite and

TABLE OF FORMATIONS

ERA	PERIOD or EPOCH	SERIES, GROUP or FORMATION	LITHOLOGICAL ROCK-UNIT	LITHOLOGY
CENOZOIC	RECENT			Sand and gravel reworked by the sea.
	PLEISTOCENE			Glacial drift: clay, sand gravel and erratics.
MESOZOIC				Lamprophyre dyke.
PALEOZOIC	DEVONIAN (?)			Granitic dykes. Dykes of equigranular and porphyritic rhyolite. Granitic stocks.
	MIDDLE ORDOVICIAN			Intermediate dykes. Sills and stocks of gabbro and diorite, including the Bridgeport stock. Diabase and diabase porphyry dykes.
		Exploits Series (Heyl, 1936) Headlands Group (Williams, 1963) Breakheart Basalt and Moreton's Volcanics (Heyl, 1936)	Volcanic flow rocks Coarse volcanic clastic rocks Thin-bedded, fine volcanic clastic rocks	Basaltic pillow lavas massive and amygdaloidal andesitic lavas. Pyroclastic breccias and conglomerates; flow breccias; epiclastic volcanic mudflows. Greywacke, arenite and siltstone; limestone lenses; red and green cherts.

pyrite, locally abundant stibnite and minor sphalerite, chalcopyrite, pyrrhotite and galena; small amounts of gold have been reported in some of the veins (Heyl,1936). The economic potential of the veins has been investigated by several mining companies in the past, but all attempts at mining have been abandoned.

VOLCANIC ROCKS

Stratigraphical classification, Distribution, Thickness, and Lithology.

A sequence of sedimentary and volcanic rocks between 13,000 and 16,000 feet thick which is present in the Bay of Exploits region has been called the Exploits Series (Heyl, 1936). The assemblage of basic volcanic rocks in Moreton's Harbour map-area is part of a stratigraphic group that is found near the top of the Exploits Series (Heyl, 1936). Heyl divided the volcanic assemblage into two formations, namely, Breakheart Basalt and Moreton's Volcanics. The Breakheart formation consists of basaltic pillow lavas with some interstitial chert and minor amounts of interbedded volcanic clastic rocks while the Moreton's formation is composed of great accumulations of volcanic clastic rocks in addition to some massive and amygdaloidal andesitic lavas (Heyl, 1936). Williams (1963) has defined the Headlands Group to include these two formations and represent the whole volcanic assemblage.

The principal area of outcrop of the volcanic rocks is the continuous shoreline extending for 10 - 12 miles from Pomley Cove eastwards around Moreton's Harbour to the center of Wild Cove. The shoreline on the north side of Bridgeport Harbour (about two miles long) has much lower relief and only intermittent exposure. Inland, the only extensive outcrop area is to the northeast of Moreton's Harbour. Elsewhere, rock outcrops comprise about one per cent of the land area; most of these are located around the small hills.

Apparently, neither the bottom nor the original top of the volcanic assemblage is present in the map-area. Therefore, the thickness estimated is probably not equal to the total thickness of the stratigraphic unit. Also, attitudes and thicknesses can only be measured on shoreline exposures so there is a break of almost a mile between the communities of Bridgeport and Moreton's Harbour for which no observations are available. Faulting has further complicated estimates of the thickness. The approximate thickness from the south shoreline of Moreton's Harbour to the north side of Wild Cove Head is 3000 - 4000 feet. The original maximum thickness may have been twice that amount, or a minimum of 6000 feet.

Lithologically, the volcanic rocks in the map-area are basic volcanic clastic rocks and lava flows.

Chemically, they are mainly basaltic and andesitic. Some dacite and trachyte lavas have been found in the Moreton's formation elsewhere in the Bay of Exploits region (Heyl, 1936). A half-mile wide zone of predominantly volcanic clastic rocks with some intercalated andesitic lava flows comprises the central part of the map-area. The lava flows and coarse volcanic clastic rocks form thick accumulations which in some places grade laterally into fine, thin-bedded volcanic clastic rocks. This zone of rocks is apparently continuous northwesterly along strike to Western Head, where rocks of similar lithology and structure were observed by Fogwill (1967). To the north and south of this zone, flows of basaltic pillow lava and massive and amygdaloidal andesitic lava are much more common than the volcanic clastic rocks.

The rocks of this volcanic assemblage are generally too altered for detailed petrographic identification. However, the original textures and mineralogy are sufficiently preserved to indicate that they are all of a basic composition. One of their outstanding features is the high sodium content, which may be an indication of a spilitic affinity (Table 2 ; Battey, 1956; Gilluly, 1935; Lisitsina, 1966). The characteristic features of the volcanic clastic rocks include poor sorting and great thicknesses of the volcanic

TABLE 1 . CLASSIFICATION OF VOLCANIC CLASTIC ROCKS

Grade size (mm)	General rock type		Specific rock type	
			Matrix	
			Abundant	Sparse
<2	Clasts angular to sub-rounded	Volcanic breccia	Tuff-breccia	Well-sorted volcanic breccia
	Clasts sub-rounded to well rounded	Volcanic conglomerate	Poorly sorted volcanic conglomerate	Well-sorted volcanic conglomerate
< 2>1/16		Volcanic sandstone	Volcanic greywacke	Volcanic arenite
< 1/16		Volcanic siltstone		

After Fiske and others (1963).

breccias and conglomerates, some graded bedding in the volcanic sandstones, and some small scale primary sedimentary structures in the volcanic siltstone.

In such a small area as Moreton's Harbour map-area, the volcanic assemblage cannot be adequately correlated with the stratigraphic map-units which have been proposed on the basis of regional mapping (Heyl, 1936; Williams, 1963). For the purposes of description, it will be divided into three lithological rock-units which are as follows:

1. Volcanic flow rocks;
2. Coarse volcanic clastic rocks; and
3. Thin-bedded, fine volcanic clastic rocks.

There is no universally accepted nomenclature for volcanic clastic rocks. Therefore, it is convenient to use the nomenclature and classification prepared by Fiske and others (1963; Table 1). The proposed rock names and terms are used in a descriptive sense and are meant to indicate fragment size, fragment shape, and sorting features. They are applied to rocks of known origin as well as to rocks of questionable origin, which might be either pyroclastic, epiclastic or autoclastic. However, specific names such as volcanic mudflow, flow breccia, and volcanic sedimentary rock are used to emphasize the probable origin of some such rocks.

Volcanic Flow Rocks.

The typical lava is a fine-grained to aphanitic and locally porphyritic rock that is light greyish green to dark greenish black in color and weathers brown or rusty brown to olive green, sometimes with a reddish hue. These lavas include massive and amygdaloidal, intermediate and basic flows, some of which must be very thick and of wide areal extent. Massive flows comprise most of Wild Cove Head, the western side of Wild Cove, and a large part of the area east of Moreton's Harbour as far south as the highway, Route 41. There is also a small amount of massive lava on the isthmus of Moreton's Harbour Head. Amygdaloidal flows, which include all of those that exhibit pillow structure, are present throughout the central part of the area interbedded with the volcanic clastic rocks. They also comprise much of the remainder of the area south of Moreton's Harbour and along the north side of Bridgeport Harbour. Excellent exposures of the pillow lava may be seen on the south shore of Frost Cove near the old stibnite workings, on the north end of Little Harbour Head, and inland on some glacially-scoured outcrops.

Originally, these lavas were andesite (or basaltic andesite) and basalt (Table 2). In the field most of them have a strikingly fresh appearance, but they are really so extensively altered that exact mineralogical

Table 2 . Rock Analyses, Moreton's Harbour, Newfoundland

	MH 549	MH 870	MH 893	MH 26	MH 876
SiO_2	51.80	48.70	50.15	59.55	76.05
TiO_2	1.71	2.28	1.08	0.93	0.00
Al_2O_3	16.68	14.68	16.10	14.84	13.98
Fe_2O_3	1.02	2.71	1.98	1.96	0.64
FeO	7.08	8.56	6.56	5.80	0.40
MnO	0.15	0.16	0.14	0.21	0.00
MgO	5.34	4.92	6.72	2.20	0.39
CaO	7.21	8.07	9.26	4.46	0.58
Na_2O	4.59	4.27	3.60	5.47	3.08
K_2O	1.02	1.32	0.86	0.42	3.48
P_2O_5	0.32	1.04	0.30	0.30	0.11
CO_2	0.54	0.21	0.56	1.46	0.10
S	0.00	0.00	0.00	0.00	0.00
H_2O	2.30	2.35	2.17	2.05	1.05
Total	99.76	99.27	99.48	99.65	99.86

Normative minerals (C. I. P. W.)

Calcite	1.22	0.47	1.27	3.32	0.22
Apatite	0.74	2.40	0.69	0.69	0.25
Ilmenite	3.24	4.33	2.05	1.76	0.00
Feldspar	66.76	60.92	60.77	59.70	48.15
K-Spar	6.02	7.80	5.08	2.48	20.56
Albite	38.83	36.13	30.46	46.28	26.06
Anorthite	21.89	16.99	25.23	10.93	1.52
Corundum	0.00	0.00	0.00	1.37	4.58
Diopside	6.98	12.50	12.55	0.00	0.00
Orthopyroxene	11.04	2.69	11.58	13.85	1.20
Enstatite	4.82	1.09	5.95	3.88	0.87
Olivine	6.87	10.53	6.46	0.00	0.00
Forsterite	2.84	4.04	3.16	0.00	0.00
Quartz	0.00	0.00	0.00	14.53	43.48
Magnetite	1.47	3.92	2.87	2.84	0.92

MH549. - Thin-bedded volcanic clastic rock.
MH870. - Basic intrusive rock.
MH893. - Massive lava flow.
MH 26. - Porphyritic dyke.
MH876. - Rhyolite dyke.

Analyst, K. Ramlal, University of Manitoba.

classification is very difficult and frequently impossible. However, on the basis of an examination of several thin sections of the least altered rocks, the two varieties can be distinguished.

The andesitic lava varies from light olive gray to greenish black in color. It is generally fine-grained to microcrystalline but locally contains phenocrysts of plagioclase and brownish green hornblende which range from 2 - 4 mm in diameter. This lava may be either massive or amygdaloidal, but it rarely exhibits pillow structure. Quartz is never visible in hand specimen and not always present in thin section, but in some places it comprises up to about five percent of the matrix. Plagioclase is present as phenocrysts as well as in the matrix, and it makes up between 40 and 50 percent of the rock. The original plagioclase is partly to completely replaced by sericite, calcite, albite, chlorite, epidote, and fibrous amphibole. Most of the albite twinning is destroyed and very little is usable for composition determination by the Michel-Lévy method. However, the compositions of both the plagioclase phenocrysts and the plagioclase in the matrix have been determined as andesine, An_{40} and An_{35} respectively. Except for the few phenocrysts of hornblende, the mafic minerals have been completely replaced. Their alteration products include chlorite, calcite, epidote and fibrous amphibole. The accessory minerals present are pyrite, apatite, sphene, and titaniferous magnetite. Leucoxene is commonly found around the sphene and magnetite. Since chlorite is present throughout all the rocks as shreds and patches, chloritization was probably by far the most extensive alteration process. Carbonatization was also prevalent and pronounced, but calcite is less abundant and more irregularly distributed than chlorite.

The basalt varies in color from dusky yellowish green through olive gray to greenish black. It is generally fine-grained to aphanitic and rarely contains any phenocrysts so that it usually has a fairly uniform texture. Pillow structure is a characteristic feature, but both massive and amygdaloidal non-pillowed lavas are also present. Quartz is very rare, with possibly 1 - 2 percent occurring locally; this amount may be secondary. Plagioclase is the most abundant mineral, comprising anywhere from 30 to 50 percent of the matrix of the rock. Albite twinning is very poorly preserved due to the alteration of the plagioclase to epidote, calcite, sericite, albite and chlorite. This twinning is practically useless for the determination of composition but the Michel-Lévy method was used on such plagioclase in one thin section and the anomalous value of An_{40} (andesine) was obtained. Of the mafic minerals, augite is preserved locally in the matrix, but it is rather rare. There are also a few unaltered augite phenocrysts. Most of the augite is altered to chlorite, epidote, calcite, and fibrous amphibole. There are some patches of serpentine which may represent the alteration of olivine. Accessory minerals include pyrite, magnetite, and hematite. Fairly large quantities of hematite are present in some of the amygdaloidal lava flows, giving them a reddish hue. Magnetite is always abundantly associated with the hematite. Euhedral pyrite crystals are widespread but minor in quantity. Leucoxene is common around the magnetite. These basaltic lavas have an intersertal texture, with altered plagioclase laths randomly oriented in and surrounded by patches and shreds of chloritic material which probably represents the primary augite. Chlorite and calcite are the most abundant secondary minerals. Much of both of them was probably derived from alteration of the essential minerals of the basalts. However, some was introduced, as is evident from their presence in veinlets. Epidote is next in abundance as an alteration mineral. It also occurs in veins and as nodules. Some epidote veins are very coarse-grained and reach six inches in thickness.

All of these alteration minerals are also present in amygdales. Amygdales are ubiquitous in the pillow lavas and are common in some of the others. They reach a maximum of half an inch in diameter and are most commonly filled with calcite and chlorite. Some contain epidote, amphibole, feldspar, or quartz. In places these amygdales are elliptical, due presumably to movement in the lava flow after the vesicle formed. In pillows the amygdales are present as concentric bands around the center. They decrease in size but increase in abundance toward the margins. Amygdales are also present in diabase dykes and the coarse fragments of some volcanic clastic rocks.

Pillow structure is a characteristic feature of some of the lava flow; some flows are made up entirely of pillows. Each pillow is a distinct entity, separate from its neighbors, and it was deposited after those on which it rests. These pillows range in diameter from about six inches to several feet (fig. 3). Many are somewhat elliptical in shape as they have been flattened, squeezed, and/or broken. The shapes indicate that the pillows were laid down while still in a plastic condition but after they had developed tough, flexible skins.

In cross-section different zones can be distinguished. Each pillow has an outer chilled crust about one centimeter thick (fig. 4). Progressively farther inward there are a finely amygdaloidal zone containing amygdales 2 - 5 mm in diameter and a moderately to coarsely amygdaloidal zone containing amygdales 0.5 - 2 cm in diameter.

Figure 3. Photograph of a pillow in a lava flow just east of the Frost Cove antimony mine. Chalcopyrite is present in amygdales in the outer zone of the pillow.

Figure 4. Photograph of a hand specimen showing the contact between two pillows of a flow on the northern end of Little Harbour Head. Magnification x 2.

Figure 3

Figure 4

Figure 5. Photograph of a thin section of the hand specimen in figure 4. The light colored zone along the bottom is the border of one of the pillows. Magnification x 8.

Figure 6. Photograph of a pillow isolated in coarse tuff-breccia near the shoreline of Taylor's Room.

Figure 5

Figure 6

The abundance of amygdales in the pillows indicates a very gas-rich lava. Ivanov (1967) has considered such gas saturation an important factor in pillow formation, possibly as important as the extrusion in subaqueous conditions; in addition, the pillows need not be restricted to flows of basaltic composition. Pillow structures in Moreton's Harbour map-area are considered to be a feature of submarine extrusion of basic and intermediate lava (Day, 1913; Lewis, 1914). This view is supported by the presence of limestone lenses and cherts in the associated volcanic clastic rocks.

Pillows are also present as isolated entities in tuff-breccias (figs. 6 , 7). This may indicate that breccias which contain pillows are autoclastic flow breccias. Henderson (1953) has observed a transition from such breccia containing pillows to pillow lavas with minimal breccia. The two varieties differ only in the relative proportions of breccia and pillows.

Volcanic clastic rocks.

The volcanic clastic rocks predominate in the central part of the area. On the western side of Moreton's Harbour, they are exposed continuously from Frost Cove northwestward along the shore to Pomley Cove, except for about 1000 feet around Moreton's Harbour Head. On the east side they are intermittently exposed from Jones' Point northeastward to about 1000 feet north of Little

Figure 7. Photograph of a pillow isolated in coarse tuff-breccia near the shoreline on the southwestern part of Little Harbour Head.

Figure 8. Photograph of part of the volcanic clastic section along the shoreline at Taylor's Room. The coarse tuff-breccia band (on the left) is overlying the thin-bedded volcanic clastic rocks. The pillow in figure 6 is indistinguishable in the bottom left corner of this photograph.

Figure 7

Figure 8

Harbour. Inland, their extent is not known because outcrops are too scarce.

These rocks include a variety of pyroclastic rocks and possibly minor amounts of epiclastic and autoclastic rocks. Texturally, coarse tuff-breccia (fig. 11) is the most abundant variety; volcanic conglomerate (fig. 10) and well-sorted volcanic breccia are associated with it. Next in order of abundance are volcanic sandstone (fig. 20), volcanic siltstone (fig. 24), thin beds of chert, and limestone lenses (fig. 25). A notable characteristic of these rocks is the alternation of the of the thick tuff-breccia beds with the thin-bedded volcanic breccias, sandstones, and siltstones. Tuff-breccias make up most of the sequence and form layers which range from a few feet to 200 feet in thickness. These layers are separated by sequences of thin-bedded volcanic clastic rocks that range from a few inches to several tens of feet in thickness (fig. 9).

These volcanic clastic rocks range in color from dusky yellowish green to greenish black. In thin section the matrix is a fine-grained to microcrystalline aggregate of angular to poorly rounded fragments of volcanic rock and crystals of plagioclase, which are enclosed within a network of secondary minerals. Quartz is present in some of these rocks as unaltered individual grains, normally

Figure 9. Photograph of a rock sequence similar to that in figure 8; it is found north of Little Harbour. In each case the coarse tuff-breccia layer is on the southern side and the rocks are facing steeply towards the southwest.

Figure 10. Photograph of a volcanic conglomerate layer near the shoreline of Taylor's Room. This exposure is found about 200 feet north of that in figure 8.

Figure 9

Figure 10

showing strain extinction. It is usually a minor constituent, but in some of the thin-bedded rocks there may be as much as 40 per cent in quartz-rich bands. Plagioclase is the most abundant normal constituent. It is extensively altered; albite twins are hardly ever usable for determination of composition. However, in one case the composition was determined as andesine, An_{35}, which is equivalent to that determined for andesite lava. The primary mafic minerals have been completely destroyed; none was seen in more than twenty thin sections studied. Fragments of volcanic rock are numerous. They appear basic in composition, but are so fine-grained and highly altered that they cannot be named more specifically. Accessory minerals of the matrix include sphene, pyrite, magnetite, and chalcopyrite. Leucoxene is found as rims around the sphene and the magnetite. The major alteration minerals of the matrix are chlorite and calcite. Others include epidote, sericite, and fibrous hornblende. Most of the volcanic clastic rocks have a mineral composition similar to that described here. Texture is the chief difference between the varieties.

Coarse volcanic clastic rocks.

The coarse volcanic breccias and conglomerates are the most distinctive rocks of the central part of the map-area. These rocks are composed of angular to irregularly rounded fragments which have sharply to poorly defined boundaries. The fragments vary in size from 2 mm to more than a foot in diameter; locally, rounded lapilli less than an inch in diameter are most common. Most of the fragments consist of highly amygdaloidal lava but some are thin-bedded sedimentary material. They are best seen on the weathered surface of shoreline outcrops (fig. 29). Their matrix is greenish black, fine-grained tuff-breccia and volcanic graywacke. It consists of small fragments of the same materials as the coarse ones, in addition to some plagioclase and quartz crystals.

These rocks are massive, thick-bedded, and unstratified but in some places they do show an ill-defined vertical sorting. This feature can be best illustrated by describing a section along Taylor's Room on the west side of Moreton's Harbour. From north to south along the shoreline, there is a volcanic clastic sequence about 500 feet thick which strikes northwesterly and dips approximately 60° to the southwest. This sequence is composed of three conformable units, each of which shows a uniform change from coarse tuff-breccia (fig. 11) or volcanic

Figure 11. Photograph of tuff-breccia in which the angularity of the fragments of volcanic rock is very pronounced. The exposure is found near the shoreline of Taylor's Room, about 500 feet south of that in figure 8.

Figure 12. Photograph of Moreton's Harbour Head breccia. The fragments consist of a variety of rocks basic to acidic in composition. Chalcopyrite is found in the interstitial calcite in some parts of the breccia.

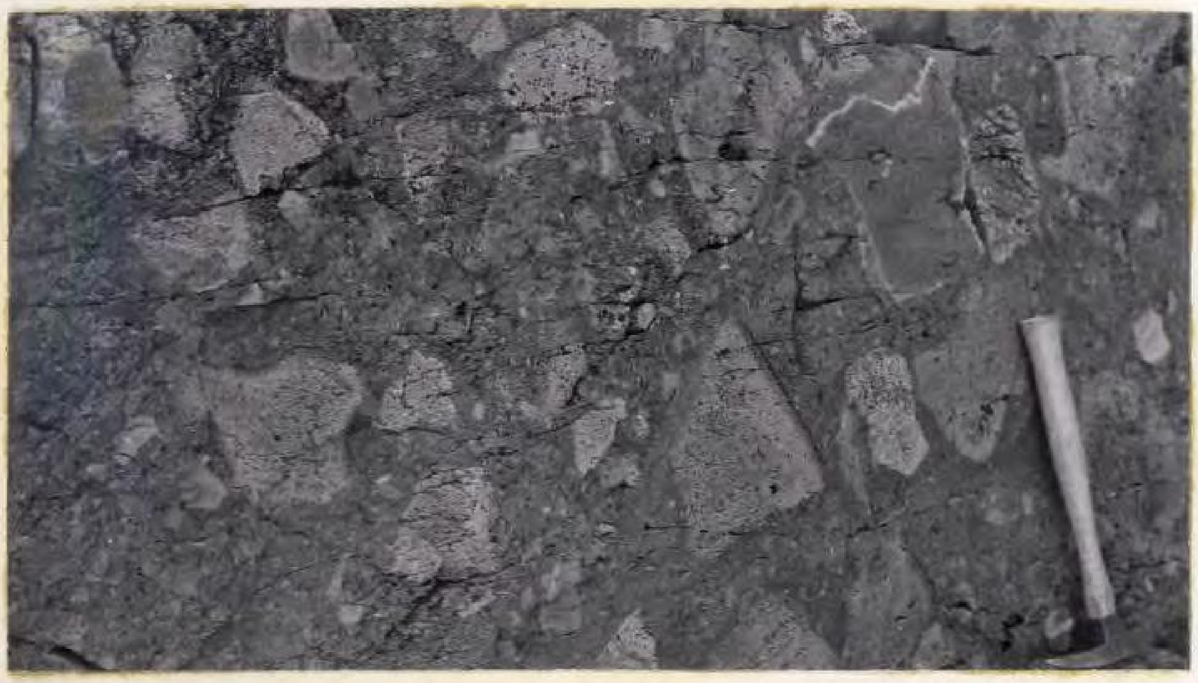


Figure 11

Figure 12

Figures 13, 14. Photographs of tuff-breccia on the southern end of Little Harbour Head. Note the amygdaloidal nature of the rounded fragments.

Figure 13

Figure 14

conglomerate (fig. 10) at the bottom to thin-bedded volcanic breccia, sandstone, and siltstone at the top (fig. 8). Tuff-breccia is the dominant volcanic clastic rock type. It makes up at least 60 per cent of the section. Volcanic conglomerate is a minor associated phase in which the fragments are more rounded. The fine-grained volcanic clastic rocks are much less abundant. They comprise well-stratified units which are less than 50 feet thick in each case.

Isolated pillows are present in the tuff-breccia near the base of two of these units (fig. 6). Such pillows are also present in similar breccia on the west side of Little Harbour Head (fig. 7). Perhaps this indicates a connection between the modes of formation of the pillows and the breccias.

In addition to being interstratified with thin-bedded volcanic clastic rocks, volcanic breccias are also found associated with some lava flows. Some of these breccias may be seen on the southern side of Moreton's Harbour east of Frost Cove (fig. 16) and in the area to the south and west of Frost Cove south of Taylor's Room (fig. 17). These are not so voluminous as the others and they are neither sorted nor stratified. However, lithologically they are very similar since they do contain amygdaloidal lava fragments, up to a foot in the maximum

Figure 15. Photograph of a hand specimen of fairly well-sorted volcanic breccia from a road-cut on the eastern side of Moreton's Harbour.

Figure 16. Photograph of a volcanic flowtop breccia near the shoreline to the east of Frost Cove.

