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Chert in the Fossil Hill Member of the Lockport Formation (Middle Silurian), Manitoulin Island, Ontario

by

Betty E. Eley

A thesis
Submitted to the Faculty of Graduate Studies
through the Department of Geology in Partial
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Windsor, Ontario
1977

ABSTRACT

A study by detailed microscopic and macroscopic examinations is made of the disposition, composition and texture of chert in the Fossil Hill dolomites.

Chert is well developed as nodules and lenses, irregularly-shaped, but conformable with the bedding in the interbiohermal facies of the Fossil Hill bioherm complex. The facies selectivity of the chertification is believed to be a function of the porosity, compactability and organic content of the original sediments. It is postulated that organic matter is a controlling factor in chert deposition by its ability to influence the pH of interstitial water. Nodules and lenses of chert form by accretion at silica-rich centres, randomly distributed in the sediment and localized at concentrations of organic matter. Remains of silicious organisms dissolved in interstitial water provide the necessary silica for chert formation. A theoretical model for epicontinental clear water sedimentation proposed by Irwin (1965), and a modern analogue, used for comparison with the Fossil Hill bioherm complex, are found to be applicable only to a limited extent. A discussion of ancient and modern models

for the genesis of chert results in the ancient model being favoured for relation with the Fossil Hill environment of chert formation.

The replacement nature of the chert and its time of origin early in the diagenetic history of the host carbonate, prior to lithification, are inferred by the recognition, in thin section, of silica void-infilling and replacement fabrics. Sequence of replacement textures, dolomite rhombs cross-cutting and encroaching on silica fabrics, indicate that silification preceded dolomitization.

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CHAPTER 1

INTRODUCTION

A. General Statement

Manitoulin Island lies on the northern rim of the Michigan Basin. It is a part of the Niagara escarpment, a broad arcuate belt of rock extending from east-central New York State through southern Ontario and Manitoulin Island into northern Michigan (Fig. 1). The escarpment exposes rocks of Lower and Middle Silurian age. On Manitoulin Island there are extensive exposures of the Lockport Formation (Middle Silurian), and, especially, of the Fossil Hill Member of this Formation. These exposures of Fossil Hill strata, with their widely developed chert nodules and lenses, permit detailed examination in the field of this member.

B. Previous Work

Studies of the stratigraphy and palaeontology of the Lockport Formation of Manitoulin Island have been carried out by Bell (1866-1869), Bolton (1954, 1957, 1968), Liberty (1968), Sanford and Moseley (1954), Shelden (1963), and Williams (1912, 1913, 1919, 1937). Many of these reports note the presence of nodules and

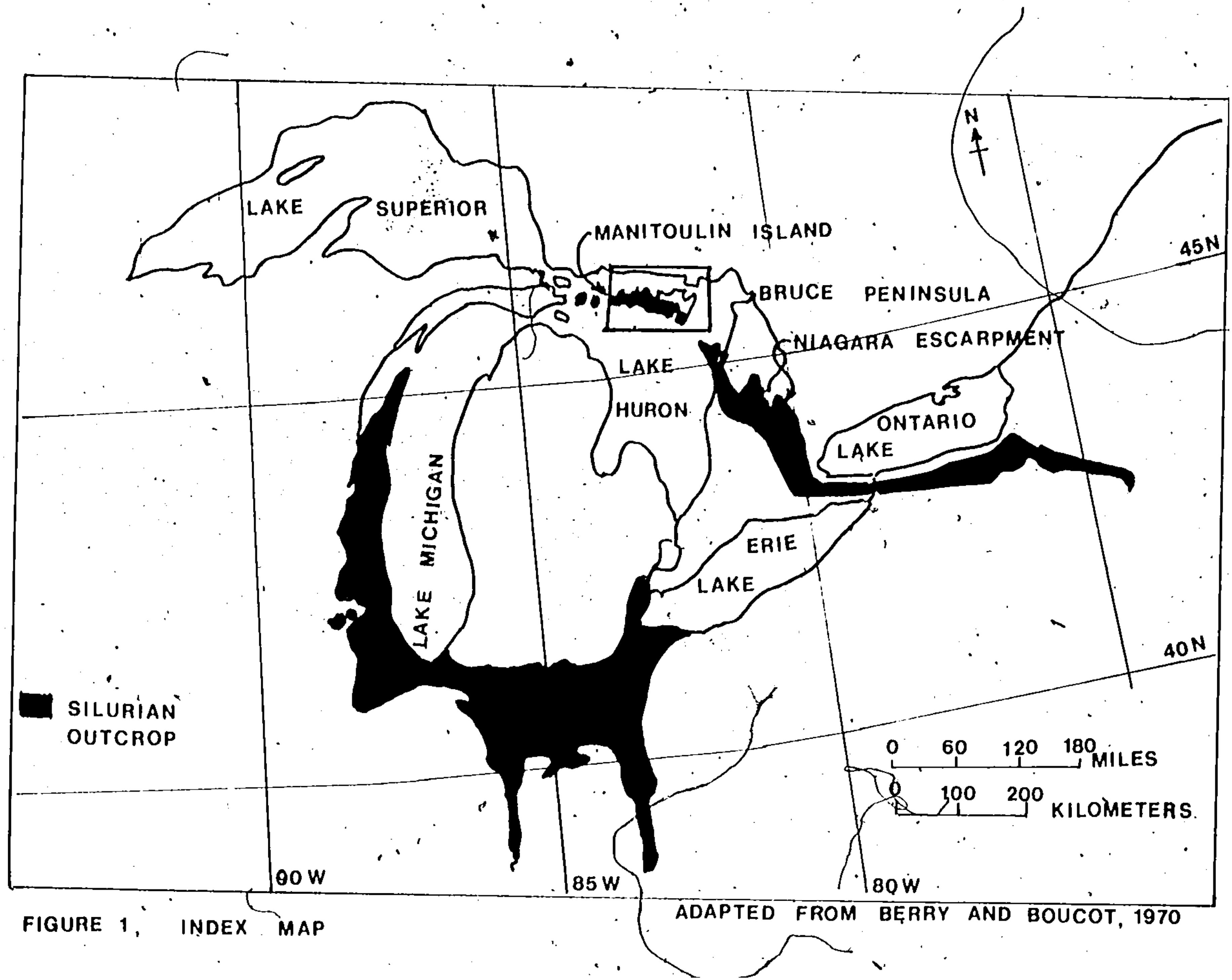

FIGURE 1, INDEX MAP

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lenses of chert in parts of the Lockport strata, but no detailed study has been made of the occurrence of this chert.

C. Objectives of the Present Study

The present study involves a detailed investigation of the chert bodies of the Fossil Hill Member of the Lockport Formation. The objectives of the study are to determine the disposition, composition and texture of the chert bodies, and to deduce the source of silica for chert formation, and the time and mechanism of chert emplacement in the original carbonate sediments.

D. Outline of Procedure

Outcrops of Fossil Hill rocks were traced from the Wikwemikong Reserve at the eastern end, to Mississagi lighthouse at the western end of Manitoulin Island, a distance of eighty miles (Fig. 2). Along this distance of eighty miles, sixteen localities were chosen as collecting sites, and for more detailed examination. Particular attention was paid at the sites to lithology, occurrence of chert in the section and fossils. These localities include the Fossil Hill type locality at Hilly Grove, L368 (Fig. 2). Sixty thin sections were cut from hand samples from the localities. A masceration

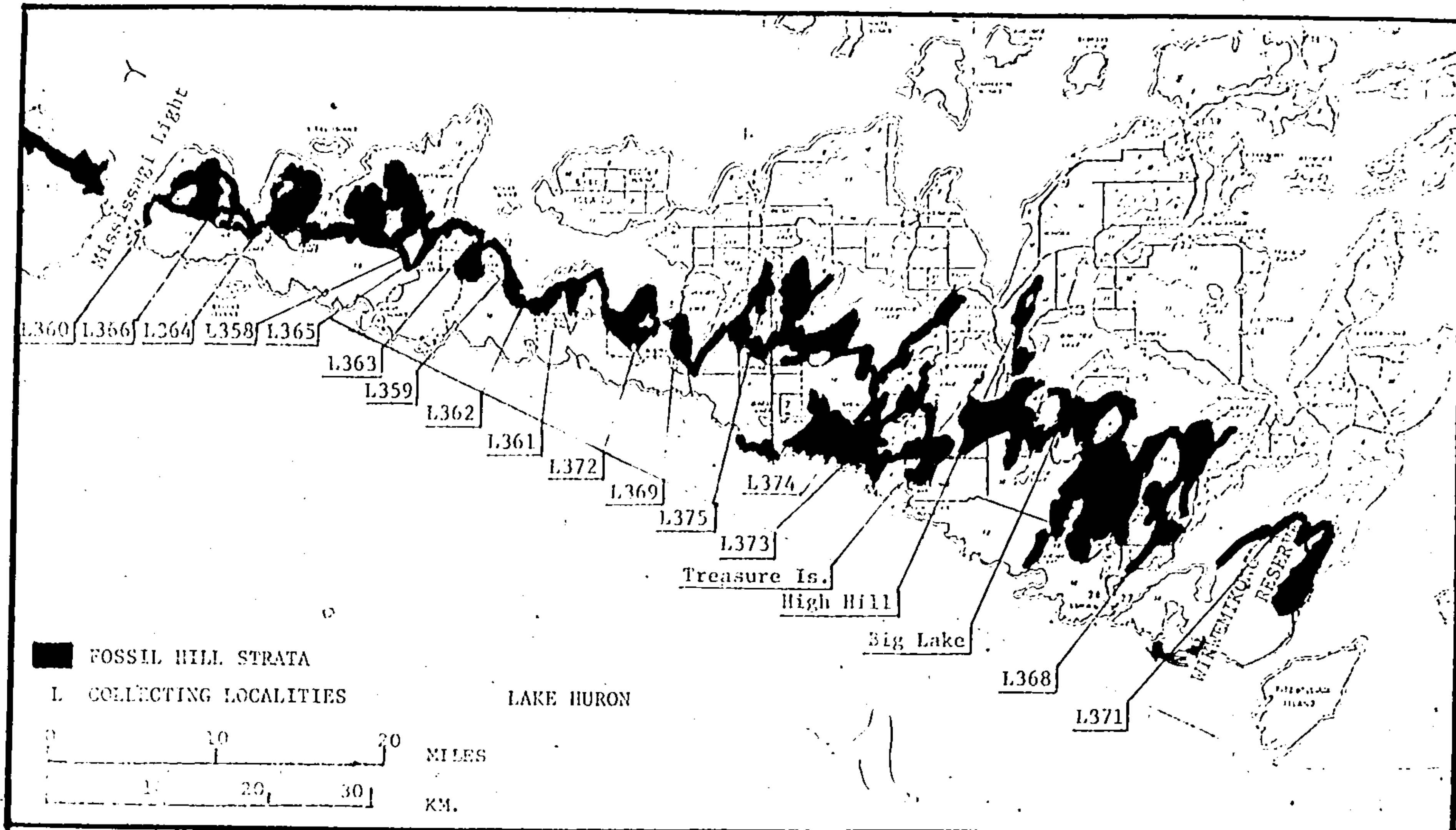

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FIGURE 2, FOSSIL HILL STRATA, MANITOULIN ISLAND process was used to collect microflora from the chert. One hundred and fifty photomicrographs were taken in order to compare fabrics, textures and enclosed fossil material of the samples. Thin sections of the cherts, and to a lesser extent, of their enclosing dolomites, were studied. A description of each was written with a view to interpreting both the environment of deposition and the diagenetic history of the chert.

Appendices include "Collecting Localities", "Glossary of Terms", "Thin Section Descriptions" and "Microfacies Descriptions".

CHAPTER II

II. Geologic Setting

A. General Statement

The Lockport Formation of Middle Silurian age is a part of the Niagara escarpment which extends from New York State into Wisconsin around the margin of the modern Great Lakes (Fig. 1). In the Manitoulin Island area it is composed essentially of dolomite rocks which strike in an east-west direction and dip southwest into the Michigan Basin at approximately thirty-five feet per mile.

B. Stratigraphy

Stratigraphically Manitoulin Island occupies an intermediate position between the Silurian sections of Michigan and the type localities in Eastern Ontario and New York. The stratigraphic nomenclature and correlation chart for the sections on Manitoulin with the sections in Northern Michigan and Ontario-New York, as proposed by Liberty and Bolton (1971), is shown in Table I. This chart has been adopted for this paper.

The Lockport Formation, on Manitoulin Island, consists of three members, designated, from oldest to

		TIME-STRATIGRAPHIC TERMS: SERIES	LITHOSTRATIGRAPHY (FORMATIONS) (sections show comparative stratigraphy only): WESTERN NEW YORK NIAGARA PENINSULAR, ONTARIO (~~Bolton 1957~~, Caley 1940)		BRUCE PENINSULA (Liberty & Bolton 1971		NORTHERN MICHIGAN (Ehlers & Kesling 1957)		HAMILTON-TOBERMORY AND MANITOULIN ISLAND (Bolton, 1957)	
UPPER SILURIAN	LUDLOW	CAYUGAN		AKRON / BERTIE; BASS ISLAND		BASS ISLAND		ST. IGNACE		
				SALINA		SALINA	SALINA GROUP	POINTE AUX CHENES		
MIDDLE SILURIAN	WENLOCK	NIAGARAN		GUELPH		GUELPH		ENGADINE	ALBEMARLE GROUP	GUELPH
				LOCKPORT	LOCKPORT FORMATION	member 3= 'Amabel' (Bolton)				AMABEL
			CLINTON GROUP	DECEW; ROCHESTER; IRONDEQUOIT		member 2= "Fossil Hill" (Bolton)	MANISTIQUE GROUP	CORDELL; SCHOOL-CRAFT	CLINTON GROUP	FOSSIL HILL; Mindemoya; St. Edmund; Wingfield
				REYNALES		member 1 (see text)	BURNT BLUFF GROUP	BYRON-HENDRICKS		DYER BAY
				NEAHGA	CABOT HEAD FORMATION, CATARACT GROUP	St. Edmund member; Wingfield member; Dyer Bay member		LIME ISLAND		
				THOROLD						
LOWER SILURIAN	LLANDOVERY	ALEXANDRIAN	CATARACT GROUP (=Medina, Caley 1945)	GRIMSBY		Cabot Head member (restricted)	CATARACT GROUP	MOSS LAKE; CABOT HEAD	CATARACT GROUP	CABOT HEAD
				POWER GLEN		MANITOULIN				MANITOULIN
				WHIRLPOOL				MANITOULIN		

MODIFIED FROM BOLTON (1957), LIBERTY & BOLTON, 1971

Table I. Silurian nomenclature and correlation chart.

youngest, the Mindemoya, Fossil Hill and Amabel Members. These Members were originally given the status of Formations (Bolton, 1957), but were reassessed as Members 1, 2 and 3 of the Lockport Formation by Liberty and Bolton (1971). This reassessment seems appropriate because of the interlensing and gradational nature of the contacts between these Members. There appears to be no breaks in Lockport sedimentation on Manitoulin Island. However, the names "Mindemoya", "Fossil Hill" and "Amabel" are firmly entrenched in the literature and they have, therefore, been retained in this paper.

C. Lockport Formation

The stratigraphic outline presented below of the Lockport Formation, and of its Members, is based mainly upon the work of Bolton (1957, 1963), Copper (1971), Liberty and Shelden (1968), Liberty and Bolton (1971), and Williams (1912, 1919, 1937).

The term Lockport Formation, on Manitoulin, is applied to the strata located above the Cabot Head Formation, and its St. Edmund Member, and below the Guelph Formation (Table I).

Lockport outcrops from Wikwemikong Reserve (L371), to Meldrum Bay (L360), Manitoulin Island, are depicted in a series of lithologic columns (Fig. 3). These columns may be coordinated with collecting localities shown in Fig. 2. The lithographic columns are somewhat schematic because contacts between the Members are frequently hidden and no outcrops occur where all three Members can be measured.

D. Subdivisions of the Lockport Formation

The subdivisions of the Lockport are shown in Table II. The term "bioherm", as a synonym for "reef" is retained in all references to Lockport Members because it is the term commonly used in the literature for the description of the Manitoulin Lockport. A "Glossary of Terms", appears in Appendix II.

(a) Amabel Member

The Amabel Member is a reefal complex consisting of biostromal, biohermal and interbiohermal facies. Thickness of the Amabel is about 150 feet where the bioherms are developed, but flank areas may be only 50 feet thick. The Amabel is correlated with the Engadine Formation of Northern Michigan and the uppermost part of the Lockport to the south of the Bruce Peninsula.

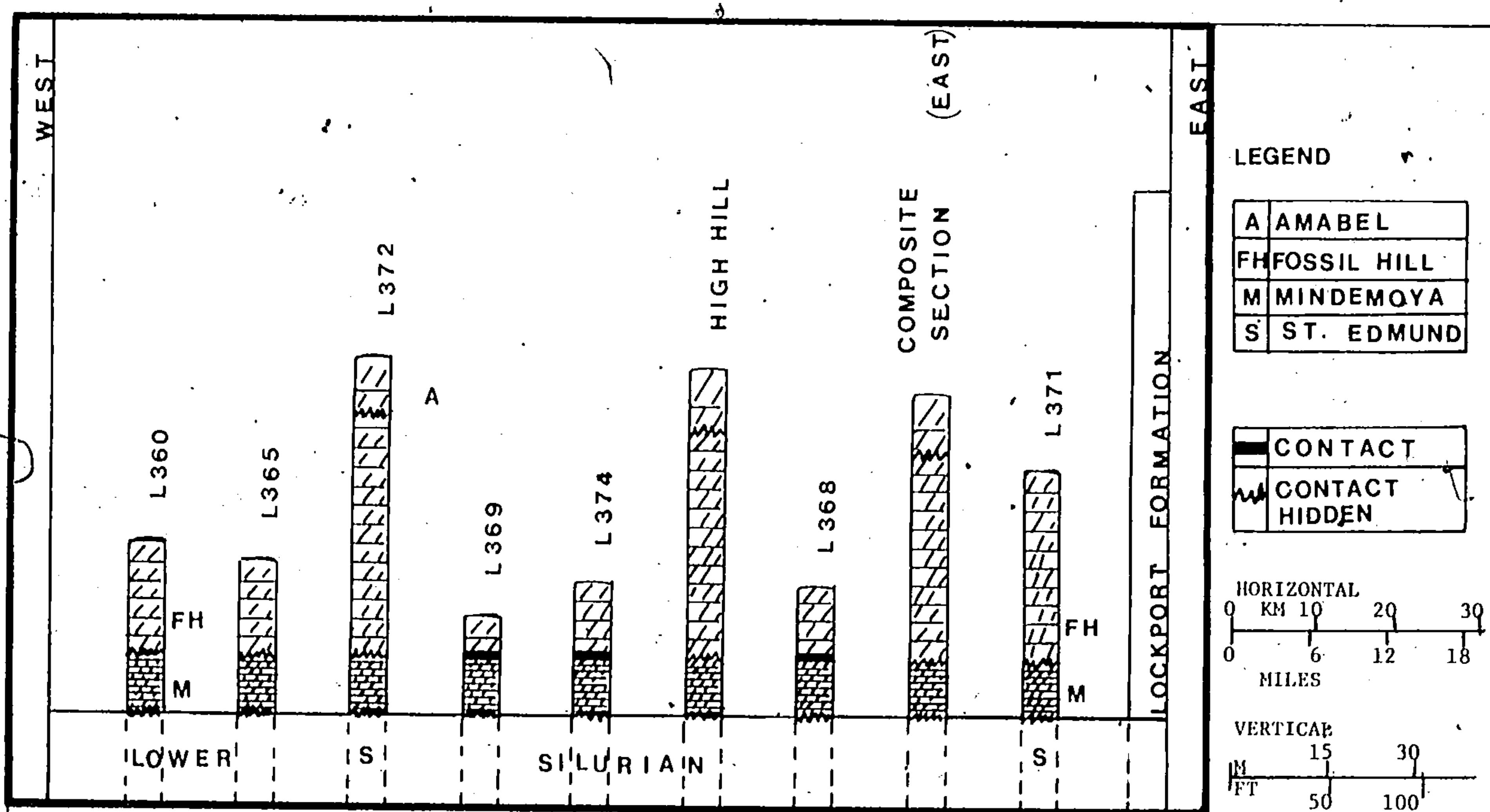


FIGURE 3. DIAGRAM SHOWING SECTIONS ALONG LOCKPORT FORMATION FROM EAST (L371), TO WEST (L360), MANITOULIN ISLAND.

(b) Fossil Hill Member

The Fossil Hill Member occurs in biohermal, interbiohermal and biostromal facies. It increases in thickness from south to north, from an average of 12-20 feet on the Bruce Peninsula to 50-90 feet on Manitoulin Island. The Fossil Hill Member is considered to be the equivalent of the Manistique Formation of northern Michigan. Southward from the Bruce Peninsula, it has been traced into the Reynales Formation of New York State.

The Fossil Hill Member is characterized by interfingering deposits of biohermal and interbiohermal facies. The biohermal facies may appear massive, with horizontal jointing being the only visible outcrop feature. The low relief of bioherms, probably less than ten feet during their time of deposition (Copper, 1971), makes it difficult to separate biohermal from interbiohermal beds. Williams (1913), described the Fossil Hill type locality as a "coral reef". A road cut here reveals horizontally-bedded strata and it is felt by the writer that, due to the nature of the beds, and the lack of mound-like structure, that this is, instead, a coral biostrome (Plate, 9 fig. 2). The most extensive Fossil Hill exposures represent interbiohermal beds which are conspicuous for

BOLTON (1957)			LIBERTY AND BOLTON (1971)	
Eramosa Member only on Manitoulin Island	AMABEL FORMATION		Member 3 (Amabel)	LOCKPORT FORMATION
FOSSIL HILL FORMATION			Member 2 (Fossil Hill)	
An Unnamed Unit that Extends From Manitoulin Island Southward to Dyer Bay (Mindemoya Formation)			Member 1 (Mindemoya)	

Modifed from Bolton (1957), Liberty and Bolton (1971)

TABLE II SUBDIVISIONS OF THE LOCKPORT FORMATION their development of chert in nodules and lenses and their highly fossiliferous content.

Coral biostromes tend to be located low in the Fossil Hill sections, but slightly higher than biostromes of pentamerid brachiopods which occur just above the contact with the Mindemoya Member.

(c) Mindemoya Member

The Mindemoya Member consists of platy, thin-bedded, white-weathering sublithographic to finely crystalline dolomite. This Member is believed to be the lithic equivalent of the Byron Formation of Northern Michigan. Southeast of Manitoulin it thins and pinches out within fifty miles.

The above interpretation of the Members of the Lockport Formation on Manitoulin Island is the generally accepted one. Another rather interesting interpretation of the entire Niagaran sequence for Manitoulin is put forth by Shelden (1963) based on his study of insoluble residues of Niagaran sediments. He suggests that the entire Niagaran sequence (Dyer Bay to Amabel) (Table III) of the northern rim of the Michigan Basin belongs to one large transgressive littoral-lagoonal-biohermal complex. The Amabel thus becomes the biohermal, the Fossil Hill, the back-biohermal, and the Mindemoya-St. Edmund, the lagoonal facies of the complex. The writer feels that there is some merit in this interpretation for the following reasons: (a) Sanford and Moseley (1954) describe the Manitoulin region during Niagaran times as being the northern marginal rim of the Michigan Basin covered with sea water, the eastern shoreline of which is migrating eastward. The character of the sediments is controlled by transgressive or regressive fluctuations of the strandline. The locally developed Wingfield and Mindemoya lagoonal facies may be a result of rapid facies changes at this strandline. The lagoonal sediments are overlain by those of the bioherm complex which results in a vertical column of laterally equivalent facies, a situation consistent with a transgressive sea margin. (b) The Manitoulin Middle Silurian section is different from the time-equivalent (and possibly non-marginal) section to the south where the Fossil Hill Members overlies the Lower Silurian (Liberty and Bolton, 1971). (c) Transitional phases are evident between the Mindemoya-Fossil Hill and Fossil Hill-Amabel Members. There are no major stratigraphic or faunal breaks in the Niagaran interval (Liberty and Bolton, 1971). (d) Much of the Fossil Hill strata is horizontally bedded, biostromal rather than biohermal in character which is not inconsistent with its interpretation as back-biohermal beds. (e) Cherty carbonate beds similar in lithology and fauna to those of the Fossil Hill, overlie Amabel biotherm core beds along the south shore of Manitoulin Island. It is possible, according to Shelden (1963), that they represent fore-bioherm detritus.

