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PETROLOGY OF THE BLACK RIVER LIMESTONES
IN SOUTHWESTERN ONTARIO

BY

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ABSTRACT

Petrographic and mineralogic characters can be used to define four major units in the outcrop area of Black River rocks of southwestern Ontario. Each of the three lower units (I, II and III) can be sub-divided into two sub-units, whereas the uppermost unit (IV) has three recognizable sub-units. The lowermost major unit is principally shale and sandstone with dolomicrite and micrite, grading upward into biomicrite. The second unit has a lower micrite and dolomicrite association and an upper biomicrite. The third unit is carbonate of a highly variable character in the lower part and an upper oösparite, biomicrite or other mixed types. The lower most part of the topmost major unit has an abundance of micrite. The middle and upper sub-units of unit IV have a more recrystallised character. Mud cracks, fucoid markings, burrows, fine lamination, calcite or gypsum nodules, solution breccia, celestite needles and molds are common in the lower units, especially in the rocks of unit II. "Birdseye" structure is a characteristic feature of unit III rocks. Cross-bedding, ripple marks and other channel filled structures occur in both units III and IV. Wavy bedding, and irregular bands and lenses of shaly material are notable in the rocks of unit IV.

Detrital heavy minerals include amphibole, apatite, epidote, garnet, ilmenite, magnetite, pyroxene, sphene, staurolite, tourmaline, and zircon (?). Authigenic minerals include dolomite, celestite, anhydrite, pyrite, anatase and minor amounts of fluorite and sphalerite. Anatase is restricted in areas west of Marmora. Pyroxene shows a restricted occurrence in the areas east of Marmora. Garnet, zircon, and hornblende have a greater abundance in the areas west of Marmora and ilmenite, magnetite, and tourmaline have an increase in occurrence toward the eastern parts. In areas east of Marmora, anhydrite, and celestite occur in notably higher concentration in the rocks of unit II as compared to the similar rocks of western areas.

Petrographic constituents include sparry calcite cement, microcrystalline calcite ooze, pellets, intraclasts, oöliths, composite grains, and various skeletal materials. Eleven carbonate petrographic types are recognizable, specifically micrite, biomicrite, pelmicrite, intramicrite, biosparite, intrasparite, oösparite, pelsparite, allochem-rich varieties e.g. bioclastite, mixed rock, e.g. micritic pelbiosparite and recrystallised (neomorphic rock). The remains of algae, bryozoa, and corals exhibit an association with particular carbonate lithologies. Chemically the rocks are grouped into four types, dolostone, calcitic dolostone, dolomitic limestone and limestone.

Textural studies suggest the following diagenetic processes have occurred - cementation, drusy cement, neomorphism, replacement, pressure solution, dolomitization and dedolomitization. The diagenetic sequence of the Black River rocks are grouped into three broad categories. Orientation studies of allochems reveal NE-SW and SE-NW maxima.

The Black River rocks represent contemporaneous deposition in co-existing adjacent niches. The lower two units (I and II) were deposited in a shallow saline, supratidal lagoon. Both penecontemporaneous and late diagenetic dolomitization effects occurred. Dolomite in the rocks unit III and IV is due to late diagenetic dolomitization due to the influx of brine from the adjacent or supratidal environment. The upper units III and IV were deposited in higher energy environments, intertidal to sub-tidal shelf lagoons respectively. NE-SW and SE-NW trending orientation maxima correspond to longshore and tidal currents respectively. The Precambrian continent towards the north and east and isolated islands contributed in restricting the circulation of unit I and II depositional areas in the areas east of Marmora. Exceptionally low content of insoluble residues in the Black River rocks suggests the low relief of and lack of effluent streams from the adjacent continent.

It has been proposed that Okulitch's (1939) original classification of four Black River units - Shadow Lake (unit I), Gull River (unit II), Moore Hill (unit III) and Coboconk (unit IV) should be retained and used in southwestern Ontario.

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PETROLOGY OF THE BLACK RIVER LIMESTONES OF SOUTHWESTERN ONTARIO

CHAPTER 1

INTRODUCTION

Southwestern Ontario, an area of about 40,000 square miles is underlain by marine sedimentary rocks of Cambrian to probable Mississippian age with an approximate total composite thickness of 5,000 feet. The area lies in the southern part of the province of Ontario bordering the Great Lakes, and is separated from the adjacent Eastern Ontario Lowlands by the Frontenac Axis (Hewitt 1965). This axis crosses the St. Lawrence River between Kingston and Brockville, and connects with the Adirondack mountains (Fig. 1). Ami (1902, p. 82) reported that Pre-middle Ordovician rocks are practically absent west of the Frontenac Axis whereas the rocks of Cambrian and lower Ordovician age are quite extensive to the east and south of the Axis.

The present investigation is restricted to the Middle Ordovician Black River Group, which occurs along a narrow belt from Kingston on Lake Ontario to Victoria Harbour on Georgian Bay (Fig. 1).

History of Nomenclature and Classification of Black River Rocks.

The type locality for the Middle Ordovician rocks is in the Mohawk River and Black River Valleys, North-western New York. Eaton (1824) first attempted to classify the Ordovician rocks in New York State.

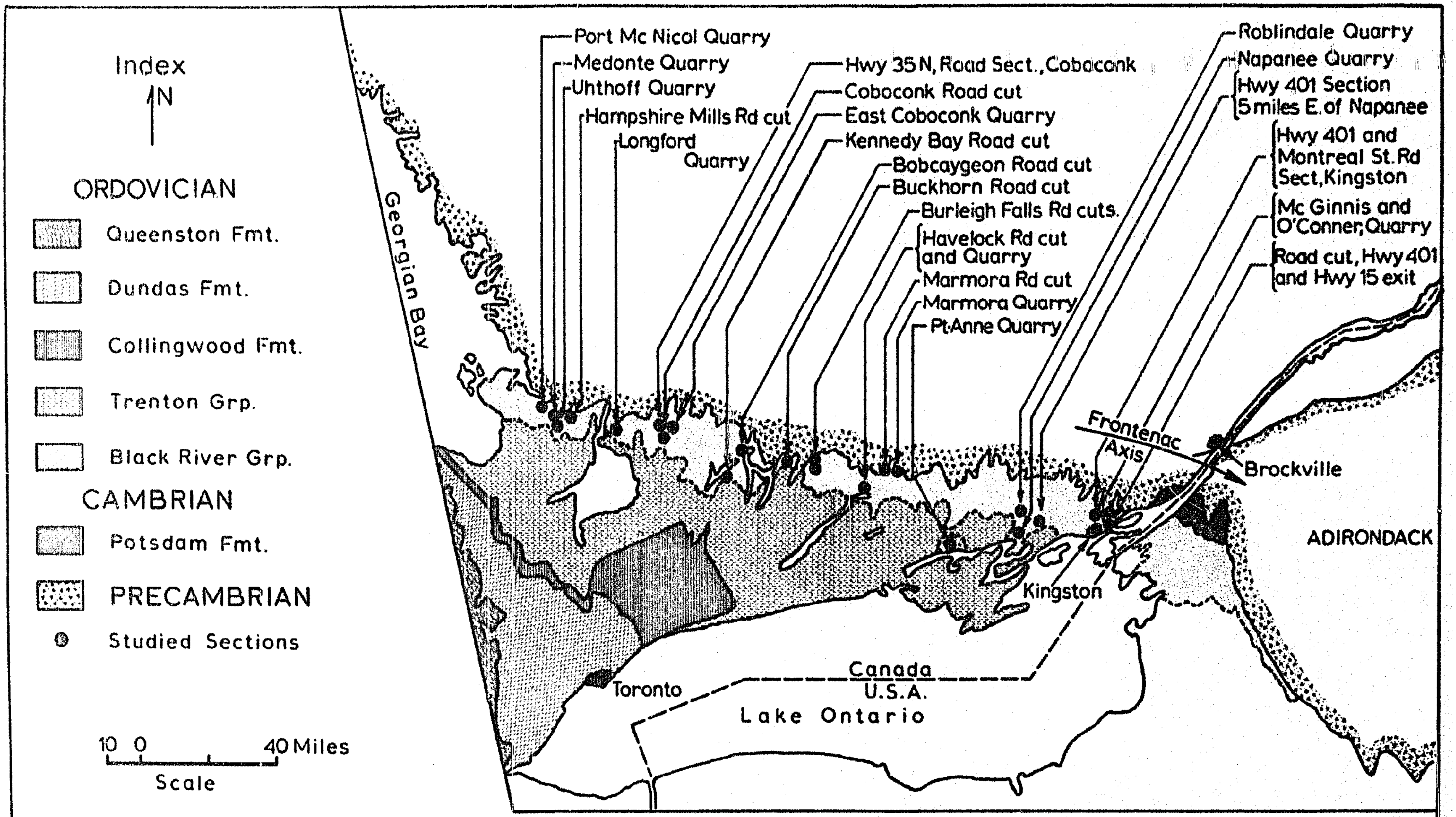

Fig.1 DISTRIBUTION of BLACK RIVER ROCKS in S.W. ONTARIO, and NEW YORK (N.W. Part)

Immediately following the formation of the Geological Survey of New York, Conrad (1837) and Vanuxem (1838) suggested classifications of Ordovician rocks. In 1847, James Hall described the Ordovician rocks in New York and subdivided the sequence into the following units in ascending order; Potsdam Sandstone, Calciferous Sandstone, Chazy, Birdseye, Black River and Trenton Limestones, Utica Slate and the Hudson River group. Sir William Logan (1863, p. 20) recognized the subdivisions of New York State geologists in Ontario. The units in descending order are given below.

Rock Unit	Lithology
7. Hudson River formation	Bluish, grey shale, sandstone with *Beatricea*, *Favistella* etc.
6. Utica formation	Black, bituminous shale with graptolites.
5. Trenton formation	Grey, buff, or blue limestone, shale, sandstones with *Stenopora*, *Leptaena*, *Strophomena* etc.
4. Birdseye and Black River formation	Grey, buff or blue limestone with shales, sandstones, and *Tetradium*.
3. Chazy formation	Grey to yellowish grey limestone and shale with *Orthis sp.*, *Leperditia sp.*
2. Calciferous formation	White to grey, caleareous sandstone, magnesian limestone with gastropod, trilobites.
1. Potsdam group	Dark brown to red, and reddish yellow to white sandstone, conglomerate, and limestone with *Scolithus*, Fucoid, ripple marks.

Clarke and Schuchert (1899) used the term Mohawkian Series and restricted its usage to the Birdseye, Black River and Trenton units. They also substituted the name "Lowville limestone" for the Birdseye formation. Cushing (1908) applied the name "Pamelia Limestone" for that part of original Black River limestone underlying the Lowville. Beds overlying the Lowville and underlying the cherty limestones were grouped as "Leray limestone". Johnston's (1912) description of the areal distribution of "Mohawkian Series" from Kingston to Lake Huron was accompanied by a classification, which for the first time differentiated formations of the Trenton on a faunal basis in Ontario. The divisions of the Trenton in ascending order, were as follows, Dalmanella beds, Prasopora beds, Hormotoma and Rafinesquina deltoidea beds. Johnston (1912) initiated the present stratigraphic names for the Black River Group which included in ascending order Basal Series or Rideau beds of Ami (1902), Lower Lowville, Upper Lowville, and the Coboconk. Kay (1929, p. 661) used the term "Chaumont Limestone" for the beds above the Lowville and below the Rockland (Basal Trenton). The Chaumont Limestone was divided into three members; the Leray Limestone, Glenburnie Shale, and Watertown Limestone.

Okulitch (1939) studied the Black River rocks at Coboconk, and proposed the following terms for the units in ascending order; the Shadow Lake, Gull River and Moore Hill. Johnston's (1912) Coboconk unit overlies the topmost Moore Hill unit of Okulitch (1939). The Shadow Lake is equivalent to the Basal beds, the Gull River was correlated with the Pamelia and the Moore Hill with the Lowville of New York State. The Tetradium beds were noted in Coboconk Limestones which were thought to be equivalent to Kay's (1929) "Chaumont." The term "Coboconk" was retained as a formation name and this unit was considered to be the equivalent of the "Leray" of New York. Young

Table 1. History of Ordovician classification and terminology in Nw. New York and Ontario (modified after Kay 1937).

TABLE 1.

		HISTORY of CLASSIFICATION and NOMENCLATURE of ORDOVICIAN ROCKS in MOHAWK VALLEY and N.W. NEW YORK										HISTORY of CLASSIFICATION and NOMENCLATURE of ORDOVICIAN ROCKS in ONTARIO						
		STANDARD UNITS	N.W. NEW YORK	MOHAWK VALLEY FORMATION	EATON 1820-1830	CONRAD 1837	VANUXEM 1838	HALL 1847	CLARKE and SCHUCHERT 1899	CUSHING and RUEDEMANN 1910	KAY 1937	LOGAN 1863	JOHNSTON ET AL. 1912	OKULITCH 1939	YOUNG 1943	LIBERTY 1956	WINDER 1960	LIBERTY 1967
CINCINNATIAN		RICHMOND		ONEIDA	MILLSTONE GRIT		HUDSON RIVER GROUP					HUDSON RIVER GROUP						
		MAYSVILLE	LORRAINE OSWEGO PULASKI															
		EDEN	WHETSTONE GULF	FRANKFORT	GRAY WACKE		GREENSHALE											
MOHAWKIAN	UTICA	GLOUCESTER	ATWATER CREEK	UTICA			BLACK SLATE	UTICA SLATE	TRENTON LIMESTONE	TRENTON LIMESTONE	GLOUCESTER	UTICA SLATE	CLIMACOGRAPTUS TYPICALIS BEDS		GLOUCESTER	GLOUCESTER		WHITBY
		COLLINGWOOD	DEERRIVER								COLLINGWOOD		OGYGITES CANADENSIS BEDS		COLLINGWOOD	COLLINGWOOD		
	TRENTON	COBOURG	HILLIER HALLOWELL			GRAYCRINOIDAL LIMESTONE		TRENTON LIMESTONE			COBOURG	TRENTON	HORMOTOMA and FUSISPIRA BEDS		COBOURG	COBOURG		SIMCOE GROUP LINDSAY
		SHERMAN FALL	DENMARK SHOREHAM	CANAJOHARIE		BLUE-FOETID LIMESTONE and SHALES of TRENTON FALLS	TRENTON LIMESTONE				SHERMAN FALL		PRASOPORA BEDS		SHERMAN FALL	SHERMAN FALL		VERULAM
		HULL		GLENS FALLS SHOREHAM LARRABEE	METALLIFEROUS LIMEROCK						HULL		CRINOID BEDS		KIRKFIELD	KIRKFIELD	KIRKFIELD	BOBCAYGEON FM UPPER
		ROCKLAND		AMSTERDAM		GRAYSBURRY LIMESTONE OF MOHAWK VALLEY					ROCKLAND	DALMANELLA BEDS	DALMANELLA BEDS		ROCKLAND		COBOCONK	MIDDLE
	BLACK RIVER	CHAUMONT	WATERTOWN LERAY	LOWVILLE			BIRDSEYE	BLACKRIVER LIMESTONE		WATERTOWN LERAY		BLACKRIVER	COBOCONK	COBOCONK		COBOCONCK	MOORE HILL	LOWER
		LOWVILLE						BIRDSEYE	LOWVILLE	LOWVILLE	BLACKRIVER GROUP CHAUMONT WATERTOWN GLENBURNIE LERAY LOWVILLE	BIRDSEYE	UPPER LOWVILLE LOWER LOWVILLE	MOOREHILL GULLRIVER	CHAUMONT LOWVILLE	MOOREHILL GULLRIVER	GULLRIVER	GULL RIVER
		PAMELIA								PAMELIA	PAMELIA		BASAL SERIES	SHADOW LAKE	PAMELIA	SHADOW LAKE	SHADOW LAKE	SHADOWLAKE
LOWER ORDOVICIAN		TRIBES HILL			CALCIFEROUS SAND ROCK	BASTARD LIMESTONE	CALCIFEROUS SAND ROCK	CALCIFEROUS SAND ROCK		THERESA		CHAZY CALCIFEROUS FORMATION						
		CAMBRIAN	THERESA POTSDAM	LITTLE FALLS		CALCIFEROUS SANDSTONE MOHAWK VALLEY		POTSDAM SANDSTONE		POTSDAM		POTSDAM						
		PRE-CAMBRIAN				GNEISS	GNEISS			PRE-CAMBRIAN								

(1943) followed Kay's terminology in a study of Black River rocks in Northwestern New York, and Eastern Ontario. He considered Okulitch's (1939) "Moore Hill" to be the Chaumont and the "Coboconk" as equivalent of the Rockland. Later, on the basis of faunal evidence it has been indicated that the Black River-Trenton transitional beds should be included in the Black River (Sinclair, 1954).

For more recent information on Black River-Trenton stratigraphy reference can be made to the works of different authors such as Caley (1936, 1941), Wilson (1946), Caley et al. (1951), Caley and Liberty (1952, 1957), Sinclair (1954, 1958) and Winder (1960). Liberty (1955) suggested that the term "Gull River" should include the carbonate strata lying below the base of the Coboconk unit. Thus, Okulitch's (1939) Moore Hill was reduced in rank and included as the uppermost beds of the Gull River. A tabular classification showing the historical development of various nomenclature is given in Table 1.

In order to maintain uniform nomenclature, and make regional comparisons, the original classification of Okulitch (1939) is used in the present investigation (Table 2).

Most studies of the Black River Group have been general stratigraphic and paleontologic investigations without a detailed systematic lithologic examination. Derry (1934) and Crombie (1943) made insoluble and heavy mineral analyses of Ordovician rocks and contributed to the lithologic investigation of Black River and Trenton. Later Beales (1958, 1965) made a petrographic study of a few selected Black River samples from Southwestern Ontario. Recently, Barnes (1967) has published a detailed account of the stratigraphy and sedimentary environ-

Table 2. Lithologic classification of Black River rocks.

SYSTEM	ROCK UNITS	FORMATIONS		PRESENT STUDY 1967	
	GROUP	NAMES	DESCRIPTION	MAJOR UNITS	SUB UNITS
MIDDLE ORDOVICIAN	Trenton	Kirkfield	Thin bedded argillaceous limestone, dolostone, and shale. (Okulitch, 1939). *Dalmanella* beds, *Receptaculites occidentalis*.		
	BLACK RIVER	Coboconk	Dark grey to blue, coarse to fine, massive thick bedded limestone with black chert nodules. (Johnston 1912; Okulitch 1939). *Stro matocerium rugosum*	IV	IVC IVB IVA
		Moore Hill	Buff to light grey, aphanitic to fine grained limestone with conchoidal fracture, calcite spots (birdseye structure), styolites, and pink patches, weathers white. (Okulitch, 1939). *Tetradium cellulosum*	III	IIIB IIIA
		Gull River	Brownish to greenish grey, aphanitic limestone in part magnesium rich, with intraformational conglomerate stylolites, cavities, mud cracks and weathers yellowish brown. (Okulitch, 1939). *Rafinesquinaminnesotensis* *Hormotoma* sp.	II	IIB IIA
		Shadow Lake	Red, maroon, and green, clastics, thin greenish shale and magnesium limestone with mud cracks. (Okulitch, 1939).	I	IB IA
Pre-CAMBRIAN	Grenville		Marble, granite, gneiss, and schist.		

ments of Middle Ordovician rocks of the Ottawa Valley.

GENERAL GEOLOGY

The Precambrian rocks of southwestern Ontario belong to the Grenville Province of the Canadian Shield and lie north of the present Paleozoic exposures (Fig. 1). The chief rock types include paragneiss, amphibolite, marble, schists, quartzite, and metavolcanics, and granites. Gabbro and syenite occur locally. The grade of metamorphism is in most cases, in the amphibolite and granulite facies. After the Grenville orogeny, peneplanation of the Precambrian shield took place, forming, in places, a palaeopeneplane with relief of 500 to 600 feet (Hewitt, 1965, p. 9).

The Paleozoic-Precambrian contact extends for a distance of over 180 miles from Midland on Georgian Bay to Kingston at the eastern edge of Lake Ontario (Fig. 1).

Over most of the area the Precambrian-Paleozoic contact surface is irregular and has a southwesterly slope with dips ranging from 20 to 30 feet per mile. The irregularity of the Precambrian peneplane results in variation of stratigraphic thickness of the Paleozoic rocks in some areas. In eastern areas, Precambrian inliers are surrounded by Ordovician rocks with relief of 100 feet or more. The Paleozoic rocks flanking these isolated Precambrian inliers many miles south of the Precambrian contact show quaquaversal dips (Kay 1942). A buried Precambrian hill produces arching of overlying Paleozoic sediments at Barriefield, near Kingston and also in the floor of the Point Ann Quarry of the Canada Cement Company near Belleville. Liberty (1960,

p. 7) described northeasterly trending normal faults affecting the Paleozoic rocks at Picton. Such lineaments in the Palaeozoic are continuous with fault trends in the Precambrian. As such north-east trending fault zones, active in Precambrian, times were possibly reactivated later.

Paleozoic beds of various units have been observed to rest directly on the surface of Precambrian monadnocks with flank dips as high as 22 degrees. The Potsdam Sandstone of Cambrian age overlying the Precambrian has been reported by various workers in areas adjacent to southwestern Ontario. Caley (1961, p. 98) considered that the unconformity marking the long interval between the Precambrian and the Ordovician rocks in southwestern Ontario, may not be one of continuous erosion. A part of Cambrian time might have been represented by sediments and subsequently eroded before the beginning of Ordovician times. The upper contact of the Middle Ordovician Black River Group lies between the thick bedded limestone of the Coboconk Formation and thin bedded units of the Kirkfield Formation of The Trenton Group. This passage from Coboconk to Kirkfield appears to be gradational and is marked by the appearance of a clastic fragmental calcarenite.

PURPOSE OF STUDY

A survey of recent geological literature clearly shows a growing interest in carbonate rocks. There is little published petrographic information on the Black River limestones in the study area.

The scope of the present study is limited to the following:-

1. Vertical measurement of thickness and description of twenty-two outcrop sections.

2. Collection of oriented samples at regular one foot intervals for orientation analysis of allochems.
3. General petrographic study of rock units from thin and peel sections and stained specimens.
4. Insoluble residue study, chiefly the heavy fraction.
5. Total carbonate analysis, determination of calcite/dolomite ratio.
6. Classification and correlation of outcrop sections.
7. Environmental reconstruction of the original condition of deposition.

SAMPLING

Twenty two outcrop sections were collected from an area extending from Georgian Bay in the west of Kingston in the east (Fig. 1). In each area, the thickest exposed section with maximum number of units was sampled. At Medonte, Hampshire Hills, Kennedy Bay, Bobcaygeon, Buckhorn and Havelock, only a few samples were taken at selected levels in order to check their petrographic and other proporties with the adjacent exposed sections.

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CHAPTER 2

REGIONAL MICROLITHOLOGIC CLASSIFICATION AND CORRELATION OF BLACK RIVER LIMESTONES

The mineralogical, chemical, macro- and micro-lithological data can be used to define four major divisions (numbered I, II, III and IV in ascending order) of the Black River Group in the outcrop of southwestern Ontario. Each division can be further subdivided into at least two sub-units; the uppermost unit has a three fold subdivision. The present classification and correlation of various major units and sub-units is based chiefly on the following premises:-

a) The units and sub-units are essentially lithostratigraphic entities.

b) Although local variations of physical, chemical or petrographic characters occur within a particular unit, correlation can be made across the area on the basis of broad similarity of lithology.

c) The four major units are of formal rock stratigraphic nature (A.A.P.G. Article 4 and 5, 1961) and marked by distinct lithologic constancy and mappability.

d) The sub-units are mostly of parastratigraphic type (Krumbein and Sloss, 1963, p. 333) i.e. lacking in mappability, so far as the large scale broad field features of the rocks are concerned.

e) A conspicuous and persistent clastic bed marking the uppermost limit of unit II rocks is a datum for regional correlation of all sections.

f) In the absence of the datum, sections are correlated with reference to other easily recognisable marker units separating the major units.

g) The contacts between different major units (particularly units III and IV) are conformable and show a sharp, (Plate 1, fig. 1) gradational, an alternation or a combined character (Winder 1958, p. 152). The local nature of paraconformities and non-conformities can be disregarded in establishing regional general lithologic breaks.

Classification and Correlation of Rock Units.

In establishing various lithologic classifications and correlations, main emphasis is placed on the observable field criteria and petrographic characters. Heavy mineral distributions and other previously described paleontologic evidences are used in further establishing the lateral persistency of units.

UNIT I

Complete development of unit I can be seen in the Marmora Quarry (Fig. 2, H) and Hwy. 401 road section near Hwy. 15 exit (Fig. 2, B) showing thicknesses of 43 feet and 13 feet respectively. The rocks are underlain directly by Precambrian rocks (Plate 2, Fig. 1). The upper limit is marked by a more frequently observed distinct green, dolomitic clastic unit ranging in thickness from 7 feet to 6 inches

Explanation of Plate 1

Fig. 1 White uniformly bedded, unit III rocks show a sharp contact with the overlying grey thin, wavy bedded rocks of unit IV. The section is exposed on Hwy. 36, 3 miles west of Burleigh Falls. An inlier of Precambrian rocks occursin the background, G.S.C. 134249.

Fig. 2 Alternate interbanded nature of unit III (thin, uniform white bed) and unit IV (thin, wavy bedded, grey, with white chert nodules) rocks. The section is exposed near Pidgeon Lake, Ontario, G.S.C. 134245.

PLATE I.

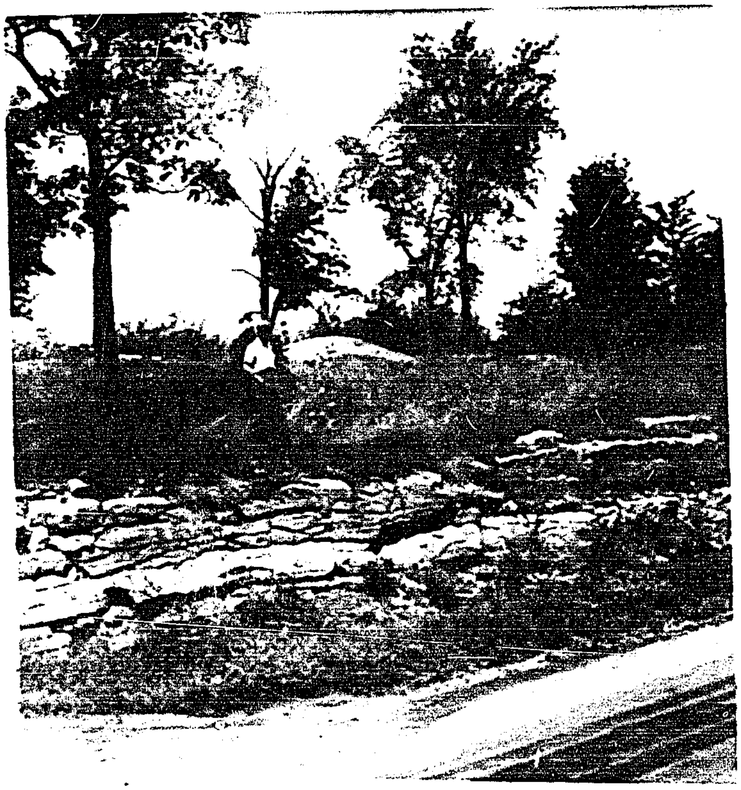


FIG. 1

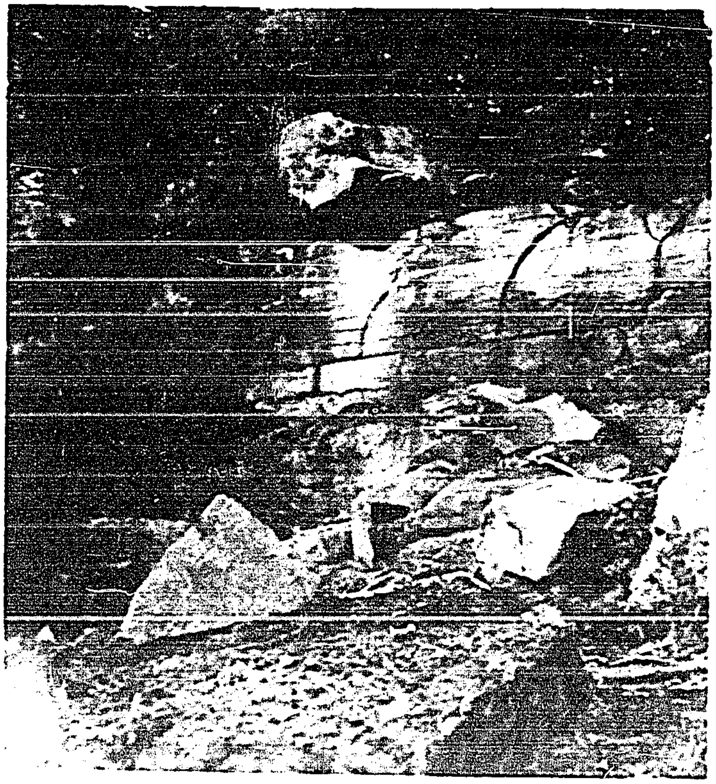


FIG. 2

Explanation of Plate 2

Fig. 1 Unconformable relation of Black River rocks (units I and II) with the Precambrian inlier. The section is exposed on Hwy. 401 near Hwy. 15 exit. Dashed line separates the rocks of unit IB from the upper white unit II A.

Fig. 2 Basal conglomerate between unit I A and Precambrian rocks. (Hwy. 401 section near Hwy. 15 exit).

PLATE 2.

FIG. 1

FIG. 2

(Fig. 2, A, B, C, H, K, N). The rocks generally lack sedimentary structures and fossils. The unit can be sub-divided into two sub-units which are described in the ascending order.

Unit I A:-

The unit can be seen in the Marmora quarry (Fig. 2, H), Burleigh Falls road section (Fig. 2, K), Coboconk road section (Fig. 2, N) and Hwy. 401 road section near Hwy. 15 exit (Fig. 2, B). The thickness varies from a maximum of 25 feet (Fig. 2, H) to a minimum of 6 feet (Fig. 2, B). The lower limit is marked by the Precambrian rocks and the upper contact underlies the thin bedded dolostone or calcitic dolostone unit. The rocks of this unit represent a dominantly shale and sandstone association, thick to thin bedded, green, red or maroon in colour. The important lithologic types include conglomerate, (Plate 2, fig. 2) calcareous arkosic sandstone, siltstone and shales with rare or minor intercalations of thin lenses and bands of carbonate rocks towards the top. The upper green clastic units exhibit frequent fucoid markings.

The coarse clastic materials are chiefly quartz, orthoclase, microcline, perthite and plagioclase. Rare carbonate-rich rocks show the presence of micritic matrix. Minor amounts of highly fragmented skeletal material may be seen in the carbonate-rich rocks of unit I A. Compositionally the carbonate-rich rocks are dolostone or calcitic dolostone.

The light minerals constitute a major portion of the insoluble residues. The road section at Coboconk (Fig. 3, N) has an exceptionally high light mineral content in the insoluble residues. The distribution of heavy minerals is irregular. Dolomite and celestite are common in most areas. Anhydrite may or may not be found. The distribution of pyrite is relatively lower in abundance as compared to dolomite and celestite.

Unit 1 B:

Complete development of the unit can be observed in the Marmora quarry, (Fig. 2, H), Burleigh Falls road section (Fig. 2, K), Coboconk road section (Fig. 2, N) and Hwy. 401 section (Fig. 2, B) with thicknesses of 17 feet, 9 feet, 11 feet and 7 feet respectively. Partial sections occur at Marmora quarry (Fig. 2, H), Burleigh Falls road section (Fig. 2, K), Coboconk road section (Fig. 2, N), Montreal Street section (Fig. 2, C), Hwy. 401 section (Fig. 2, B) and McGinnis and O'Conner quarry (Fig. 2, A). The upper limit is marked by the upper green clastic marker bed of unit I. The rocks are the first carbonate sedimentation. The rocks are pink to green in colour and include chiefly aphanocrystalline dolostone, calcitic dolostone or dolomitic limestone (Fig. 2, A, B, C, H, K and N), with frequent intercalations of clastics. At highway 401 section (Fig. 2, B) the carbonates are calcitic dolostone to dolomitic limestone in nature and include abundant coarse allochemical fragments. Burrow structures, colour mottling and thick to thin bedded nature are very characteristic features of the rocks. Micritic matrix constitutes the major portion of carbonate rocks. Areas lying to the east of Marmora (Fig. 2, A, B, C) have frequent occurrences of intraclasts and also pellets. High concentration of intraclast (55%), pellet

(23%), composite grains, sparry calcite cement (8%), finely branched filamentous algae (5.5%) can be recognized locally in Hwy. 401 section (Fig. 2, B). Most carbonate rocks show evidences of neomorphism (recrystallisation). Micrites and biomicrites constitute the major petrographic types (Fig. 4). The Hwy. 401 section (Fig. 4, B) is exceptional, because pelmicrites and intramicrites show a local development within unit IB. The section at Montreal Street (Fig. 4, C) also has minor concentration of pelmicrite and intramicrite.

The distribution of light minerals shows a similar trend as the underlying unit 1A. Some exceptionally high concentrations (6% or more) of light minerals were found in Marmora Quarry (Fig. 3, H). Local high concentrations of the heavies are particularly characteristic of areas such as Coboconk Road section (Fig. 3, N), Burleigh Falls Road section (Fig. 3, K) and Hwy. 401 section (Fig. 3, B). The distribution pattern of heavies is irregular in unit IB. Garnet, zircon, tourmaline, apatite, amphibole all seem to be common in most areas. Pyrite is a minor constituent while dolomite, celestite, and anhydrite may form the bulk of the heavy fractions (50% or more). In areas west of Marmora (Fig. 3, J to Q), anhydrite is absent or insignificant in the heavies.

UNIT II

The complete section of unit II can be observed in the Marmora Quarry (Fig. 2, H), Montreal Street section (Fig. 2, C) and McGinnis and O'Conner quarry (Fig. 2, A) with thicknesses of 42 feet, 20 feet and 28 feet respectively. The upper boundary of unit II is marked by a regionally persistent, thick to thin bedded, brown, weathering yellowish brown, carbonate-rich clastic or extremely argillaceous limestone bed ranging in thickness from 6 feet 6 inches (Fig. 2, F) to 6 inches (Fig. 2, I).

Pure carbonate is a distinguishing feature of the unit. Okulitch (1939) first reported the occurrences of recognizable fossils of ostracodes, trilobites, corals etc. within the rocks of unit II. The rocks of unit II have been subdivided into a lower unit IIA and an upper unit IIB.

Unit IIA:-

The rocks of unit IIA are developed in most western areas with the following exceptions: Longford (Fig. 4, O), Coboconk quarries (Fig. 4, L), Coboconk Road section (Fig. 4, H), Marmora Road section (Fig. 4, I). The rocks can be recognized in Montreal Street section (Fig. 4, C), Hwy. 15 section (Fig. 4, B) and McGinnis and O'Conner quarry (Fig. 4, A). The complete sections at Marmora quarry, Montreal Street and McGinnis and O'Conner quarry show thicknesses of 24 feet, 13 feet and 8 feet 6 inches respectively. The upper limit is marked by a thick to thin bedded, pure to argillaceous dolostone, calcitic dolostone or dolomitic limestone unit ranging in thickness from 1 foot to 2 feet. The rocks are for the most part thick bedded, massive to blocky in character, with minor association of interbedded thin, flaggy units. Chemically, the rocks are dolostone or calcitic dolostone with some dolomitic limestones (Fig. 2, H). The rocks are crypto- to finely crystalline in nature and may or may not show frequent thin shaly or silty intercalations in the basal parts. Hwy. 401 section near Hwy. 15 exit (Fig. 2, B) does not have dolomite in the carbonate rocks of unit IIA. Frequent large mud crack polygons (Plate 3, Fig. 1), showing selective dolomitization along the cracks, are very characteristic of the rocks of unit IIA. Towards the upper part, the rocks contain distinct needle-like molds of celestite. In rare instances, such molds can be observed in the overlying rocks of unit IIB (Fig. 2, I). Very fine laminations are also a characteristic feature of the rocks.

Micritic matrix is the chief constitutent of most rocks. Other allochems, if present usually form a very insignificant part of the rock, (10%). Biomicrite and intramicrite may or may not be represented in the rocks of unit IIA. Commonly, finely branching slender fan shaped, and boring algae can be recognized in most areas. Of all other organic groups, ostracodes seem to be important in some sections of the unit IIA. One example of extreme lithologic variability of unit IIA can be observed in the Uhthoff quarry section (Fig. 2, P). The basal beds are marked by the sudden appearance of various skeleton material, oöliths and sparry calcite cement. However micritic matrix still constitutes a dominant portion (50% to 75%) of the rocks.

Generally, the rocks show an appreciably low content of light minerals in the insoluble residues. Some local high values of the light mineral fractions can be observed in McGinnis and O'Conner (Fig. 3, A) and Marmora quarries (Fig. 3, H). Commonly, the detrital heavy minerals represent a minor distribution in the rocks. High concentrations of various detrital heavy components occur in Hwy. 15 section (Fig. 3, B) and Coboconk road section (Fig. 3, N). Pyrite is a minor constituent, whereas dolomite, celestite, and anhydrite form a major part (50% or more) of the total heavy residues. In areas west of Marmora, anhydrite tends to become insignificant or absent (Fig. 3, K,

Explanation of Plate 3

Figure 1	Large mud polygons in unit IIA rocks, exposed in a small quarry 1 mile west of Burleigh Falls on Hwy. 36. G.S.C. 10: 134271.
Figure 2	Frequent borings and intraclast in unit IIB rocks. The rocks are exposed in a small quarry 1 mile west of Burleigh Falls on Hwy. 36. G.S.C. 134270.

PLATE 3.

FIG. 1

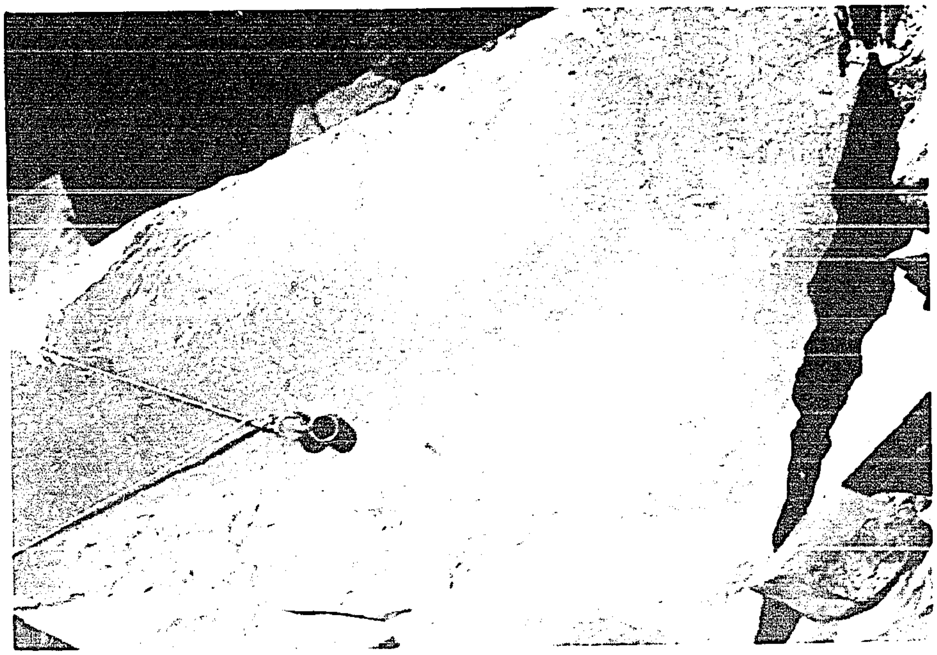


FIG. 2

N, P and Q).

Unit IIB:-

Complete development of the unit is seen in Port McNicol, Uhthoff, Marmora, quarries, Montreal Street section, and McGinnis and O'Conner quarry with thicknesses 9 feet 11 inches, 22 feet, 18 feet, 7 feet and 19 feet 6 inches respectively (Fig. 4, A, C, H, P and Q). The rocks are not developed in the Coboconk road section (Fig. 4, N), Coboconk quarry (Fig. 4, L), Coboconk road section (Fig. 4, H). East of Marmora, the unit is not seen in Point Anne quarry, (Fig. 4, G), 401 section (Fig. 4, D) and Hwy. 401 section (Fig. 4, B). The upper limit is marked by the argillaceous marker bed of unit II.

Dolostone and calcitic dolostone may form a major portion of the rocks in some sections e.g. Port McNicol, Uhthoff quarries (Fig. 2, P and Q), Montreal Street and McGinnis and O'Conner quarry sections (Fig. 2, A and C). Commonly, these dolomite-rich lithologies exhibit various relict structure of the host rocks and mottlings. The rocks of unit IIB show buff to light brownish colour and are resistant to differential weathering. Thick bedded, massive to blocky strata are a diagonstic feature of the rocks of the upper part of unit IIB. Minor intercalations of shaly or silty beds may also be seen. The rocks in Longford quarry (Fig. 2, O) do not exhibit various features as mentioned above, but are aphanocrystalline and thin bedded limestone. The rocks of unit IIB are also characterized by isolated masses of abundant coarse sparry calcite or gypsum (rare) filled nodules. In Kingston areas frequent occurrence of nodular solution breccia can be seen.

Micrite is the major petrographic type in unit IIB. Biomicrites, pelmicrites, and intramicrites are common (Fig. 4). The Marmora area has a local association of pelsparite, allochem-rich and other mixed lithologies (Fig. 4). Kingston areas reveal greater abundance of neomorphic (recrystallised) carbonate lithologies (Fig. 4).

Various desiccation features and boring structures (Plate 3, fig. 2) are common. The association of extremely elongated, flat, rounded, intraclast fragments is a characteristic feature of unit IIB rocks. Micritic matrix forms a major part of the petrographic constituents, however local occurrence of sparry calcite cement is not uncommon. Most areas show an abundance of intraclasts, frequent presence of pellets and rare oöliths; boring, filamentous, and slender branching algae are the most commonly occurring skeletal elements in these rocks. In many sections, corals make their first appearance in the rocks. Other organisms may also show minor local concentration.

The distribution of light minerals does not show any marked changes. Tourmaline, is distributed in minor amounts in most sections. Pyrite shows an appreciable increase. Dolomite and celestite constitute a major part of the heavy residues. In areas east of Marmora quarry, celestite, seems to be dominant over dolomite (Fig. 3, A to G) whereas in areas west of Marmora dolomite tends to be more abundant (Fig. 3, Q to G) at this stratigraphic level. Areas west of Marmora quarry (except Burleigh Falls road section, fig. 3, K) exhibit the first and common occurrence of anatase in the heavy residues.

UNIT III

Complete sections of unit III in Uhthoff, Marmora, Roblindale, Napanee quarries and Marmora Road sections show thicknesses of 15 feet, 32 feet, 31 feet 3 inches, 28 feet 3 inches and 29 feet respectively (Fig. 4, E, F, H, I and P). The upper boundary is sharply defined by the thin bedded, pure to argillaceous limestone bed (unit IV) showing a typical wavy bedding and frequent association of stromatolites. The rocks of unit III are divided into a lower unit IIIA and an upper unit IIIB. On weathered surface, the rocks exhibit a typical chalk white colour.

Unit IIIA:-

Complete sections at Uhthoff, Marmora, Roblindale, Napanee, McGinnis and O'Conner quarrier and Marmora Road sections expose the following values: 5 feet 10 inches, 21 feet, 24 feet 10 inches, 16 feet, 7 feet 10 inches and 18 feet 6 inches respectively (Fig. 4). Coboconk (Fig. 2, N) and Burleigh Falls (Fig. 2, K) Road sections do not expose unit IIIA beds. The upper boundary is characterised by thick to thin bedded, commonly argillaceous, dolomitic limestones of unit IIIB. These upper beds have appreciable amounts of dolomite content in sections at Port McNicol, Uhthoff quarries (Fig. 2, P and Q), Montreal Street (Fig. 2, C) and McGinnis and O'Conner quarry (Fig. 2, A). The argillaceous intercalations are lacking in the above sections. Coboconk quarry and road sections also mark the absence of argillaceous intercations of the upper marker beds (Fig. 2, L, and M). The rocks of unit IIIA represent an essentially pure coarse to cryptocrystalline limestone or dolomitic limestone. Usually, the rocks are devoid of argillaceous intercalations and show pink to grey colours on a fresh surface. Towards the base the rocks are thick bedded (1 foot) and grade into thin bedded units upward. These rocks exhibit the first persistently developed coarse allochemical materials e.g. intraclasts,

Explanation of Plate 4

Figure 1 Exceptionally high concentration of *Tetradium cellulosum* in unit IIIA micrites. The rocks are exposed in a road cut 1 mile north of Rockcroft, Ontario. G.S.C. 134246.

PLATE 4.

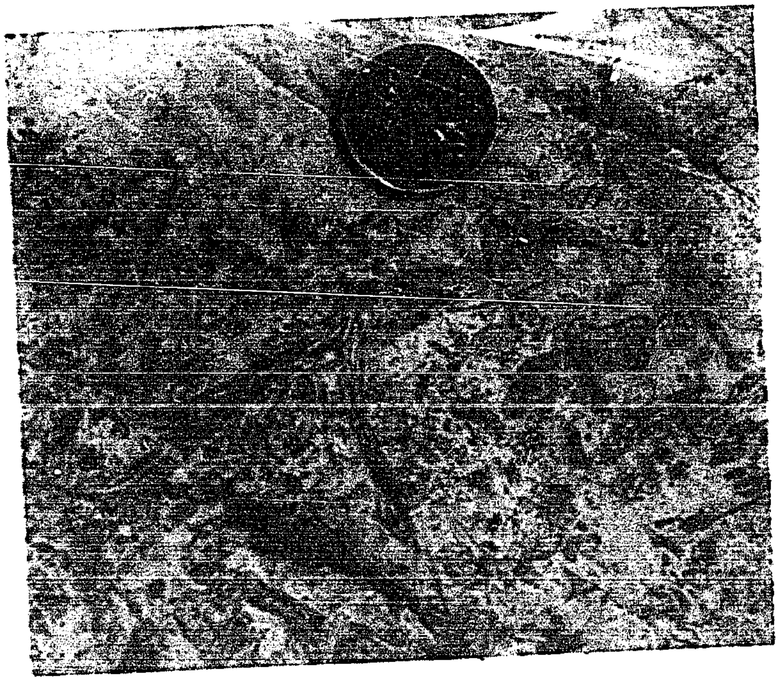


FIG.1

corals, (Plate 4, fig. 1) oöliths and other skeleton particles. Commonly, the coarser allochems occur as alternate continuous thick bands and irregular lenses within aphanocrystalline micrites. These rocks display the characteristic "birdseye structure". Small mud crack polygons and ripple marks can be seen in places.

The rocks frequently contain sparry calcite cement, intraclasts, pellets, oöliths, and algae (crust forming type). The presence of composite grains is also recognized. Various skeleton constituents show a wide variation in distribution. Locally corals become very abundant. Brachiopods and pelmatozoan debris and other skeletal fragments are frequent in the rocks. Chemically the rocks can be grouped into calcitic dolostone, and dolomitic limestone types. Various diagenetic alterations such as dolomitization and dedolomitization make identification of the allochems difficult in several locations e.g. Montreal Street section (Fig. 2, C), McGinnis and O'Conner and Uhthoff quarries (Fig. 2, A and P). Extremely variable lithology is a characteristic feature of unit IIIA rocks. Biomicrites, intramicrite, and pelmicrites, are abundant. Sparry calcite-cement rich rocks also are frequent. Spar-rich petrographic varieties include oösparite, and other allochem-rich and mixed types. The distribution of all petrographic types may not persistently develop in each section; however, the general variable character is reflected in most sections (Fig. 4). In areas east of Napanee, the characteristic variable petrographic nature of the rocks may not be easily recognized due to extreme dolomitization and dedolomitization. Frequent relict allochems suggest the probable abundance of various allochems in the original sediment.

The light minerals show irregular distributions in most sections with some local high concentrations. The heavy minerals mark a considerable change in the distribution pattern. Garnet, zircon and tourmaline, are locally frequent except in sections at Napanee quarry and Hwy. 401 (Fig. 3, D and E). A local increased concentration of staurolite was found in the Marmora area (Fig. 3, H and I). Pyrite has a marked increase in distribution whereas dolomite has a decreasing trend as compared to the underlying units; celestite is a minor constituent. However, exception to the above relation can be observed in Point Anne quarry (Fig. 3, G), where pyrite-dolomite relation is reversed i.e. Pyrite shows an appreciable decrease while dolomite has an increase in occurrence.