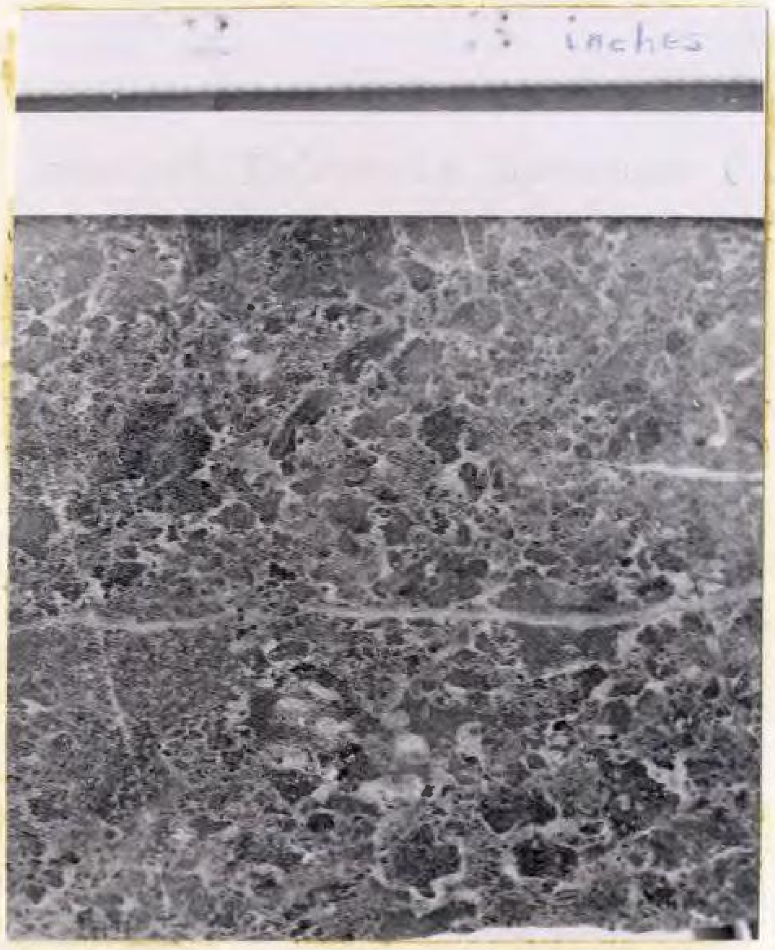


Figure 15

Figure 16

Figure 17. Photograph of the "clotted lava" type breccia in a roadcut to the northwest of Frost Cove.

Figure 18. Photograph of a hand specimen of the rock in figure 17.

Figure 17

Figure 18

dimension, embedded in a fine-grained matrix. In this rock the grayish fragments seem to grade into the greenish black matrix; the difference between the fragments and the matrix is that the fragments preferentially alter to calcite and the matrix to chlorite. This has led previous workers to call this rock type "clotted lava" (Fogwill, 1967).

Three modes of origin may be considered for the volcanic breccias. They may be autoclastic flow breccias, pyroclastic agglomerates, or epiclastic mudflow breccias. Autoclastic flow breccia, which comprises horizons associated with the tops of flows, results from fracturing of the lava due to flowage (Henderson, 1953). There is no evidence of flowage and no contacts with the lava flows were observed, but otherwise the "clotted lava" might be considered flowtop breccia since the matrix does have a primary igneous texture. On the other hand, the breccias in the clastic sequences, despite their containing scattered isolated pillows, are considered to be of pyroclastic origin since there is no other evidence to indicate the possibility of an autoclastic origin. The lack of stratification and poor sorting may be considered evidence for an epiclastic mudflow origin, but this can be equally well explained by a pyroclastic origin, so it is doubtful whether or not there are any epiclastic mudflow breccias associated with the pyroclastic agglomerates.

Thin-bedded, fine volcanic clastic rocks.

The thin-bedded, fine-grained volcanic clastic rocks are most commonly found interstratified with thick layers of tuff-breccia. However, minor quantities are found as thin units separating flows of pillow lava. These rocks consist mainly of volcanic sandstone and siltstone, but they also contain some interbedded volcanic breccia. The three varieties are present as alternating bands which vary from a fraction of an inch (fig. 21) to about eight feet in thickness. The volcanic sandstones are consistently parallel-bedded; many are also vertically graded (fig. 20). The siltstones are thinly laminated and, in some localities, delicately cross-bedded. Small scale current ripple marks and load casts are found but neither feature is common. Small lenses and thin beds of volcanic breccia are locally abundant. These breccias are similar in composition and texture to the thick-bedded breccias. The sandstones and siltstones are composed of similar materials.

Graded bedding is a common feature of the volcanic sandstone. It is shown by a transitional change in fragment size, which can be observed in field outcrops, varnished hand specimens, borehole core samples, and, microscopically, in thin sections. It is a useful feature for determination of structure and facing of the sedimentary assemblages (Kuenen, 1953) and is an

Figure 19. Photograph of an outcrop of thin-bedded volcanic sandstone north of Little Harbour.

Figure 20. Photograph of a hand specimen of volcanic sandstone showing graded bedding. Magnification x 1.

Figure 19

Figure 20

Figure 21. Photograph of an outcrop north of Little Harbour showing thin-bedded volcanic sandstone interbedded with narrow volcanic breccia layers.

Figure 22. Photograph of a hand specimen of rock similar to that in figure 21. Magnification x 1.5.

Figure 21

Figure 22

Figure 23. Photograph of a hand specimen of volcanic siltstone and sandstone.

Figure 24. Photograph of finely laminated volcanic siltstone. Magnification x 1.

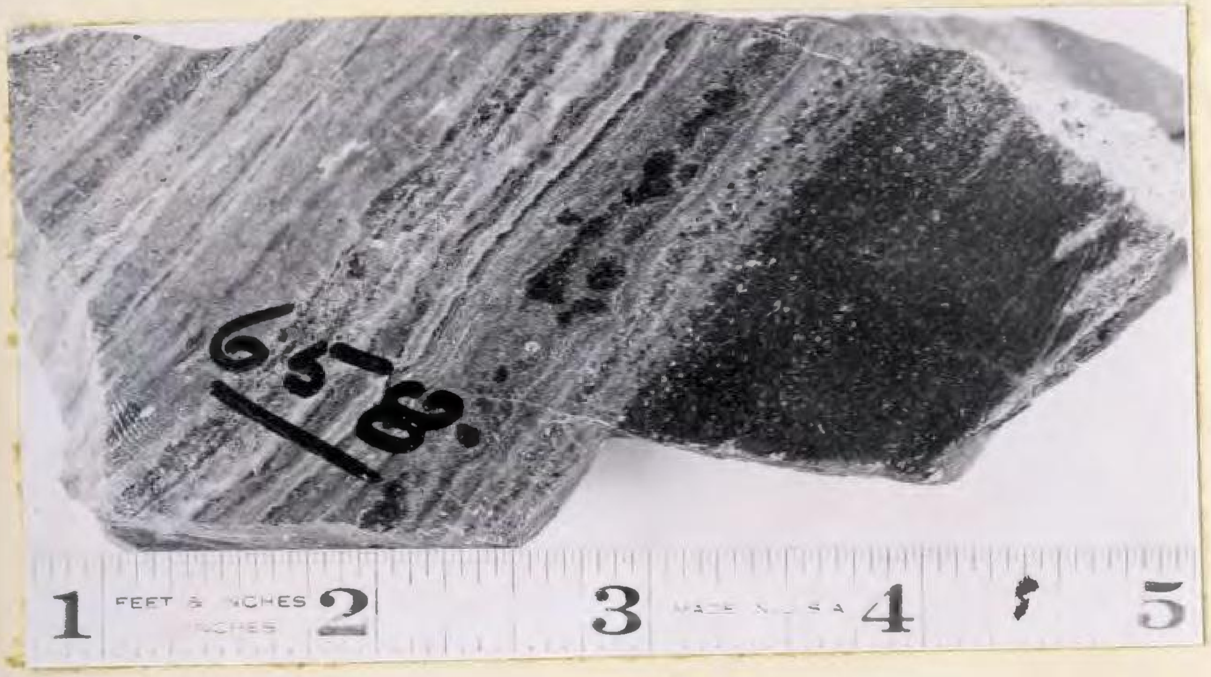


Figure 23

Figure 24

aid in obtaining structural control of the whole assemblage of volcanic rocks.

Contemporaneous deformation of the thin-bedded volcanic rocks is shown by small convolute folds which are present at several localities (fig. 43 ; Holland, 1959).

These rocks could be both epiclastic and pyroclastic in origin. The current structures indicate that much of the material was water-lain. On the other hand, the abundance of crystals and lava fragments suggests an ultimate pyroclastic origin for the clastic material. The parallel bedding of much of the sandstone could indicate ash-fall deposition.

Chert is present throughout the area. Beds of grey to olive green chert occur in the thin-bedded clastic sequence. Some pyrite-rich jasperoid cherts are also found in these rocks. These chert beds pinch and swell; they often lens out or break up into discontinuous pods. Chert red to purple and greenish gray in color is associated with the lava flows. It forms fillings between pillows and lenses and irregular horizons between flows. In addition, some chert fragments up to two inches in diameter are present in a few of the volcanic breccia units. Sampson (1923) has discussed the origin of similar cherts from the Notre Dame Bay region. He considers them to be chemical precipitates deposited during the extrusion of the lava from volcanic gases rich in silica.

Small, very fine-grained, dark gray limestone lenses up to 6 inches by 1 inch in size are present in some of the thin volcanic breccia beds on the east side of Little Harbour Head (fig. 25). Espenshade (1937) has reported similar small unfossiliferous limestone lenses in sedimentary rocks associated with lava flows in Pilleys Island area of Notre Dame Bay. Heyl (1936) has discussed limestone lenses 5 - 10 feet thick which are found between or immediately above some lava flows in Bay of Exploits area. He reports marine fossils in these lenses but does not identify them. No fossils have been found in the lenses in Moreton's Harbour map-area. X-ray diffraction and microscopic studies of these lenses indicate that they are composed mainly of calcite but do contain about 5 percent chlorite, quartz, and albite. A few euhedral pyrite cubes are also present. Both Heyl and Espenshade consider these lenses to be chemical precipitates. Since there is no evidence to indicate otherwise in Moreton's Harbour area, the writer concurs with this opinion.

Figure 25. Photograph of an outcrop of fine tuff-breccia containing a limestone lens about 6 inches long (in the center to the left of the key). The exposure is found on the southeast part of Little Harbour Head.

Figure 26. Photograph of a hand specimen consisting of a fragment of a limestone lens on tuff-breccia. The limestone lens is located in the same area as that in figure 25. Magnification x 1.

Figure 25

Figure 26

Figure 27. Photograph of varnished drill core from the NALCO boreholes. From left to right, the varieties of rock are mottled rhyolite, amygdaloidal basalt, tuff-breccia, and diabase.

Figure 28. Photographs of varnished drill cove from the NALCO boreholes. The four core samples are different varieties of volcanic breccia.

Figure 27

Figure 28

Origin and age of the volcanic rocks.

The major problem of origin is a source and mode of deposition for the large quantities of clastic rocks. Their compositions indicate clearly that they must have had a volcanic source. The composition of the fragments shows that they were probably supplied by the same volcanic centers as the lava flows. Angularity of the fragments indicates that most of them were transported and deposited immediately after explosive eruption (fig. 11).

The thin-bedded volcanic clastic rocks were deposited in water. This is indicated by well-developed stratification, graded bedding, small scale ripple marks, cross bedding, and load casts, and the presence of precipitated limestone and chert. Poor development of the current structures indicates that deposition occurred in water where the currents were weak, possibly in a sheltered sea or large lake (Fiske, 1963). Since some of these rocks do not exhibit such structures at all, they may have formed in deeper waters. The coarse clastic rocks form thick layers between units of the thin-bedded rocks. This indicates that they, too, were deposited under water. Since most of the material in all of these rocks appears to have been supplied by explosive eruptions, the whole volcanic clastic sequence may be considered to have originally been of submarine pyroclastic origin.

Pillow structure may or may not be considered as evidence of extrusion of lava in subaqueous conditions (Ivanov, 1967). However, in Moreton's Harbour map-area, flows of pillow lava are found in association with marine sedimentary rocks. Therefore, these pillows probably do indicate that the lavas were parts of submarine flows.

The age of these volcanic rocks cannot be determined from within the map-area since no paleontological evidence is available and no physical age determinations have been made. However, it is clear from regional field relations that the rocks of the map-area are part of the Headlands Group (Williams, 1963). The Headlands Group comprises the Breakheart and Moreton's formations of the Exploits Series (Heyl, 1936). At Lawrence Harbour in the Bay of Exploits, Heyl (1936) found a typical Normanskill graptolite fauna of Middle Ordovician age in beds a short distance below the Moreton's formation in the Series. In addition, there is a formation of tuffs, cherts and shales overlying the Breakheart formation in the New Bay area which is also considered to be of Middle Ordovician age (Heyl, 1947). Accordingly, the Headlands Group must be of Middle Ordovician age since it is a conformable assemblage within the Exploits Series. Therefore, the volcanic rocks of Moreton's Harbour map-area are Middle Ordovician in age.

INTRUSIVE ROCKS

The rock types forming intrusive bodies are very diverse. They range in composition from ultra - mafic lamprophyre through gabbro, diorite, and granite to rhyolite. None of the bodies exposed is of very great size and, except for a few stock-like bodies of diorite and granite, all are dykes and sills. They vary from a few inches to 50 feet or so in thickness, the majority being between 5 - 10 feet thick. All of these rocks are intruded into a volcanic assemblage of Middle Ordovician age.

Except for some of the dykes and possibly some of the granitic bodies, most of the intrusions were probably emplaced before the deformation of the region (Espenshade, 1937). Accordingly, they may be divided into two groups:

1. Pre-tectonic, or earlier than the regional folding; and
2. Post-tectonic, or after the deformation and near the end of the orogenic cycle.

In the first group are mafic and intermediate rocks which were intruded as dykes, sills, and stocks. These include dykes and sills of diabase, gabbro, and intermediate rocks as well as a stock of pyroxene diorite (Heyl, 1936), the Bridgeport stock. These rocks, which are generally rather extensively altered, are believed to be genetically related to the basic and intermediate lava flows (Heyl, 1936; Espenshade, 1937). Heyl believes they are definitely older than the regional folding and the emplacement of the granitic bodies, and that they are probably of Middle of Late Ordovician age. The writer agrees with these opinions.

The second group includes dykes of rhyolite, granite, and lamprophyre and some small stocks of granitic rock. The lamprophyre is believed to be of Mesozoic age (Wanless, 1965 and 1967) and is definitely post-deformation. The rhyolite and "granite" dykes crosscut the granitic stocks but are believed to be genetically related to them. In the map-area not enough evidence is available from the few outcrops present to indicate the time of intrusion of the granitic stocks. However, on a regional scale, Heyl (1936) and Espenshade (1937) believe that the emplacement of such stocks in the Notre Dame Bay area was related to the Acadian orogeny, but it was post-tectonic and followed the folding and deformation. The stocks are believed to be of Middle Paleozoic age; they were probably intruded early in the Devonian period.

Plutonic rocks.

Bridgeport Stock

A small stock classified by Heyl (1936) as "augite diorite" is located about one mile east of Bridgeport. It is the only intrusion of this rock type in the map-area. It outcrops on both sides of Bridgeport Harbour but it was examined only on the north side, where it is intermittently exposed for more than half a mile. No contacts with the host rocks were observed and no outcrops were found away from the shoreline. Therefore, not enough is known of its structural relations to postulate about the mode or time of intrusion. There is a possibility that it was intruded before the metamorphic phase of the Acadian orogeny since some of the fibrous amphibole appears to be of metamorphic origin. On the basis of comparisons and correlations throughout the Bay of Exploits area, Heyl (1936) considers the stock to be Middle or Late Ordovician in age and genetically related to the basic lavas of the Breakheart formation.

The rock of this stock is coarse-grained, massive, and equigranular; crystals average about five millimeters in diameter. The color is light dusky green, from the whitish plagioclase and the greenish black mafic minerals. The rock is stained brown due to weathering. Neither quartz nor potash feldspar is present. Plagioclase is the major constituent, making up about 50 -- 60 per cent of the rock; however, it is extensively altered to epidote, calcite, chlorite, sericite, and albite so that its original composition is very difficult to determine. A value of An_{30}, andesine, was obtained using some very poorly preserved albite twins and the Michel-Lévy method. Heyl (1936) found an average composition of An_{40}, andesine. This rock is also characterized by an abundance of colorless to pale brown augite. It comprises about 35 - 40 per cent of the rock. Some alteration of the augite to chlorite and fibrous amphibole has taken place, but a fairly large amount of unaltered augite is still present. The accessory minerals present include apatite, magnetite, and pyrite.

Granitic intrusive rocks

There are two occurrences of granitic rock in the area between Moreton's Harbour Pond and Moreton's Harbour and one to the southeast of Moreton's Harbour Pond. All three of these intrusive bodies are rather small and poorly exposed. The easterly body north of Moreton's Harbour Pond has the largest area of outcrop, with dimensions of approximately 500 x 300 feet. It is slightly elongated along a north-south axis. The contacts of these stock-like bodies with the basic lavas were not observed; thus the intrusive relationships cannot be demonstrated.

These granitic rocks differ in texture, grain size, and composition. They range from light gray, medium-grained granodiorite to coarse-grained, pink to brick red granite. The largest stock consists of this coarse granitic rock. It contains approximately 20 percent quartz, 15 percent potassium feldspar, and 50 percent plagioclase. The plagioclase is andesine, An_{34}, in composition. Micrographic intergrowths of quartz and plagioclase are abundant. The original mafic minerals are completely altered to chlorite. Some of the chlorite looks like pseudomorphs of biotite shreds. The plagioclase feldspar has undergone varying degrees of alteration to calcite, sericite, and chlorite. Some accessory minerals present are zircon, pyrite, magnetite, and apatite.

The western granitic body situated north of Moreton's Harbour Pond is medium-grained, dark gray in color, and has an equigranular texture. Its essential minerals are quartz, plagioclase, and potassium feldspar. The plagioclase, which is andesine, An_{35}, in composition, makes up about 70 percent of the rock. Quartz comprises about 10 percent while potassium feldspar makes up a smaller amount. Chlorite, which is present as alteration of the mafic minerals, is about equal to quartz in abundance. Sericite and calcite are found as alteration of the plagioclase. Some accessory minerals are apatite, pyrite, and zircon.

The small stock southeast of Moreton's Harbour Pond is medium to coarse grained, gray in color, and of uniform texture. It weathers light gray. It is composed essentially of quartz (5 - 10%), plagioclase (50 - 60%), and hornblende (25 - 30%). There is a subordinate amount of potassium feldspar. The plagioclase is andesine, An_{35}, in composition. It is somewhat altered to calcite, sericite, and epidote. The hornblende is generally well-preserved but some of it is altered to chlorite. Accessory minerals include apatite, pyrite, sphene, and magnetite. Some cloudy leucoxene is found around the sphene and magnetite. On the basis of their mineralogy, these rocks may be classified as grandiorites to quartz diorites.

Hypabyssal rocks.

Diabase dykes

Numerous dykes of diabase and rhyolite are found throughout the area. They form swarms with a dominantly northeasterly strike. Steep dips are a characteristic feature; only a few dykes depart more than ten degrees (easterly) from the vertical. The dykes of diabase are more abundant than those of rhyolite. They are usually less than ten feet thick, but some are considerably thicker, up to 50 feet thick. They are never very persistent along strike and frequently are sheared and faulted. These dykes were among the earliest intrusions into the volcanic assemblage. They closely resemble some of the lava flows in texture and composition (Table 2). Because of their close association with the lavas, it is believed that they represent the feeders to the flows. Therefore, the dykes were contemporaneous with the flows and formed from the same magma.

Two types of diabase were recognized. One is fine-grained, grayish black, and equigranular; the other, fine to medium grained, greenish gray, and porphyritic with phenocrysts of plagioclase. The former type is the more common. The porphyritic diabases are more distinctive because weathering produces a light-colored, speckled pattern of plagioclase phenocrysts against dark

Figure 29. Photograph of a diabase dyke crosscutting tuff-breccia on the southern end of Little Harbour Head.

Figure 30. Photograph of a diabase dyke in tuff-breccia about 500 feet north west of that in figure 29. Both dykes strike SW - NE. This one has a very low dip towards the east.

Figure 29

Figure 30

Figure 31. Photograph of a diabase dyke in tuff-breccia about 700 feet north of that in figure 29. Note the bands of amygdales parallel to the contacts of the dyke.

Figure 32. Photograph of a hand specimen showing a contact between a porphyritic diabase dyke and andesitic lava. This hand specimen was taken from a roadcut to the south of Frost Cove. Magnification x 1.

Figure 31

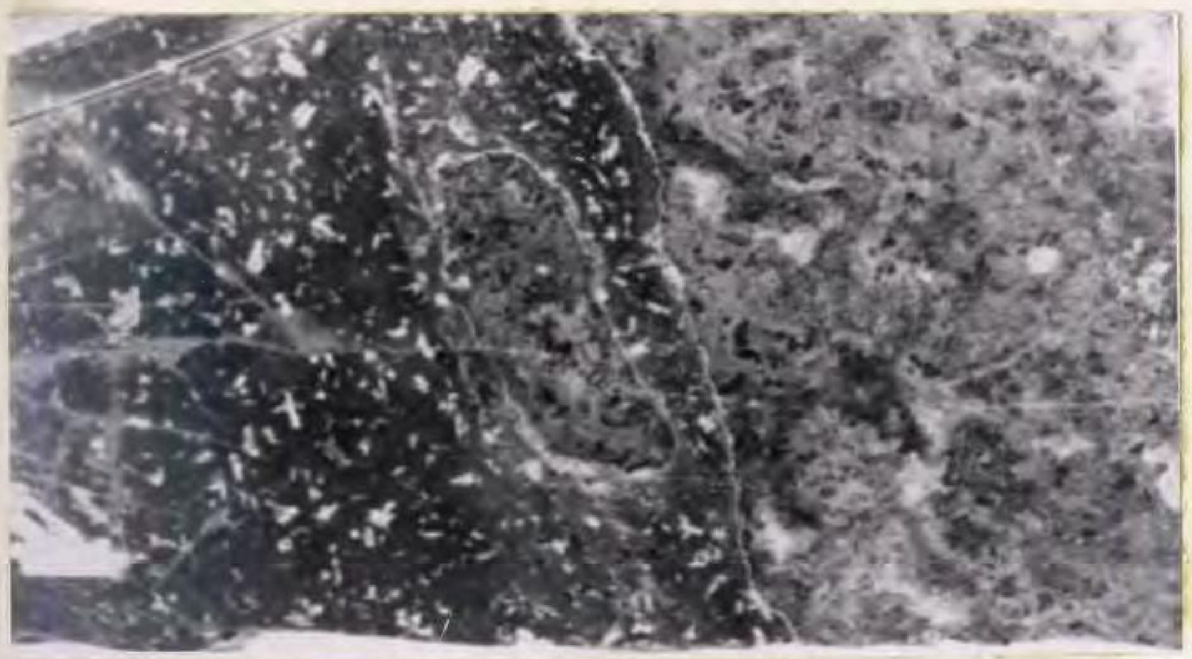


Figure 32

groundmass of mafic minerals (fig. 32). The massive, fine-grained variety appears almost the same on both weathered and fresh surfaces. Many of these equigranular dykes contain amygdales in bands parallel to their contacts (fig. 31). In some cases these amygdale bands extend across the entire width of the dyke and are absent only from the chilled margins. In others the amygdales are prominent only in the central part. Due to this vesicularity, loose fragments of the dykes cannot be distinguished from lava fragments and small isolated outcrops can easily be misinterpreted. On the other hand, porphyritic dykes are not amygdaloidal.

A small amount of quartz is present locally in these dykes. The chief mineral of the dykes is plagioclase. It comprises about 50 percent of the rock. It occurs as stubby crystals in the matrix and as phenocrysts up to 5 x 1 mm in size. The composition varies from about An_{40} to An_{35}. Composition is difficult to determine since the plagioclase is extensively altered to sericite, calcite, and epidote; twinning is often unrecognizable. The primary mafic minerals have been completely changed to fibrous hornblende and chlorite as well as calcite and epidote. Pyrite and titaniferous magnetite are widespread accessory minerals; clouds of leucoxene usually shroud the magnetite.

Gabbro.

A number of small outcrops of gabbroic rock were found on a ridge to the north of the highway about half way between Moreton's Harbour and Wild Cove. No contacts with the volcanic rocks were observed so the character and extent of the rock are not known. However, it is located in an area of massive lava flows to the east of the main zone of volcanic clastic rocks.

In one outcrop the gabbro has a coarse-grained diabasic texture, with crystals averaging about 5 mm in size. In others it is medium-grained, varying from 3 to 5 mm in grain size. In the later there is a vague lineation of the plagioclase and augite crystals. This rock is greenish black to black in color, but it has a speckled appearance due to the fairly even admixture of light-colored plagioclase and dark mafic minerals.

In thin sections about 2 to 3 percent quartz is present locally. Plagioclase and augite are the essential minerals; each comprises between 40 and 50 per cent of the rock. The plagioclase laths originally consisted chiefly of labradorite, An_{60}. However, they have been extensively altered and now consist of almost completely saussuritized cores of calcite, chlorite, and epidote surrounded by relatively unaltered rims of clear albite. There is normal zoning in some of these rims but the variation in composition could not be determined. Commonly only the crystal outline of the plagioclase, as defined by the albite rims, is preserved. It is generally much more altered than the augite. This augite is colorless to pale brown and may be twinned or zoned. In all cases it has been slightly to wholly altered to pale green fibrous hornblende and chlorite. An x-ray diffraction pattern indicates that chlorite, amphibole, and albite are now the major minerals of the rock. Some accessory minerals observed in thin section include pyrite, sphene, rutile, apatite, and ilmenite. Leucoxene is present as alteration of the titaniferous minerals.