			Beds	Sediments	
MIDDLE SILURIAN	Wenlockian		Guelph	grey to brown dolomites (thin to absent)	
MIDDLE SILURIAN	Wenlockian		Amabel	light grey, fine grained dolomites; biostromal, biohermal and inter-biohermal facies	
MIDDLE SILURIAN	Llandoverian	Upper	Fossil Hill	brown, fine and medium crystalline dolomite; biostromal, biohermal and interbiohermal facies	
MIDDLE SILURIAN	Llandoverian	Upper	Mindemoya	light grey, thin-bedded, sub-lithographic to lithographic dolomites	
LOWER SILURIAN	Llandoverian	Upper	Cabot Head	St. Edmund Member:	brown, finely crystalline dolomite
LOWER SILURIAN	Llandoverian	Upper	Cabot Head	Wingfield Member:	green and grey dolomite thin shale partings
LOWER SILURIAN	Llandoverian	Middle	Cabot Head	Dyer Bay Member:	brownish grey-bluish grey dolomite, ripple marks
LOWER SILURIAN	Llandoverian	Lower	Cabot Head	Cabot Head Member:	greenish-grey and red shale
LOWER SILURIAN	Llandoverian	Lower	Manitoulin	grey, fine-grained to dense; biostromal in upper strata	

Modified from Copper (1971)

Table III. Silurian Stratigraphy Manitoulin Island

Chapter III

Chert

A. Microscopic Examination of Fossil Hill Nodular Chert

A description of the thin sections of the Fossil Hill cherts and of their enclosing dolomites appears in Appendix III.

In general, thin sections of the chert show that it is a fine-grained, dense material consisting largely of chalcedony and quartz.

1. Impurities in the Chert

Cloudiness in parts of the thin sections, and yellow-to-brownish colouration of the ground mass or silica fabrics, is taken to be due to the presence of finely disseminated particles of micrite, clay, carbonaceous matter and ferruginous material. This interpretation of the impurities is based on an analysis of the impurities in nodular chert of a similar nature by Blatt et al (1972). Laird (1935) found the same type of foreign material of "dust-like fineness" in Ancaster nodular cherts. The remains of soft parts of organisms are presumed to be responsible for the carbonaceous traces.

2. Silica Fabrics in the Chert

(a) Origin

Two processes are involved in producing silica fabrics: (a) the dissolution of original minerals and growth of the replacement mineral in the small space, and (b) growth of crystals in pre-existing void spaces.

(b) Description

Two petrographic end members, microfibrous chalcedony and microcrystalline quartz, make up the silica fabrics. As Pelto (1956) has pointed out, there is no sharp break between quartz and chalcedony, chalcedony may grade into quartz, and classification may sometimes be a matter of personal preference.

The silica fabrics are divided into two main groups, void-infilling fabrics, and replacement fabrics. The descriptions of the fabrics are broadly based on the works of Folk and Weaver (1952), Orme (1974), Walker (1962), and Wilson (1966). Terms used to describe the fabrics are used in the sense of Orme (1974). All of the fabrics described below, can be seen in crossed polarized light.

(i) Void-infilling Fabrics

1. Microdrusy Chalcedony (Chalcedonic Quartz)

Microdrusy chalcedony occurs most frequently as a lining of primary or secondary cavities and infilling spaces between silicified allochems. Chalcedony is described by Folk and Weaver (1952) as being composed of minute crystals of quartz with sub-microscopic, water-filled pores of about 0.1 micron diameter. It occurs as spherulites or as colloform bands. It is optically fibrous, fibres appear to be arranged normal to cavity limits. Microdrusy chalcedony may grade into microcrystalline quartz or drusy quartz mosaic (Plate 1, figs. 1, 2).

2. Drusy Quartz Mosaic

Drusy quartz mosaic consists of equant, anhedral quartz crystals which increase regularly in size away from cavity walls and the outer edges of bioclasts. It occurs as an infilling between bioclasts, and of small veins (Plate 1, figs. 1, 2).

3. Composite Void-infilling Fabric

A very common composite infilling fabric, consists of an area of drusy quartz mosaic bounded by microdrusy chalcedony. This fabric lines cavity walls or surrounds bioclasts (Plate 1 fig. 2). The texture of this composite fabric may be very fine between small fossil fragments or coarse, where larger cavity-infilling has taken place.

In void-infilling a drusy quartz mosaic is considered by Orme (1974) and Tarr (1926) to result from slower crystallization than the microdrusy chalcedony. Whether a void becomes occupied solely by one or the other fabric is a matter of speed of crystallization of the silica, which is related to the dimensions of the void and amount of silica solution (Tarr, 1926). This problem may be resolved by present studies of oceanic nodular chert now in progress.

In replacement fabrics the only difference between the quartz crystals in replacement microcrystalline quartz in the matrix and replacement quartz in the bioclasts, is in size. This size difference in crystals makes the bioclasts stand out in thin section (Plate 1 fig. 3). It may be the presence of the impurities in the matrix, as mentioned above, that affects the crystallization size. It is the opinion of Laird (1935) and of Sargent (1921) that the calcite shell material would be free from this impure matter and the quartz crystals replacing the calcite ~~crystals could grow larger.~~

(ii) Replacement Fabrics

1. (i) Microcrystalline Quartz

Microcrystalline quartz is the commonest replacement fabric found in the chert samples. Folk and Weaver

(1952) have shown from electron microscope examination that this fabric is composed of distinct, polyhedral, equant quartz crystals which show undulatory extinction. The finest of these crystals may grade into cryptocrystalline quartz which does not show optical properties. This microcrystalline quartz forms the matrix of most of the cherts and represents the replacement of the original micrite (Plate 1, fig. 3).

2. Spherulitic Chalcedony -

Spherulitic chalcedony frequently replaces small bioclasts. These small spherulites show their replacement nature by cross-cutting original fabrics (Plate 1, fig. 4). Spherulitic chalcedony also crystallizes around small opaque nuclei which are probably organic in nature.

(iii) Complex Replacement and Recrystallization Fabrics

1. Pseudodrusy Quartz Mosaic

This fabric resembles drusy quartz mosaic but its constituent crystals are usually larger and increase in size inward from the boundaries of the bioclasts. It is frequently seen in brachiopod shells and sponge spicules (Plate 2, fig. 1). In brachiopod and other shells replaced by pseudodrusy quartz mosaic, there is usually a zone of small elongate or acicular crystals that rim the shell. Such crystals have grown with their c-axes normal to a solid surface. Under crossed polarizers one sees "marching men" pass the N-S cross hair as individual crystals go to extinction. The size of the quartz crystals then increases and the crystals become equant and anhedral inwards (Plate 2, fig. 1). This demonstrates a replacement fabric by its relation to void-exfilling fabrics and bioclasts. There is almost always a band of microcrystalline quartz between the replaced shell fragment and the zone of microdrusy chalcedony. On the other hand, void-infilling microdrusy chalcedony passes directly into the void-infilling drusy quartz mosaic (Plate 1 fig. 1).

As pointed out by Orme (1974) it is apparent that a crystalline quartz mosaic does not necessarily signify primary formation in voids, despite a regular increase in grain size toward its centre. These characteristics are more likely to indicate a primary origin if they pass directly into a peripheral zone of microdrusy chalcedony.

2. Syntaxial rims

Around many of the crinoid fragments, calcite recrystallized from finer-grained micrite to result in sparry syntaxial replacement rims. These were later replaced by quartz crystals in optical continuity with the host (Plate 1,fig. 3).

3. "Ghost fabrics".

Calcite "ghost" fabrics may be preserved, especially in the fibrous layer of shells where silica pseudomorphs original fibrous structure (Plate 2,fig. 2). In order to preserve the evidence of the original calcite, the growth of the quartz must have taken place simultaneously with the step-by-step dissolution of the calcite. This implies that the pore water must be in delicate balance so that it will dissolve one phase and precipitate another at the same time.

(c) Sequence of Fabric Emplacement

The crystallization sequence of phases of silica to form fabrics appears to be similar to that suggested by Pelto (1956) from chalcedony to quartz (Plate 1,fig. 1). Recent studies of deep-sea cherts in calcareous sediments indicate a sequence of silica diagenesis from disordered cristobalite (from biogenic silica), to chalcedony, to quartz. The "maturation hypothesis" of Wise and Weaver (1974) proposes that disordered cristobalite is the first form of silica to precipitate from the biogenic source. This process, involving conversion from a metastable form of silica (disordered cristobalite) to the most stable form (quartz), could probably be favoured by high temperature or long periods of time (Lancelot, 1973; Robertson, 1977). Wise and Weaver (1974) also suggest that a high initial content of impurities will tend to retard the internal ordering of cristobalite and delay the final conversion to quartz. A hypothesis put forward by Lancelot (1973) gives clay minerals a key role in controlling the precipitation of disordered cristobalite. Both of these hypotheses are supported by some recent workers and rejected by others. In the Fossil Hill chert the transition from chalcedony to quartz can be observed, but, without the benefit of X-ray diffraction study, the presence or absence of cristobalite cannot be confirmed. The oldest reported occurrence of cristobalite in calcareous sediments on land is in the Upper Cretaceous of Cyprus by Robertson (1977).

(d) Replacement Selectivity of Silica

When abundant silica is available it shows a replacement selectivity. This appears to be governed by the nature of the carbonate being replaced. Silica seems to penetrate first along intergrain boundaries. Brachiopod shells show this selective replacement. Here replacement commences between the calcite laminae and prisms of pentamerid shells. Probably because their fabric is coarser than that of the matrix, they are more easily penetrated by silica-bearing solutions and are thus loci for early replacement. Finer-grained micrite and wall fabrics appear to be replaced later. As silicification proceeds, the finer bioclasts are completely replaced and interstices are filled with chalcedony and drusy quartz mosaic (Plate 1,fig. 1). In advanced silicification the matrix has become microcrystalline quartz. The primary nature of the carbonate host, therefore, is a critical replacement factor. This selective replacement of coarser-grained in preference to finer-grained carbonates, has been observed also by Dapples (1967), Laird (1935), Newell <u>et al</u>. (1953), Orme (1974). The very fossiliferous nature of the Fossil Hill limestones assisted in their silicification.

3. Fossils in the Chert

The thin sections are characterized by the presence in abundance of certain fossils. Some of the conclusions regarding the environment of deposition and of the origin of the chert are based on the presence of these fossils.

Many of the fossil components are not identifiable because of silica replacement. The most abundant, recognizable components are: shell fragments of pentamerid brachiopods (Plate 2, fig.3) (Plate 5, fig.4); monaxon spicules characteristic of the Lithistid group of sponges (Plate 2, fig. 4); bryozoan and crinoid fragments (Plate 1, fig. 3); stromatoporoids similar to Clathrodictyon (Plate 3, figs. 1, 2); and, algal remains. This algal material gives the chert a mottled appearance in the hand samples. A clotted microfabric results from a tangle of Girvanella-like algae and recrystallized micrite (Plate 3, fig. 5). Sphaerocodium appear in the form of rounded or irregular balls (Plate 3, fig. 4). Spores and acritarchs in great numbers (Plate 3, fig. 3) were recovered from the chert by the masceration process. The acritarchs are mostly of the Baltisphaeridium type (Plate 4).

Pellets, poorly consolidated aggregates bound by organic matter, round to oval in shape, add to the mottling of the chert (Plate 3, fig. 6). When seen in thin section, the decomposed organic compounds appear as dense dark films of opaque matter coating allochems, or as opaque material intercalated with silica fabrics (Plate 5, fig. 1). This is a common association in the cherts. The opacity of the organic remains makes interpretation of its structure difficult. The organic matter and ubiquitous ferruginous material stain many of the microfabrics brown or yellow-brown.

B. General Occurrences of Chert

1. General Statement

Ancient occurrences of chert have been discussed in the literature as being either bedded chert associated with shales or iron formation, or nodular chert in carbonate rocks. A great deal of recent work has focused on siliceous sediments encountered by the Deep Sea Drilling Project (DSDP). Chert in the Pacific, Atlantic, Indian and Southern Oceans is reported by Keene and Kastner (1974) as occurring both as nodules and lenses, and as layers. Associated sediments include carbonate, biogenous silica, brown clay and volcanic ash. To distinguish nodular chert from bedded chert the writer is following the definitions proposed by Dunbar and Rodgers (1957) and Heath and Moberly (1971) which are cited by Wise and Weaver (1974). They define nodular cherts as those which occur in carbonate host rocks whereas bedded cherts occur in siliceous sequences. Mineralogy of the silica phases of each is not considered in these definitions.

2. Origin of Bedded Chert

Modern studies have altered and updated theories of bedded chert formation; nevertheless questions such as silica sources for chertification remain controversial. The three main sources cited are: (1) biogenous silica, an organic source from the dissolution of silica-secreting organisms; (2) inorganic silica produced from the alteration of volcanic detritus; and,(3) inorganic silica from submarine diagenesis of clay minerals. It is the opinion of Wise and Weaver (1974) that both nodular and bedded cherts can form exclusively from biogenous silica. The same opinion is held by Garrison (1974), Heath (1974), Keene and Kastner (1974) and Robertson (1977). For present ocean basins, no extensive deposits of undoubted chemically precipitated silica has yet been found despite substantial sampling of oceanic sediments of varied age and location during the DSDP (Garrison, 1974).

The following brief summary of bedded chert formation is based on the work of Heath and Moberly (1971) and Wise and Weaver (1974).

The factors controlling the diagenetic mobilization and deposition of silica as bedded chert are not understood. It appears that biogenous opaline silica has dissolved and migrated within the sediments to form bedded porcellanites (opaline-rich claystones) in clayey and siliceous deposits. A high <u>in situ</u> temperature may be a necessary condition for the formation of young cherts, or the passage of a sufficiently long period of time (tens of millions of years).

3. Origin of Nodular Chert

It is the occurrence of chert in the nodular form in carbonate rocks that is the prime concern of this paper. The main theories for nodular chert formation, incorporating silica from any of the sources listed below, are as follows:

(a) Syngenetic theory - nodular cherts are formed by direct precipitation of masses of silica gel on the sea floor. Pettijohn (1975) cites the following writers as supporting this theory: Tarr (1917, 1926), Trefethen (1947), Twenhofel (1950), Harris(1958) and Fernandez (1961). Some objections to the inorganic precipitation theory have been summarized by Pittman (1959). They are:

1. Silica has been shown to be transported in true

solution, and in this state it is insensitive to the action of electrolites in sea water and so it would not precipitate. The work of Krauskopf (1959) and Siever (1962) confirms this conclusion that geochemical considerations make it seem unlikely that silica gel would be precipitated from normal marine waters.

2. Silica present in sea water is in a very dilute solution and if it could precipitate, even in theory, enormous amounts of sea water would be required to furnish enough silica for even a small amount of chert.

3. If foreign particles could be picked up by a rolling gel on the sea floor, their orientation should be influenced by the manner in which they were picked up. Fossiliferous cherts show no difference in orientation of their fossils from those of the enclosing rock.

The fact that throughout the past three decades of modern ocean-basin exploration, no discernible accumulations of silica gel have been found on the sea floor or within the underlying sediments is mentioned by Wise and Weaver (1974). This strongly suggests that the theory of direct precipitation is not realistic.

(b) Replacement theory - replacement of the carbonate host rock by silica. According to Pettijohn (1975) the majority opinion at present seems to incline toward a replacement origin of nodular chert. Supporting the replacement origin are: (i) the occurrence of chert fissures in limestone; (ii) the very irregular shape of some chert nodules; (iii) the presence of irregular patches of limestone within some nodules; (iv) the association of siliceous fossils and cherts in some limestones; (v) the presence of replaced calcite fossils; (vi) the preservation of structures such as bedding in some cherts; (vii) the occurrence of silicified oolites formed by replacement of calcareous ones. These criteria were first put forward by Van Tuyl (1918), and have been endorsed by Biggs (1957) as commonly accepted criteria in support of the replacement origin of chert.

4. Sources of Silica for Ancient Chert Formation

(a) Inorganic

The inorganic sources for silica have been summarized from Biggs (1957) as follows: volcanic springs active on the sea floor may contribute silica directly to the accumulating sediments; hydrothermal solutions may introduce silica into already lithified rocks; groundwater may dissolve silica from siliceous rocks and deposit it in carbonate environments; and silica, dissolved from rocks undergoing subaerial weathering, may be transported to the sea and there deposited with the carbonate sediments.

(b) Organic

The organic source of silica is from silica-secreting organisms. The key to the origin of most post-Precambrian chert in the opinion of Blatt et al (1972) is the chemical activity of organisms, the most important of which are diatoms (Triassic to present; mostly marine), radiolaria (Cambrian to present; marine only), and siliceous sponges (Cambrian to present; both marine and nonmarine). Other writers concur with this opinion (Dapples, 1959; Pittman, 1959; Siever, 1962; Wilson, 1966; Robertson, 1977).

5. Evaluation of Origin Theories and Silica Sources for Fossil Hill Nodular Chert Formation

(a) Origin

The evidence from field observations, macroscopic and microscopic studies, favours the contemporaneous Replacement theory for the Fossil Hill chert bodies. Silica was deposited in the carbonate sediment and rearranged by diagenesis before the lithification of the sediment. The silica replaced the matrix, and enclosed and replaced organisms, in the carbonate.

The evidence for replacement in Fossil Hill cherts is abundant: (a) deflection of bedding laminae by chert shows that the carbonate was incompletely consolidated at the time of chert emplacement so that the chert began to lithify slightly before the carbonate resulting in differential compaction (Plate 7); (b) chert occurs in interbiohermal rather than bioherm areas suggesting early diagenetic control by sediments (see C-3, below); (c) nodules and lenses of chert occur along, or between, bedding planes in a horizontal attitude indicating adjustment in unlithified sediment i.e. silica coalesced in porous units and silica gel pinched and swelled along bedding planes in the still-plastic sediments it produced the irregular contacts and shapes of the chert bodies (Plate 7); (d) laminae of stromatoporoids pass from carbonate into chert without interruption; (e) bioclastic fragments may be seen lying across the junction between chert and carbonate (Plate 8); (f) inclusions of original calcite and calcite "ghost" fabrics remain in chert matrix (Plate 2, fig. 2); (g) the preservation of microscopic organisms in a silica-rich matrix must have taken place before it hardened into chert (Plate 4) and (h) silicification of calcareous fossils inside nodules. (Plate 3, fig. 5)

(b) Silica Source

The geographical location of the Fossil Hill

Member precludes any sources of inorganic silica from siliceous magmas or siliceous springs, and from circulating groundwaters moving downward through overlying siliceous rocks. An organic source of silica from sponge spicules has been cited as the source of silica in a number of studies of nodular chert Lowenstam (1942), Namy (1974), Meyers (1977), Pittman (1959), Wilson (1966). Remains of siliceous spicules are common in Fossil Hill chert. It seems reasonable that they were the main source of silica for these cherts. Communities of sponges were indigenous to interreef strata of the Michigan Basin during the Middle Silurian Period according to Lowenstam (1949). However, in order to consider all possibilities, a possible source of inorganic silica from rocks undergoing subaerial erosion is mentioned. If the quartzite mountains of the Precambrian Shield were emergent, erosion could have supplied seasonal influxes of silica from them to the sea. Accelerated rates of sponge production, similar to modern "blooms" of siliceous organisms due to a sudden increase in their nutrient supply, may have occurred. Sponge spicules have been preserved in many of the cherts and some chert nodules are composed almost entirely of spicules forming spiculites (Plate 5, fig. 2)

C. Macroscopic Examination of Fossil Hill Chert

1. Distribution and Mode of Occurrence

Chert is not limited to certain horizons, but occurs throughout the sections of the interbiohermal strata.

The nodules and lenses of chert are conformable with the bedding of the dolomites. The shape of the nodules varies from spherical to ellipsoidal to highly irregular tuberous bodies. These may appear elongated in the plane of bedding. Nodules may be concentrated along particular bedding planes and nearly absent along adjacent ones (Plate 7). The nodules are fossiliferous. Some cherts which appear dense, and megascopically unfossiliferous, are seen to contain fossil remains when examined in thin section.

The term "lens" may be used to describe the larger masses of chert which may be 6 inches or more in thickness, and several feet in length. It would appear that nodules were formed initially, but if the supply of silica were sufficient, accretion gave rise to lenses which often coalesced. Although two terms are used, nodule and lens are closely associated and grade imperceptibly into one another. The crowding of nodules may give rise to a more or less continuous layer or lens, but this cannot usually be traced for more than a few feet. However, in some areas, the lenses may combine in the plane of bedding to form small discrete beds three feet or more in thickness, and six feet or more in length (Plate 8).

2. Colour

The chert shows a colour range of white, grayish yellow, pinkish gray and light bluish-gray. Mottling is one of the most conspicuous features of the chert. This mottling is shown by thin section examination to be related to carbonaceous matter enclosed in the chert. The reddish-to-brown discolourations in some cherts is attributed to the alteration of pyrite crystals to iron oxide.

3. Facies Control of Chert Deposition

A control on chert deposition is suggested by its preference for certain carbonate facies. The chronologically and geologically adjacent strata of the Fossil Hill facies differ in chert content. Nodular chert is abundant in the interbiohermal facies, while the associated biohermal and lagoonal facies are relatively chert-free.

During Middle Silurian Time there were many reef-interreef complexes, analagous to the Fossil Hill complex. The Thornton Reef Complex of Illinois was found to show an aureolic increase in chert outward from the reef core with chert concentrations replacing the interreef beds, by Ingles (1963), and Weiner and Koster Van Groos (1976). Lowenstam (1942) studying Niagaran formations in Illinois, Wisconsin and Indianna, found that chert is absent from the reef rock, but abundant in interreef strata. Five Niagaran reefs of the Indiana-Ohio platform studied by Textoris and Carozzi (1964) were found to have chert nodules as a common feature of their interreef beds.

Other examples, from other time periods, also appear to be suitable analogues. Barnes (1952) states that chert is restricted to the interreef facies in the Pennsylvanian limestone of the Marble Falls Formation, Texas. The Cretaceous Edward Limestone of Texas is described by Pittman (1959) as having the least amount of chert in the reef rocks. Pray (1958), discussing Mississippian bioherms of southwestern United States, mentions that there is typically a much greater amount of silica in the interreef limestones. A summary of the interreefal occurrence of chert is made by Dapples (1967), who comments that cherty carbonates commonly constitute ancient interreef deposits, whereas the associated carbonate reefs tend to be characteristically low in chert. The reason for this distribution is attributed to a difference in their original sediments. The Fossil Hill interbiohermal facies accumulated as loose sediment. During their time of growth bioherms are lithified, and they probably compacted little after burial. As stated by Lowenstam (1942): "Reefs are thick and rigid uncompactible bodies which grew as rocky wave-resistant structures." The occurrence of chert in the interbiohermal facies suggests the penetration of silica-bearing solutions in unconsolidated sediments and a consequent emplacement of silica, prior to the lithification of those sediments. This view concurs with that of Chilingar et al. (1967) and Jodry (1969). Dapples (1954) suggests that silica-bearing solutions could penetrate the soft sediments of flank and interreef areas more easily than reef cores which were at all time lithified.