Unit IIIB:-

Unthoff quarry, (Fig. 2, P), Coboconk quarry and road sections (Fig. 2, L and M), Marmora quarry, and road sections (Fig. 2, I and H), Point Anne, Robinlindale and Napanee quarries (Fig. 2, G, F, F, G) and 401 section (Fig. 2, D) have notable development of unit IIIB with thicknesses of 9 feet, 9 feet, 12 feet, 10 feet 5 inches, 10 feet 10 inches, 15 feet, 6 feet 8 inches, 12 feet, and 17 feet 6 inches respectively. The upper limit is marked by the wavy, thick to thin bedded, massive coarse, weathered brown or yellowish brown rocks of unit IV. Unlike unit IIIA, the rocks of unit IIIB are thin bedded in nature. Intercalation of thin shaly partings and laminae may be a common feature of the rocks.

Texturally, the rocks are very fine to coarse grained and contain a wide range of allochemical particles in varying amounts. Sparry calcite cement is common, alternate interbanding of thin micrites and coarse spar-rich rocks are very frequent. They display grey to black colours. In Uhthoff, Napanee and McGinnis and O'Conner quarries (Fig. 2, A, E and P), the rocks are characterised by the general lack of coarser allochems, or an abundance of crystalline carbonate minerals. The rocks exhibit cross-bedding, ripple marks and channel filled structures.

The allochems constitute a significant part of all petrographic types. Pellets are abundant in most, sections. The association of oölith and sparry calcite becomes increasingly abundant. Locally, bryozoa may have a minor increase and corals become very persistent. Commonly, the rocks are dolomitic limestone to pure limestone in nature. However, dolomite-rich varieties are not uncommon in areas of intense diagenetic alterations.

Micrite and biomicrite are less common, whereas sparry calcite and allochem-rich lithologies are increasingly abundant. Oösparites and mixed lithologic types are commonly associated in the rocks of unit IIIB. Like the immediate underlying units, intense diagenetic changes have caused obliteration of various allochems and other textural features in many areas for example, Napanee and Uhthoff area.

The light minerals have an irregular distribution in most sections. The heavy minerals show a considerable change in the distribution. Pyrite is abundant in most sections. Unlike unit IIIA, the Napanee area (Fig. 3, D and E) and Point Anne quarry (Fig. 3, G) contain garnet, zircon and tourmaline in the rocks of unit IIIB. Celestite is an important constituent of heavy fractions in most areas.

Explanation of Plate 5

Figure 1	Characteristic thin, wavy bedded nature of unit IV A rocks with black chert nodules and lenses. The section is exposed just south of Pigeon Lake, near Lakehurst, Ont. G.S.C. 134238.
Figure 2	A flat limestone exposure showing frequent presence of stromatolites in the rocks of unit IV B. The rocks are exposed just east of McCrackens Landing, Ontario. G.S.C. 134283.

PLATE 5.

G.1

FIG.2

UNIT IV

Complete exposure of unit IV can be seen at Point Anne and Roblindale quarries with thicknesses of 28 feet 6 inches and 24 feet respectively (Fig. 2, F and G). The upper contact is sharp with the coarse, thin bedded, allochem-rich argillaceous units of the overlying Trenton rocks.

The rocks of unit IV have been subdivided into the following three units: Unit IVA, unit IVB and unit IVC.

Unit IVA:-

Complete sections of the unit in Marmora, Point Anne, and Roblindale and Napanee quarries show thicknesses of 10 feet, 9 feet, 9 feet, 6 feet 4 inches and 8 feet 6 inches respectively. Unit IVA cannot be recognized at Port McNicol, Longford quarries, Burleigh Falls, Montreal Street, Hwy. 401 Road section and McGinnis and O'Conner quarry (Fig. 4, Q, O, K, L, C, B and A). The upper boundary underlies the thin, uniformly-bedded limestone beds without black cherts. The rocks are chiefly fine to cryptocrystalline limestone with lenses and bands of coarse skeletal- and intraclast-rich material. The lower beds show distinct wavy bedding with stromatolites (Plate 5, fig. 1). Towards the top, the rocks grade into horizontal thick bedded units, with frequent occurrence of black chert nodules. Commonly, the chert nodules can be observed in the Marmora and Napanee areas.

Usually micritic matrix predominates over other constituents with an abundance of pellets and less amounts of intraclasts. In some places corals and bryozoans are in great abundance. Massive, cylindrical algae also are a characteristic skeletal constituent of the rocks. Other allochemical constituents may show minor and irregular distribution in unit IVA. Dolomitic limestones and pure limestones are the chief chemical types in unit IVA rocks. In areas of diagenetic alterations, extremely dolomite-rich lithologies are not uncommon. Micrite-rich lithologies become increasingly prominent, while pelmicrites and intramicrites have a frequent association.

A slight increase of light minerals can be recognized in most areas. Garnet, zircon, and tourmaline along with amphiboles, are important constituents of the detrital heavy mineral fractions. Pyrite, and dolomite may constitute a significant part of the total heavies. Pyrite exhibits a general decrease in abundance whereas celestite has a highly variable distribution.

Unit IVB:-

The unit can only be seen in the Marmora, Point Anne, Roblindale quarries (Fig. 2, H, G, F) and Hwy. 401 road section (Fig. 2, D) with total thicknesses of 20 feet, 8 feet, 4 feet 10 inches, and 12 feet respectively. A partial development ofthis unit can also be observed in Napanee quarry. The upper limit (not well defined) is gradational and underlies thin to thick bedded fine limestones of unit IVC. The rocks are thick bedded, grey, pink, massive, blocky, fine to medium grained in character. Occasional lenses and bands of coarse allochem-rich materials are frequently observed in the micrite-rich rocks. The presence of coarse white calcite filled burrow structures and ripple marks may be seen in some places.

The rocks are characterized by a high concentration of micritic matrix. Sparry calcite cement, if present, constitutes only a minor portion of the rock. Rocks in the Marmora quarry (Fig. 2, H) have 10%

to 12% of sparry calcite cement. In most sections, the pellets become abundant and characteristic features whereas intraclasts are less common. Corals, chiefly the massive cerioid (compound) type (Plate 5, fig. 2) and pelmatozoan fragments are frequent. Massive cylindrical bryozoans are also very characteristic features of the rocks. The rocks are chiefly pure limestone or dolomitic limestone types. Pelsparite and other mixed petrographic types seem to be of rare (Fig. 4). The abundance of neomorphic (recrystallised) types can be persistently seen in the rocks of unit IVB. An exceptional high concentration of neomorphic type lithology can be observed in Roblindale quarry (Fig. 4). The spar-rich lithologies are only developed in Marmora quarry (Fig. 4).

Garnet, tourmaline, zircon and amphiboles show a slight increase in the distribution as compared to the underlying unit IVA except Napanee areas. Pyrite, dolomite and celestite constitute a major portion of the heavy residues. Pyrite has a greater abundance than dolomite and celestite.

Unit IVC:-

The rocks of unit IVC can only be seen in Marmora, Point Anne, Roblindale quarries, and Hwy. 401 road sections (Fig. 2, H, G, E and D). The measured thicknesses of the unit at Point Anne and Roblindale are 10 feet, 6 inches, and 10 feet respectively. The upper boundary of the unit underlies the coarse, thin bedded, argillaceous units of Trenton rocks. The rocks are thick to thin bedded with greater abundance of coarser bands and lenses of allochem-rich materials. The rocks show occasional ripple marks, cross-bedding and frequent coarse spar-filled burrow structures and rare desiccation features.

The rocks are marked by the common abundance of sparry calcite cement, though micritic matrix still remains as a major constituent. The pellets are in increasing amounts. Brachiopods, and pelmatozoan debris are common in most sections and show increasing abundance. Chemically the rocks are pure limestone or dolomitic limestone. Some occurrences of calcitic dolostones are not unusual, especially in areas of diagenetic alterations. Micrites, biomicrites and pelmicrites become conspicuously abundant lithologic types (Fig. 4). Pelsparite, allochem-rich and other mixed types were observed only in Marmora quarry (Fig. 4). Point Anne and Roblindale quarries show the presence of abundant neomorphic (recrystallised) type lithologies.

Light minerals show a slight increase in abundance. The detrital heavy minerals exhibit irregular distribution with local high values in Marmora (Fig. 3, H) and Point Anne quarries (Fig. 3, G). Pyrite represants a dominant constituent of the total heavy residues and shows a greater abundance than dolomite and celestite. The Napanee area has a marked departure of heavy minerals distribution from other areas. Both dolomite and pyrite constitute a major portion of the heavy residues. Other minerals show very minor, irregular distribution.

Trenton Rocks

The Trenton rocks overlie the topmost beds of unit IV. The change of unit IV beds to fine argillaceous, thin bedded rocks of the Trenton Group is marked by a sharp contact. Frequent extremely shell-rich lenses and bands are characteristic of the Trenton rocks. Pelmatozoan debris has an exceptionally high concentration in the skeleton-rich fractions.

Conodont distribution

A preliminary study of the distribution of conodont genera in Marmora quarry and road sections suggests a four fold classification as discussed and established in the present section. The distribution of conodont genera in Marmora areas exhibits the following characters:

a) The genus *Cardiodella* first appears in unit IB.

b) *Polycaulodus*, *Microcoelodus* and *Pteroconus* appear in unit IIA and become abundant in units II and III and less abundant in unit IV.

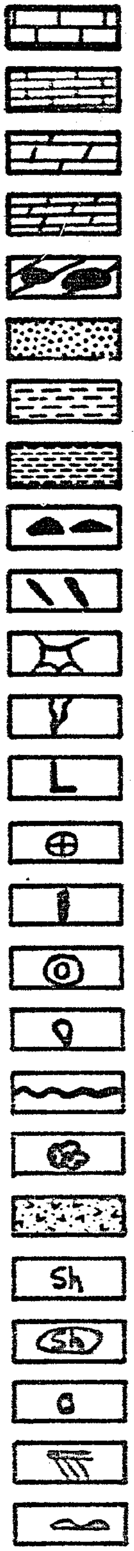
c) *Curtognathus* is restricted in unit III.

d) *Panderodous* is characteristic of unit IV, and appears for the first time in unit IVA.

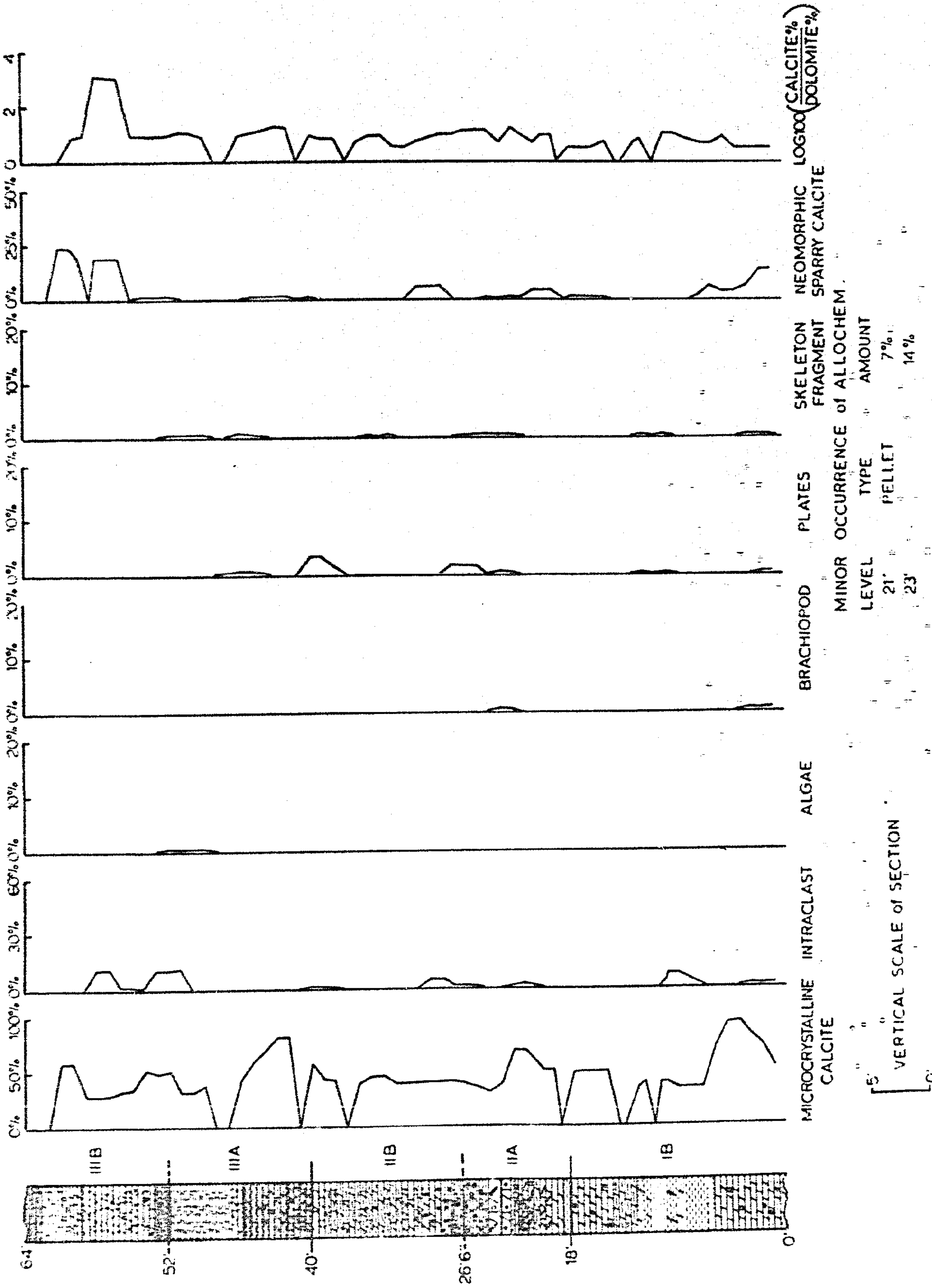
e) Exceedingly large number of broken forms are restricted in unit III.

Barnes (1967) has recently described similar results from the study of conodont distributions in the Black River rocks of the Ottawa Valley.

GENERAL LITHOLOGIC INDEX



Limestone Thick Bedded
Limestone Thin Bedded
Dolostone Thick Bedded
Dolostone Thin Bedded
Conglomerate
Sandstone
Siltstone
Shale
Chert
Celestite Molds, Needles Etc.
Mud Polygons
Desiccation Features (other)
Fine Lamination
Coral
Intraclast
Oölith
Birdseye Structure
Wavy Bedding
Stromatolites
Precambrian Rocks
Shell Rich Bands
Shell Rich Lenses
Calcite Nodules
Cross Bedding
Ripplemark



MINOR OCCURRENCE of ALLOCHEM.

LEVEL	TYPE	AMOUNT
21'	PELLET	7%
23'		14%

FIG.2B MICROLITHOLOGIC VARIATIONS in ROAD CUT on HWY 401 and HWY 15 EXIT.

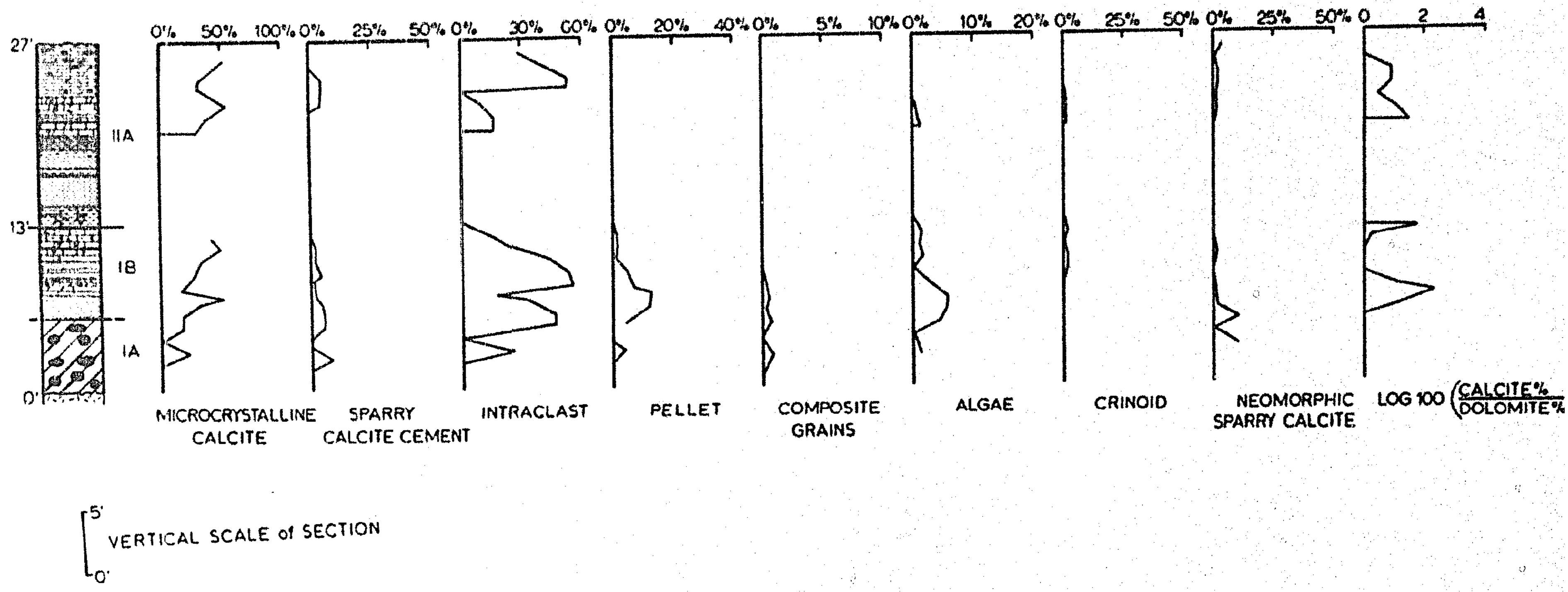
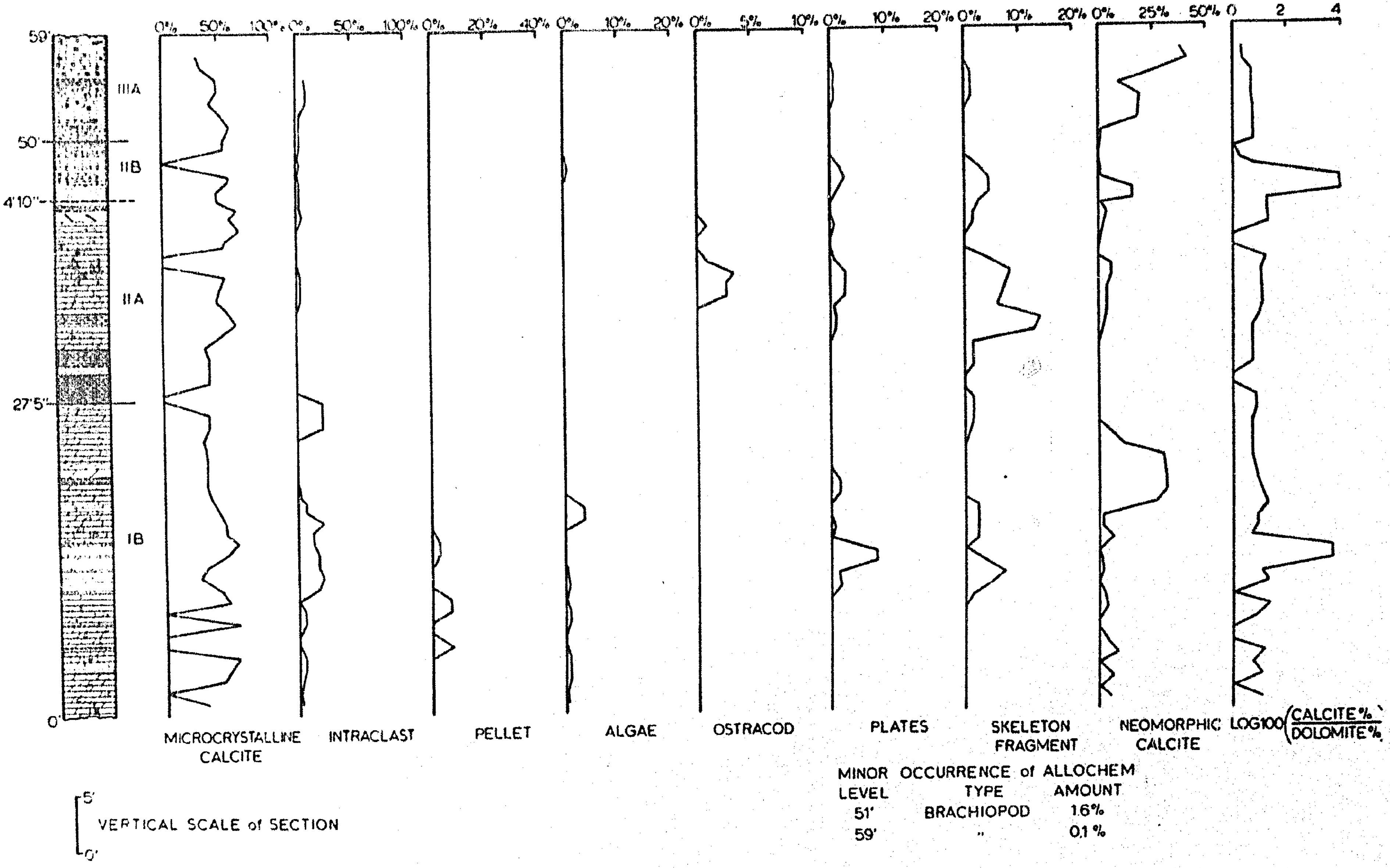


FIG.2[illegible] MICROLITHOLOGIC VARIATIONS in ROAD SECT on HWY 401 at MONTREAL ST EXIT, KINGSTON.



MINOR OCCURRENCE of ALLOCHEM

LEVEL	TYPE	AMOUNT
51'	BRACHIOPOD	1.6%
59'	"	0.1 %

FIG 2D MICROLITHOLOGIC VARIATIONS in ROAD CUT on HIGHWAY 401, 5 MILES EAST of NAPANEE.

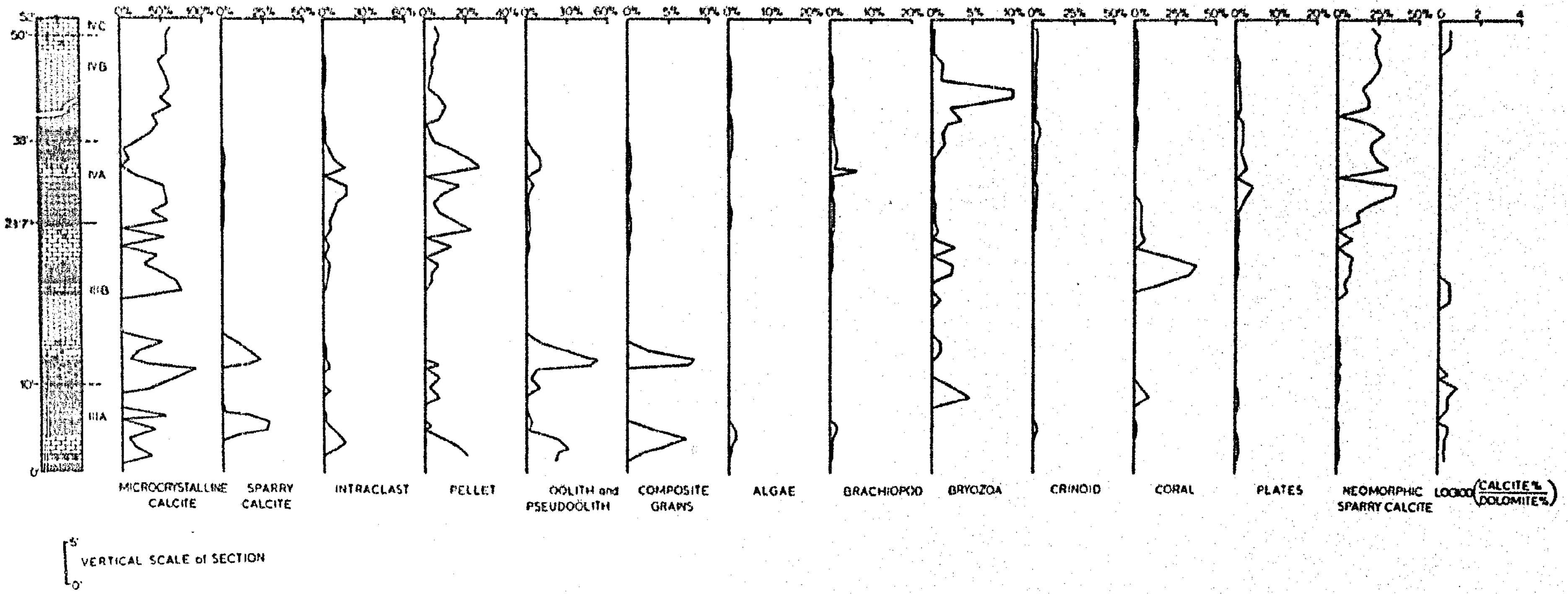
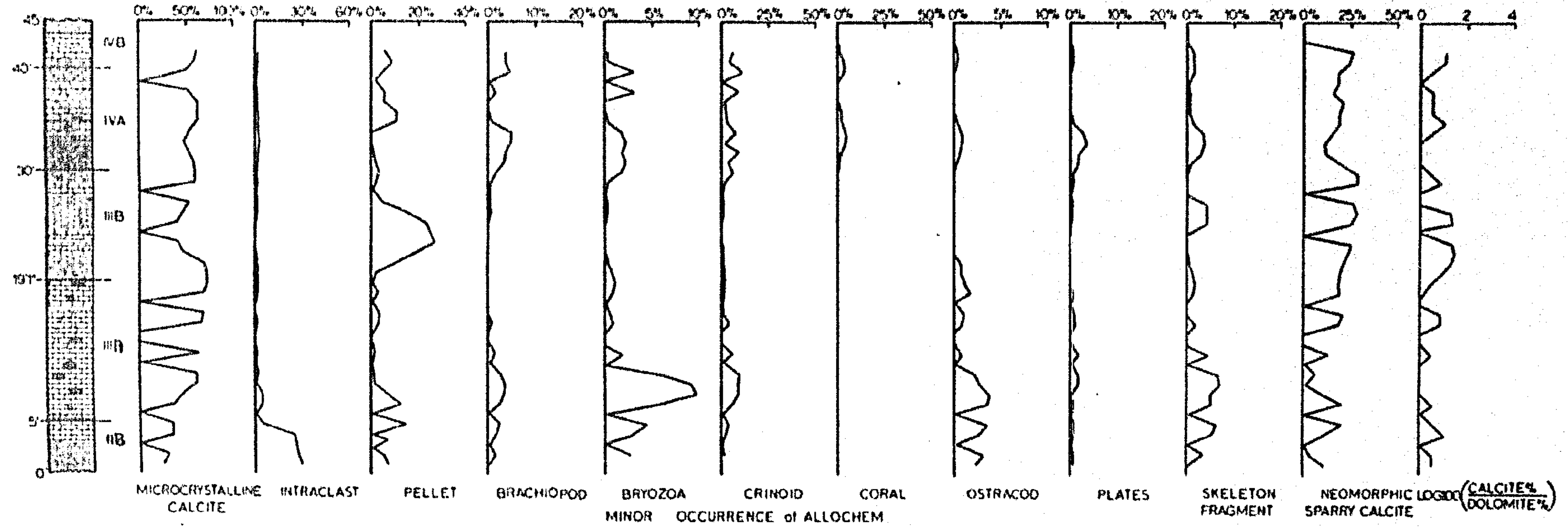


FIG.2E MICROLITHOLOGIC VARIATIONS in NAPANEE QUARRY.



MINOR OCCURRENCE of ALLOCHEM

LEVEL	TYPE	AMOUNT
1'	OÖLITH and PSEUDOOÖLITH	13%
2'	"	"
1'	ALGAE	0.167%

FIG. 9 MICROLITHOLOGIC VARIATIONS in ROBLINDALE QUARRY

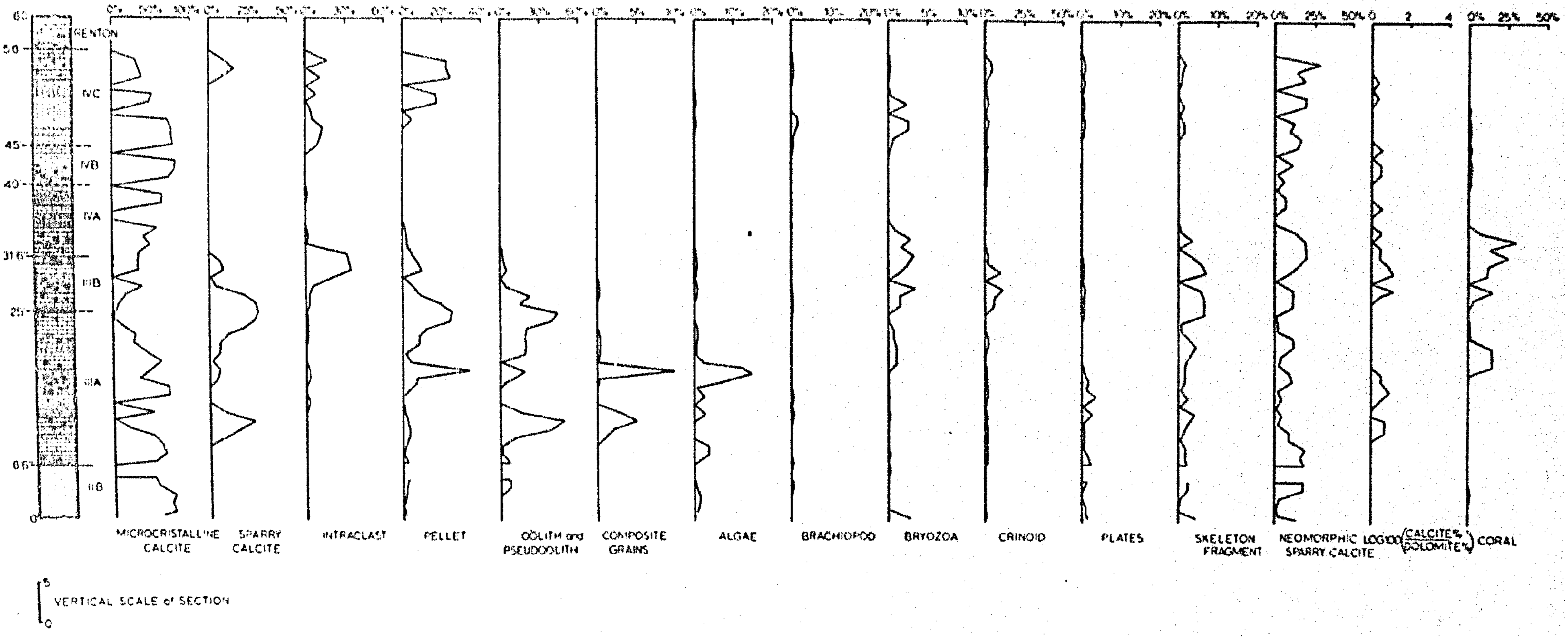


FIG 26 MICROLITHOLOGIC VARIATIONS in POINT ANN QUARRY

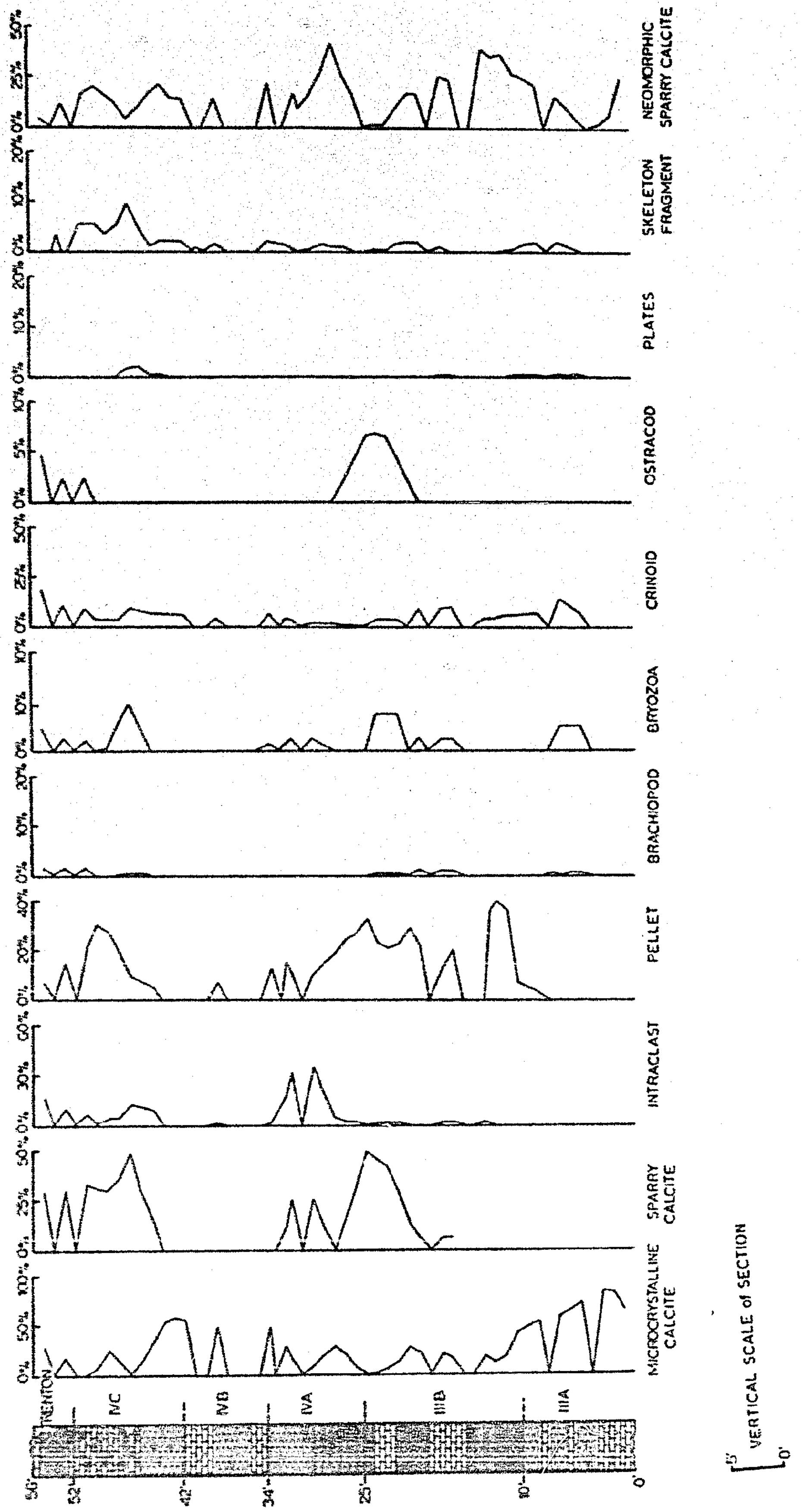


FIG. 2H. MICROLITHOLOGIC VARIATIONS in MARMORA QUARRY.

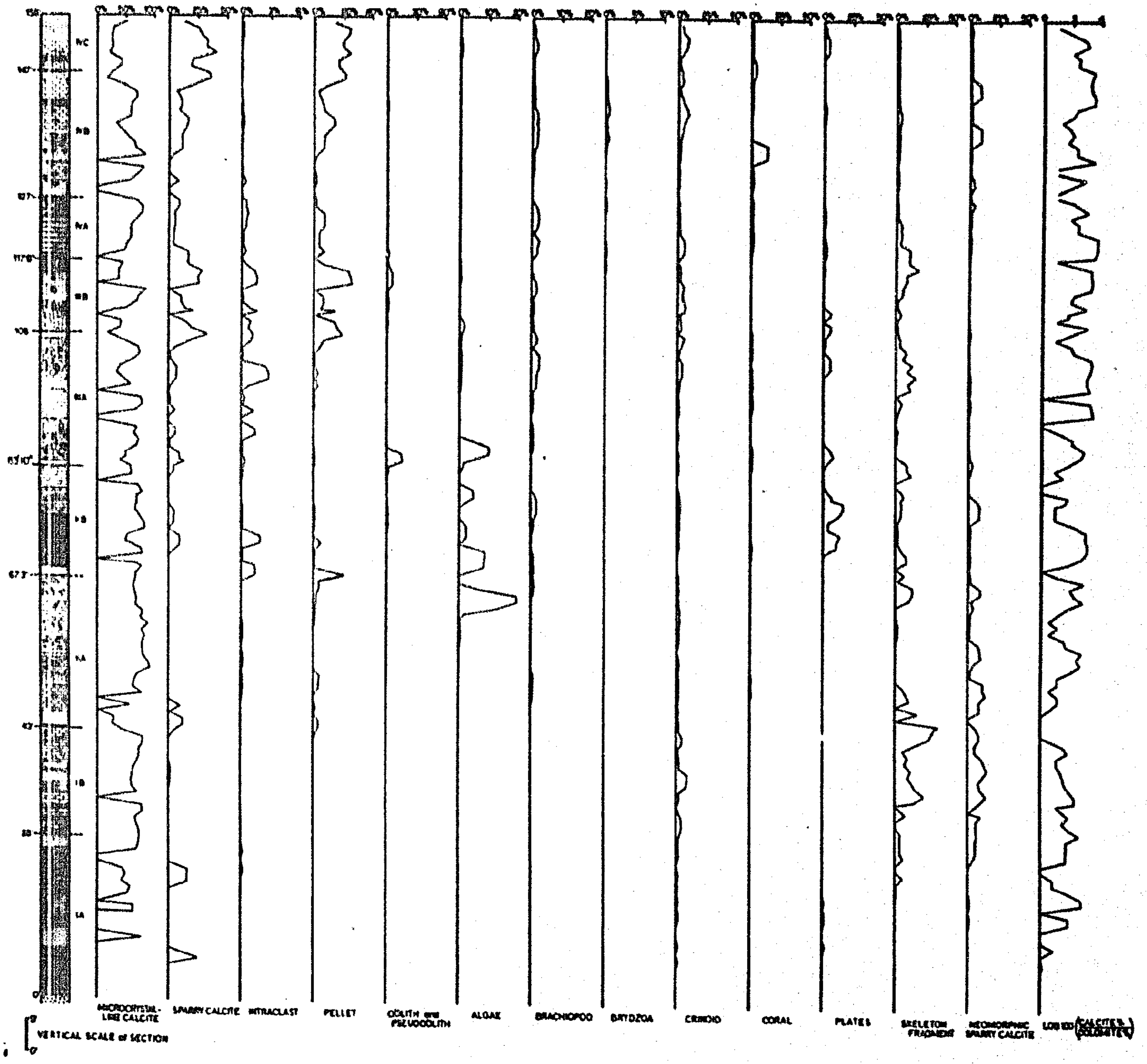
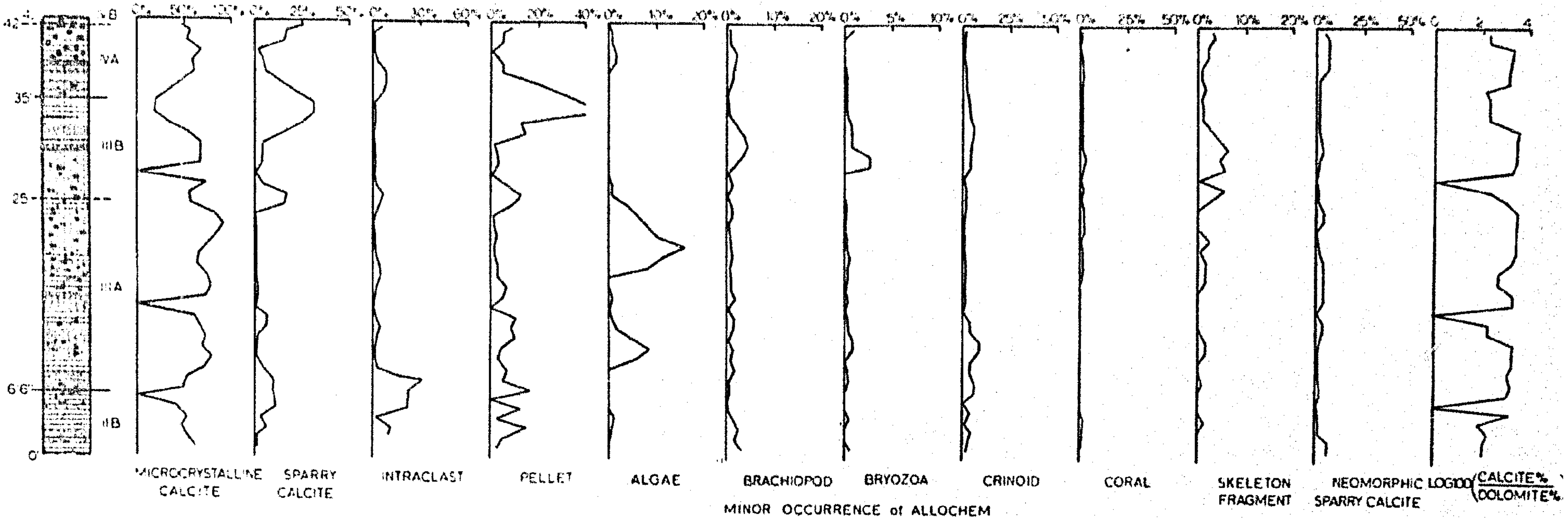


FIG.21 MICROLITHOLOGIC VARIATIONS in MARMORA ROAD CUT



MINOR OCCURRENCE of ALLOCHEM

LEVEL	TYPE	AMOUNT
4'8"	OOLITH and PSEUDOOLITH	2%
5'	"	2%
6	"	2%

FIG.2J.MICROLITHOLOGIC VARIATIONS in BURLEIGH FALLS ROAD CUT.

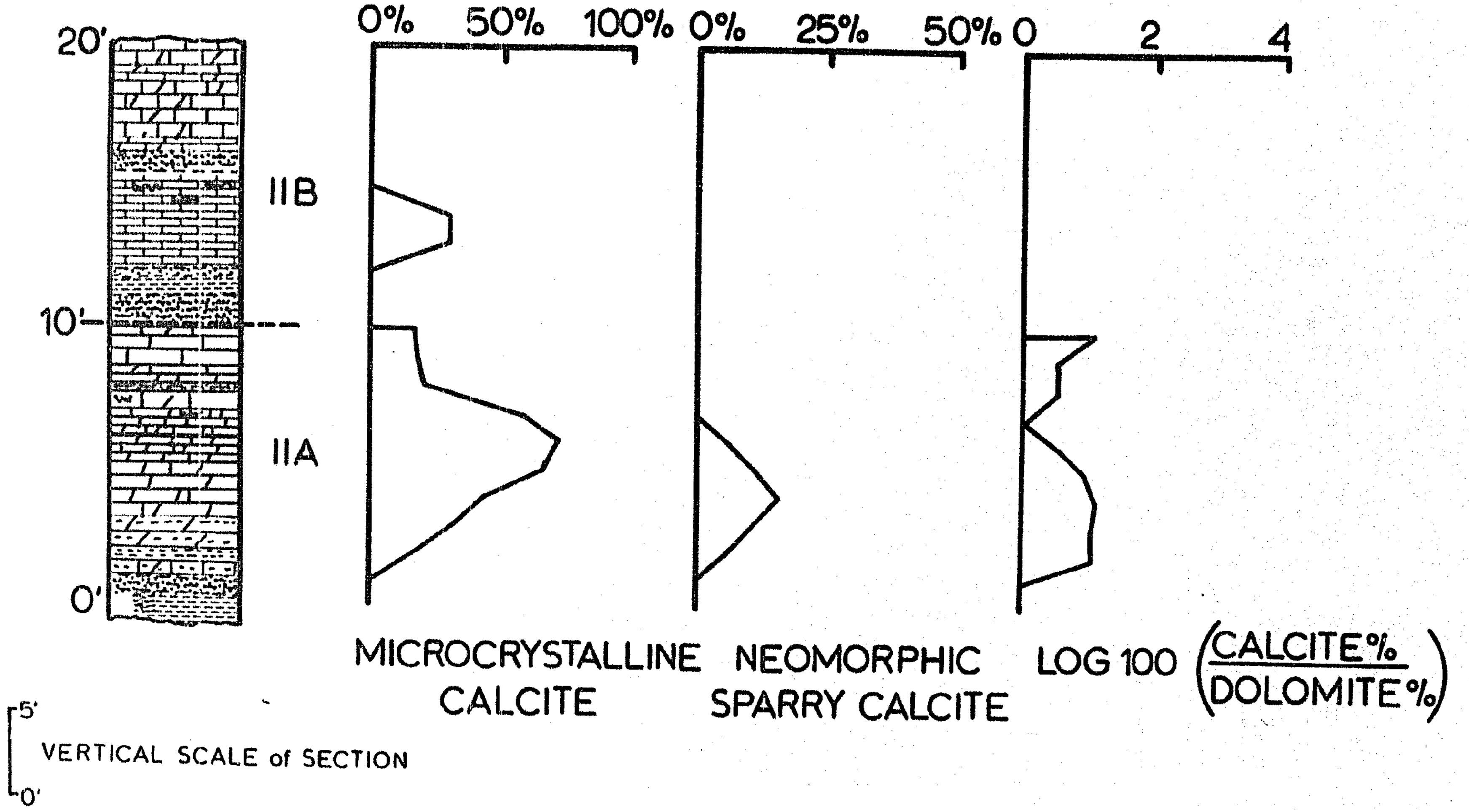


FIG.2K.MICROLITHOLOGIC VARIATIONS in BURLEIGH FALLS ROAD CUT

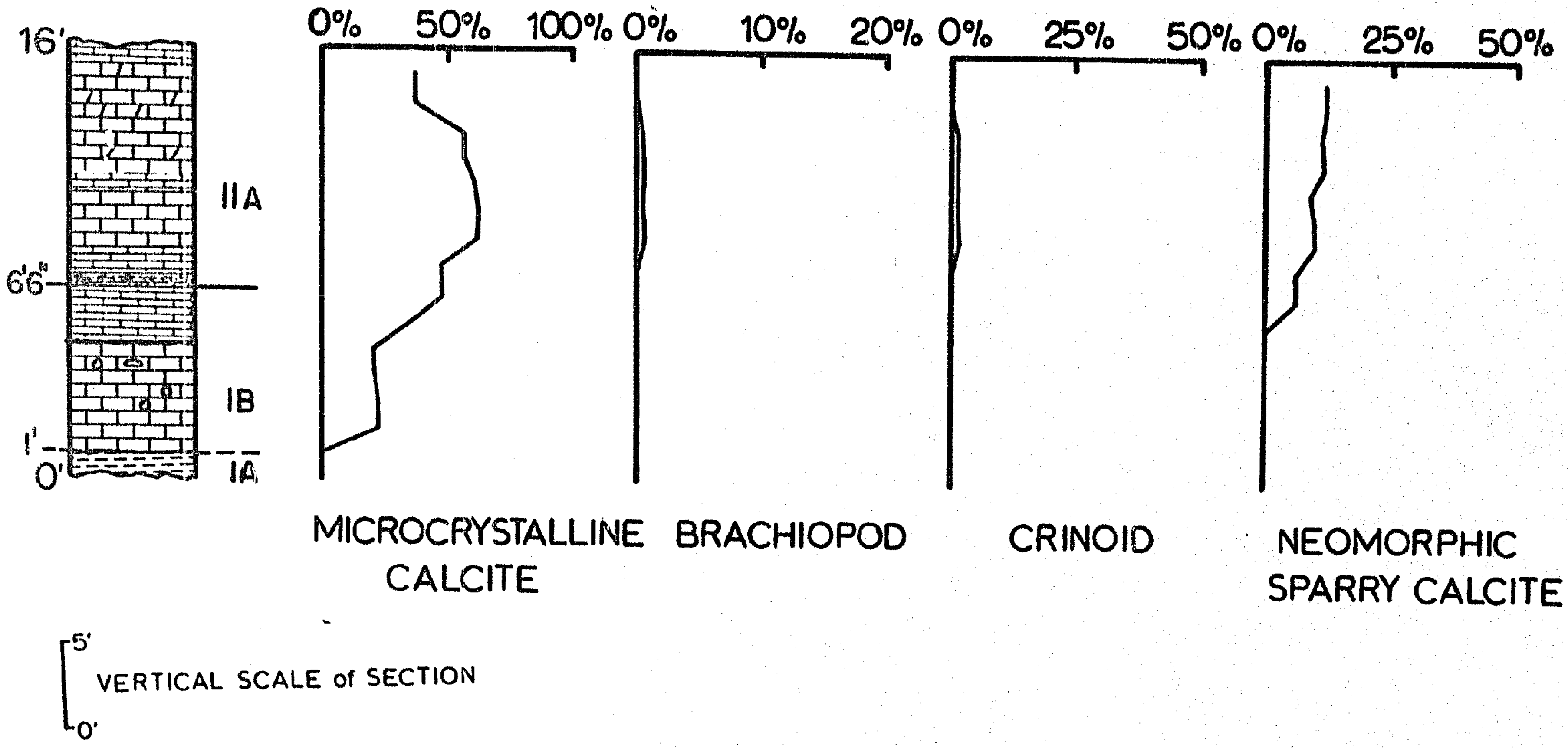


FIG 21. MICROLITHOLOGIC VARIATIONS in COBOCONK EAST QUARRY.