Mineralogically, this rock appears to be related to the basic lava flows in composition. It is also similar chemically (Table 2 ;MH870). It is thought that this gabbro may have formed by intrusion of the same magma that produced the volcanic rocks. It may be a sill or a feeder dyke. Consequently, the age of this rock is probably Middle or Late Ordovician.

Figure 33. Photograph of a hand specimen of gabbroic rock which is present in a ridge to the north of the road at about two-thirds of the distance from Moreton's Harbour to Wild Cove. Magnification x 1.5.

Figure 34. Photograph of a hand specimen of a porphyritic dyke of intermediate composition.

Figure 33

Figure 34

Dykes of intermediate composition.

There are a few dykes which differ mineralogically from both diabase and rhyolite. Some of these are mainly feldspathic and may be considered intermediate between those types in composition (fig. 34). In their field relations, they are younger than the diabase but older than the rhyolite. It is not known whether they are of Ordovician or Devonian age, but they have been grouped with the basic assemblage solely on the basis of having been intruded before the rhyolite.

These rocks are grayish olive to grayish orange in color, fine-grained, and of uniform texture except for phenocrysts in a few places. In thin section they are seen to consist mainly of plagioclase. Quartz and potassium feldspar are present in subordinate amounts. The plagioclase is found as phenocrysts up to 2 mm in size and as the predominant mineral in the matrix. The phenocrysts are andesine, An_{34}, in composition. The composition of the plagioclase laths in the matrix cannot be readily determined due to alteration and lack of albite twinning, but oligoclase, An_{26}, is indicated by two measurements made. Mafic minerals have been completely altered to chlorite, which comprises about 10 per cent of the rock. Plagioclase is altered to calcite, sericite, and chlorite. Magnetite with leucoxene alteration is an abundant accessory mineral. Mineralogically this rock may be classified as latite or rhyodacite.

Rhyolite dykes.

No rhyolitic volcanic rocks are found, but rhyolite dykes are very common throughout all of the map-area. These are most abundant in the shoreline exposures around Moreton's Harbour. Generally they are less than ten feet thick. There are two general types of dykes:

1. Mottled red and green felsites; and
2. Buff-colored, aphanitic rocks which are locally porphyritic.

The first type consists of fine-grained non-porphyritic rocks that are red to green in color and commonly weather pinkish white to light gray. Aphanitic, buff-colored rocks which may contain phenocrysts of quartz and plagioclase comprise the second type. The two varieties grade into each other along strike in a single dyke. None of these dykes are very persistent for any great distance along their strike. Frequently they are slightly offset by small faults and show well-developed jointing. Another characteristic feature is shearing which occurs parallel to the contacts along directions that appear to be planes of foliation. Some of these rhyolite dykes are strongly sheared and altered (fig. 35).

Figure 35. Photograph of a foliated rhyolite dyke on the southwestern part of Little Harbour Head.

Figure 36. Photomicrograph of a porphvritic rhyolite dyke containing phenocrysts of quartz and plagioclase. Crossed nicols, magnification about 100x.

Figure 35

Figure 36

The dykes have a very fine-grained matrix of quartz and plagioclase. In some places they contain quartz phenocrysts averaging about 5 mm in diameter. These phenocrysts are invariably rounded and embayed by resorption. Phenocrysts of plagioclase locally accompany the quartz. These phenocrysts are oligoclase, An_{20}, in composition. No potassium feldspar was definitely recognized but in view of the relatively high K_2O in analysis MH876 (Table 2), it is probably present in the groundmass. The plagioclase phenocrysts and the feldspar in the matrix are considerably altered to sericite, calcite, and fibrous amphibole. Biotite shreds are the only mafic mineral and these are not common since chlorite has replaced most of them. Apatite, pyrite, and sphene are present as accessory minerals. Leucoxene is commonly found around the sphene.

These rhyolite dykes crosscut the granitic intrusive rocks so they are later than the period of granodiorite intrusion. Heyl (1936) and Espenshade (1937) have examined similar rocks throughout Notre Dame Bay area. They consider the dykes to be genetically related to the granodiorite batholiths which were emplaced early in the Devonian period. Perhaps the dykes represent a later stage of differentiation of the same parent magma.

Considerable movement occurred after the intrusion of the rhyolite dykes. This is shown by their displacement along faults and by the thin shear zones which are sometimes developed along the contacts. These shear zones later acted as channels of circulation for ore bearing solutions. As a result, numerous mineralized veins are now associated with these dykes throughout Moreton's Harbour map-area.

"Granitic" dykes.

Those dykes are very small and uncommon; the largest one examined was only about two inches in thickness (fig. 37) and the smallest, less than an inch. They are found intruded into amygdaloidal lava. One unusual feature of the biggest dyke is that it contains angular fragments of the lava. Another significant feature is the grain size; it varies from 3 to 5 mm, which is abnormally coarse for a dyke of this size.

Petrographically, the rock is whitish gray in color and fairly uniform in texture. About 60 per cent of it is plagioclase, which is zoned from andesine, An_{34}, to oligoclase, An_{24}. Quartz and potassium feldspar comprise about 20 and 10 per cent of the rock respectively. There is also about 5 per cent green hornblende, which is the only original mafic mineral present. It is slightly altered in places to chlorite. The plagioclase, on the other hand, is rather extensively altered to epidote, calcite, sphene, and sericite. Leucoxene and pyrite are the other minerals present in the rock.

Figure 37. Photograph of a hand specimen of a coarse-grained "granitic" dyke about two inches in thickness, which contains zoned plagioclase crystals. Note the fragment of massive basic lava parallel to the contact of the dyke.

Figure 38. Photograph of the lamprophyre dyke extending from the bottom of the photograph under the hammer to the shoreline. The host rock is tuff-breccia.

Figure 37

Figure 38

Lamprophyre dyke.

The youngest intrusive rock in the area is a single small but persistent dyke of lamprophyre. It crosscuts a rhyolite dyke on the shoreline where it is found about 1000 feet north of Taylor's Room. The dyke has a northeasterly trend; although it is only 8 inches thick, it can be traced continuously along strike for approximately 50 feet. It is steep-dipping, very close to vertical. The average strike is constant N30°E, but it curves and winds somewhat. The dyke is jointed perpendicular to its walls. At the shoreline, the sea has eroded the dyke more easily than the surrounding rock mainly because of this jointing (fig.38). The dyke appears on the whole little disturbed; only very small displacements of a few inches have occurred on minor faults.

This rock is black in color and aphanitic and panidiomorphic in texture. It looks the same on fresh as on weathered surfaces. The groundmass is composed of abundant stubby euhedral augite grains. Apatite, pyrite, magnetite, and ilmenite are present as accessory minerals, with the ilmenite altered to leucoxene. There are minor amounts of calcite and chlorite as alteration minerals. Several roughly hexagonal patches of serpentine in the thin section may possibly be pseudomorphs after olivine. All of the minerals are set in an isotropic base of colorless analcite and patches of brownish glass.

This dyke resembles the lamprophyres described in detail by Heyl (1936) in the Bay of Exploits area and by Espenshade (1937) in the Pilleys Island area. They have described them as the latest intrusion in the magmatic sequence. Heyl (1936) has written that "their spatial relationship indicates that they are genetically connected with the batholiths of the region, and therefore a result of their differentiation". Recently, age determinations of 115, 129 and 144 million years made on similar dykes in the Notre Dame Bay region by K-Ar methods indicate that the lamprophyre dyke is of Late Jurassic to Early Cretaceous age. Apparently, it is not related to the early orogenic and plutonic events in this area (Wanless, 1965 and 1967).

Age relationships and origin.

The intrusive rocks in the map-area were emplaced over a period of more than 300million years from the Ordovician to the Mesozoic. Their order of intrusion cannot be determined at any single locality. A probably succession of intrusive events can be postulated by examining the intrusive relationships throughout the whole map-area and comparing these with more regional events around Notre Dame Bay (Heyl, 1936; Espenshade, 1937; Hayes, 1951). A summary of the sequence given in order of decreasing age is as follows:

1. Diabase dykes and related basic rocks, including gabbro sills and the Bridgeport augite diorite stock;
2. Dykes of intermediate composition;
3. Granitic stocks;
4. Rhyolite dykes;
5. "Granitic" dykes; and
6. One lamprophyre dyke.

This order of intrusion shows a general increase in silica and alkalies from Stage 1 to Stage 5, followed by intrusion of markedly basic material in Stage 6.

The relationships and compositions of these intrusive rocks indicate that groups of them are genetically related. The diabasic and gabbroic rocks are chemically and texturally similar to the basic lava flows (Table 2). They were probably derived from the same magma and the dykes and sills now represent feeders to the flows. On this basis, Stage 1 rocks are considered to be of Middle or Late Ordovician age (Heyl, 1936). On the other hand, Stages 3 - 5 are acidic intrusions whose sole comparison with the basic rocks is their occurrence in the same area along similar structures. There is no evidence to indicate that they are a chemical differentiate of the same magma that produced the basic rocks. It appears more likely that they are related to the intrusion of nearby batholiths of granodiorite (Heyl, 1936). Accordingly, the age of these rocks could be Early Devonian. Stage 6, the lamprophyre dyke, is somewhat of a curiosity. Heyl (1936, 1937) considers similar dykes in the Bay of Exploits area to be a further differentiate of the granodiorite magma, which would place them within the Devonian epoch in age. However, on the basis of isotopic age determinations, it is now believed that the lamprophyre dykes of the Notre Dame Bay region are of Mesozoic, probably Late Jurassic to Early Cretaceous age (Wanless, 1965 and 1967).

Chemical composition.

Five rock samples from the map-area were chemically analysed for this project by K. Ramlal, University of Manitoba. In addition, several rocks from the Headlands Group and its associated intrusions in areas other than Moreton's Harbour had been previously analysed (Heyl, 1936; Espenshade, 1937). Some outstanding features of the chemical compositions of the lavas and associated rocks are:

1. The large content of sodium relative to the content of potassium, except in the rhyolite dykes;
2. The high silica content of the rhyolite dykes;

and 3. The similarity of the basic lava to the volcanic clastic rocks and to the diabase by which both are intruded.

To facilitate comparison, the analyses were recalculated into C.I.P.W. and Barth-Niggli norms. Of the analysed rocks from Moreton's Harbour, the volcanic clastic rocks, the massive lava, and the gabbroic intrusions are very similar in both the analyses and the norms. All three are somewhat undersaturated and contain between 6 - 10 percent normative olivine. Accordingly, they may have originated from magma of olivine basalt composition.

However, on the basis of research on similar volcanic rocks of the Whalesback - Little Bay area, Dr. V. S. Papezik (personal communication) feels that the C.I.P.W. norms do not accurately reflect the true modal compositions of the volcanic rocks. Rather, they show the present compositions of rocks which have been desilicified and altered during extrusion and cooling under submarine conditions and now have a spilitic affinity. The high content of sodium in the chemical analyses is additional evidence in support of this conclusion (Table 2).

On the other hand, the rhyolite dykes are characterised by a very high silica content; they contain more than 40 per cent normative quartz. Unlike the rocks of the volcanic assemblage, many of them have approximately equivalent contents of soda and potash. These features exemplify a genetic relationship between the dykes and the granodiorite batholiths.

Alteration and metamorphism.

Alteration in the map-area is a combination of several effects. These include the following:

1. Alteration which accompanied the extrusion of volcanic rocks in water;
2. Low grade regional metamorphism during the Taconic orogeny;
3. Pervasive hydrothermal alteration connected with the intrusion of granitic rocks during the Acadian orogeny; and
4. Thermal metamorphism related to the intrusive rocks.

Alteration of the third and fourth types can be effectively grouped together since the hydrothermal activity is associated with intrusive rocks, especially rhyolite dykes. Thermal metamorphism is insignificant. Garnet has been reported by Fogwill (1967) in Western Head area but none was found in Moreton's Harbour area. On the other hand, metasomatism associated with hydrothermal activity was quite pervasive, producing complete hydration and alteration of most of the original minerals in the rocks.

Alteration which accompanied submarine volcanic activity resulted in rocks consisting almost entirely of chlorite, albite, fibrous amphibole, and epidote. In some places the original texture of the volcanic rocks has been almost completely destroyed. Where the texture is still somewhat preserved, the primary minerals show various stages of replacement. The alteration minerals are the same in different rock types but are present in different proportions.

The mafic minerals were affected by alteration more readily than the plagioclase; they are generally completely altered to a fine-grained assemblage of chlorite, calcite, and fibrous amphibole. Chlorite, which is the most common, gives a light olive to grayish green color to some of these rocks. The plagioclase is altered in most cases to fine-grained aggregates of epidote, sericite, calcite, and chlorite. In some places, plagioclase has saussuritic centers bordered by clear rims of albite. Calcite is the second most abundant alteration mineral. Much of the calcite was undoubtedly derived from decomposition of calcic-rich plagioclase and pyroxene, but some is related to hydrothermal activity. The epidote present is found in veins and as irregularly distributed stringers and knots throughout the rock. Irregular veins of pure coarse-grained epidote nearly six inches thick are found in places . Thus, the volcanic rocks are so extensively altered that precise identification by petrographic methods is almost impossible.

The low grade regional metamorphism which is responsible for some of this alteration is of the chlorite subfacies of the greenschist facies.

Pleistocene and Recent deposits.

The map-area was affected by general continental glaciation during the Pleistocene Period. Features characteristic of glacial deposition and erosion are present throughout the area. The mantle of glacial drift is fairly thin as seen in several prospect pits. However, it is sufficiently thick inland to mantle all but about one per cent of the bedrock. Glacial till is exposed in some of the road cuts and along the shores of some of the ponds, including Moreton's Harbour Pond. Erratics are scattered throughout the whole area.

Sand and gravel, probably derived from these glacial deposits, are being reworked by the sea along small beaches. The largest beach is found at Beachy Cove. Others are located in Rose's Harbour, Wild Cove, Little Harbour, Moreton's Harbour, Frost Cove, and east of Pomley Cove.

CHAPTER IV.

STRUCTURAL GEOLOGY

General features.

Moreton's Harbour map-area is at the northeastern end of an extensive belt of folded and faulted Paleozoic strata intruded by many types of plutonic and hypabyssal rocks. This belt, known as the Appalachian Orogen, includes all of Notre Dame Bay, a major part of the province of Newfoundland, and extends southwards into the Maritime Provinces and the New England States. The entire belt has been subjected to intense deformation that took place over a long period of time. The map-area has been affected by some of the major orogenic events that are reflected in the deformation of the Appalachian system.

The general structural trend of the Appalachian Mountain system is east-northeast. As can be seen from the geological map, the general structure in Moreton's Harbour area trends northwesterly. This is a considerable local modification of the major Appalachian trend. The reason for these northwesterly trends is not determinable from the limited area studied. However, six miles to the southwest and the northeast one finds the Long Island and Twillingate granodiorite batholiths respectively, and ten

Figure 39. Air photograph of the northern part of the map-area. Note the northerly trends to the east of Moreton's Harbour.

Figure 39

Figure 40. Air photograph of the southern part of the map-area showing the east-west trends of Bridgeport Harbour and the southern side of Moreton's Harbour Pond.

Figure 40

miles to the south, the Loon Bay granodiorite batholith (Heyl, 1936; Williams, 1963). Each of these batholiths modifies the regional structural trend to a certain extent. Each has a substantial number of dykes of rhyolite, quartz keratophyre, granite porphyry, and lamprophyre associated with it. In Moreton's Harbour map-area, numerous dykes of similar composition are present. Perhaps this may indicate that a granitic batholith is present not far beneath the surface. Such an intrusion could have caused the local deviations from the regional trend.

The volcanic rocks of the map-area form a homoclinal structure. All of the volcanic rocks have been tilted on a northwest-trending axis. Dips are to the southeast and rather steep, in most places greater than 30°; in many localities the beds are nearly vertical. Details of the structure are obscure and detailed interpretation is difficult because of the close lithological similarity of the rocks throughout large parts of the section. These difficulties are increased by the massive character of the lava flows and the coarse volcanic clastic layers. The presence of well-defined stratigraphic horizons of thin-bedded volcanic clastic rocks in the shoreline exposures around Moreton's Harbour does lend some structural control to the central part of the area. However, these are not present elsewhere, nor can they be followed along strike due to the scarcity of outcrop. It has been necessary to use the minor primary structures of the assemblage to determine the present attitudes of the rocks and to work out the structure of the area. The most useful and reliable criteria available are crossbedding and graded bedding in the volcanic sedimentary rocks and pillow structure in some of the lava flows. According to these features, the volcanic sequence is upright and facing to the southwest.

Faulting further complicates the structure. Faults are seen very commonly in the field; the structure of the map-area is characterized by the large number of faults. All of the Paleozoic rocks in the area are cut by faults. These faults range in size from small fractures of diverse strikes that have displacements of only a few inches to high angle faults having possible movements of hundreds of feet. All faults large enough to be shown on the scale of the area may have steep to vertical dips.

On the other hand, small scale folding is inconspicuous. The thick lava flows and layers of coarse volcanic clastic rocks were too competent to be folded intensely. However, the more plastic thin-bedded volcanic clastic rocks were often crumpled around those competent units. Some small scale convolute folding also occurred in the fine-grained clastic rocks.

Faults.

Faults are the most prominent structural features of the map-area. These faults may be readily located in the field and on aerial photographs; most of them have noticeable topographic expressions. It is believed that some of the embayments in the coast line have been eroded along such faults and perhaps some of the ponds and valleys occupy faults or shear zones. The valleys were apparently excavated by Pleistocene glaciers along zones of weakness provided by the faults. No direct evidence regarding actual movement along these faults could be observed because the valleys are partly filled with glacial debris and ponds and covered by marshland and thick forest.

One major fault has been postulated to cross the area from west to east through Moreton's Harbour Pond (Heyl, 1936). Considering the east-west trend of the south side of the pond this appears possible; however, the fault plane was not observed anywhere within the map-area. On the other hand, most of the other major lineaments trend in a northerly to northeasterly direction. One of those is the valley containing Church Hill Pond; another is the eastern side of the ridge to the east of Moreton's Harbour. The latter indicates a possible fault extending from Wild Cove southwards to Moreton's Harbour Pond whereas the former feature extends from the south side of Church Hill Pond northwards to Wild Cove.

Substantial minor faulting has also taken place in the map-area but there is generally little displacement discernible on the surface. These faults are fairly abundant. They cut all types of rocks at various angles ranging from northeast to northwest. They are best exposed on the coastal cliffs, especially around Moreton's Harbour Head and Wild Cove Head. The pattern of displacement of the rocks cannot be observed because of the monotonous nature of the rock assemblage. Only a few of these faults can be identified definitely as normal faults. However, most of

Figure 41. Photograph of a hand specimen of fault breccia from the northern side of Wild Cove Head. Magnification x 1.5.

Figure 42. Photograph of an outcrop to the north of Little Harbour showing slight crumpling of the thin-bedded volcanic sandstone.

Figure 41

Figure 42

Figure 43. Photograph of convolute folds in some beds of thin-bedded volcanic clastic rocks in an outcrop near the shoreline to the north of Taylor's Room.

Figure 44. Photograph of a thin section showing folding in volcanic sandstone. Magnification x 8.

Figure 43

Figure 44

them have steep dips and face southeastward to southwestward. None can be traced very far along strike.

Folds.

The general structure is that of a northwesterly-striking homocline which dips steeply to the southwest. Minor folding is not very conspicuous. Because of their massive character, the volcanic flows and coarse clastic layers are very competent and have resisted close folding. Small scale primary convolute folding is found in the zones of thin-bedded volcanic sedimentary rocks which are present between the massive layers. These small folds, in addition to such depositional features as crossbedding, graded bedding, and pillow structure, were of assistance in determining tops and bottoms of beds.

Orogeny.

The main deformation in the Notre Dame Bay region of the northern Appalachian system apparently occurred in two stages. The first was the Taconic orogeny at the end of the Ordovician period, and the second, the Acadian orogeny of Devonian age (Hayes, 1951). In the Bay of Exploits, New Bay, and Twillingate areas there is no strong evidence that there was a major orogeny at the close of the Ordovician period, thus ruling out the Taconic orogeny as a time of major deformation in Moreton's Harbour area (Heyl, 1936, 1947; Williams, 1963). On the other hand, the granitic intrusions in the Notre Dame Bay region appear to have been intruded along elongated zones of structural weakness which might have accompanied a period of deformation (Heyl, 1936, 1937; Espenshade, 1937; Hayes, 1951; Williams, 1963). Evidence concerning the age of those intrusions is meagre but it is believed that most of them may be assigned to the Acadian orogeny of Devonian age (Hayes, 1951). This indicates that it was probably during the Acadian orogeny that the volcanic rocks of Moreton's Harbour area were deformed and metamorphosed. Later faulting affected both the intrusions and the volcanic rocks of the area.

on the basis of this evidence, the sequence of events in Moreton's Harbour map-area is postulated as follows:

1. Eugeosynclinal conditions of deposition during the middle Ordovician when the volcanic rocks were deposited (Heyl, 1936). Extrusion of basaltic and andesitic lava flows as well as considerable volcanic activity of an explosive type. Volcanic flow rocks and coarse pyroclastic agglomerates were interbedded with fine-grained, thin-bedded volcanic clastic rocks under marine conditions of deposition.

2. Contemporaneous intrusion of diabase dykes and gabbro sills, possibly as feeders to the flows (Heyl, 1936).

3. Intrusion of granitic stocks during the Acadian orogeny in the Devonian period (Hayes, 1951). This was accompanied by additional faulting, folding, and shearing of the whole assemblage.

4. Intrusion of rhyolite dykes soon after the granitic stocks during the Devonian period. Formation of hydrothermal veins in faults and shear zones spatially related to the rhyolite dykes. The veins may be genetically related to all of those acidic rocks.

5. Additional faulting followed the vein formation. Intrusion of lamprophyre dykes during the Mesozoic era (Wanless, 1965 and 1967).

6. Pleistocene glaciation during Wisconsin time (Heyl, 1936; Espenshade, 1937).

7. Post-Pleistocene emergence of the coast, still in progress.

CHAPTER V

ECONOMIC GEOLOGY

History of mining.

Heyl (1936) has given a detailed report on all mining which has been carried on in the map-area. A summary of his description will be given here.

The largest mining operation was at the Frost Cove antimony deposit. The deposit consists of two narrow stibnite-rich veins on either side of a rhyolite dyke. This deposit was first worked shortly before the year 1890. During that year $1200 worth of antimony ore was exported from Newfoundland. Mining continued for several years but ceased about 1898. In 1906 the mine was reopened and again worked for a short interval, at which time about 100 long tons of picked ore was produced. It was reopened again during the early part of the first World War, but closed for the last time in the year 1916.

At the time of its final closing in 1916, the mine consisted of two adits, one 230 feet long at ten feet below sea level and a shorter one about 100 feet long at 55 feet above sea level. The adits are fairly well preserved. During the 52 years since 1916 substantial caving has taken place in the lower adit; only about 100 feet is still open. However, the upper adit has not caved at all.

The second mining operation was Stewart's mine, a gold mine north of Little Harbour. Little is known of the history of this mine. It was worked in the last decade of the nineteenth century on a narrow arsenopyrite-rich vein associated with a rhyolite dyke. A shipment of 125 tons of gold-bearing arsenopyrite was made in 1897. By 1900 the work of sinking a shaft upon the lode had been completed to a depth of 108 to 100 feet. Mining was discontinued very soon afterwards.

At present the workings consist of a trench about six feet deep extending along the vein outcrop for nearly 100 feet, and a shaft filled with debris and water located approximately midway along the trench. The shaft entrance measures 6 x 12 feet. The mine dumps are located near the south end of the trench.

No other mining has been carried on in the area. However, several prospects pits have been dug on various veins, especially the gold-arsenopyrite veins in Taylor's Room area.

The two mining properties and the Taylor's Room prospects are held under Fee Simple Grants. They are not included in mining company concession areas.

Distribution and paragenesis of the veins.

More than fifty veins were found in the map-area. A zone containing most of the veins extends from the west side of Moreton's Harbour Head eastward along the shoreline to about 1000 feet north of Little Harbour. The distribution of the largest veins is shown on the accompanying map. Those veins range in thickness from a fraction of an inch to approximately ten inches, but the average is 1 - 2 inches thick. Generally, each vein is exposed for only 2 - 3 feet along strike, but some may be traced for about 100 feet. Heyl (1936) states that the Frost Cove mine veins can be followed southwards for more than half a mile. The writer agrees that this is possible but feels that outcrop is too sparse to accept the statement without reservations. The widely separated vein exposures could just as well be other veins as a continuation of the former.

Before the veins were formed, substantial shearing and faulting of the dykes and other rocks developed permeable zones. It has been assumed that transport of ore and gangue minerals was brought about by means of hypogene solutions rising through these fractures from a granodiorite magma at depth. In some places there is evidence that a small amount of shearing has occurred in the veins since mineralization.

Figure 45. Photograph showing the locations of the four major gold-bearing veins in Taylor's Room area. Note the black spots above and to the right of the church.

Figure 46. Photograph of a prospect pit dug on the vein in Locke's garden, second from the right in figure 45. This vein varies from 6 to 10 inches in thickness. The host rock is tuff-breccia.

Figure 45

Figure 46

Figure 47. Photograph from Little Harbour to the northeast towards Stewart's mine. Note the tailings dump in the top center behind the garden.

Figure 48. Photograph of the shaft of Stewart's mine. The boulder in the foreground is a section of the vein, which is approximately nine inches in thickness.