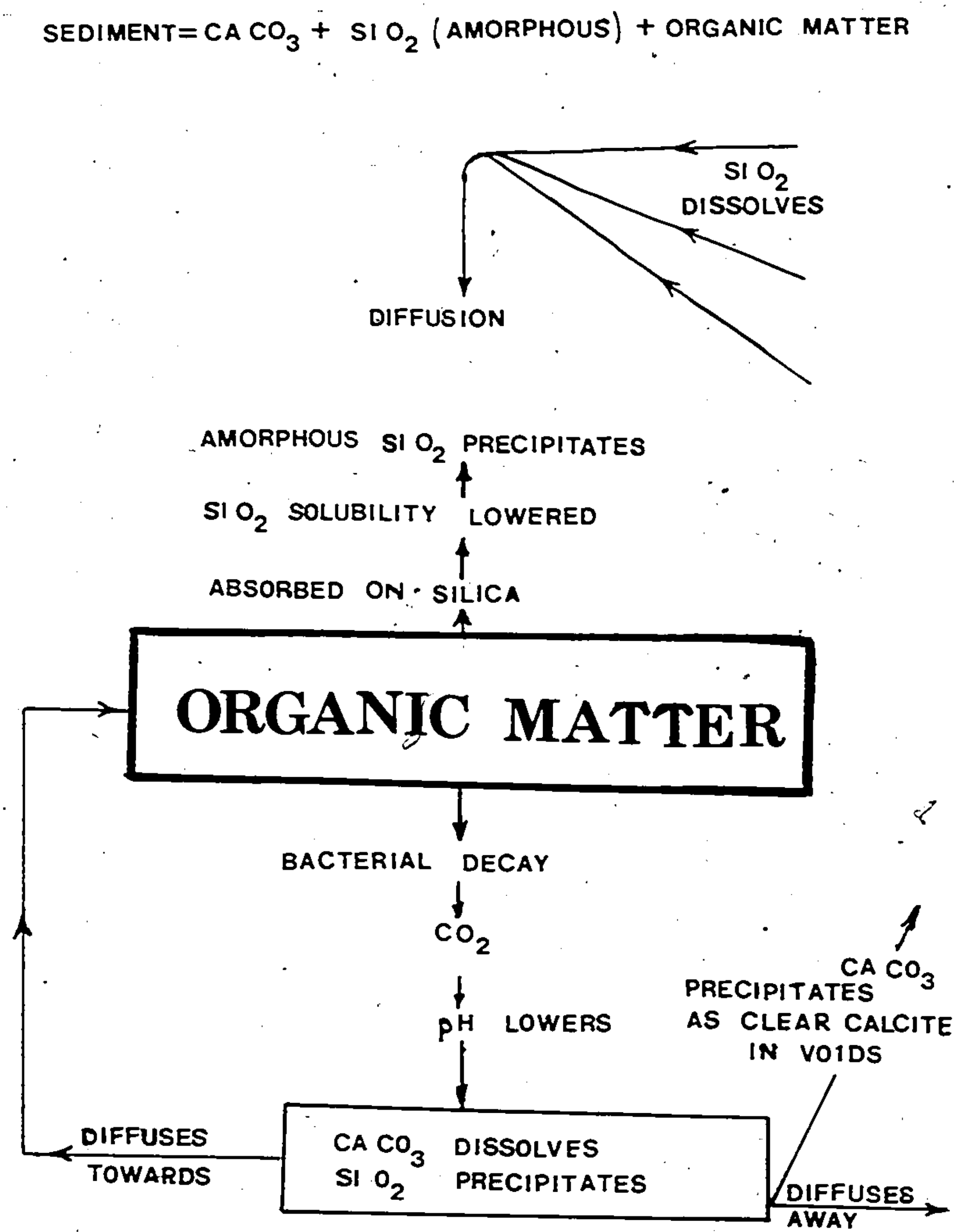
D. Model for Chert Formation

1. General Statement

A model for silica emplacement as nodular chert in ancient rocks is outlined below. It is a compilation of the work of Dapples (1959, 1967), Emery and Rittenberg (1954), Krauskopf (1959), Newell et al. (1953), Siever (1962) and Walker (1966).

2. Model (Fig. 4)

Organically precipitated SiO_2 from siliceous organisms is incorporated in the $CaCO_3$ sediment. It is



MODEL FOR CHERT FORMATION

BASED IN PART ON SIEVER (1962)

FIGURE 4

in equilibrium with the interstitial water of the sediments. An increase in pH of the water will cause more silica to be dissolved, and a decrease in pH will cause silica to be precipitated. The solubility of $CaCO_3$ is affected in a reverse manner, so that pH changes which tend to precipitate SiO_2 tend to dissolve $CaCO_3$.

The following mechanisms account for the precipitation of SiO_2 and the dissolution of $CaCO_3$. Organic matter in clumps is irregularly distributed in the sediment. At sites of organic matter SiO_2 is precipitated by pH change and, possibly, by adsorption of organic matter on silica whereas, siliceous organisms in the surrounding area would be free to dissolve. A concentration gradient of dissolved silica would be set up, making possible diffusion from the surroundings into the site. At the same time, at the site, decay of the organic material by bacterial action, is proceeding. This adds CO_2 to the system which creates local acidic environments and lowers the pH of the interstitial water. The localization of the increases in CO_2 may be attributed to the irregular distribution of organic matter. At the sites of organic decay $CaCO_3$ would dissolve, and a concentration gradient would be set up between the sites and surrounding areas where no CO_2 was added, making possible diffusion away of $CaCO_3$. The lowering of the pH would also assist the precipitation of SiO_2 at the site. The writers, cited above, are divided in their opinion as to the pH value at which SiO_2 is precipitated. However, as pointed out by Walker (1962), the fact that conditions commonly exist in which shift in pH through a small range can precipitate SiO_2, seems to be gaining acceptance.

The process of $CaCO_3$ dissolving and SiO_2 precipitating, at the site of organic decay, would continue until all the organic matter was oxidized by bacteria and CO_2 production ceased. As the sediments accumulate and compact interstitial water moves through the sediments and can come in contact with the organic matter.

3. Comparison of the Fossil Hill Chert with the Theoretical Model

The Fossil Hill nodular chert may now be tested against the theoretical model. A source of silica from organisms has been proposed for both (see Chapt. III B-5). According to the model, organic matter plays a key role in chert formation, an idea that is supported by the writer. The close association of organic matter and chert in Fossil Hill cherts is stressed because of evidence from thin sections (see Chapt. III, B-4(b)),(Plate 3) The driving force in the model is the movement of interstitial water of variable compositions through the sediments. The porosity and permeability to permit the migration of interstitial fluids is a feature of sediments such as the Fossil Hill biocalcarenites(see Ch. IV, E). The theoretical model is accepted as being applicable for the formation of Fossil Hill nodular cherts.

E. Recent Continental Chert Formation

1. Occurrences

Peterson and Von Der Borch (1965), made the first report of nodular chert formation in a Recent environment, in Holocene Lake deposits of Australia. Here, surface lake brines with pH as high as 10.2 are supersaturated with respect to calcite and magnesite. Consequently, calcite and magnesite are precipitated from evaporating surface brines. Silica is dissolved from detrital quartz and other silicates by brine water at the surface. Decaying organic matter just beneath the surface reduces pH to as low as 6.5. Silica is precipitated from solutions characterized by low pH in proximity to the organic matter.

Other reports of Recent chert formation are as follows: (a) Eugster (1967), Quaternary, Lake Magadi, Kenya; (b) Hay (1968) Quaternary, East Africa; (c) Surdam et. al. (1972), Jurassic and Eocene to Pleistocene, Wyoming; Sheppard and Gude (1974), Pliocene, Oregon. These occurrences are all in highly alkaline lacustrine environments.

(b) Comparison with Fossil Hill Occurrence

There is a similarity between the factors involved, the role of organic matter, pH change etc. in chert formation in the Fossil Hill and Recent Formations. The very specialized alkaline lacustrine environment of Recent Formations no doubt existed, in certain times and places, in the geologic past. However, there are no evaporitic-type sediments in the Fossil Hill beds, and the flourishing biota of the Fossil Hill could not have been sustained in such a specialized environment. It is considered, therefore, that the Fossil Hill and Recent lacustrine chert formations are not analagous.

F. Recent Marine Chert Formation

1. Hypotheses

Classical theories of marine chert formation formulated by geologists working with ancient sediments are typified by the Model above (see D-2). The Deep Sea Drilling Project has made possible modern studies of younger sediments, Middle Cretaceous to Miocene in age. Long cores of sediment which have encountered widespread cherts in incipient stages of development have been recovered and are available for study. The cherts occur as discordant stringers and nodules in the calcareous sediments, and as porcellanites (granular chert) in clayey and siliceous pelagic deposits. The nodules are hard with a vitreous lustre and conchoidal fracture, and are composed largely of quartz and chalcedony. It is this nodular type of chert that is considered to be comparable to ancient nodular cherts and will be discussed further.

The drilling programme has resulted in the advancement of new hypotheses regarding the early diagenetic history of silicified sediments. Two basic theories of nodular chert formation are currently under debate. One is a "maturation" theory advocated by Berger and von Rad (1972), Heath and Moberly (1971), and Wise and Weaver (1972, 1974). This theory holds that chert nodule formation begins with precipitation of disordered cristobalite from biogenic silica. The cristobalite, through time, recrystallizes to true quartz chert. Virtually all diagenetic silica is more crystalline than biogenic silica which is amorphous. The crystalline phases have much lower solubilities than amorphous biogenic silica. This difference in solubilities between biogenic and diagenetic silica is probably the major driving force for chertification. The second theory is the "quartz precipitation" theory advanced by Keene and Kastner(1974)and Lancelot(1973). The quartz precipitation theory holds that mineralogy and porosity of the host sediments are critical in chertification. It proposes that clay minerals are responsible for the diagenetic precipitation of disordered cristobalite in clayey sediments. The cations supplied by the clay minerals cause disorder in the crystalline structure of silica during growth so that only disordered cristobalite can precipitate, if these cations are present in sufficient amounts. Whenever permeability increases, as in carbonate sediments, the ratio of silica to metallic cations increases sharply and quartz can precipitate because of the increase of this ratio.

Two theories as to the source of silica, biogenous versus volcanic, are also being debated. However, the great majority of workers endorse biogenous silica as being the volumetrically significant source.

2. Model

A model, proposed by Meyers (1977), for the chertification process, has been selected from recent literature for examination for the following reasons:

(a) it is a model for chertification in epeiric strata (Mississippian), and the Fossil Hill is epeiric strata, (b) it is a model for formation of nodular chert in a carbonate host, a situation similar to that of the Fossil Hill, (c) the source of silica from sponge spicules.

for chert formation is comparable to the source postulated for the Fossil Hill, (d) the model embraces the "maturation" theory for chert production which is accepted by a majority of the workers studying modern silica sediments. The basic elements of the model for the ancient epeiric formation derive from analogy with chertification processes thought to be occurring in modern oceanic sediments, providing a link between ancient and modern situations.

Model for Chertification in Epeiric Strata (Meyers, 1977)

1. Biogenic amorphous silica, as sponge spicules, dissolved during burial to yield interstitial solutions supersaturated with respect to cristobalite and quartz. The precipitation of cristobalite kept the solutions undersaturated with amorphous silica.

2. Cristobalite precipitated in pores of lime mud and skeletal fragments as microspherules that subsequently grew and coalesced with neighbours to replace mud and skeletal grains. Most of the microcrystalline quartz is probably a recrystallization of this cristobalite.

3. Cristobalite also precipitated in large voids and intraskeletal pores, and within spicules. On recrystallization this yielded chalcedony.

4. As chertification continued, the supply of biogenic silica decreased, yielding progressively more dilute solutions, resulting in the precipitation of megaquartz (drusy quartz mosaic) as the last stage of chertification.

Biogenic silica tends to dissolve to concentrations of 125-140 p.p.m . However, these concentrations are not attained in interstitial waters in carbonate strata because, as the concentrations reach 20-30 p.p.m. , the waters will be over-saturated with respect to cristobalite and cristobalite will tend to precipitate. This process will continue until all the biogenic silica is converted to diagenetic silica by solution and reprecipitation. The main driving force, then, for chertification was the difference of solubility of biogenic amorphous silica from that of crystalline secondary silica. Under the model other factors interstitial water temperature and pH variations, other ions such as Al^{3+}, and evaporation - have negligible effects in creating oversaturation, or determining phase or fabric of the diagenetic silica. One, or more of these factors have been emphasized in other models.

It is possible that this model could be used for comparison with the Fossil Hill chert and found applicable. But, as there is insufficient evidence available of the early crystalline stages of the Fossil Hill chalcedony and quartz phases, no comparison can be made, at this time, between the two chertification processes. In addition, Meyer's model does not discuss the dissolution of calcium carbonate. As a model for the formation of the Fossil Hill chert, therefore, it is not, in the writer's opinion, acceptable at the present time.

3. Conclusion

It should be emphasized that all of the hypotheses discussed above are tentative working models. Progress has been made in determining the nature of chert, but no satisfactory explanation has been given, to date, to account for its worldwide distribution, as well as for its preferred occurrences in some sections of the stratigraphic column.

Chert is present in Tertiary marine sediments, but, although the potential for chert formation is present in interstitial waters of present day marine sediments, no appreciable concentrations of chert are found. This may imply that there was some difference, fundamental to chert formation, in the oceanic environment of the Fossil Hill time and other times in the stratigraphic column of preferred chert occurrences.

Chapter IV

Interbiohermal Facies of the Fossil Hill Member

A. General Statement

The nodular chert is confined for the most part to the interbiohermal facies of the Fossil Hill Member. The term facies as used here refers to "some areally restricted part of a designated stratigraphic unit"(Moore 1949), where environmental conditions were stable for a sufficient length of time to permit the accumulation of deposits with distinct lithologic and faunal characteristics.

B. Lithologies

The dominant lithology of the interbiohermal facies is dolomite. The chert which the dolomite encloses is discussed in Chapter II. The very minor argillaceous lithology, also included in this facies, is discussed below.

The dolomite consists of unevenly bedded, buff to brown or gray, siliceous, fine to coarsely crystalline vuggy, very fossiliferous rocks. Beds of this dolomite are well developed at localities L365, L369, L369 (Plate 9).

Laterally, they grade into, or interfinger with, biohermal sediments.

These sediments show a number of characteristics of "interreef" rock as observed by Textoris and Carozzi (1964). These are: horizontal bedding, high chert and fossil content and "interreef" microfacies, typically grain-supported biocalcarenite with some occurrences, also, of mud-supported biocalcarenite (Microfacies types 1 and 2, described in Appendix IV). A fine fraction, possibly representative of micrite entrapped by organisms and algae, is persistent. It is seen in thin section replaced by finely crystalline dolomite or microcrystalline quartz.

The dolomite is a replacement of the original calcium carbonate deposit. This is obvious from the dolomitization of calcarenous bioclasts, the inclusions of calcite crystals and the presence of calcite "ghost" fabrics within the dolomite (Plate 6, fig. 3).

The argillaceous deposits within the dolomite lithology are very thin, comparable in thickness to a sheet of paper. They occur throughout the dolomite at irregular intervals which may be from one to several inches apart. Their dark gray colour makes them conspicuous in the lighter brown host. These thin shale deposits may be due to intermittent turbulence, such as that induced by storm activity, which resulted in a sudden influx of mud over the interbiohermal sediments. Articulated remains of crinoid columnals on the shale, apparently buried *in situ*, indicate burial of a living community of the interbiohermal area.

C. Fossils

Corals, stromatoporoids, algae, brachiopods, crinoids, bryozoans and sponges dominate the biota of the interbiohermal beds.

Biostromes are developed locally. The main biostromal builders were corals, stromatoporoids and the brachiopod *Pentamerus oblongus*. The biostromes of pentamerids may be characterized by horizontally-bedded encrusting stromatoporoids (Plate 8). The pentamerid biostromes are located toward the base of the Fossil Hill, above the Mindemoya contact. Broad banklike accumulations of pentamerids are frequently concentrated at bedding planes which may extend laterally for hundreds of square feet. These banks consist almost entirely of *Pentamerus oblongus*. The high proportion of mature individuals and the large number of specimens preserved with articulated valves, suggests life assemblages (Plate 10).

There is considerable microflora present in the Fossil Hill rocks which may be recovered by using a masceration process, (Plate 4). It is pointed out by Thusu (1973), that acritarchs were first reported in Silurian chert nodules of New York state by White (1962), who identified them as reproductive bodies of sponges. However, they were neglected and forgotten in North America for seventy-three years, until Laird (1935), again discovered them in the Lockport Formation of Ontario. He, also, gave them sponge affinities. They were identified as algal spores by Fisher (1953), working with Silurian shales from New York State. Their present status is that of organic microfossils of unknown and varied affinities (Evitt, 1969).

The Fossil Hill material has been tentatively identified to genera level by comparison with the work of Thusu (1973), who studied the acritarchs of the Middle Silurian Rochester Formation of Southern Ontario.

The following is a list adapted from Sanford and Moseley (1954), of the most common macrofossils. A more complete list may be found in Bolton (1968), or

Williams (1919).

Corals

Arachnophyllum pentagonum
Favosites favosus
Favosites hispidus
Halysites catenularia
Halysites microporus
Heliolites elegans
Kionelasma spongaxis
Lyellia americana
Omphyma verrucosa
Plasmopora follis
Ptychophyllum stokesi
Streptelasma conulus
Zaphrentis stokesi

Brachiopods

Pentamerus oblongus
Homeospira apriniformis
Eospirifer radiatus
Stricklandia manitouensis

Cephalopods

Discosorus
Huronia

Stromatoporoidea

Clathrodictyon ostiolatum

D. Interpretation

The abundance of fossil material in the dolomite beds is evidence that they were the sites of flourishing communities. The diverse biota, of primarily suspension feeders, suggests some water agitation of their environment to replenish nutrients and remove suspended mud. Purdy (1964), envisages a similar environment for suspension feeders, and makes the additional comment that such an assemblage of crinoids, brachiopods, corals etc. indicate an environment with a firm substrate. Algae, such as are found in the Fossil Hill sediments, contribute much to the stability of the mud or mud-carbonate sediments. In discussing the modern environment of the Little Bahama Bank, Bathurst (1975) notes the considerable effect which algae can have on the stabilization of sediment surfaces.

Closest to the bioherm are beds which may constitute interbiohermal-flanking sediments composed of a breccia type deposit. They contain corals and stromatoporoids in tumbled position and showing abrasion, along with other bioclastic debris in a matrix of calcarenite. Also present are many whole or only disarticulated shells, including brachiopods and crinoids, which show little abrasion. The indications are that transport of some material has occurred, but it may not have been very far.

The bulk of the interbiohermal beds consist of cherty biocalcarenite. Some micrite, possibly entrapped by organisms, is a persistent fraction of the sediments. The use of micrite (calcilutite) content of carbonate sediment to indicate low energy conditions at the site of deposition must be used with caution.

Bathurst (1975), after studying present-day conditions in the Bahamas and elsewhere in the Caribbean region, states that the only proper inference to be drawn from the occurrence of ancient calcilutites is that the original mud was deposited faster than it was removed. Dunham (1962), suggests that, although distinction between sediment deposited in calm water and sediment deposited in agitated water, is fundamental, emphasis on currents of delivery (of sediments) does not work well in lime sediments because of the local origin of many coarse grains. He advises placing emphasis on the fact that some fine material is able to remain at the site of deposition. Since there seems to be a muddy fraction remaining in many of the Fossil Hill sediments studied, the currents of removal must not have been of sufficient strength to remove all of the micrite. However, the dominant microfacies type is the biocalcarenite with the potential for a high primary porosity. Sand sized particles are formed in situ with some silt-and-mud sized particles from the breakdown of organic debris or by precipitation. Primary pores may occur within and between fossils, and fragments of fossils, and pellets. The body cavities of bryozoans, corals, crinoids etc. are intraparticle pores. Brachiopod valves, if disarticulated, may create shelter pores. As pointed out by Pettijohn (1975), a carbonate sand with a grain-supported framework has a large (30-40 percent), initial porosity.

Summary

The main indications from fossil and sediment evidence seem to be for an environment of clear, warm marine water of some agitation over a firm substrate stabilized by organisms. There are some signs of transport of material but not necessarily of any great distance. The retention of a micrite fraction places emphasis on currents of removal rather than on currents of deposition. A high primary porosity of the sediments seems evident, its compactability has been discussed previously (Ch. III, C-3).

An environment of low to medium water energy, lower than that of the biohermal environment, but of some agitation, is favoured as the depositional environment for the interbiohermal facies.

The recognition of the Fossil Hill sediments in a theoretical model and in a present-day epicontinental environment is discussed below.

E. Facies of Underlying Mindemoya Member

(a) Lithology and Origin

The Mindemoya strata consists of thin, white-weathering beds of buff to gray, sublithographic to finely crystalline dolomite. Beds of this dolomite are well developed at localities 1369, 1373 (Plate 9), where they underly the Fossil Hill Member. These beds are referable to a lagoonal facies associated with a bioherm complex the characteristics of which are well-described in the literature, and which are summarized by Wilson (1975). They are as follows: water is shallow generally less than thirty feet deep; salinity varies from essentially normal marine to somewhat higher; circulation is very moderate, water conditions are not favourable for the support of a widely diversified biota; sediments are texturally varied but contain considerable amounts of lime mud.

The sediments are siliceous but relatively chert-free. Dolomite or quartz-filled vugs which resemble "birdseye" structures are found in the sediments. They are believed to originate by the infilling of voids in the original calcite sediment due to shrinkage of the muds or to the dissolution of calcite bioclasts.

The microfacies is a calcilutite or calcisiltite (Microfacies type 3, described in Appendix IV).

Chapter V

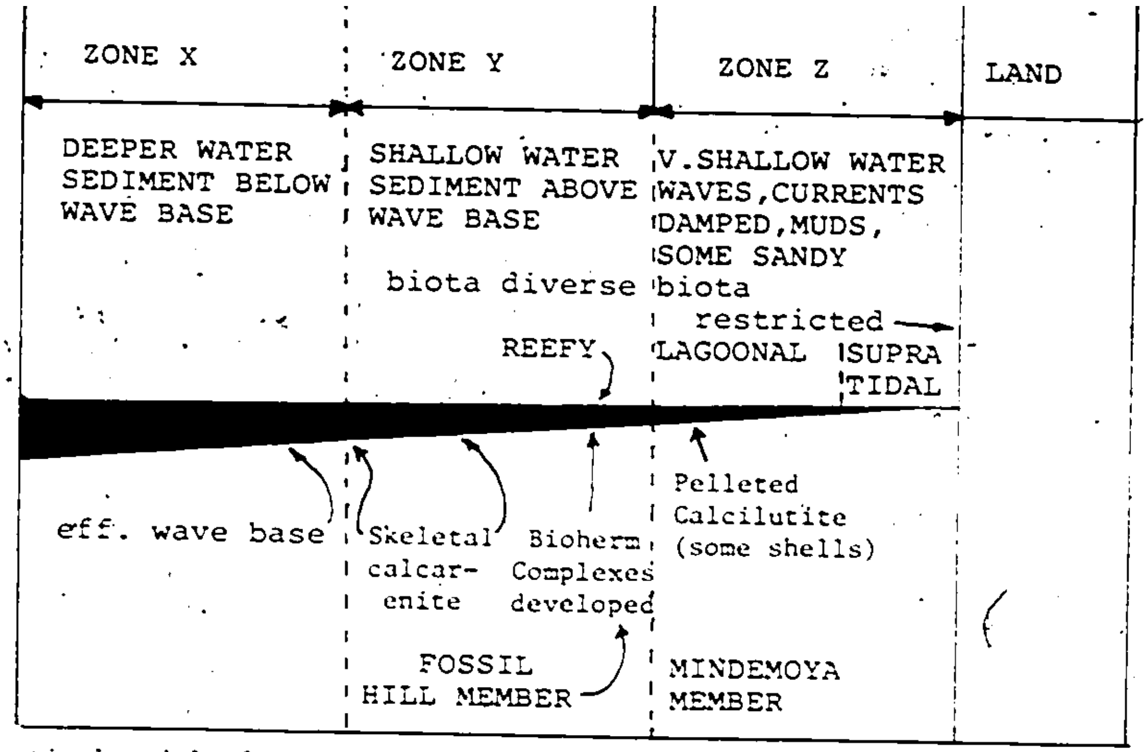
Comparison of Mindemoya, and Fossil Hill Interbiohermal, Facies with Theoretical Model and Modern Example.

The Michigan Basin has been referenced in the literature as the prototype of the intracratonic basin covered by an epeiric sea (Kay, 1947; Sloss, Krumbein and Dapples, 1949). During Middle Silurian time carbonate buildups were prolific on the basin shelf. Wilson (1975), describes these buildups as typifying a sequence of growth stages seen also in other carbonate buildups of Ordovician, Permo-Pennsylvanian and Jurassic ages. Ancient analogues to the Middle Silurian Fossil Hill situation seem fairly common. It is more difficult to find a modern analogue which matches Middle Silurian conditions when an epeiric sea lay across a major cratonic block. The Persian Gulf is the single modern example of a land-locked epicontinental sea basin existing in a sub-tropical carbonate-producing realm (Heckel 1974; Wilson, 1975). Modern reefal complexes are commonly associated with pericontinental seas.