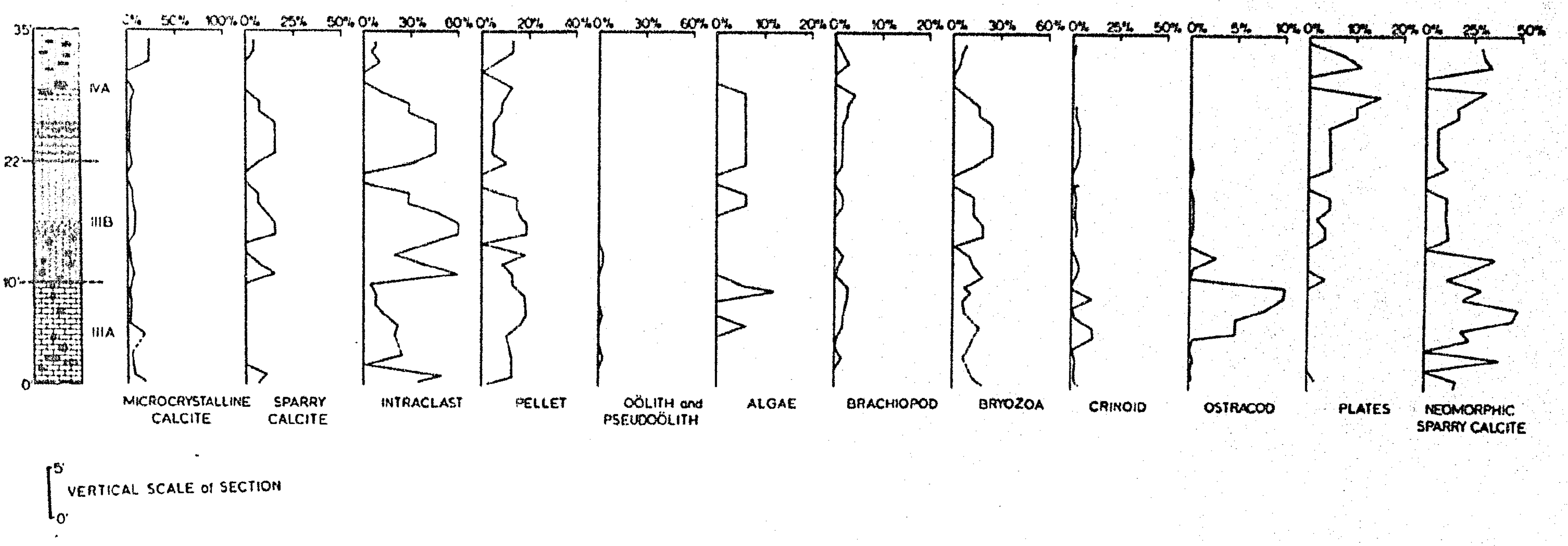


FIG.2M MICROLITHOLOGIC VARIATIONS in COBOCONK ROAD CUT

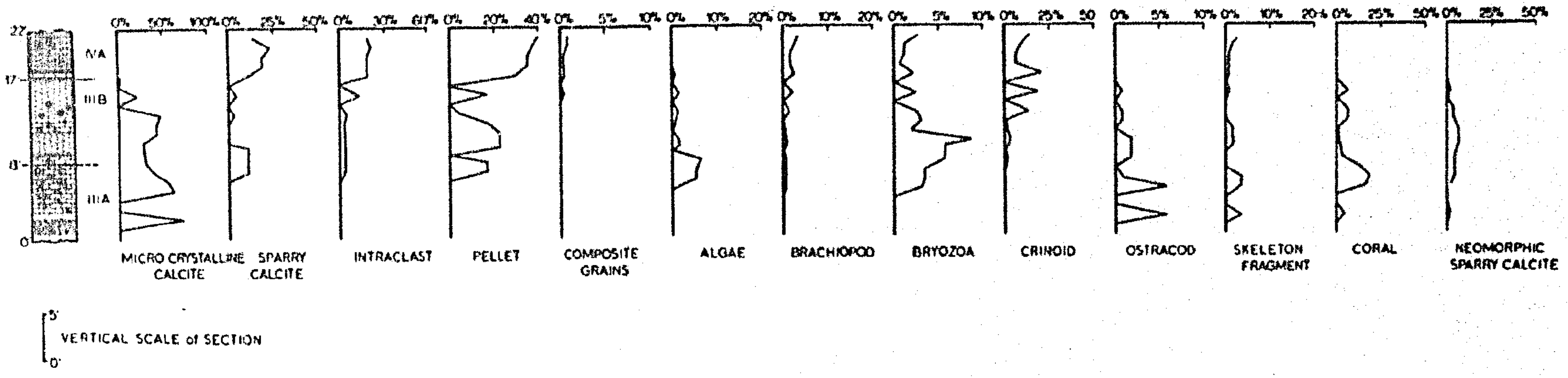


FIG.2N. MICROLITHOLOGIC VARIATIONS in ROAD CUT on HWY 35 N, COBOCONK

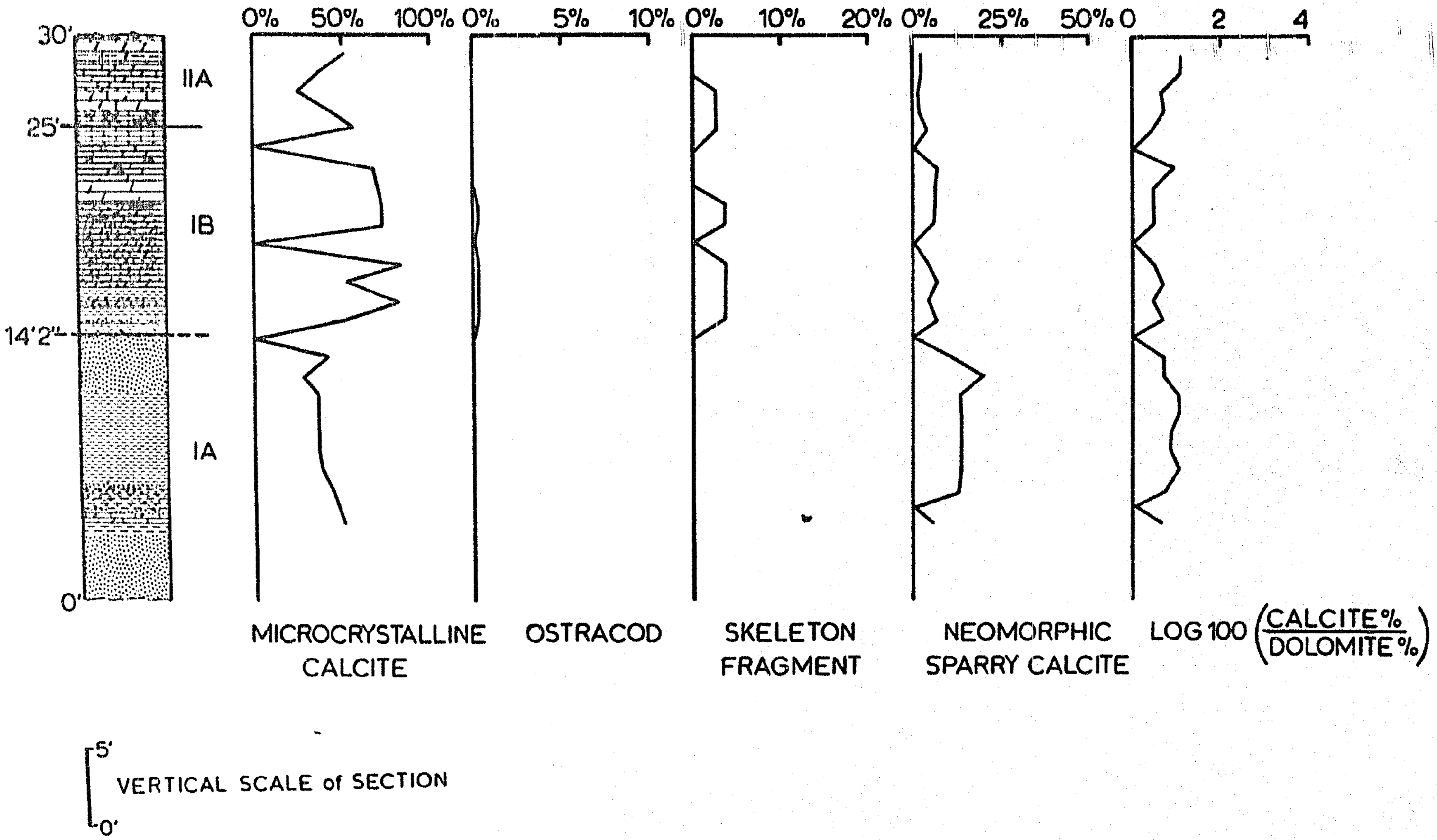
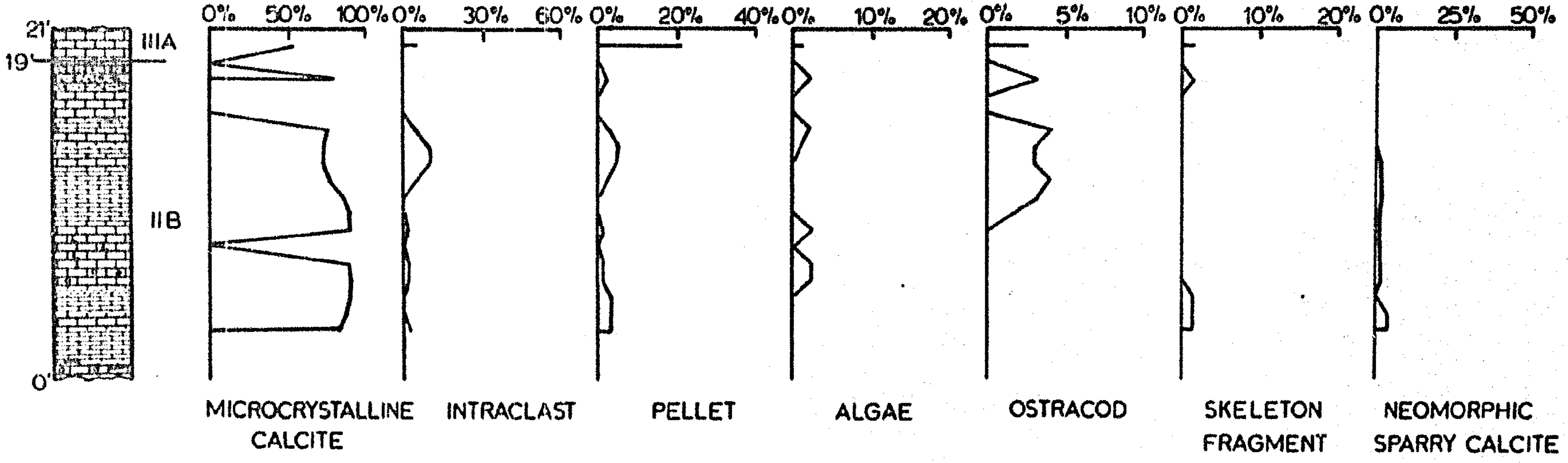
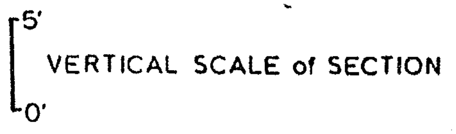


FIG.20. MICROLITHOLOGIC VARIATIONS in LONGFORD QUARRY.





MINOR OCCURRENCE of ALLOCHEM

LEVEL	TYPE	AMOUNTS
18'	SPARRY CALCITE CEMENT	TRACE
20'	OÖLITH	TRACE

FIGURE [illegible] MICROLITHOLOGIC VARIATIONS in UHTHOFF QUARRY

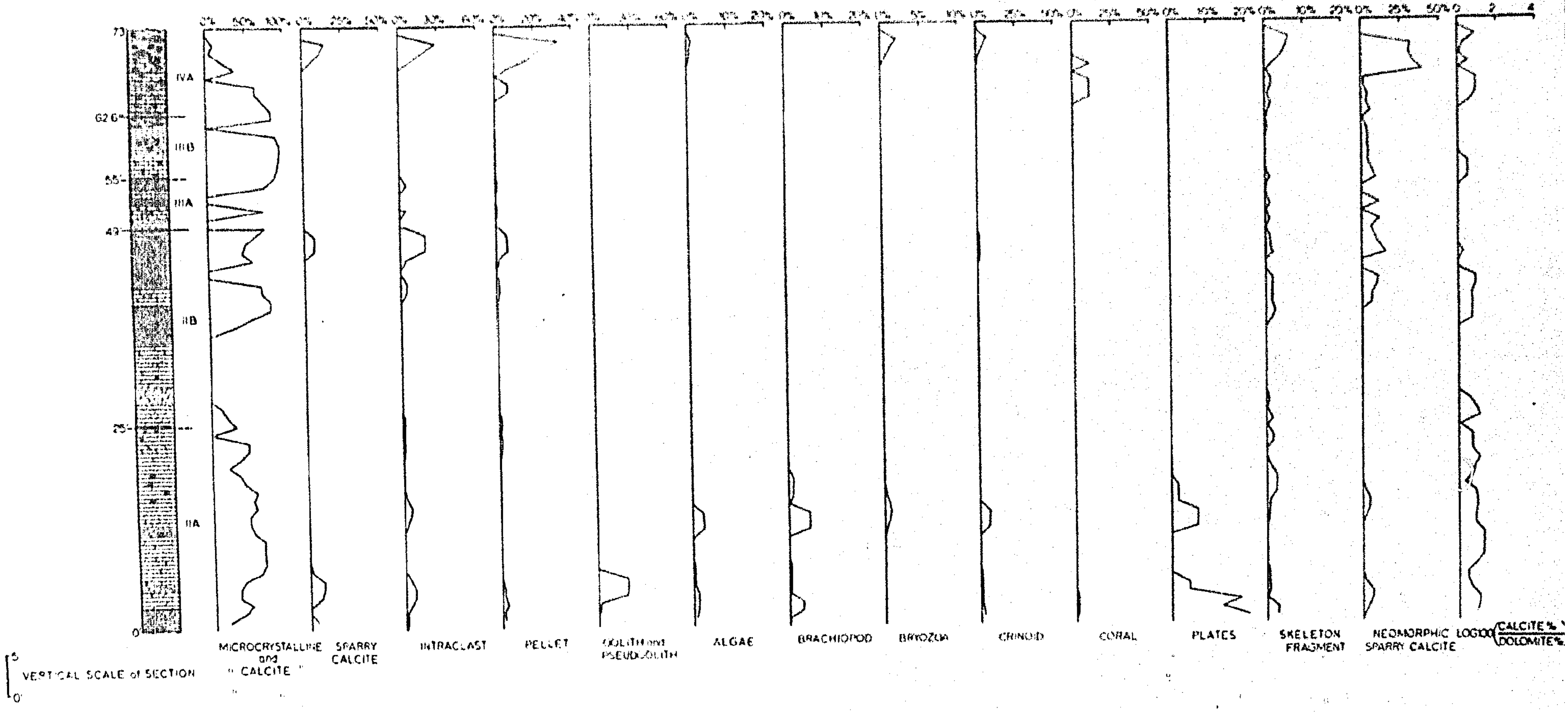


FIG 20 MICROLITHOLOGIC VARIATIONS in PORT MCNICOL QUARRY

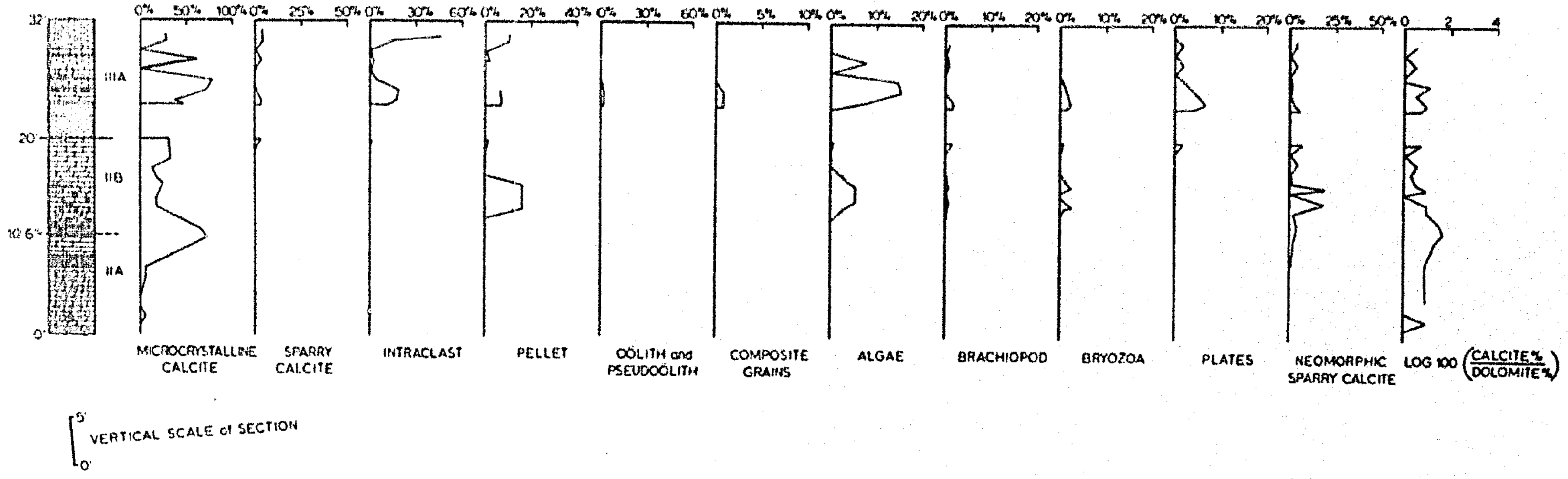
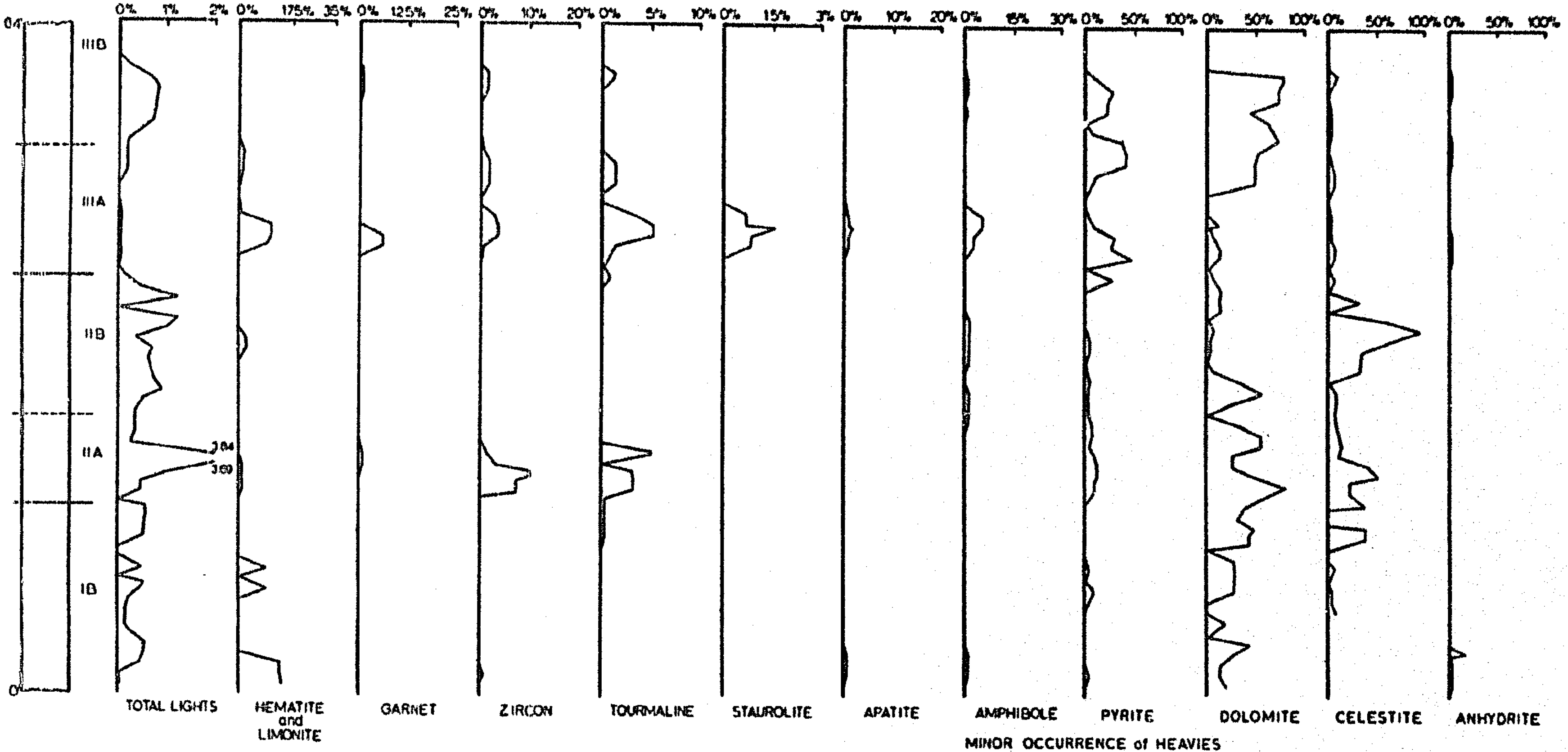


FIG 3A.DISTRIBUTION of INSOLUBLE RESIDUES in McGINNIS and O'CONNER QUARRY KINGSTON



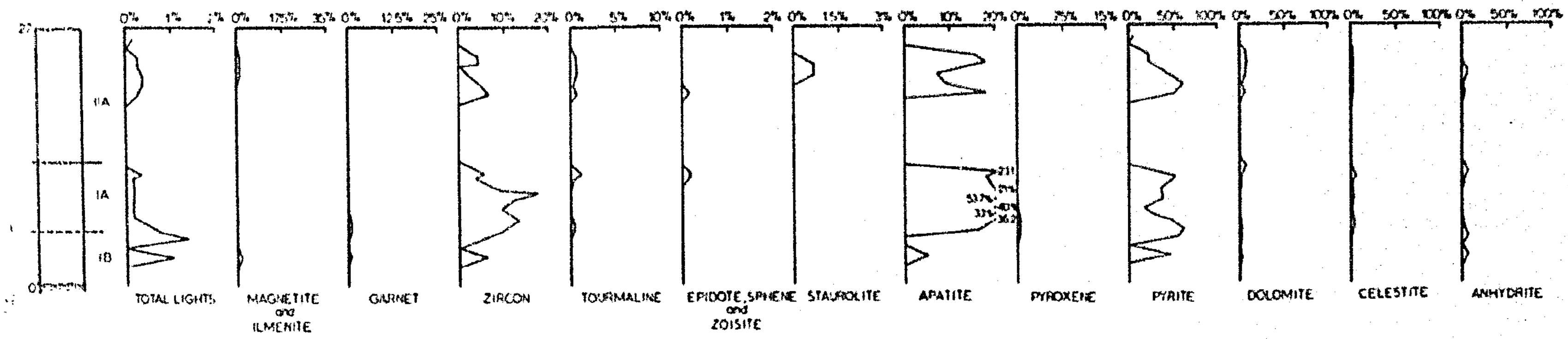
WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

5'
VERTICAL SCALE of SECTION
0'

MINOR OCCURRENCE of HEAVIES

MINERAL	PERCENTAGE	STRATIGRAPHIC LEVEL
MAGNETITE and ILMENITE	1.75	43'
	7.04	44'
	7.04	45'
	5.28	46'
PYROXENES	2.03	43'
	2.03	44'
	2.03	45'
ZOISITE	0.813	45'
	0.813	44'
	0.813	43'

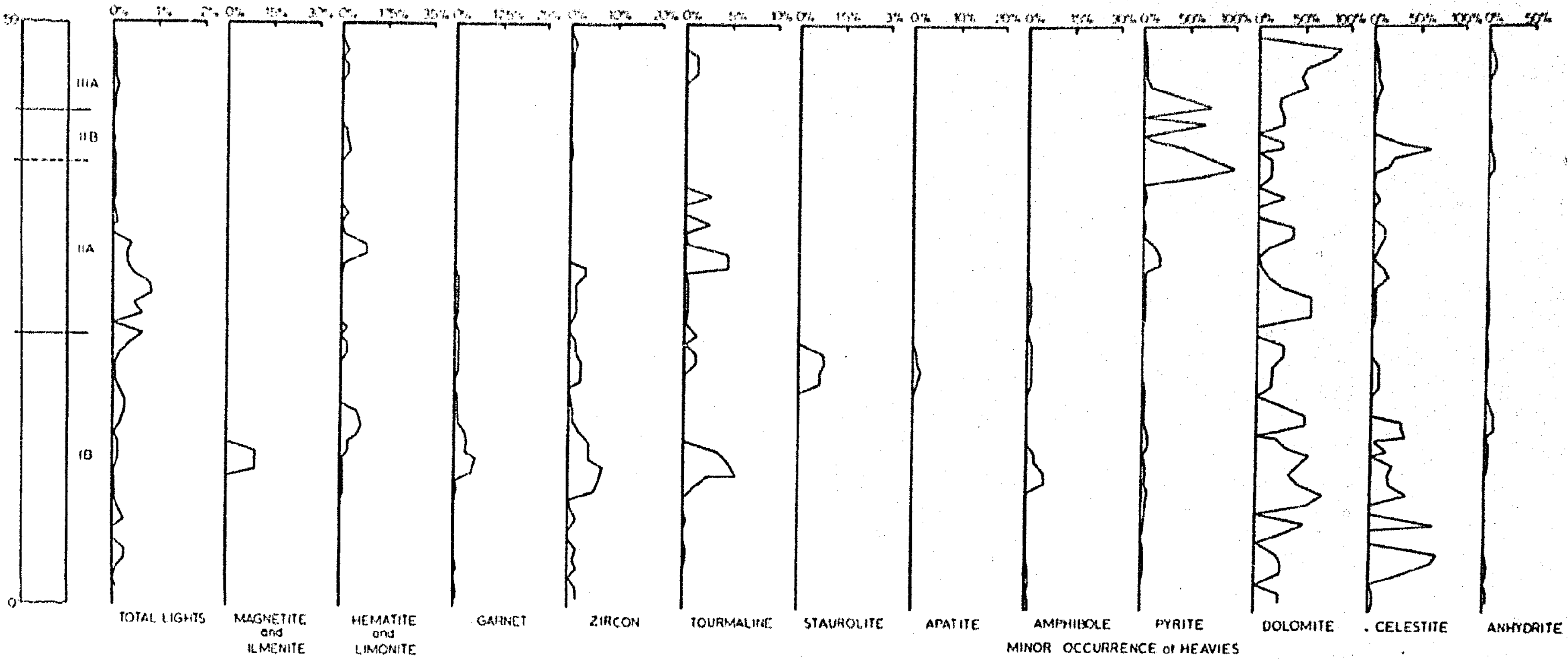
FIG.38 DISTRIBUTION of INSOLUBLE RESIDUES in ROAD CUT on HWY 401E NEAR HWY 15 EXIT



WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

5'
VERTICAL SCALE of SECTION
0'

FIG 3C DISTRIBUTION of INSOLUBLE RESIDUE in HWY 401 ROAD SECTION at MONTREAL STR. EXIT, KINGSTON



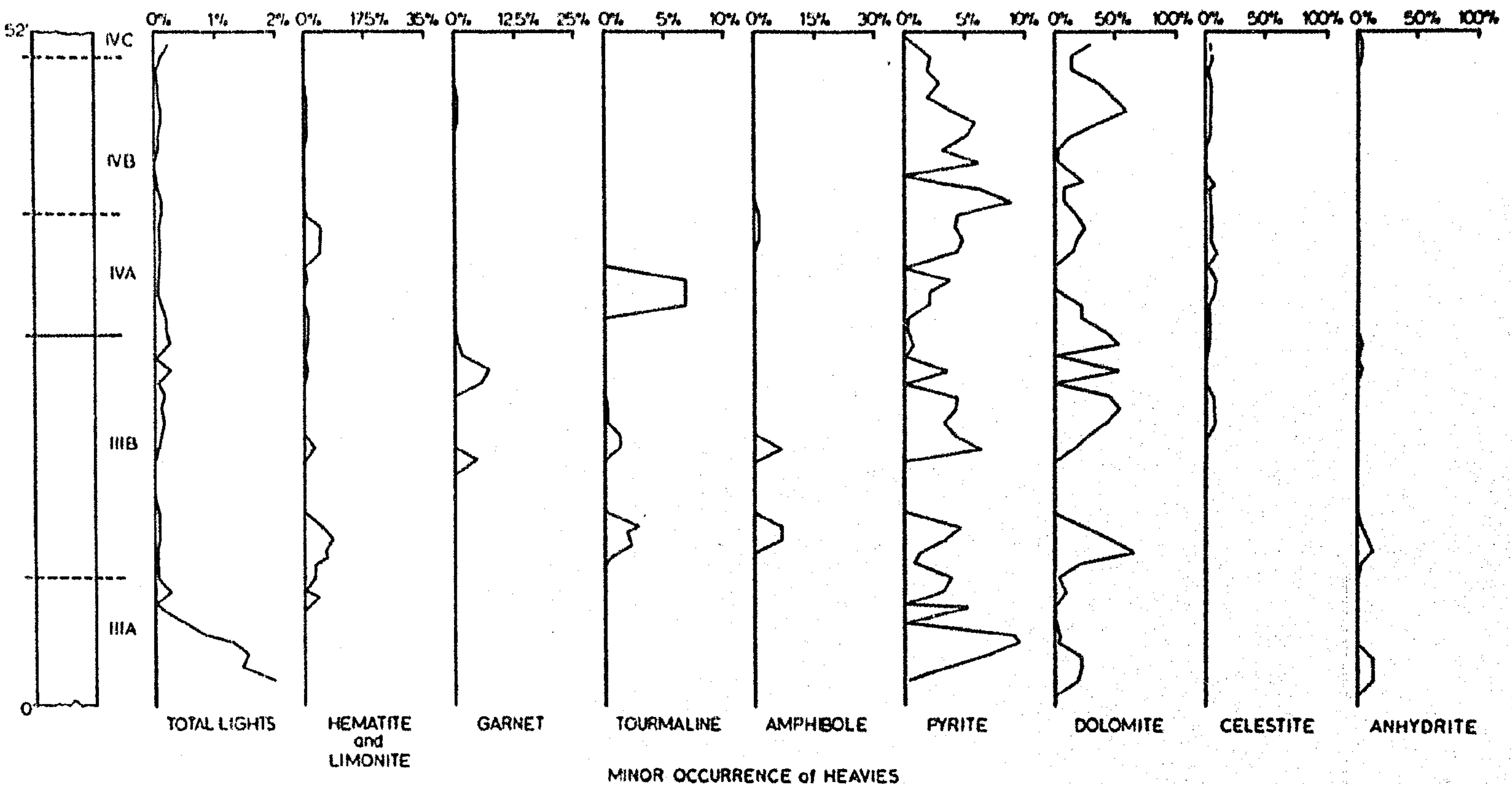
MINOR OCCURRENCE of HEAVIES

MINERAL	PERCENTAGE	STRATIGRAPHIC LEVEL
EPIDOTE	1.45	20'
and SPHENE	1.45	21'
	1.45	22'
PYROXENES	0.430	2'
	0.433	3
	0.433	4'

WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

5'
VERTICAL SCALE of SECTION
0'

FIG 3D DISTRIBUTION of INSOLUBLE RESIDUES in HWY 401 ROAD SECT 5 MILES EAST of NAPANEE.



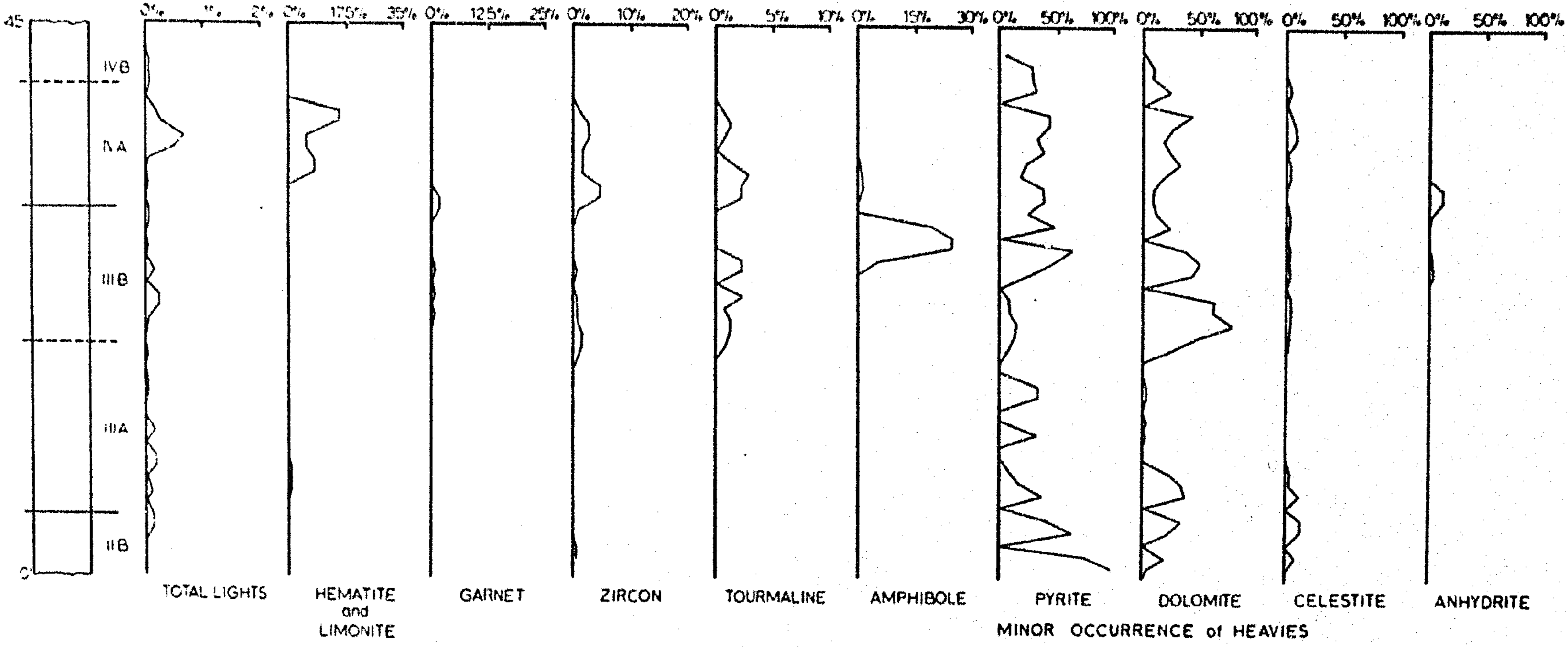
WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

5'
VERTICAL SCALE of SECTION
0'

MINOR OCCURRENCE of HEAVIES

MINERAL	PERCENTAGES	STRATIGRAPHIC LEVELS
MAGNETITE and ILMENITE	5.12	38'
	5.12	30'
	5.12	40'
ZIRCON	4.87	31'
	4.87	32'
	4.87	38'
APATITE	0.770	31'
	0.770	32'
	0.770	38'
PYROXENE	1.540	31'
	1.540	32'
	1.540	38'
STAUROLITE	0.770	31'
	0.770	32'
	0.770	38'
EPIDOTE and SPHENE	0.770	31'
	0.770	32'
	0.770	35'

FIG 3E. DISTRIBUTION of INSOLUBLE RESIDUES in NAPANEE QUARRY



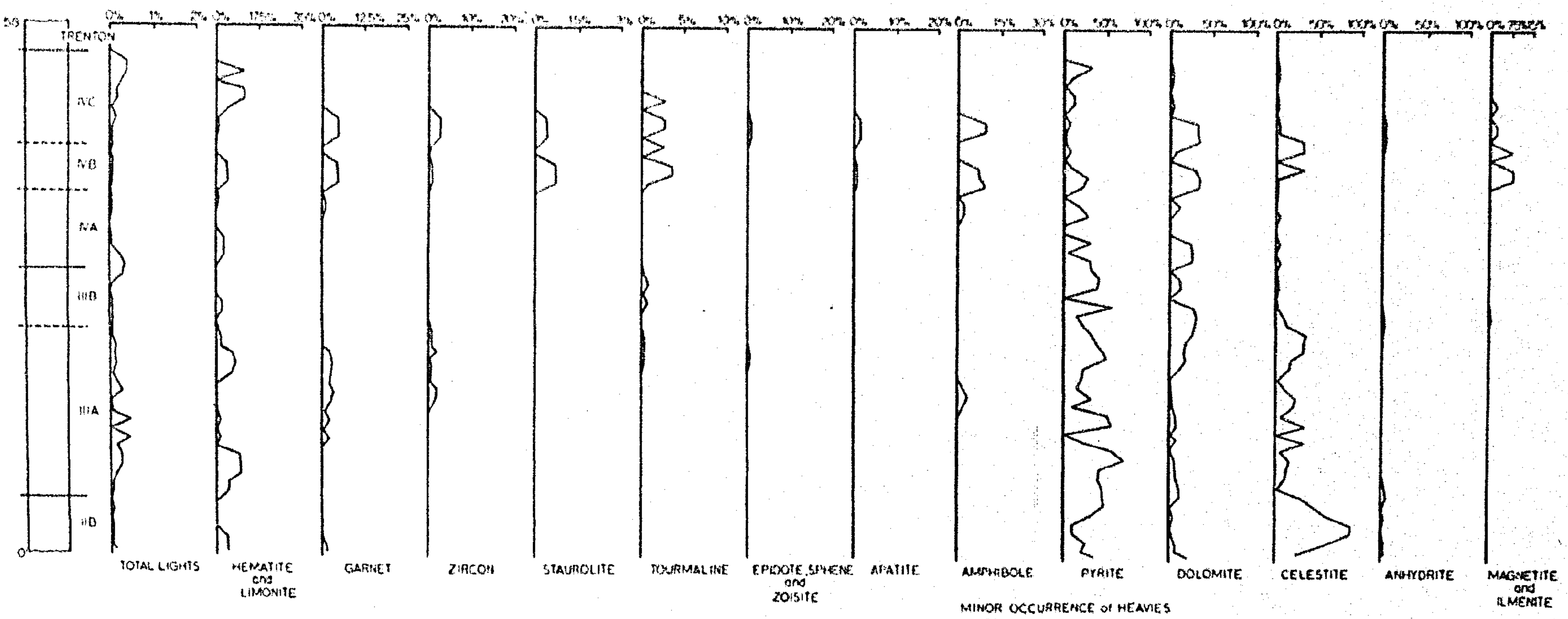
WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

5'
VERTICAL SCALE of SECTION
0

MINOR OCCURRENCE of HEAVIES

MINERAL	PERCENTAGE	STRATIGRAPHIC LEVEL
MAGNETITE	4.270	32'
ILMENITE	4.270	31'
	0.427	30'
ZOISITE	0.427	31'
	0.427	32'
PYROXENES	0.853	30'1'
	0.853	31'
	0.853	32'
FLUORITE	24.130	21'
	24.137	22'
	24.137	23'

FIG. 11 DISTRIBUTION of INSOLUBLE RESIDUES in ROBERINDALE QUARRY



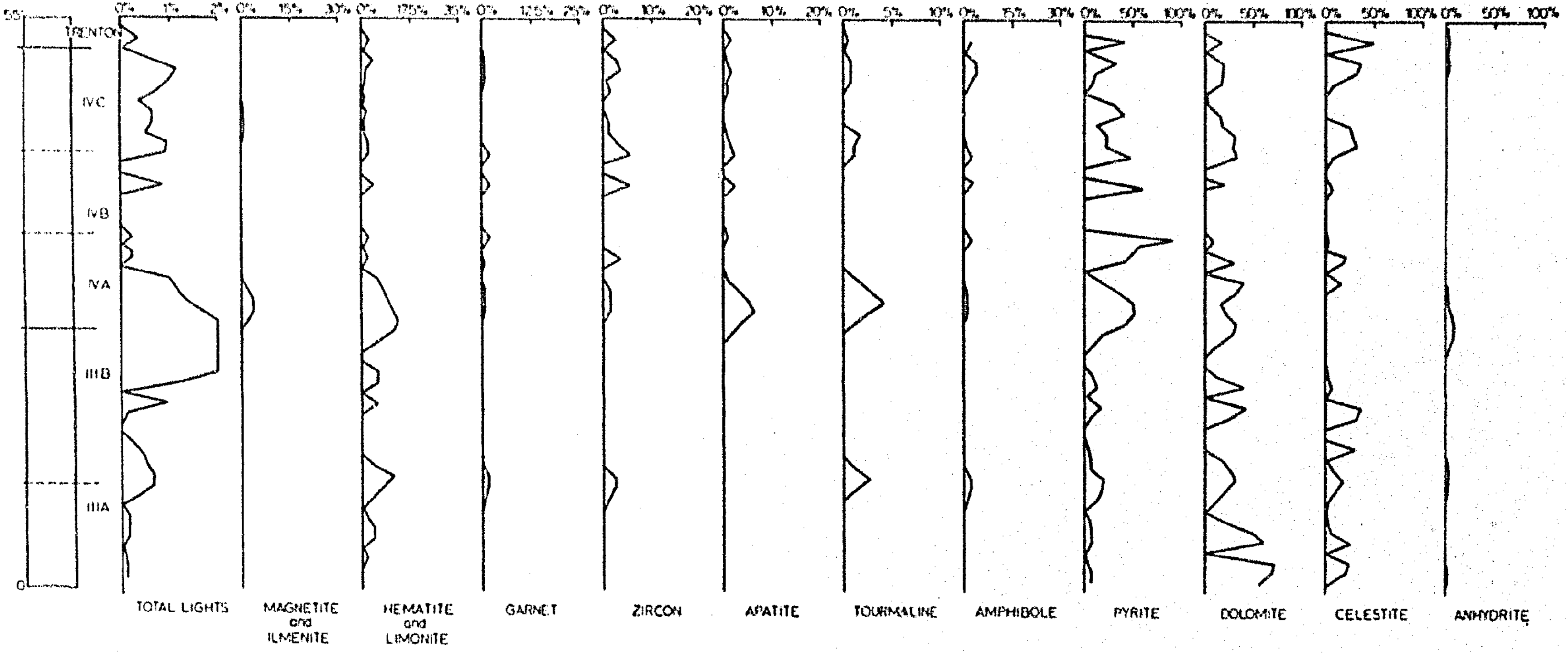
WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

MINOR OCCURRENCE of HEAVIES

MINERAL:	PERCENTAGE:	STRATIGRAPHIC LEVEL
PYROXENE	0.360	46'
	0.360	47'
	0.360	48'

5'
VERTICAL SCALE of SECTION
0'

FIG 3G DISTRIBUTION of INSOLUBLE RESIDUES in POINT ANN QUARRY



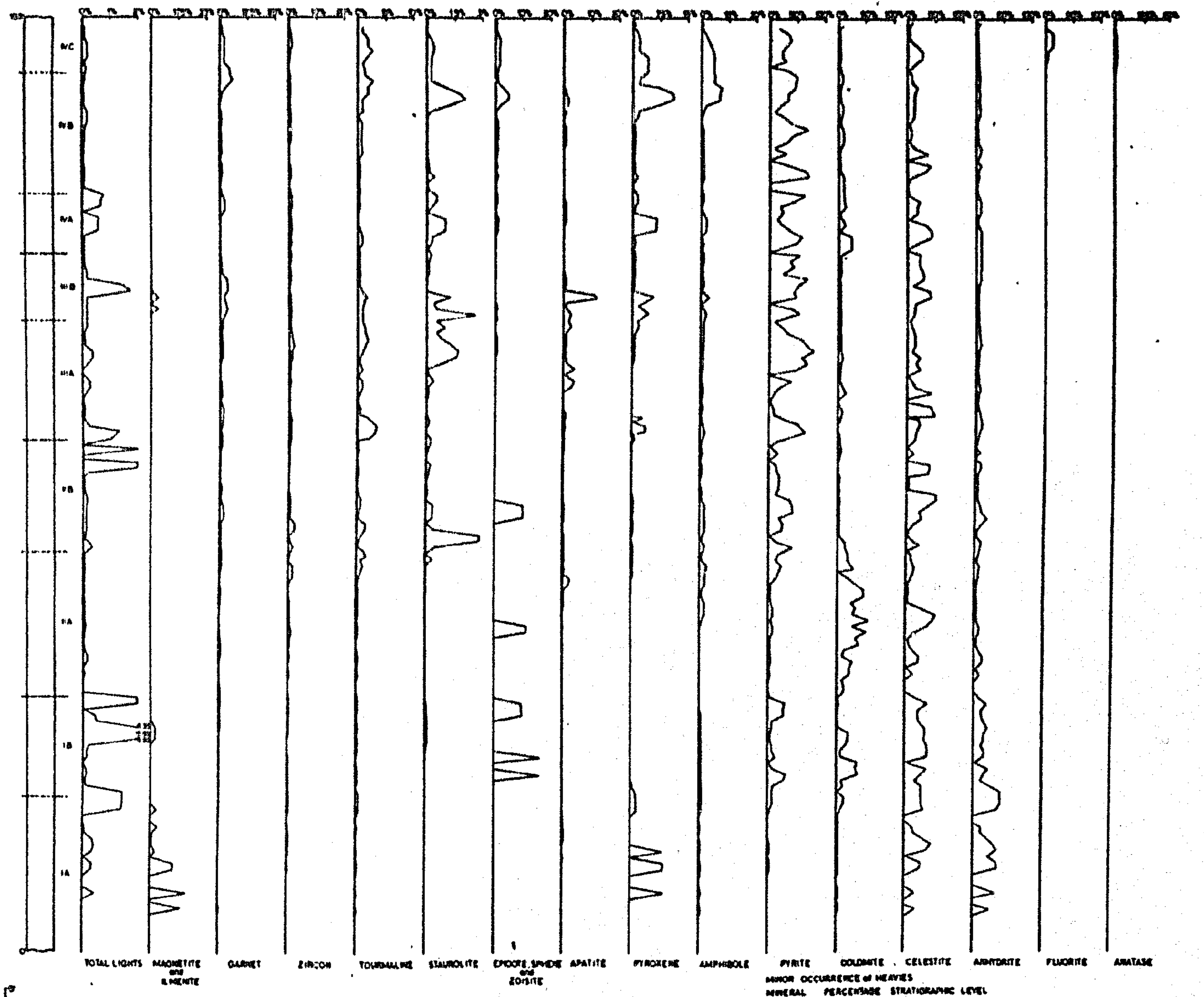
5'
VERTICAL SCALE of SECTION
0'

WEIGHTS of LIGHT MINERALS ARE RECALCULATED TO ORIGINAL WEIGHT PERCENTAGES of ROCKS.
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED TO ORIGINAL ROCK COMPOSITIONS

MINOR OCCURENCE of HEAVIES

MINERAL:	PERCENTAGE:	STRATIGRAPHIC LEVEL:
EPIDOTE	0.03	1'
	0.03	2'
PYROXENE	0.653	25'
	1.307	26'
	1.307	27'
	0.653	28'