Figure 47

Figure 48

The primary minerals present in the veins throughout the area are arsenopyrite, pyrite, pyrrhotite, chalcopyrite, galena, sphalerite, and stibnite. Of the gangue minerals, quartz predominates but calcite is common. Stibnite is most abundant at Frost Cove mine; arsenopyrite predominates at Stewart's mine. Galena, sphalerite, pyrite, and pyrrhotite become abundant in local masses in various veins throughout the area. Quartz is generally found as massive vein quartz but in places it forms euhedral crystals. Rarely, an imperfect comb structure is formed at the center of some veins by euhedral arsenopyrite and quartz crystals pointing towards the center, and embedded in calcite. Most commonly quartz predominates near the margins and arsenopyrite and other ore minerals toward the center; this gives a fairly well-developed banding in some veins. Scorodite ($FeAsO_4 \cdot 2H_2O$) was identified by x-ray diffraction methods on fragments of greenish black gossan from Stewart's mine. No alteration products of stibnite were identified but Heyl (1936) reports kermesite (Sb_2S_2O) and cervantite (Sb_2O_4) in small amounts from the prospect pits south of Little Harbour.

Arsenopyrite is present in about forty of the veins. However, only nineteen contained a sufficient amount for a usable sample to be separated for cell determinations by x-ray diffractometer. Eleven additional samples were

Figure 49. Photograph looking southwards towards the Frost Cove antimony mine.

Figure 50. Photograph of a hand specimen consisting of rhyolite and one-inch thick vein. The hand specimen was collected at the road supposedly along strike from the old mine workings.

Figure 49

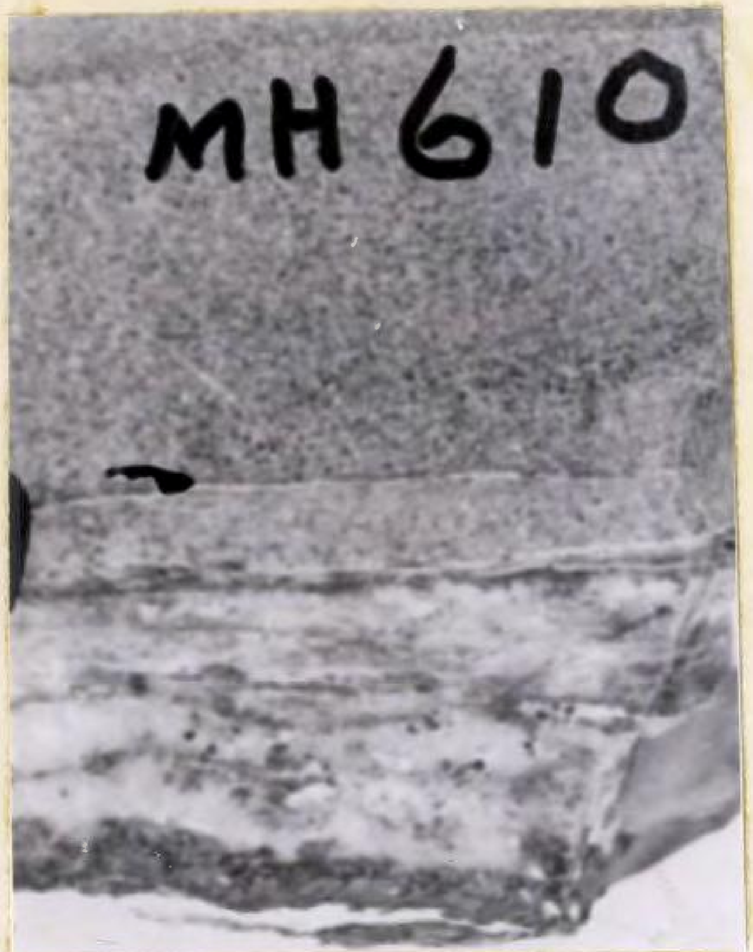
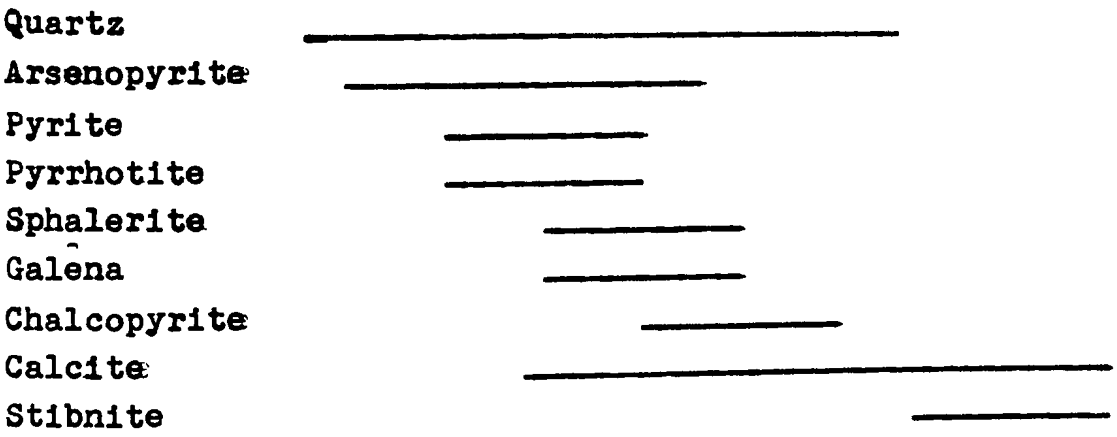


Figure 50

separated from veins intersected in boreholes; these borehole samples came from the two holes drilled in the Taylor's Room area by Newfoundland and Labrador Corporation in 1965.

A general paragenetic scheme for the ore and gangue minerals has been determined. Several of the relations are uncertain but the overall sequence of deposition is fairly clear. Some 58 polished sections were examined microscopically in the course of this paragenetic study.



The first two metallic minerals to be introduced were arsenopyrite and pyrite, both of which replaced the host rock to a certain extent. Pyrrhotite appears to have been contemporaneously deposited in the Taylor's Room area, but elsewhere it is not present. Quartz gangue crystallized simultaneously throughout the whole area. The next minerals to be deposited were sphalerite, galena, and chalcopyrite, along with calcite. The sphalerite always contains thin lamellae of chalcopyrite. Except for this mode of occurrence chalcopyrite is relatively rare; however, locally it is present in concentrations large enough to be seen in hand specimen. It replaces pyrite and, to a limited extent, calcite. Stibnite was the last metallic mineral to be deposited anywhere in the area. In Frost Cove mine it comprises most of the two veins. Stibnite sometimes crosscuts sphalerite in the form of irregular thin veinlets; it also replaces galena and calcite.

As this study is mainly concerned with arsenopyrite, its relations with other minerals were considered in greater detail. The relations between arsenopyrite and the other sulfides in those veins are similar to the relations described by many other authors for comparable occurrences. Detailed parageneses of the veins at Stewart's mine and Frost Cove mine are given by Heyl (1936).

Arsenopyrite either forms euhedral, wedge-shaped crystals disseminated in the wall rocks, or massive aggregates of coarse subhedral-euhedral grains comprising the cores of veins. The euhedral crystals are generally short and stubby. This euhedral nature of much of the arsenopyrite hinders clarification of its paragenetic relations with its associated minerals. It appears unlikely that any replacement of the arsenopyrite occurred;

the arsenopyrite seems to have been chemically stable during the deposition of later minerals.

The relations between arsenopyrite and pyrite are important in interpreting the compositional data. The pyrite forms euhedral cubes which are occasionally veined by chalcopyrite. The contacts between grains of arsenopyrite and pyrite were observed in some sections and the two appear to have formed simultaneously. Rarely, arsenopyrite forms thin veinlets in pyrite-quartz veins; it was apparently deposited later than that assemblage. The evidence is not conclusive but arsenopyrite is considered to have begun crystallization first, together with quartz. After a short period pyrite and pyrrhotite were deposited simultaneously with them. Some arsenopyrite was deposited after pyrite crystallization had ceased. There is no positive indication that the formation of later pyrite and pyrrhotite induced compositional change in responce to either falling temperature or changing sulfur fugacity due to pyrite and pyrrhotite deposition. Attempts were made to separate arsenopyrite from these tiny veinlets but they were not successful. On the basis of these relations, it is concluded that arsenopyrite probably began to crystallize above 500°C.

No loellingite was detected either by x-ray powder diffraction methods or by microscopic examination of polished sections.

Figure 51. Photograph of an amygdaloidal lava ribboned by quartz veins and crosscut by a very narrow (less than one inch thick) "granitic" dyke.

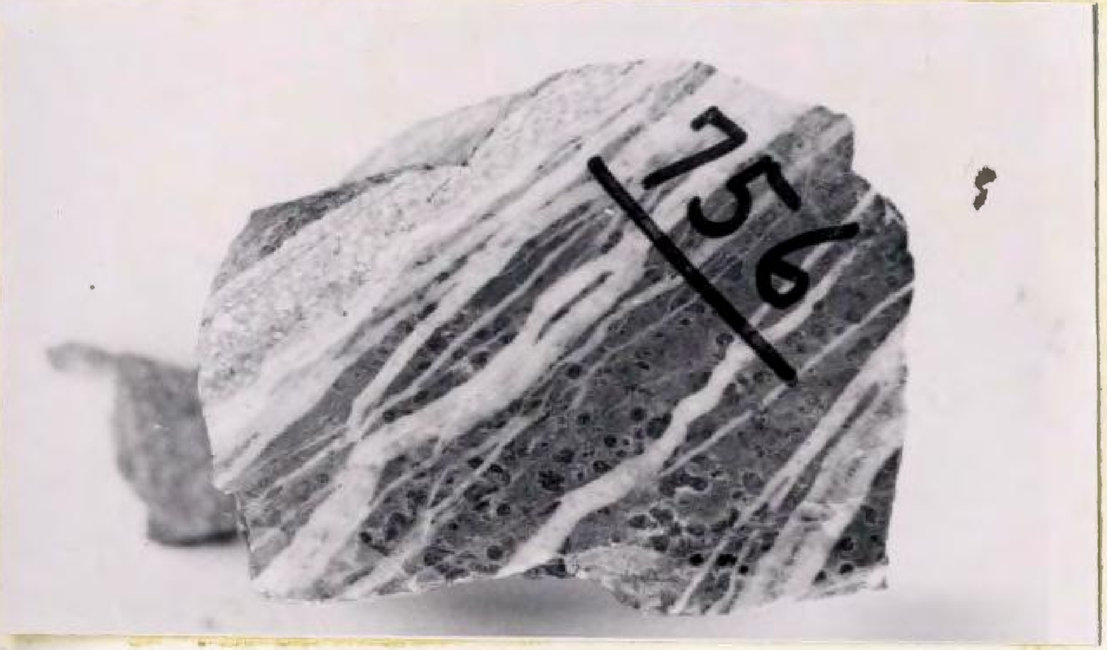


Figure 51

CHAPTER VI.

ARSENOPYRITE

Introduction.

"Recent experimental studies on the phase equilibria of the more important sulfide systems have encouraged the estimation of the P-T conditions prevailing during mineralization in a considerable number of sulfide deposits. Although the sphalerite geothermometer (Kullerud, 1953) has been shown by Barton and Toulmin (1964) to be of probably dubious validity, the temperatures of formation of many sulfide assemblages may be deduced with some degree of confidence. Less is known, however, about the confining pressures under which ore deposits have formed, a factor of importance in the classification of mineral deposits, and in the detailed study of mineralized areas. Under favourable conditions, the depth at which mineralization occurred may be estimated by calculation of the superincumbent strata, or by the study of fluid inclusions in minerals, but these approaches have generally proved successful only for deposits of shallow formation. In a general geological context a reliable mineral "geobarometer" would be of great value in the interpretation of mineral parageneses." (A.H. Clark, 1965).

L.A. Clark (1960a,b), in an experimental investigation of the Fe-As-S system, found that the solvus curves relating the composition of arsenopyrite to the temperature of deposition are very steeply inclined, and are markedly affected by confining pressure. Accordingly, he has suggested that the composition of arsenopyrite could be used in the determination of confining pressures and temperatures of mineral deposits. It is not very precise as a geothermometer but, if the temperature of deposition could be estimated by independent means, it is potentially a useful geobarometer, since arsenopyrite is often associated with mineral deposits. In Moreton's Harbour map-area this mineral is a major constituent of some of the veins. Thus a detailed study of the arsenopyrite may yield interesting results. The composition of the mineral has been examined by x-ray powder diffraction techniques, and consideration was given to the applicability of variations in d (131) values and As:S ratios to changes in physical conditions of deposition, applying the methods and experimental results of L.A. Clark (1960 a,b).

Experimental basis and previous applications of the data.

A.H. Clark (1965) has summarized the experimental investigations on which this research project is based, so only a brief review of L.A. Clark's conclusions will be given here.

L. A. Clark (1960a) determined the equilibrium phase relations in the ternary system Fe-As-S at 600° C, and studied the changes in the stable assemblages from 400° C to 800° C. The more important conclusions of his work, as far as the study of natural assemblages containing arsenopyrite is concerned, are as follows:

1. Arsenopyrite is stable in the presence of vapour at all temperatures to 702 ± 3° C. Thus the presence of arsenopyrite is not in itself a criterion for deposition at high temperatures.

2. The assemblage native arsenic-arsenopyrite is unstable above about 688° C.

3. Pyrite and arsenopyrite cannot coexist in equilibrium with vapour above 491 ± 12° C at $<$ 1 bar of confining pressure. If these minerals are in contact, and equilibrium is assumed to have been obtained during deposition, one or both minerals must have been deposited below this temperature.

The arsenic:sulfur ratio of arsenopyrite varies on either side of ideal FeAsS. This variation is dependent on the temperature and confining pressure during deposition, as well as on the nature of the coexisting minerals. Morimoto and Clark (1961) have reviewed the more reliable chemical analyses of arsenopyrite, and conclude that the Fe:As+S ratio of this mineral is

Figure 52. T-X plot showing the fields of stability of arsenopyrite at less than one bar and 2000 bars confining pressure; the section at 1000 bars, occupying an intermediate position, has been omitted. The phase relations are projected from P-T-X space onto a part of the Fe S_2 - Fe As_2 pseudobinary T-X section. The 131 spacing of arsenopyrite varies as a function of the arsenic: sulfur ratio. Abbreviations: asp, arsenopyrite; po, pyrrhotite; py, pyrite; lo, loellingite; and L, liquid. (After L.A. Clark, 1960 b).

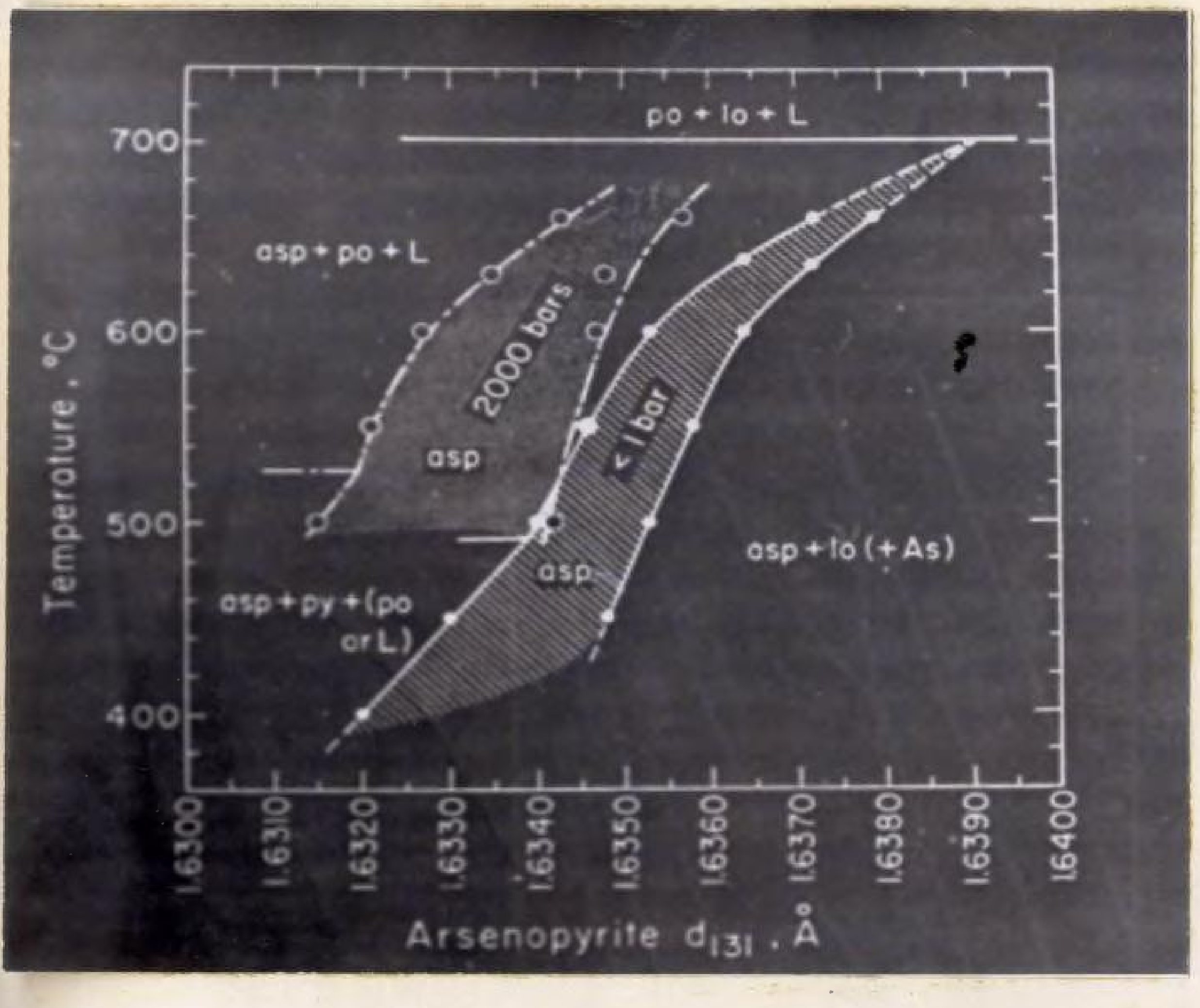

po + lo + L
700
600
500
400
Temperature, °C
asp + po + L
2000 bars
asp
< l bar
asp
asp + lo (+ As)
asp + py + (po or L)
1.6300
1.6310
1.6320
1.6330
1.6340
1.6350
1.6360
1.6370
1.6380
1.6390
1.6400
Arsenopyrite d_{131}, Å

Figure 52

consistently 1:2, the iron content remaining constant at 33 1/3 atomic per cent. Therefore, the arsenic:sulfur ratio is the most important parameter in the study of arsenopyrite compositions and phase relations. It may be estimated rapidly by measurement of the (131) spacing of the metrically monoclinic unit-cell (L.A. Clark, 1960a; Morimoto and Clark, 1961).

This idea was used extensively by A.H. Clark in his work on the Ylojarvi copper - tungsten deposit. He writes:

> "In an extension of the original work on the Fe-As-S system, Clark (1960b) examined in more detail the dependence of the composition of arsenopyrite on temperature and confining pressure. This study has been the basis of the present work. Clark determined the variations of arsenopyrite composition in equilibrium with sulfur - and arsenic - rich fluids at confining pressures of < 1, 1000, and 2000 bars, and at temperatures from 702° C to below 500° C (fig. 52). The data for the sulfur-rich P-T-X surface are redrawn on the P-T plot of fig. 53, the (131) spacing contours representing lines of constant As:S ratio. This diagram facilitates the application of the compositional data to the estimation of temperatures and confining pressures of arsenopyrite deposition. In order to make an estimation of confining pressure, it is necessary to ascertain that the arsenopyrite was deposited in association with sulfides as opposed to arsenides, and that the combined minor element content in the arsenopyrite does not exceed 1.0 weight per cent. It was suggested by Clark that determinations of the temperature of deposition to within 40° C would permit the estimation of confining pressure to within 400 bars." (A.H. Clark, 1965).

A.H. Clark (1965) has also summarized the previous applications of the data on arsenopyrite compositions.

Figure 53. Lines of constant 131 spacing, and As:S ratio projected from the sulfur-rich P-T-X surface of the arsenopyrite stability field, and projected as contours on the P-T projection. The upper stability curve of the pyrite - arsenopyrite assemblage (L.A. Clark, 1960 a) is also shown; the contour positions on the low-temperature side of this curve are approximate because pressure data were not obtained below 500° C. (After L. A. Clark, 1960 b).

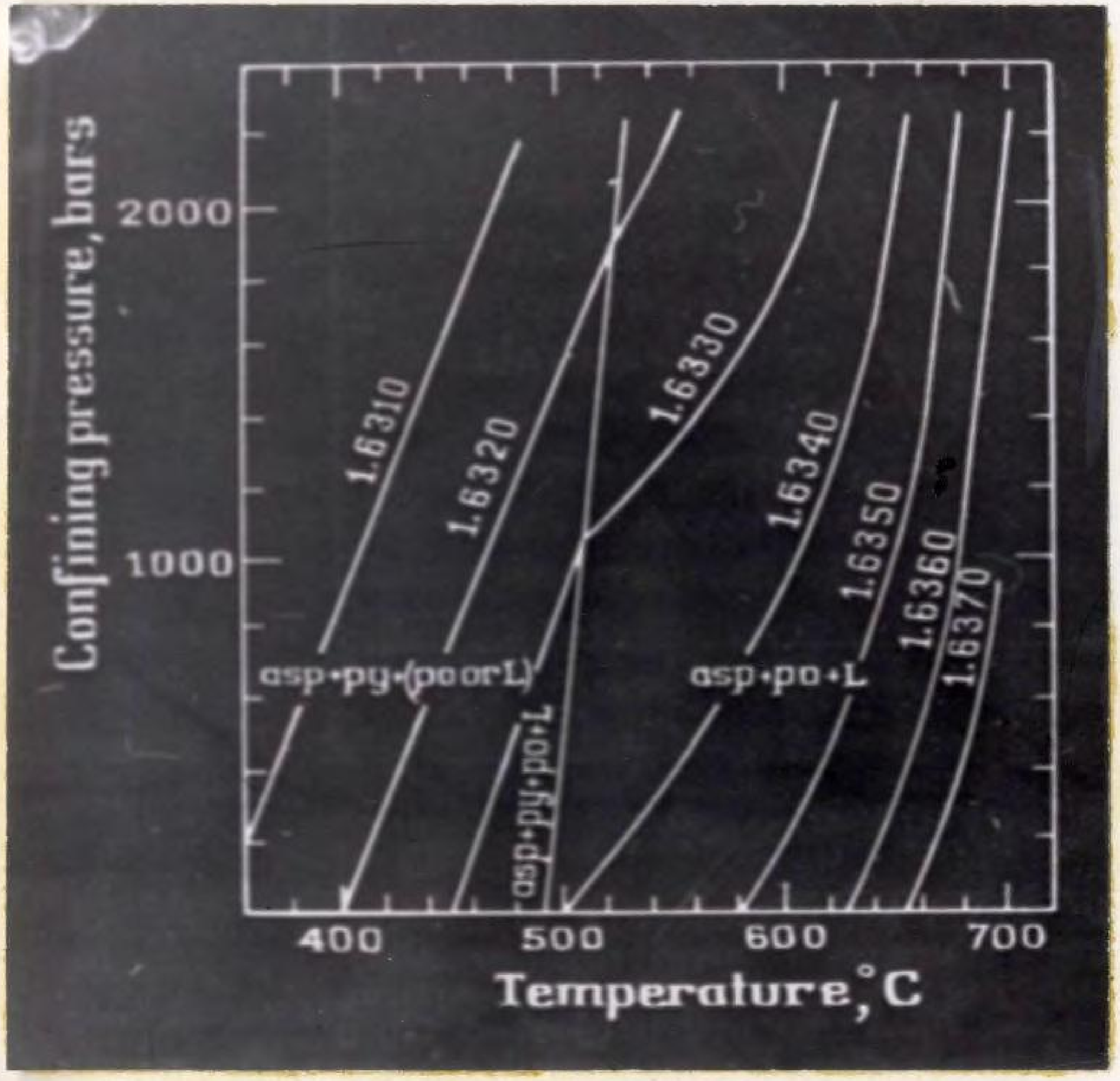

Confining pressure, bars
2000
1000
400
500
600
700
Temperature, °C
1.6310
1.6320
1.6330
1.6340
1.6350
1.6360
1.6370
asp+py+(po or L)
asp+po+L
asp+py+po+L

Figure 53

Except for his own research on the Ylojarvi deposit, Finland, no extensive detailed work has been carried out on the variations in composition shown by arsenopyrite in mineral deposits. L.A. Clark (1960b) did estimate the confining pressures affecting sulfide deposition in the Giant Yellowknife (Northwest Territories) and Parrex prospect, Hansen Lake (Saskatchewan) deposits, but in each case only one arsenopyrite was examined. A.H. Clark (1965) has quoted other similar applications but none dealt with a large number of samples. In his study of the Ylojarvi deposit, A.H. Clark (1965) made accurate determinations of the d_{131} values of 214 arsenopyrites. On the basis of his results and a temperature of deposition estimated on the basis of the compositions of pyrrhotite and sphalerite, he concludes that the confining pressure of deposition was between 2000 and 2500 bars.