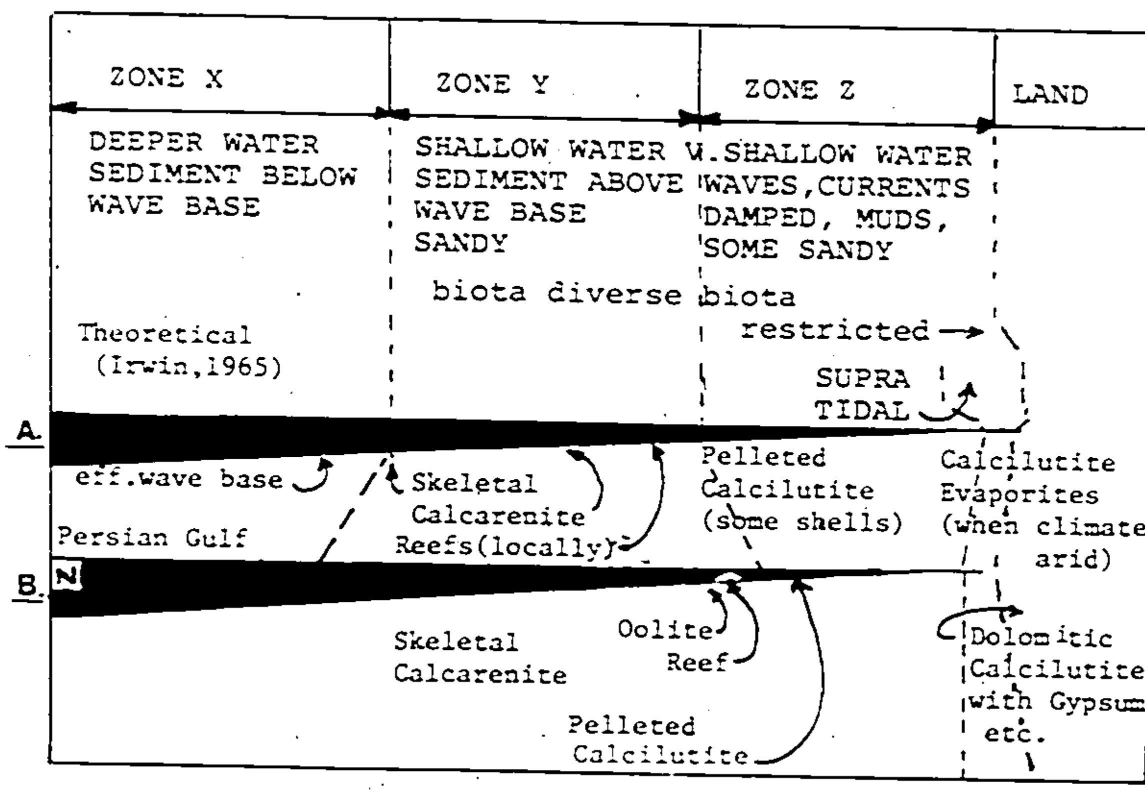
A model for epicontinental clear-water sedimentation has been envisaged by Irwin, (1965). He considers that deposition within a broad, shallow epeiric sea, exhibiting non-detrital clear water sedimentation, results in the development of a distinct and consistent pattern of sedimentary facies. As the depositional slopes would have been gentle, three major zones would have been characterized on the basis of hydrodynamic regime (Fig. 5).

Heckel (1972), has reproduced Irwin's model and he compares the carbonate sedimentation pattern of the Persian Gulf with the model (Fig. 5). In Zone Y of the model, the "Shallow Water Sediment Above Wave Base Zone", reefs are developed. The Persian Gulf also shows reefal development along the shallowest fringe of this zone. The zone is characterized by diverse biota and off-reef skeletal calcarenite, with the addition of glauconite and oolites in the Persian Gulf. The resulting microfacies is a biocalcarenite. Patches of mud are locally developed within the calcarenite.

Shoreward, in the "Shallow-Water, Waves Currents Damped", Zone Z, the energy is low compared with Zone Y. This is a zone of shallow water, largely in the form of lagoons. It is characterized by a restricted biota and the sediment type is a pelleted calcilutite (microfacies



Theoretical model of epicontinental clear water sedimentation (after Irwin 1965) related to rocks of the present study (not to scale).



Model of shallow marine sedimentation showing theoretical and actual distribution of major sediment types (after Heckel 1972)

FIGURE 5

type-calcilutite).

During transgression of the epeiric sea each sedimentation zone migrates shoreward resulting in reef complex sediments overlying the lagoonal sediments. This results in a vertical stratigraphic succession of units. The gross sedimentary features and the distribution of biota of the model and of the Persian Gulf, Zone Y, may be equated with the Fossil Hill environment, and those of Zone Z with the Mindemoya environment.

For Zone Y there is no distinction made between reef and interreef facies (bioherm and interbiohermal), and no mention made of the occurrence of biostromes in the model or in the Persian Gulf. The biota of the model is not discussed. The biota of the Persian Gulf reef area consists of a few genera of corals which can tolerate high salinity and temperature, coralline algae, foraminifera, echinoids and sponges. It is a different, and more restricted biota than that of the Fossil Hill, but one which may be considered functionally comparable as it is composed of framebuilders and suspension feeders.

For Zone Z, the "Shallow Water Zone" of the model and the "nearshore zone" of Heckel (1972), the sediments are described as pelleted calcilutite, and the biota is described as restricted. The Mindemoya facies seems to be generally comparable with these situations.

It is concluded that the model is not specific enough for detailed comparison with the Fossil Hill inter-biohermal environment which comprises only a small area of the shallow water marine sedimentation pattern. The modern example, the Persian Gulf may be used as a general, but not as an explicit analogue.

Chapter VI

Sequence of Replacement Fabrics

A. Dolomitization

The following interpretation of the process of dolomitization, as ascertained by thin section study, is based on the work of Friedman and Sanders (1967), and Textoris and Carozzi (1964).

Dolomitization began with incipient, inclusion-filled dolomite crystals which replaced the original calcite. The resulting dolomite crystals show a variable crystal size and display buff or tan colours. Apparently iron, which was associated with the calcite lattice, was released upon dolomitization and, subsequently, concentrated around the margins of the newly formed dolomite crystals. The included finer-grained bioclasts were dolomitized next. Crinoids which are magnesium-rich were the most resistant to dolomitization and tended to remain as calcite. Some calcite bioclasts dissolved before recrystallization began and formed vugs. This accounts for the dense dolomitized calcisiltite and porous vuggy dolomitized biocalcarenite. The original textures of the carbonate controlled the size of the dolomite crystals. Calcisiltites produced dolomite crystals ranging from 0.02 mm.-0.08 mm. A matrix of finer bioclasts and more permeable mud and grain-supported sediments produced crystals ranging from 0.05 mm. - 0.2mm (Plate 6, figs. 1, 4).

All of the Members of the Lockport Formation have been dolomitized. The dolomitization of the Fossil Hill sediments may, or may not, have been contemporaneous with sedimentation. Wilson (1975), has summarized recent thought on dolomitization associated with platforms carbonates. According to this summary, platforms could have been preferred locations for at least two processes logically causing the replacement of calcite by migrating fluids: (1) density reflux of high Mg/Ca brines from sabka evaporation which could have occurred penecontemporaneously, and (2) movement down a hydrologic gradient of a phraetic water lens mixing with connate water or purely marine water along old coastlines. This is a post-depositional process. Repeated fluctuations of sea level aids either, or both, of these processes.

From their study of Niagaran dolomites of the Great Lakes Area, Liberty and Bolton (1971), reach the conclusion that it is a realistic possibility that circulating solutions produced dolomitization so quickly after deposition of the primary sediments that they should be termed penecontemporaneous dolomite.. If this proves to be so, a similar origin is likely for the Fossil Hill dolomites because they are a part of the widespread Niagaran system. However, the writer would like to comment that the hypothesis for Holocene dolomite formation employing the model of penecontemporaneous sabka dolomitization is applied to supratidal evaporitic areas. The Fossil Hill Member, both in its sediments and in its faunal content, represents completely marine conditions.

F. Dolomitization-Silicification Sequence

Evidence from thin section study of the Fossil Hill cherts suggests that the major episode of silicification preceded dolomitization. Numerous examples of dolomite rhombs, cross-cutting or encroaching on established silica fabrics, can be seen (Plate 5, fig. 3). In general the dolomite-chert boundaries are well-defined. Other writers have studied Niagaran nodular cherts in an effort to establish the dolomitization-silicification sequence. Textoris and Carozzi (1964), state that silicification preceded dolomitization because dolomite rhombs can be seen replacing chert. It is the opinion of Ingles (1963), that, although the preservation of morphologic detail of fossils is very good, suggesting that silicification preceded dolomitization, the evidence is inconclusive. According to Laird (1935), who based his opinion on the observation of silicified rhombohedra of dolomite throughout the matrices of the chert, dolomitization preceded silicification. Careful study of the thin sections of the Fossil Hill cherts failed to reveal similar rhombohedra. Walker (1962), discussing carbonate-chert reversals, gives an explanation of the sequence of events which seems applicable to the Fossil Hill cherts. Euhedral dolomite crystals, although surrounded by chert, show no evidence of penetration by silica; commonly they transect siliceous textures. Such crystals are probably dolomite metacysts that originated by replacing the chert. Where such crystals occur in chert they provide strong evidence that dolomitization followed silicification (Plate 5, fig. 3)

Summary of Diagenesis

General stages of diagenesis appear to have been as follows:

1. Solution or recrystallization of some fossils or fossil fragments.

2. Quartz or chalcedony replacement of some matrices and bioclasts, deposition of void-infilling silica fabrics.

3. Dolomitization of calcite sediments, finer grained bioclasts.

4. Partial to complete dolomitization of some larger bioclasts. Dolomite rhombs may be seen replacing chert or cross-cutting silica fabrics.

5. Dissolution of remaining calcite bioclasts.

6. Dolomite sparry-infilling of vugs formed at stage 5.

Chapter VII

Conclusions

1. A facies control of chert deposition is suggested by the stratigraphical distribution of chert. The inter-biohermal beds are chertified while the associated bioherm and lagoonal facies are relatively chert-free.
2. An early diagenetic origin for chert, before lithification of the carbonate host, is indicated by: (a) interbedding with carbonate host in horizontal bedding planes, (b) irregular shapes of chert bodies, (c) presence of well preserved microorganisms in the cherts, and (d) unreplaced calcite in bioclasts within nodules.
3. The source of silica is principally organic from siliceous sponge remains in the sedimentary environment.
4. Nodular chert indicates concentrations of silica at particular sites in the sediments. As organic materials were centres of silicification, the random occurrences and concentrations of organic matter is a controlling factor in nodule distribution. The irregular shapes of chert bodies suggests their growth by accretion.
5. The triggering device in chert emplacement is pH change

in pore water due to release of CO_2 by bacterial oxidation of organic matter.

6. The mechanism for emplacement is the establishment of diffusion gradients between microenvironments. $CaCO_3$ is dissolved and SiO_2 is precipitated and they respectively diffuse, away from and toward, sites of organic decay.

7. The time and mode of replacement of the carbonate by silica are elucidated by the recognition of void-infilling and replacement silica fabrics in chert nodules.

8. Silicification precedes dolomitization.

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EXPLANATION OF PLATES

Plate 1

Photomicrographs of fossiliferous cherts.

Fig. 1. - Microdrusy chalcedony (CH) fringes void-
(L359) infilling areas of drusy quartz mosaic (DQ). Crystal size of quartz increases toward the centre. Top right shows intermediate crystallization between chalcedony and quartz. Crossed polarizers, X 12.

Fig. 2. - Microdrusy chalcedony (CH) fringes drusy quartz
(L359) mosaic (DQ). Composite void-infilling fabric. Microcrystalline quartz matrix top centre (M). Plane-polarized light X 12.

Fig. 3. - Replacement quartz in bryozoan fragment (BR),
(L368) and in syntaxial rims (Q) of crinoid fragments (CR), is coarser-grained than matrix of microcrystalline quartz (M). This makes bioclasts conspicuous in thin sections. Crossed polarizers, X 20.

Fig. 4. - Spherulitic chalcedony (SC) replaces small bio-
(L371) clasts. Crossed polarizers, X 12.

Plate 2

Photomicrographs of fossiliferous cherts.

Fig. 1. - Pseudodrusy quartz mosaic (PQ) replaces
(1371) recrystallized sponge spicules. Small elongate quartz crystals rim the shell oriented with their c-axes normal to shell surface (Q). Spicules replaced by quartz also seen in cross-section. Matrix is micro-crystalline quartz. Crossed polarizers, X 50.

Fig. 2. - Brachiopod shell fragment showing quartz replace-
(1363) ment of laminated calcite fabric (L). Silica pseudomorphs original fibrous structure. Matrix is dolomite (D). Crossed polarizers, X 12.

Fig. 3. - Quartz replacement of the laminated calcite
(1360) fabric of brachiopod shell fragment (L). Quartz has also pseudomorphed prismatic fabric of inner shell layer (P). Matrix (M) of microcrystalline quartz is replaced micrite. Dolomitization after silicification forms matrix of dolomite crystals (D) outside shell. Dolomite rhombs (R) cross-cut silica fabric. Crossed polarizers, X 12.

Fig. 4. - Spiculite. Sponge spicules replaced, or
(1371) infilled by quartz. Some of the spicules

exhibit mud-filled interiors in longitudinal and cross-section. Crossed polarizers, X 12.

Plate 3

Photomicrographs of fossiliferous cherts.

Fig. 1. - Original stromatoporoid-constructed limestone (L368) has been replaced by silica fabrics. Laminae and interlamellar pillars consist of anhedral quartz crystals (Q). The former voids are filled with chalcedony and larger quartz crystals. Crossed polarizers, X 12.

Fig. 2. - As Fig. 1, but Plane-polarized light.

Fig. 3. - Spores and acritarchs (AC) in cryptocrystalline (L359) quartz matrix (CM). Plane polarized light, x 125.

Fig. 4. - Microfacies shows Sphaerocodium-like algal balls (L359) (A) in matrix of microcrystalline quartz (M). Associated composite void-infilling fabric is of chalcedony and an intermediate stage in crystallization of quartz between chalcedony and quartz (IS). Crossed polarizers, x 12.

Fig. 5. - Clotted microfabric of algal material and

(L359) recrystallized micrite (CL). Crossed polarizers, x 12.

Fig. 6. - Microfacies shows algal laminae which grade (L361) into discontinuous streaks of pellet-like bodies (A). Associated is composite void-infilling silica fabric (V), x 12.

Plate 4

Photomicrographs of acritarchs

All figures X 400.

Representative acritarch microflora recovered from Fossil Hill chert nodules.

Plate 5

Photomicrographs of fossiliferous chert.

Fig. 1. - Organic matter (C) intercalated with silica (L361) fabrics. This association is commin in the cherts. Crossed polarizers, x 12.

Fig. 2. - Spiculite. Cross-sections of sponge spicules. (L371) Matrix is replacement microcrystalline quartz (M). Interiors of spicules replaced by pseudo-drusy quartz mosaic (PQ). Walls replaced by acicular quartz crystals (Q). Crossed polarizers, x 50.

Fig. 3. - Replacement dolomite rhombs (R) cross-cutting (L360) the silica fabric of a brachiopod shell pseudo-

morphed by quartz (Q). Small elongate crystals of replacement quartz (Q) rim the shell fragment. Crossed polarizers, x 20.

Fig. 4. - Brachiopod shell fragment (B) and recrystallized (I359) sponge spicules (S) of quartz in a matrix of microcrystalline quartz (M). Crossed polarizers, x 12.

Fig. 5. - Photomicrograph of crinoid plate in a chert nodule. It contains unreplaced calcite (C). Matrix of nodule is microcrystalline quartz (M). Crossed polarizers, x 12.

Plate 6

Photomicrographs of associated dolomites.

Fig. 1. - Matrix shows contact between chert and dolomite. (I364) Dolomite (D) appears light in the centre and at top of the photo. Quartz crystals (Q) in a band above dolomite and in bottom ½ of photo appear darker. Microfacies may have been originally interbedded calcilutite and calcisiltite. Crossed polarizers, X 12.

Fig. 2. - Matrix of very find crystalline dolomite of (I369) Mindemoya Member, X 12.

Fig. 3. - Ghost of laminated shell fabric preserved as (I360) calcite inclusions in shell replaced by silica before dolomitization. Dark spots are ferruginous material. Plane-polarized light, X 12.

Fig. 4. - Matrix of very coarse dolomite crystals which
(1366) are anhedral to subhedral and full of inclusions. (1). There are no silica fabrics or fossil remains in this dolomite. It may represent the most advanced stage of dolomitization. Crossed polarizers, X 12.

Plate 7

Photograph of 2' section of Fossil Hill Member, Lockport Formation. Location 365 western Manitoulin Island. Bedded dolomite (D) with chert (CT) nodules and lenses. Note concentration of nodules along particular bedding planes and differential compaction effects.

Plate 8

Photograph of chert lens about 1' thick in Fossil Hill dolomite. Location 359, Elizabeth Bay, Manitoulin Island. Carbonaceous matter enclosed in chert gives mottled appearance. Pentamerid brachiopod (B) lies across junction of chert (CT) and dolomite (D). Stromatoporoid (ST) overlies chert.

Plate 9

Photographs of Lockport Dolomite

Fig. 1. - Mindemoya (MI), and Fossil Hill (FH), Members,

Lockport Formation, location L369.

Fig. 2. - Fossil Hill Member, Lockport Formation, location L368.

Fig. 3. - Fossil Hill Member, Lockport Formation, location L365.

Fig. 4. - Close-up view of chert (CT), in Fossil Hill dolomite, location L368.

Plate 10

Photograph of the brachiopod *Pentamerus oblongus* accumulated along a bedding plane in the Fossil Hill dolomite. Location L362.