FIG 31 DISTRIBUTION of INSOLUBLE RESIDUES in MARMORA QUARRY

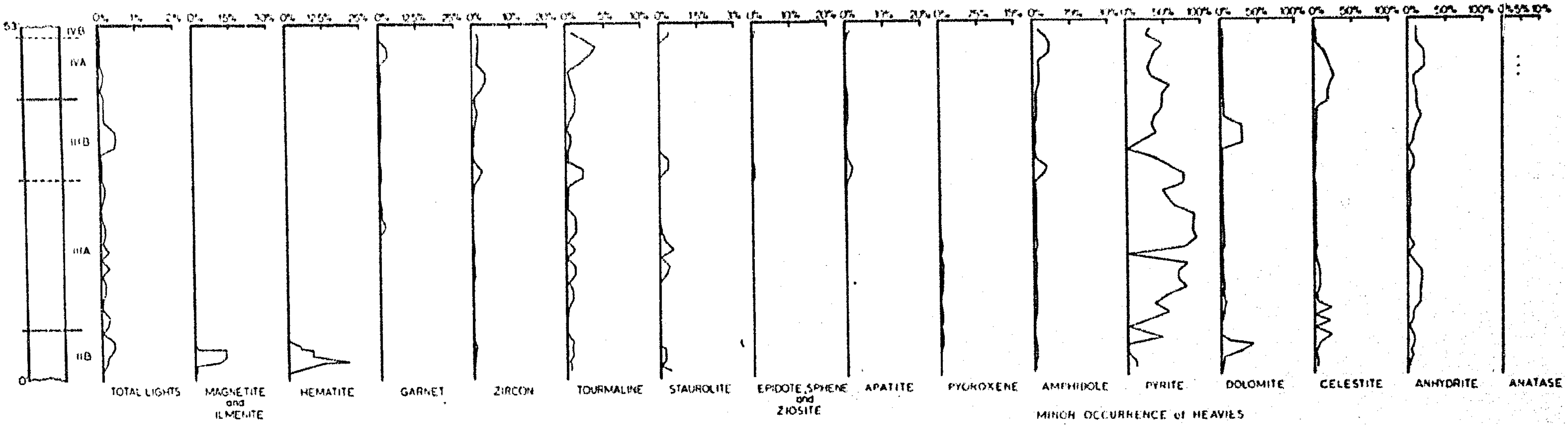


WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS

MINOR OCCURRENCE of HEAVIES

MINERAL	PERCENTAGE	STRATIGRAPHIC LEVEL
SPHALERITE	0.480	127'
	0.480	127'
	0.480	104'
HEMATITE and LIMONITE	0.427	17'
	0.427	18'
	0.337	18'

FIG 31 DISTRIBUTION of INSOLUBLE RESIDUES in MARMORA ROAD SECTION



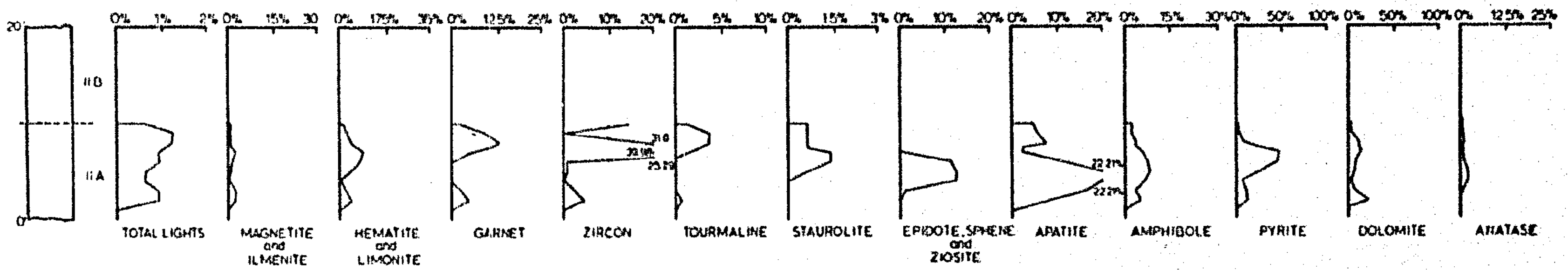
MINOR OCCURRENCE of HEAVIES

MINERAL	PERCENTAGE	STRATIGRAPHIC LEVEL
FLUORITE	1.12	1'8"
	1.12	2'8"
	1.12	2'4"
SPHALERITE	4.62	38'
	4.62	39'

WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

5'
VERTICAL SCALE of SECTION
0'

FIG 3J. DISTRIBUTION of INSOLUBLE RESIDUES in BURLEIGH FALLS ROAD CUT



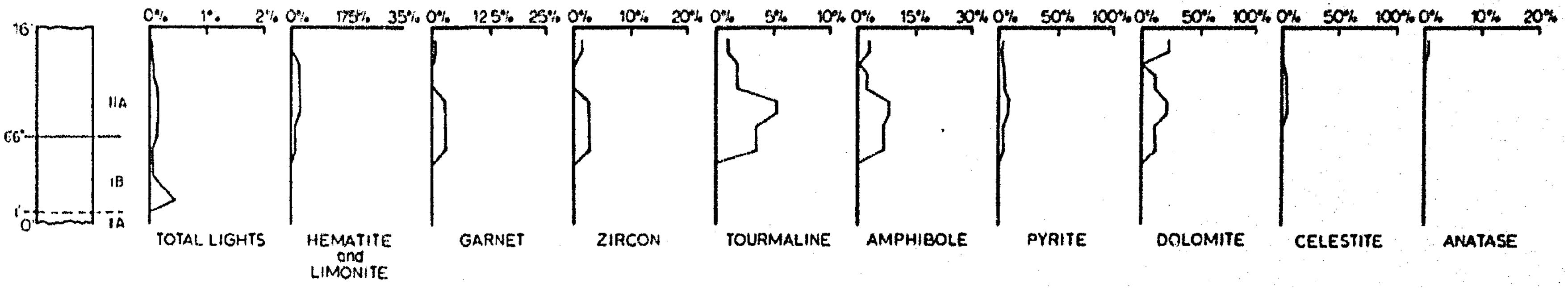
WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

5'
VERTICAL SCALE of SECTION
0'

MINOR OCCURRENCE of HEAVIES

MINERAL:	PERCENTAGE:	STRATIGRAPHIC LEVEL:
RUTILE	0.667	11'
	0.667	12'-13'
	0.667	14'-15'

FIG.3K DISTRIBUTION of INSOLUBLE RESIDUES in BURLEIGH FALLS ROAD CUT (2)



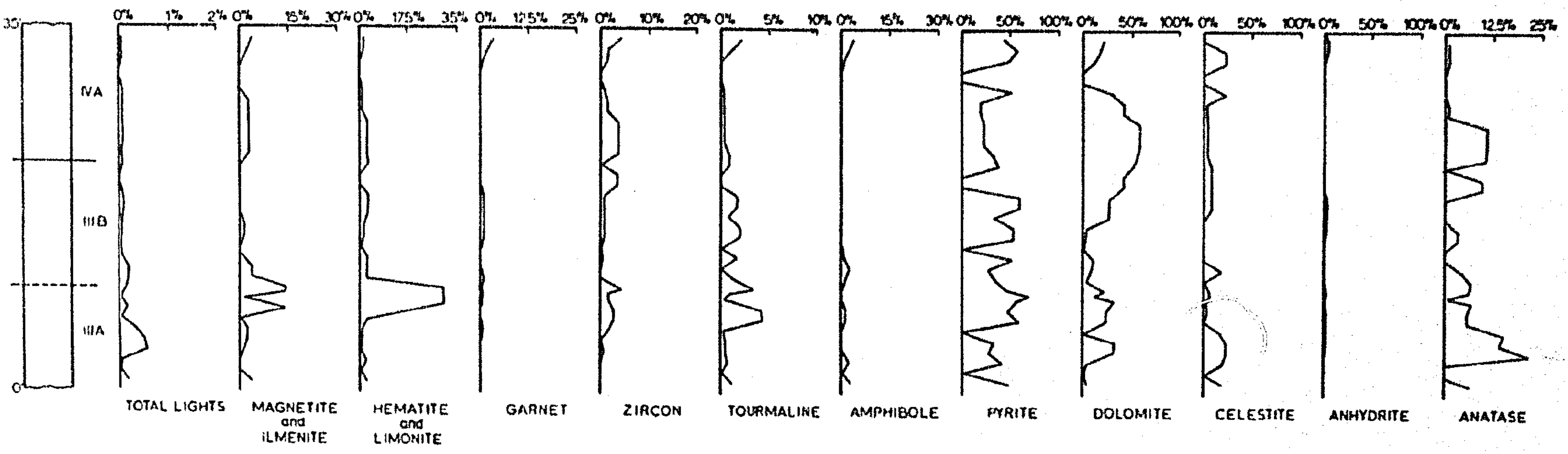
WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

MINOR OCCURRENCE of HEAVIES

MINERAL:	PERCENTAGE:	STRATEGRAPHIC LEVEL:
RUTILE	0.537	7'
	0.547	8'
	0.010	9'

5'
VERTICAL SCALE of SECTION
0'

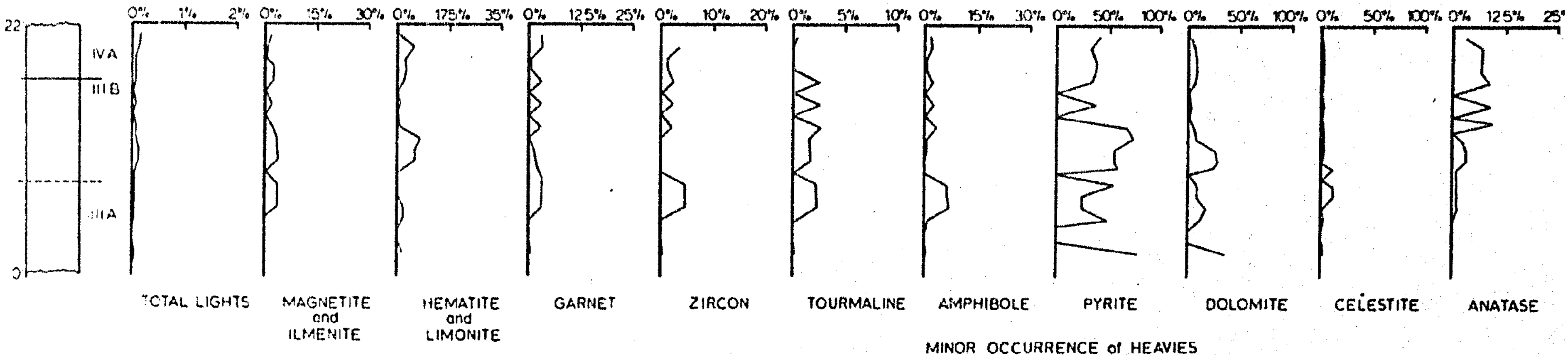
FIG 3L DISTRIBUTION of INSOLUBLE RESIDUES in COBOCONK EAST QUARRY



WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

5'
VERTICAL SCALE of SECTION
0'

FIG.3M DISTRIBUTION of INSOLUBLE RESIDUES In COBOCONK ROAD CUT.



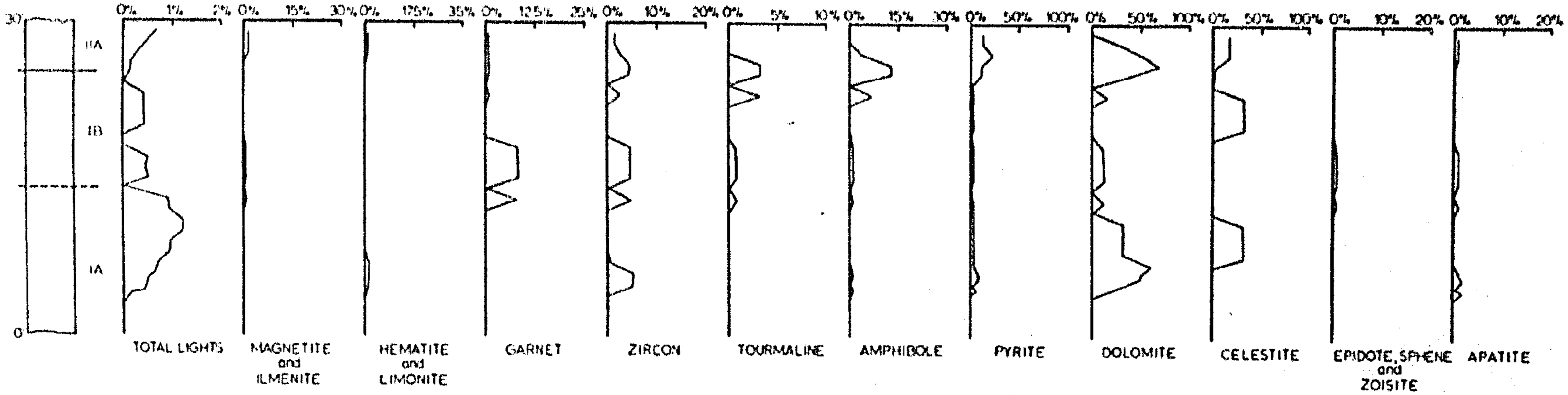
MINOR OCCURRENCE of HEAVIES

MINERAL	PERCENTAGE	STRATIGRAPHIC LEVEL
APATITE	1.813	22'
	0.813	21'
	0.813	20'

WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

5'
VERTICAL SCALE of SECTION
0

FIG 3N DISTRIBUTION of INSOLUBLE RESIDUES in HWY 35N ROAD CUT (COBOCONK)



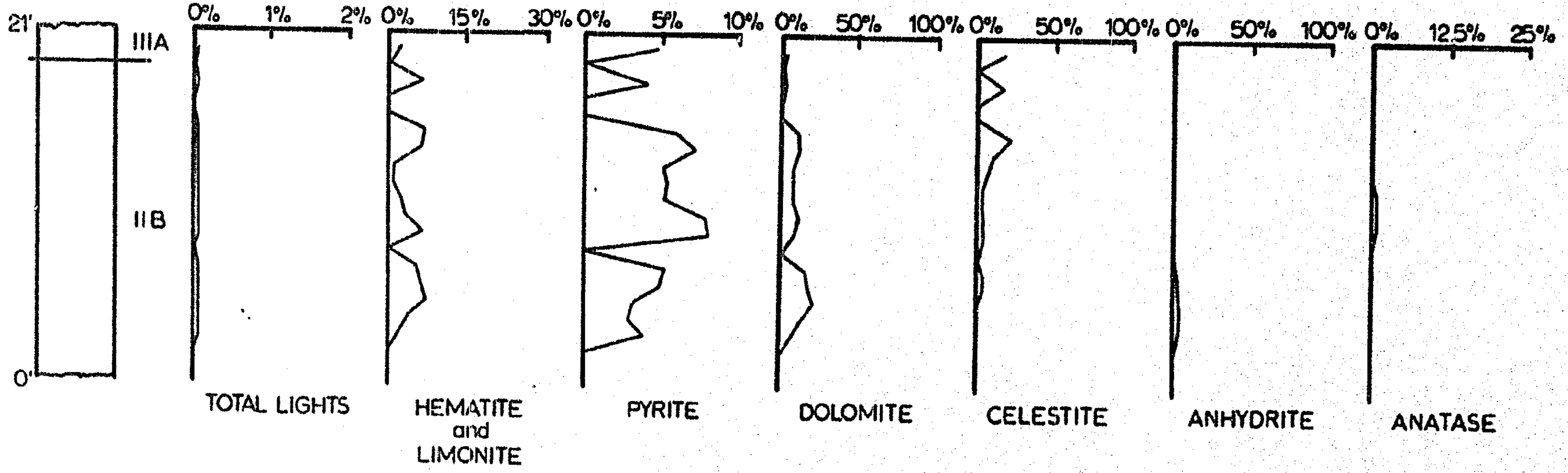
WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

5'
VERTICAL SCALE of SECTION
0'

MINOR OCCURRENCE of HEAVIES

MINERAL	PERCENTAGE	STRATIGRAPHIC LEVEL
RUTILE	0.410	13'
	0.410	15'
	0.410	16-18'

FIG.30. DISTRIBUTION of INSOLUBLE RESIDUES in LONGFORD QUARRY.



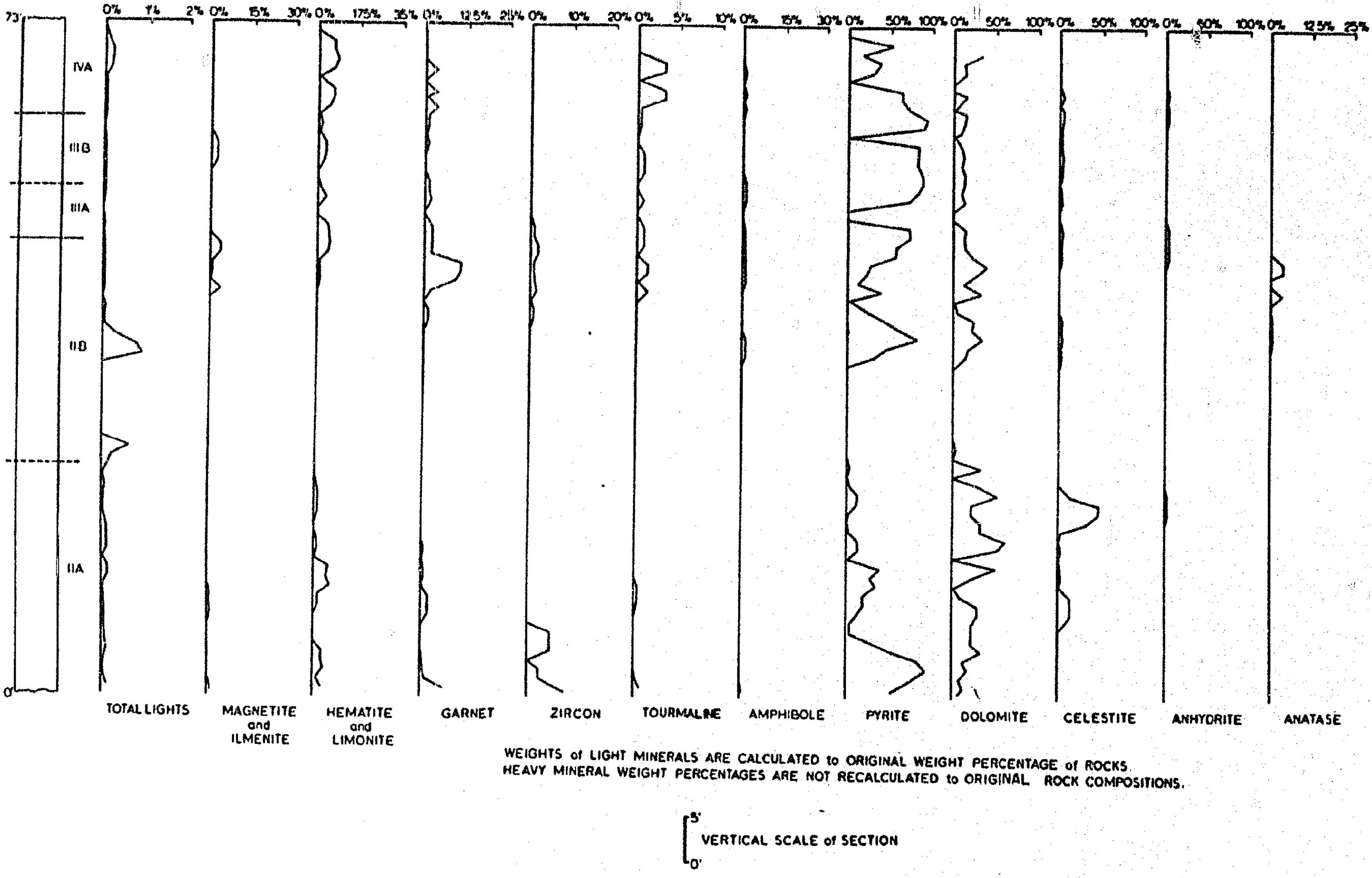
MINOR OCCURRENCE of HEAVIES

MINERAL	PERCENTAGE	STRATIGRAPHIC LEVEL
TOURMALINE	0.833	7'
	0.833	9'
	0.833	10'

WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS.
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

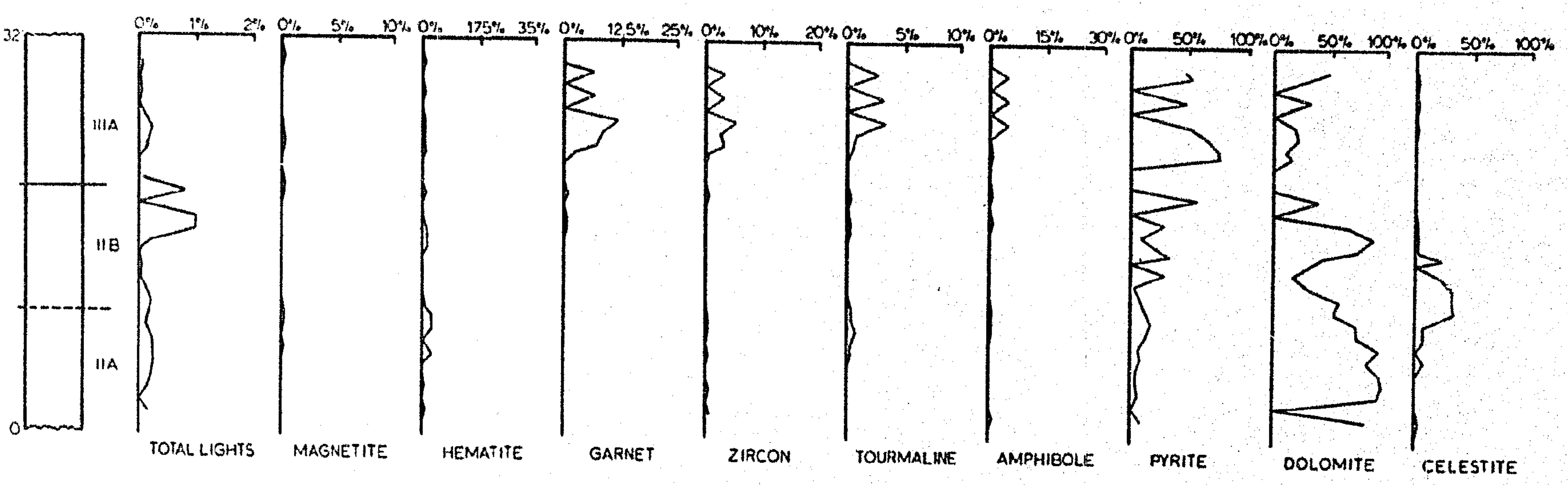
5'
VERTICAL SCALE of SECTION
0'

FIG.3P. DISTRIBUTION of INSOLUBLE RESIDUES in UHTHOFF QUARRY.



WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS.
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

FIG.30 DISTRIBUTION of INSOLUBLE RESIDUES in PORT McNICOL QUARRY.



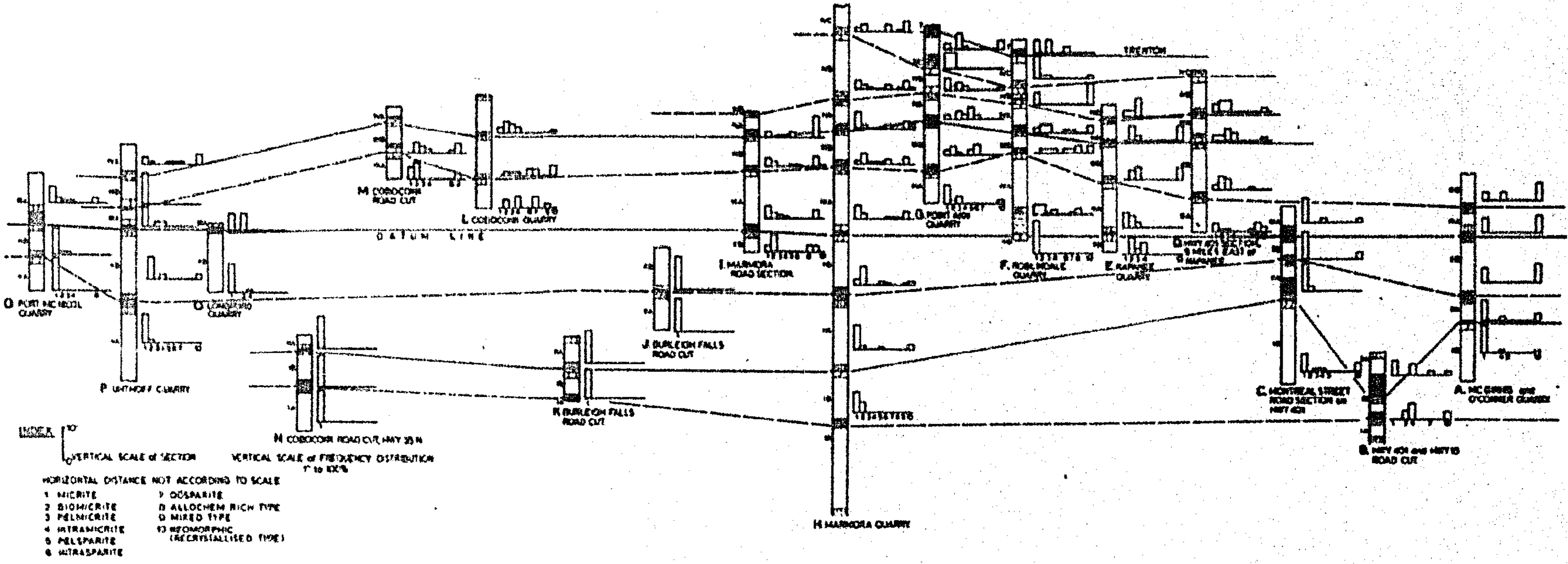
WEIGHTS of LIGHT MINERALS ARE CALCULATED to ORIGINAL WEIGHT PERCENTAGE of ROCKS
HEAVY MINERAL WEIGHT PERCENTAGES ARE NOT RECALCULATED to ORIGINAL ROCK COMPOSITIONS.

MINOR OCCURENCE of HEAVIES

MINERAL	PERCENTAGE	STRATIGRAPHIC LEVEL
APATITE	0.237	23' 6"
	0.237	24' 6"
PYROXINE	0.233	25'

5'
VERTICAL SCALE of SECTION
0'

FIG 4 REGIONAL PETROGRAPHIC CORRELATION of BLACK RIVER ROCKS in SOUTH WESTERN ONTARIO
(HISTOGRAMS REPRESENT FREQUENCY DISTRIBUTION of PETROGRAPHIC TYPES in EACH CLASSIFIED UNIT of INDIVIDUAL SECTION)



CHAPTER 3

SEDIMENTARY STRUCTURE

Sedimentary structures include large scale features, which can be studied either in outcrop or in hand specimen. Such structures may be of organic, inorganic or mechanical origin. The inorganic structures represent both "primary" and "secondary" types (Pettijohn 1957, p. 157). Since the time of Sorby (1853) cross-bedding, ripple marks and other linear features have been used to determine stratigraphic sequence and paleocurrent azimuths. Because sedimentary structures largely develop during deposition, they provide information on the depositional process, and on the general geologic, and climatic condition.

During the past decade various sedimentary features of recent environments have been studied by a number of geologists, (Moore and Scruton, 1957; McKee, 1957a; Potter and Pettijohn, 1963; Logan et. al.; 1964; Evans, 1965; Imbrie and Buchanan, 1965). These results provide a better understanding of modern environments regarding ecological and hydro-dynamical properties. Earlier workers described some sedimentary features from the Ordovician carbonate rocks of southwestern Ontario, but most of their remarks were cursory. Barnes

Explanation of Plate 6

Figure 1 Section showing uniform, horizontal, thick and thin bedded nature of units II, III with flaggy, slabby and blocky characters. The section is exposed near Montreal Street east on Hwy. 401, at Kingston.

Figure 2 Alternate thick and thin bedded, blocky to slabby nature of the rocks in unit IV. The section is exposed 5 miles west of Kingston on Hwy. 401.

PLATE 6.

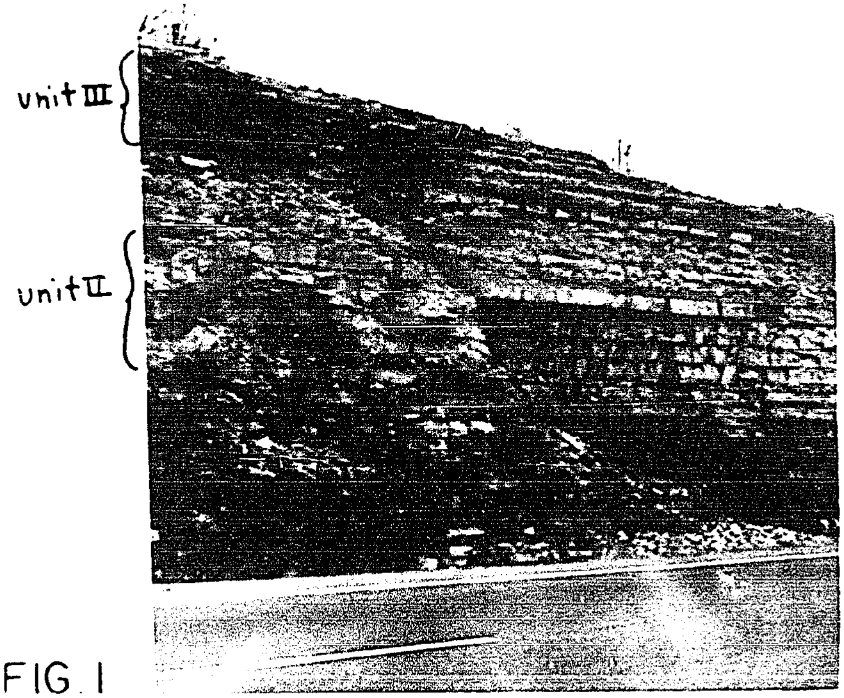


FIG. 1

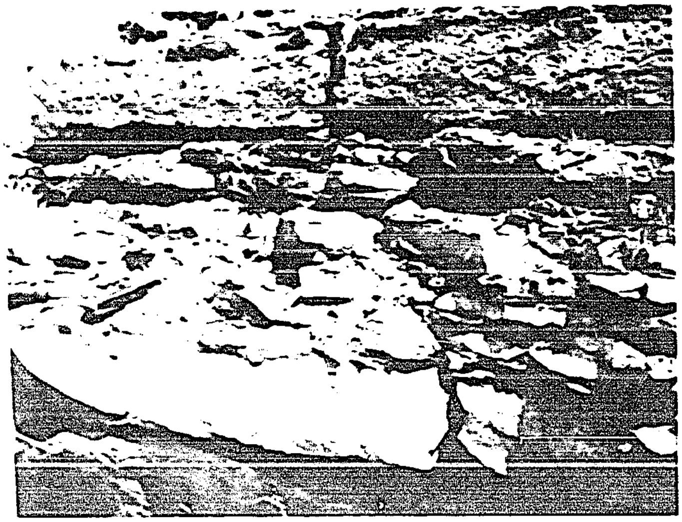


FIG. 2

(1965; 1967) attempted to interpret sedimentary features of the Wilderness (Ordovician) limestones of the Ottawa Valley.

The present study of the Black River (Middle Ordovician) limestones in Southern Ontario revealed a number of sedimentary features that were of great value in the reconstruction of ancient carbonate depositional environment.

Stratification

Stratification is the fundamental structure of a sedimentational unit, and refers to the general layering of rocks. Undefined usage of such terms as "thick bedded", "thin bedded" units are commonly found in literature. In order to maintain uniformity of description, McKee and Weir's (1953) system of terminology is followed to describe bedding characteristics. Kelley's (1956) suggested value of 1 foot is used as the lower limit of thick bedded units in limestone.

Black River limestones represent horizontal, uniformly homogenous to gradational lithology with thin (2-12 inches), and thick bedded (1 foot to 4 feet) bedded units exhibiting flaggy, slabby or blocky nature (Plate 6, figure 1). Basal coarse clastic beds (Unit I), dolostone, impure dolomitic limestones (Units II and III) and the upper coarse shell-rich carbonate rocks (Unit IV) are thick to thin bedded with blocky to slabby character (Plate 6, fig. 2). Pure lithographic limestones or micrites (Unit II) and coarser carbonate rocks (Unit III and Unit IV) are thin to thick bedded.

Impure argillaceous carbonate rocks are usually characterized by their very thin bedded (1/2 to 2 inches), finely laminated (0.08 inch to 1/2 inch), flaggy to papery nature. Thin bedded fine grained shell

Explanation of Plate 7

Figure 1 Section exposed on Hwy. 7 just west of Marmora, near the bridge over Crowe River. Note the wavy nature of bedding within unit IVA below the black chert bearing horizon and overlying the lower thick beds of unit III.

Figure 2 Finely laminated alternate grey micrite and white to grey argillaceous material in unit II, Marmora quarry.

PLATE 7.

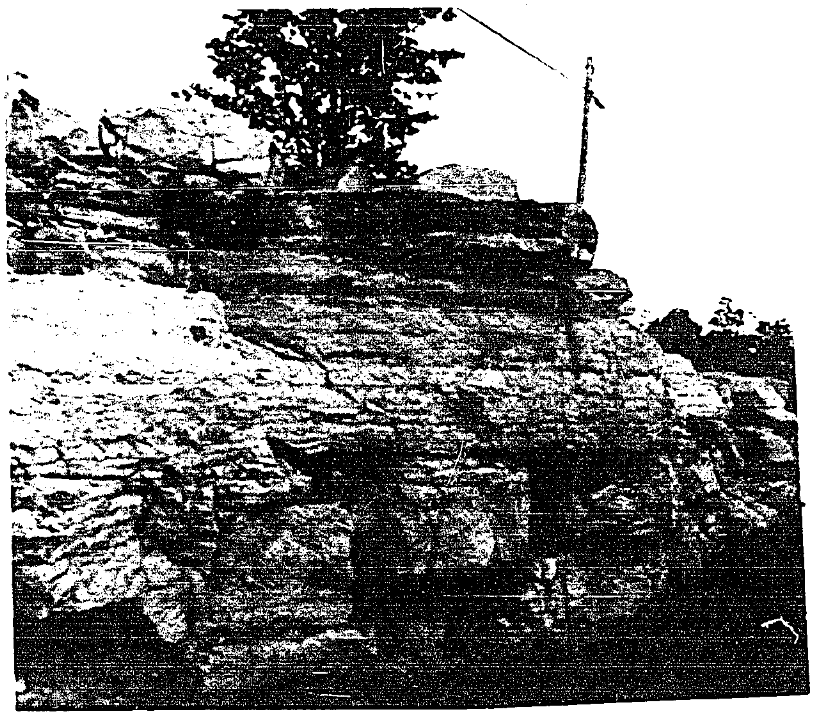


FIG. 1

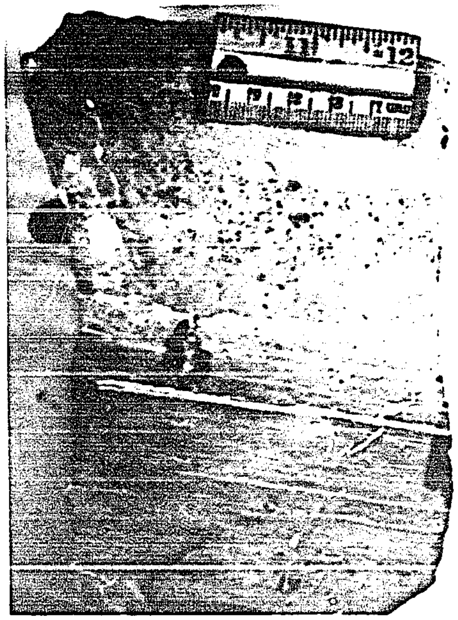


FIG. 2

rich rocks of upper units (III and IV) frequently show wavy bedding (Plate 7, fig. 1) and thin intercalation of calcareous shaly material.

Vertical variation of bedding thickness in different areas, clearly reveals the following: (1). Beds of Unit I and Unit II are mostly thick bedded with occasional thin intercalation especially towards the upper part of Unit II, (2). Beds of Units III and IV are thin bedded in character with very frequent alternation of thicker units. Most rocks of Units III and IV show black carbonaceous shaly intercalations with very fine to fine laminations.

Lagoon deposits range in structure from massive, blocky to finely laminated and show dominantly horizontal beds (Krumbein and Sloss 1963). McKee (1957b) stated "their structures are non distinctive. Correct interpretation of this environment in ancient rocks depends on the recognition of distinctive features of adjacent environment and on features of composition and texture". Tidal flat deposits include black mud, fine sand and shell accumulations, with frequent flat pebble conglomerate (edgewise, intraformational or intraclastic), and ripple marks. Stratification is usually horizontal and shows variable thickness. Asquith (1967, p. 312) described the thin wavy bedded nature of fossiliforous carbonate rocks from Platteville limestones (Middle Ordovician) of Southwestern Wisconsin. He interpreted wavy bedding and other features as due to continuous movement of the depositional interface by wave and current action, and thus indicating a very shallow water condition.

Finely laminated, alternate grey lithographic carbonate mud and white to grey argillaceous material can be seen in the lower dolomitic

Explanation of Plate 8

Figure 1 Microstylolitic relief in the so called "Birdseye" (Unit III, Montreal Street section) limestone, possibly developed due to extreme irregular nature of argillaceous laminae. Note the abrupt lateral termination and vertical bifurcation of some stylolitic laminae. Dark patches are clear spar filled, resembling desiccation features. Scale in inches.

Figure 2 Disrupted bedding in upper (Unit III, Roblindale quarry) shell-rich coarse limestone and shell-rich fine argillaceous carbonate rock. Note contorted fragments in the upper part of lower bed.

Figure 3 Bedding surface in rocks of unit IV (Coboconk quarry) showing irregular concentration of dark carbonaceous material and pitted undulating relief.

PLATE 8.

FIG. 1

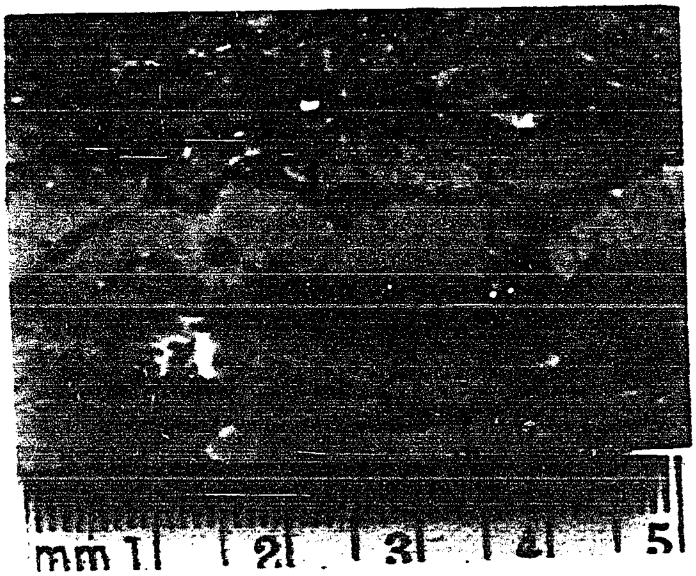


FIG. 2

FIG. 3

beds of unit II (Plate 7, Fig. 2).

The distinct nature and good preservation of undisturbed fine laminae may indicate the tranquil nature of the waters in which the sediments accumulated (Pettijohn 1957, p. 163).

Shale Laminae

Discontinuous shale laminae (0.06 inch to 0.08 inch thick) with irregular surfaces, are common in the upper parts (Units III and IV) of the sections. The individual laminae are extremely undulose with average relief of 0.5 to 2 inches. Sometimes they are extremely irregular, and on a small scale attain an almost microstylolitic relief (Plate 8, Fig. 1 and 3). Laterally such laminae show abrupt termination. In a vertical plane some lateral bifurcation of laminae can be seen.

Barnes (1967, Plate 2, figs. 4 and 5) described irregular shale laminae from Chaumont calcarenite of the Ottawa Valley. Some of the laminae have become irregular either through burrowing activity or pressure solution. Barnes (1967) interpreted that such irregular concentrations could result from (a) periodic influx of clayey material, (b) periods of noncarbonate deposition, or (c) collection of drifting clay and silt by some organic process. Newell <u>et</u> <u>al</u>. (1959, p. 220) described discontinuous algal mats covering parts of the sea floor in the Bahama Banks during periods of slow or arrested deposition. In the Florida Bay area, binding, and trapping of clay and silt particles by marine algae has been reported by Ginsburg and Lowenstam (1966, p. 310). Ginsburg (1957, p. 94 , Figures 15 and 16) described similar features from the interior mud flats of Florida Key areas and suggested that such irregular clayey patches could represent algal crenulated sheets formed during exposure of sediments.

Folk and Robles (1964) suggested development of a black organic film by decomposition of fecal pellets.

Black carbonaceous films were frequently observed during acid digestion of rocks, with irregular clayey laminae or microstylolitic relief. Thus the role of organic activity in the development of such sediments is evident. The presence of desiccation features in carbonate materials, and occasional ripple marks probably indicate a shallow carbonate flat with frequent exposure. However, in the absence of some more definite evidence, the chief mechanism for the formation of irregular clayey patches can not be determined. Some of the carbonaceous, clay rich, yellow limonite stained pitted surface could also represent minor discontinuity surface (Jaanusson 1961) due to subaerial exposure with leaching of carbonate material.

Disturbed Bedding

The contact between beds of two different lithology in Units III and IV is highly irregular in places. Such disturbed zones may have a vertical relief of 0.4 inch to 6 inches or more and in most cases persist laterally in local areas. The upper part of the lower bed is commonly contorted, (Plate 8, fig. 2). Winder (1953, p. 23, fig. 5; 1958, p. 153) reported the occurrence of similar features along contacts between carbonate rocks of differing lithology from Burleigh Falls area. He suggested that these features represent a change in depositional conditions.

Under certain bottom conditions, partly indurated calcareous material may be ripped up by unusually strong tides, storm waves, and other similar phenomena which cause temporary depression of the base level of submarine erosion (Shrock 1948, p. 69). The disturbed bottom materials are finally deposited as a brecciated mass. Similar brecciated structure may also develop by subaerial slumping. Absence of graded structure, flame structure, scouring marks, presence of disturbed beds in the basal narrow zone suggest that these features could only form under fluctuating condition of energy in the depositional environment. Similar deposits are forming in modern intertidal areas.

Intraformational Conglomerate:-

This type of structure is common in the upper units, particularly in the alternating thin, and thick bedded, shell or oölite-rich carbonate rocks, and fossiliferous fine grained limestones. In most cases, the fine grained unit underlies the coarser. The fragments are flat, elongate, and well rounded and range in size from 0.1 to 6 inches in length. Some irregular and elliptical fragments are also present. These are grey to dark grey in colour, fine grained, and show all the characteristics of the immediately underlying beds. In some cases fragments are embedded in fine grained, grey carbonate mud while in others, interfragmental space is filled with coarse shells, oölites and crystalline calcite. In some cases these fragments show weak imbrication (Plate 9, fig. 1). The base of this kind of deposit is sharply delineated by the abrupt appearance of broken fragments.

The size of fragments decreases stratigraphically upward. Frequently beds underlying conglomerate bearing horizons show various desiccation features. Shrock (1948, p. 71) suggested that "trans-

Explanation of Plate 9

Figure 1 Intraformational conglomerate (unit III) Marmora Quarry showing slight imbrication of large fragments on bedding surface. Scale in mm.

Figure 2 Mud crack in the lower impure laminated calcareous bed (unit II, Burleigh Falls area). White, thin raised ridges are infilled with carbonaceous material and dolomite.

Figure 3 Mud polygons in impure dolomitic fine carbonate rock (unit II , Uhthoff Quarry), with burrows (isolated, dark, elliptical patches) and trails (elongated, curved, straight intersecting tube like structures).

PLATE 9.

FIG. 1

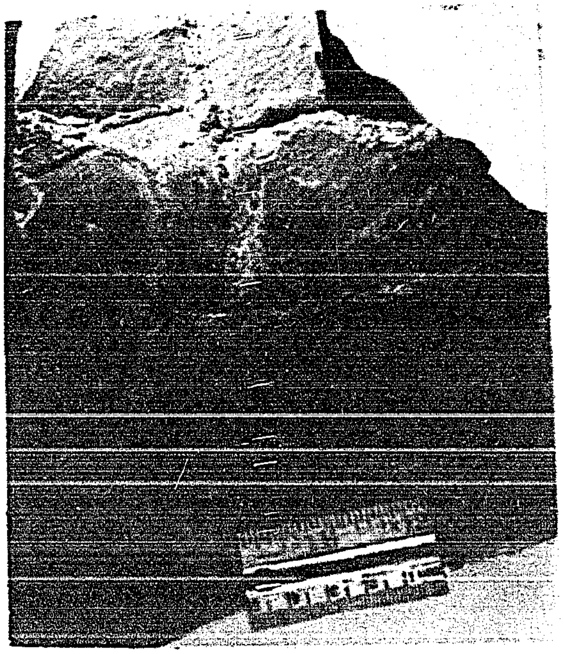


FIG. 2

FIG. 3

PLATE 9.

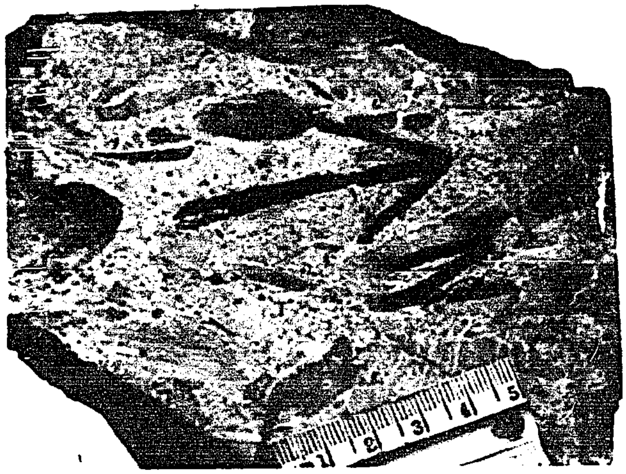


FIG. 1

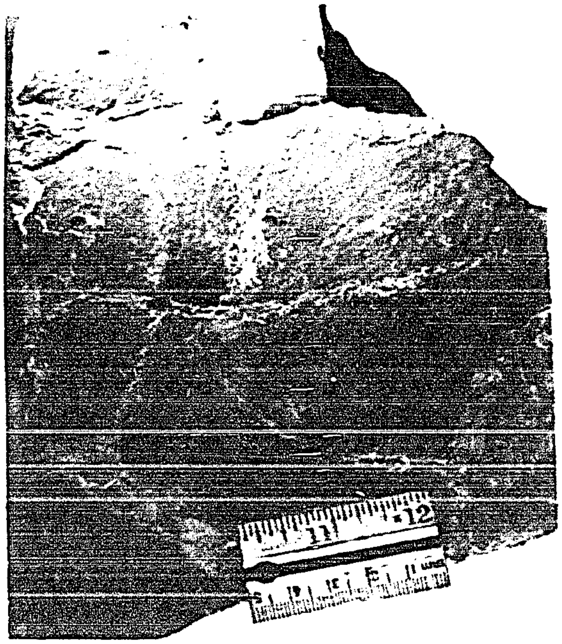


FIG. 2

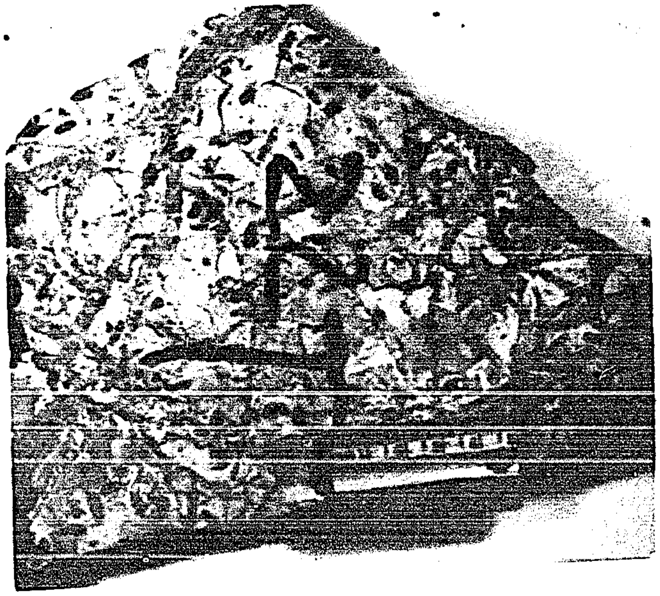


FIG. 3

porting current ripped up partly indurated mud bottoms and then imbricated the platy fragments". A sudden resubmergence of mud cracked flat could also cause development of similar structure.

Very little is known concerning the environment of formation of such structures. However, a shallow water (probably intertidal areas or tidal inlets) environment would permit formation of intraformational conglomerate beds.

Desiccation Features

Mud Cracks

Mud cracks are the most common type of shrinkage structure and occur in argillaceous, and fine grained, laminated impure carbonate rocks. The cracks are usually curved in plan, and the bounding polygons have curvilinear sides. The polygons range from 2 to 6 inches across, and cracks are usually 1/2 to 2 inches in depth. Some cracks penetrate deeper into the sediments. The cracks are infilled with fine quartz sand, silt and black carbonaceous or green chloritic material and dolomite (Plate 9, fig. 2). In places mud polygons are impressed with burrows and trails. Mud cracks most commonly develop subaerially.