Determinations of arsenic:sulfur ratios and d (131) spacings of arsenopyrite.

The physical and chemical conditions during the deposition of arsenopyrite produce variations in its arsenic and sulfur contents mostly within the range $FeAs_{0.9}S_{1.1}$ and $FeAs_{1.1}S_{0.9}$. The compositional variations cause substantial changes in the interplanar spacings of arsenopyrite. These changes result in characteristically different d (131) values from x-ray diffraction studies (L.A. Clark, 1960a,b,).

X-ray diffraction procedures.

All measurements were made on a Norelco Philips X-Ray Diffractometer, using nickel-filtered Cu K α radiation (λ = 1.54178 Å). The angular positions of the (131) $K\alpha$ reflections were measured relative to the (311) α reflection of CaF_2 (fluorite); natural fluorite was found to be a satisfactory internal standard. Calibration of the position of the (311) reflection of the fluorite was made against NaCl (halite).

Both the arsenopyrite and the fluorite were finely ground to approximately -300 mesh by machine grinding for about 40 minutes and hand grinding until all grittiness had disappeared. Samples were prepared by mixing one part of fluorite with three to five parts of arsenopyrite, and hand grinding the product for five to ten minutes to ensure a fair degree of homogeneity. The sample was pressed into a cavity (20 x 11 x 2 mm) in an aluminum holder. The same mounting was used for all measurements on a particular sample to ensure internal consistency. However, check mountings run on two samples showed that results are reproducible well within the accuracy limits of the method.

In each determination the final d (131) value was the mean of six scans across the diffraction peak. Only the peak separations given by scans from lower to higher angles were used since low angle runs consistently gave readings about 0.07° 2θ different from high angle runs.

Instrumental settings were varied throughout the preliminary experimenting and the final work, for the best resolution of the (131) reflection. The following settings gave satisfactory results for most samples:

Divergence and scatter slits, 4°;

Receiving slit, 0.2 mm;

Scan speed, (1/8)° 2θ per minute;
Chart speed, 300 mm per hour;
Time constant, 10 seconds;
Rate meter, 300 counts per second; and
Electrical settings, 40 kilovolts and
20 milliamperes.

The charts were measured using a straight edge scale calibrated in 50ths of an inch, reading accurately to ± 0.002 to ± 0.010 °2θ. The reflections were measured at their centers of gravity, which were visually estimated at about three-quarters of the peak height. The mean and standard deviation were calculated for each series of measurements. The measurements were precise within the range 0.0001 - 0.0003 Å in cases where the (131) reflection was well-resolved. Only for three specimens was the precision of measurement greater than 0.0003 Å, but then it was less than 0.0004 Å.

The general range of values obtained indicates that the results are comparable with the values obtained by A. H. Clark (1965).

The arsenic:sulfur ratios of the arsenopyrite were determined by using the measurements of the d (131) spacings and the relationship

$$d\ (131) = 1.60060 + 0.00098\ X$$

where d (131) is an Ångstrom units and X is the atomic per cent of arsenic (Morimoto and Clark, 1961). Morimoto and Clark (op.cit.) suggest that measurement of the d (131) values to ± 0.0003 Å will give the arsenic content to approximately one atomic per cent. It is also considered that minor variations in the composition of this mineral may be reliably detected by accurate determination of the d(131) spacing.

To provide a check on the measurement of As:S ratio by x-ray diffraction, five purified samples of arsenopyrite were analyzed by wet chemical methods in the laboratories of the Mines Branch, Department of Energy, Mines, and Resources, Ottawa, Canada. The results are given in table 3.

ARSENIC ATOMIC PERCENT

SAMPLE NUMBER	CHEMICAL ANALYSIS	DIFFRACTION MEASUREMENT
MH 741	30.91	30.35
MH 498	30.82	30.45
MH 910	32.17	31.59
Sm 1	32.07	31.34
MUN228	34.77	35.53

Table 3. Comparison of arsenic atomic percents determined from chemical analyses and diffraction measurements.

TABLE 4 . ARSENOPYRITE ANALYSES,
Moreton's Harbour, Newfoundland

	MH498	MH741	SM-1	MH910	MUN228*
Fe	NOT DETERMINED				
As	42.54	42.67	44.28	44.40	48.01
S	20.91	21.02	19.02	20.19	17.31
Ba	ND	ND	ND	ND	ND
Mn	ND	ND	ND	ND	ND
Sb	ND	ND	ND	ND	ND
Mg	0.08	0.06	0.08	0.03	0.04
Mo	ND	ND	ND	ND	ND
Pb	0.50	ND	ND	ND	ND
Sn	ND	ND	ND	ND	ND
Cr	ND	ND	ND	ND	ND
Si	0.03	0.02	0.09	0.02	0.02
Bi	ND	ND	ND	ND	ND
Al	0.03	0.01	0.02	ND	0.004
V	ND	ND	ND	ND	ND
In	ND	ND	ND	ND	ND
Zr	ND	ND	ND	ND	ND
Cu	0.1	0.07	0.08	0.08	0.1
Ag	0.01	0.002	0.003	0.002	0.004
Zn	1.0	ND	ND	ND	ND
Ti	0.009	0.002	0.004	0.005	0.002
Ni	0.03	0.04	0.04	0.05	0.07
Co	ND	0.01	0.02	0.01	0.1
Sr	ND	ND	ND	ND	ND
Au	ND	ND	ND	ND	ND
W	ND	ND	ND	ND	ND
d(131)	1.63044	1.63034	1.63131	1.63156	1.63542
Trace Element Total	1.789	0.214	0.337	0.197	0.300

ELEMENTS - Per Cent ND - not detected

Analyses done by the Mines Branch, Mineral Sciences Division, Department of Energy, Mines, and Resources.

* This sample was collected from a granitic pegmatite about 10 miles east of Port aux Basques, Newfoundland.

According to L. A. Clark, one percent of minor constituents is sufficient to cause minor errors in the estimation of the arsenic:sulfur ratios (Clark, 1960 a). Table 4 shows that in only one of the five analysed samples (MH 498) was the combined content of minor constituents found to exceed one percent by weight (Table 4). In view of the high Pb and Zn, the writer believes that this was due to a contamination of the arsenopyrite sample by a small amount of mechanically included galena and sphalerite rather than to the presence of these elements in the arsenopyrite lattice, so the actual minor element content of the arsenopyrite itself was probably normal. Although the minor element concentrations have been chemically determined in only five samples, the writer believes that the measured variations in d(131) values reflect real changes in the arsenic:sulfur ratios and are not significantly affected by fluctuations in the minor element content.

Most specimens studied gave sharp, well-resolved (131) reflections, but some samples showed a broadening of the diffraction peak. This feature may be an indication of the variable composition of the arsenopyrite, either as small scale compositional zoning or due to more than one phase. Microscopic study of 58 polished sections of the mineral assemblages does not indicate any zoning. However, tiny veinlets of late arsenopyrite were observed but could not be studied separately by x-ray diffraction.

Arsenic: Sulfur ratios and d(131) values of arsenopyrite from Moreton's Harbour map-area.

The d(131) values of thirty arsenopyrites from the map-area were accurately determined. Several other veins were samples in the field, but these did not contain sufficient arsenopyrite for a usable amount to be separated by any method. Six specimens from outside areas were measured in order to obtain some comparative data.

The arsenopyrite has a variable composition throughout the area. The determined compositions range from approximately 30.08 to 33.83 atomic percent arsenic; the d(131) values, from 1.6301 to 1.6338 Å ± 0.0003 Å.

Twenty-eight of the samples from Moreton's Harbour map-area have arsenic: sulfur ratios characteristic of sulfur-rich arsenopyrite. The sulfur-rich compositions vary from near the minimum limit almost up to ideal FeAsS. The two samples which have arsenic contents exceeding that of the ideal theoretical composition FeAsS can hardly be considered to represent an arsenic-rich maximum, however, because their compositions are very near the ideal in the range of 33.57 to 33.83 atomic percent arsenic (1.63350 to 1.63375 Å). Within the limits of precision of the analytical method, these compositions are identical.

An arsenopyrite sample from a pegmatite near Port aux Basques, Newfoundland (MUN228) has a measured d (131) spacing of 1.63542 Å. Its arsenic atomic percent is 34.77 according to a chemical analysis (Table 3) and 35.53 based on calculations from the d (131) value. The larger value is fairly near the upper limit of natural arsenopyrite at the Ylojavri copper-tungsten deposit, Finland (A. H. Clark, 1965).

The arsenopyrite data are presented in two forms. The values obtained for the surface samples are plotted on a map with a scale of 500 feet to one inch on which the sample locations have been accurately recorded. All the values, including those for the surface samples, are given in frequency histograms.

Figures 54a to 54d are histograms which illustrate the range and frequency of d (131) values and arsenic contents of all the arsenopyrite studied. The plotted values do not show a single, well-defined distribution for the map-area. Considering the histograms of the surface samples, there seems to be a primary maximum in the range 1.6300 - 1.6309 Å (about 30 - 30.9 atomic percent arsenic) and three respectively smaller subsidiary phases in the following ranges:

1.6313 - 1.6318 Å (31.2 - 31.8 atomic % As);

TABLE 5 .

Arsenic atomic percentages calculated using the d(131) values and the relationship

$$d(131) = 1.60060 + 0.00098X$$

SAMPLE NUMBER	d (131) SPACING	ARSENIC ATOMIC PERCENT
D3-1R	1.63227	32.32
2R	1.63180	31.84
3R	1.63019	30.19
5R	1.63220	32.24
6R	1.63218	32.22
10R	1.63228	32.33
12R	1.63240	32.45
13R	1.63145	31.48
14R	1.63211	32.15
D4-1R	1.63179	31.83
2R	1.63058	30.59
JP- 1	1.63045	30.46
LHP-3	1.63165	31.68
MH401	1.63148	31.51
498	1.63044	30.45
561	1.63008	30.08
569	1.63375	33.83
580	1.63350	33.57
605	1.63135	31.38
609	1.63228	32.33
690	1.63261	32.66
732	1.63282	32.88
733	1.63251	32.56
741	1.63034	30.35
750	1.63061	30.62
803	1.63024	30.24
845	1.63052	30.53
875	1.63039	30.40
910	1.63156	31.59
SM- 1	1.63131	31.34
1.	1.63111	31.13
2.	1.63152	31.55
3.	1.63155	31.58
4.	1.63197	32.01
5.	1.63443	34.52
6.	1.63542	35.53

The localities of the six comparative samples were as follows:

1. Cobalt, Ontario;
2. Sulfide Lake, Saskatchewan;
3. Tilt Cove, Newfoundland in a rhyolite dyke;
4. Deloro, Ontario;
5. Grey River, Newfoundland in a quartz vein; and
6. East of Port aux Basques, Newfoundland in a granitic pegmatite.

1.6321 - 1.6330 Å (32.1 - 33.0 atomic % As);

and 1.6335 - 1.6338 A (33.5 - 33.9 atomic % As).

The histogram of the borehole distribution shows a maximum in the range 1.6320 - 1.6327 Å (32.0 - 32.7 atomic percent arsenic) and indicates minima in the two lower ranges. As a whole, the area appears to have two equally strong maxima in the ranges

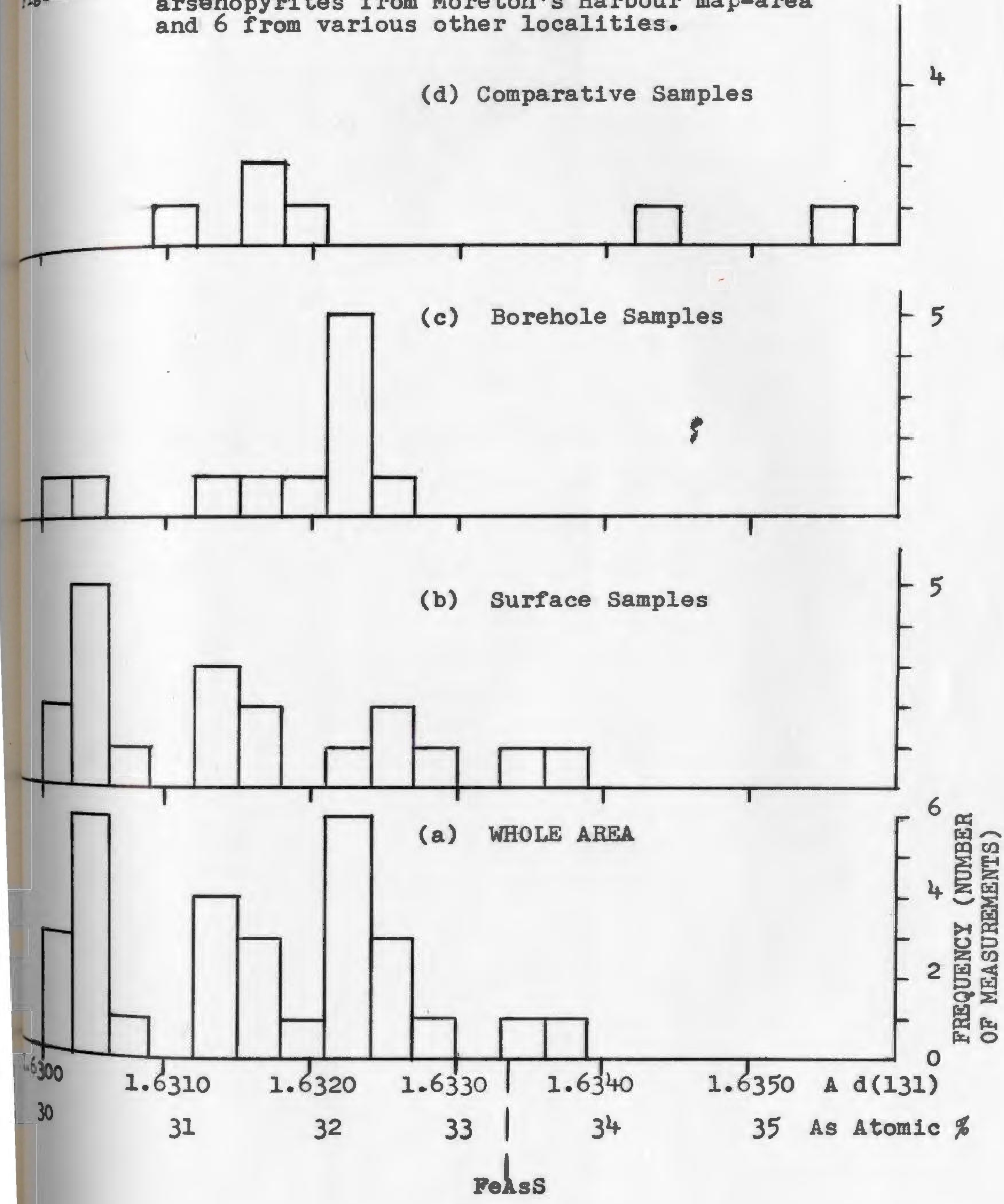
1.6300 - 1.6309 Å (30 - 30.9 atomic % As)

and 1.6321 - 1.6330 Å (32.1 - 33.0 atomic % As),

with a smaller distribution in the range 1.6312 - 1.6320 Å (31.2 - 32.1 atomic percent arsenic).

On the map distribution the variation in d(131) values is generally random. There is no consistent gradient in composition from one part of the area to another. However, the range of values does indicate that each different composition distribution shown by the histograms (fig. 54) is somewhat characteristic of a different area of sampling; that is, certain d(131) values do occur more abundantly at particular localities within the map-area. The mean values in the vicinities of Taylor's Room and Little Harbour are 1.6304 and 1.6315 Å respectively. These differences are paralleled by variations in the mineral phases in the veins. In Little Harbour area, arsenopyrite is the main mineral with

Figure 54. Histograms showing the arsenic content of 30 arsenopyrites from Moreton's Harbour map-area and 6 from various other localities.



small amounts of pyrite whereas in Taylor's Room area both pyrrhotite and pyrite are present with the arsenopyrite. Therefore, those (131) values may be of some importance in interpreting the conditions of deposition of arsenopyrite in these two parts of the map-area. However, other values equal to the mean values are found spuriously scattered throughout the map-area. Therefore, no attempt to prove a single consistent pattern of deposition across the map-area can be very successful although there are possibilities that there was a gradient in the conditions of mineralization between Little Harbour and Taylor's Room.

The significance of the arsenopyrite data.

Arsenopyrite occurs commonly in both sulfide and arsenide mineral assemblages. Variations in its arsenic and sulfur contents is primarily dependent on confining pressure, temperature, and composition of the environment of deposition. The influence of the "arsenic: sulfur ratio" of the environment of deposition on the composition of the arsenopyrite decreases with increasing temperature and pressure, as reflected in the convergence of the sulfur- and arsenic-rich solvus curves (Figure 52; Clark, 1965). Therefore, the d (131) values determined should reflect the mode of formation of the arsenopyrite, especially if the chemical nature of the mineral assemblage is known; that is, whether it is arsenide - bearing or sulfide - bearing (L.A. Clark, 1960 a,b,).

On the basis of published chemical analyses, Morimoto and Clark (1961) suggested that most ("probably 70 percent") natural arsenopyrite is more sulfur-rich than ideal FeAsS, reflecting the predominance of sulfide-bearing environments. In support of this, L.A. Clark determined the d (131) spacings of a number of arsenopyrites from various localities, finding a range from 1.6300 Å to

1.6352 Å, with most values falling between 1.6300 and 1.6330 Å (A.H. Clark, 1965). Similar determinations were made by the writer on six random samples from Saskatchewan, Ontario, and Newfoundland. A range of d (131) values from 1.6310 to 1.6354 Å was obtained. Only two of these values were greater than 1.6330 Å (Table 5).

Of the thirty specimens studied from Moreton's Harbour map-area, twenty-eight contain more sulfur than arsenic. These have d (131) values falling in the range 1.6300 - 1.6328 Å, which indicates that the environment during deposition was probably relatively rich in sulfur. L. A. Clark has suggested that arsenopyrite crystallizing above about 400° C may be assumed to have formed in equilibrium with its environment (A.H. Clark, 1965). Mineralogical study of the veins shows that sulfide minerals are abundant throughout the area but no arsenide minerals are present. Therefore, supersaturation with respect to arsenic did not occur at any locality and the arsenopyrite was deposited in a sulfur-rich environment. The two very slightly arsenic-rich specimens appear to have been deposited under the same conditions as all the others. Accordingly, the data accumulated on arsenic:sulfur ratios and d (131) values should provide some evidence of the range of pressure and temperature conditions prevailing during arsenopyrite deposition, although precise estimations of the temperatures and pressures may not be possible (A.H. Clark, 1965).

In the estimation of a minimum temperature of mineralization, arsenic-rich arsenopyrites with d (131) values greater than 1.6340 Å are most precise (Figure 53). Arsenopyrites with d (131) values less than 1.6340 Å are correspondingly less precise as indicators of temperature but more concise as indicators of confining pressure of deposition (Clark, 1960). It is preferable to have available an independent means of determining temperature since most assemblages are sulfur-rich and contain arsenopyrite which is more precise as a geobarometer than a geothermometer. L.A. Clark has suggested that determination of the temperature of deposition to within 40° C would permit the estimation of confining pressure to within 400 bars, using arsenopyrite as a geobarometer (A.H. Clark, 1965).

The range of d (131) values for the arsenopyrite suite from Moreton's Harbour map-area is 1.6300 - 1.6338 Å. Consequently, it is more precise as an indicator of confining pressure than of temperature. Unfortunately, we were unable to obtain a temperature estimate for the map-area by any other method so the estimates of temperature and pressure have to be rather general.

Range of pressure and temperature conditions during arsenopyrite deposition.

The upper stability limit of arsenic-rich arsenopyrite is 702 ± 3° C, the invariant temperature for the incongruent breakdown of arsenopyrite. This is the maximum temperature at which any arsenopyrite may have been deposited.

The arsenopyrite from Moreton's Harbour map-area is mostly richer in sulfur than the ideal composition FeAsS. Experimental work by L. A. Clark (1960 a,b,) clearly indicates that such arsenopyrite could only form at temperatures below 500° C at <1 bar of confining pressure. However, it could form at temperatures up to 640° C at pressures of 2000 bars. Figure 53 shows that these temperatures are equivalent to those at which arsenopyrite with d(131) = 1.6338 Å would crystallize in equilibrium in a sulfur-rich environment at confining pressures of <1 bar and 2000 bars respectively. The temperature at which arsenopyrite of the same composition can exist at 1000 bars of pressure in a sulfur-rich environment is approximately 580° C. At confining pressures between 1000 and 2000 bars, which seem reasonable to assume for the map-area, such arsenopyrite would be stable between 580° C and 640° C. Therefore, a temperature of 610° ± 30° C may be considered as the upper temperature limit of arsenopyrite deposition in the map-area. However, since only two arsenopyrites have this composition and all others have (131) values less than 1.6330 Å, it is possible that there was a minor, early phase of deposition at such high temperatures which was followed after a short time by the main mineralization.

Several paragenetic relationships in the veins also place restrictions on the probable maximum temperature attained during the early stages of mineralization.

The presence of pyrite indicates temperatures below about 743° C (Kullerud and Yoder, 1959) but the deposition of some pyrite followed or was simultaneous with that of arsenopyrite. Where these two minerals occur together, one or both of them must have formed at some temperature below 491° ± 12° C or 528° ± 10° C at confining pressures of < 1 bar and 2070 bars respectively (L. A. Clark, 1960 a).

Pyrrhotite and pyrite occur in contact in veins in Taylor's Room area. Magnetite was not observed in the veins but it is present in the wallrock. Barnes and Kullerud (1961) have shown that the assemblage pyrrhotite + pyrite + magnetite + vapour is stable only above 675° C. If these minerals do coexist, their deposition must have occurred below 675° C.

The two phases relationships just described do not contradict the temperature of 610° ± 30° C postulated for the initial deposition of arsenopyrite.

On the other hand, the lowest (131) value measured for arsenopyrite from the map-area is 1.6301 Å. Figure 53 shows that the minimum pressure at which arsenopyrite of this composition can be deposited in a sulfur-rich environment is approximately 1000 bars, at which the minimum temperature of deposition is about 360° C. If the confining pressure is 2000 bars, the minimum temperature of deposition is about 420° C. Therefore, according to the x-ray diffraction data, the temperature at which arsenopyrite deposition ceased may have been 390° ± 30° C at confining pressures between 1000 and 2000 bars.

In some veins, sphalerite was deposited after the arsenopyrite. The presence of exsolution lamellae of chalcopyrite in the sphalerite indicates that the vein minerals must have been deposited at temperatures above 350° C - 400° C, at which chalcopyrite could dissolve in sphalerite (Baker, 1960). Published experimental data indicate that chalcopyrite exsolves from sphalerite when cooling through 350° C. This evidence supports the consideration that the minimum temperature of formation of arsenopyrite in Moreton's Harbour map-area may have been about 390° ± 30° C.

It is therefore considered that the range in arsenic:sulfur ratios of the arsenopyrite from the veins around Moreton's Harbour was caused primarily by a decrease in temperature of deposition from about 610° ± 30° C to 390° ± 30° C. Deposition of the whole range of compositions is considered to have been essentially continuous. The composition maxima shown on histograms (figure 54) may represent pulses of relatively intense deposition which occurred in different parts of the area.

Summarizing, the data available do yield significant information on the probable physical conditions of deposition of the arsenopyrite. Estimations have been made of ranges of temperature and confining pressure. Since all the arsenopyrite has (131) values less than 1.6340 Å in the range 1.6301 Å - 1.6338 Å, or 1.6319 ± 0.0018 Å (figure 54), this average composition will be used to make another estimation of pressure. The mean of the probable range of temperature indicates that arsenopyrite with d(131) = 1.6319 Å was deposited at approximately 500° ± 30° C. Application of this data to figure 53 leads to an estimation of confining pressure between 1000 and 2000 bars. If arsenopyrite with d(131) = 1.6319 Å was deposited at somewhat higher temperatures, the estimated confining pressure would be similarly higher. Likewise, if the sulfur-rich arsenopyrite with d(131) = 1.6301 Å was deposited at temperatures greater than 600° C the confining pressures might have been above 3000 bars during deposition. So evidently there is no way in which a valid choice may be made between the several possible pressure-temperature estimates in the absence of a second reliable geobarometer or geothermometer. However, the nature of the veins indicates that the confining pressures were not extremely high and were probably less than 2000 bars.

In his description of Appalachian geology, Alcock (1947) estimated that the Central Mobile Belt may have been covered by from 7000 to 20,000 feet of younger formations at the time of the Devonian intrusions, when the mineralized veins were deposited. This would correspond to confining pressures of 1000 to 3000 bars. If 2000 bars was the maximum confining pressure in Moreton's Harbour map-area, an overlying section of about 15,000 feet can be assumed. Therefore, it appears that arsenopyrite was deposited at a depth of less than 5 kilometers.

Conclusion.

The high temperatures determined for the deposition of arsenopyrite suggest a magmatic hydrothermal origin for the ore solutions which were responsible for the formation of these veins. The source of the fluids could not have been very far from the site of deposition and, with due consideration for the nearby granodiorite batholiths, was probably within a few kilometers at depth. Since the veins are spatially, and appear to be genetically, related to the rhyolite dykes, the batholiths immediately recommend themselves as the source for both.