PLATE 1

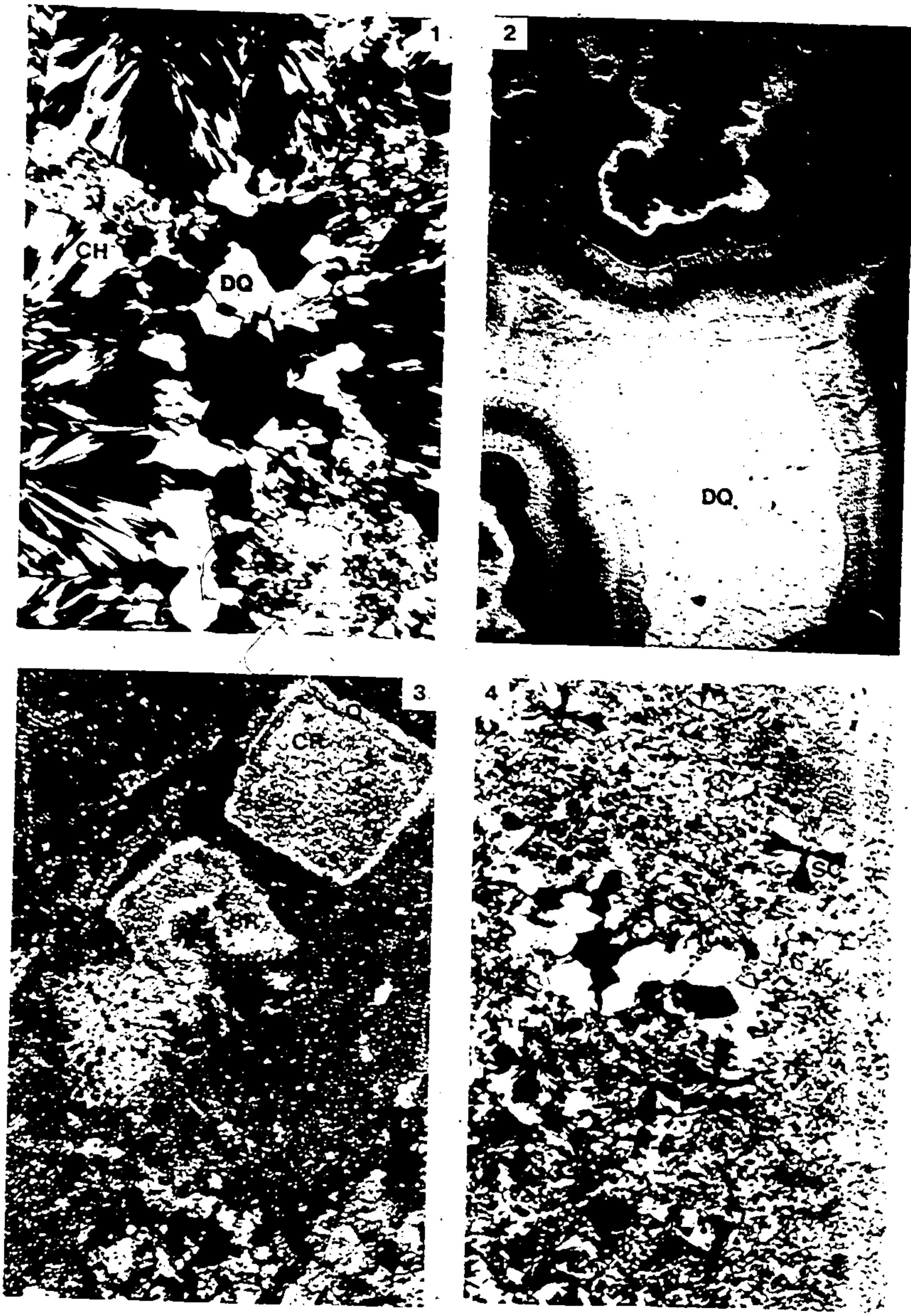


PLATE 2

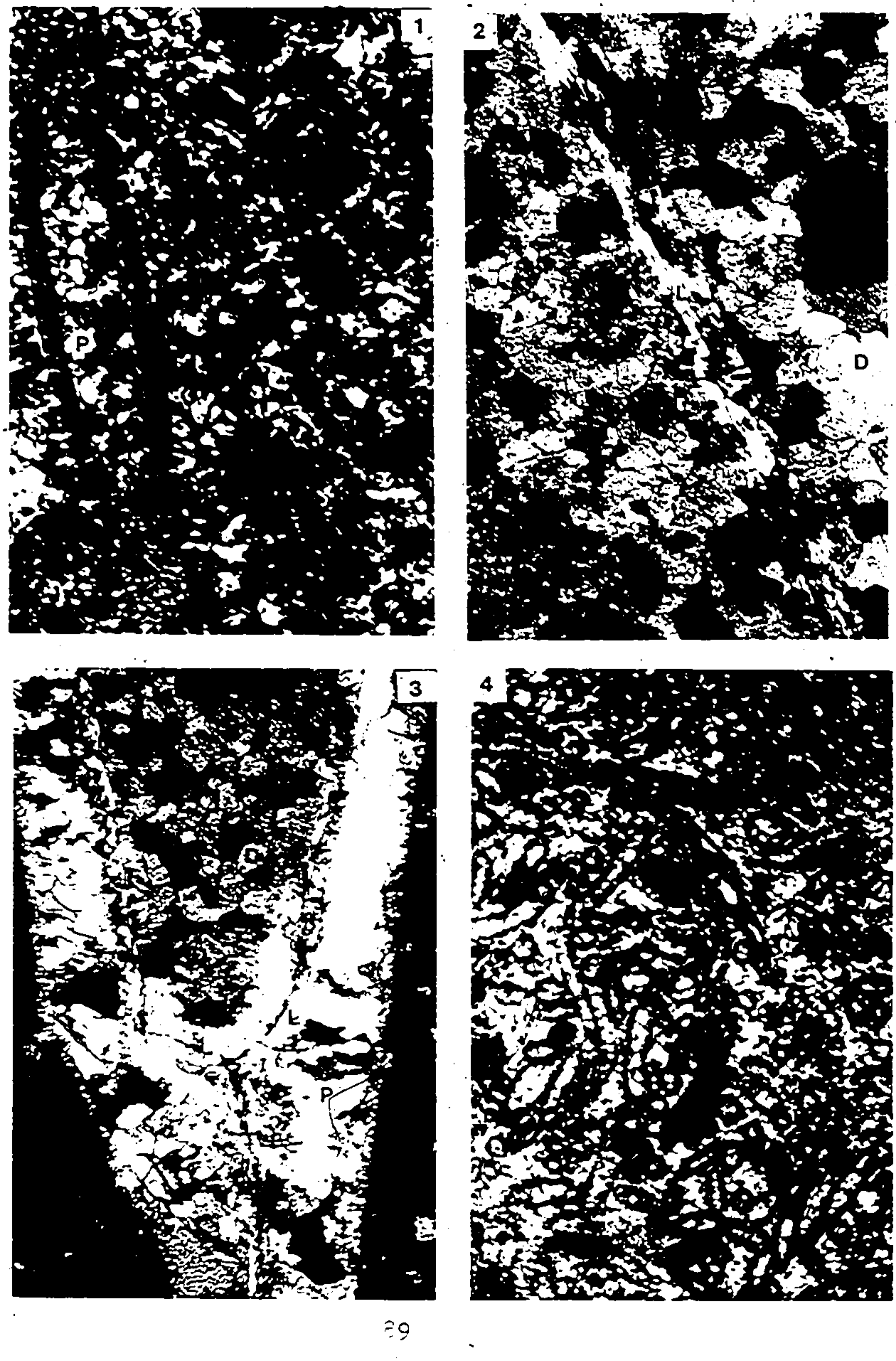


PLATE 3

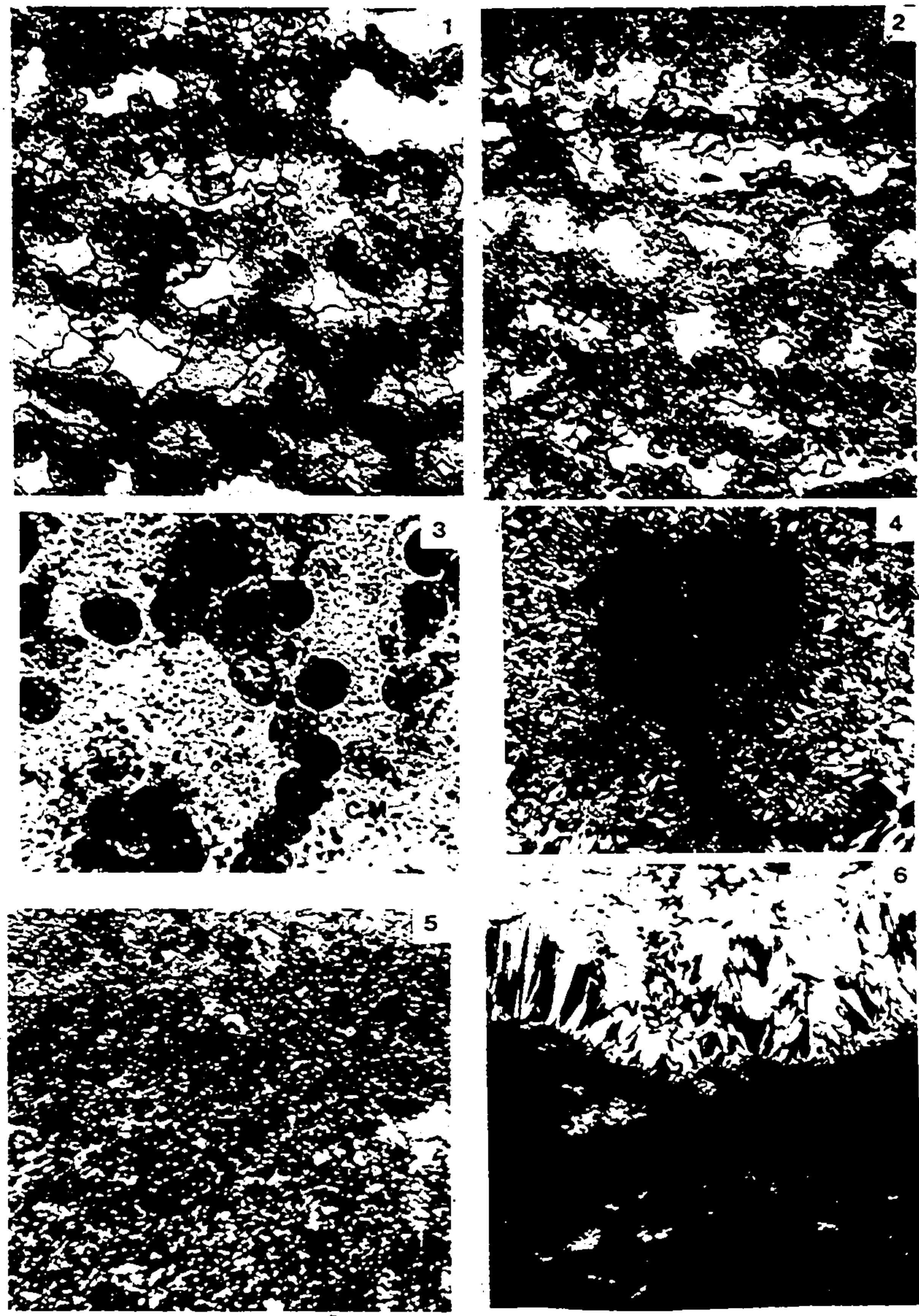


PLATE 4

PLATE 5

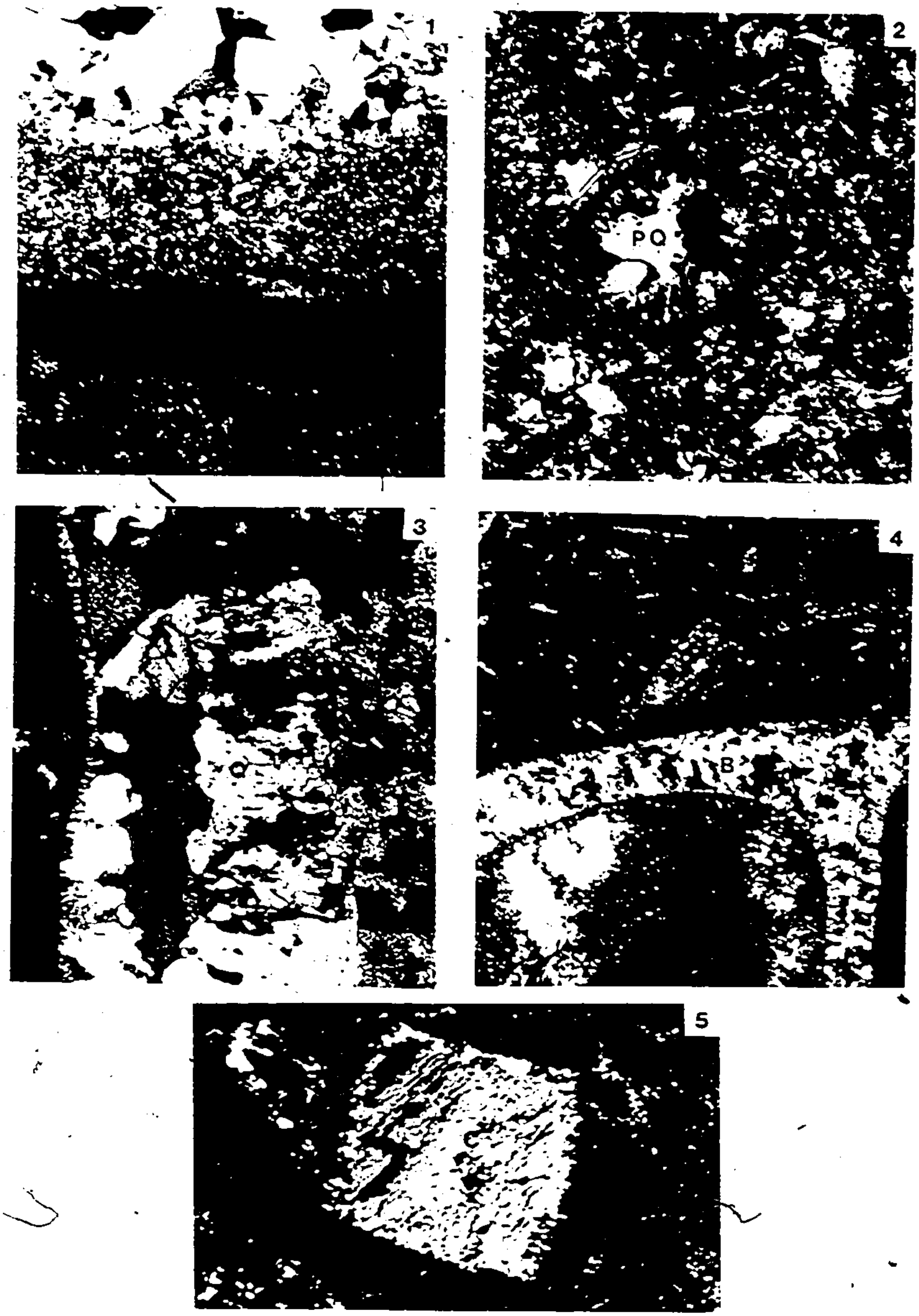


PLATE 6

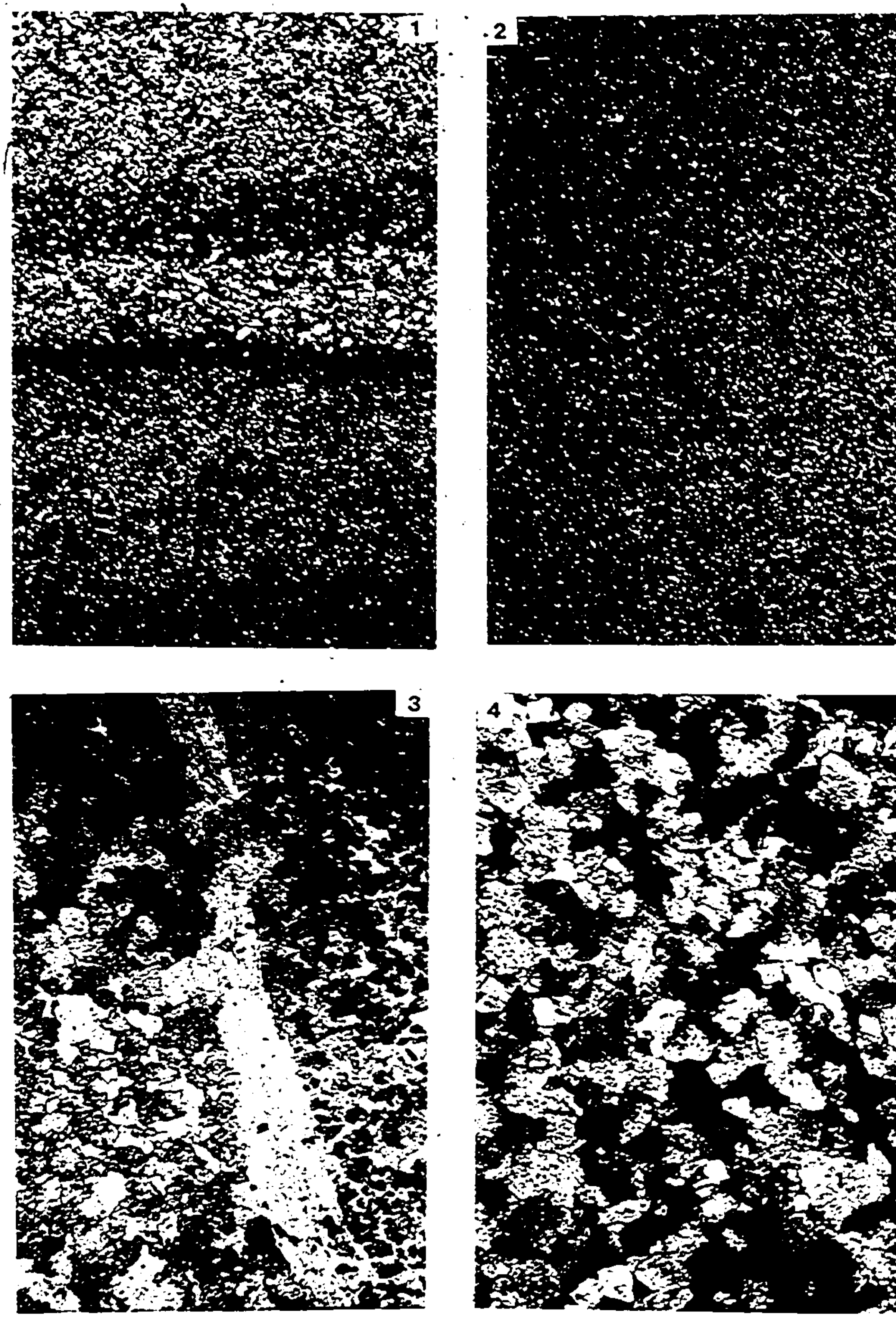


PLATE 7

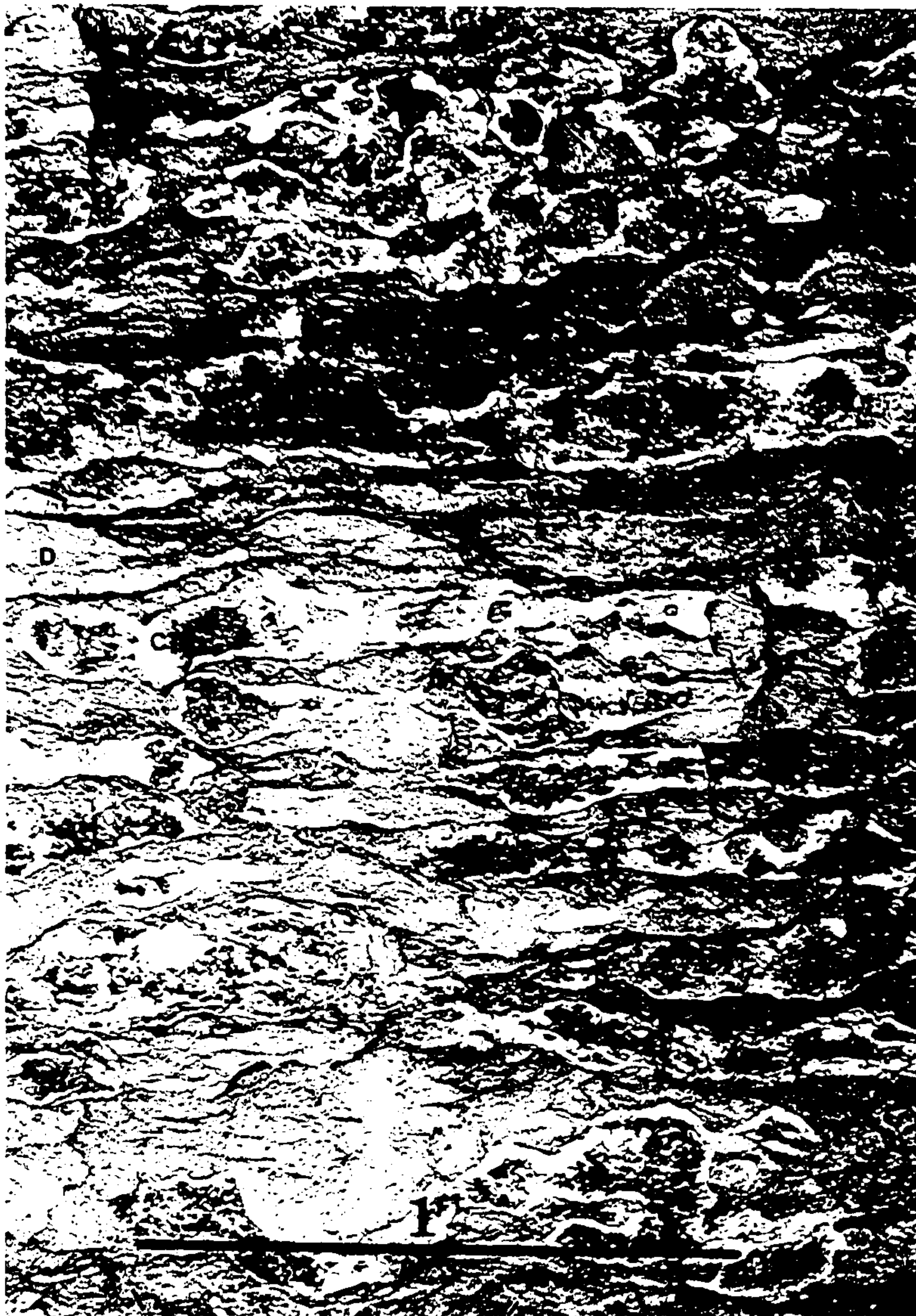


PLATE 8

PLATE 9

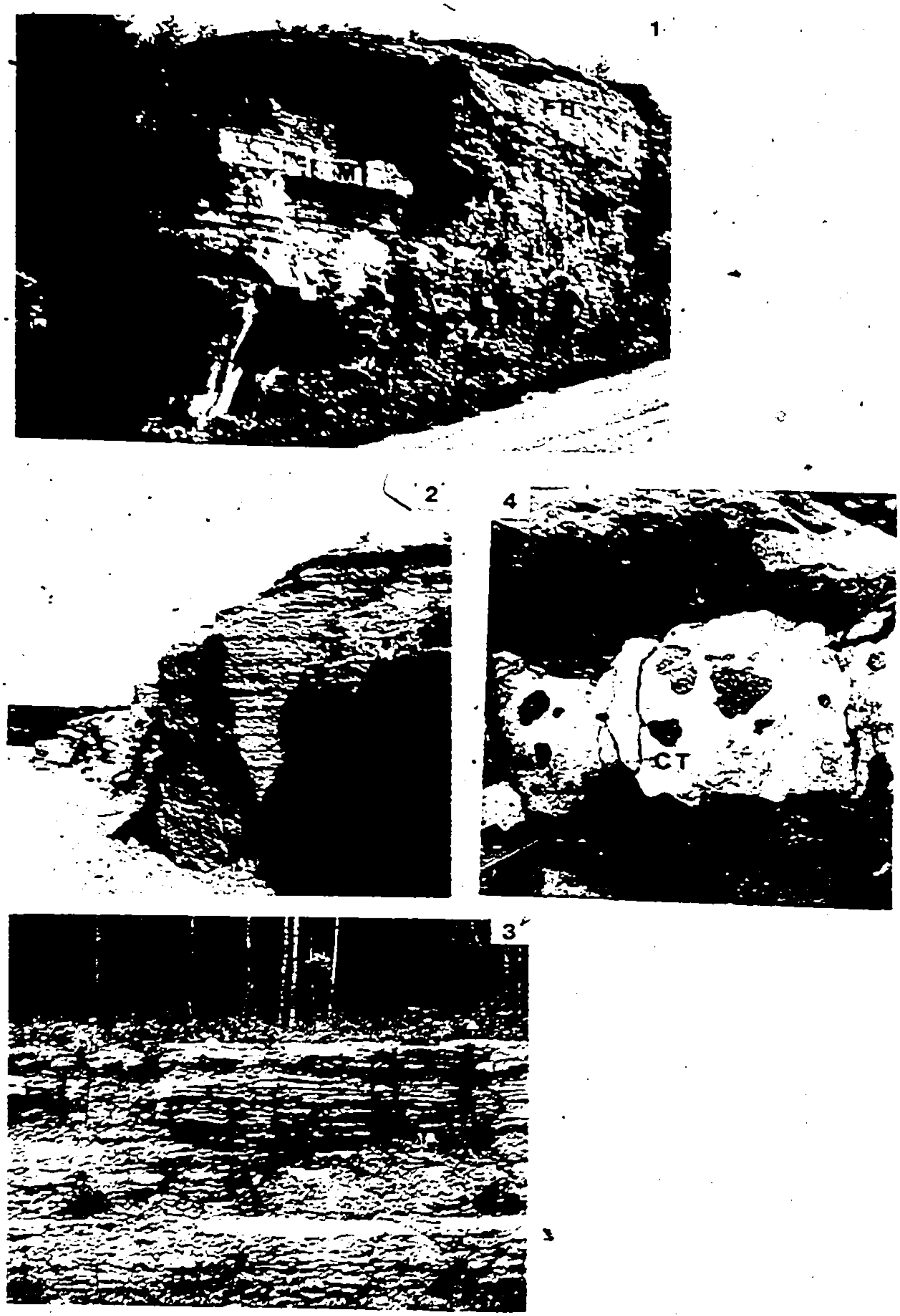


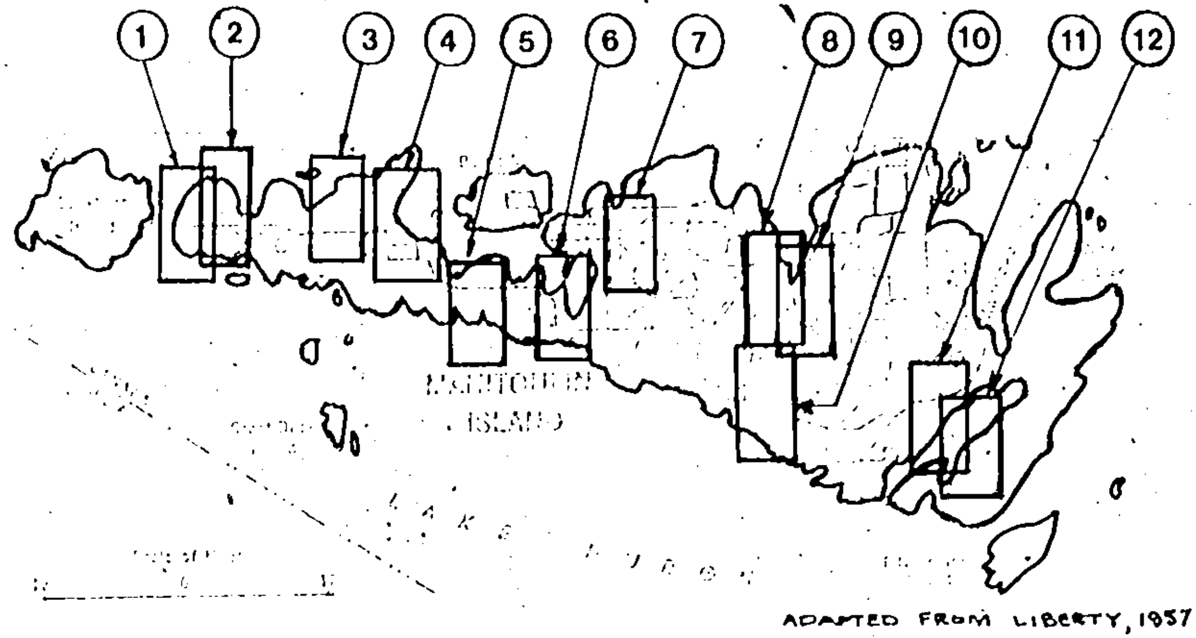
PLATE 10

Appendix I

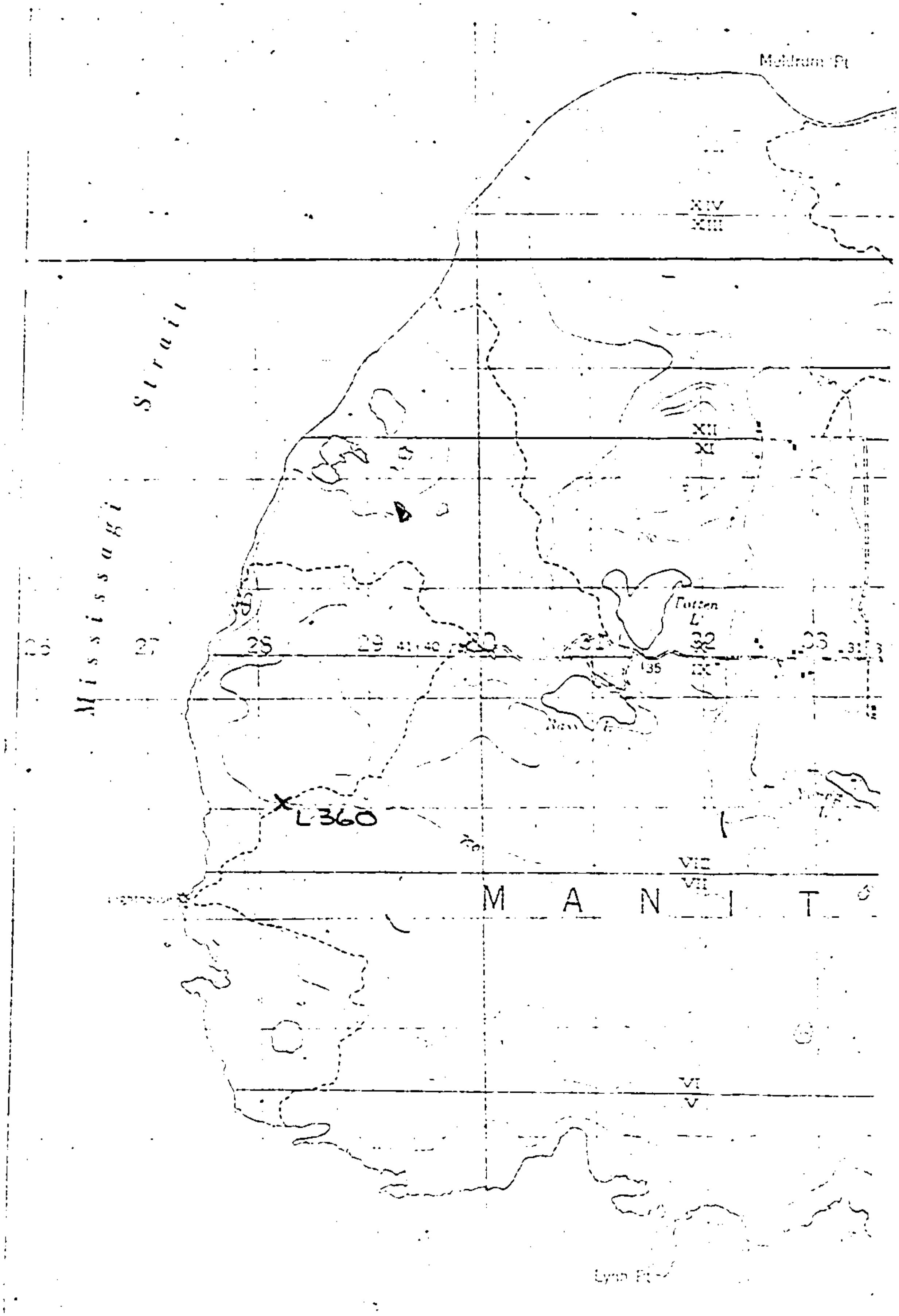
Collecting Localities

National Topographic Series, District of Manitoulin

1. N.T.S., Meldrum Bay, 41G/14 East Half (A), L360.
2. N.T.S., Meldrum Bay, 41G/14 East Half (B), L366.
3. N.T.S., Silver Water, 41G/15 West Half (B), L364, L358.
4. N.T.S., Silver Water, 41G/15 West Half (A), L365, L363, L359.
5. N.T.S., Silver Water, 41G/15 East Half (A), L362, L361.
6. N.T.S., Silver Water 41G/15 East Half (B), L372, L369.
7. N.T.S., Kagawong 41G/16 West Half, L375.
8. N.T.S., Kagawong 41G/16 East Half (A), L374.
9. N.T.S., Kagawong 41G/16 East Half (B), High Hill.
10. N.T.S., Providence Bay 41G/9 East Half, L373.
11. N.T.S., Manitowaning 41G/12 West Half L368, Hilly Grove.
12. N.T.S., Manitowaning 41G/12 West Half, L371.