Fischer (1964, figs. 8 and 9, p. 114 and 115) described similar mud cracks features from Alpine Triassic algal mat facies and calcilutites of the intertidal environment. Such cracks formed not on the surface but under a cover of tough algal material. Newell and Rigby (1957, p. 50, Plate 9, fig. 1) described similar desiccation features from algal rich tidal pool deposits of the intertidal zone. Ginsburg (1957, p. 93) reported similar desiccation feature from the interior mud flats of Florida Bay. The surface of mud flats is covered by a mat of blue green algae and the underlying sediments consist of alternate algal and sediment laminae. Blue green algae are the most abundant organisms in areas of mud crust formation (Fagerstrom 1967, p. 73). In warm waters of high pH the algae grow rapidly and the filaments penetrate deep into the mud to bind sediment. On drying, the algae increase the cohesion of muds to produce crusts which maintain their integrity with rewetting.

Dolomite forms in sediments when supratidal areas are exposed. Evaporation combined with upward capillary migration of saline water concentrates sea salt in the upper few inches of the sediment surface. Continued drying and wetting of sediments cause spalling of semiconsolidated mud which forms a blanket over the mud flats and also fills in cracks and worm burrows. The coarse nature of such infilled material permits movement of highly saline water along cracks resulting in selective dolomitization.

It seems reasonable to assume that both organic and inorganic agents played an important role in development of mud crusts in the Black River limestones. Perhaps desiccation features formed in chiefly shaly or silty rock are products of normal desiccation whereas such features, in calcareous impure carbonate rocks are products of organic activity. Mud crusts are seldom observed in the upper coarser units. Mud cracks developed in some noncalcareous fine upper units are smaller in size and do not show the effect of selective dolomitization mentioned earlier.

Sheet Cracks

This type of desiccation feature does not exhibit polygonal pattern,

Explanation of Plate 10

Figure 1 Sheet cracks (in unit II Longford quarry). The cracks are on bedding and are filled with clear coarse calcite spar in fine grained carbonate mud. (Dark round spots are due to faulty peel preparation). Transverse calcite filled areas are shrinkage pores (positive print. X 22.

Figure 2 Alternate thick and thinly laminated micrite showing development of shrinkage structures in rocks of unit II (Hampshire road section). Weakly defined dark laminae are possibly algal material.

PLATE 10.

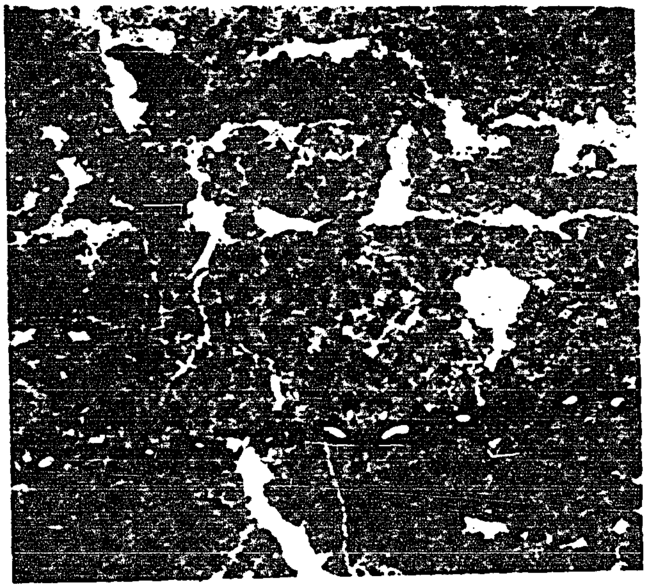


FIG. 1

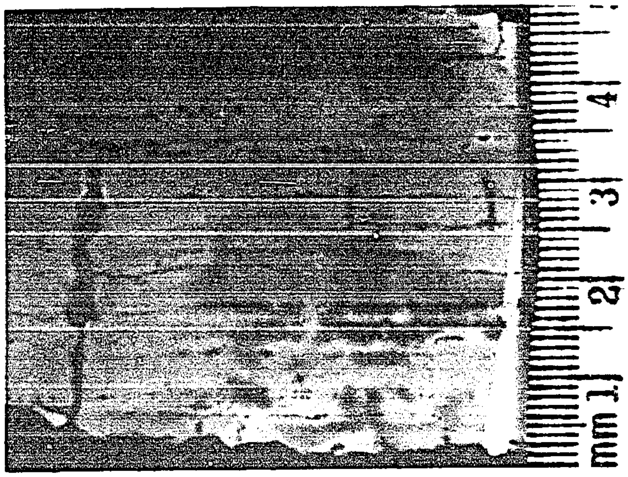


FIG. 2

but shows a planar form. Cracks are commonly filled with coarse clear granular calcite. These occur parallel to bedding plane ranging from microscopic size to several inches in size (Plate 10, fig. 1). These structures are very common in the lower dolomitic limestones and lithographic limestones of Unit II.

Shrinkage Pores

Shrinkage pores are much larger than intergranular pores and extremely irregular in shape and size. Some are difficult to distinguish from burrow structures. The pores are filled with clear calcite even though the surrounding host sediment is partly dolomite. Shrinkage pores are commonly seen in rocks of Unit II and Unit III. Similar spar filled features have been termed "birdseye" structure by many workers. A careful examination should be made to differentiate shrinkage pores from clear calcite filled fossils, as each reflects a different genetic history.

Fischer (1964) described shrinkage pores in very fine pellet-rich and fine grained carbonate units. In most cases, mud cracks (prism crack of Fischer) sheet cracks, shrinkage pores and algal mats are closely associated (Plate 10, fig. 2), representing a littoral condition where sediments undergo shrinkage due to desiccation.

Birdseye Structure

The term has been used for clear calcite filled cavities that tend to weather out as glittering blebs in freshly broken surface. Logan (1863, p. 136) described birdseye as "slender tube like forms

Explanation of Plate 11

Figure 1 Interconnected or isolated tube like clear calcite filled "Birdseye" structures, characteristic of fine grained grey weathering white carbonate rocks of unit III (Hwy. 401 section, 5 miles east of Napanee). Scale in inches.

Figure 2 "Birdseye" structure in fine shell and oölite-rich carbonate rocks of unit III (Roblindale quarry). Note isolated, oval, or elliptical shape of calcite filled dark birdseye areas.

PLATE II.

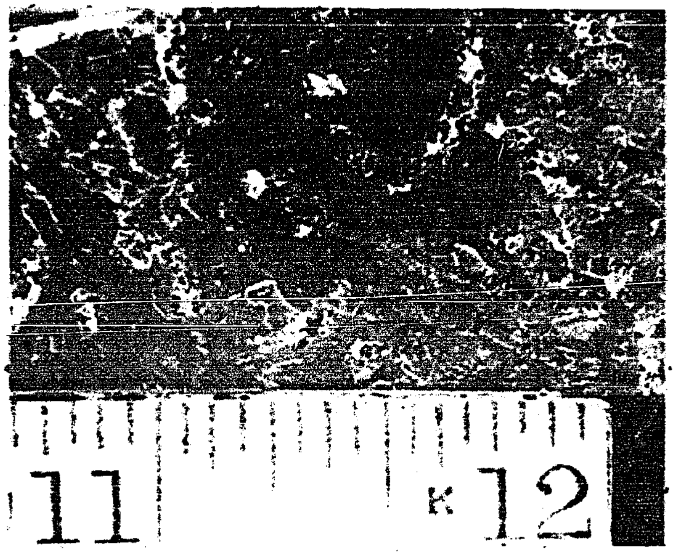


FIG. 1

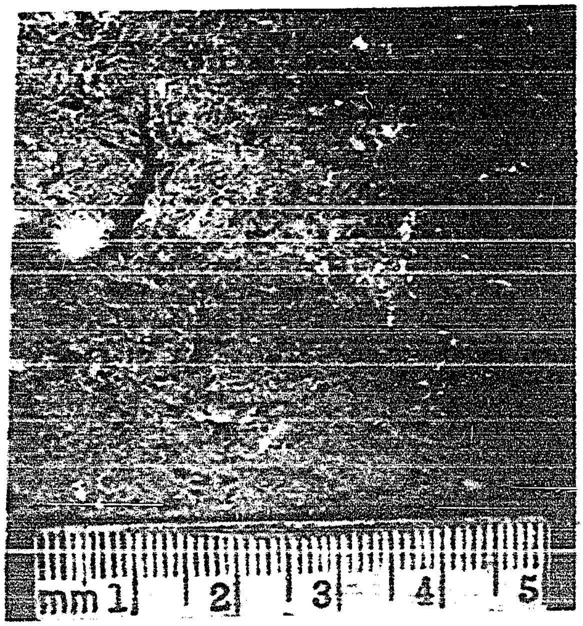


FIG.2

running in various direction in the rock filled with crystals of calcspar, probably replacing the remains of Tetradium fibratum". These features are commonly observed in rocks of Unit III, ranging from 0.05 to 0.4 inch in size, and varying in shape from oval, tubular, to irregular. Interconnected tubes are not uncommon. Rare cases of such structures infilled with surrounding sediments or shell fragments can be seen. Interconnected patches and rod shaped areas can be easily mistaken for shrinkage feature and burrows respectively (Plate 11, fig. 1).

Birdseye ~~structures~~ are very characteristic of pellet, organic, and oölitic fine carbonate rocks and very fine grained grey to white, shell-rich carbonate rocks of Unit III (Plate 11, figs.1 and 2). The markings may be elongate in both vertical or horizontal directions. Sometimes these vugs are intersected by clear finer grained secondary calcite veins. Cloud (1960, Plate 2, fig. B) described the development of birdseye structure as due to accumulation and migration of gas in sediments. He suggested the following stages in the development of birdseye features:

1. Deposition of mud and organic material.
2. Organic decay, causing generation of H_2S, by bactarial activity and interstitial reducing condition.
3. Mobilization of iron within sediment, reaction with H_2S to form pyrite, and increase in pH.
4. Increase of carbonate ion concentration and carbon dioxide pressure, with the result that previously dissolved mud recrystallised as calcite or dolomite.

Gases of biologic origin play a significant role in sealed basins or in embayed intertidal environments of wide extent.

Cloud's inorganic gas bubble mechanism would seem to account for these features in the present area, where neither shrinkage features nor abundance of coral growth can be observed. It is interesting to note that some extremely fine grained pellet-rich carbonate units showing birdseye structure yield appreciable amount of pyrite in the insoluble fraction.

Borings and Burrows

Tubelike structures are common in Black River rocks (Plate 9, fig. 3), and are associated with bored discontinuity surfaces. The discontinuity features are restricted to the upper few inches of a bed while the borings penetrate in depth to several inches.

Commonly, borings are vertical tube-like features, filled with sediment which differs from the surrounding host sediment or overlying material. Extensive boring of sediments may produce a networklike structure. Usually the burrows end at the bedding surface with a circular or elliptical section (Plate 9, fig. 3). Horizontal, vertical and oblique tubes are commonly seen in the rocks (Plate 12, fig. 1). Borings range from 0.1 to 0.25 inch in diameter, and from 0.5 to 2 inches in length. Usually borings are filled with light brown, fine, silty argillaceous dolomitic material. In some cases the bored tubes may show partial or complete infilling of cavities with the surrounding sediments.

Burrows are rare in coarse grained limestones, and pure very fine grained carbonate rocks; they are abundant in fine grained shell-rich

Explanation of Plate 12

Figure 1 (Bedding plane view). Intense boring in fine dolomitic micrite (unit II, Marmora quarry). Note the colour difference of surrounding matrix and infilling of burrows. Elongated tubes are horizontal (parallel to bedding). Scale in mm.

Figure 2 Birdseye or boring structures on bedding surface. (Unit II, Longford quarry).

Figure 3 Long horizontal tube-like burrows, on the bedding surface together with weakly defined small ridge like tubes are also seen. (Unit II, Uhthoff quarry). Irregular relief of bedding is due to boring activity of organisms distorting original smooth surface.

PLATE 12.

FIG. 1

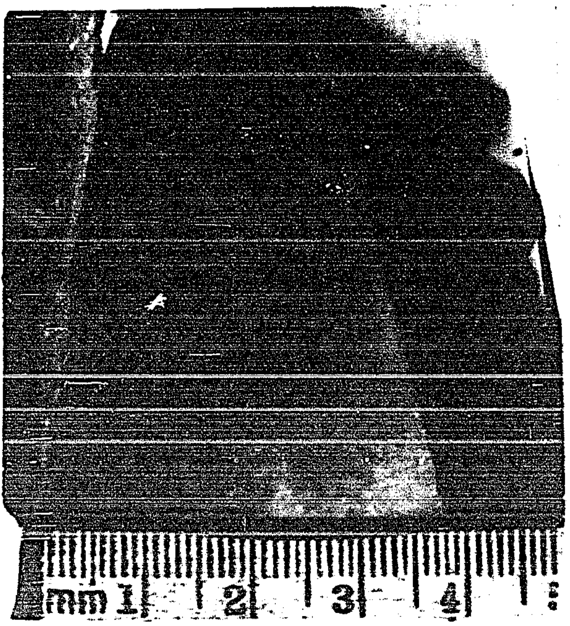


FIG. 2

FIG. 3

units. Some borings are filled with clear calcite, so that distinction from birdseye structures is extremely difficult (Plate 12, fig. 2).

Ginsburg (1957) reported the occurrence of extensive burrowing in the Florida Bay area from the intertidal zone to depth of 50 feet. Similar borings can be seen in deeper water environments. Extreme scavenging activity of organisms causes disruption of all primary depositional features. Extremely disrupted bedding is present in the lower most green, sandy dolomitic rocks of Units I and II in the study area (Plate 12, fig. 3). Excellent examples of such features occur at Marmora and Uhthoff quarries.

Calcite Nodules

Crystalline calcite nodules are spherical, elliptical or elongate and range from 1 to 6 inches or more in size. They occur at a definite stratigraphic level. These show a restricted distribution within brown to buff coloured thick bedded dolostone or dolomitic limestone of Unit II, (Plate 13, fig. 1). Nodules are particularly more abundant in areas east of Marmora. Nodular cavities are filled with a coarse mosaic of white to brownish, clear calcite with rare occurrence of irregular anhydrite patches.

Some nodules contain broken angular to rounded fragments of the surrounding host rock ranging from 0.1 inch to more than 1 inch in size. The fragments are concentrated parallel to the basal margin of cavities and show irregular orientation of long axes (Plate 13, fig. 2). Most commonly fragments are horizontally aligned, with a few in a vertical position (Plate 13, fig. 3). Some fragments show traces of original

Explanation of Plate 13

Figure 1 Calcite nodule in thick bedded, blocky, brown to buff coloured dolostone of unit II. (Montreal Street section on Hwy. 401).

Figure 2 Calcite and rock fragment filled nodular cavity (Unit II, Montreal Street section). Lower margin is lined with angular to rounded fragments. Note horizontal nature of most fragments with few in vertical position. The presence of isolated fragments along the upper margin and the curved nature of the upper sediment layer are due to collapse.

Figure 3 Horizontal nature of fragments parallel to the cavity floor (Unit II, McGinnis and O'Conner quarry). One vertically oriented fragment occurs near left hand margin. Note the presence of cracks in the fragments. Splitting probably took place along these cracks. White areas represent coarse calcite crystals.

PLATE 13.

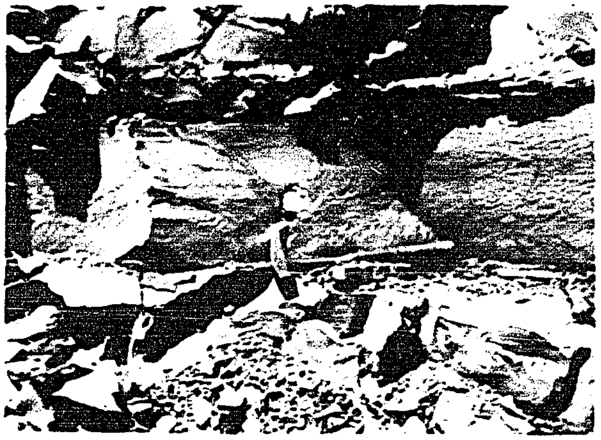


FIG. 1

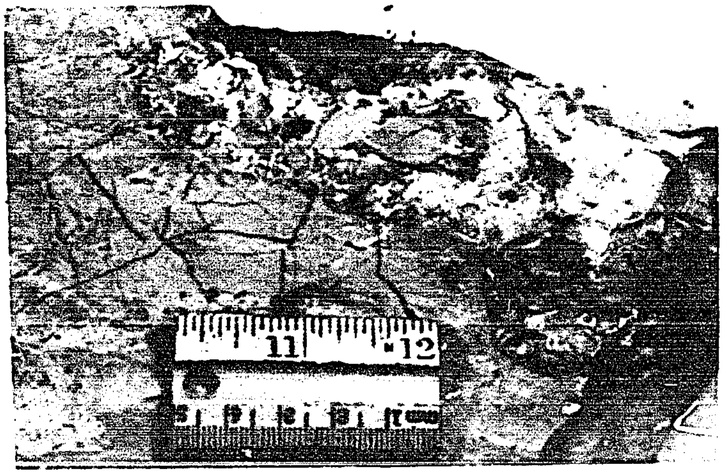


FIG. 2

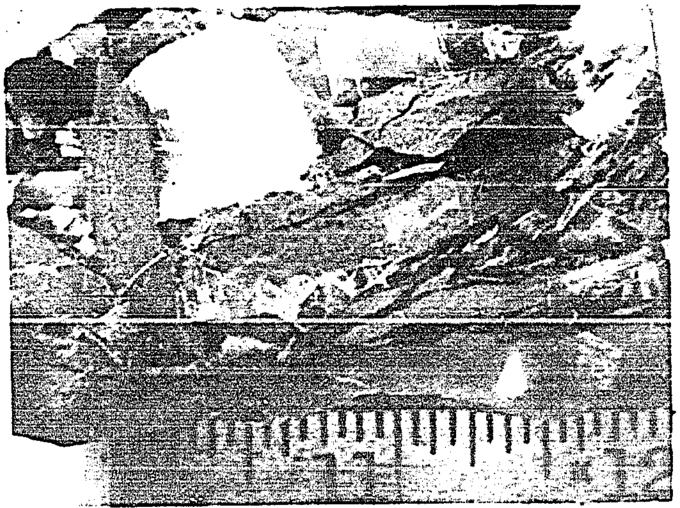


FIG. 3

fractures along which splitting had started.

Various workers reported these calcite nodules but no satisfactory explanation has been given. Kinsman (1966b) described extensive formation of nodular anhydrite in supratidal coastal flats of Trucial coast. According to Kinsman "nodules vary greatly in development and may range from less than 0.05 inch to more than 6 inches in diameter, shape ranges from spherical to strongly flattened and they may occur as individuals or as complex intergrown masses". Gypsum is also reported in the nodules where anhydrite is being rehydrated following contact with ground water from the inland areas. Gypsum is also scattered throughout the sediment. Both anhydrite and gypsum grow interstitially, and never as a precipitate on the upper sediment surface.

The presence of fragmented wall rock around the basal margin of present cavities might suggest splitting of semiconsolidated carbonate rock during crystallisation of gypsum. Calcite infillings may represent a secondary replacement mechanism of original cavity filling, through a void stage, as evidenced by the collapse of the overlying sediment layer on the upper margin (Plate 13, fig. 2). Occurrence of empty nodular cavities bears support to the existence of a void stage. The most probable mechanism to provide space for the growth of gypsum will be the separation of lower cavity wall margin through forces exerted by directional crystal growth of gypsum. Following Bundy (1956, p. 247, fig. 13), "The forces were directed normal to the walls. The solutions saturated with $CaSO_4$ were supplied by capillary opening normal to the plane of weakness". A parallel system of fine cracks in the fragments may have formed during desiccation. The absence of brecciated appearance in other nodules may reflect localized development of desiccation cracks which are quite likely to form in intertidal or supratidal flats.

Chert Nodules

Chert nodules are abundant in some of the Black River limestone units. Grey to black chert nodules occur as flat, elongated, to elliptical and irregular bodies 1 to 6 inches in size. Chert is associated only with certain beds of units III and IV (Plate 14, fig. 1). Most chert nodules are associated with coarse fossiliferous carbonate horizons, and contain many well preserved replaced shell fragments. Evidence of boring activity through nodules (Plate 14, fig. 1) suggests irrefutable indication of primary or very early origin of such siliceous material. Moore (1957, p. 120) described similar chert nodules from Mississippian carbonate deposits, and thought that in the absence of siliceous organisms, such nodules could be of primary inorganic origin. Fossil fragments enclosed in chert nodules consist of clear calcite. In a few cases, brachiopods show replacement by chalcedony. The irregular surface of these nodules, inclusion of original limestone patches within chert, and interpenetration of siliceous material and surrounding carbonate rock are very commonly observed.

Newell _et al_. (1953) and Dott (1958) described similar features and suggested a secondary replacement origin for chert nodules. The solubility of silica and calcium carbonate in water under varying pH conditions suggests that under alkaline condition solubility of calcium carbonate is decreased, and silica is increasingly soluble.

Explanation of Plate 14

Figure 1	Chert nodule with patches of limestone inclusions (grey oval area in right hand corner) and along basal margin (Unit II, Uhthoff quarry). Burrow structure filled with fine grained calcareous material and clear crystalline calcite, cuts across chert nodules. Scale in inches.
Figure 2	Needle like molds in white lithographic dolomitic limestone (Unit II, Marmora quarry). Needles are generally irregularly scattered but follow a micro-stylolitic structure at the base. Photograph shows view perpendicular to bedding in rock of unit II.

PLATE 14.

FIG. 1

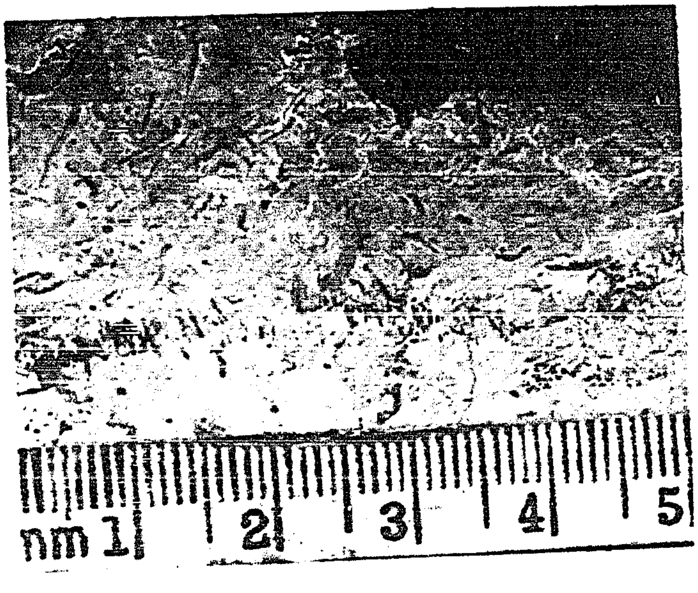


FIG. 2

Silica may be derived from the following sources: (1) dissolved silica in sea water, (2) devitrification of volcanic material, (3) weathering of siliceous rocks, and quartz sand grains, (4) siliceous organism (Newell _et. al._ 1953, p. 162). Moore (1952) reported occurrence of three types of siliceous sponges in the Middle Ordovician rocks.

In sediments with varying quantities of organisms in different parts, bacterial action may lead to the formation of organic acids in certain parts of the beds while alkaline conditions exist above and below. If connate water saturated with silica and calcium carbonate comes in contact with such sediments, more silica will be precipitated in the acid enriched part of the bed while calcium carbonate will continue to concentrate in other parts. This reaction will continue as long as sediment porosity, permeability, and chemical gradient permits diffusion of ions within the bed and the adjacent beds (Newell _et. al._, 1953).

A cyclical distribution of chert-bearing horizons is common in regions characterized by a shallow fluctuating, sediment-water interface e.g. tidal or intertidal areas. In the Black River rocks, other sedimentary features (discussed subsequently seem to indicate that the upper units of the Black River rocks represent deposition in a shallow fluctuating environment.

Replacement of fossils varied greatly depending on the size and nature of original organisms. Brachiopods and bryozoa are least resistant to such replacement while massive crinoids and other boring organisms are highly resistant to such process and maintain their original

Explanation of Plate 15

Figure 1 Platy isolated crystal or rosette like cluster of celestite infilling molds in acid digested rock. (Same rock as in Plate 14, fig. 2).

Figure 2 White irregular patches of original fine grained limestone in a matrix of coarse brown, argillaceous dolomitic rock (Unit II, Uhthoff quarry). (Concentric striations are saw marks).

PLATE 15.

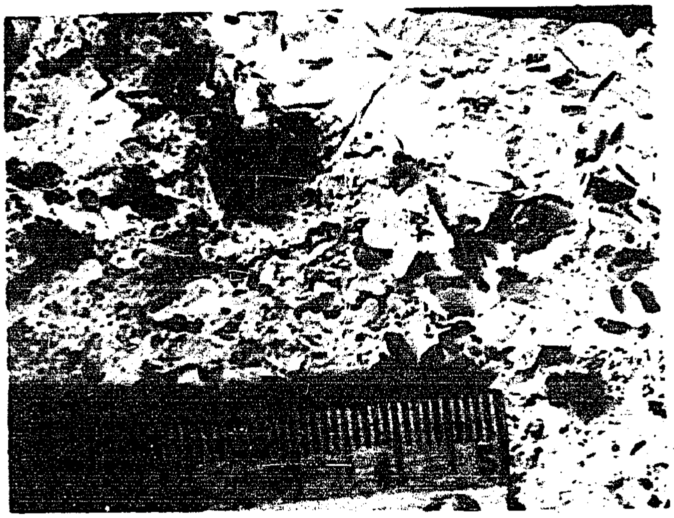


FIG.1

FIG.2

composition. Newell et al. (1953) also noted that smaller fragments are completely replaced by quartz or chalcedony while larger ones are less severely affected. The reason for the selective nature of the replacement mechanism is unknown.

Crystal Molds

Crystal molds are fine slit like cavities probably resulting from solution of some original crystalline fillings. The slits or molds are 0.15 to 0.25 inches long, scattered irregularly through white to grey pure lithographic dolomitic limestone. Often these constitute a conspicuous horizon with abundant microstylolitic surfaces (Plate 14, fig. 2). Young (1943) reported similar molds in Ontario from Lowville and Pamelia beds and described such structures as "cuneiform texture". Summerson (1966, p. 221) described similar molds from the Salina beds of Northern Ohio and suggested that such features represent leaching of gypsum by solution.

The present study reveals that molds represent solution of celestite. Ehlers (1945) reported similar celestite molds from Upper Silurian rocks in the Mackinac straits region. Several samples showing crystal molds were acid digested for 4 days. Undissolved portion of such rocks showed infilling of molds with platy isolated crystals or rosette like clusters (Plate 15, fig. 1). X-ray study of infilled material showed the presence of celestite (peaks at 2.97 Å, 3.30 Å, 2.73 Å) only.

Illing et al. (1965) reported authigenic celestite as sheaves and needles less than 0.1 inch long occurring sporadically in the upper two feet of landward part of the sebhka in Perian Gulf areas. The presence of celestite could be explained by early diagenises of aragonite mud to supply strontium, for the formation of celestite in an extremely saline environment.

Mottling

Mottling is the spotty or patchy colour pattern created in rocks by the presence of contrasting matrix and enclosed bodies. Relict patches, lenses, and irregular bands of very fine grained white to grey limestone occur embedded in a brown to buff coloured coarse anhedral mosaic of dolomite. Relict lenses are 0.2 inch to 4 inches in length, and show sharp to gradational contact with the surrounding argillaceous dolomitic matrix (Plate 15, fig. 2). Beales (1956) described dolomitic mottling from the Devonian Palliser Formation of Alberta and concluded that "Bank sediments appear to be suceptible to dolomitization. Bahama well cuttings show considerable alteration".

The dolomitization process is selective, and depends on the porosity of sediments, and supply of magnesium. Occasionally dolomitization is selectively controlled along borings (Plate 12, fig. 1) and stylolitic planes. A detailed discussion of dolomitization will be given in a subsequent section.

Pisolith

Pisolitic structures are noted in coarse grained shell-rich and fine pellet-rich limestones of upper units (II and III). The greater portion of the rock is composed of broken fragments of original limestone, elliptical, flat rod, spherical or irregularly shaped ranging from 0.05 to 0.4 inches in size. In most cases particles or grains show a white to grey, very fine carbonate envelope surrounding the external margin. The envelopes may be uniform or irregular in thickness, and in places extend within the inner nucleus as small tubular projections (Plate 16, fig. 1). Under high magnification the envelopes show weak, very fine laminated structure. In most cases a single envelope is present around the core. Behrens (1965, p. 48, Plate X, fig. B) and Lebauer (1965, p. 440, fig. 16) described very similar features from high energy intertidal limestone deposits and considered them to be algal pisoliths.

Frequent presence of algal material in rocks of Black River limestones suggest the possibility of an algal origin for the pisoliths.

Stylolites

In Black River rocks, stylolites are commonly developed in the lower units (I and II) but are rare in the upper units. Most stylolites run parallel to bedding planes though some transverse types also occur. Stylolites form zig-zag structures with alternate pits and vertical columns. Stylolitic planes develop in fine laminated limestone. Occasional discontinuous stylolites occur in some coarser rocks. The amplitude of stylolites varies from a fraction of an inch to 1 inch or more. Stylolites may be very closely or widely spaced (Plate 16, fig. 3) with frequent wedging and splitting of planes.

Various interpretations have been made regarding the genesis of stylolitic structures. Manten's (1966, p. 269) paper gives an excellent

Explanation of Plate 16

Figure 1 Algal pisolith in fine fragmental limestone of unit III. (Coboconk road section). Note irregular and selective growth of envelope around grains. Scale in inches.

Figure 2 Algal envelope around dark, rounded to irregular fragments in unit III (Roblindale quarry). Note grey laminated area (algal) near left hand lower corner.

Figure 3 Very closely spaced microstylolitic structures showing frequent wedging and splitting in fine grained rocks of unit II. (Hwy. 401 section near Hwy. 15 exit).

PLATE 16.

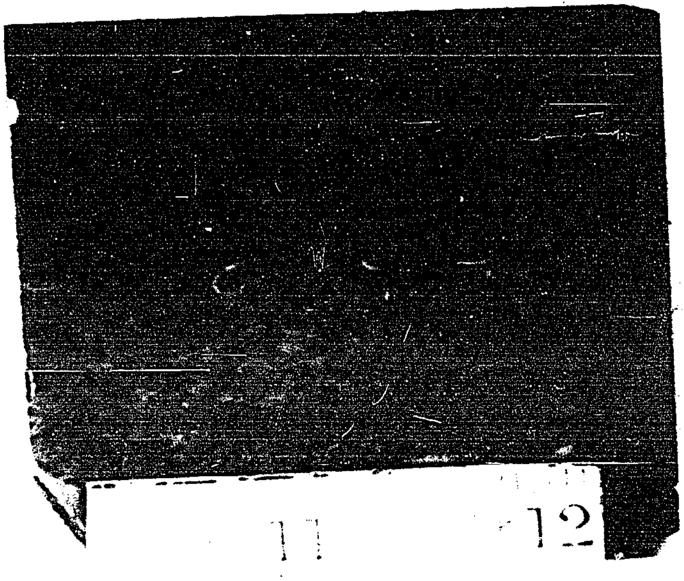


FIG. 1

FIG. 2

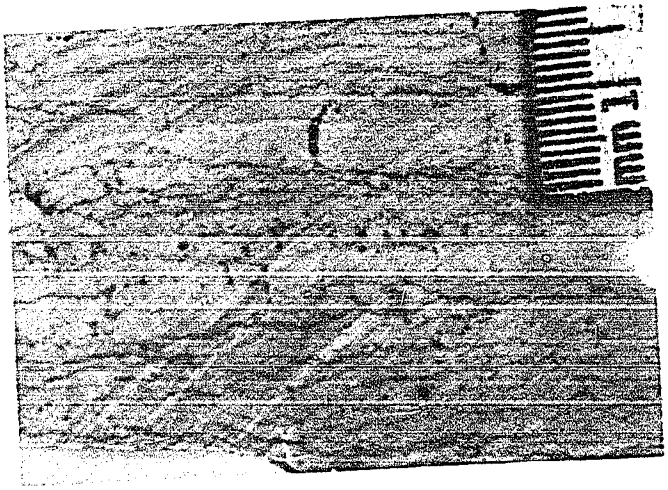


FIG. 3

Explanation of Plate 17

Figure 1 Symmetrical and interference ripples in fine, impure calcareous siltstone (unit III). The hammerhead is parallel to strike of ripples approximately NE-SW in Marmora Quarry at 149' level.

Figure 2 Tabular cross bed in coarse, öölitic limestone of unit III. Fore set beds dip SW. (Section on 401 Hwy. 5 miles W. of Kingston. Extreme eastern part of section exposed along the median).

PLATE 17.

FIG. 1

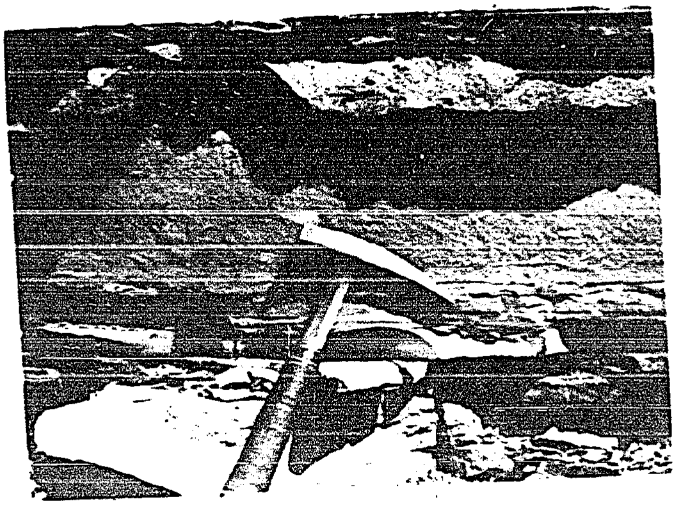


FIG. 2

review of various ideas.

Cross cutting relation of stylolitic planes, displacement of shells and other grains along stylolitic planes etc, suggest later solution of sediments after consolidation. Differential solution of various materials under directed pressure on bedding planes causes formations of stylolites. Stylolitic planes are covered with dark argillaceous material, quartz silt and dolomite. Differential solution of carbonate materials provides concentration of magnesium, iron and insoluble residues, which are deposited along the stylolitic contact.

Ripple Marks

Ripple marks have been reported by various workers from the Black River rocks. During the present investigation ripple marks were noted only in widely separated areas. Most of the ripples were symmetrical or interference type, and no attempt at palaeocurrent analysis was made for such structures. Rippled surfaces are common in the lower units (I and II) and less abundant towards the top (Units III and IV). They occur in impure, fine limestones and siltstones. The ripple marks usually have amplitudes 0.5 to 2 inches, and wave-lengths ranging from 3 to 6 inches (Plate 17, fig. 1). Rippled surfaces are rare in coarse bioclastic rocks.

Symmetrical ripples occur in recent shallow, lagoons or tidal shelf areas. These ripples are generated where oscillatory waves are of equal strength and duration in both directions, and where no current motion is involved. The ripples have been found parallel to strand line (shore line) in modern and ancient carbonate environments (Potter and Pettijohn, 1963).

Explanation of Plate 18

Figure 1 Trough shaped cross-lamination in fine, well sorted shell-rich limestone of unit IV. (Marmora road section).

PLATE 18.

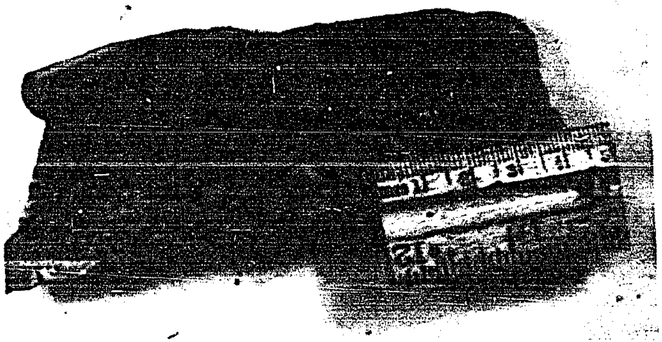


FIG. 1

Internal Features

Cross stratification features are the only internal features observed in Upper (Unit III and IV) Black River rocks. No systematic analysis of cross-stratification was attempted because sections are too poorly exposed, and widely separated to provide adequate data. Cross-stratification is associated with upper oölith and skeleton rich, fine to medium grained carbonate rocks. In most cases stratified units are very thin to thickly bedded (after McKee's classification 1953). Two distinct types of cross-bedded structures occur.

1. Steep tabular cross stratification:- The foreset strata dip at an angle of approximately 20° to 30° and terminate abruptly at the lower bounding horizontal surface. Coarser particles are concentrated along the lower margin of inclined foreset beds. These units range from 2 to 20 inches in thickness and usually show a flow direction to the southwest (Plate 17, fig. 2).
   Imbrie (1964) Imbrie and Buchanan (1965) reported similar cross-stratification from oölitic shoals of Bimini, in Bahama Banks. Tabular cross-beds are formed by normal currents in a wide range of water depths.
2. Trough cross stratification:- Each trough-shaped set consists of an elongate erosional scour infilled with curved laminae. Troughs average 0.5 inch in thickness, and 1 to 2 inches wide, (Plate 18, fig. 1). These are developed in the uppermost units (III and IV) of fine grained well sorted limestone beds. Grains are mostly less than 0.2 inches in size. This type of cross-stratification is less than 6 inches thick. According to Harms and Fahnestock (1965) "Small scale trough cross stratification

forms by ripple migration in the lower part of the lower flow regime".

CHAPTER 4

INSOLUBLE RESIDUE

In recent years considerable attention has been given to the relationship between dolomite/calcite ratios and insoluble residues in carbonate rocks (Fairbridge, 1957; Bisque and Lemish, 1959; Kahle, 1965a; Zenger, 1965; and Hatfield and Rohbacher, 1966). Most workers have attempted to use the relationship of clay mineral and dolomite/calcite ratio to explain the origin of mineral dolomite in limestone.

Insoluble materials were obtained as residues after acid digestion of limestones. The residues include both light and heavy fractions. Insoluble fractions between 250 mesh (0.0625 mm or 0.063 mm) and 150 mesh ([illegible] 0.104 mm) were separated into light and heavy minerals. Details of procedure are given in appendices IV and VIII. Heavy minerals were studied using standard optical methods. X-ray diffraction and powder photograph methods were also used in some cases, where optical methods did not provide satisfactory identification of mineral species. No attempt was made to study light minerals in detail, and only the presence of common minerals constituting such fractions were noted.

Total insoluble content of rocks (in +250 mesh -150 mesh) may range between 0.001% to 10% (rare), but usually values around 0.01%

Explanation of Plate 19

Figure 1 Nodular to irregular concretion of pyrite (photographed in reflected light). X 30.

Figure 2 Spherical nodules of pyrite (photographed in reflected light). X 30.

Figure 3 Euhedral pyrite (plane polarised light). X 50.

D - dodecahedron

c - cube

PLATE 19.

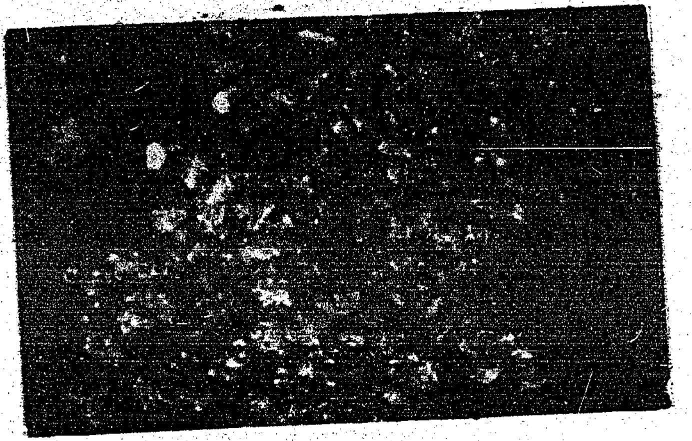


FIG. I

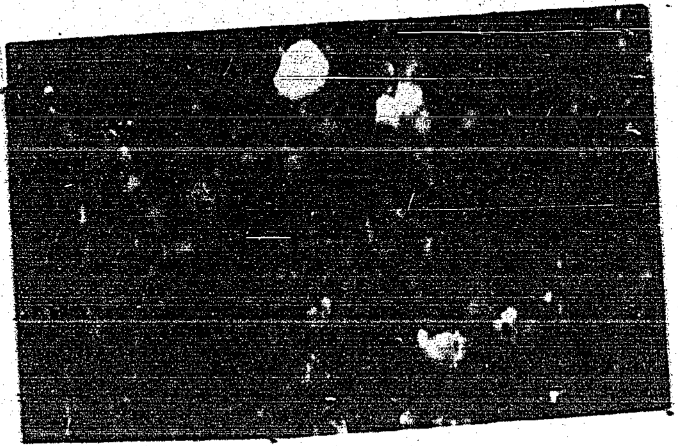


FIG. 2

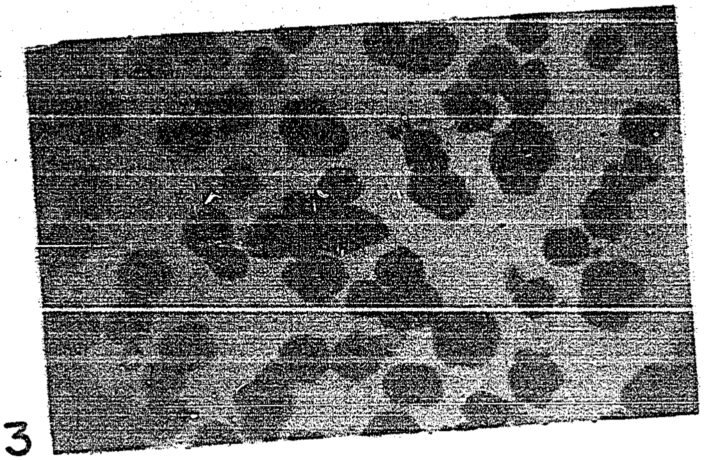


FIG. 3

to 1% are common. Heavy minerals may constitute 0.0001% to 0.5% of total rock but commonly values between 0.001% to 0.03% occur.

Heavy Minerals

Authigenic heavy minerals include the following types pyrite, dolomite, celestite, anhydrite, anatase, sphalerite, galena, and fluorite. The following detrital minerals were found:- magnetite, hematite, rutile, ilmenite, garnet, zircon (?), tourmaline, epidote, sphene (titanite), staurolite, zoisite, pyroxene, amphibole, apatite, and chlorite.

Authigenic Minerals

Pyrite:- Pyrite occurs as small grains, concretions (Plate 19, fig. 1), spherical nodules (Plate 19, fig. 2) and euhedra (dodecahedran, cubes and pyritehedran) (Plate 19, fig. 3). The usual colour is brass yellow, but the pyrite is brownish yellow or black, when tarnished. In most cases grains occur as aggregates. Interpenetration of euhedral grains is frequently observed. Some merging of nodular or concretionary grains yields extremely irregular masses (Plate 20, fig. 1). X-ray diffraction patterns showed peaks at 2.74Å, 7.65Å, and 2.45Å corresponding to pyrite. No marcasite was noted in the study area. Nodular or concretionary grains commonly occur in burrows or as replaced shell fragments.

There is considerable variation in the distribution of pyrite, which may constitute upto 100% of the total heavy mineral residues. Commonly an increase in pyrite content is marked by a corresponding decrease of dolomite in the heavy residues (Fig. 3, A to Q). The

Explanation of Plate 20

Figure 1	Irregularly shaped pyrite caused by merging of nodular or concretionary grains (plane polarised light). X 50.
Figure 2	Rhombohedral grains of dolomite. Note colourless (appears light greenish) and white grains with or without dark central or marginal inclusions (plane polarised light). X 22.
Figure 3	Tabular to prismatic celestite grains with extremely rugged outer margin (plane polarised light). X 55.

PLATE 20.

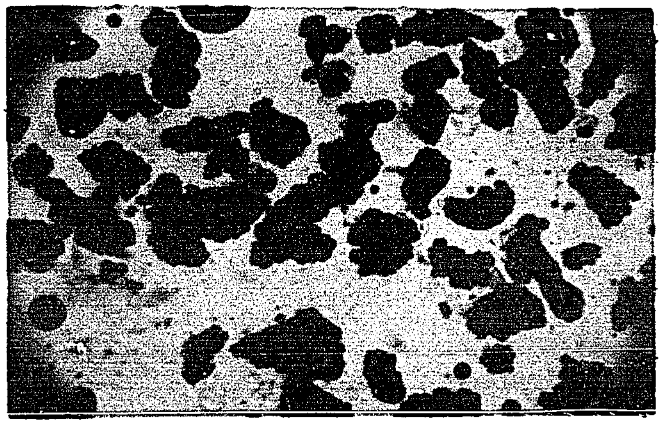


FIG. 1

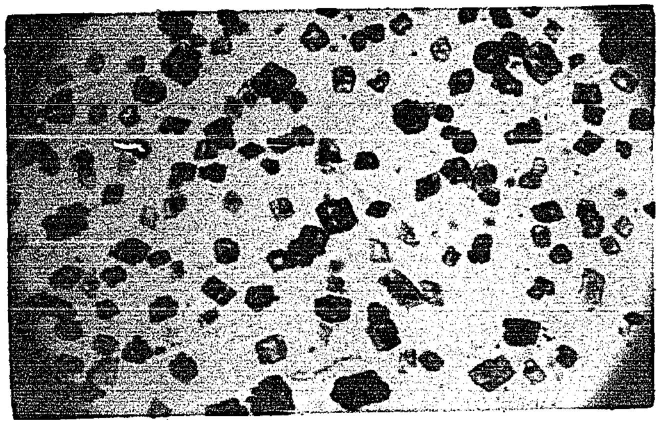


FIG. 2

FIG. 3

basal units (I and II) of Black River carbonates show an appreciable decrease in pyrite content relative to the overlying units III and IV (Fig. 3, A). Pyrite forms a common constitutent of heavy minerals, and can be traced persistently across the present area.

Pyrite represents a common precipitate in sediments, which underwent diagenesis in an alkaline reducing environment. The formation of pyrite may have taken place early in diagenesis at the time of greatest bacterial activity, just below the sediment water interface (Honjo _et al_. 1965, p. 484).

Dolomite:- Dolomite is chiefly recognized as grains, with simple rhombohedral habit which is rare in calcite, characteristic "twinkling" and sometimes by zoning. Grains are colourless, white, or reddish brown, transparent to translucent in character (Plate 20, fig. 2). Rhombohedra may show curved or irregular margins. Most translucent grains contain dark marginal or central inclusions (clay or organic materials?). X-ray diffraction pattern of ground residue gave peaks at 2.90Å, 2.19Å and 1.77Å corresponding to dolomite. Dolomite occurs as isolated scattered rhombs or as irregular patches of anhedral grains in the limestones.

Dolomite shows a wide variation in distribution throughout the study area. Dolomite may constitute 100% of the total heavy residues. Commonly, the lower units (I and II) of the Black River rocks are characterized by a high concentration of dolomite in the heavy fractions (fig. 3, A). Occasional high values of dolomite occur in the rocks of upper units (III and IV) are not uncommon (fig. 3, E, H). Dolomite-rich rocks of the upper units do not reveal the inverse relationship of pyrite and dolomite in the heavy residues (Fig. 3, E, H). Also the rocks display various relict textures and structures on both macro- and micro-scales.

Dolomite probably represents authigenic growth during early and late diagenesis of carbonate sediments.

Celestite:- Celestite grains are tabular to irregular in shape with extremely rugged outer margin (Plate 20, fig. 3), sharply angular cleavage fragments are also common. Grains are colourless to white with or without irregular dark brown, and black inclusions (Plate 21, fig. 1). X-ray diffraction study revealed peaks at 2.90 Å, 3.30 Å and 2.73 Å corresponding to celestite. Celestite occurs as needle-shaped individual grains or rosette filling various cavities and occurring as cement.

Celestite is persistent in the Black River rocks and displays a wide variation in distribution. In some cases celestite may constitute the entire portion (100%) of the heavy residues. The lower units (I and II) are marked by a high content of celestite in the heavy fractions. In the lower units, high celestite content may be associated with a corresponding high dolomite distribution (Fig. 3, A to Q). In the rocks of the upper units (III and IV) a direct relation between celestite and dolomite has not been observed (Fig. 3, E, F, and H).

Celestite formed in sediments during early and late diagenesis of carbonate sediments.

Anhydrite:- Anhydrite is invariably associated with residues containing celestite, and sometimes differentiation of the two is difficult. Grains are rectangular to irregular, colourless to white and show

Explanation of Plate 21

Figure 1 Celestite grains with brown inclusions (plane polarised light). X 55.