During mineralization the temperature of the ore fluids decreased somewhat irregularly throughout the map-area, resulting in changes in the arsenic and sulfur contents of the arsenopyrite. A.H. Clark (1965) regards the range in arsenopyrite composition over a small area such as Moreton's Harbour map-area as a rough indication of the duration of arsenopyrite deposition in that area. In a broad sense, the composition of this mineral in different parts of the map-area could represent a a progressive penetration of the metal-bearing fluids throughout the area. It is assumed here that the volcanic rocks and the basic and rhyolitic dykes had little, if any, effect on the arsenic:sulfur ratios of the arsenopyrite.

On this basis, an examination of the data shows that there are some indications that deposition of arsenopyrite took place at higher temperatures in the Little Harbour area than in the Taylor's Room area. However, in some parts of the map-area, there are anomalous values which indicate that deposition was probably not a simple progressive process from east to west. This is especially true for Taylor's Room area, where (131) spacings determined from borehole samples reach 0.0020 Å greater than the mean value of 1.6304 Å. Consequently, it appears impractical to postulate a single wave of solutions which deposited arsenopyrite. The data does not indicate a consistent gradational change in the physical conditions of arsenopyrite deposition throughout the map-area.

Appendix: Computer programs, data and results.

1. Program for the calculation of d(131) spacings and arsenic atomic percent of arsenopyrite.
2. Input and output data.
3. Program for the calculation of C.I.P.W. norms.
4. Program for the calculation of Barth-Niggli norms.
5. Input and output data.

```
                                                                          03/24/69
 CALCULATION OF D131 SPACINGS OF ARSENOPYRITE      RVGIBBONS     31JA
 DIMENSION X%6□,STD%6□,D%40□,AS%40□
 D311F#1.647035871
 CUKA#1.54178
 TH2#55.81547097
 DN#78.50
 N#0
 PRINT 5,CUKA
 FORMAT%34H ARSENOPYRITE  D131  SPACING  DATA,10X,9H   CUKA #F8.5□
 PRINT 10,D311F,TH2
 FORMAT%16H D311 FLUORITE #F12.9,15H   AT 2-THETA #F12.8,//□
 PRINT 12
2FORMAT%1H ,44H NO.        FL.STD.     ERROR    ASP131    2TH131,4X,
114H D131    ST.DV.,/□
 READ 20,HE,AD,%X%I□,I#1,6□
 FORMAT%2A4,2X,6F10.5□
 SX#0.0
 SXM#0.0
 SSTD#0.0
 READ 25,%STD%J□,J#1,6□
 FORMAT%10X,6F10.5□
 DO 30 K#1,6
 X%K□#55.5&X%K□/DN
 STD%K□#55.5&STD%K□/DN
 SX#SX&X%K□
 SSTD#SSTD&STD%K□
 ASTD#SSTD/6.0
 N#N&1
 ASX#SX/6.0
 ERROR#TH2-ASTD
 A131#ASX&ERROR
 RA#A131*3.1416/360.0
 D%N□#CUKA/%2.0*SINF%RA□□
 AS%N□#%D%N□-1.60060□/0.00098
 D131#D%N□
 DO 40 L#1,6
 X%L□#X%L□&ERROR
 RA#X%L□*3.1416/360.0
 X%L□#CUKA/%2.0*SINF%RA□□
 SXM#SXM&%X%L□-D131□**2
 STDV#%SXM/6.0□**0.5
 PRINT 50,HE,AD,ASTD,ERROR,ASX,A131,D131,STDV
 FORMAT%1X,2A4,4F9.4,2F9.5□
 IF%N-38□15,60,60
 CONTINUE
 PRINT65
 FORMAT%1H1,10X,31H ARSENIC CONTENT AND D-SPACINGS□
 PRINT70
 FORMAT%11X,@NO.@,9X,@D131@,6X,@AS AT.PC@□
 PRINT75,%D%I□,AS%I□,I#1,38□
 FORMAT%20X,F9.5,F12.5□
 CONTINUE
 STOP
 END
```

-1R	57.5	58.5	56.5	57.25	57.0	58.5
	15.0	15.25	14.75	14.0	14.5	15.0
-2R	68.0	67.0	67.0	67.0	68.0	66.5
	23.0	24.0	22.5	22.75	22.0	22.25
-3R	60.0	60.75	59.1	59.50	58.5	59.25
	11.25	11.0	10.0	9.25	9.0	11.0
-5R	58.0	58.0	58.25	58.0	57.0	58.0
	14.5	15.75	15.0	14.25	13.75	14.0
-6R	57.5	56.25	58.5	58.0	57.0	58.0
	14.5	14.5	14.0	14.0	14.0	14.0
-10R	62.25	62.0	62.0	61.5	61.0	61.25
	18.5	19.0	18.5	18.5	19.0	18.0
-12R	57.0	57.25	56.5	57.5	57.0	56.5
	15.25	14.0	14.0	15.5	14.0	14.5
-13R	62.25	62.5	61.5	61.25	62.25	62.0
	17.0	16.5	16.5	16.5	16.0	16.0
-14R	58.75	59.5	58.5	59.0	58.0	59.5
	15.5	15.5	15.0	15.75	15.0	15.0
-1R	58.0	58.0	57.0	57.0	57.0	57.5
	13.0	13.0	13.0	13.0	13.0	12.25
-2R	62.0	62.0	60.75	61.5	61.5	62.25
	13.0	13.25	13.75	13.75	14.5	13.0
P-1.	73.0	71.0	71.5	71.5	73.0	72.0
	23.5	23.5	23.5	23.5	23.5	23.5
P-3	69.0	69.0	68.0	67.75	69.0	68.75
	23.0	24.0	24.5	23.0	24.0	23.5
P-3	68.25	70.0	70.0	68.5	68.5	68.0
	24.5	24.5	23.0	24.0	24.0	23.25
#401	68.0	67.25	66.5	68.5	67.0	67.75
	23.0	21.75	21.5	23.0	21.5	21.5
#498	70.5	70.25	70.5	69.5	71.0	70.5
	21.0	21.0	22.75	22.0	22.0	22.25
#561	64.5	64.5	65.0	64.0	66.0	64.5
	15.0	15.5	15.0	15.0	15.25	15.25
#569	52.0	51.0	52.5	52.0	53.0	52.0
	14.0	12.0	13.0	13.0	14.5	13.5
#580	51.5	52.0	51.5	53.0	52.5	52.5
	13.0	13.0	12.0	13.0	12.5	12.5
#605	60.0	60.0	58.0	60.0	60.0	59.0
	13.5	14.5	14.0	13.0	13.0	14.0
#609	66.5	68.0	67.5	68.0	67.5	67.5
	23.25	25.25	25.0	24.0	24.0	25.0
#690	66.5	66.5	66.5	66.75	66.0	65.0
	24.0	23.75	23.25	24.25	24.25	25.0
#732	65.0	64.75	65.25	65.0	65.5	63.75
	23.75	23.5	23.5	22.75	23.5	23.25
#733	64.5	65.0	65.0	65.25	65.0	65.0
	23.0	22.25	22.25	22.5	22.75	22.5
#741	81.0	77.25	78.5	78.5	78.5	78.5
	29.5	29.75	30.0	30.0	30.5	29.5
#750	60.75	62.0	60.0	61.0	60.25	62.0
	13.25	13.25	13.75	13.0	12.5	12.0
#803	63.0	64.0	64.5	63.0	64.0	64.5
	14.75	15.0	14.5	15.0	14.0	15.0
#845	72.0	73.25	73.0	72.5	72.0	72.0
	24.5	23.0	24.5	24.0	24.5	24.5

675	66.5	66.0	64.75	64.0	66.0	64.0
	17.0	17.0	16.25	16.0	16.5	16.5
910	68.0	68.75	71.5	70.5	70.0	70.0
	25.0	23.5	24.0	26.5	24.5	24.0
-1.	68.0	68.5	69.0	68.25	69.5	69.0
	23.0	22.75	23.5	22.75	22.0	22.0
-1.	67.0	67.0	68.0	67.25	67.25	67.25
	21.25	21.25	21.5	21.0	22.0	21.5
19 GC	52.0	52.0	52.25	51.75	51.25	51.0
	15.0	15.75	14.75	16.0	15.0	13.25
BALT	63.0	63.5	62.5	62.5	62.0	63.0
	15.25	17.0	16.5	16.0	16.0	16.5
2951-2	67.0	67.0	67.0	67.0	67.0	66.0
	23.0	23.0	23.0	23.0	23.0	22.0
N228	57.5	58.0	59.0	58.75	58.0	57.75
	24.0	24.25	24.0	25.0	24.25	24.5
L LAKE	61.5	63.0	61.0	62.0	61.5	62.5
	16.0	17.5	16.5	16.5	16.0	17.0
LTCOVE	60.5	59.5	61.0	61.0	61.0	59.0
	14.5	15.0	15.0	15.0	15.0	16.0
ZZ						