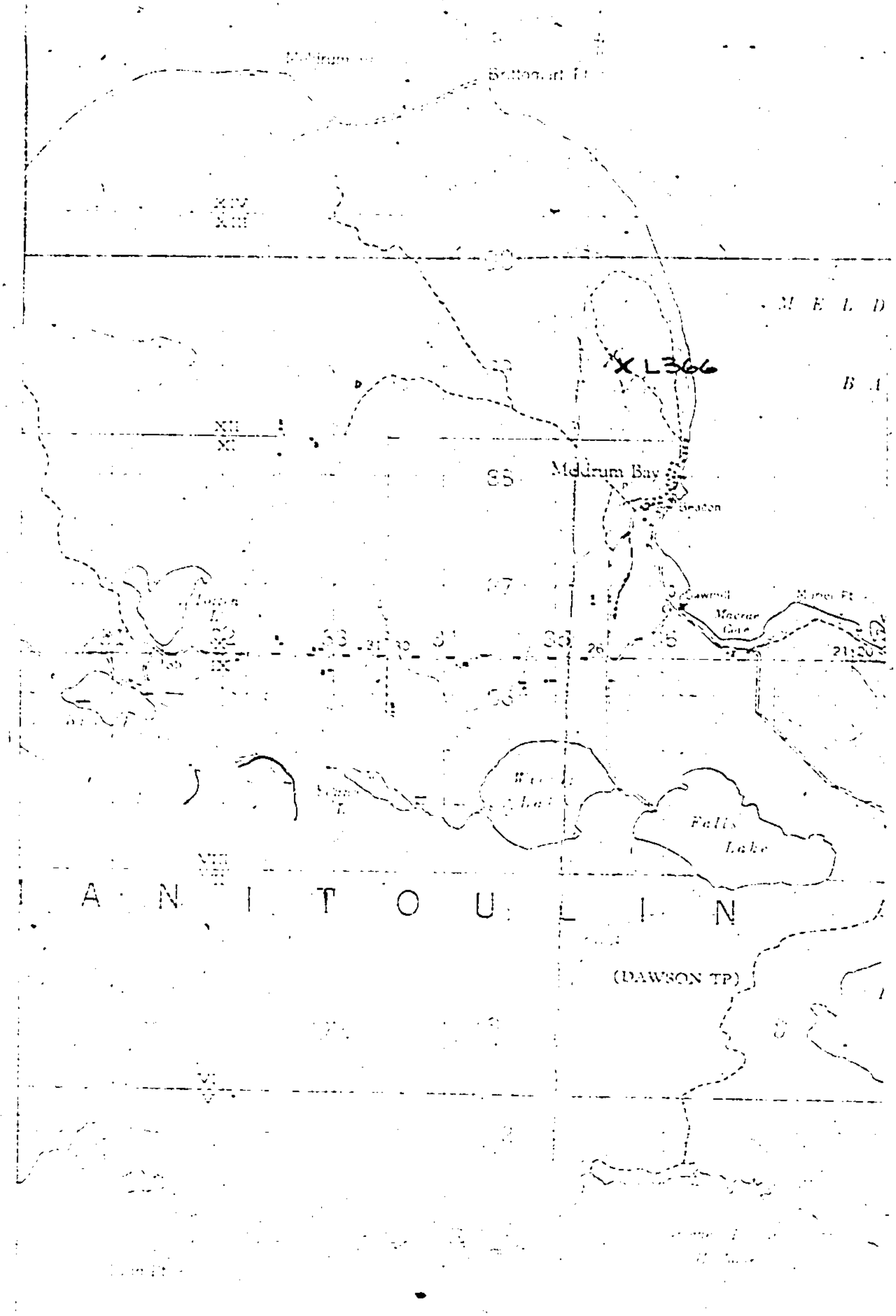


MAP KEY FOR N.T.S. SHEETS APPENDIX I



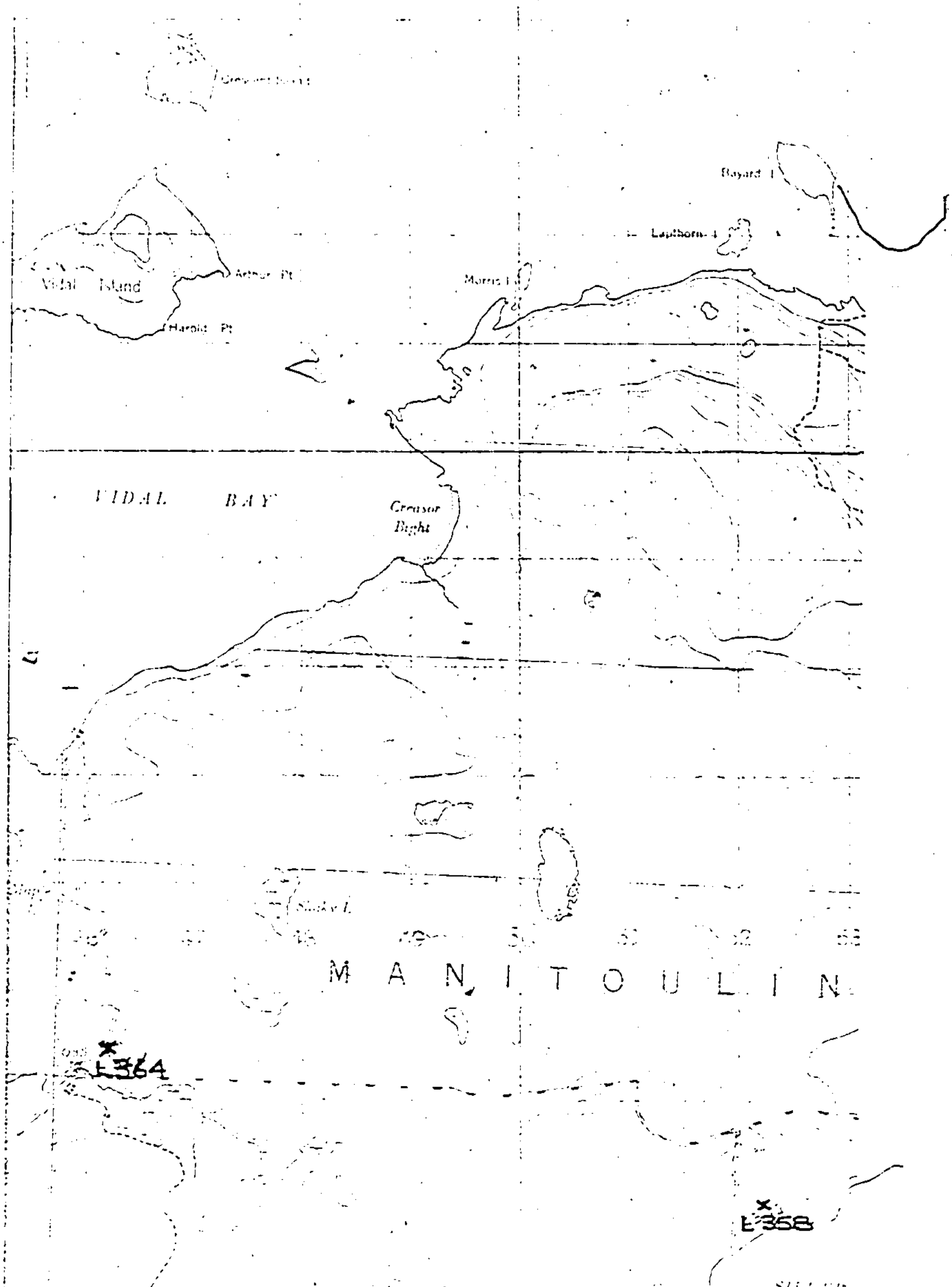
1. N.T.S. MELDRUM BAY 41G14 EAST HALF (A)

Light copy



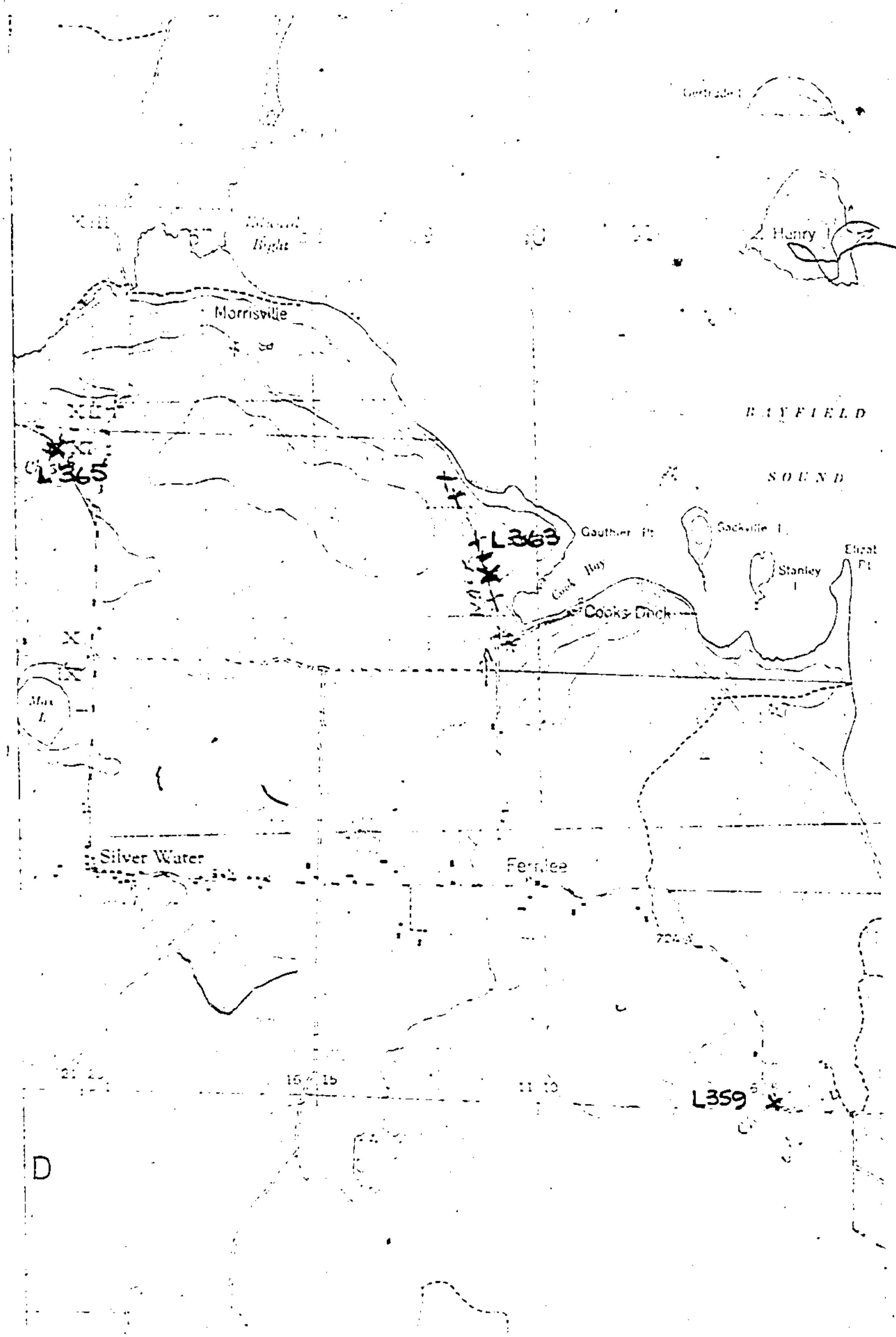
2. N.T.S. MELDRUM BAY 41G14 EAST HALF (B)

Light copy



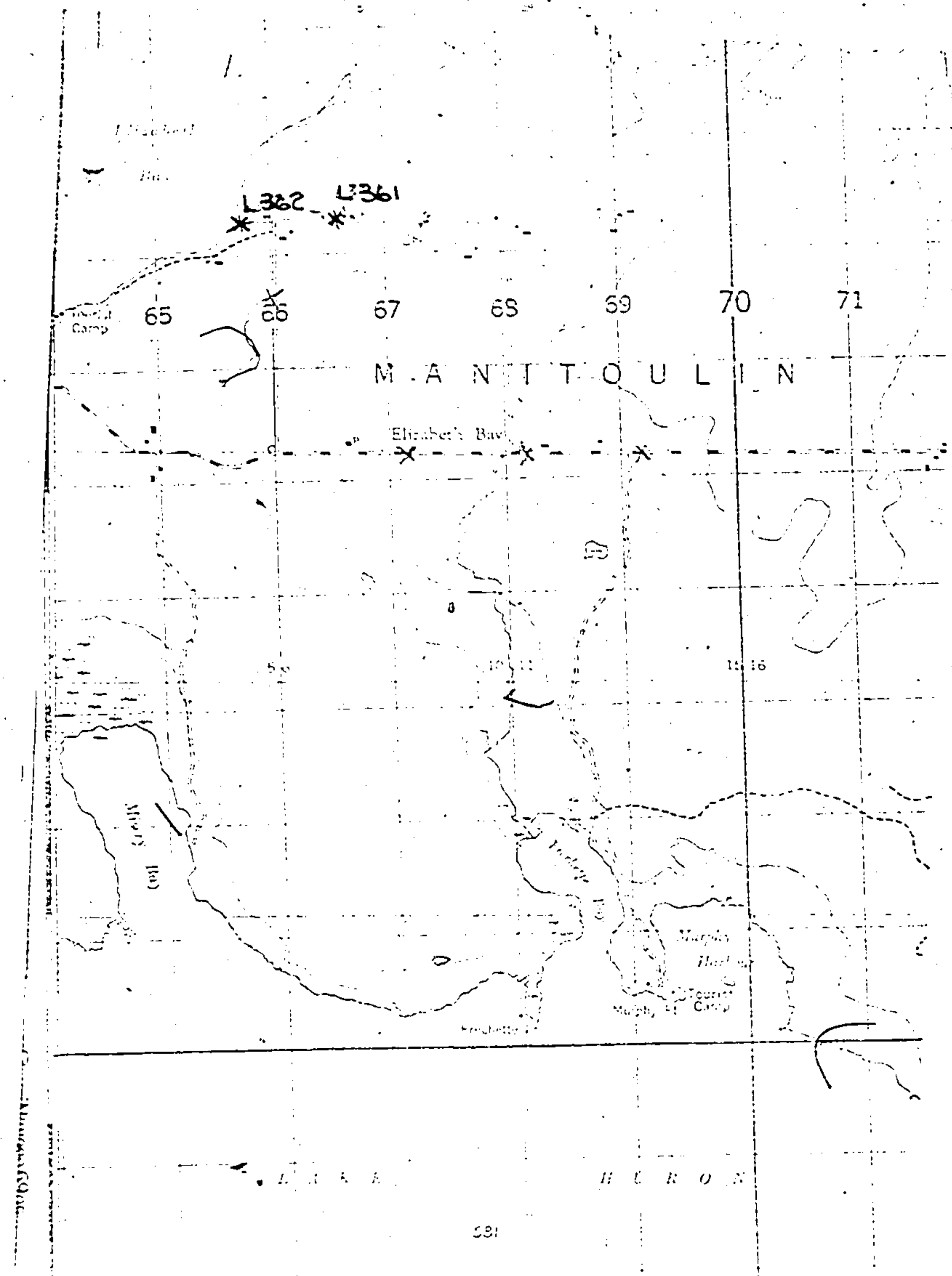
3. N.T.S. SILVERWATER 41G15 WEST HALF (8)

Light copy



4.N.T.S. SILVERWATER 41G15 WEST HALF (A)

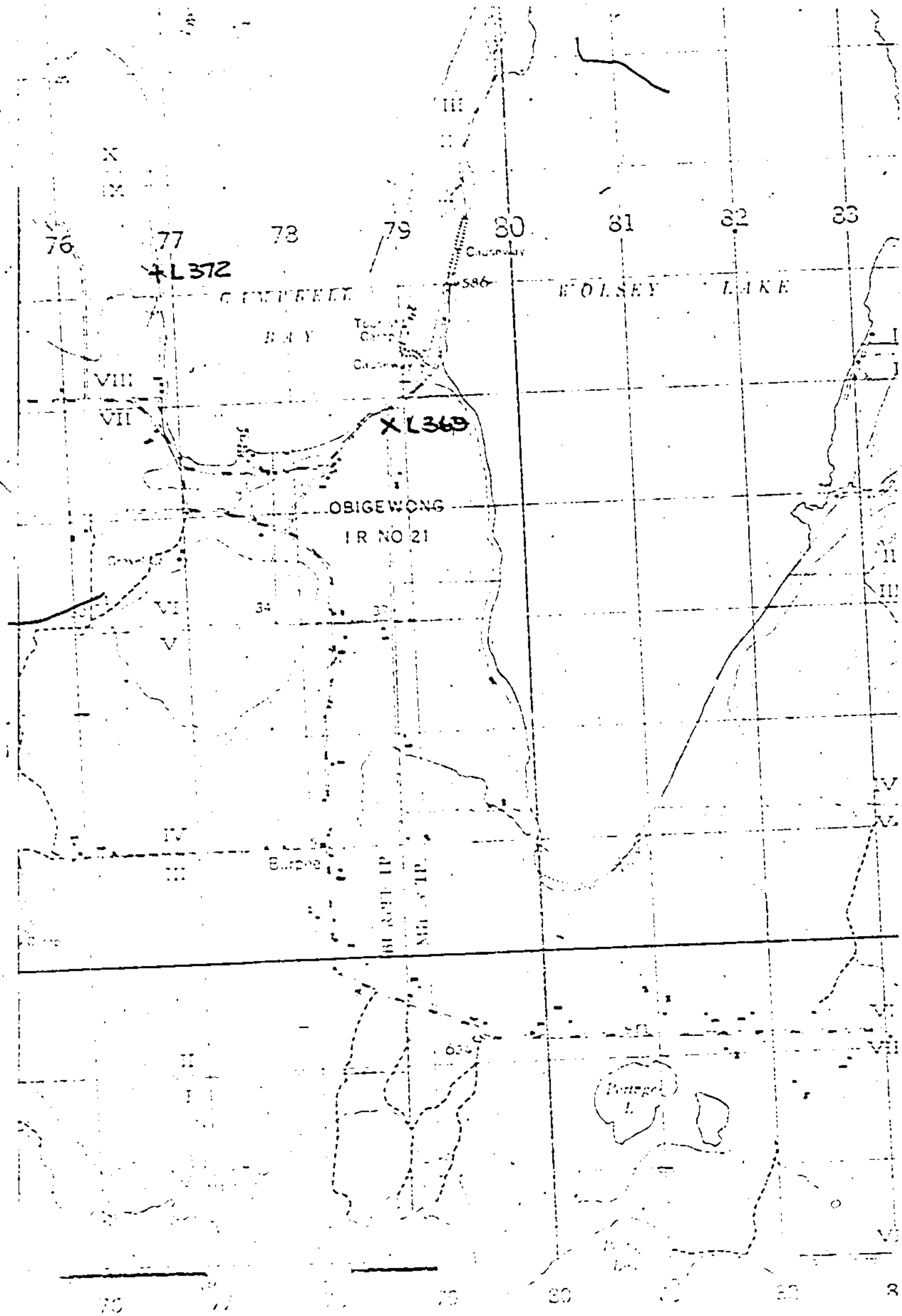
Light copy



5. N.T.S. SILVERWATER 41G15 EAST HALF (A)

365000m E. 66 67 68 69 70 71

Light copy



6. N.T.S. SILVERWATER 41G15 EAST HALF (B)

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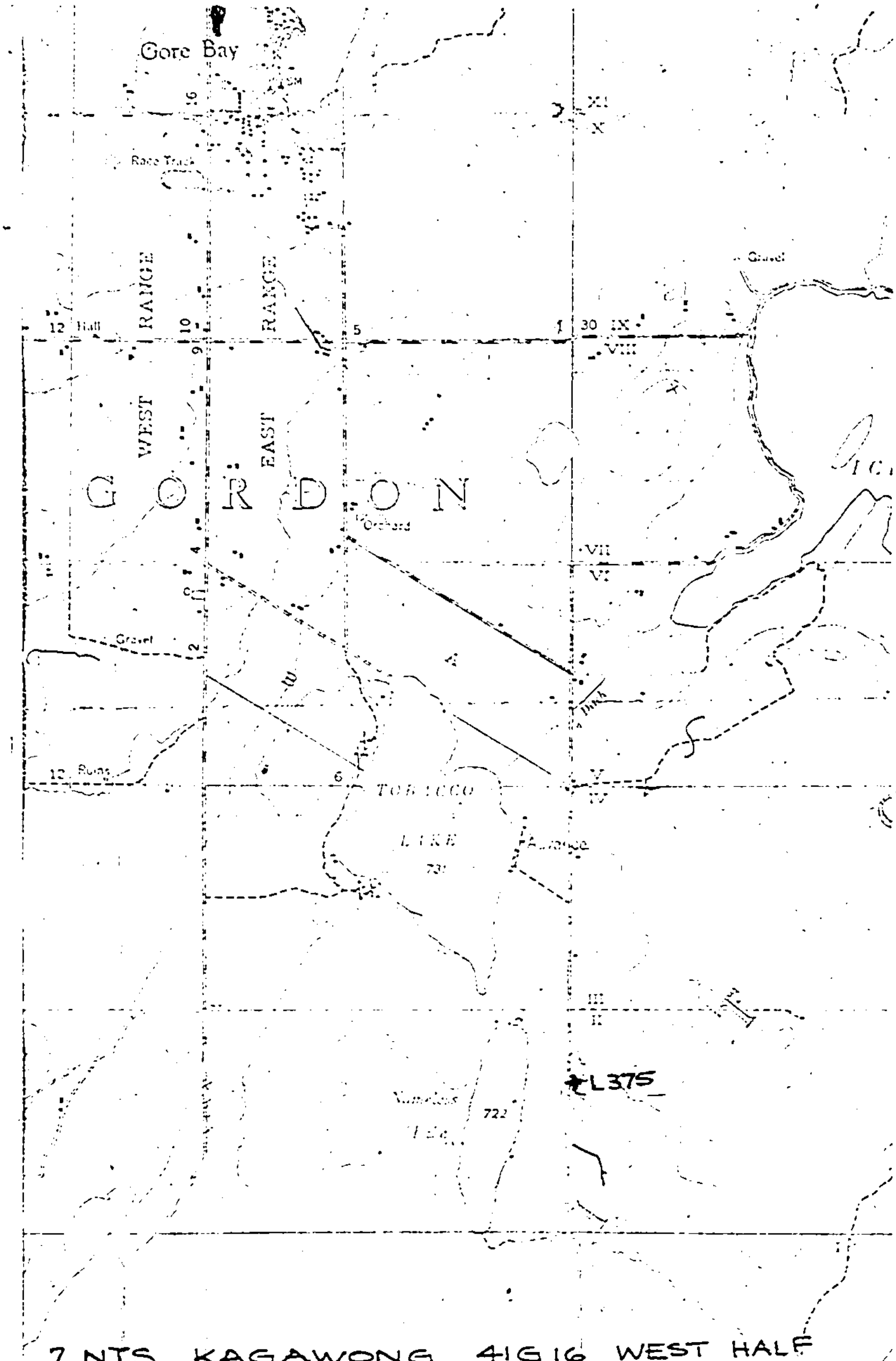
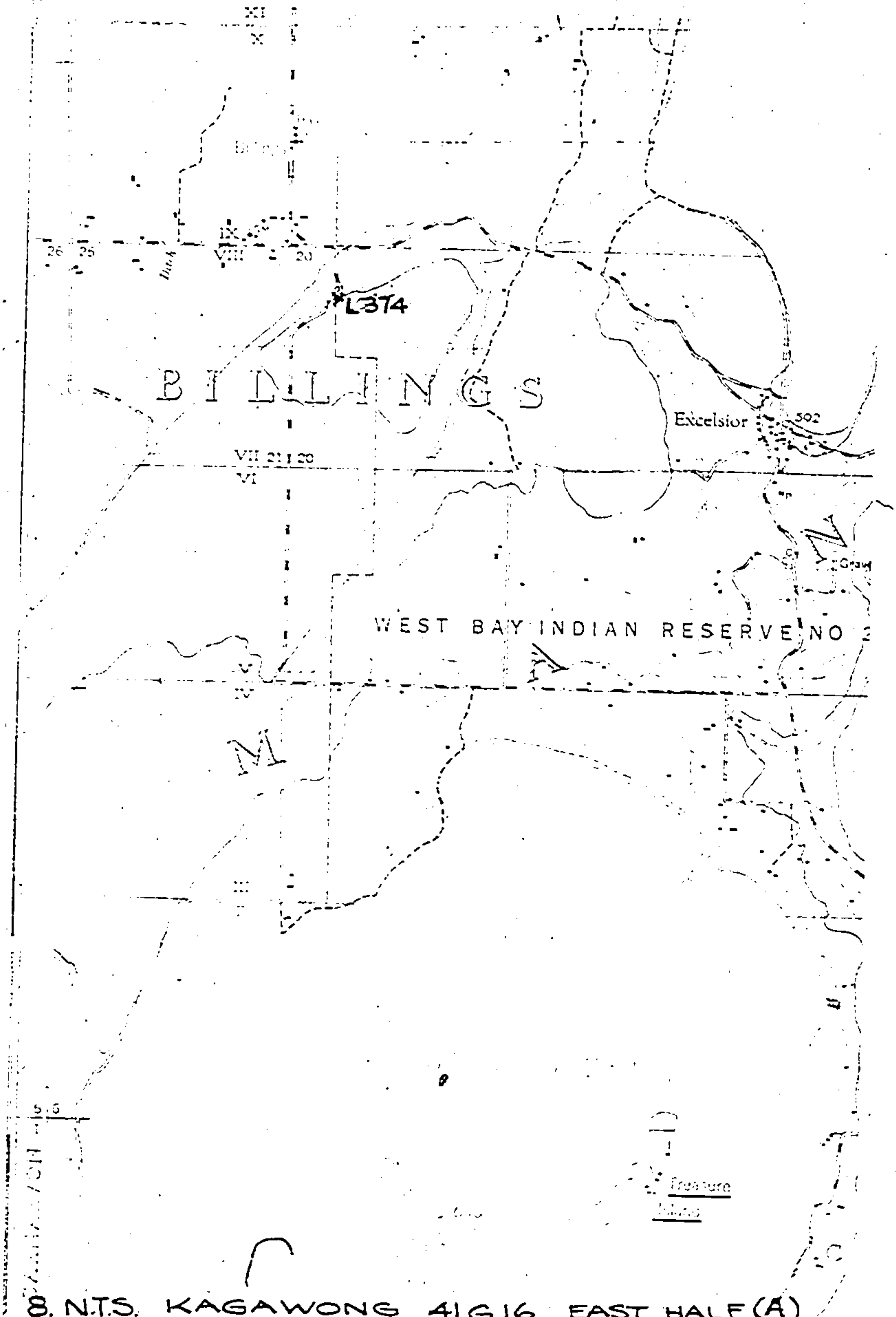