Figure 2 Anatase with (001)and (111) faces, and geometric patterning (plane polarised light). X 100.

Figure 3 Brownish stained fluorite grains with distinct cleavage (3 grains in the centre of field of view). (plane polarised light). X 55.

E - sphene
F - fluorite
L - limonite

PLATE 21.

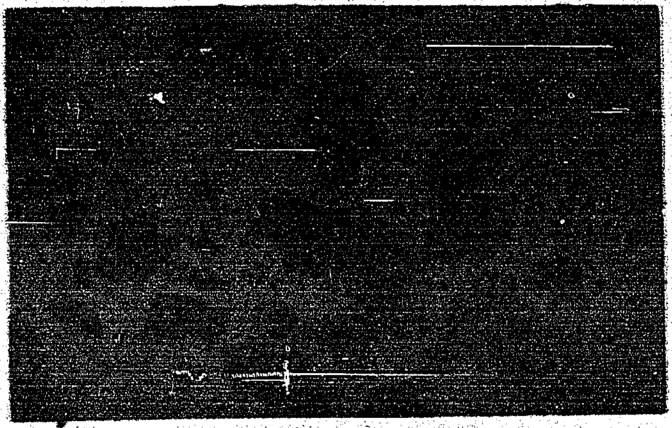


FIG.1

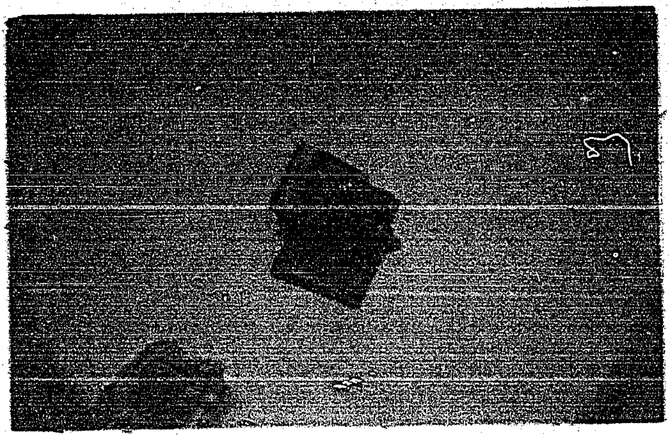


FIG.2

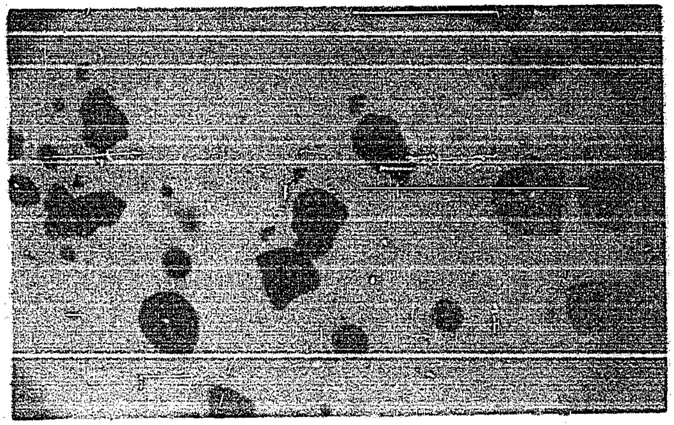


FIG.3

characteristic rectangular cleavages, and strong birefringence. Aggregate and compound grains show dark brown to black inclusions. Anhydrite is distinguished from celestite by cleavage pattern and lower refractive index. X-ray peaks at 3.50 Å, 2.76 Å and 2.44 Å correspond to anhydrite.

Anhydrite occurs as widely scattered elliptical to irregularly shaped nodules. Anhydrite may constitute from 1% to 50% of the total heavy mineral residues. Like celestite, anhydrite may reflect a direct distribution relation with dolomite, in the rocks of lower Black River units (I and II) (Fig. 3, A). Regionally the distribution is irregular. Anhydrite forms a very common constituent of rocks in Marmora and other eastern areas (Fig. 3, A, B, C, D, E, F, G, H and I). In western areas anhydrite is less common or absent (Fig. 3, J to Q).

Anhydrite also represents a product of diagenesis (early?) of carbonate sediment.

Anatase:- Tabular basal (001) grains are most common, showing bevelled 111 faces. The grains are yellow transparent to semi-opaque and show extremely high refractive index. Some grains appear to be isotropic and yield a well centred uniaxial figure in convergent light. Dark coloured varieties may show an anamalous biaxial figure. Rectangular grains show frequent zoning or geometric patterning (Plate 21, fig. 2). Inclusions of quartz are present in some cases. Occurrence of anatase is restricted in Uhthoff quarry (Fig. 3, P), Longford quarry (Fig. 3, O), Coboconk areas (Fig. 3, M, L), Burleigh Falls area (Fig. 3, K, J) and Marmora areas (Fig. 3, I and A). Anatase may constitute upto 25% of the total heavies. The distribution is extremely irregular.

Euhedral form suggests derivation of grains from alteration of titaniferous minerals e.g. ilmenite, which is commonly present in crystalline igneous and metamorphic rocks.

Fluorite:- Fluorite occurs as cubes or interpenetrating twins. Commonly grains are irregular, colourless, white, pink or light brown, with perfect cleavage, high relief and isotropic nature (Plate 21, fig. 3). Dark brown, and black inclusions (organic or inorganic?) are common. Some dark brown stain permeates the grains to give a blotchy appearance. X-ray diffraction pattern has peaks at 1.93 Å, 3.16 Å and 1.65 Å corresponding to fluorite.

Fluorite shows extremely local concentration in the Marmora areas (Fig. 3, A and I) and Napanee quarry (Fig. 3, D). It may constitute upto 25% of the heavies. Fluorite is distributed in the rocks of upper units (III and IV). One minor occurrence of fluorite was noted in rocks of unit II in Marmora quarry (Fig. 3, A).

Fluorite is usually derived from acid igneous rocks and metalliforous veins. Occurrence of fluorite bearing deposits near Madoc and other areas might suggest a possible detrital origin. The extremely angular to cubic form of the grains presumably indicate an authigenic nature. Amstutz (1964, p. 79, 145, 48) reported similar occurrences of fluorite as a late diagenetic product in carbonate sediment.

Sphalerite:- The mineral occurs as translucent yellow to brownish irregular grains with very high refractive index, and obvious isotropism and distinct cleavage. Sphalerite occurs in contact metamorphic deposits. In organic-rich carbonate sediment zinc ions may react with H_2S, liberated from organic decay, and precipitate as sulphides during diagenesis (Amstutz 1964; Chilingar et al. 1967). Winder (1964) reported rare sphalerite grains in shell-rich fine grained limestones of the upper Middle Ordovician in Ontario.

Galena:- Rare occurrence of cubic, black isotropic grains of galena are noted in some beds. The grains appear white to grey in reflected light and are marked by cleavage partings.

Sphalerite and galena occur rarely in the Marmora areas specially in the upper units (III and IV). However these do not constitute a significant portion of the heavy fraction and thus no definite distribution can be established. Like sphalerite, galena is also considered to be a late diagenetic product of organic-rich carbonate sediments.

Detrital Minerals

Magnetite:- Magnetite occurs as irregularly shaped black, isotropic grains (Plate 22, fig. 1). The grains have strong magnetism and thus can be separated from the heavy mineral fractions by a hand magnet. Some highly angular to rounded grains are also noted. Magnetite is irregularly distributed in the beds of unit I. Impure argillarceous shale and siltstone of coarser beds of upper units show frequent occurrence of magnetite. Magnetite constitutes a minor portion of the total heavy fraction. Magnetite is probably derived as detrital grains from the igneous and metamorphic rocks in the shield area to the north.

Ilmenite:- Ilmenite commonly occurs as irregular, subangular to rounded grains, black to brownish yellow in colour. It is distinguished from magnetite by weaker magnetism, and also by distinct brownish grey colour in reflected light. Ilmenite is irregularly distributed in all units

Explanation of Plate 22

Figure 1 Dark reddish brown, rounded rutile (marked R). Note elongated subangular zircon (marked Z) and angular to subangular, grains of garnet (marked G). (plane polarized light). X 22.

G_1 = colourless garnet with reentrant angle

m = magnetite

Figure 2 Subrounded, irregular, orange garnet. X 22.

G = garnet T = brown tourmaline. E = epidote

Am = Actinolilic amphibole.

Figure 3 Angular, irregular pink garnet with conchoidal fracture. (plane polarised light). X 22.

G = garnet

St = staurolite

PLATE 22.

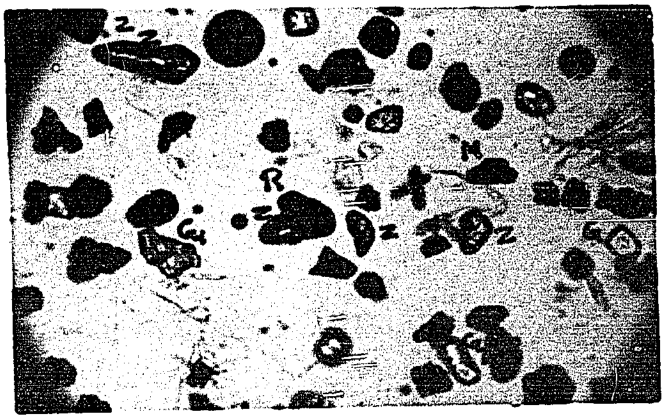


FIG. 1

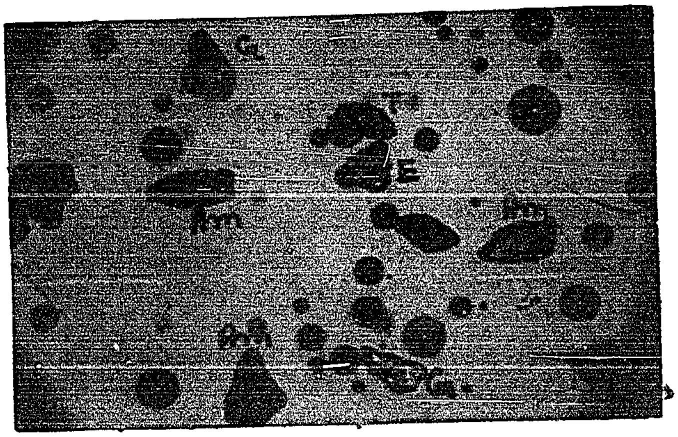


FIG. 2

FIG. 3

of the Black River limestones and constitute a very minor portion of heavy residues.

Ilmenite is chiefly derived from basic igneous and metamorphic rocks.

Magnetite and ilmenite are present in every section. In rare instances, these may constitute 25% of the total heavy mineral residues.

Hematite:- Hematite grains show similar optical and distributional characteristics to magnetite and ilmenite grains. Bright reddish brown colour of the grains in reflected light distinguishes hematite from magnetite and ilmenite.

The highly angular to rounded nature of the grains suggest a detrital origin from igneous or metamorphic source.

Limonite:- Limonite grains are irregular, to rounded, with ochreous dark brown to yellowish brown colour. In places it occurs as pseudomorphs after pyrite. Limonite is widely distributed in all the units throughout the entire region.

Limonitic minerals could be authigenic. However, in most cases, it is formed by oxidation or alteration of iron rich minerals e.g. pyrite, hematite and others.

Hematite and limonite may form 30% of the total heavy mineral residues and show an extremely irregular distribution in the present area. No definite relation between the distribution of hematite, limonite and the nature of carbonate lithology can be established.

Rutile:- Rare, rounded, (Plate 22, fig. 1) elongate grains of rutile have a deep reddish brown colour with extremely high refractive index and weak pleochroism, reddish brown to brown, Some grains show distinct

Explanation of Plate 23

Figure 1 Ap = well rounded apatite
T = green, subrounded tourmaline
G_1 = pitted surface in garnet
G = garnet angular to subrounded
Z = rounded zircon
(plane polarised light). X 22.

Figure 2 Euhedral prismatic zircon. Note yellow stained cracks and zones and also dark black inclusions. Note elliptical cavity-like inclusion in central grain (plane polarised light). X 55.

Figure 3 Ap = Dahllite type apatite with pitted surface.
Z = euhedral zircon with brown stained zoning and black opaque inclusion
(plane polarised light). X 55.

PLATE 23.

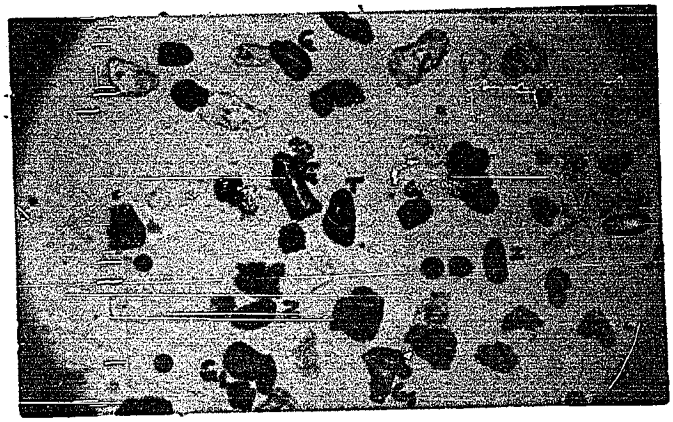


FIG. 1

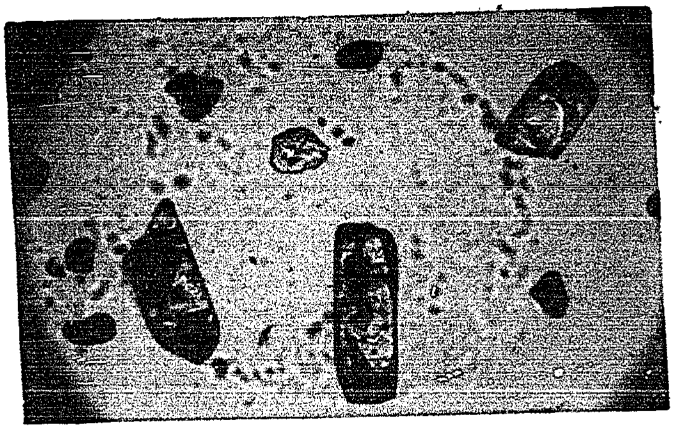


FIG. 2

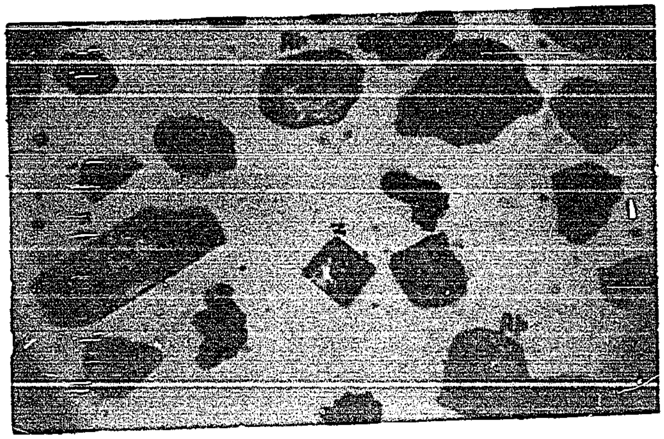


FIG. 3

striations. The mineral is extremely rare and constitutes a very insignificant portion of the heavy mineral residues. Rutile is entirely restricted in occurrence to the Coboconk and Burleigh Falls area (Fig. 3, K, L, J).

The highly rounded nature of the grains seems to indicate a detrital origin from source areas with acid igneous and metamorphic rocks.

Garnet:- The grains are irregular, angular (Plate 22, fig. 3) to subrounded (Plate 22, fig. 2) with conchoidal fracture (Plate 22, fig. 3), and prominent re-entrant angles (Plate 22, fig. 1). Garnets vary in colour from pink (Plate 22, fig. 3) and orange (Plate 22, fig. 2) to colourless (Plate 22, fig. 1). Occasional dark inclusions of opaque minerals and quartz are observed. Surface pitting (Plate 23, fig. 1) and grooving are also noted in most grains. The grains are isotropic. Garnet constitutes a significant portion of the heavy mineral fractions and shows recognisable variation in distribution in most sections throughout the area.

Garnet is persistently recognized in all the sections (Fig. 3, A to Q). It may form 25% of the total heavy mineral content of the rocks. The distribution pattern of garnet is irregular. However a high garnet content is observed in rocks of the upper units (III and IV) (Fig. 3, A, C, D, I, L, P).

Garnets are derived as detritals from igneous and metamorphic rocks.

Zircon:- Zircon grains show variable character from elongate, irregular to ellipsoidal types, with splintery, angular (Plate 22, Fig. 1) round (Plate 23, Fig. 1) and euhedral margins (Plate 23, Figs. 2 and 3). The grains are colourless or pink to brown, with very high refractive index and strong birefringence, and uniaxial positive character. Often the euhedral grains show no sign of abrasion (Plate 23, figs. 2 and 3). The common types of inclusions include, a) Tubular, elliptical cavities across the grains, b) rod-like prismatic crystals with an acicular habit c) red brown inclusion of rutile (?). Some euhedral grains show fracture with brownish yellow stained inclusions (Plate 23, fig. 2). Hutton (1950) explained such cracks as due to possible radioactivity of the mineral. Some grains also contain black inclusions of opaque minerals. Rare instances of zoning were seen in some euhedral zircon. These appear as fine thread like bands parallel to the crystal boundaries. Zircon constitutesa major part of the heavy residues and shows significant variations in some sections. Zircon has a distribution pattern similar to garnet. It may constitute upto 20% of the total heavy minerals residues.

Zircons form in sedimentary, metamorphic and igneous environments. A recent investigation by Saxena (1966) showed that roundness of zircon is highly deceptive as a criterion of their detrital origin. Elongation of crystals or presence of overgrowths could not be used as a distinguishing features of igneous or metamorphic origin. Given suitable conditions similar features may develop in any environment. Kalsbak and Zwart (1967) concluded that subrounded and irregular zircon might not indicate a sedimentary history.

Tourmaline:- Tourmaline occurs as elongate prismatic grains and irregularly broken pieces showing angular rounded, to irregular margins. Inclusions include 1) cavities, b) zircon and quartz, c) other unidentified minerals. The grains are dark brown (Plate 22, fig. 2), and green (Plate 23, fig. 1). Grains show strong pleochroism, uniaxial negative character and striations.

Tourmaline can be traced continuously in every section (Fig. 3, A to Q). It can constitute upto 10% of the heavy residues. Like garnet and zircon, tourmaline also tends to show relatively increased distribution in the rocks of units III and IV (Fig. 3, A, C, D, I, L and P).

Authigenic types of tourmaline were not observed. Most of the observed characters strongly indicate a detrital origin from pneumatolytic and acid igneous rocks.

Epidote:- Epidote grains are irregular in shape and have a greenish yellow colour (Plate 22, fig. 2, weak pleochroism (pale green to colourless) and high refractive index. The grains show typical ringed high interference colour (green, purple and red).

Rare occurrences of irregular grains of zoisite with typical ultrablue interference colour were noted in some samples.

A metamorphic terrain is probably the source of detrital epidote in the present area.

Sphene (Titanite):- Sphene is brown or brownish yellow in colour, with very high refractive index (Plate 21, fig. 3). The grains are irregularly shaped with slightly rounded margins. Grains lack complete extinction. Crystalline igneous and metamorphic source can be suggested for detrital sphene.

Grains of epidote, sphene and zoisite exhibit irregular distribution in the present area. In rare cases these may form 20% of the total heavies but commonly less than 5% of the total heavy mineral residues. Only the Marmora areas has a more or less continuous distribution of these minerals throughout the entire stratigraphic sections (Fig. 3, A and I). The minerals are more frequently observed in rocks of units III and IV.

Staurolite:- The grains are irregular to platy with hackly fracture, and mineral inclusions. Staurolite grains are yellow to golden brown in colour (Plate 22, fig. 3) with distinct pleochroism X = colourless to pale yellow, Z = golden yellow, and biaxial positive character.

Staurolite makes up a minor portion of the heavy mineral residues. It may form upto 3% of the total heavy residues.

The grains are mostly derived from crystalline schist and other contact metamorphic rocks.

Pyroxenes:- Pyroxenes include augite with occasional occurrences of hypersthene. Grains are rounded primatic in form. Augite is identified by cleavage and extinction angle $Z \wedge C$ 48° to 51°. Grains show dark platy or cloudy inclusions.

Hypersthene is characterised by striking pleochroism X = red or pink, Z = green; parallel extinction, conspicuous striations, cleavage and highly coloured (brown) plate like inclusions (schiller) transverse to cleavage, and biaxial positive nature.

Pyroxenes may constitute upto 15% of the total heavy residues (Fig. 3, A). In areas east of Marmora pyroxene can be recognized in most sections (Fig. 3, A to I). The distribution of pyroxenes is rare in the areas lying west of Marmora (Fig. 3, J to Q).

Pyroxenes seem to indicate a basic or ultrabasic igneous source.

Amphibole:- Amphibole includes hornblende and actinolitic varieties. Grains are elongate, prismatic with rounded to irregular shape and well developed longitudinal cleavage. Their colour is dark green to greenish brown. Grains show strong pleochroism and inclined extinction $Z \wedge C$ ranging from 15° to 22°.

Common hornblende was identified by higher extinction angle $Z \wedge C =$ 20° to 22° and pleochroism, X = pale green, Z = brown or dark green. Actinolitic types show somewhat fibrous habit, bright green colour (Plate 22, fig. 2), weaker pleochroism and low extinction angle.

Amphibole is a common constituent of heavy residues (Fig. 3, A to Q), and may constitute upto 25% of the total heavy minerals. In the areas east of Marmora actinolite forms a major part of the amphiboles while in western areas common hornblende becomes important.

Hornblende may be derived from igneous and metamorphic areas. The presence of actinolite in areas east of Marmora probably suggest a partial derivation of amphiboles from calc-silicate type rocks, e.g. marble.

Apatite:- Apatite grains are oval, spherical, or elongate prismatic in nature, with high refractive index, weak birefringence and uniaxial negative character (obtained with difficulty, mostly showing an anomalous figure). Grains are rounded to angular (Plate 23, fig. 1). Usually most grains lack inclusions, while others show a dusty central part.

Dahllite:- Dahllite has similar morphological and optical characters to apatite. The grains show very high refractive index and higher interference colour in shades of grey to yellow. In most cases grain surfaces are pitted into small curved irregularities (Plate 23, fig. 3). Commonly the grains are elongate tabular in shape with apparent lack of any rounding. X-ray powder photograph patterns showed the presence of dahllite with peaks of 2.768 Å, 2.714 Å, 3.723 Å, 2.232 Å, 4.13 Å and

1.89 Å, arranged in order of decreasing intensity.

The presence of dahllite is restricted in the lower 10 to 15 feet of limestones and calcareous shaly and sandy units lying in direct contact with Precambrian rocks in the section exposed on Hwy. 401 east of Kingston near exit to Hwy. 15.

In areas east of Marmora a persistent occurrence of apatite has been observed (Fig. 3, A to I). Apatite may constitute upto 25% of the total heavy residues (Fig. 3, G). In areas west of Marmora, the distribution of apatite becomes less persistent, irregular or absent (Fig. 3, J to Q).

The presence of apatite indicates an igneous source in the surrounding exposed Precambrian rocks. Local occurrence of dahllite can be explained as due to alteration of apatite grains by carbonated water during exposure.

Chlorite:- Chlorite grains are flat, rounded, to irregular in shape with green to yellowish green colour, basal cleavage, weak birefringence and low refractive index. In places inclusions of black opaque materials are common.

Chlorite can be recognized in all the sections. However no detailed study of chlorite has been made in the present investigation.

Chlorite is derived from igneous and metamorphic rocks.

Biotite and muscovite are present in some samples, but these constitute a very insignificant part of heavy residues.

Light Minerals

The light fractions of insoluble residues include quartz and clay minerals with some feldspar and chert. No detailed study of optical

Explanation of Plate 24

Figure 1 Well rounded, spherical quartz grain with pitted and polished surface. X 100.

Figure 2 Authigenic doubly terminated prismatic quartz (reflected light). X 30.

PLATE 24.

FIG. I

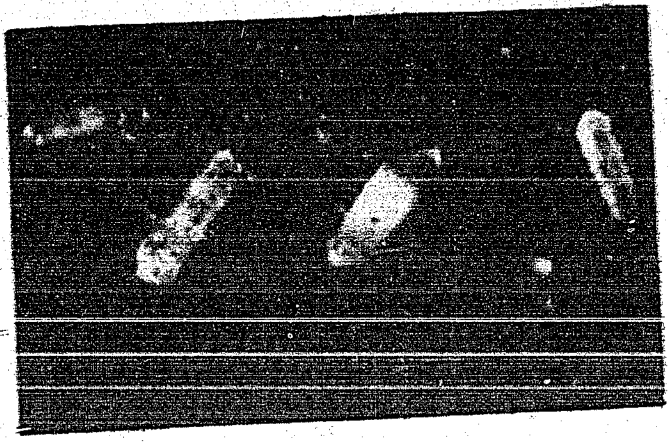


FIG. 2

or distributional characters was attempted. The total weight percentage of light insoluble material was recorded and used for comparison in various sections. A brief description of quartz and feldspar is included here.

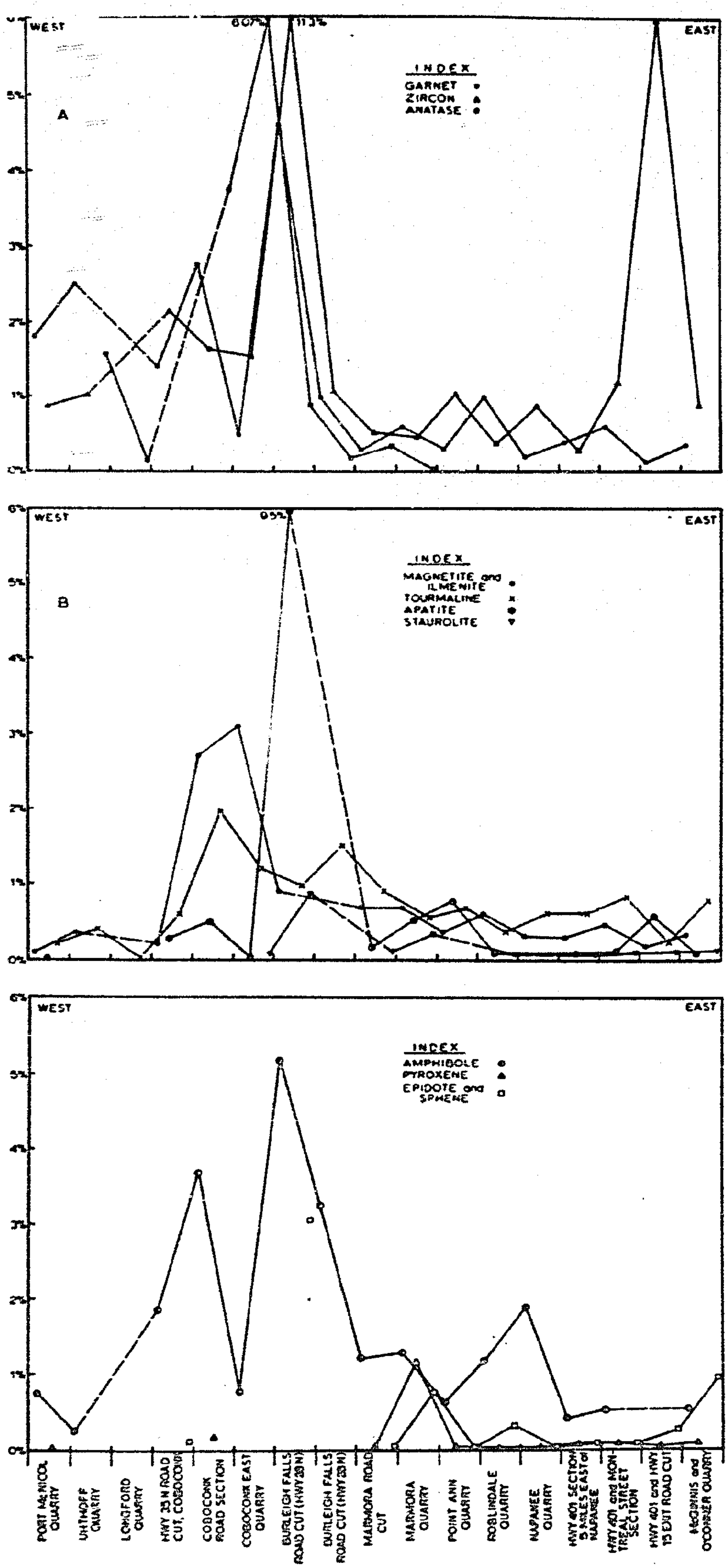
Quartz:- Quartz occurs both as detrital grains and authigenic crystals. Detrital grains are spherical well rounded to angular with clear to highly clouded central inclusions. Grains show straight to undulose extinction. Spherical, rounded grains (Plate 24, fig. 1) are more abundant in the western part of the present area and show highly glazed, polished and pitted surfaces. Extremely angular angular grains are common in the eastern areas. Some grains show intense fracturing.

Authigenic Quartz:- Authigenic quartz occurs as doubly terminated prismatic crystals (Plate 24, fig. 2), colourless, white, transparent to translucent in nature. Some grains show dusty inclusions in the centre. X-ray diffraction pattern gave peaks at 3.34 Å, 4.25 Å and 1.81 Å corresponding to α-quartz.

Authigenic grains are very common in the eastern section of the study area. These are formed during diagenesis of carbonate sediment (Beales 1958). Detrital quartz is chiefly derived from exposed igneous and metamorphic areas. Presence of extremely rounded spherical polished grains suggests a second cycle of erosion with derivation from an existing sandstone.

Feldspar:- Feldspars of both detrital and authigenic origin were noted. Potash feldspar (microcline, orthoclase) and low albite are common in the rocks. Detrital fragments are essentially composed of potash feldspars. Most of the authigenic feldspars are tabular in shape. In some

FIG.5 REGIONAL PERCENTAGE (MEAN) DISTRIBUTION of DETRITAL HEAVY MINERALS from GEORGIAN BAY to LAKE ONTARIO, in the BLACK RIVER ROCKS of SOUTH WESTERN ONTARIO



cases crystals appear to be pseudomorphs after carbonate rhombohedrans with dusty central inclusions indicating a possible replacement growth (Baskin 1956, p. 138, Plate 1, C). X-ray diffraction pattern showed peaks corresponding to low albite at 3.21 Å, 4.03 Å, and 3.65 Å.

Light minerals are found in every section. These constitute up to 6% of the total rock. In most cases, high concentrations of light minerals mark a corresponding increase in detrital heavy minerals (Fig. 3, A, B, C, D etc). Highly rounded, polished quartz grains show greater abundance in the light residues of areas lying to the west of Marmora. Doubly terminated prismatic quartz euhedra and angular quartz grains form a major constituent of the light minerals in areas east of Marmora.

Regional Distribution of Heavy Minerals

In order to study the regional distribution pattern of various heavy minerals, the average (mean) percentage composition of different minerals at each stratigraphic section was plotted (Fig. 5, A to C). The following distribution characteristics were noted:-

a). Garnet and zircon show a greater abundance in areas west of Marmora. Two exceptionally high values of zircon at Burleigh Falls and in the Kingston area are possibly due to local derivation (Fig. 5, A).

b). Anatase is entirely restricted to areas west of Marmora (Fig. 5, A).

c). Magnetite, ilmenite and tourmaline exhibit greater abundance in areas east of Marmora. The Coboconk area marks a local increased distribution of magnetite, ilmenite and tourmaline (Fig. 5, B).

d). Staurolite can be recognized continuously in areas east of Marmora, while it tends to be insignificant or absent in areas west of

Burleigh Falls and Coboconk (Fig. 5, B).

e). Apatite shows a persistent irregular distribution in areas east of Marmora. The Burleigh Falls area shows exceptionally high, local concentration apatite. Apatite becomes insignificant, or irregular in distribution in areas west of Coboconk (Fig. 5, B).

f). Epidote, sphene and zoisite are entirely restricted in distribution to areas east of Marmora (Fig. 5, C). These minerals show minor isolated local occurrences in Burleigh Falls and Coboconk areas (Fig. 5, C).

g). Pyroxenes also show a restricted distribution in areas east of Marmora (Fig. 5, C). A minor local occurrence of pyroxene can be seen in the western area at Coboconk (Fig. 5, C).

h). Amphiboles show extremely irregular distribution in areas west of Marmora. East of Marmora, the distribution of amphibole becomes less irregular. Extremely high local concentrations can occur in the Burleigh Falls, Coboconk and Napanee areas (Fig. 5, C). As noted earlier, amphiboles of the eastern areas are characterised by abundance of actinolite, while hornblendes is more common in the areas west of Marmora.

i). Longford quarry shows a remarkable lack of heavy minerals (Fig. 5, A, B, C).

CHAPTER 5

PETROGRAPHIC CONSTITUENTS

Carbonate rocks constitute one fifth of the total sedimentary mass (Hamand Pray 1962), and are widely distributed in time and space. Limestones form a distinct group of rocks which stand apart from other sedimentary rocks by (1) Local intrabasinal nature; (2) dependence on organic activity; (3) extremely polygenetic nature; (4) susceptibility to early and post depositional modifications.

A successful classification of carbonate rocks can only be attained by a thorough understanding of the constituents and genetic processes. In recent years various workers have proposed different classifications. Each is designed on the basis of limited descriptive or purely genetic parameters. Ham's (1962) work on the classification of carbonate rocks, and other papers by Wolf (1960), Todd (1966), Sander (1967) provide an excellent opportunity to appreciate the rapidly expanding nature and complexity of limestone petrography.

Folk's (1952; 1959, p. 1; 1962, p. 62) system of terminology and classification has been used throughout the present investigation for the following reasons: (a) applicability to all unmetamorphased carbonate rocks; (b) blending of both descriptive and genetic qualities; (c) largely clastic nature of the present limestones; (d) chief importance on the relative amounts of framework (allochems), matrix (microcrystalline calcite ooze), pore filling cement (sparry calcite cement) and utilisation of these groupings as end members, (e) simplicity of terminology with intelligible meaning, (f) broad flexible nature permitting expansion in specialised field, (g) wide acceptance and applicability in both recent and ancient sediments. The present work is chiefly directed towards the descriptive aspect, and therefore, the practical disadvantage of Folk's classification such as lack of emphasis on porosity, chemical composition etc. can be disregarded.

All sedimentary rocks can be considered to be mixtures of end members in different ratios (Krynine 1948). Recognition and distribution of various end members in rocks lead to the basic principles of classification. It is therefore essential to determine, and describe the constitutent end members in the Black River limestones.

Petrographic Constituents

Petrographic constitutents of carbonate rocks (Folk 1959) include the following: (1) insoluble material or terrigenous material (2) allochem constituents (3) orthochems.

Insoluble materials include both heavy and light minerals which are derived chiefly as detritals. Authigenic silicate minerals of minor importance are also included in this group. Details of description of insoluble materials are given in the preceding section.

Orthochemical Constituents

Orthochems or orthochemical constituents include all normal percipitates, formed within the depositional environment or within the sediments, showing no evidence of significant transport (Folk 1959). Orthochems are essential elements of indurated rock. Two main types of orthochems are recognised, and used in the present petrographic work.

Microcrystalline calcite ooze (micrite):-

The term was first used by Folk (1959) to describe brownish or dark grey, subtranslucent crystals of calcite [illegible] 0.001 mm. to [illegible] 0.004 mm. in size, with equant or irregular shape, and showing weakly defined outer margins under petrographic microscope. The recent literature does not show uniformity of terminology for this very fine silt to clay size carbonate material. Various terms such as microcryptocrystalline particles or calcite (Matthews, 1966, p. 437), microcrystalline carbonate (Plumley _et al._ 1962) etc. are all synonymous to Folk's microcrystalline calcite grains. Various synonyms of the term microcrystalline calcite ooze or micrite are "lime mud ooze" (Newell and Rigby 1957; Leighton and Pendexter 1962; Shin _et al._ 1965; Matthews 1966); "matrix" (Plumley _et al._ 1962), and mud (Powers 1962; Dunham 1962). Since the present study involves ancient lithified carbonate rocks, usage of terms e.g. ooze, mud or lime mud signifying unconsolidated sediment, will be avoided. However, for the sake of breivity in description the term micritic matrix is used with the same petrographic connotation of Folk's micrite.

Considerable disagreement exists between various workers regarding the size limits of calcite grains in micrite. Folk's (1965, p. 31) recent paper provides the most up-to-date statement on this problem. In order to maintain a general conformity with Folk's system, a 0.001 mm. to 0.003 mm. size limit is followed in the present study.

Microcrystalline calcite ooze constitutes a major portion of the

Black River limestones in southwestern Ontario. Microcrystalline calcite material may occur as a homogeneous bed or it may occur with varying amounts of other petrographic constituents. Irregular calcite grains in the micritic matrix may show an uniform size distribution. It is now generally assumed that fine grained carbonate sediments usually form under quiet water condition. In the normal depositional realm, the relative amount of micritic matrix in a rock may reflect the degree of textural maturity (Folk 1959, 1962; Leighton et al. 1962; Dunham 1962; Powers 1962; Todd 1966). Studies of recent shallow water carbonate sediments in the Bahamas, Florida Bay, Persian Gulf, and Southern British Honduras have clearly shown that aragonite, and high magnesium calcite, represent the chief calcium carbonate phase (Stehli and Hower 1961; Skinner 1963; Friedman, 1964, 1965; Folk 1965; Fyfe and Bischoff 1965; Matthews 1966). Both varieties of calcium carbonate are highly metastable and undergo neomorphism (Folk 1965) or penecontemporanous change to the stable form calcite (low magnesium calcite). Lithification of fine grained carbonate sediments to micrite or micritic matrix takes place by various diagenetic processes, which will be discussed in a subsequent section.

The origin of fine grained calcium carbonate (aragonite or high magnesium calcite) in sediment is controversial. Four general theories of origin have been proposed.

1. Bacterial origin (Black 1933; Vaughan 1918; Purdy 1963).
2. Derived origin (geologically of minor importance).
3. Physiocochemical origin (Cloud 1962; Beales 1958; Folk 1959, 1962).

4. Skeletal disintegration origin (Lowenstam 1955; Lowenstam and Epstein 1957; Newell and Rigby 1957; Feray et al. 1962; Purdy 1963; Ginsburgh 1966; Matthews 1966).

Textural inversion of coarse carbonate rocks to microcrystalline carbonate rock by diagenesis is not uncommon (Wardlaw 1962; Orme and Brown 1963). Thus a synthesis of all recent work by various investigators reveals that different types of lime mud or microcrystalline calcite-rich rocks result from a complex interplay of physical, chemical and biological factors. It is probable that physiocochemical, bacterial and biological processes contributed to the formation of lime mud in the Black River rocks. Later, the relative importance of each mechanism will be determined from combined textural, structural, petrographical and chemical aspects of Black River limestones.

Sparry Calcite Cement:-

Sparry calcite cement occurs as a pore filling material precipitated in place within the sediment (Folk, 1959; 1962). The size of calcite crystal may range from 0.004 mm to 0.01 mm or more in size. Sparry calcite grains are characterised by their coarse size, clarity, distinctness of grain boundaries, and extremely variable crystal size. Some kind of pore space is essential for the growth of sparry calcite cement. The pore space is provided by three dimensional packing of frame building allochems. Burrows, skeleton molds, and desiccation cavities may also provide voids but such infillings by coarse crystalline calcite are not included as sparry calcite cement. Sometimes sparry calcite grains encrust allochems as radial fringing mass.

Explanation of Plate 25

Figure 1 Sharp contact of the upper sparry calcite, allochem-rich and the lower micrite-rich unit (photomicrograph of a sample of unit III rock taken from the Coboconk quarry). Note the assumed gentle erosional irregularities on the top surface of the lower dark layer. X 22.

PLATE 25.

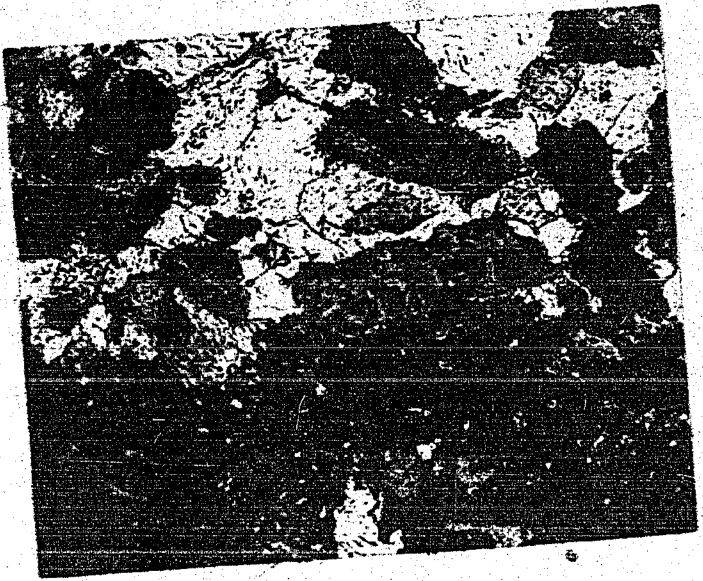


FIG.1

Folk (1962) has pointed out that large clear calcite grains with similar textural characters to true sparry calcite cement may result from neomorphism of carbonate mud and differentiation is extremely difficult. A similar problem is encountered in the present study, but details of identification of two types of coarse calcite will be described in a subsequent section. Presence of absence of a framework, relict texture, inclusion in grains, textural fabric...etc. will be considered in assigning an origin to sparry calcite type cement.

Sparry calcite cement is commonly encountered in rocks with an allochemical framework. Finely intercalated alternate microcrystalline calcite and sparry calcite-cement-rich beds are sometimes observed in Black River rocks, (Plate 25, fig. 1). In every case both rock types show sharp contacts. Where a microcrystalline calcite rock is overlain by a sparry cement-rich rock, there is commonly evidence of erosional irregularities suggesting ~~to~~ a higher energy environment (Plate 25, fig. 1). Sparry cement, and allochem-rich rocks are more frequently observed in the Upper units of III and IV of the Black River rocks. These occur as individual thick beds or may be interbedded with micritic matrix-rich lithologies.

Sparry calcite cement is thought to have formed in a shallow water, higher energy environment. Various workers have shown the occurrence of cement-rich rock in the tidal areas of Bahama, and Florida.

Allochemical Constituents

Allochems or "allochemical constituents" include materials that

Explanation of Plate 26

Figure 1	Uniform distribution of size and shape of pellets in spar rich cement (Unit III Roblindale quarry). Note occasional dark opaque carbonaceous (organic) material in pellets assumed to be organic. Average size of pellet is about 0.06 mm. X 22.
Figure 2	Uniform, oval, ellipsoidal, spherical shape and size of pellets with large skeletal fragments (Unit IV, Marmora quarry). Note presence of minute unidentifiable, white elongate shell fragments in pellets marked X. X 22.
Figure 3	Tubelike burrow in the pellet-rich micrite rock (Unit II, Montreal Street section). The cavity is filled with a coarse mosaic of calcite, with patches of dark inclusions. A thin micritic envelope marks the outer margin of the tube. Note dark organic-rich materials in pellets, and lining of pellets along the external margin of the burrow. Micritic matrix recrystallises into white coarse spar area. Note dark black irregularly sized carbonaceous pellets and light grey uniformly sized carbonate pellets. X 55.

PLATE 26.

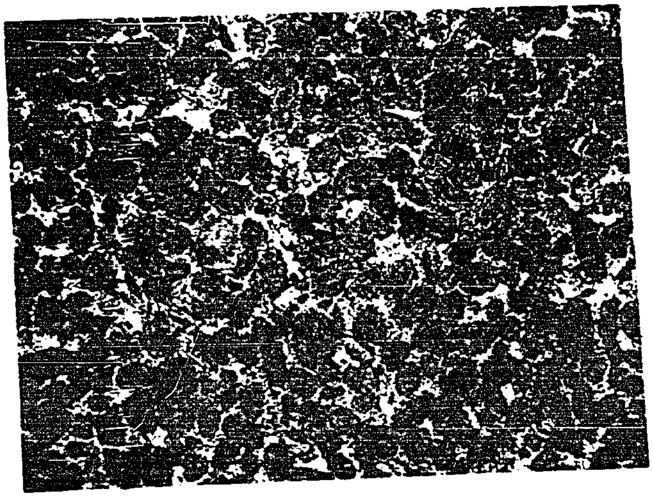


FIG. 1

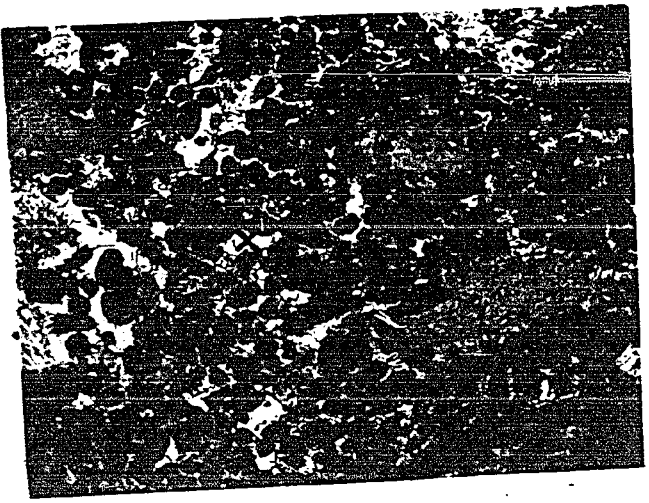


FIG. 2

FIG. 3

are formed by inorganic or organic processes within the basin of deposition, and which have undergone some transportation (Folk 1959) before final deposition. Allochems constitute a major portion of the framework in limestones and include the following chief types: 1) pellets, 2) oöliths, 3) skeleton fragments, and 4) intraclasts.

Pellets:-

The term "pellet" is used for round, spherical, elliptical, ovoid to elongated bodies of microcrystalline calcite lacking internal structure (Folk 1959, 1962). The pellets range from 0.03 mm to 0.15 mm in size. The average size of pellets in Black River rocks is 0.09 mm. In some cases the pellets are rich in dark brownish or grey organic matter. The pellets exhibit a uniform distribution of size and shape (Plate 26, fig. 1).

The term pellet is used in a descriptive sense in investigation. The upper size limit of pellets is taken at 0.2 mm. Larger pellet-like grains are encountered and are designated as "intraclasts".

Pellets are of polygenetic origin. Fecal pellets are very common constituents of present day carbonate environments e.g. interior Bahama Banks, and Great Salt Lake of Utah. The genesis of these is evident in recent environments.

Pellets of probable organic nature:-

The following features suggest an organic origin: 1) uniform size, 2) ovoid to elliptical shape, 3) limited occurrence or complete lack of coarse skeletal debris, 4) presence of black, opaque patches (carbonaceous, organic?), and 5) frequent incorporation of minute unidentifiable shell materials with microcrystalline calcite matrix (Plate 26,

Explanation of Plate 27

Figure 1 Branching colonial algal body attached to recrystallised fragment of brachiopod(lower coarse white calcite filled area). Note presence of pellet-like grains with or without dark organic patches toward the upper part of algal colony. (Unit III, Coboconk quarry). X 22.

Figure 2 Enlarged view of pellets with irregular, central or marginal concentration of dark carbonaceous material (organic?). Presence of minute irregular skeletal fragments is also preserved as white areas in pellets. X 55.

Figure 3 Sharp contact of lower dark pellet rich zone with upper sparry calcite cemented intraclast-bearing layer. (Unit III, Roblindale quarry). Both intraclasts and pellets show similar composition of microcrystalline calcite type material. Note no evidence of any composite pellet structure in larger interclast fragments. X 22.

PLATE 27.

FIG. 1

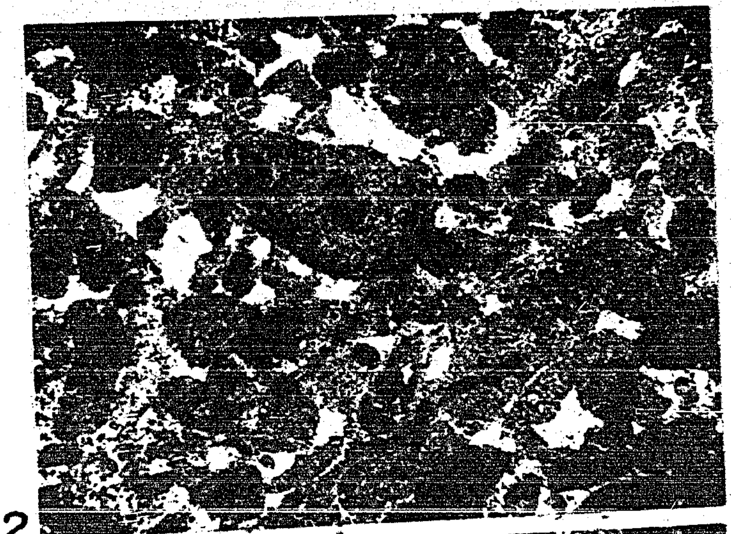


FIG. 2

FIG. 3

PLATE 27.