SENOPYRITE D131 SPACING DATA CUKA = 1.54178
11 FLUORITE = 1.647035600 AT 2-THETA = 55.81547000

O.	FL.STD.	ERROR	ASP131	2TH131	D131	ST.DV.
-1R	55.6879	.1276	56.2375	56.3648	1.63227	.00022
-2R	55.7898	.0257	56.3567	56.3825	1.63180	.00019
-3R	55.6306	.1849	56.2582	56.4431	1.63019	.00024
-5R	55.6852	.1302	56.2373	56.3675	1.63220	.00014
-6R	55.6805	.1350	56.2330	56.3680	1.63218	.00025
-10R	55.7367	.0787	56.2856	56.3643	1.63226	.00015
-12R	55.6810	.1345	56.2256	56.3601	1.63240	.00012
-13R	55.7091	.1063	56.2893	56.3956	1.63145	.00015
-14R	55.6948	.1207	56.2500	56.3707	1.63211	.00018
-1R	55.6640	.1515	56.2314	56.3829	1.63179	.00015
-2R	55.6725	.1430	56.2856	56.4286	1.63056	.00017
-1.	55.7994	.0161	56.4172	56.4333	1.63045	.00026
P-3	55.8015	.0140	56.3737	56.3877	1.63160	.00017
P-3	55.8041	.0113	56.3774	56.3887	1.63163	.00028
401	55.7808	.0347	56.3599	56.3946	1.63146	.00022
498	55.7781	.0373	56.3965	56.4338	1.63044	.00015
561	55.6932	.1223	56.3248	56.4471	1.63008	.00021
569	55.6699	.1456	56.1635	56.3091	1.63375	.00021
580	55.6614	.1541	56.1645	56.3187	1.63350	.00019
605	55.6741	.1414	56.2580	56.3993	1.63135	.00026
609	55.8110	.0044	56.3599	56.3643	1.63228	.00017
690	55.8068	.0087	56.3434	56.3521	1.63261	.00020
732	55.7978	.0177	56.3264	56.3441	1.63282	.00019
733	55.7872	.0283	56.3275	56.3558	1.63251	.00008
741	55.8806	-.0651	56.5027	56.4375	1.63054	.00038
750	55.6651	.1504	56.2771	56.4275	1.63061	.00026
803	55.6874	.1281	56.3132	56.4413	1.63024	.00021
845	55.8079	.0076	56.4230	56.4307	1.63052	.00017
875	55.7107	.1047	56.3307	56.4354	1.63039	.00034
910	55.8132	.0023	56.3891	56.3914	1.63156	.00039
-1.	55.7887	.0267	56.3753	56.4020	1.63128	.00017
-1.	55.7728	.0426	56.3572	56.3999	1.63134	.00011
19 GC	55.6906	.1249	56.1587	56.2836	1.63445	.00015
SALT	55.7065	.1090	56.2994	56.4084	1.63111	.00016
951-2	55.7909	.0246	56.3514	56.3760	1.63197	.00013
N228	55.8100	.0055	56.2410	56.2465	1.63542	.00018
L LAKE	55.7113	.1042	56.2887	56.3930	1.63152	.00023
LTCOVE	55.6921	.1233	56.2686	56.3919	1.63155	.00027

```
 ARSENIC CONTENT AND D-SPACINGS
NO.          D131        AS AT.PC
           1.63227      32.31500
           1.63180      31.84010
           1.63019      30.19582
           1.63220      32.24306
           1.63218      32.22867
           1.63228      32.32949
           1.63240      32.44459
           1.63145      31.48031
           1.63211      32.15674
           1.63179      31.82561
           1.63058      30.58929
           1.63045      30.45990
           1.63166      31.69612
           1.63163      31.66735
           1.63148      31.50929
           1.63044      30.44571
           1.63008      30.08663
           1.63375      33.82847
           1.63350      33.56898
           1.63135      31.37980
           1.63228      32.32939
           1.63261      32.66071
           1.63282      32.87684
           1.63251      32.55969
           1.63034      30.34520
           1.63061      30.61806
           1.63024      30.24439
           1.63052      30.53174
           1.63039      30.40255
           1.63156      31.59541
           1.63128      31.30786
           1.63134      31.36541
           1.63443      34.52133
           1.63111      31.13531
           1.63197      32.01286
           1.63542      35.53306
           1.63152      31.55235
           1.63155      31.58102
```

```
0032007013600032007024902402511963611300102        COLD START
FORX 3
 C  CIPW   PETROGRAPHIC NORMS    REX GIBBONS    5/10/67
    DIMENSION X(12),Y(12),Z(12),B(13),D(13)
  5 FORMAT(6F10.4)
    READ 5,(Y(I),I=1,12)
 10 FORMAT(2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3)
    READ 10,(B(K),D(K),K=1,13)
 15 FORMAT(12F6.2,2A4)
 20 READ15,(X(I),I=1,12),HE,AD
    S=0.0
    SS=0.0
    DO 30 I=1,12
    Z(I)=X(I)/Y(I)
    S=S+X(I)
 30 SS=SS+Z(I)
    PUNCH 35,HE,AD
 35 FORMAT(19H SILICATE ANALYSIS 2A4,//)
 40 FORMAT(5X,2A3,F12.2,F12.4)
    PUNCH 40,(B(I),D(I),X(I),Z(I),I=1,12)
    PUNCH40,B(13),D(13),S,SS
    AP=0.0
    PY=0.0
    CC=0.0
    TIL=0.0
    OR=0.0
    PMS=0.0
    AB=0.0
    COR=0.0
    AN=0.0
    SPH=0.0
    RU=0.0
    AEG=0.0
    SMS=0.0
    TMT=0.0
    HM=0.0
    PEN=0.0
    DI=0.0
    WO=0.0
    HY=0.0
    Q=0.0
    OL=0.0
    PF=0.0
    ANE=0.0
    ALC=0.0
    CAORS=0.0
    AKP=0.0
    ZZ=0.0
    EN=0.0
    FS=0.0
    FO=0.0
    FA=0.0
    DIEN=0.0
    DIFS=0.0
```

```
      DIWO=0.0
      AP=Z(10)
      Z(7)=Z(7)-10.0/3.0*Z(10)
      Z(10)=0.0
      PY=0.5*Z(12)
      Z(5)=Z(5)-0.5*Z(12)
      Z(12)=0.0
      IF(Z(2)-Z(5))45,45,50
   45 TIL=Z(2)
      Z(5)=Z(5)-Z(2)
      Z(2)=0.0
      GO TO 60
   50 TIL=Z(5)
      Z(2)=Z(2)-Z(5)
      Z(5)=0.0
   60 CC=Z(11)
      Z(7)=Z(7)-Z(11)
      Z(11)=0.0
      IF(Z(9)-Z(3))65,65,70
   65 OR=Z(9)
      Z(3)=Z(3)-Z(9)
      ZZ=6.0*Z(9)
      Z(9)=0.0
      GO TO 75
   70 OR=Z(3)
      Z(9)=Z(9)-Z(3)
      PMS=Z(9)
      ZZ=6.0*Z(3)+PMS
      Z(3)=0.0
      Z(9)=0.0
   75 IF(Z(8)-Z(3))80,80,85
   80 AB=Z(8)
      Z(3)=Z(3)-Z(8)
      ZZ=ZZ+6.0*Z(8)
      Z(8)=0.0
      GO TO 90
   85 AB=Z(3)
      Z(8)=Z(8)-Z(3)
      ZZ=ZZ+6.0*Z(3)
      Z(3)=0.0
      GO TO 105
   90 IF(Z(7)-Z(3))95,95,100
   95 AN=Z(7)
      Z(3)=Z(3)-Z(7)
      Z(7)=0.0
      COR=Z(3)
      Z(3)=0.0
      ZZ=ZZ+2.0*AN
      GO TO 105
  100 AN=Z(3)
      Z(7)=Z(7)-Z(3)
      Z(3)=0.0
      ZZ=ZZ+2.0*AN
  105 IF(Z(2)-Z(7))110,110,115
```

```
110   SPH=Z(2)
      Z(7)=Z(7)-Z(2)
      Z(2)=0.0
      ZZ=ZZ+SPH
      GO TO 118
115   SPH=Z(7)
      ZZ=ZZ+SPH
      Z(2)=Z(2)-Z(7)
      Z(7)=0.0
      RU=Z(2)
      Z(2)=0.0
118   IF(Z(4)-Z(8))120,120,125
120   AEG=Z(4)
      Z(8)=Z(8)-Z(4)
      Z(4)=0.0
      SMS=Z(8)
      ZZ=ZZ+4.0*AEG+SMS
      Z(8)=0.0
      GO TO 130
125   AEG=Z(8)
      Z(4)=Z(4)-Z(8)
      Z(8)=0.0
      ZZ=ZZ+4.0*AEG
130   IF(Z(5)-Z(4))135,135,140
135   TMT=Z(5)
      Z(4)=Z(4)-Z(5)
      Z(5)=0.0
      HM=Z(4)
      Z(4)=0.0
      GO TO 145
140   TMT=Z(4)
      Z(5)=Z(5)-Z(4)
      Z(4)=0.0
145   HY=Z(6)+Z(5)
      PFS=0.0
      IF(HY)147,147,146
146   PEN=(Z(6)*Y(6))/(Z(6)*Y(6)+Z(5)*Y(5))*100.0
      PFS=100.0-PEN
147   IF(Z(7))165,165,150
150   IF(Z(7)-HY)160,155,155
155   DI=HY
      Z(7)=Z(7)-HY
      HY=0.0
      WO=Z(7)
      Z(7)=0.0
      ZZ=ZZ+2.0*DI+WO
      GO TO 165
160   DI=Z(7)
      HY=HY-Z(7)
      Z(7)=0.0
      ZZ=ZZ+2.0*DI+HY
      GO TO 169
165   ZZ=ZZ+HY
169   CONTINUE
```

```
      PUNCH 360
  360 FORMAT(//,19H NORMATIVE MINERALS)
      SI=0.0
      IF(ZZ-Z(1))166,166,168
  166 Q=Z(1)-ZZ
      GO TO 350
  168 Q=ZZ-Z(1)
      SI=Q*Y(1)
      PUNCH 175,SI
  175 FORMAT(20H QUARTZ DEFICIENCY =F7.2)
      IF(Q-0.5*HY)185,185,190
  185 OL=Q
      HY=HY-2.0*Q
      Q=0.0
      GO TO 350
  190 OL=0.5*HY
      HY=0.0
      Q=Q-OL
      IF(Q-SPH)205,205,210
  205 SPH=SPH-Q
      PF=Q
      Q=0.0
      GO TO 350
  210 PF=SPH
      SPH=0.0
      Q=Q-SPH
      IF(Q-4.0*AB)215,215,220
  215 ANE=Q/4.0
      AB=AB-ANE
      Q=0.0
      GO TO 350
  220 ANE=AB
      AB=0.0
      Q=Q-4.0*ANE
      IF(Q-2.0*OR)225,225,230
  225 ALC=Q/2.0
      OR=OR-ALC
      Q=0.0
      GO TO 350
  230 ALC=OR
      Q=Q-2.0*OR
      OR=0.0
      IF(Q-0.5*WO)235,235,240
  235 CAORS=Q
      WO=WO-2.0*Q
      Q=0.0
      GO TO 350
  240 CAORS=WO/2.0
      Q=Q-CAORS
      WO=0.0
      IF(Q-DI)245,245,250
  245 CAORS=CAORS+Q/2.0
      OL=OL+Q/2.0
      DI=DI-Q
```

```
      Q=0.0
      GO TO 350
  250 CAORS=CAORS+DI/2.0
      OL=OL+DI/2.0
      Q=Q-DI
      DI=0.0
      AKP=Q/2.0
      ALC=ALC-AKP
      Q=0.0
  350 CONTINUE
      Q=Q*Y(1)
      OR=OR*(Y(3)+Y(9)+6.0*Y(1))
      AB=AB*(Y(3)+Y(8)+6.0*Y(1))
      AN=AN*(Y(3)+Y(7)+2.0*Y(1))
      COR=COR*Y(3)
      AP=AP*(Y(10)+10.0/3.0*Y(7))
      PY=PY*(Y(5)+2.0*Y(12))
      TIL=TIL*(Y(2)+Y(5))
      CC=CC*(Y(7)+Y(11))
      PMS=PMS*(Y(1)+Y(9))
      SPH=SPH*(Y(1)+Y(2)+Y(7))
      RU=Y(2)*RU
      AEG=AEG*(Y(4)+Y(8)+4.0*Y(1))
      SMS=SMS*(Y(1)+Y(8))
      TMT=TMT*(Y(4)+Y(5))
      HM=HM*Y(4)
      EN=PEN*HY*(Y(1)+Y(6))*0.01
      FS=PFS*HY*(Y(1)+Y(5))*0.01
      HY=EN+FS
      DIWO=DI*(Y(7)+Y(1))
      DIEN=PEN*DI*(Y(1)+Y(6))*0.01
      DIFS=PFS*DI*(Y(1)+Y(5))*0.01
      DI=DIWO+DIEN+DIFS
      FO=.01*PEN*OL*(Y(1)+2.0*Y(6))
      FA=.01*PFS*OL*(Y(1)+2.0*Y(5))
      OL=FO+FA
      WO=WO*(Y(1)+Y(7))
      ALC=ALC*(Y(3)+Y(9)+4.0*Y(1))
      ANE=ANE*(Y(3)+Y(8)+2.0*Y(1))
      AKP=AKP*(Y(3)+Y(9)+2.0*Y(1))
      CAORS=CAORS/2.0*(2.0*Y(7)+Y(1))
      PF=PF*(Y(7)+Y(2))
      FELD=0.0
      FELD=OR+AB+AN
      POR=0.0
      PAN=0.0
      PAB=0.0
      PAB=AB/FELD*100.0
      POR=OR/FELD*100.0
      PAN=AN/FELD*100.0
      SALIC=0.0
      SALIC=Q+COR+OR+AB+AN+ALC+ANE+AKP
      FEMIC=0.0
      FEMIC=AEG+SMS+PMS+DI+WO+HY+OL+CAORS+TMT+HM+TIL+SPH+PF+RU+AP+CC+PY
```

```
      PUNCH 370,CC,AP,PY,TIL
  370 FORMAT(8H   CC = F7.2,8H   AP = F7.2,8H   PY = F7.2,7H   IL = F7.2)
      PUNCH 380,FELD,POR,PAB,PAN
  380 FORMAT(8H FELD = F7.2,8H  POR = F7.2,8H  PAB = F7.2,7H PAN = F7.2)
      PUNCH 390,COR,OR,AB,AN
  390 FORMAT(8H  COR = F7.2,8H   OR = F7.2,8H   AB = F7.2,7H  AN = F7.2)
      PUNCH 395,DIWO,DIEN,DIFS,DI
  395 FORMAT(8H DIWO = F7.2,8H DIEN = F7.2,8H DIFS = F7.2,7H  DI = F7.2)
      PUNCH 400,EN,FS,HY,PEN
  400 FORMAT(8H   EN = F7.2,8H   FS = F7.2,8H   HY = F7.2,7H PEN = F7.2)
      PUNCH 405,FO,FA,OL,PFS
  405 FORMAT(8H   FO = F7.2,8H   FA = F7.2,8H   OL = F7.2,7H PFS = F7.2)
      PUNCH 410,PMS,SMS,Q,WO
  410 FORMAT(8H  PMS = F7.2,8H  SMS = F7.2,8H    Q = F7.2,7H  WO = F7.2)
      PUNCH 420,ANE,AEG,TMT,HM
  420 FORMAT(8H   NE = F7.2,8H  AEG = F7.2,8H   MT = F7.2,7H  HM = F7.2)
      PUNCH 430,ALC,AKP,CAORS,SPH
  430 FORMAT(8H   LC = F7.2,8H   KP = F7.2,8H CAORS= F7.2,7H SPH = F7.2)
      PUNCH 440,SALIC,FEMIC,PF,RU
  440 FORMAT(8H SALIC= F7.2,8H FEMIC= F7.2,8H   PF = F7.2,7H  RU = F7.2)
      PUNCH 455
  455 FORMAT(//)
      GO TO 20
  460 CONTINUE
      END
 60.0848   +79.8988 +101.9612 +159.6922   +71.8464   +40.3114
 56.0794   +61.9790  +94.2034 +141.9446   +44.0099   +32.0640
02 =TIO2 =AL2O3=FE2O3=FEO   =MGO   =CAO   =NA2O =K2O   =P2O5 =CO2   =S     =TO
1.00   1.12 14.20   3.30   9.24   5.95   6.64   3.88   0.04   0.11   1.53   0.00P6
3.82   1.25 15.52   2.56   9.47   3.85   6.12   3.80   0.08   0.21   0.02   0.00A9
9.60   1.03 14.80   2.75   9.59   6.50   5.15   3.47   2.40   0.22   1.05   0.00F1
5.65   1.02 14.00   2.68   8.52   5.60   4.40   4.62   0.04   0.22   0.57   0.00F1
1.12   1.17 14.89   2.84   9.49   5.38   5.73   4.50   0.08   0.18   0.10   0.00F1
4.55   1.09 16.08   3.33   7.69   4.01   5.24   4.36   0.05   0.12   0.17   0.00F1
4.65   0.80 15.30   1.87   6.70   7.85   4.70   4.72   0.72   0.15   0.00   0.00F1
0.20   0.80 14.85   2.67   7.90   7.00   7.45   4.71   0.02   0.20   0.92   0.00F1
3.15   0.66 14.40   5.00   4.66   6.30  11.20   1.54   0.17   0.18   0.60   0.00F4
1.23   0.70 15.37   2.53   7.39   7.59   8.18   3.42   0.11   0.08   0.09   0.00F1
7.52   0.87 16.67   1.77   9.21   7.94   8.49   3.12   0.07   0.10   0.02   0.14BX
1.10   1.67 14.80   4.46   8.44   5.75   8.15   3.42   0.07   0.11   0.00   0.00F1
1.00   0.68 16.00   4.08   5.78   6.30  11.25   2.04   0.17   0.22   0.48   0.00F2
8.67   1.06 18.97   1.45  17.41  10.72   1.13   1.82   0.05   0.11   0.10   0.69BX
8.23   0.76 16.01   2.46   7.3.7  7.86  11.20   2.50   0.35   0.08   0.10   0.00OB
4.25   0.12 13.51   0.62   0.46   0.18   0.31   4.10   5.47   0.02   0.11   0.00B-
1.05   0.87 17.04   2.44   6.22   5.72   8.83   3.70   1.18   0.17   0.30   0.00B-
5.77   0.01 12.45   1.55   0.34   0.05   0.05   2.37   6.78   0.03   0.00   0.00RH
4.03   0.27 12.73   1.15   1.56   0.31   0.48   3.67   5.09   0.05   0.27   0.00 T
3.89   0.41 12.46   1.07   0.13   0.05   0.25   3.60   5.71   0.04   0.00   0.00 T
3.86   0.20 13.75   0.78   1.18   0.26   0.72   3.51   5.13   0.14   0.00   0.00 T
8.67   2.28 15.91   3.24   7.28   7.72   8.02   4.26   1.28   0.62   0.00   0.00 T
6.15   2.98 15.48   3.41   8.85   8.17   8.85   3.00   1.22   0.59   0.00   0.00 T
3.12   2.11 13.86   2.45  10.72  13.07  11.02   2.55   0.60   0.38   0.00   0.00 T
2.71   0.47 18.59   4.23   2.05   1.75   2.77   9.23   3.81   0.65   0.00   0.00 T
4.03   0.27 12.73   1.15   1.51   0.31   0.48   3.67   5.09   0.05   0.27   0.00 T
```

```
0032007013600032007024902402511963611300102         COLD START
FORX 3
C  BARTH-NIGGLI METHOD FOR PETROGRAPHIC NORMS   BY REX GIBBONS   3/10/67
   DIMENSION X(12),Y(12),XX(12),Z(12),C(13),B(13),D(13),E(13)
   READ 5,(Y(I),I=1,12)
 5 FORMAT(6E10.4)
   READ10,(C(K),D(K),K=1,13)
   READ10,(B(K),E(K),K=1,13)
10 FORMAT(2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3,2A3)
15 FORMAT(12F6.2,2A4)
20 READ15,(X(I),I=1,12),HE,AD
   S=0.0
   SS=0.0
   SSS=0.0
   DO25 I=1,12
   Z(I)=X(I)/Y(I)
   S=S+X(I)
25 SS=SS+Z(I)
   DO30 I=1,12
   XX(I)=Z(I)/SS*100.0
30 SSS=SSS+XX(I)
   PUNCH 35,HE,AD
35 FORMAT(19H SILICATE ANALYSIS 2A4,//)
40 FORMAT(5X,2A3,F10.2,5X,2A3,F10.4,F10.2)
   PUNCH 40,(C(I),D(I),X(I),B(I),E(I),Z(I),XX(I),I=1,12)
   PUNCH 40, C(13),D(13),S,B(13),E(13),SS,SSS
   CC=0.0
   CC=2.0*XX(11)
   XX(7)=XX(7)-XX(11)
   AP=0.0
   PHO=0.0
   IF(XX(7)-1.67*XX(10))43,42,42
42 AP=XX(10)+1.67*XX(10)
   XX(7)=XX(7)-1.67*XX(10)
   GO TO 44
43 AP=XX(7)+1.0/1.67*XX(7)
   XX(7)=0.0
   PHO=XX(10)-1.0/1.67*XX(7)
44 PY=0.0
   PY=XX(12)*1.5
   XX(5)=XX(5)-0.5*XX(12)
   TIL=0.0
   TIL=XX(2)*2.0
   XX(5)=XX(5)-XX(2)
   PUNCH 45
45 FORMAT(//,19H NORMATIVE MINERALS)
   OR=0.0
   AB=0.0
   AN=0.0
   COR=0.0
   AC=0.0
   TMT=0.0
   HM=0.0
   WO=0.0
   EN=0.0
   FS=0.0
   W=0.0
   DI=0.0
   HY=0.0
   HEN=0.0
```

```
      ANE=0.0
      ALC=0.0
      AKP=0.0
      PAN=0.0
      PAB=0.0
      POR=0.0
      FELD=0.0
      OR=5.0*XX(9)
      XX(3)=XX(3)-XX(9)
      XX(1)=XX(1)-3.0*XX(9)
      XX(9)=0.0
      IF(XX(3)-XX(8))80,55,55
   55 AB=5.0*XX(8)
      XX(3)=XX(3)-XX(8)
      XX(1)=XX(1)-3.0*XX(8)
      XX(8)=0.0
      IF(XX(3))85,85,60
   60 IF(XX(3)-2.0*XX(7))70,65,65
   65 AN=XX(7)*5.0
      XX(3)=XX(3)-2.0*XX(7)
      XX(1)=XX(1)-2.0*XX(7)
      XX(7)=0.0
      COR=XX(3)
      GO TO 85
   70 AN=XX(3)*2.0+0.5*XX(3)
      XX(1)=XX(1)-XX(3)
      XX(7)=XX(7)-0.5*XX(3)
      XX(3)=0.0
      GO TO 85
   80 AB=5.0*XX(3)
      XX(1)=XX(1)-3.0*XX(3)
      XX(8)=XX(8)-XX(3)
      XX(3)=0.0
      AC=6.0*XX(8)
      XX(1)=XX(1)-4.0*XX(8)
      XX(4)=XX(4)-XX(8)
      XX(8)=0.0
   85 V=XX(4)-2.0*XX(5)
      IF(V)95,95,90
   90 TMT=3.0*XX(5)
      XX(4)=XX(4)-2.0*XX(5)
      XX(5)=0.0
      HM=XX(4)
      GO TO 100
   95 TMT=1.5*XX(4)
      XX(5)=XX(5)-0.5*XX(4)
      XX(4)=0.0
  100 CONTINUE
      IF(XX(7))110,110,105
  105 WO=2.0*XX(7)
      XX(1)=XX(1)-XX(7)
      XX(7)=0.0
  110 CONTINUE
      EN=2.0*XX(6)
      XX(1)=XX(1)-XX(6)
      XX(6)=0.0
      IF(XX(5))120,120,115
  115 FS=2.0*XX(5)
      XX(1)=XX(1)-XX(5)
      XX(5)=0.0
  120 CONTINUE
      SUM=0.0
      SUM=EN+FS
```

```
    WO=0.0
    GO TO 124
123 DI=2.0*SUM
    WO=WO-SUM
    HY=0.0
124 HEN=EN*100.0/SUM
    Q=XX(1)
    IF(Q)125,155,155
125 CONTINUE
    Q=ABSF(Q)
    PUNCH130,Q
130 FORMAT(20H QUARTZ DEFICIENCY =F7.2)
    IF(HY-4.0*Q)135,133,133
133 HY=HY-4.0*Q
    OL=3.0*Q
    Q=0.0
    GO TO 155
135 OL=0.75*HY
    Q=Q-0.25*HY
    HY=0.0
    IF(AB-2.5*Q)140,137,137
137 AB=AB-2.5*Q
    ANE=1.5*Q
    Q=0.0
    GO TO 155
140 ANE=0.6*AB
    Q=Q-0.4*AB
    AB=0.0
    IF(OR-0.5*Q)145,143,143
143 OR=OR-0.5*Q
    ALC=4.0*Q
    Q=0.0
    GO TO 155
145 ALC=0.8*OR
    Q=Q-0.2*OR
    OR=0.0
    IF(ALC-4.0*Q)150,147,147
147 ALC=ALC-4.0*Q
    AKP=3.0*Q
    Q=0.0
    GO TO 155
150 AKP=0.75*ALC
    Q=Q-0.25*ALC
    ALC=0.0
155 FELD=OR+AB+AN
    POR=OR/FELD*100.0
    PAB=AB/FELD*100.0
    PAN=AN/FELD*100.0
    PUNCH50,CC,AP,PY,TIL
 50 FORMAT(8H   CC = F7.2,8H   AP = F7.2,8H   PY = F7.2,7H  IL = F7.2)
    PUNCH165,FELD,POR,PAB,PAN
165 FORMAT(8H FELD = F7.2,8H  POR = F7.2,8H  PAB = F7.2,7H PAN = F7.2)
    PUNCH170,COR,OR,AB,AN
170 FORMAT(8H  COR = F7.2,8H   OR = F7.2,8H   AB = F7.2,7H  AN = F7.2)
    PUNCH175,WO,EN,FS,DI
 75 FORMAT(8H   WO = F7.2,8H   EN = F7.2,8H   FS = F7.2,7H  DI = F7.2)
    PUNCH180,HY,HEN,Q,OL
180 FORMAT(8H   HY = F7.2,8H  PEN = F7.2,8H    Q = F7.2,7H  OL = F7.2)
    PUNCH185,ANE,AC,TMT,HM
185 FORMAT(8H   NE = F7.2,8H   AC = F7.2,8H   MT = F7.2,7H  HM = F7.2)
    PUNCH190,ALC,AKP,PHO
190 FORMAT(8H   LC = F7.2,8H   KP = F7.2,8H  PHO = F7.2)
    PUNCH195
```

```
SILICATE ANALYSIS  MH549.          C.I.P.W.


   SIO2  =         51.80        .8621
   TIO2  =          1.71        .0214
   AL2O3=          16.68        .1635
   FE2O3=           1.02        .0063
   FEO   =          7.23        .1006
   MGO   =          5.34        .1324
   CAO   =          7.21        .1285
   NA2O  =          4.59        .0740
   K2O   =          1.02        .0108
   P2O5  =           .32        .0022
   CO2   =           .54        .0122
   S     =          0.00       0.0000
   TOTAL=          97.46       1.5145


NORMATIVE MINERALS
QUARTZ DEFICIENCY =    2.40
  CC =    1.22   AP  =      .74   PY  =    0.00  IL  =     3.24
FELD =   66.76  POR  =     9.02  PAB  =   58.17 PAN  =    32.79
 COR =    0.00   OR  =     6.02   AB  =   38.83  AN  =    21.89
DIWO =    3.49 DIEN  =     1.52 DIFS  =    1.96  DI  =     6.98
  EN =    4.82   FS  =     6.21   HY  =   11.04 PEN  =    50.50
  FO =    2.84   FA  =     4.03   OL  =    6.87 PFS  =    49.49
 PMS =    0.00  SMS  =     0.00    Q  =    0.00  WO  =     0.00
  NE =    0.00  AEG  =     0.00   MT  =    1.47  HM  =     0.00
  LC =    0.00   KP  =     0.00 CAORS=    0.00 SPH  =     0.00
SALIC=   66.76 FEMIC=     31.60   PF  =    0.00  RU  =     0.00



SILICATE ANALYSIS  MH549.        Barth-Niggli


   SIO2  =       51.80      SIO2  =      .8621      48.66
   TIO2  =        1.71      TIO2  =      .0214       1.20
   AL2O3=        16.68      ALO1.5       .3271      18.46
   FE2O3=         1.02      FEO1.5       .0127        .72
   FEO   =        7.23      FEO   =      .1006       5.67
   MGO   =        5.34      MGO   =      .1324       7.47
   CAO   =        7.21      CAO   =      .1285       7.25
   NA2O  =        4.59      NAO0.5       .1481       8.36
   K2O   =        1.02      KO0.5=       .0216       1.22
   P2O5  =         .32      PO2.5=       .0045        .25
   CO2   =         .54      CO2   =      .0122        .69
   S     =        0.00      S     =     0.0000       0.00
   TOTAL=        97.46      TOTAL=      1.7716     100.00


NORMATIVE MINERALS
QUARTZ DEFICIENCY =    2.25
  CC  =    1.38   AP  =      .67   PY  =    0.00  IL  =    2.41
FELD  =   70.12  POR  =     8.71  PAB  =   59.60 PAN  =   31.67
 COR  =    0.00   OR  =     6.11   AB  =   41.80  AN  =   22.21
  WO  =    0.00   EN  =    14.95   FS  =    8.22  DI  =    6.78
  HY  =   10.75  PEN  =    64.52    Q  =    0.00  OL  =    6.76
  NE  =    0.00   AC  =     0.00   MT  =    1.08  HM  =    0.00
  LC  =    0.00   KP  =     0.00  PHO  =    0.00
```

```
  CONTINUE
  END
+60.0848  +79.8988  +50.9811  +79.8466  +71.8464  +40.3114
+36.0794  +30.9895  +47.1017  +70.9823  +44.0099  +32.0640
2 =TIO2 =AL2O3=FE2O3=FEO   =MGO   =CAO   =NA2O =K2O   =P2O5 =CO2   =S
2 =TIO2 =ALO1.5FEO1.5FEO   =MGO   =CAO   =NAO0.5KO0.5=PO2.5=CO2   =S
```

```
SILICATE ANALYSIS   MH870.          C.I.P.W.

     SIO2 =         48.70         .8105
     TIO2 =          2.28         .0285
     AL2O3=         14.68         .1439
     FE2O3=          2.71         .0169
     FEO   =         8.72         .1213
     MGO   =         4.92         .1220
     CAO   =         8.07         .1439
     NA2O  =         4.27         .0688
     K2O   =         1.32         .0140
     P2O5  =         1.04         .0073
     CO2   =          .21         .0047
     S     =         0.00        0.0000
     TOTAL=         96.92        1.4823


NORMATIVE MINERALS
QUARTZ DEFICIENCY =    3.64
 CC =      .47   AP  =     2.40   PY  =     0.00  IL  =     4.33
FELD =   60.92   POR =    12.80   PAB =    59.30 PAN  =    27.88
 COR =    0.00    OR =     7.80    AB =    36.13  AN  =    16.99
DIWO =    6.23 DIEN  =     2.55 DIFS  =     3.71  DI  =    12.50
  EN =    1.09    FS =     1.59    HY =     2.69 PEN  =    47.44
  FO =    4.04    FA =     6.49    OL =    10.53 PFS  =    52.55
 PMS =    0.00   SMS =     0.00     Q =     0.00  WO  =     0.00
  NE =    0.00   AEG =     0.00    MT =     3.92  HM  =     0.00
  LC =    0.00    KP =     0.00 CAORS=     0.00 SPH  =     0.00
SALIC=   60.92 FEMIC=     36.88    PF =     0.00  RU  =     0.00

SILICATE ANALYSIS   MH870.     Barth-Niggli


     SIO2 =       48.70      SIO2 =       .8105       46.75
     TIO2 =        2.28      TIO2 =       .0285        1.64
     AL2O3=       14.68      ALO1.5       .2879       16.61
     FE2O3=        2.71      FEO1.5       .0339        1.95
     FEO   =       8.72      FEO   =      .1213        7.00
     MGO   =       4.92      MGO   =      .1220        7.04
     CAO   =       8.07      CAO   =      .1439        8.30
     NA2O  =       4.27      NAO0.5       .1377        7.94
     K2O   =       1.32      KO0.5=       .0280        1.61
     P2O5  =       1.04      PO2.5=       .0146         .84
     CO2   =        .21      CO2   =      .0047         .27
     S     =       0.00      S     =     0.0000        0.00
     TOTAL=       96.92      TOTAL=      1.7335      100.00


NORMATIVE MINERALS
QUARTZ DEFICIENCY =    3.49
  CC =      .55    AP =     2.25    PY =     0.00  IL =     3.29
FELD =    65.44   POR =    12.35   PAB =    60.73 PAN =    26.91
 COR =     0.00    OR =     8.08    AB =    39.74  AN =    17.61
  WO =     0.00    EN =    14.08    FS =     8.75  DI =    12.36
  HY =     2.67   PEN =    61.66     Q =     0.00  OL =    10.48
  NE =     0.00    AC =     0.00    MT =     2.93  HM =     0.00
  LC =     0.00    KP =     0.00   PHO =     0.00
```

```
SILICATE ANALYSIS  MH893.       C.I.P.W.


   SIO2 =         50.15        .8346
   TIO2 =          1.08        .0135
   AL2O3=         16.10        .1579
   FE2O3=          1.98        .0123
   FEO   =         6.70        .0932
   MGO   =         6.72        .1667
   CAO   =         9.26        .1651
   NA2O  =         3.60        .0580
   K2O   =          .86        .0091
   P2O5  =          .30        .0021
   CO2   =          .56        .0127
   S     =         0.00       0.0000
   TOTAL=         97.31       1.5256


NORMATIVE MINERALS
QUARTZ DEFICIENCY =   2.32
 CC =     1.27   AP  =      .69   PY =    0.00  IL  =    2.05
FELD =   60.77  POR  =     8.36  PAB =   50.12 PAN  =   41.51
 COR =    0.00    OR =     5.08   AB =   30.46  AN  =   25.23
DIWO =    6.34  DIEN =     3.19 DIFS =    3.01  DI  =   12.55
  EN =    5.95    FS =     5.63   HY =   11.58 PEN  =   58.14
  FO =    3.16    FA =     3.30   OL =    6.46 PFS  =   41.85
 PMS =    0.00   SMS =     0.00    Q =    0.00  WO  =    0.00
  NE =    0.00   AEG =     0.00   MT =    2.87  HM  =    0.00
  LC =    0.00    KP =     0.00 CAORS=    0.00 SPH  =    0.00
SALIC=   60.77 FEMIC=     37.50   PF =    0.00  RU  =    0.00

SILICATE ANALYSIS  MH893.       Barth-Niggli


   SIO2 =        50.15     SIO2 =       .8346      47.28
   TIO2 =         1.08     TIO2 =       .0135        .76
   AL2O3=        16.10     ALO1.5       .3158      17.89
   FE2O3=         1.98     FEO1.5       .0247       1.40
   FEO   =        6.70     FEO   =      .0932       5.28
   MGO   =        6.72     MGO   =      .1667       9.44
   CAO   =        9.26     CAO   =      .1651       9.35
   NA2O  =        3.60     NAO0.5       .1161       6.58
   K2O   =         .86     KO0.5=       .0182       1.03
   P2O5  =         .30     PO2.5=       .0042        .23
   CO2   =         .56     CO2   =      .0127        .72
   S     =        0.00     S     =     0.0000       0.00
   TOTAL=        97.31     TOTAL=      1.7652     100.00


NORMATIVE MINERALS
QUARTZ DEFICIENCY =   2.19
 CC =     1.44   AP  =      .63   PY =    0.00  IL  =    1.53
FELD =   63.76  POR  =     8.11  PAB =   51.60 PAN  =   40.28
 COR =    0.00    OR =     5.17   AB =   32.90  AN  =   25.68
  WO =    0.00    EN =    18.88   FS =    7.62  DI  =   12.38
  HY =   11.55   PEN =    71.22    Q =    0.00  OL  =    6.57
  NE =    0.00    AC =     0.00   MT =    2.10  HM  =    0.00
  LC =    0.00    KP =     0.00  PHO =    0.00
```

```
SILICATE ANALYSIS  MH26.        C.I.P.W.

   SIO2 =        59.55       .9910
   TIO2 =          .93       .0116
   AL2O3=        14.84       .1455
   FE2O3=         1.96       .0122
   FEO   =        6.01       .0836
   MGO   =        2.20       .0545
   CAO   =        4.46       .0795
   NA2O  =        5.47       .0882
   K2O   =         .42       .0044
   P2O5  =         .30       .0021
   CO2   =        1.46       .0331
   S     =        0.00      0.0000
   TOTAL=        97.60      1.5063

NORMATIVE MINERALS
 CC =     3.32   AP  =     .69   PY  =   0.00 IL  =    1.76
FELD =   59.70  POR  =    4.15  PAB  =  77.52 PAN =   18.31
 COR =    1.37   OR  =    2.48   AB  =  46.28  AN =   10.93
DIWO =    0.00 DIEN  =    0.00 DIFS  =   0.00  DI =    0.00
  EN =    3.88   FS  =    9.97   HY  =  13.85 PEN =   33.88
  FO =    0.00   FA  =    0.00   OL  =   0.00 PFS =   66.11
 PMS =    0.00  SMS  =    0.00    Q  =  14.53  WO =    0.00
  NE =    0.00  AEG  =    0.00   MT  =   2.84  HM =    0.00
  LC =    0.00   KP  =    0.00 CAORS=   0.00 SPH =    0.00
SALIC=   75.61 FEMIC=    22.48   PF  =   0.00  RU =    0.00


SILICATE ANALYSIS  MH26.       Barth-Niggli

   SIO2 =      59.55     SIO2 =      .9910     56.34
   TIO2 =        .93     TIO2 =      .0116       .66
   AL2O3=      14.84     ALO1.5      .2910     16.54
   FE2O3=       1.96     FEO1.5      .0245      1.39
   FEO   =      6.01     FEO   =     .0836      4.75
   MGO   =      2.20     MGO   =     .0545      3.10
   CAO   =      4.46     CAO   =     .0795      4.52
   NA2O  =      5.47     NAO0.5      .1765     10.03
   K2O   =       .42     KO0.5=      .0089       .50
   P2O5  =       .30     PO2.5=      .0042       .24
   CO2   =      1.46     CO2   =     .0331      1.88
   S     =      0.00     S     =    0.0000      0.00
   TOTAL=      97.60     TOTAL=     1.7589    100.00

NORMATIVE MINERALS
  CC =     3.77   AP  =     .64   PY  =    0.00  IL  =    1.32
FELD =    63.88  POR  =    3.96  PAB  =   78.54 PAN  =   17.48
 COR =     1.53   OR  =    2.53   AB  =   50.17  AN  =   11.17
  WO =     0.00   EN  =    6.20   FS  =    6.79  DI  =    0.00
  HY =    12.99  PEN  =   47.74    Q  =   13.75  OL  =    0.00
  NE =     0.00   AC  =    0.00   MT  =    2.09  HM  =    0.00
  LC =     0.00   KP  =    0.00  PHO  =    0.00
```

C.I.P.W.

```
    SIO2  =          76.05        1.2657
    TIO2  =           0.00        0.0000
    AL2O3=           13.98         .1371
    FE2O3=             .64         .0040
    FEO   =            .40         .0055
    MGO   =            .39         .0096
    CAO   =            .58         .0103
    NA2O  =           3.08         .0496
    K2O   =           3.48         .0369
    P2O5  =            .11         .0007
    CO2   =            .10         .0022
    S     =           0.00        0.0000
    TOTAL=           98.81        1.5220


NORMATIVE MINERALS
 CC  =      .22   AP  =     .25   PY  =    0.00  IL  =    0.00
FELD =    48.15  POR  =   42.70  PAB  =   54.12 PAN  =    3.17
 COR =     4.58   OR  =   20.56   AB  =   26.06  AN  =    1.52
DIWO =     0.00 DIEN  =    0.00 DIFS  =    0.00  DI  =    0.00
 EN  =      .87   FS  =     .33   HY  =    1.20 PEN  =   77.67
 FO  =     0.00   FA  =    0.00   OL  =    0.00 PFS  =   22.32
PMS  =     0.00  SMS  =    0.00    Q  =   43.48  WO  =    0.00
 NE  =     0.00  AEG  =    0.00   MT  =     .92  HM  =    0.00
 LC  =     0.00   KP  =    0.00 CAORS=    0.00 SPH  =    0.00
SALIC=    96.22 FEMIC=     2.61   PF  =    0.00  RU  =    0.00
```