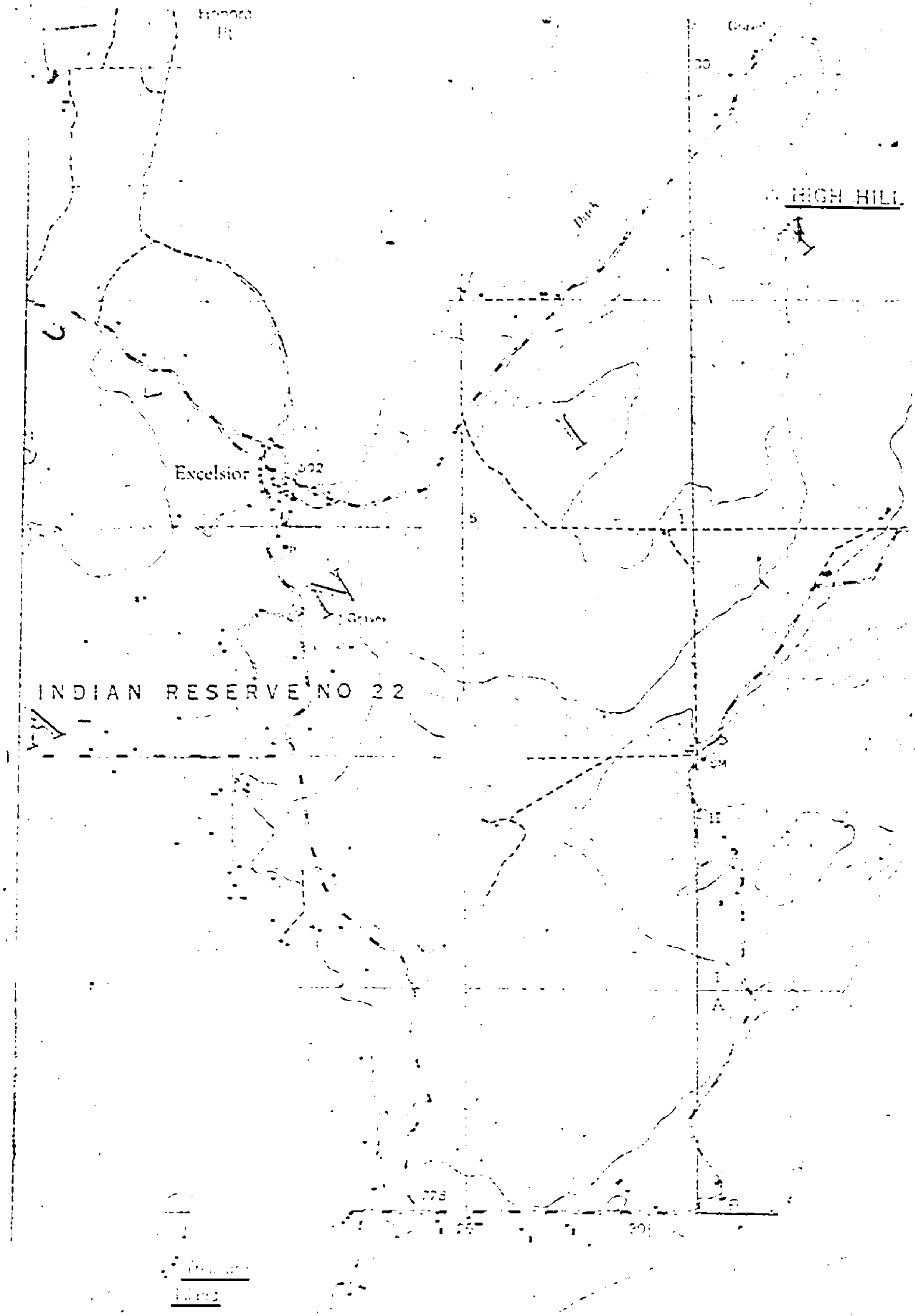
7. N.T.S. KAGAWONG 41G16 WEST HALF

Light copy



8. N.T.S. KAGAWONG 41 G 16 EAST HALF (A)

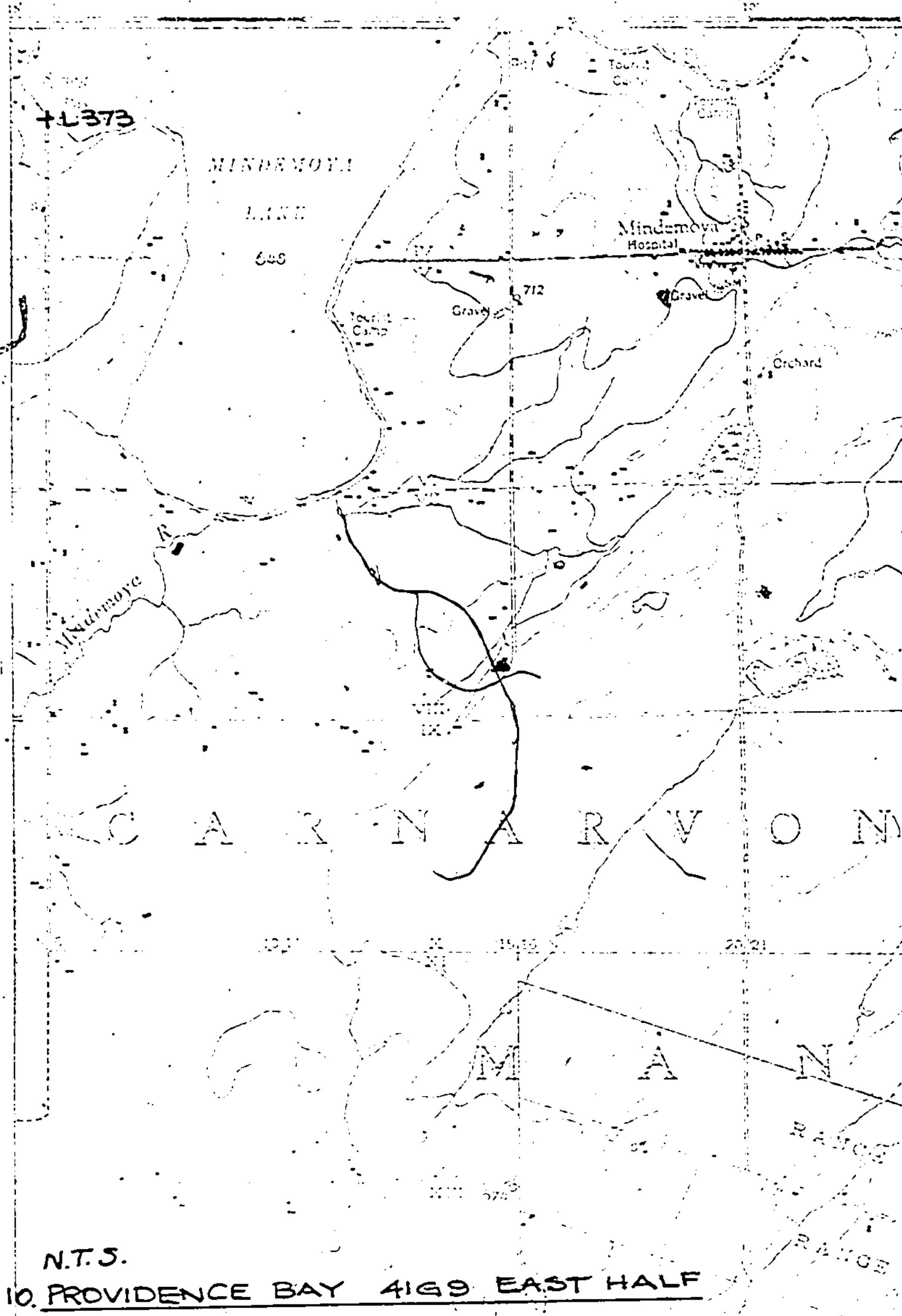
Light copy



9. N.T.S. KAGAWONG 41G16 EAST HALF (B)

Light copy

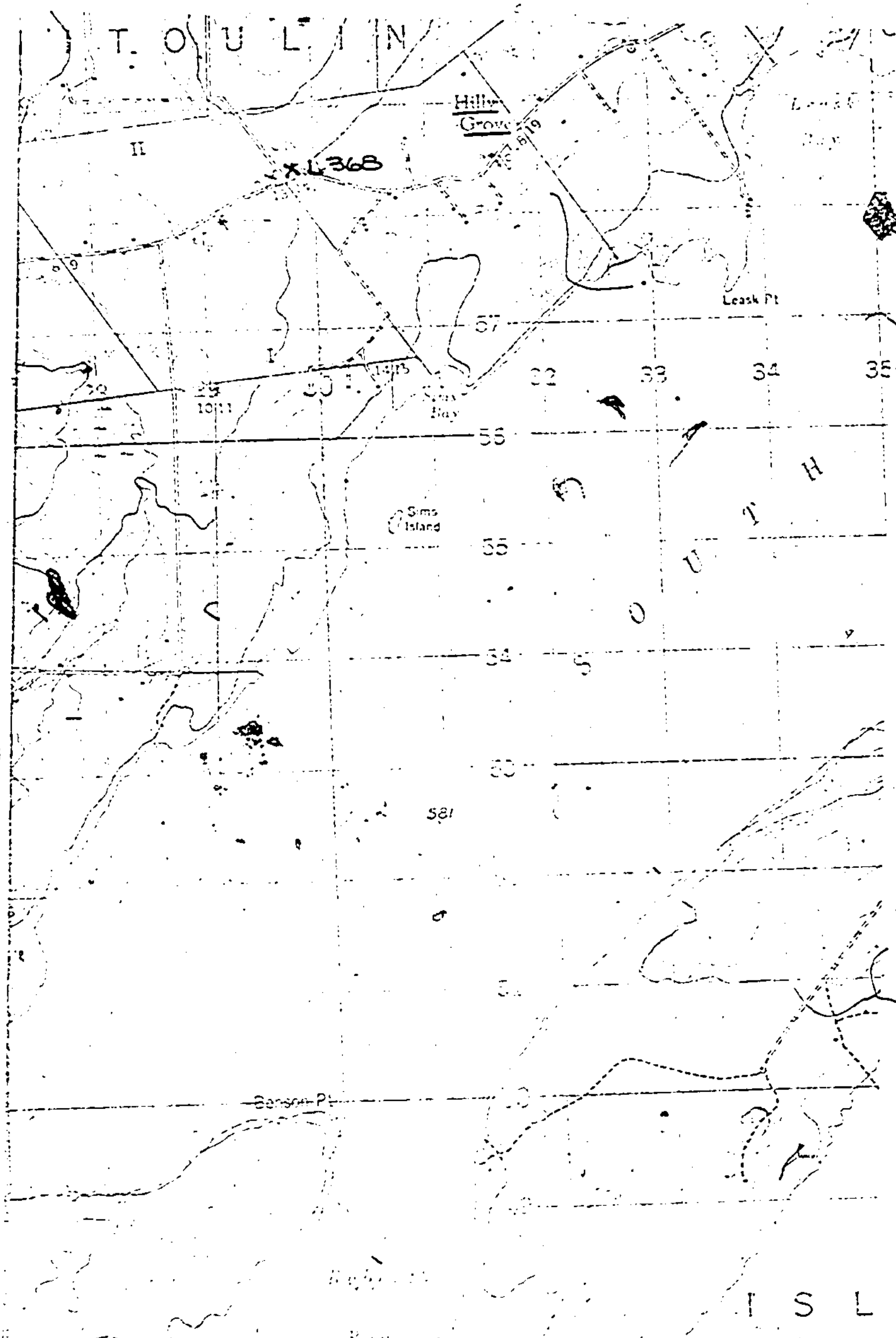
NATIONAL TOPOGRAPHIC SERIES 1:50,000



N.T.S.

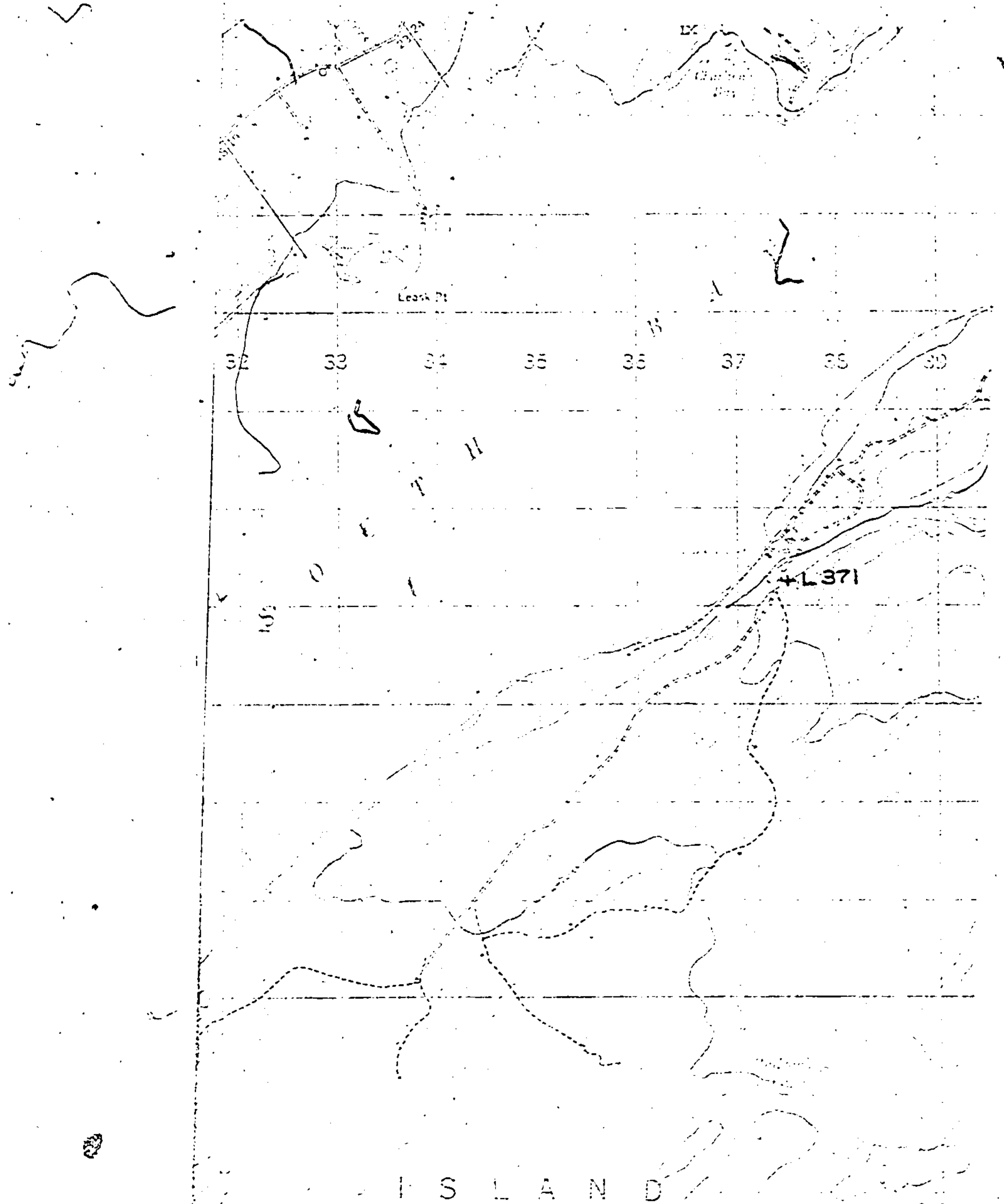
10. PROVIDENCE BAY 41G9 EAST HALF

Light copy



11. NTS. MANITOWANING 41H12. WEST HALF (A)

Light copy



12. N.T.S. MANITOWANING 41 H 12 WEST HALF (B)

Light copy!

Appendix II

Glossary of Terms

Terms used in the description of carbonates are in the sense of Folk, (1959).

Terms used to describe silica fabrics are in the sense of Orme, (1974).

The following terms are in the sense of Carozzi and Textorus, (1967):

microcrystalline: Crystals less than 0.01 mm, and used to describe interlocking or granular-appearing textures.

finely crystalline: Crystals between 0.1 and 0.01 mm, and used to describe an interlocking texture.

medium crystalline: Crystals between 0.2 and 0.1 mm, and used to describe an interlocking texture.

coarsely crystalline: Crystals larger than 0.2 mm, and used to describe an interlocking texture.

The following terms are in the sense of Bissell and Chilingar, (1967).

bank: an _in situ_ skeletal limestone deposit formed by organisms which do not have the ecological potential to erect a rigid, wave-resistant structure.

bioherm: an organic reef or mound built by corals, stromatoporoids, gastropods, echinoderms, Foraminifera, pelecypods, brachiopods, algae, and other organisms. It is a reef, bank, or mound that is reeflike, moundlike, lenslike or an otherwise circumscribed structure of strictly organic origin, embedded in rocks of different lithology.

biostrome: a term for stratiform deposits, such as shell beds, crinoid beds, and coral beds, consisting of, and built mainly by organisms, or fragments of organisms, (mostly sedentary), and not swelling into moundlike or lenslike forms.

birdseye: spots or tubes of sparry calcite in limestones (and some dolomites). These "calcite eyes" are common to pelsparites, and may have resulted from one of the following (or certain combinations thereof): (1) precipitation of sparry calcite in animal burrows, or in worm tubes; (2) soft-sediment slumping or mud cracking; (3) precipitation of sparry calcite in tubules resulting from escaping gas bubbles; (4) re-working and rapid deposition of soft sediment containing semi-coherent clouds of calcareous mud and spar; (5) recrystallization of calcareous (or dolomitic) mud in patches; and (6) "arrested" dolomitization.

energy level: the kinetic energy that exists in the water at the depositional interface and a few feet above. This energy of motion may be due to either wave or current action, or to surf surge.

fabric: arrangement of discrete particles (grains), crystals, and cement relative to each other in a sedimentary carbonate rock.

The following term is in the sense of Siever (1962).

amorphous silica: included as amorphous silicas are the different varieties of hydrated and dehydrated silica gels, silica glass, siliceous sinters, opals, and the skeletal remains of silica-secreting organisms, such as diatoms, radiolaria, and siliceous sponges.

Appendix III

Thin Section Descriptions

Location	Lithology	Thin Section
L358	chert	F1,F2,F3,F4,F6,F7,F8
L358B	carbonate	F5

Description L358 chert (Plate 5, fig. 4)

Some, or all, of the fabrics can be seen in each thin section. Number in brackets indicates a good example of a particular fabric.

Components

1. Matrix - matrix is of microcrystalline quartz, some coarser quartz (5); dark carbonaceous and algal material and ferruginous matter (4,7) are present which cause brown staining of some cherts. Some remnant calcite remains as inclusions in quartz (7).
2. Allochems - abundant bioclasts are quartz-replaced. Pelletoidal material present (5,6,7).

Fabrics

1. Simple replacement by microcrystalline quartz of micrite (1-7).
2. Replacement spherulitic chalcedony (6).
3. Replacement by pseudodrusy quartz mosaic in pentamerid shells--shell walls completely replaced, inside of shell, microcrystalline quartz replaces micrite.
4. Syntaxial rim on crinoids quartz-replaced (3,6).
5. "Ghost" calcite fabric in laminae of brachiopod shell, pseudomorphed by quartz (1).
6. Void-infilling drusy quartz mosaic.

7. Void-infilling microdrusy chalcedony (5,6).
8. Composite void-infilling fabric (6).
9. Transition from chalcedony to drusy quartz mosaic, coarse mosaic of quartz, saw-toothed and straight crystal boundaries which radiate from a number of centres, the undulose and fibrous extinction suggest this mosaic is a result of recrystallization of a group of chalcedony spherulites.
10. A few scattered anhedral quartz crystals, larger than the matrix with calcite inclusions (2,7).
11. Drusy quartz mosaic infilling small vein (2).

Fossils

Bryozoan (1,2,4,5)

Sponge spicules (3)

Pentamerid shell (all)

Crinoid (1,6)

Stromatoporoid (5,6,7)

Small corals (solitary) (2)

Acritarchs, spores, algae (5,6)

Many small bioclasts replaced by quartz.

Texture

The texture of a biomicrite or biomicrudite is suggested by this chert.

Environment of Deposition

Shallow marine, low to medium energy.

L358B

Description

Matrix is mainly dolomite crystals of various sizes from fine to coarse. There is some layering with alternating fine and coarser layers. Dolomite crystals are anhedral to subhedral, full of inclusions--"dirty dolomite". Microfacies may have originally been an interbedded calcilutite and calcisiltite which dolomitized to finely crystalline and coarser laminae. Some very large dolomite crystals have chalcedony in the centre. Dolomite has replaced quartz. Large rounded grains in dolomite matrix, filling in spaces around crystals of dolomite, may represent post-dolomitization calcite or dolomite.

Location	Lithology	Thin Section
L359	chert	F10,F11,F12,F13,F14

Description L359 (Plate 1, figs. 1,2), (Plate 3, figs. 3,4,)

Some or all of the fabrics can be seen in each thin section. Number in brackets indicates a good example of a particular fabric.