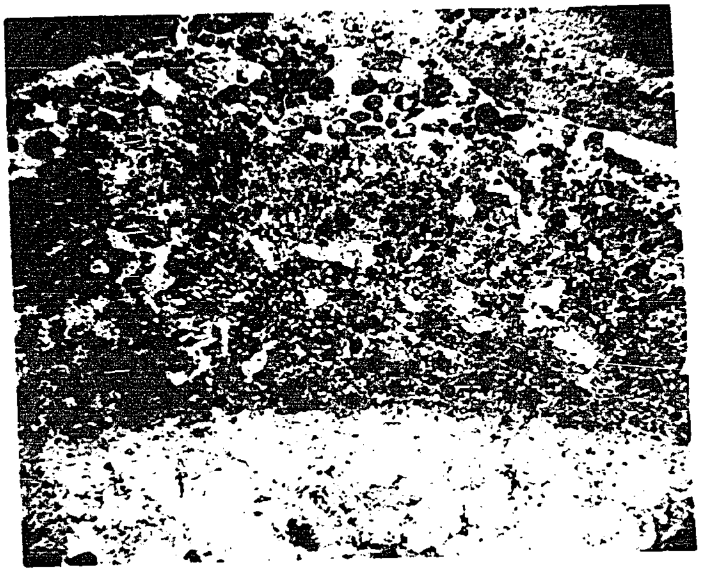


FIG. 1

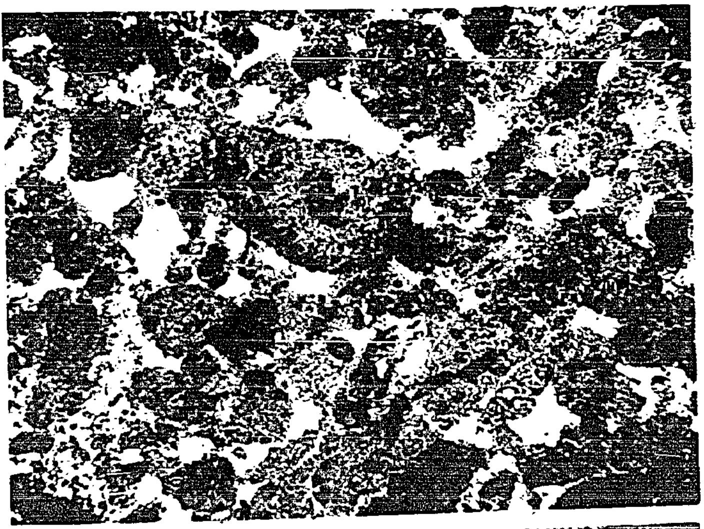


FIG. 2

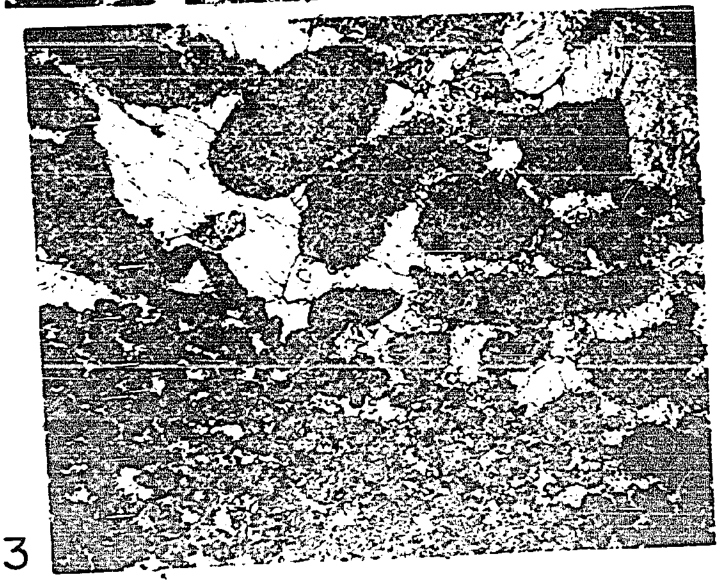


FIG. 3

Explanation of Plate 28

Figure 1 Clear to fused contact of microcrystalline calcite rich intraclasts with V shaped cracks (Unit III, Port McNicol quarry). There is a coarse calcite mosaic which fills cracks and cavities. Note presence of small pellet like fragment (marked X) enclosed with large intraclasts. X 55.

PLATE 28.

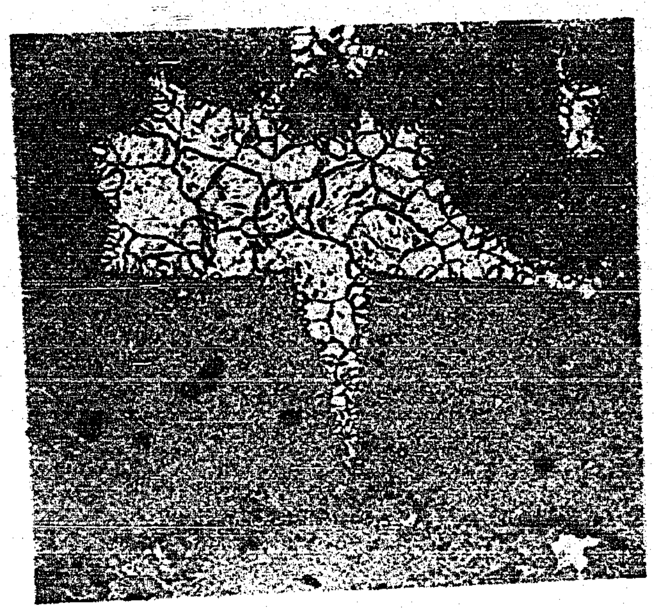


FIG. I

fig. 1; Plate 27, fig. 1). Similar pellets are extensively developed in present day Bahama areas, Gulf of Batabano, and Great Salt Lake areas. Eardley (1938), Illing (1954), Newell and Rigby (1957), Daetwyler and Kidwell (1959), Folk (1959, 1962), Cloud (1962), Purdy (1963) suggested that the majority of the pellets are of fecal origin.

This type of pellet-rich rock is most abundant in the study area. In rare cases, burrow structures are preserved thus lending support to the theory of organic fecal origin for the pellets. The cavities of burrow structures are generally filled with a coarse, clear, mosaic of calcite, showing irregular patchy inclusions of original fine carbonate material. The outer margin of the burrow is marked by a thin wall of micritic material. Most pellets show the presence of organic matter as of dark opaque inclusions. Pellets may be concentrated around the external surface of tubular burrows (Plate 26, fig. 3). Wolf (1965a) described the presence of similar pellets from the Devonian reef limestones of New South Wales and suggested as algal origin. Association of pellets with fragmented algal colonies has been observed in rare cases (Plate 27, fig. 1). However, a definite differentiation of such pellet-like objects from other minute fragmented algal accretions or the common pelletoid deposit was not possible. Further studies are necessary to determine the exact nature of such pellets.

Pellets of possible mechanical origin:-

Identification of pellets from intraclast is often extremely difficult even on a purely descriptive basis (Beales (1958, 1965) and Folk (1959). Some examples of such enigmatic framework constituents occur in the Black River rocks.

In thin sections sharp transitions between fine pellet-rich zones and coarser intraclast rich, clear sparry calcite cemented layers are commonly observed. The dark microcrystalline calcite materials constituting both pellets and intraclast do not show any observable difference in texture or composition. Intraclasts are of variable size and shape, with rounded to slightly irregular outer margin and do not display any indication of possible composite pellet-like structure (Plate 27, fig. 3). No evidence of any accretionary structure has been observed in the pellet-rich zone. In most cases, pellet fragments show distinct outlines with occasional merging of grain boundaries. Interstitial space between pellets is filled with clear sparry calcite having similar morphology to the overlying coarse clear sparry calcite. No skeletal material was observed in coarse intraclast or pellet-rich areas. Often large elongate, oval, and rounded fragments composed of microcrystalline calcite material, ranging from 0.5 mm to 1.4 mm or more in size with distinct or fused contact are observed. Some of these fragments, show V-shaped cracks, narrowing downward from the upper margin. The cracks are filled with a coarse, clear anhedral mosaic of calcite (Plate 28, fig. 1). Small rounded spherical pellet like fragments of micritic material, 0.09 mm to 0.14 mm in size occur together with the larger fragments of similar composition (Plate 28, fig. 1). It is strongly suspected that these smaller pellets had a similar genetic history to their larger counterparts. Illing (1954, p. 26) and Folk (1962, p. 66) suggested that mud sized crystals on the sea floor would adhere to each other and become ovoid by a gentle rolling on the bottom due to moderate wave action. These grains would finally show extreme well rounded margin with no trace of once composite nature. Possibly some of the pellets in the study area originated by this type of mechanical process, and their observed size differences may reflect a change in water turbulence. Presence of cracks in larger intraclasts indicate a very early development of such features when the fine sediment was still soft.

Purdy (1965) and Wolf (1965a) showed that recrystallisation of skeletal or pelletoidal mud to crypto- or microcrystalline carbonate would cause complete obliteration of all original pellet characters. Similarity of the micritic matrix of pellets and intraclsts to other homogeneous microcrystalline calcite-rich rocks seems to preclude the possibility of textural inversion in present rocks, as invoked by Purdy (1965) and Wolf (1965a).

Pellet-rich rocks are usually characterized by the presence of dark coloured microcrystalline calcite matrix. Recrystallisation of micritic matrix is common. A detailed account of this type of diagenetic feature will be given in a subsequent section. Pellet-like grains also occur in rocks with clear sparry calcite cement. This type of occurrence can be seen in the rocks of units III, IV and upper parts of unit II.

Extensive pellet accumulations have been reported in areas of notable bottom stability by many workers in water depths ranging from 1 to 4 fathoms (Purdy 1963b). Interior bankward lagoon type of environments (e.g. Bimimi Lagoon in Bahamas) show most prolific development of pellet-like grains.

Explanation of Plate 29

Figure 1 Black, grey, spherical highly rounded uniform sized oöliths with minute surface pitting (Unit III, Hwy. 401 section, 5 miles east of Napanee). X 140.

Figure 2 Rock composed of oöliths of more or less uniform size and shape (Unit III, Roblindale quarry). Note elongate oöliths show elongate central nuclei. A large irregular black intraclastic fragment (right margin) shows growth of one superficial oölitic envelope. X 22.

Figure 3 Dark rounded, spherical, elliptical grains of superficial oöliths showing very weak development of envelopes (Unit III, Hwy. 401 section, 5 miles east of Napanee). Note similarity of shape and size of superficial oöliths to normal oöliths.

PLATE 29.

FIG. 1

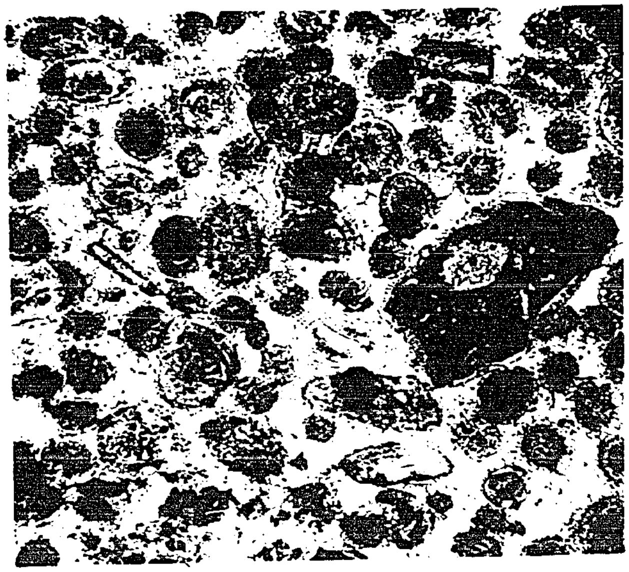


FIG. 2

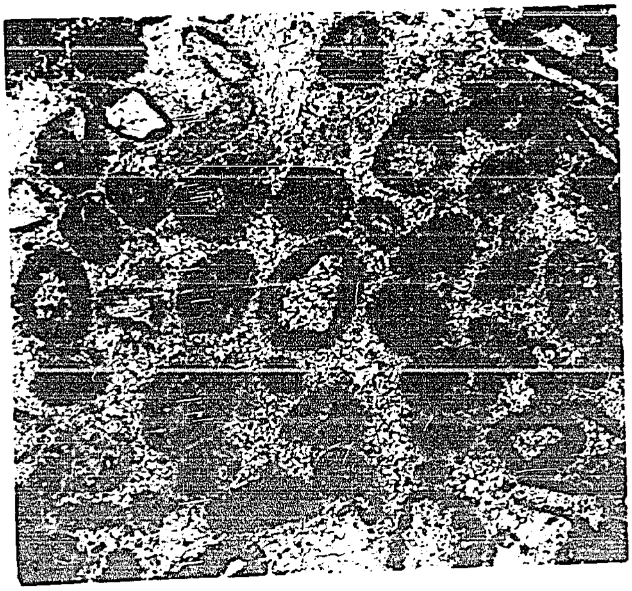


FIG. 3

Oöliths:-

The terms "oölite", "oölith", "oölitic" and "ovoid" have been variously used by different workers. In this present investigation the term "oölith" will be used in referring to sand or larger size grains exhibiting concentric envelopes. The term "oölite" is used to include collectively all grains displaying characteristic structure or the rock containing appreciable amounts of oöliths. Oölith is defined as a spherical or ellipsoidal body, 0.25 mm. to 2 mm. in diameter which may or may not have a nucleus and show concentric radial structure or both (Howell 1957). Two distinct types of oöliths have been recognized in Black River limestones, - (a) Normal oöliths, showing more than one concentric envelope around the nuclei, (b) Superficial oöliths with only one distinct or weakly defined envelope around the central cores.

Physical disaggregation of oölitic rock yielded oöliths, which are black or cream and have a somewhat shiny lustre. The surface of oöliths is often minutely pitted (Plate 29, fig. 1). The oölitic grains are spherical, elliptical or rarely elongated. The shape may be controlled by the nature of original nucleus (Plate 29, fig. 2). As noted by Beales (1958), the average grain size and degree of sorting in oölitic grains showed considerable variation in different rocks. The oöliths range in size from 0.2 mm to 0.7 mm. Composite or intraclastic grains associated with oölitic rocks show development of superficial envelopes and may in some cases range upto 3 mm. or more in size (Plate 29, fig. 3). Composite oölitic structure will be described in a later

Explanation of Plate 30

Figure 1 Elongate white shell fragments and dark elliptical pellets as nuclei in oöliths. (Unit III, Hwy. 401 section 5 miles east of Napanee). All oöliths display similar rounding of external margin irrespective of shape and nature of nuclei. Recrystallization causes spread of dark radial zones, from margin towards centre. A partial or complete obliteration of oölith structure may be caused by recrystallization (marked x). X 55.

Figure 2 Large oöliths show a relatively larger nuclei (Unit III, Roblindale quarry). Smaller oöliths display smaller nuclei. Central large oölith with very fine, white clear concentric laminae is crossed by thin dark distinct or patchy radial calcite fibres. Note clear nature of calcite laminae in central large oölith. Some oöliths show both clear and dark rings. X 55.

Figure 3 Oöliths showing weakly defined structure is recrystallized carbonate matrix (Unit III, Hwy. 401, 5 miles east of Napanee). Presence of microcrystalline dark globular patches in outer rings of oölith (at the centre of photograph) may be the effect of partial recrystallization. Also note more or less microcrystalline calcite nature of other oöliths with no apparent differentiation of concentric structures. This possibly represents textural inversion during diagenesis. The inner pellet-like structure of the nucleus may be due to the presence of broken bryozoan fragment. X 45.

PLATE 30.

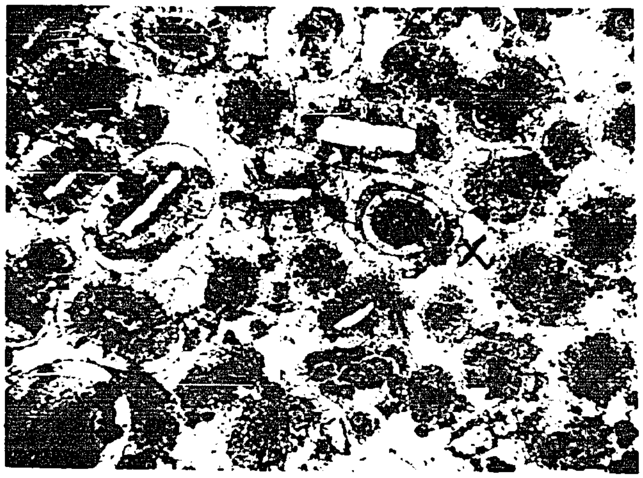


FIG. 1

FIG. 2

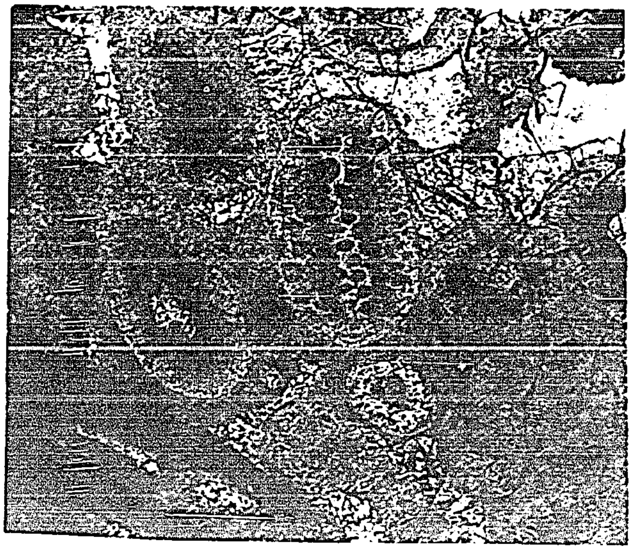


FIG. 3

section along with intraclasts in the Black River limestones. Every gradation exists between rocks with composite grains and no oöliths to purely oölitic rock without any composite grains.

Oölitic structure is best developed in those size grades which are most abundant in the rock. Commonly, oöliths are associated with varying amounts of accessory allochems. Superficial oöliths are all of the same size as the normal types, and identification of concentric envelopes is extremely difficult in some cases (Plate 29, fig. 3).

The nuclei of oöliths are composed of pellets, shell fragments, composite grains or intraclasts, and rarely quartz grains. Pellet and shell fragments are by far the commonest nuclei in oöliths (Plate 30, fig. 1). The final size of oölitic grains depends largely on the size of the nucleus (Plate 30, fig. 2). Commonly, the shape of nuclei do not show any relationship to the final rounded nature of oöliths (Plate 30, fig. 1).

Each nucleus is surrounded by a series of very fine concentric laminae which may be crossed by very fine, dark radial calcite fibers (Plate 30, fig. 2). Presence of dark opaque patches of probable organic origin are common in oöliths. Careful examination of oölitic envelopes under high magnification reveals that concentric rings are not continuous in nature. The laminae generally overlap or merge with one another. Two distinct type of structures can be recognized in the envelopes, (a) clear calcite rich laminae possibly representing oriented aragonite lamillae of Newell <u>et al</u>. (1960, p. 490) (Plate 30, fig. 2), (b) a cryptocrystalline grey envelope of concentric rings or laminae.

This represent the so-called unoriented aragonite lamellae of Newell et al. (1960, p. 491). (Plate 30, figs. 1 and 2). Both types of lamellae may constitute the envelope (Plate 30, fig. 2) or these may occur as completely isolated rings (Plate 30, figs 1 and 2). The dark coloured unoriented rings may often transect the clear calcite lamellae. The development of clear lamellae indicates inorganic deposition of oriented aragonite needles during the agitated phase of formation. The formation of unoriented lamellae possibly marks a quiet water phase with uneven coating of organic detritus. The presence of a black oily film observed during acid digestion of oölitic rocks clearly suggeststhe possible role of organic activity in the formation of Black River rocks.

Development of fine radial structures across the concentric lamellae is thought to be a recrystallisation feature developed during diagenesis (Carozzi, 1960, p. 239). Recrystallisation of lamellae spreads from the margin towards the centre of oöliths (Plate 30, fig. 1). Commonly irregular patchy recrystallised type oöliths are abundant. In some cases diagenetic changes may result in completely structureless, dark mass of microcrystalline calcite with partial (Plate 30, fig. 3) or total obliteration of oölitic identity (Carozzi, 1960; Purdy, 1963a; Robinson, 1967) (Plate 30, fig. 1). Details of various diagenetic textural changes of oöliths and the associated rocks will be discussed in a subsequent section.

Oöliths of organic origin:

One occurrence of extremely irregular oöliths was noted in rocks at the Marmora section. These oöliths were associated with normal

Explanation of Plate 31

Figure 1 Irregular growth of envelope showing variable thickness of concentric lamillae (cracks are due to faulty peel making). Oöliths are widely scattered in the grey micritic matrix. (Unit III, Hwy. 401, 5 miles east of Napanee). X 22.

Figure 2 Extremely irregular shape of oöliths controlled by original shape of nuclei (Unit III, Marmora quarry). Most oöliths exhibit two thick dark microcrystalline rings. Coarse clear calcite mosaic fills the annular space between rings. Irregular inclusion of dark material in clear calcite is common. Extension of outer dark ring as tubes into coarse calcite layer is common (marked X). Finely laminated, alternate dark and white nature of inner ring or core is not uncommon (marked X_1). X 45.

Figure 3 Note frequent irregular patches of lace-like network of alternate dark and white organic material. No uniformity of size and shape of oöliths. X 22.

25

PLATE 31.

FIG. 1

FIG. 2

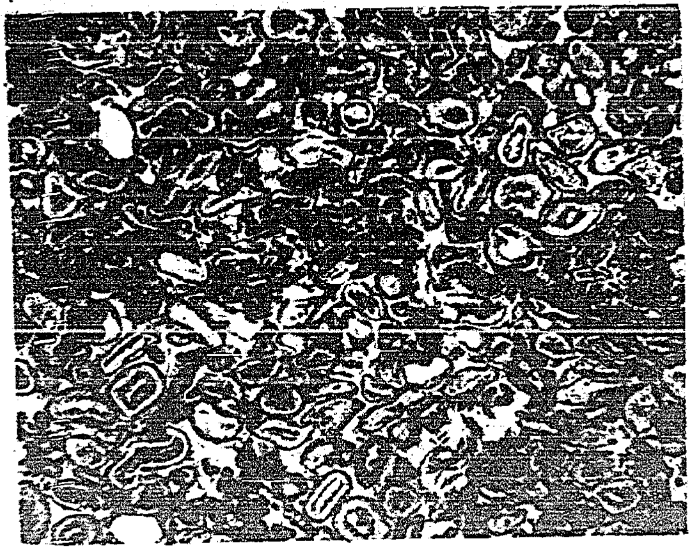


FIG. 3

oöliths. The oöliths show irregularly shaped nuclei with dark microcrystalline concentric rings. Irregular shell fragments invariably form central nuclei. Most oöliths show two dark thick concentric rings. The space between the rings is filled with a coarse mosaic of crystalline calcite. Occasional inclusion of irregular dark patches can be seen in a clear coarse calcite mosaic. Extension of the outer dark ring as minute tubes into the adjacent clear calcite area is also present in some oöliths. Alternate black and white finely laminated nature of inner dark layer and the core is not uncommon (Plate 31, fig. 2). Some oöliths show complete replacement by coarser calcite mosaic with little preservation of original structure. In rare cases, envelopes show thicker growth around one side of the nuclei (Plate 31, fig. 1). The final shape of oöliths are controlled by the original nature of nuclei. No evidence of rupturing or deformation of envelopes can be seen. Irregular patches of very fine alternate dark and white finely laminated lace-like network of organic material is common in rocks containing irregular oöliths (Plate 31, fig. 3). Oöliths may occur as isolated grains or in contact with one another. No evidence of uniformity of size distribution is apparent in the rocks (Plate 31, fig. 3). Bradley (1929, p. 219) described similar algal pebbles (algal pisolith of Pettijohn 1957, p. 391, plate 26), from reef rocks of the Green River Formation (Eocene). Illing (1954, p. 37, Plate 9, fig. 9, and Plate 4, p. 39, fig. 1) noted the presence of dark, thick algal layer around isolated and composite carbonate allochemical grains in the Bahamas. Ginsburg (1966, p. 22) reported existence of boring blue green algae (cyanophyceae) in the shelf lagoon areas of the Bahamas, and crust forming algae in the marginal zone of Florida Bay areas around tidal channels. An algal nature of growth is suggested for the irregularly shaped oöliths based on following observations:

1. Presence of organic material in oöliths.
2. Occurrence of dark laminated organic rich areas as irregular patches and network in the matrix of oölitic rocks.
3. Association of uniformly shaped and sized oöliths in immediately overlying and underlying layers.
4. Localised nature of irregular, organic-rich oölith bearing layers within uniformly shaped normal oölitic rocks.

The origin of normal and of superficial oölitic grains has been discussed in detail by Eardley (1938), Illing (1954), Beales (1958), Carozzi (1960), Newell _et al_. (1960) and Purdy (1963a).

It is thought that concentric envelopes result from superposition of layers corresponding to successive periods of accretion of chemically precipitated aragonite needles followed by phases of interruption or erosion (Carozzi 1960). Some strong evidences support precipitation of calcium carbonate from sea water and mechanical agglutination of oöliths in an agitated environment are as follows: (a) Presence of current bedding and lensing out of beds, (b) rounded nature of cores, (c) lack of oöliths with size less than 0.2 mm, (d) Absence of concentric structure on large skeletal or other allochems, (e) Development of oölitic structure only around grains, which are most abundant in the rocks, (f) Lack of oöliths with organic-rich envelopes, and irregular shape of the grain, conforming with the inner core suggest a possible biologically induced precipitation of calcium carbonate around the nuclei, in a quiet water environment. The allochemical nuclei might have been trapped in the algal-rich mat before undergoing complete erosion and thus maintained the irregular shape.

Present day oölith accumulations are restricted to areas of shallow (6 feet or less), warm, highly agitated waters. Accumulation of oölitic sands form irregular ridges parallel to the coastal margin, e.g. Florida Bay, or outer bank margin e.g. Bahama Bank. These ridges may extend upto mean sea level and thus create intertidal barriers with narrow tidal channels. Tidal fluctuations keep the bottom sands in continuous motion without removing the particles. Tiny aragonite needles can be precipitated when super-saturated (calcium carbonate) sea water is warmed and depleted of carbon dioxide on the shallow ridges (shoals). Precipitation of calcium carbonate takes place only when mobile particles are available as nuclei and the growth of oöliths continues till the particles are large enough to be moved by currents (Baars 1963, p. 107). Oölitic sediments show a sharp change to skeletal or grapestone sands, in a seaward direction, while a gradual transition is observed towards the bankward shelf lagoon direction. According to Purdy (1963b), the greater bankward transporting capacity of storm generated waves and flood tides account for a gradual bankward change of oölitic sands to lime mud.

Oölitic rocks are very common, and irregularly distributed throughout the unit III of the Black River sequence. Contrary to Beales' (1958, p. 1863) observation, oölitic rocks are practically absent or rare in other units of the Black River succession. Only one occurrence

Explanation of Plate 32

Figure 1 Recrystallization of brachiopod to give a coarse clear calcite mosaic (Unit IV, Havelock quarry). Note presence of original dark fine carbonate material as inclusions in clear calcite grains. X 22.

Figure 2 Broken and complete brachiopod shells showing filling of cavities by clear fibrous drusy calcite (in unbroken forms). (Unit II, Marmora road section). Note growth of calcite perpendicular to cavity wall, and gradual increase in size towards the centre. Irregular size and anhedral mosaic in broken forms represent recrystallization calcite. Note presence of carbonaceous material (right lower margin). X 22.

Figure 3 Transverse section of bryozoa zoarium and infilling of zooecial openings by drusy clear calcite (Unit IV, Marmora quarry). X 22.

Figure 4 Longitudinal section of bryozoa zoarium with slender, cylindrical branching tubes (Unit III, Roblindale quarry). Zooecial openings are filled with recrystallized calcite material. X 22.

PLATE 32.

FIG. 1

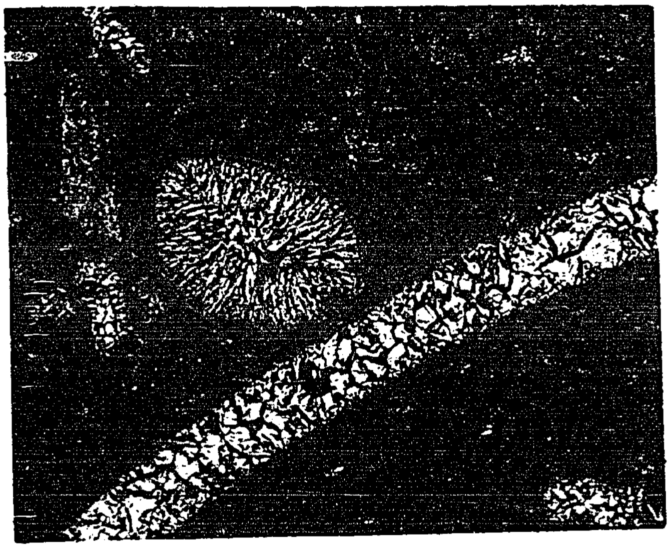


FIG. 2

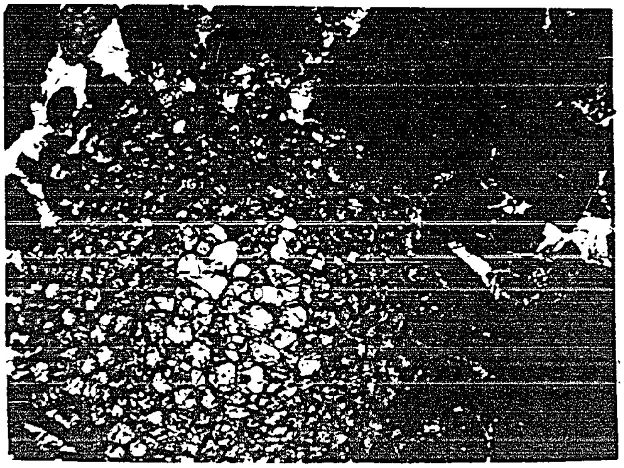


FIG. 3

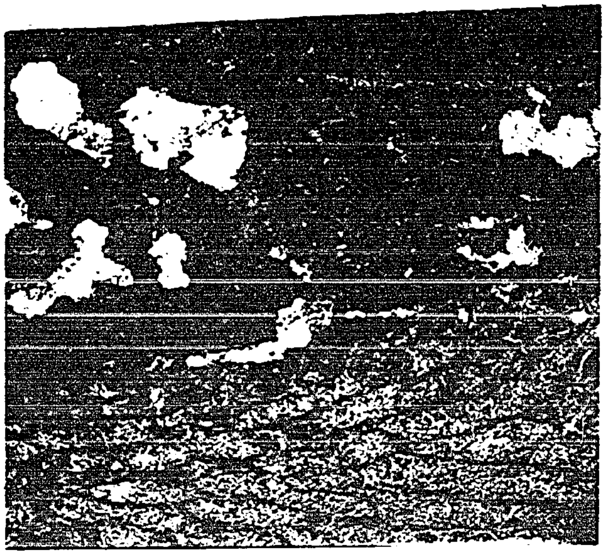


FIG. 4

of oölitic rock was noted in the basal part of unit II in Unthoff quarry. These oöliths show the characteristics of the normal type and are embedded in a dark microcrystalline calcite matrix. This perhaps suggests a local influx of oöliths into a lagoon environment from the tidal zone.

Skeletal Materials:-

Skeletal materials constitute a considerable part of the Black River carbonate rocks. Both broken and complete skeletal materials are present in the rocks. Broken forms without any identifiable features are grouped together as "unidentifiable shell fragments". Macro fossils of Black River rocks include the following types: brachiopods, bryozoans, pelmatozoa, corals, gastropods, ostracods, algae, plates and trilobites, micro-fossils include conodonts and sponges. For details of description of various fossils, the works of Okulitich (1939), Young (1943), Wilson (1946a, 1946b, 1947, 1948, 1951, 1961), Fritz (1957) and Barnes (1967) should be consulted.

Brachiopod:-

Brachiopods include both broken and complete forms of inarticulate and articulate types. The shells are characterised by fine lamellar fibrous structure. Brachiopod shells range from 0.06 mm or less to more than 10 mm in size. Most commonly the shells are 2 mm in size. Fragments invariably show recrystallisation of skeletal material into coarse anhedral calcite mosaics (Plate 32, figs. 1 and 2). The external margins commonly have thin dark microcrystalline calcite envelopes. Bathurst (1966) described similar micritic dark envelopes

Explanation of Plate 33

Figure 1 Presence of massive cylindrical bryozoa (right margin) and two horizontal sections of a rugose coral showing distinct septae (lower centre of the field). Presence of brachiopod and crinoid fragments is also observed along the upper left hand corner (unit III, Napanee quarry). X 22.

Figure 2 Rounded fragments of bryozoa zoarium as intraclast in a rock with sparry calcite cement (unit IV, Point Anne quarry). Other intraclasts are pellets and algal fragments. X 22.

PLATE 33.

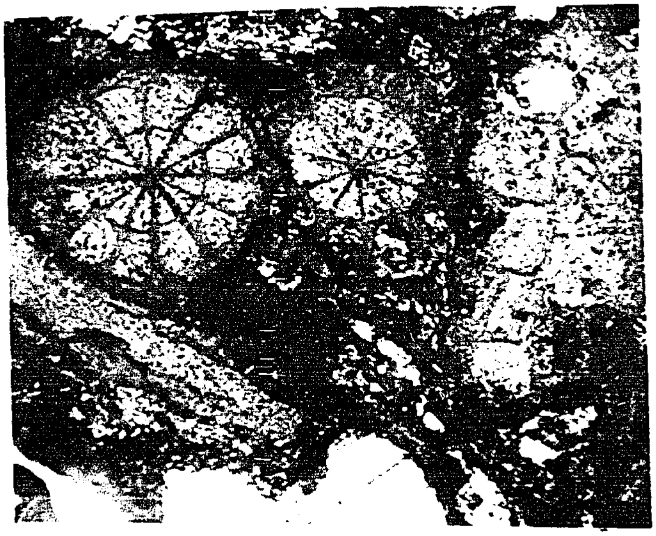


FIG. 1

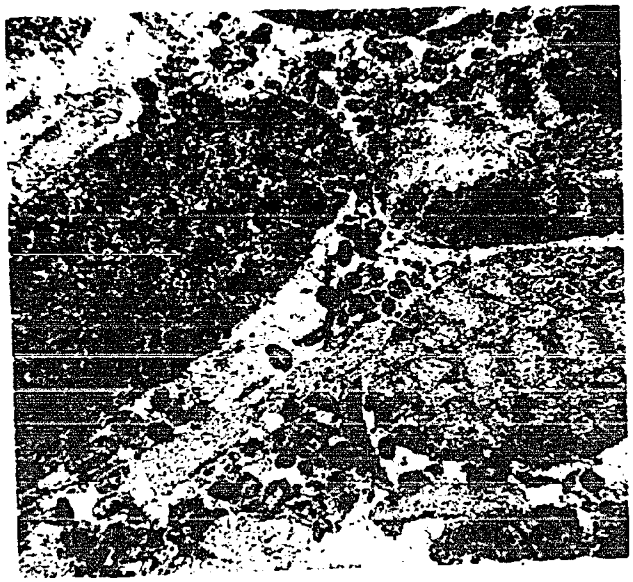


FIG. 2

as due to algal boring. Unbroken shells usually show drusy calcite filled molds (Plate 32, fig. 2). Brachiopods become increasingly abundant towards the upper parts of the Black River succession (Units III and IV). Broken forms are common,associated in clear sparry calcite cemented rocks.

Bryozoans:-

Bryozoa are common in the Black River limestones. Two distinct forms can be recognized; (1) Massive cylindrical zoarium with a smooth surface (Plate 33, fig. 1); (2) Zoarium consisting of slender cylindrical branches (Plate 32, figs. 1 and 4). In most cases, zooecial openings are infilled with drusy clear coarse calcite or recrystallised (neomorphic) fine calcitic material (Plate 32, figs.3 and 4). Bryozoan fragments are extremely variable in size. Rounded, massive zoarium fragments are common in sparry calcite-cemented rocks, with abundant intraclastic and algal materials (Plate 33, fig. 2). The slender branching type is common in rocks with microcrystalline calcite matrix. Recently, Hoffmeister et al. (1967, p. 175) reported the presence of large knobby type bryozoans in areas bordering the oölitic facies of the Miami limestone of Florida. Branching slender forms replace the former types towards the Everglades (Hoffmeister et al. 1967, p. 184, fig. 4). In the 1964 Miami meeting of the Geological Society of America, Imbrie suggested to Hoffmeister and Multer that a similar relationship could be observed in the distribution of recent Bahamian occurrence of *Schizoporella floridiana* (bryozoa) and environmental hydraulic energy. In the present investigation, a few thin sections of coarse skeleton-rich

Explanation of Plate 34

Figure 1 Transverse section (lower left) of elongated (crinoid) Pelmatozoan stem or arm with wedge-shaped columnals surrounding central canal. Large fragments of Pelmatozoan and intraclast (dark, round fragment in the upper right corner) embedded in pellet-rich micritic matrix. Irregular white, clear crystalline patches in interallochem areas represent sparry calcite cement (Unit IV, Point Annequarry). X 22.

Figure 2 Horizontal section of pelmatozoan plate showing central circular canal infilled with microcrystalline calcite material. Fragments are embedded in dark micritic matrix. (Unit III, Roblindale quarry). X 22.

Figure 3 Horizontal section of pelmatozoan ossicle showing central pentagonal cavity infilled with dark microcrystalline calcite (Unit III, Marmora road section). Dark micritic matrix constitutes the ground mass. X 22.

PLATE 34.

FIG. 1

FIG. 2

FIG. 3

Trenton rocks also showed an abundance of massive bryozoans in sparry calcite-cemented rocks.

Pelmatozoans:-

Pelmatozoan fragments occur as rounded, elongated or elliptical bodies 0.03 mm to 4 mm in size. The most common average size is .2 mm. Most of the fragments represent broken portions of stem (Plate 34, fig. 1) and show central cavity, circular or pentagonal in shape (Plate 34, figs. 2 and 3). The central cavity may be infilled with dark microcrystalline calcite material (Plate 34, figs. 2 and 3). Each individual fragment of pelmatozoan is composed of single, clear, or turbid calcite crystal. Most fragments do not display any evidence of recrystallisation (neomorphism) or diagenetic alteration. Pelmatozoans, exhibiting most morphological characters and lack of current abrasion, are associated with dark coloured microcrystalline calcite matrix. Fragments with rounded margin and secondary growth are invariably observed in the upper coarse, sparry calcite cemented pellet or other allochem rich rocks. Pelmatozoan fragments are frequently penetrated by algal boring (Plate 38, fig. 3).

Coelenterates:-

Corals constitute a major part of skeleton materials in the upper parts of Black River rocks. As noted by Winder (1960), a considerable variation in form of coralla occur in the limestones. Commonly present species include Tetradium syringoporoides, T. halysitoides, T. cellulosum and T. fibratum (Okulitch, 1939; Winder 1960). The individual coral-

Explanation of Plate 35

Figure 1 Horizontal section of isolate Tetradium with distinct septae (Unit III, Marmora quarry). X 22.

Figure 2 Longitudinal section of a compound corallite with recrystallization of tabulae (Unit IV, Hwy. 401 section, 5 miles east of Napanee). Branching is not fine. X 55.

PLATE 35.

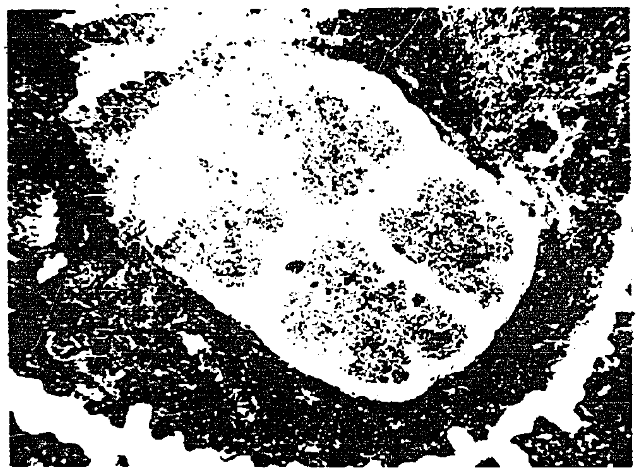


FIG.1

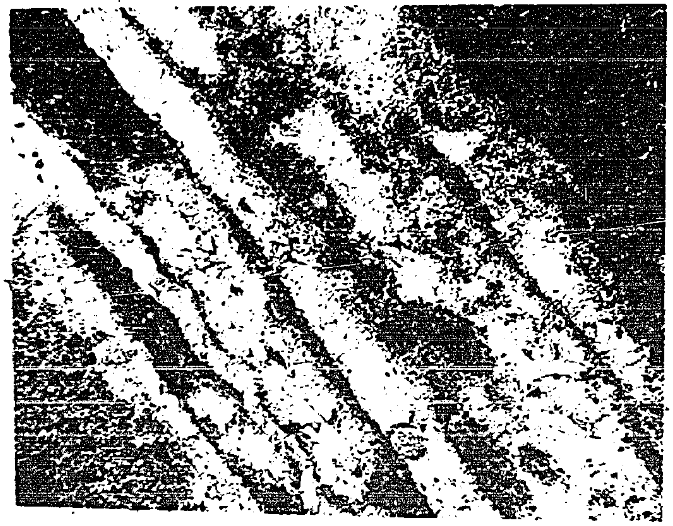


FIG.2

lites average [illegible] 1 mm. in diameter and are characterized by rounded to oval polypary tubes bearing distinct septae (Plate 33, fig. 1; Plate 35, fig. 1). Three distinct types of coral can be recognized.

1. Individual isolated corallite (Plate 33, fig. 1; Plate 35, fig. 1).
2. Colonial corals with bundles of corallites (Plate 35, fig. 2).
3. Colonial corallites forming heavily branching massive hemispherical form (Plate 36, fig. 2).

Corals invariably show intense recrystallisation (neomorphism) with partial or total obliteration of internal structures. Preservation of tabulae or septae can be observed in rare cases (Plate 35, figs. 1 and 2).

In some cases coelenterates show development of thin crust like black algal encrustation along the outer margins (Plate 36, fig. 2).

Isolated individual corallites and long, moderately branching compound corallites are commonly associated with microcrystalline calcite-rich rocks. Heavily branching, short, compound corallites with dark algal encrustation are typically associated with oölitic rocks or other sparry calcite-cemented allochem rich lithologies. Winder (1953, p. 64; 1960) gave the interpretation that "the morphology of the coralla of Tetradium may merely be an ecological series, indicative of increased water movement rather than an evolutionary series". In recent quiet water areas such as Bahama and Florida a high percentage of lithothamnian corals have a cellular character, but in the seaward side, due to more stronger wave action the same group of corals is replaced by massive colonial, heavily branching types (Baars 1963, p. 116; Newell and Rigby 1957, p. 41).

Explanation of Plate 36

Figure 1 Gastropod shell showing recrystallization of outer hard parts and infilling of inner chambers with dark micritic matrix. (Unit III, Napanee quarry). X 55.

Figure 2 Heavily branching, massive compound corallites with dark algal envelopes around outer margins (Unit IV, Havelock road section). Note presence of dark wing shaped trilobite fragment or plate (upper central part of the field). X 55.

Figure 3 Small curved ostracod fragments together with other pelmatozoan debris. (Unit III, Napanee quarry). X 55.

PLATE 36.

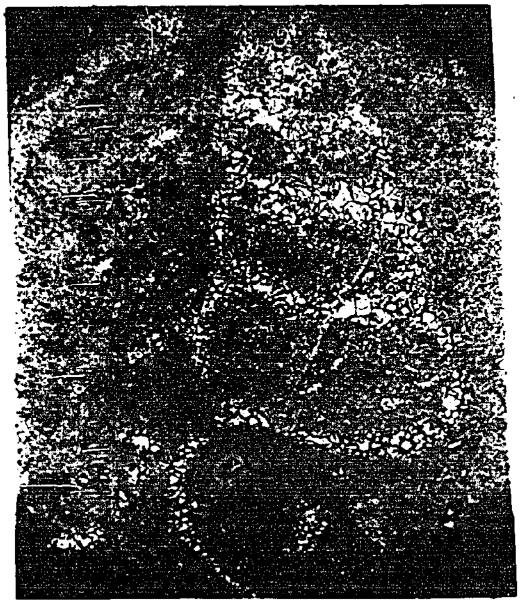


FIG. 1

FIG. 2

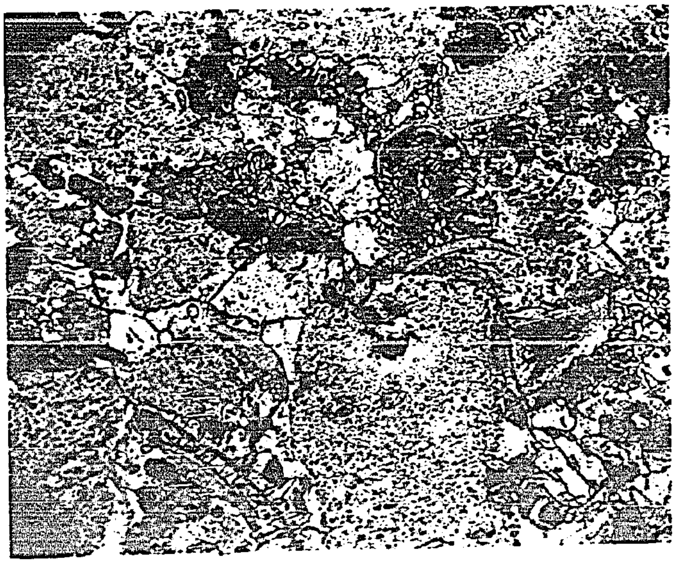


FIG. 3

Gastropods:-

Gastropods are minor constituents and are usually recrystallised. The inner chambers are commonly filled with dark micritic matrix (Plate 36, fig. 1).

Ostracod:-

Ostracod shells are common in Black River rocks. These are identified as small bivalved shells [illegible] 0.5 mm to [illegible] 2 mm in size. Mostly the shells are disarticulated (Plate 31, fig. 3). The fragments show a very obvious orange colour. Ostracods invariably resist even the most intense diagenetic changes. These are more abundant in microcrystalline calcite rich rocks with associated dolomite.

Plates and Trilobites:-

These are orange to brown in colour, with irregular long plate like shape ranging [illegible] 1 mm to [illegible] .5 mm in size. Plates are distributed irregularly throughout the entire Black River rocks. Some plates resemble fragmented parts of trilobite shells (Plate 36, fig. 2). Most fragments invariably resist even the most intense diagenetic changes. No definite morphological identification was possible and all fragments of similar appearance were grouped under the general term "plate".

Algae:-

In recent years, the importance of algae in carbonate sedimentation has been emphasized. "Through photosynthesis, algae provide the first

Explanation of Plate 37

Figure 1	Internal section of fragments of fan shaped, finely branching algal tubes in dark fine micritic matrix (unit II, Medonte section). Cylindrical, radiating closely spaced tubes with fine crystalline calcite infilling. X 22.
Figure 2	A fragment of fan shaped finely branching algal colony (unit III, Roblindale quarry). Note random branching of tubes and parallel nature of growth of new tubes with former ones. X 22.
Figure 3	Horizontal section of a fragment of finely branched algal colony (unit III, Coboconk road section). X 22.

PLATE 37.

FIG. 1

FIG. 2

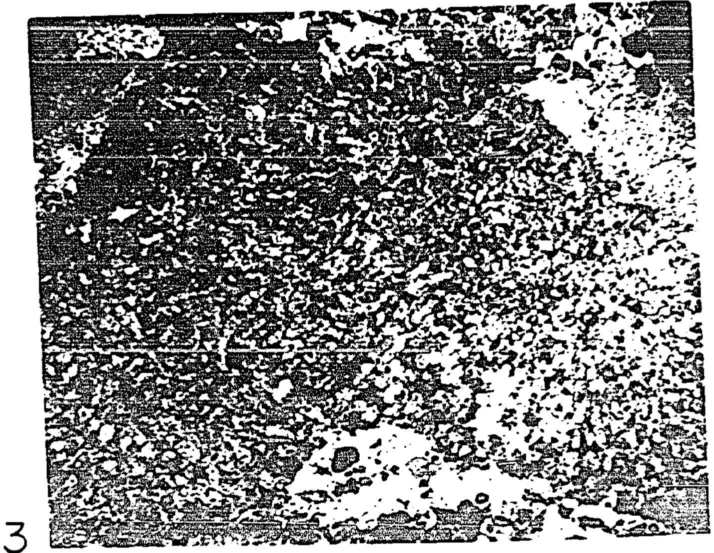


FIG. 3

link in marine food chain and thus all life in the sea will depend on them directly or indirectly" (Ginsburg 1966, p. 21).