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SILICATE ANALYSIS   MH876.
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Barth-Niggli

```
    SIO2  =      76.05      SIO2  =      1.2657      72.30
    TIO2  =       0.00      TIO2  =      0.0000       0.00
    AL2O3=       13.98      ALO1.5        .2742      15.66
    FE2O3=         .64      FEO1.5        .0080        .45
    FEO   =        .40      FEO   =       .0055        .31
    MGO   =        .39      MGO   =       .0096        .55
    CAO   =        .58      CAO   =       .0103        .59
    NA2O  =       3.08      NAO0.5        .0993       5.67
    K2O   =       3.48      KO0.5=        .0738       4.22
    P2O5  =        .11      PO2.5=        .0015        .08
    CO2   =        .10      CO2   =       .0022        .12
    S     =       0.00      S     =      0.0000       0.00
    TOTAL=       98.81      TOTAL=       1.7506     100.00


NORMATIVE MINERALS
  CC  =      .25    AP  =     .23   PY  =     0.00  IL  =    0.00
FELD  =    51.05   POR  =   41.33  PAB  =    55.60 PAN  =    3.06
 COR  =     5.14    OR  =   21.10   AB  =    28.38  AN  =    1.56
  WO  =     0.00    EN  =    1.10   FS  =      .17  DI  =    0.00
  HY  =     1.28   PEN  =   86.11    Q  =    41.33  OL  =    0.00
  NE  =     0.00    AC  =    0.00   MT  =      .68  HM  =    0.00
  LC  =     0.00    KP  =    0.00  PHO  =     0.00
```

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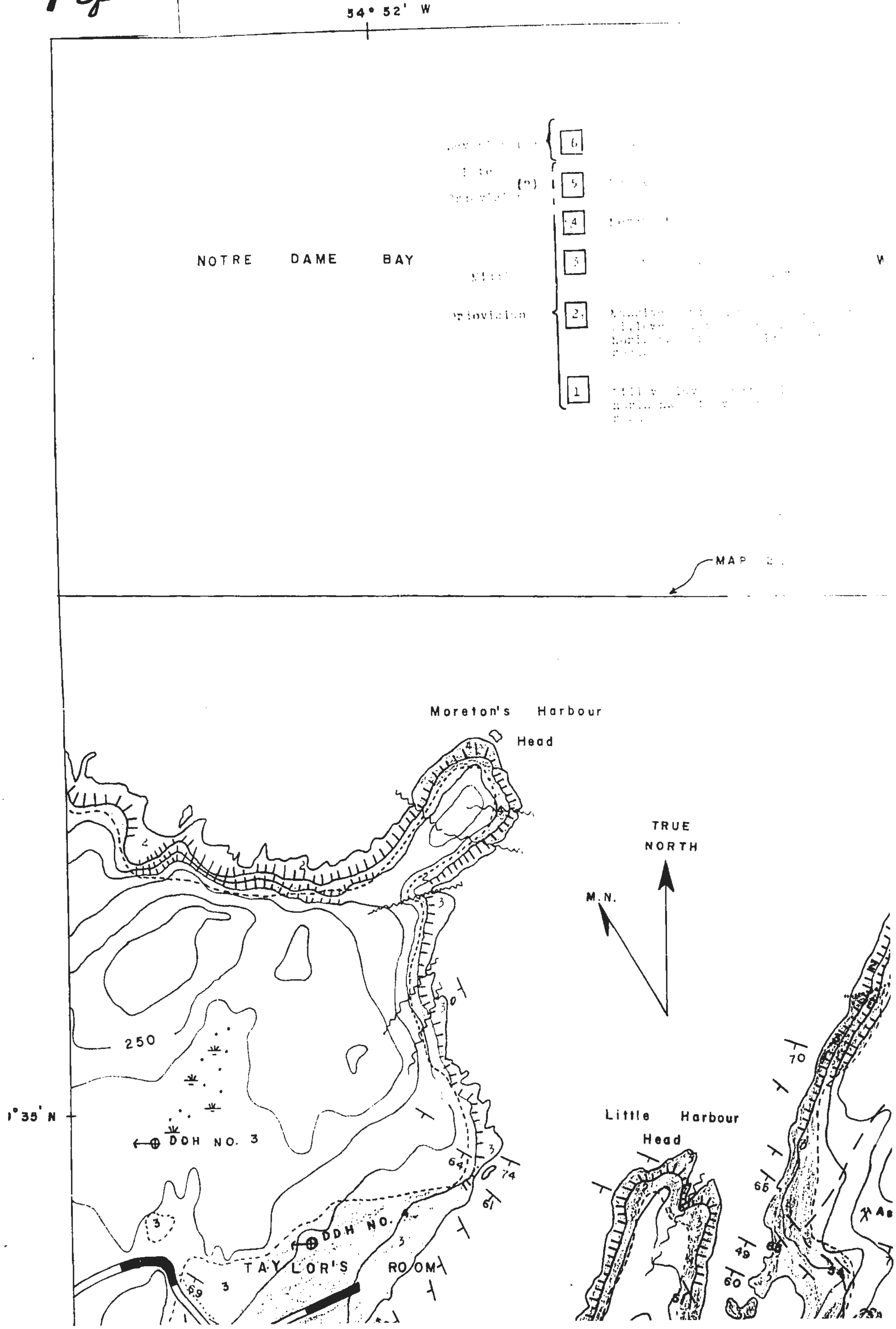
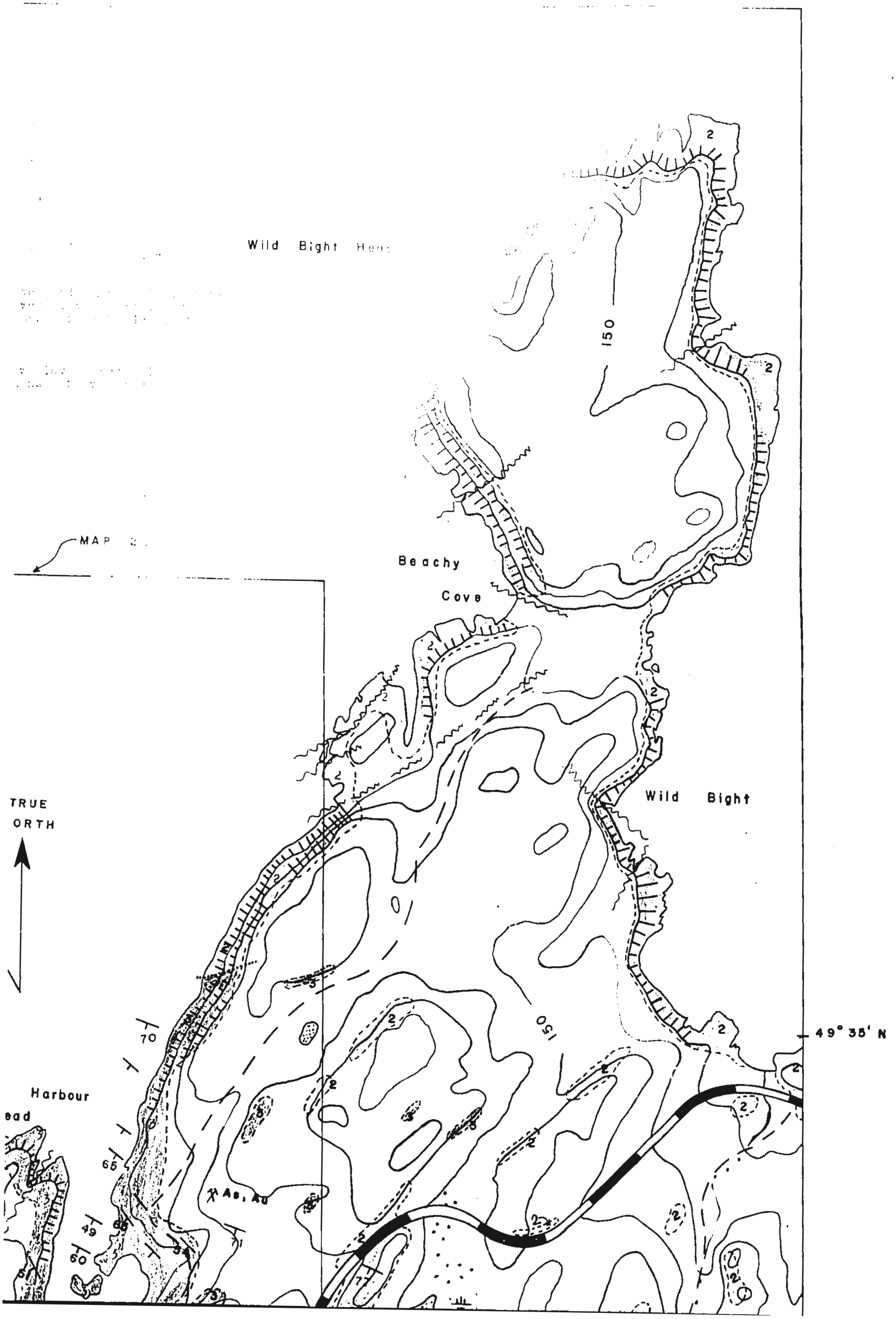
1 of


54° 52' W
6
(?)
5
4
NOTRE DAME BAY
3
W
rdovician
2
1
MAP
Moreton's Harbour Head
4
2
3
TRUE NORTH
M.N.
30
250
1°35' N
Little Harbour Head
70
DDH NO. 3
64
3
74
61
65
DDH NO. 4
3
TAYLOR'S ROOM
69
49
60


Wild Bight Hea
MAP 2
Beachy Cove
Wild Bight
TRUE
ORTH
Harbour
ead
150
150
49° 35' N
70
65
49
60
66
As, Au
2
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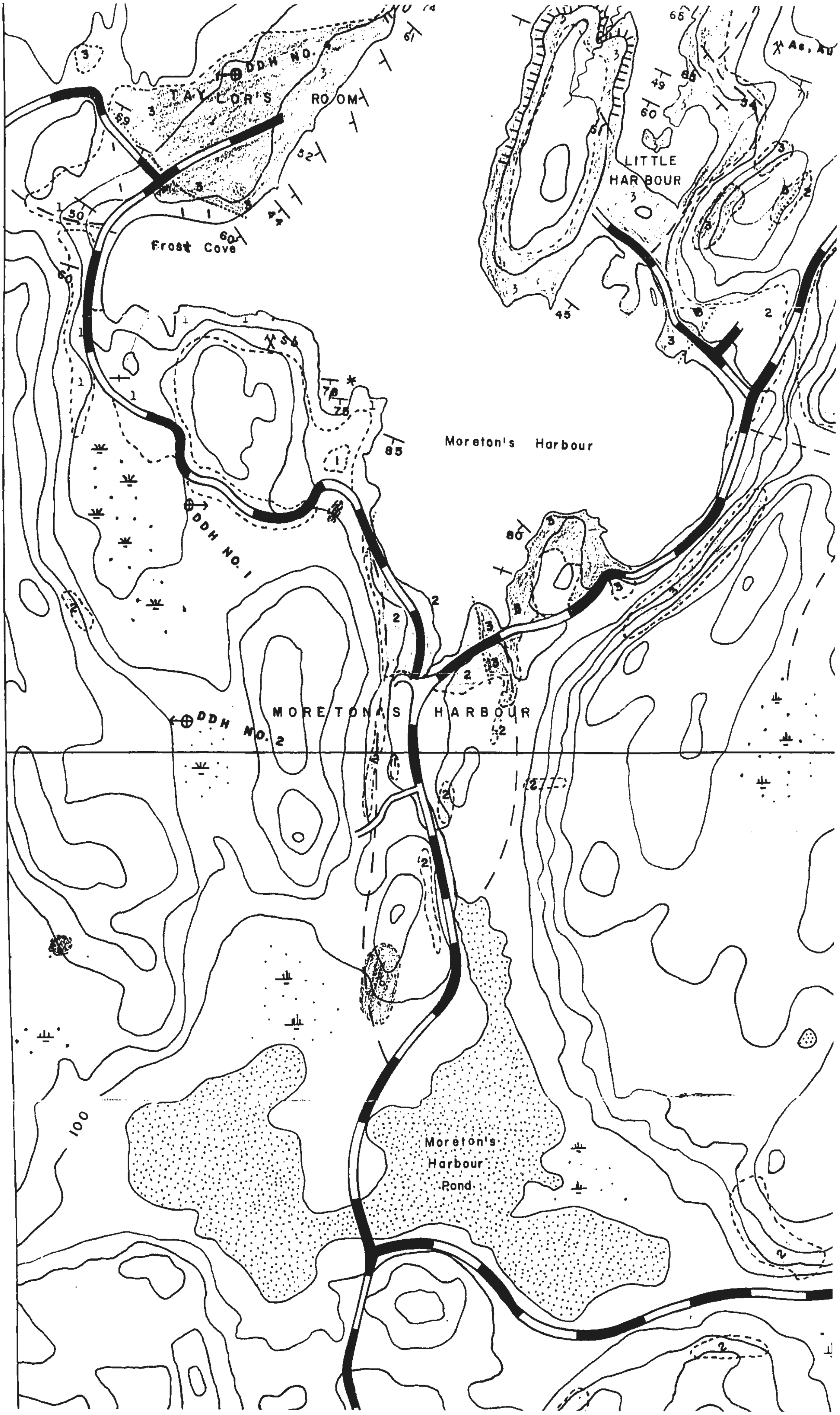
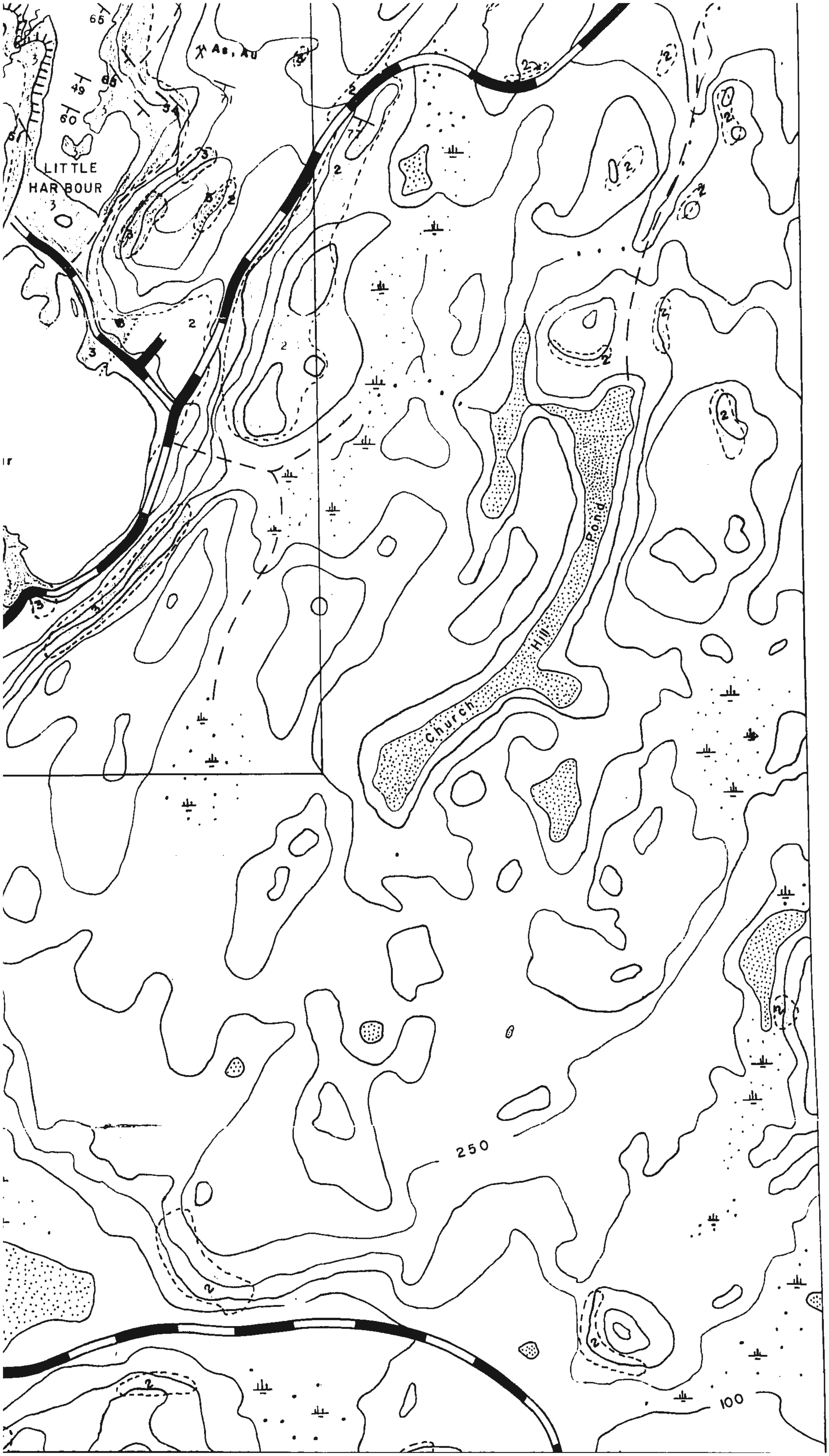
7

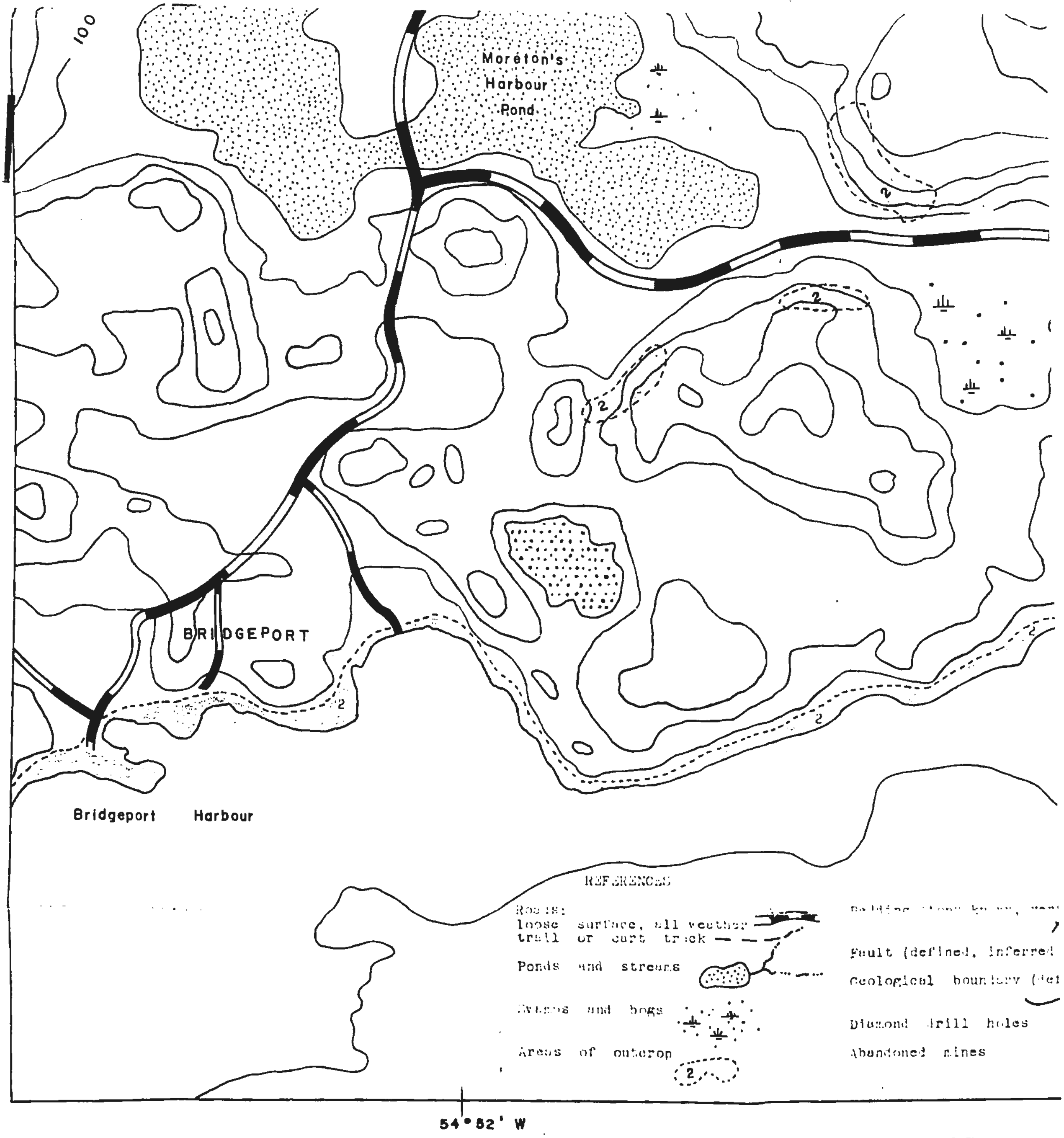
2 of


DDH NO. 4
TAYLOR'S ROOM
Frost Cove
LITTLE HARBOUR
As, Au
Moreton's Harbour
DDH NO. 1
DDH NO. 2
MORETON'S HARBOUR
Moreton's Harbour Pond
100



LITTLE HARBOUR
Church Hill Pond
As, Au
65
49
66
60
34
71
77
250
100
2
3
5

3 of 3



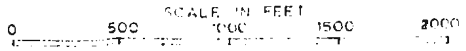
GEOLOGY OF

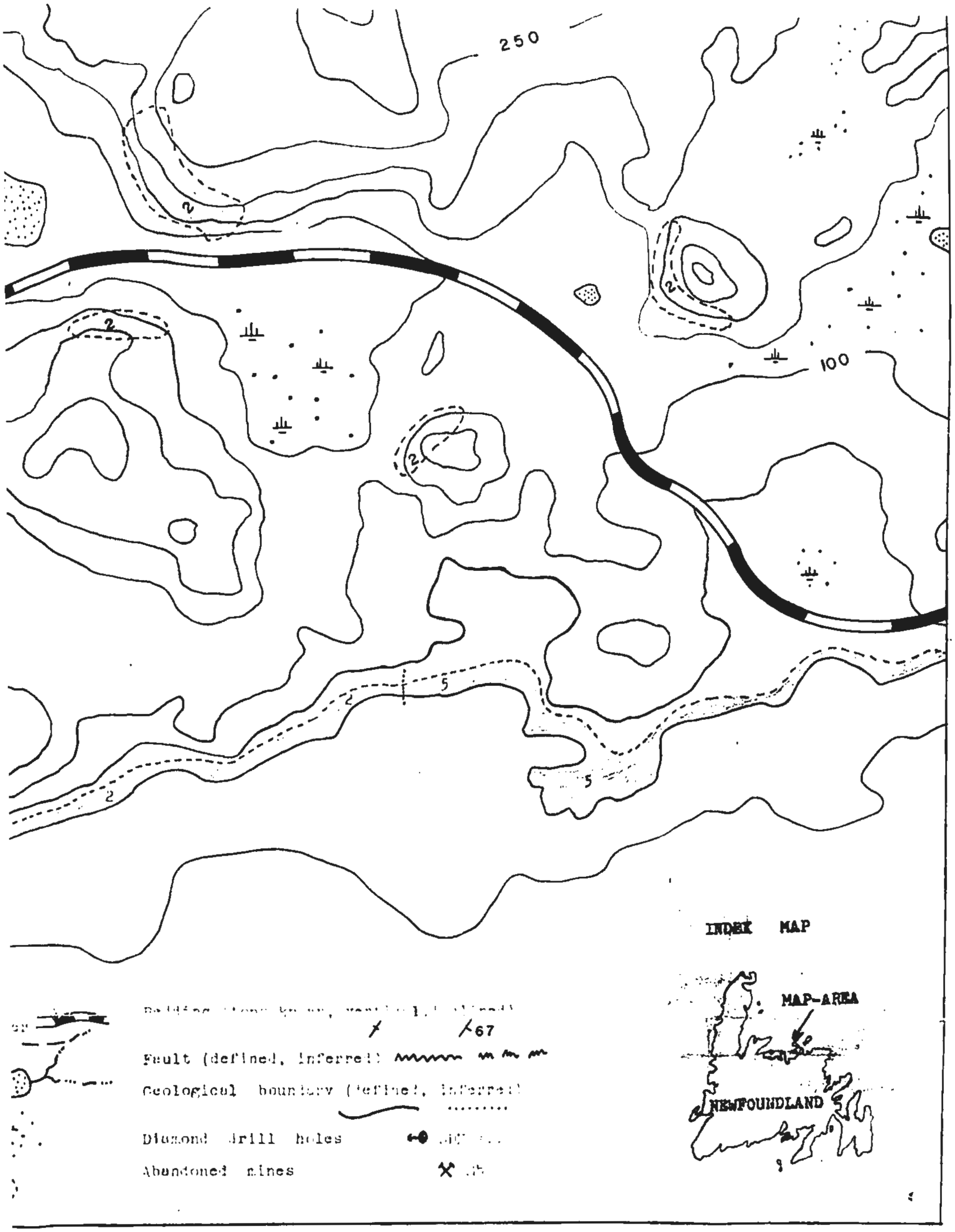
MORETON'S HARBOUR MAP-AREA, NEWFO

SCALE: 1 INCH = 500 FEET

CONTOUR INTERVAL = 50 FEET

GEOLOGY BY R.V.GIBBONS 196





GEOLOGY OF

ARBOUR MAP-AREA, NEWFOUNDLAND

LE: 1 INCH = 500 FEET

UR INTERVAL = 50 FEET

GY BY R.V. GIBBONS 1969

SCALE IN FEET

500 1000 1500 2000

MAP 2. AREAL DISTRIBUTION OF (131) VALUES DETERMINED FOR ARSENOPYRITE FROM 19 HYDROTHERMAL VEINS.

SCALE: 1 INCH = 500 FEET