Components

1. Matrix is of microcrystalline quartz containing carbonaceous, algal and ferruginous matter causing brown-staining of fabrics.
2. Allochems - abundant bioclasts are quartz-replaced. Pelletoidal and algal material present.

Fabrics

1. Simple replacement by microcrystalline quartz of micrite (10-14).
2. Replacement spherulitic chalcedony (10).
3. Replacement by pseudodrusy quartz mosaic in shells (1).
4. Void-infilling drusy quartz mosaic (10).
5. Void-infilling microdrusy chalcedony (10,11,12), colour banding.
6. Composite void-infilling fabric (10,11).
7. Association of algal material with void-infilling fabrics (11).

Fossils

Bryozoan (12,13)

Sponge Spicules (10,12)

Brachiopod shell fragments (10).

Stromatoporoid (12,13,14)

Acritarchs, spores, algae (10,11)

Many small bioclasts replaced by silica fabrics (10-14)

Texture

The fabric of the cherts F10 and F11 suggest a replaced algal-supported biomicrite. The microfacies show algal-like laminae which may grade into discontinuous streaks of pellet-like bodies. Acritarchs and spores are found with the algae. The original micrite entrapped in the algae has been replaced by microcrystalline quartz. The bioclastic debris has been replaced by quartz. The dark zones somewhat resembling pellets are interpreted as poorly developed algal laminae perhaps of the Spongiostroma-type. Void-infilling silica fabrics and algal or carbonaceous material are found in close association in all cherts where they occur.

Chert in F12, F13, and F14 was originally a stromatoporoid-constructed limestone of the Aulocera-type. In longitudinal section vesicular or cystose plates are shown. Former wall structure has a dense dark median line. Galleries have been filled by chalcedony.

Environment of Deposition

Shallow marine, medium energy. The presence of the stromatoporoid and more void-infilling silica fabric suggest a slightly higher energy regime than L358.

Location	Lithology	Thin Section
L360	chert	F20,F21
L360-3	mostly dolomite	F22

Description L360 chert (Plate 2, fig. 3),(Plate 5, fig. 3), (Plate 6, fig. 3)

Some or all of the fabrics can be seen in each thin section. Number in brackets indicates a good example of a particular fabric.

Components

1. Matrix is of microcrystalline quartz. F21 shows more brown staining as matrix contains more carbonaceous material.
2. Allochems - large pentamerid shells are replaced as well as sponge spicules and a great deal of shell debris. Pelletoidal and algal material present.

Fabrics

1. Simple replacement by microcrystalline quartz of micrite (20).
2. Replacement by pseudodrusy quartz mosaic in shells (20,21). Most conspicuous are the brachiopod shells in which silica has pseudomorphed both the fibrous laminae and the prisms of the shell walls. Zone of small elongate crystals of quartz rims the shell.
3. Void-infilling drusy quartz mosaic (20).
4. Void-infilling microdrusy chalcedony (21) colour-banded.
5. Composite void-infilling fabric (20,21).
6. Association of algal material with void-infilling fabrics (21).

Fossils

Sponge spicules (20,21)

Brachiopod shell fragments (20,21)

Stromatoporoid 20

Algal lamellar structure (20,21)

Texture

Texture of this chert is a biopelmicrudite. The original microfacies was an algal and stromatoporoid-constructed limestone. The micrite trapped in, and bound by, these structures is now microcrystalline quartz. The laminae and interlamellar pillars consist of dark brown crystals, and the voids between them are now filled with quartz. It resembles a dolomitized and silicified colony of Clathrodictyon.

A conspicuous feature of F20 is the replacement of a large pentamerid shell and its median septum. Silicification occurred first. Silica pseudomorphed the calcite outer shell of fibrous lamellae. The lamellae have their long axes subparallel to the shell surface. It also pseudomorphed the inner shell layer. This layer consists of an aggregate of closely packed, quadrangular geometric prisms of calcite, oriented with the long dimension perpendicular, or slightly inclined, to the shell surface. Each prism is an individual crystal with unit extinction. The micrite contained within the shell was replaced by microcrystalline quartz. Dolomitization followed silicification. The matrix outside the shell is composed of dolomite crystals. Dolomite has begun to replace the quartz of the shell walls. Close examination shows dolomite crystals cross-cutting silica fabrics. Dolomite rhombs encroach upon the pseudomorphing quartz crystals. The dolomite crystals are cloudy with inclusions.

Beneath the stromatoporoid in the thin section are pelletoidal-algal remains. In chert F21, the very dense, dark material photographs poorly. The dark pattern may represent poorly defined layering as in some algal mats and suggests pellets that are difficult to recognize because of their dense composition and close packing. The white network is interpreted as quartz which may be replacing sparry calcite.

<u>Description</u> <u>L360-3 F22</u>

The matrix of this thin section is mostly dolomite. A chert-carbonate contact is shown (lower-left). The very anhedral dolomite crystals make a mosaic of different-sized grains which are full of inclusions. There are ferruginous grains present but no fossils in the carbonate.

The small chert area appears to have been an algal-supported micrite, now replaced by quartz.

<u>Environment of Deposition</u>

Shallow marine, medium energy.

Location	Lithology	Thin Section
L361	chert	F30,F31,F32

Description L361 (Plate 5, fig. 1), (Plate 3, fig. 6)

Some or all of the fabrics can be seen in each thin section. These three are very similar. Number in brackets indicates a good example of a particular fabric.

Components

1. Matrix - matrix is of microcrystalline quartz containing abundant pelletoidal-algal material. There is some layering shown from bottom to top of sample. A layer of replaced biomicrite is followed by an opaque carbonaceous layer. Above this is coarse silica void-infilling fabric. This association has been noted numerous times in the chert. A layer of microcrystalline quartz replacement fabric overlies, followed by dark pelletoidal-algal material in similar matrix.
2. Allochems - quartz-replaced bioclastic fragments. Pellets are irregularly-shaped to rounded bodies possibly of algal origin.

Fabrics

1. Simple replacement by microcrystalline quartz of micrite (30,31).
2. Replacement by pseudodrusy quartz mosaic (30).
3. Quartz pseudomorph after radiating fibrous calcite (31).
4. Intermediate fabrics between chalcedony and quartz.
5. Composite void-infilling fabric (30).

Fossils

Bryozoan (31)

Brachiopod shell (30)

Algal material (30,31)

Texture

This chert has the texture of a biopelmicrite or biopelmicrudite. The large areas of void-infilling fabric may indicate winnowing out of micrite by current action in original sediment. The silica fabric may be replacing sparry calcite.

Environment of Deposition

Shallow marine, low to medium energy.

Location	Lithology	Thin Section
L362	carbonate	F40,F41

Description L362 -1, -2

Components

1. Matrix - matrix is a mosaic of anhedral, medium to coarsely crystalline dolomite crystals which are full of inclusions. There is some layering and the coarser layers of dolomite contain scattered pockets of quartz crystals, small, anhedral and, in appearance, in a transition stage from chalcedony. Dolomite is replacing this silica fabric which was probably void-infilling. Anastomosing stylolites with concentrations of iron mineral may be chemical unconformities marking changes in deposition.
2. Allochems - a few crinoid fragments.

Texture

This carbonate has the texture of a grain-supported calcarenite close to a pentamerid brachiopod biostrome.

Environment of Deposition

Shallow marine, medium energy, biostrome.

Location	Lithology	Thin Section
L363	carbonate and chert	F52

Description L363 carbonate and chert (Plate 2, fig. 2)

Components

Matrix - carbonate matrix is mainly of coarsely-crystalline dolomite, crystals are anhedral and full of inclusions, some variation in grain size from medium to coarse is shown. Spherulitic chalcedony and patches of replacement micro-crystalline quartz matrix still present. Allochems in the matrix are represented by carbonaceous matter and silica replacement fabrics, often closely associated. Bachiopod shell fragments pseudomorphed by quartz show "ghost" lamellar structure of original calcite shell. Dolomite is replacing silica fabrics. Sequence of events has been from calcite shell-silicification-dolomitization. Numerous crinoid fragments are present, most of them are replaced by dolomite.

Fossils

Crinoid

Brachiopod

Texture

The texture of a biomicruidite or bioclastic calcarenite is suggested.

Environment of Deposition

Shallow marine, medium energy.

Location	Lithology	Thin Section
L364	carbonate and chert contact	F60

Description L364 chert and carbonate (Plate 6, fig. 1)

Components

Matrix shows contact between chert and dolomite and layering of the two. Under crossed polarizers the dolomite crystals appear light (photo centre and top). The quartz crystals are darker in a band above the dolomite in photo centre and in bottom half of photo (Plate 6, fig. 1). The microcrystalline quartz matrix of the chert is brown-stained and contains carbonaceous material. Dolomite crystals are larger than quartz crystals but are fine-grained and anhedral. The carbonate-chert contact is well-defined by dark lines which may represent chemical unconformities. All contacts between dolomite and chert do not show this.

In the chert, silica void-infilling fabric occurs. Similar patches of large dolomite crystals occur in the dolomite. These void-infilling fabrics may be related to solution of some bioclasts forming vugs in the original limestone sediment which became infilled with dolomite spar.

Allochems

No distinguishable allochems are present.

Texture

The texture of an interbedded calcilutite and calcisiltite is suggested.

Environment of Deposition

Shallow marine, low energy.

Location	Lithology	Thin Sections
L365-2, -4	chert	F71, F73
L365-1, -3, -5, -6	chert & carbonate	F70,F72,F74,F75

Description L365-2, L365-4

Components

Matrix is of microcrystalline quartz, a silica replacement fabric, containing and stained by, carbonaceous and ferruginous material. Replacement spherulites of chalcedony are common. The microfacies was originally a stromatoporoid and algal-constructed limestone. Brown-stained framework of stromatoporoid is of Aulacera type.

Allochems of organic or pelletal origin have been replaced by spherulites of chalcedony. Sponge spicules are trapped in an algal or coprolite ball.

Description L365-1, L365-3, L365-5, L365-6

Components

Matrix is a mosaic of anhedral, coarsely-crystalline dolomite with crystals full of inclusions. There are scattered grains of detrital quartz and iron mineral. Silica replacement and void-infilling fabrics occupy veins and former open spaces. Crinoid debris, now dolomitized has quartz-replaced syntaxial rims. Prismatic shell structure is pseudomorphed by silica.

Contact between chert and dolomite in some places is sharp. In other areas, the contact is not clearly defined and there is a mixing of smaller dolomite and quartz crystals along the contact edge. Dolomitization has followed silicification. Evidence for this can be seen where dolomite rhombs encroach on silica replacement fabrics in a brachiopod shell. This is similar to (Plate 5, fig. 3). There is a close association between algal material and chert as is common in nearly all of the cherts. Allochems are common, bioclasts and algal or pelletal balls, often entrapping spicules.

Fossils

Stromatoporoid (2,6)

Sponge spicules (4,5)

Brachiopod shell (6)

Acritarchs, spores, algae (6)

Crinoid (3)

Bryozoan (4)

Many small bioclasts replaced by quartz.

Texture

The microfacies was originally a stromatoporoid-algal constructed limestone which trapped micrite and had many associated faunal elements.

Environment of Deposition

Biostrome in shallow marine water of medium energy.

Location	Lithology	Thin Section
L366	carbonate	F80

Description L366

Components

Matrix composed of medium to coarsely crystalline dolomite of anhedral, "dirty" crystals. No fossil fragments and no quartz present. Microfacies may have been a calcarenite or calcilutite associated with pentamerid bank.

Environment of Deposition

Shallow marine, low energy.

This is the Fossil Hill Type Locality L368

Location	Lithology	Thin Section
L368-1	stromatoporoid-constructed carbonate	F100
L368-6	dolomite and chert	F105

Description L368-1, -6 (Plate 1, fig. 3)(Plate 3, figs. 1,2)

Components

This is a stromatoporoid-constructed carbonate of the Clathrodictyon type. Silica in the form of quartz and chalcedony has replaced the original stromatoporoid structure. The laminae and interlamellar pillars consist of anhedral quartz crystals. The former voids are filled with chalcedony and larger quartz crystals Chert has occupied the former stromatoporoid and infilled the voids. The matrix around the stromatoporoid is of dolomite which has replaced the original micrite. Silica has shown preferential selection of the organic structure.

The dolomite matrix is composed of anhedral to subhedral medium crystalline crystals full of inclusions. Former voids, parallel to the bedding are filled with large dolomite crystals. Beneath the stromatoporoid structure very coarse dolomite crystals may represent an area of high porosity in the original sediment under the stromatoporoid dome.

Description L368-2, -3 F101, F102

Components

This appears to have been an algal biomicrite. Contact between replacement silica and secondary dolomite is well-defined. The matrix of the chert is microcrystalline quartz full of carbonaceous material, quartz-replaced shell fragments, calcite crinoid fragments with syntaxial calcite rims replaced by quartz, bryozoan fragments replaced by quartz, and sponge spicules. The sponge spicules have been preserved in the silica-rich environment of the chert nodule. The dark organic material is within the chert. The original micrite has been dolomitized. The dolomite matrix consists of medium-sized crystals which are full of inclusions giving them a "dirty" appearance. The fossils in the dolomite were replaced by quartz before dolomitization.

Description L368-4 F103 carbonate and chert

Components

The contact between the microcrystalline quartz matrix of the chert and the dolomite is sharp. There are some dolomite crystals in the quartz near the contact. This dolomite matrix is cleaner, medium crystalline, anhedral, and contains iron mineral. It is replacing the chert.

Description L368-7 F106 chert and carbonate

Components

Matrix of chert is composed of crypto to microcrystalline quartz which is very dark and contains fossil fragments and round opaque objects resembling algal balls. These balls are possible Spaerocodium--"spaghetti"-like with the aspect of small intertwined calcareous tubes. These were presumably green or blue-green algae The matrix contains dolomite-replaced fossil fragments as well as some small dolomite crystals. Silica fabric rims organic nuclei.

Description L368-5 F104 carbonate

Components

This dolomite may represent a laminated dolosiltite replacing calcisiltite. There are stylolites paralleling the bedding. There are no fossil fragments, no silica fabrics of any kind, some opaque mineral present. The layering from the bottom to the top of the thin section shows the following sequence: coarse, fine, very fine, coarse, very fine, coarse, very fine. There is more opaque mineral in the coarse layer. The fine crystals are sublithographic. A similar type of dolomite is shown in Plate 6, fig. 1.

Environment of Deposition

Shallow marine, medium energy. Algae probably contributed to stabilization of substrate.

Location	Lithology	Thin Section
L369	carbonate	F110

This location is at the top of Wolsey Lake South roadcut. There is a good exposure of the contact of the Mindemoya and Fossil Hill Members of the Lockport Dolomite. The Fossil Hill dolomite about 14' (4m.) thick, is weathered brown, very fossiliferous, vuggy, medium to thin-bedded, medium textured, with chert nodules. Underlying is about 20' (6m.) of Mindemoya dolomite. It weathers grey in thin to medium bedded, lithographic to sublithographic dolomite.

A "False Mindemoya" bed appears at the top of the section. Study of thin sections leads to the conclusion that it is lithologically similar to the Mindemoya. It may represent a regression of the sea with lagoonal sediments deposited over the back-reef area

Description L369-1 F110 (Plate 6, fig. 2)

This thin section represents the transition zone between the Fossil Hill and Mindemoya Members. The matrix is of finely crystalline dolomite with scattered larger dolomite rhombs, iron mineral and some anhedral detrital quartz. There are areas of larger dolomite crystals which resemble "birdseye" structure and may be void-infilling fabric. There are no silica fabrics.

Description L369-2-3 F111, F112

Matrix is sublithographic dolomite with a few scattered grains of detrital quartz and ubiquitous iron mineral. Patches of medium crystalline dolomite elongate, and parallel to bedding, resemble "birdseye" structure. These may represent original voids in the micrite.

L369-2 "False Mindemoya" closely resembles the Mindemoya Member.

Description L369-4 F113 chert and carbonate

This thin section is of Fossil Hill dolomite. The groundmass is a mosaic of subhedral to anhedral coarsely crystalline dolomite containing inclusions. A few crinoid fragments are preserved as ghosts of sparry dolomite. Spherulitic chalcedony represents silica fabrics.

Description L369-5 F114 carbonate

This thin section is cut from a sample of the "False Mindemoya" at the top of the section. It contains no chert, no fossils, no detrital quartz. The matrix is sublithographic dolomite.

Description L369B F115 carbonate

This thin section is cut from a Mindemoya Member hand specimen. The matrix is of sublithographic dolomite. A coarser layer at the top contains coarser-grained dolomite and a few crystals of feldspar and detrital quartz grains.

Location	Lithology	Thin Section
L371-1, -3	chert spiculite	F120, F122
L371-2	carbonate	F121

Description L371 chert (Plate 1, fig. 4), (Plate 2, figs. 1, 4) (Plate 5, fig. 2)

In the hand sample this white chert appears very dense and unfossiliferous, but thin section study shows it to be filled with sponge spicules. These were probably preserved in the silica-rich environment of the chert. The spiculite shows a number of silica fabrics. The matrix of the chert is replacement microcrystalline quartz. The walls of the spicules have been replaced by acicular quartz crystals. Their interiors are filled with chalcedony or drusy quartz mosaic. Many small bioclasts have been replaced by spherulitic chalcedony. Drusy quartz mosaic fills voids between spicules. Some of the spicules exhibit mud-filled interiors in transverse and longitudinal section and are brown-stained by carbonaceous matter

Description L371-2 F121 carbonate

The associated Fossil Hill dolomite has a matrix of fine to medium crystals with no fossil remains or silica fabrics. There is some anhedral detrital quartz present, especially in the coarser layers.

Environment of Deposition

Shallow marine, obviously favourable for growth of sponges, low energy.

Location	Lithology	Thin Section
L372-1	carbonate	F130

Description L372-1

This carbonate was collected low in the Fossil Hill section at this locality. Matrix is composed of anhedral, fine crystals of dolomite making a uniform mosaic. Where fine layers grade into coarser crystals some grains of detrital quartz are present. There are no fossils or silica fabrics. The microfacies may have been originally a micrite or calcisiltite. Some winnowing has occurred producing voids now filled with larger dolomite crystals resembling "birdseye" structure.

This dolomite resembles the "False" Mindemoya which occurs consistently in the Fossil Hill sections across the Island, 10'-12' (3-4m.) above the base.

L372-2	carbonate	F131

Description L372-2

This carbonate was collected from the Mindemoya Member underying the Fossil Hill Member at this location. Matrix is composed of anhedral, very fine to sublithographic crystals of dolomite. Anhedral detrital quartz grains, larger than matrix crystals, are fairly common along with iron mineral. There are no fossils or silica fabrics.

L372-3 chert and carbonate F132

This chert and carbonate were collected high in the Fossil Hill Member at this location. It was originally a stromatoporoid-constructed limestone similar to the one shown in Plate 3, fig. 4 Chalcedony infilled the void spaces and the quartz-replaced framework is yellow-stained by the abundant carbonaceous material. Composite void-infilling silica fabric of brown-stained chalcedony and drusy quartz mosaic is common in the chert.

The carbonate matrix consists of very "dirty" anhedral, medium crystalline dolomite.

Location	Lithology	Thin Section
L373-1-2	chert	F140, F141

Description L373-1-2 chert

This chert was collected at the base of the Fossil Hill Member at the contact with the underlying Mindemoya Member. It is stained pink by sulphide, probably pyrite, now hematite. It represents a replaced colonial coral, first silicified and later dolomitized. Some voids in the coral are occupied by quartz, others by dolomite. Replacement dolomite rhombs encroach upon silica fabric. The matrix was a pelletoidal micrite, now dolomite.

Environment of Deposition

Shallow, warm, normal marine conditions, medium energy.

Location	Lithology	Thin Section
L374-1-2	carbonate and chert	F150, F151

Description L374-1-2

These samples were collected high in the Fossil Hill section at this locality and show advanced dolomitization. The matrix is mostly carbonate, anhedral, medium crystalline dolomite with numerous irregular bands of coarser dolomite crystals. There is a lot of iron mineral present and some grains of detrital quartz. Some patches of quartz remain which show the effects of later dolomitization. The only fossils appear to be quartz-replaced shell fragments. Stylolites mark post-depositional chemical surfaces.

Location	Lithology	Thin Section
L375	chert and carbonate	F160

Description L375

This sample of Fossil Hill chert and carbonate was collected low in the Fossil Hill section just above the contact with the Mindemoya. The matrix of the thin section is composed of anhedral, medium crystalline dolomite. Some dolomite rhombs can be seen in the chert close to the contact which is well-defined.

Appendix IV

Microfacies Descriptions

A. General Statement

Microfacies descriptions are used by the writer in two ways. By comparing Fossil Hill microfacies with "type" microfacies described by Textoris and Carozzi (1964), Carozzi and Textoris (1967), they are being used, in a genetic sense, to interpret the depositional environment and diagenetic history of the Fossil Hill cherts and enclosing dolomites. The descriptions are also used in the sense of Fairbridge (1954), to correlate and compare the depositional environments at all of the collecting localities.

Basic types of microfacies in sedimentary carbonate rocks have been described and illustrated by Carozzi and Textoris (1967), Horowitz and Potter (1971), and Wilson (1975). The descriptions of the Fossil Hill and Mindemoya microfacies are based on the work of these writers.

The general microfacies types which characterize the Fossil Hill interbiohermal, and Mindemoya lagoonal beds, in order of decreasing energy level of the depositional environment are: grain-supported biocalcarenite, mud-supported biocalcarenite, calcisiltite-calcilutite. The sequence of diagenetic action based on the study of microfacies is believed to be solution and infilling or recrystallization of original bioclasts and matrix, followed by silicification, followed by dolomitization.

2. Microfacies Descriptions

(a) Fossil Hill Interbiohermal Facies

Microfacies 1

Megascopically, Microfacies 1 is siliceous, very fossiliferous, irregularly bedded, buff to brown, medium to coarsely crystalline, vuggy dolomite.

Microscopically, Microfacies 1 is a grain-supported biocalcarenite which may also be pelletoidal. It consists of more than 50% bioclasts in a medium to coarsely crystalline dolomitized matrix. Some of the original limestone was of algal-stromatoporoid construction which entrapped micrite. The most abundant fossil remains consist of crinoids, bryozoans, sponge spicules, brachiopods, corals, algae and stromatoporoids. Pyrite occurs in grains scattered throughout the matrix. The chert contains silica replacement and void-infilling fabrics.

This microfacies reflects the highest energy level of the Fossil Hill microfacies. Winnowing, fragmentation and abrasion indicate a moderate degree of current activity. The sediments represented by this microfacies were deposited closest to the bioherm. However, the lack of evidence of sorting of bioclasts or of current orientation of bioclasts, indicates a short distance of transport and a moderate energy regime (Plate 5, fig. 4). The presence of the algal material suggests a shallow, warm, clear-water marine environment (Plate 3, figs. 3, 4, 5, 6).

Microfacies 2

Megascopically, Microfaces 2 is siliceous, less fossiliferous, buff to brown, finely to medium crystalline dolomite, in thin to medium beds.

Microscopically, Microfacies 2 is a mud-supported calcarenite. The term "mud-supported" is used after Dunham (1962), and implies collapse of the allochems if the matrix is removed. The matrix contains bioclasts in a finely to medium crystalline dolomite which probably developed from a calcilulite or calcisiltite. Where sponge spicules are present mud may remain in the spicules. The most abundant fossil remains consist of sponge spicules. Much of the replaced bioclastic debris is unidentifiable (Plate 2, fig. 4). Dolomitic or siliceous "birdseye" or fenestral fabric is fairly common. The chert contains silica replacement and void-infilling fabrics.

This microfacies reflects a lower energy regime than Microfacies 1. The sediments represented by this microfacies were deposited in fairly quiet water. There is no sorting or orientation of bioclasts and little abrasion (Plate 2, fig. 4).

(b) Mindemoya Facies

Microfacies 3

Megascopically, Microfacies 3 is siliceous, but, non-cherty, relatively unfossiliferous, sublithographic to very finely crystalline, buff to gray, white-weathering, thinly bedded dolomite. Microscopically, Microfacies 3 is a calcilutite or calcisiltite which may contain some bioclastic debris. The matrix probably developed from a micrite or argillaceous micrite represented by sublithographic to very finely crystalline dolomite (Plate 6, fig. 2). Fenestral fabric is common.

Pyrite grains and grains of detrital quartz are scattered throughout the matrix.

This microfacies represents a lower energy regime than Microfacies 2. The muddy sediments represented by this microfacies were deposited in a sheltered environment of quiet water. The lack of biota may indicate unsuitable environmental conditions for growth.

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