The exceedingly small size of algae, their fine structure, suceptibility to diagenetic alteration, and lack of description of any comparable living forms makes the identification of algal bodies in rocks extremely difficult. Several workers reported algae from Black River limestones, but no systematic classification or grouping has previously been attempted. However, no specific identification of the algal forms can be made, excepting some broad family level grouping.

As defined by Johnson (1961) "the algae are a group of plants characterised by having most of the functions of life carried on by amost all parts of each plant unlike higher plants". The algae secrete calcite in various forms but most commonly as aragonite.

Based on the general external shape, several different types of algal structures can be identified in the Black River limestones.

1. Fine slender branching type - Commonly the fragments are broken and the exact nature of original growth form cannot be clearly ascertained. Careful examination reveals a weakly developed fan shaped branching nature with a somewhat tapered base (Plate 37, figs. 1 and 2). Internally these algal fragments show closely spaced, very fine radiating tubes which are cylindrical in shape and in most cases filled with fine grained clear calcite (Plate 37, fig. 1). Cross partitions in tubes are seldom seen. New tubes branch off almost at random and growth is parallel to the earlier formed tubes (Plate 37, fig. 2). Fragments of these algae are common in microcrystalline calcite matrix rich rocks (Plate 37, fig. 1), though rounded or irregular fragments

Explanation of Plate 38

Figure 1 Section of an elliptical algal fragment (Unit III, Roblindale quarry). Note branching of irregularly sized, arched tubes in hypothallus on either side of a central elongate, raised coaxial perithallus. Branching of tubes does not take place at the same level on both sides. Associated rock is oölite or allochem-rich sparry calcite cemented. Fragments show encrustation around the outer surface. X 55.

Figure 2 Boring dark carbonaceous filamentous algal tubes encrusting crinoid fragments (Unit II, Hwy. 401 section near Hwy. 15 exit). Note spreading of filaments from margin towards centre. X 22.

Figure 3 Boring algal tubes in pelmatozoan fragments (Unit II, Hwy. 401 section near Hwy. 15 exit). X 55.

PLATE 38.

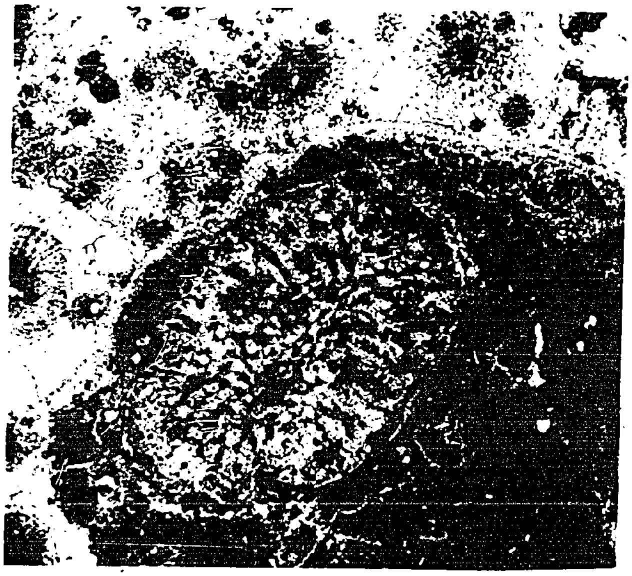


FIG. 1

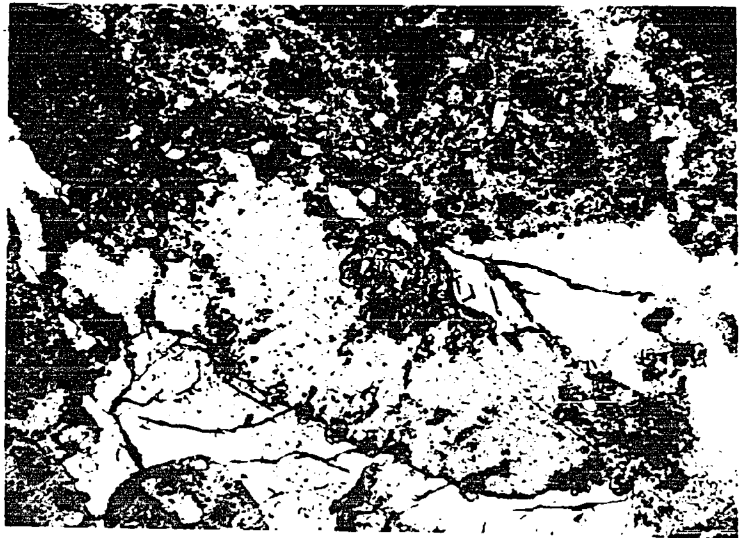


FIG. 2

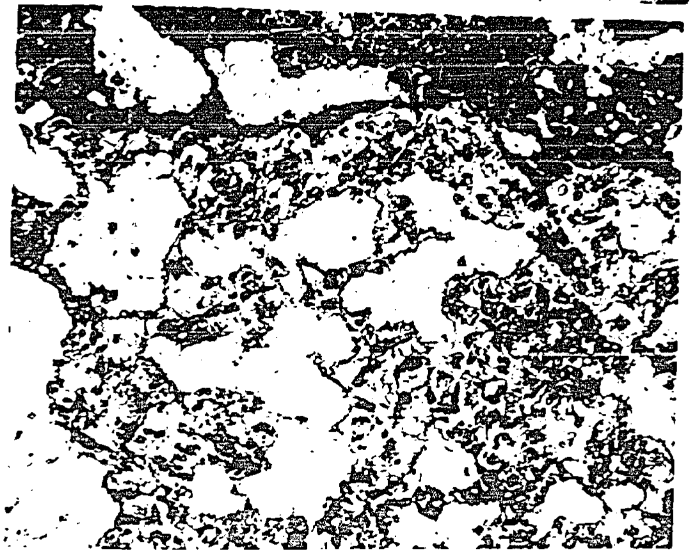


FIG. 3

Explanation of Plate 39

Figure 1 Highly fragmented algal plates in micritic matrix-rich rock. (Unit III, Port McNicol quarry). Note radial disposition of some plates suggesting fragmentation of a large algal colony. X 22.

Figure 2 Branching straight or slightly curved filamentous tube like algae, in micritic rock (Unit III, Roblindale quarry). Most tubes branch at 90°. Some tubes branch irregularly but maintain parallelism with the main branch. X 55.

Figure 3 Dark and white wrinkled tubes of filamentous algae boring in crinoid fragment. (Unit II, Longford quarry). Tubes are constricted at the edges in contact with other tubes. Note dark thick carbonaceous filament around external walls. Micrite is partly recrystallised. X 55.

PLATE 39.

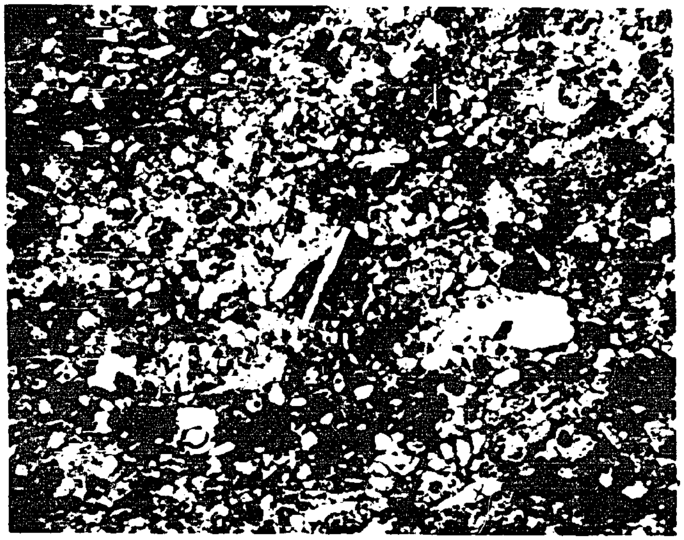


FIG. 1

FIG. 2

FIG. 3

can occassionally occur in allochem and sparry calcite cement-rich lithologies (Plate 37, fig. 2). In morphology these fragments resemble codiaceaen type green algae. Laporte (1963, p. 645) described similar looking algal fragments as *Garwoodia* Sp. from the Manlius (Devonian) Formation and suggested a shallow lagoonal environment of growth.

2. Massive branching type - The fragments are spherical or ellipsoidal in shape. Algal tubes are closely spaced and variable in thickness. The tubes branch on both sides of a central raised elongate coaxial perithallus region. The branches in hypothallus are arched and do not originate at the same level on both sides of the central coaxial region (Plate 38, fig. 1).

The general morphology of these algal fragments closely resemble *Archaeolithophyllum* type algae of Johnson (1956b) and Rácz (1966, p. 86). It is thought that the algal fragments presumably represent some kind of Rhodophyceaen red algae. The Rhodophyceaen type red algae usually occur as frame builders in oölitic or other allochem-rich, sparry calcite cemented rock. Framework building colonial,massive red algae are reported in the windward outer margins of the Bahama Bank (Baars 1963, p. 120; Ginsburg 1966, p. 25). In most cases these occur as a thin grey coloured encrustation, (Plate 38, fig. 1). A similar encrusting habit of red algae was recognised by Ginsburg (1966, p. 25).

Intense fragmentation of colonial algae results in rock composed mostly of discoidal to elongated fine silt sized particles of algal fragments. In Black River rocks, fragmented algal plates are usually associated with dark micritic matrix rich rocks (Plate 39, fig. 1). The fragments show a faint orange tinge. Extensive deposits of similar

Explanation of Plate 40

Figure 1 Growth of alternately laminated uniform encrustation on brachiopod shell (Unit III, Coboconk road section). Growth is concentric with distinct separation of dark, opaque carbonaceous and light grey microcrystalline material. Rings develop around upper surface of host fragments. X 55.

Figure 2 Growth of algal encrustation of rings around composite grains (Unit III, Marmora quarry). Rings are of irregular shape and are interconnected. Very fine alternate carbonaceous laminae and calcite layers are visible within the encrustation. X 55.

Figure 3 Irregular isolated light grey algal encrustation with tube-like boring in host fragment. (Unit III, Roblindale quarry). X 55.

PLATE 40.

FIG.1

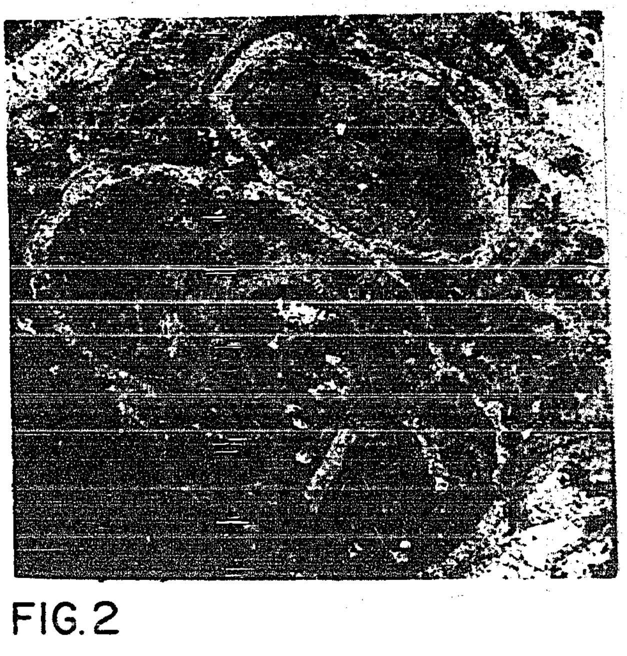


FIG. 2

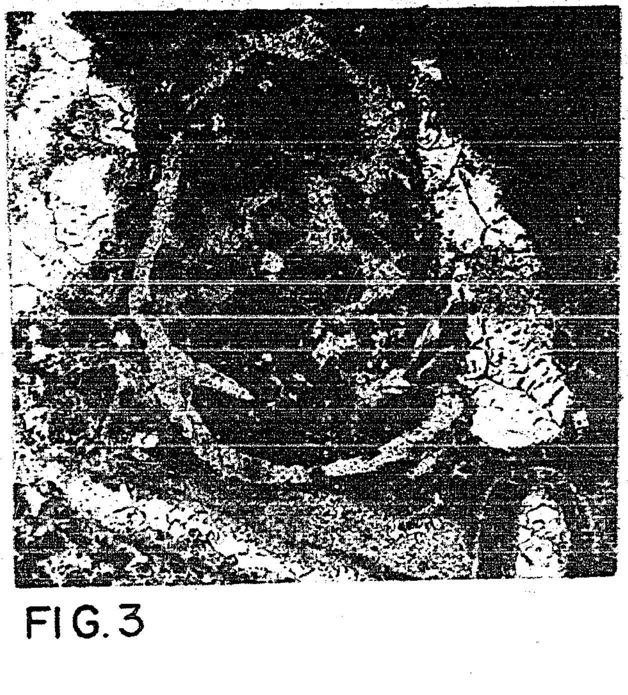


FIG. 3

skeletal calcareous plate-rich sediments are known in the quiet water interior of the Bahama Banks. It has been shown that fragmentation of bush-like Codiaceaen-type green algae (Halimeda) causes development of algal,plate-rich deposits in recent environments.

3. Thread-like filamentous algae - These algae may form slender long straight finely branching tubes (Plate 39, fig. 2) or laminated, wrinkled tubes (Plate 39, fig. 3). In the former type individual tubes branch at right angles to the main tube, while secondary tubes may branch at different angles (Plate 39, fig. 2). The laminated filamentous type algae show constricted tubes at the terminal edges along the contact with other adjacent tubes (Plate 39, fig. 3). The external wall of each tube is marked by dark thick carbonaceous material, while the inner area is recrystallised. Commonly, this type of laminated filamentous alga tends to bore into calcareous shell fragments (Plate 39, fig. 3). Both types of filamentous tube-like algae are associated with micritic matrix-rich rocks with varying amounts of other skeletal materials. Extremely delicate branching structures of the first type (Plate 39, fig. 2) suggest growth of the organisms in a calm environment.

4. Encrusting-type algae - Encrusting algae are the most common of all algal structures in the Black River rocks. The algae invariably grow around composite grains, and intraclastic particles and form a ring like very thin crust of light grey microcrystalline calcite (Plate 40, fig. 1). Most of the algal bodies show no observable structures excepting occasional irregular fine growth of calcite mosaic and concentration of highly crumpled dark carbonaceous laminae (Plate 40, fig. 2). Under high magnification some of the crusts show

Explanation of Plate 41

Figure 1 Coarse pelmatozoan fragment converted to dark microcrystalline calcite by intense algal boring. (Unit II, Port McNicol quarry). X 55.

Figure 2 Stromatolite with finely laminated structure; grey layers represent micritic material. (Unit IV, Coboconk quarry). Cell structures are present in white layers. Note rectangular to elliptical shape of discontinuous white patches (cell) separated by thin micritic bars.

PLATE 41.

FIG. 1

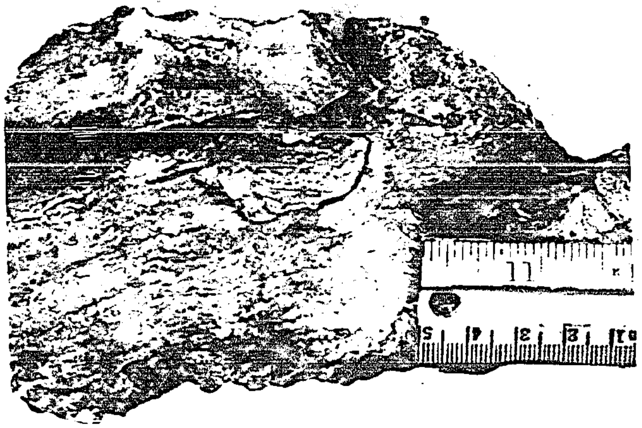


FIG. 2

a very fine, weakly defined laminated structure with transverse bar-like thin partitions. The shape of the crust is extremely variable. The crusts often extend into the inner core of host fragments as small tube-like projections (Plate 40, fig. 3). The thickness of encrustations may range from [illegible] (0.05 mm to [illegible] (0.01 mm. Occasional opaque carbonaceous patches are not uncommon. The encrusting rings may occur as isolated or interconnected bodies (Plate 40, figs. 2 and 3). Similar encrusting ring with perfectly spherical shape may be mistaken for calcisphera. A second type of encrusting alga shows development of uniformly thick, concentric laminae, around various allochemical fragments. The encrustation only forms on the upper surface of allochems. Alternating dark carbonaceous and light grey microcrystalline calcite layers can be distinctly seen (Plate 40, fig. 1). Wolf (1965a, p. 9) described similar structures as oncolites and suggested that individual oncolites were moved around by currents and waves.

The concentric, laminated, ring-like crusts are only observed in coarser allochem-rich, sparry calcite cemented rocks.

5. Boring type algae - Boring filamentous type algal structures are frequently observed in skeleton-rich, micritic rocks. Only pelmatozoan fragments bear evidence of boring activity by algae. The algae may encrust the host fragments, (Plate 38, fig. 1) or may invade indiscriminately into the central host fragment (Plate 38, fig. 2). The final result of intense boring activity is marked by textural inversion of original coarser fragments into dark microcrystalline calcite (Plate 41, fig. 1).

6. Algal stromatolites - Stromatolites show megascopic growth features

and are easily recognized in the field. Stromatolites are characterised by undulating to hemispherical shape. Internally these show alternate lamination of grey carbonate mud and porous, algal, cell-like structures (Plate 41, fig. 2). The cells are rectangular to ellipsoidal in shape with transverse bar-like partitions. The outer walls of cells are composed of dark micritic material, while the cell cavities are intensely recrystallized (Plate 52, fig. 3). Similar structures are reported by Okulitch (1939),Winder (1953), Barnes (1967) and others from the upper units of Black River rocks.

In a recent symposium on stromatolites, Ginsburg (1967, p. 339) reported that Golubic (1967) described complex biological stratification in algal stromatolites. Many workers believe that different species of algae form different laminae in stromatolites as opposed to a single type of alga constituting the entire stromatolites. The laminated structures of particulate sediments produced by the influence of algal mats is also questioned by many workers. Hemispherical stromatolytic structures are common in the upper units (III and IV) of the Black River rocks. The rocks contain coarse allochem and sparry calcite cement. Laporte (1967, p. 87) described similar algal structures from the Manlius Formation (Lower Devonian) of New York state. According to Logan _et al._ (1964) these head-like structures are developed on a firm substrate in the intertidal areas.

In conclusion it can be said that both red and blue-green algae were probably dominant during the deposition of Middle Ordovician carbonate rocks. The algal varieties represent ancient analogues of similar forms which exist in modern carbonate environments. Algae contributed

Explanation of Plate 42

Figure 1	Spherical, elliptical intraclasts (micritic) with rounded, sub-angular margin, embedded in sparry calcite cement (unit III, Marmora quarry). X 55.
Figure 2	Irregular, angular intraclasts derived from erosion of an oolite and shell-rich carbonate mud layer (unit III, Roblindale quarry). Note sharp contact of high energy upper spar-rich oolite layer (with intraclast) and lower allochem-rich micritic layer representing a lesser energy environment. X 22.
Figure 3	Elongate smooth to angular large fragments of fine carbonate mud with internal structure e.g. lamination, cross-lamination etc. (unit II, Marmora quarry). Note imbrication of intraclasts and poorly sorted nature (negative peel print). X 2½.

PLATE 42.

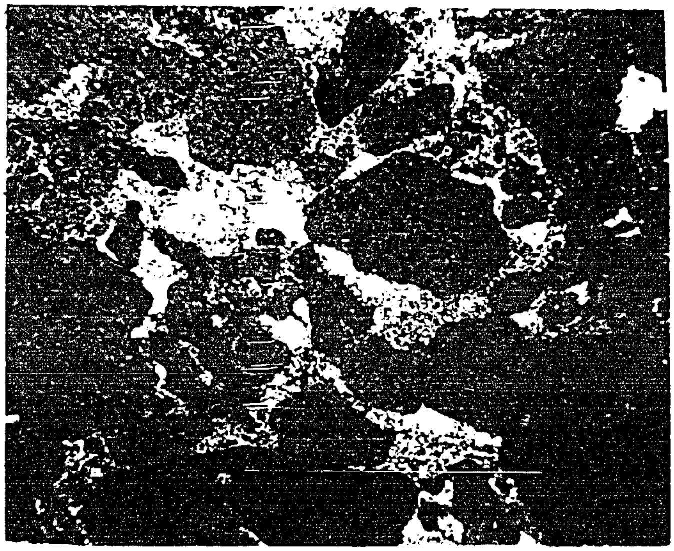


FIG.1

FIG.2

FIG.3

significantly in modifying the sedimentary environments. The green algae were probably more active in littoral to sublittoral areas. These mostly acted as sediment binding, trapping and building agents and less commonly as framework builders. The massive variety of red algae dominated in strongly agitated marginal areas of tidal zones and chiefly acted as frame builders.

Intraclasts:-

Intraclasts are fragments of weakly consolidated carbonate sediment which are produced by erosion of sedimentary layers (Folk 1959, 1962). The fragments are spherical, elliptical (Plate 42, fig. 1), elongate (Plate 42, fig. 3) to irregular in shape, with smooth (Plate 42, fig. 3) rounded (Plate 42, fig. 1) or subangular margin (Plate 42, fig. 2). They range in size from 0.03 mm to 0.5 mm or more. Intraclasts are composed of pure homogeneous micritic matrix or allochem-rich carbonate matrix. Intraclasts can be grouped into three distinct types, each with characteristic features.

A. Intraclasts composed of extremely homogeneous micritic matrix (Plate 42, fig. 3) have the following characteristics: (a) fragments are flat and elongate with smooth margins, (b) size may range upto 70 mms, with poor sorting, (c) original bedding are preserved, (d) frequent imbricated arrangement, (e) absence of recognizable change in depositional energy in immediate under and overlying layers, (f) fragments are embedded in matrix of similar composition and (g) association with extremely fine dolomitic carbonate units.

B. This type of intraclast is composed of allochem-rich micrite

Explanation of Plate 43

Figure 1 Elongate, flat, intraclasts with rounded margins set in dark carbonaceous, finely laminated carbonate matrix (unit II, Hwy. 401 section near Hwy. 15 exit). Note occasional truncation of fragments by dark network of dark laminae (algal?). Also note development of white isolated patches of dolomite in dark matrix. X 55.

PLATE 43.

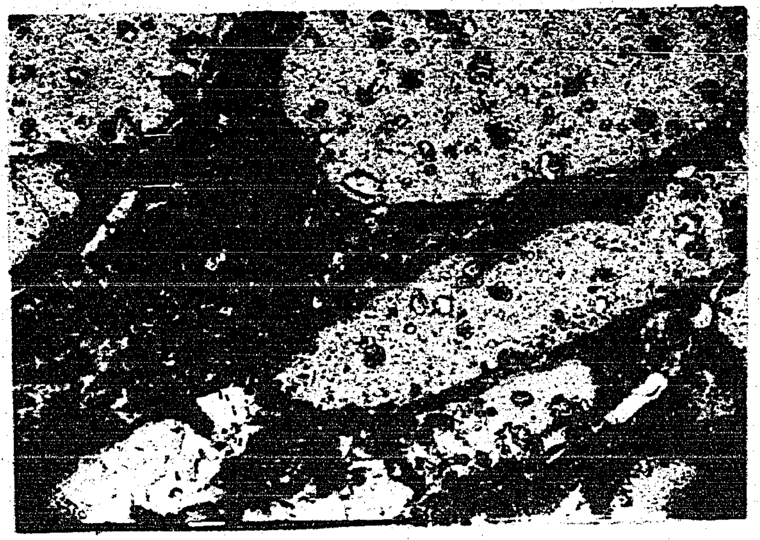


FIG. I

(Plate 42, figs. 1 and 2) with the following features: (a) elongate, elliptical to irregular shape of fragments with rounded to angular margin, (b) size rarely exceeds 20 mm, (c) uniform distribution of size in some cases, (d) sharp contact with underlying or overlying rocks, (e) irregular to smooth nature of contact in underlying beds, (f) association with allochem-rich and sparry calcite cemented rocks and (g) merging of intraclastic fragments.

C. A third type of intraclast-rich rock (Plate 43, fig. 1) is noted in Black River units and has the following distinct characters: (a) flat, extremely elongate shape, (b) alignment usually parallel to bedding with larger fragments horizontal and smaller ones showing random distribution, (c) disruption of fragments with transverse spar or microcrystalline calcite filled cracks, (d) association of dark laminated carbonaceous material in the matrix and penetration of laminated network in the intraclast, (e) frequent presence of desiccation features on bedding planes of intraclastic layer or in adjacent units, (f) lenticular or discontinuous nature of intraclast bearing units, (g) concentration of dolomite in laminated layers and (h) restricted occurrence in the lower units (I and II) of Black River rocks.

Intraclasts of A and B types presumably represent development by processes of erosion and transportation (Folk 1959, Beales 1958). Beales (1958) suggested that intraformational conglomerate could result from turbidity current deposits derived from a nearby shelf which was undergoing periodic emergence and desiccation. Kepper (1966, p. 560) suggested that long thin platy fragments of intraclast could not retain such shape under transport by turbidity current for any appreciable distances. Poor sorting in intraclastic rocks is further evidence of restricted local origin. It is thought that most of the intraclast formed by gentle wave action on exposed mud flats. Association of dolomite intraclast-rich beds indicate a supratidal environment, occasionally flooded by tides. Matter (1967) described similar deposits from Ordovician tidal flat rocks of Western Maryland. Burrowing organisms could also aid in the brecciation of muddy rocks (Lebauer 1965, p. 509).

Intraclastic rocks with finely laminated carbonaceous matrix (type C) are thought to be of organic origin. Recent investigations by various workers in the Bahama and Florida areas have shown that sediment binding activity, and growth of algae in subaerially exposed mud flats play an important role in forming edgewise conglomerate. Drying of carbonate mud causes formation of intraclastic grains which are then held together by algae. Development of algae in highly laminated mud crack-rich sediment has already been discussed.

Composite fragments:

The term composite grain or fragment is used to include various allochems, which become cemented together to form a lump or accretion. Most of these grains are similar to aggregates called "grapestones" by Illing (1954, p. 30). Composite grains are found in oölite pellet, and intraclast-rich rocks. Composite structure is virtually absent from mixed allochem-rich rocks. The characteristics of three different allochem-rich composite grains are given below.

1. Pellet composite fragments:- Commonly these occur as elongate, spherical, fragments with component grains made up of highly rounded spherical to ellipsoidal pellets which form the internal structure

Explanation of Plate 44

Figure 1 Typical composite (pellet) grain with elongate elliptical shape and rounded to curved, wavy margins. (Unit III, Longford quarry). Note the presence of minute shell fragments (white elongated fragment) in rounded spherical pellets (upper left and centre). Also note development of small sparry calcite crystals along the margins of grains. Some composite grains (upper right margin) do not show obvious grain and cement. X 55.

Figure 2 Composite intraclastic grains, elongate rounded elliptical fragments of micrite, (intraclast), showing typical grapestone structure with extremely bumpy margin and lack of any abrasion. (Unit III, Coboconk quarry). X 55.

PLATE 44.

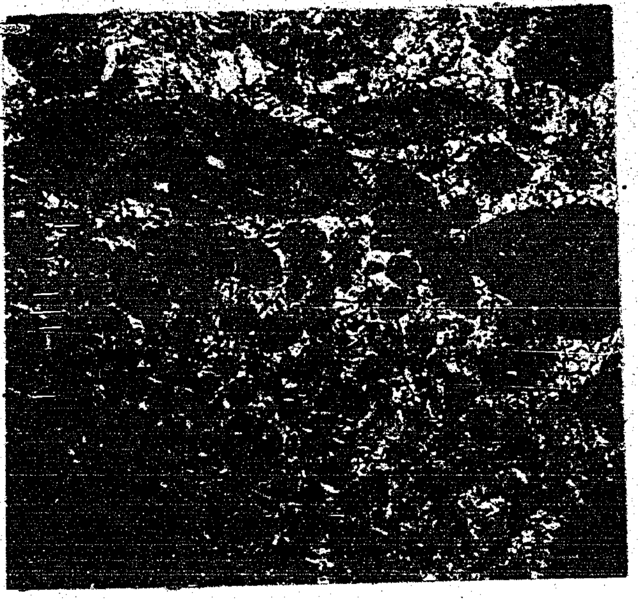


FIG.1

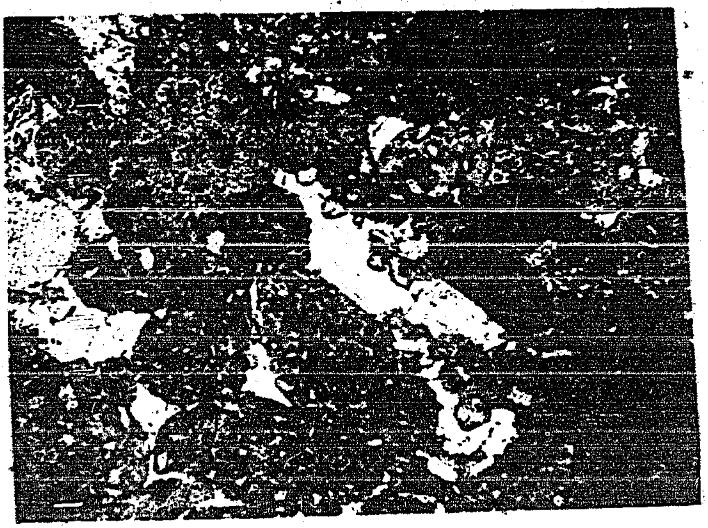


FIG.2

(Plate 44, fig. 1). The outer margin of composite grains may be smooth, or curved. The contact of component internal grains shows fine, clear sparry calcite cement-like material. Mostly the lumps seem to be composed of uniform matrix with no sign of obvious composite character and these could easily be mistaken for intraclasts (Plate 44, fig. 1). Illing (1954), Newell and Rigby (1957) Cloud (1962), Imbrie and Purdy (1962) reported extensive formation of similar pellet-rich composite or "grapestone" structures from Bahama Bank areas. Beales (1958) noted similar composite grains or "bahamite" from Ordovician rocks in Ontario, and Devonian rocks of Alberta. It is probable that constituent pellets in composite grains are cemented along points of contact and the cavities between the grains are filled with aragonitic material (Illing, 1954). Later inversion of aragonite will leave a fine mosaic of calcite cement between the pellets. Absence of surface irregularities on composite grains suggests considerable abrasion.

Composite grains of pellets or the so-called "grapestone facies" are common in areas bordering the inner margin of the Bahama Banks (Imbrie and Purdy 1962). The effect of tides or current activity is less pronounced in such an environment. Composite pellet grains are only observed in sparry cemented, pellet-rich rocks.

2. Intraclastic composite grains:- Intraclastic composite grains occur as extremely irregular shaped fragments. The component grains are composed of microcrystalline calcite material ranging from [illegible] (0.6 mm to [illegible] 0.18 mm in size. Individual fragment may be extremely rounded with elongate, spherical or ellipsoidal shape. The outer margins of composite grains show frequent protruberences of component grains. Intergranular pore space is large and filled with coarse crystalline

calcite. The grain contacts are not distinct and show thin black carbonaceous film, possibly representing organic material (Plate 44, fig. 2). The extremely lumpy nature (Plate 44, fig. 2) of composite grains reflect, lack of current action.

From the study of Paleozoic carbonate rocks in Ordovician, Devonian, and Mississippian units of Canada, Beales (1958) concluded that intraclasts would be largely formed by the grapestone method. He expressed doubts as to the intraformational attritionary nature of true intraclastic fragments. Beales (1958) also pointed out that grapestones are the most important type of intraclasts in modern carbonate environment. Folk (1962) suggested that "this was by no mean true throughout much of the Paleozoic or Mesozoic time". The lack of any obvious abrasion of pellet aggregates, the coarse nature of the matrix of individual fragments, and the large size of the component grains (Plate 44, fig. 2) clearly justify the use of the term "intraclast" for describing such isolated fragments in a rock (Plate 42, fig. 1). The term composite grain or bahamite will be used when aggregate lumpy nature of intraclastic grains is obvious (Plate 44, fig. 2). The presence of intraclastic composite grains indicates transportation of these fragments into a grapestone or bahamite-forming environment. This type of composite intraclastic grain is rarely seen in pellet-rich rocks.

3. Oölitic composite grains:- Composite oölitic grains show botryoidal structure (Plate 45, figs. 1 and 2). Individual oöliths are elliptical or spherical in shape. Irregular dark organic patches are common in oölitic grains (Plate 45, figs 1 and 2). The contacts of oölites show presence of dark microcrystalline calcite material. Most composite grains show development of envelopes around the compound core.

Explanation of Plate 45

Figure 1 Composite grains showing botryoidal lump structure (Unit III, Roblindale quarry). The nucleus of individual grains is composed of pellet-like material. Also note dark opaque patches (organic) across oölitic structure. X 55.

Figure 2 The contacts between oöliths are marked by the presence of cryptocrystalline material (Unit III, Hwy. 401 section, 5 miles east of Napanee). Envelopes may be made of oriented clear calcite laminae or irregular microcrystalline material. X 55.

Figure 3 Protointraclasts showing nodular, lensoid and irregular shape of white micrite in a dark argillaceous carbonate-rich silty matrix (Unit II, Uhthoff quarry). Note extremely gradational boundary between protointraclasts and matrix.

PLATE 45.

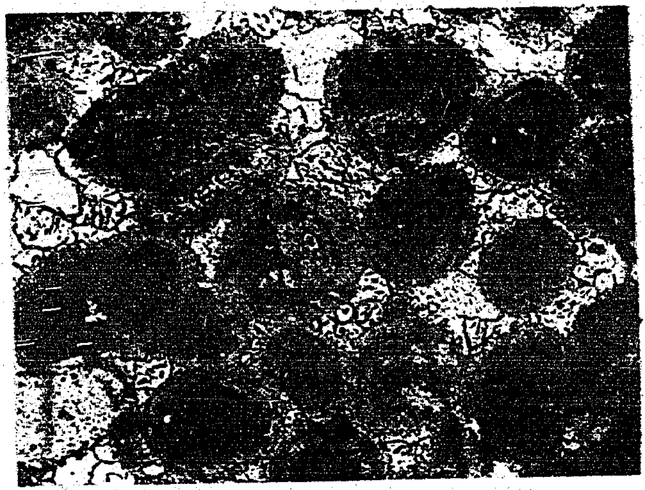


FIG.1

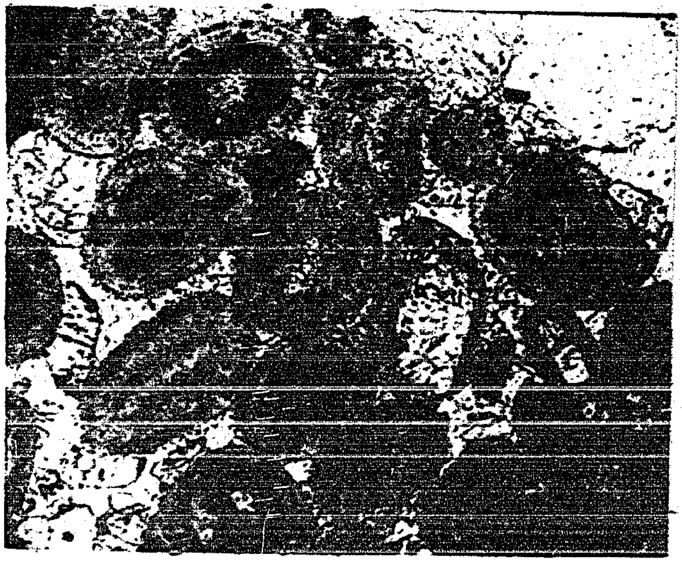


FIG.2

FIG.3

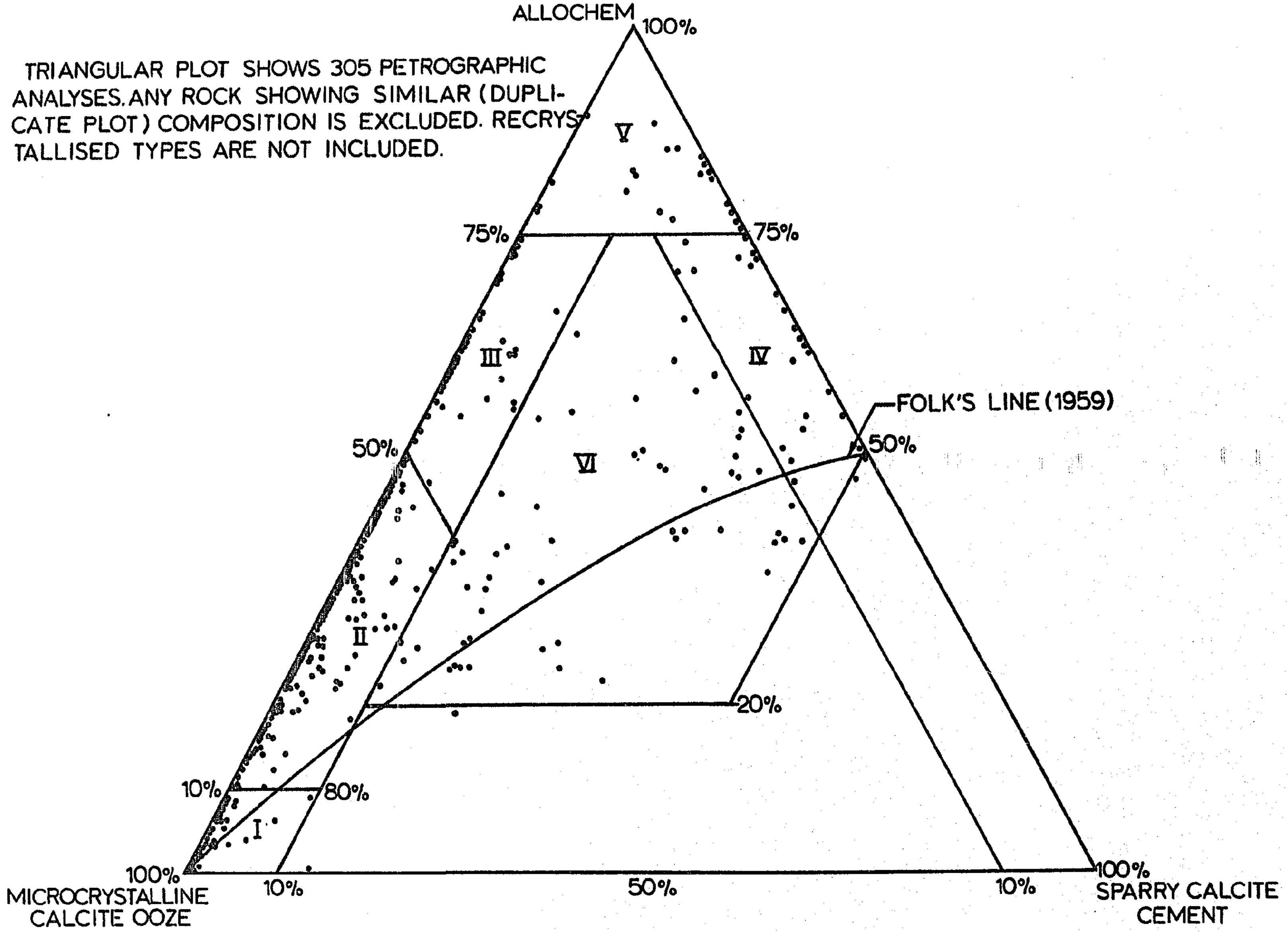
Newell et al. (1960) and Purdy (1963b) described similar composite structures from the Bahama areas. Decomposition of organic matter causes recrystallisation and results in the development of unoriented microcrystalline calcite material along contacts of öolitic grains to form a composite structure. Presence of black opaque patches in öoliths and development of an oily black film during acid digestion of öolitic rocks support the idea of the importance of organisms in the formation of composite grains. According to Newell et al. (1960) öolitic composite grains occur in shallow water between and behind the cays at the outer edge of the Bahama platform. Typical pellet grapestone development is seen along the inner bankward edge of marginal areas.

Purdy (1963b, p. 480) considered localized precipitation of calcium carbonate between component grains of composite or grapestone grains to be due to an intergrain chemical environment. This type of intergrain chemical environment is more favourable to precipitation between intergrain areas than on the surface. The presence of organic matter is an important factor in inducing deposition of calcium carbonate. Decomposition of organic matter by amnonifying and nitrate reducing bacteria causes reaction with calcium bicarbonate in immediately surrounding areas and forms calcium carbonate. In areas where current action is slight, organic detritus settles out of water and accumulate between the grains on the sea floor. Occasional stronger currents or waves prevent unlimited growth of composite grains. Short periods of bottom agitation followed by long period of bottom stability and cement precipitation favour the development of composite grains. In areas of greater and longer stability, organic detritus accumulates as a film covering the depositional interface and deposition of calcium carbonate takes place on both surface and intergrain areas resulting in diminishing original grain outline and grapestone structures.

Protointraclasts:-

Recently Bosellini (1966) used the term "protointraclast" to describe some characteristic nodular micritic carbonate layers within intercalated argillaceous silty layers and micritic limestones sequence (Plate 45, fig. 3). Micritic argillaceous films are observed to surround and isolate purer micritic carbonate areas. Bosellini (1966) defined such micritic carbonate areas as an embryonic stage of intraclast formation. The shape of micritic carbonate areas can be extremely varied e.g. lensoid, spherical, or irregular. The size ranges from [illegible] 3 mm to [illegible] 30 mm or more. Some of the clasts may show recrystallisation effects. The outer margin of clasts may be weakly defined and grade into argillaceous carbonate rich matrix.

Due to intermittent wave action reaching the base level of submarine erosion, the micritic carbonate layers are partially broken and remained trapped in the more plastic, water-rich argillaceous material of the matrix. This type of structure probably occurs in intertidal areas. Protointraclast features are commonly associated with micritic carbonate rock of upper Black River units (III and IV.



TRIANGULAR PLOT SHOWS 305 PETROGRAPHIC ANALYSES. ANY ROCK SHOWING SIMILAR (DUPLICATE PLOT) COMPOSITION IS EXCLUDED. RECRYSTALLISED TYPES ARE NOT INCLUDED.

Fig.6. CLASSIFICATION of BLACK RIVER LIMESTONE

CHAPTER 6

PETROGRAPHIC CLASSIFICATION

The Black River limestones are made up of three principal end members - (1) discrete carbonate aggregates or "allochems", (2) microcrystalline calcite ooze, (3) normal, chemically precipitated pore filling sparry calcite cement. They show little admixture of terrigenous sand, silt or clayey materials. A broad classification of the limestones following Folk (1959, 1962) can be made chiefly on the basis of relative distribution of the three essential end member constituents. A ternary compositional diagram (Fig. 6) is made on the assumption that the sparry calcite cement and microcrystalline calcite ooze represent true interallochemical material. Rocks showing any effect of aggrading or degrading recrystallisation (neomorphism) are excluded from the present classification.

The entire sequence of Black River limestones in southwestern Ontario can be classified into six major rock groups (Fig. 6). The compositional characteristics of each major group are as follows:

Group I: Microcrystalline calcite ooze may constitute 80% to 100% of the total volume in a rock. The upper limits of allochemical material and sparry calcite cement are taken at the 10% level (Folk 1959, 1962; Wolf 1960; Leighton and Pendexter 1962; Dunham 1962; and Powers 1962). Rocks lying within this compositional range are termed micrite.

Group II: The upper limit of sparry calcite cement is taken at the 10% level. The allochems content may range between 10% and 50%. Microcrystalline calcite ooze constitutes 50% to 90% of the total volume, in a rock (Wolf 1960; Leighton and Pendexter 1962; Todd 1966).

Any composition within the limits of group II, can be described by a composite rock name. The first part of the name refers to the allochemical constituent and the second part represents the main rock name "micrite". Following Folk (1959), an abbreviated prefix of allochem name is also adopted e.g. "intra-" for intraclast, "oo-" for oölite, "pel-" for pellet and "bio-" for bioclast or skeleton debris. In a mixed allochemical rock additional prefixes describing various allochems precede the main rock name. The element of lowest frequency is placed first and succeeded by increasingly more abundant allochems, e.g. a rock with 20% pellets, 15% intraclasts, and 65% microcrystalline calcite is called "Intrapelmicrite".

Group III: Allochems constitute 50% to 75% of the total volume, in a rock. Microcrystalline calcite ooze range between 10% to 50% of these rocks. The upper limit of sparry calcite cement content is taken at 10%.

The main rock name "micrite" is still followed with a prefix of full allochemical name. The term "rich" is added immediately preceding the name micrite in order to indicate abundance of allochem over microcrystalline calcite ooze, e.g. a rock with 65% intraclast, 10% pellets, and 25% microcrystalline calcite is termed "Pelletintraclast rich micrite". Alternatively the main rock name can also be given after the name of most abundant allochemical constituent by adding a suffix "ite". The first part of the rock name carries the term "micritic" and indicates the presence of matrix. Thus the same rock as was described above may be termed "micritic pelintraclastite".

Group IV: The maximum limit of microcrystalline calcite ooze content is selected at the 10% level. Allochemical constituents may range between 50% and 75%. The lower limit of sparry calcite content is arbitrarily taken at 10% while the upper limit is marked at 50%.

The main rock name is shown by the term "sparite". As described earlier (Group II) the abbreviated form of the allochem names (or name) precedes the main rock name.

Group V: The rocks belonging to this group constitute a minor portion of the Black River limestones. Microcrystalline calcite ooze and sparry calcite cement limits are both taken at 25%. Allochems constituting the rock may range from 75% to 100%. However, rocks with allochems contents exceeding 90%, were not encountered.

The rocks are named by adding suffix "ite" at the end of chief allochem constituent e.g. a rock with 85% skeletal material and 15% sparry calcite is termed "Bioclastite."

Group VI: The rocks belonging to this group are termed "mixed" or "intermediate" type. The rocks are characterized by wide variation in the relative abundance of all three end members. Allochems may range from 20% to 75%. Sparry calcite cement shows the lower and upper limits at 10% and 50% respectively. Microcrystalline calcite ooze content varies between 10% to 70%.

A rock can be described by a composite name consisting of three parts. The last part represents the main rock name e.g. micrite or sparite depending on whether a rock is rich in cement or micritic

TABLE. 3. CLASSIFICATION and TERMINOLOGY of BLACK RIVER LIMESTONES

MODIFIED AFTER FOLK (1959) and TODD (1966)			NORMAL CARBONATE ROCKS								RECRYSTALLIZED ROCKS
			PERCENTAGE DISTRIBUTION of ALLOCHEM								
			>75%	<75%->10%			<75% >50%	<50% >10%	<10%		
			SPAR ANDOR MICRO <25%	SPAR >10%<50%		SPAR >10% MICRO >30% <70%	SPAR<10%				
				MICRO <10%	MICRO >10%		MICRO 10%-50%	MICRO 50%-90%	MICRO 80%-100%	GRAIN SIZE of AUTHIGENIC CONSTITUENTS	
GRAIN SIZE of ALLOCHEMS	CALCIRUDITE	>1mm	BIOCLASTITE	INTRASPARITE		MIXED TYPES (SPARRY PELBIOMICRITE, SPARRY BIOINTRAPELMICRITE)	MICRITIC INTRACLASTITE	INTRAMICRITE		VERY COARSELY CRYSTALLINE	RECRYSTALLIZED LIMESTONES (NEOMORPHIC)
	CALCARENITE	1mm——.062mm		PELSPARITE BIOSPARITE OÖSPARITE	MIXED TYPES (MICRITIC PELBIOSPARITE, MICRITIC BIOINTRAPELSPARITE, MICRITIC BIOPELINTRASPARITE)		MICRITIC BIOCLASTITE	OÖMICRITE BIOMICRITE		MEDIUM to COARSELY CRYSTALLINE	
	CALCISILTITE	.062mm——.004mm					MICRITIC PELLETITE	PELMICRITE		VERY FINE to FINELY CRYSTALLINE	
	CALCILULITE	.004mm——.001mm	(GROUP V)	(GROUP IV)	(GROUP IV)		(GROUP III)	(GROUP II)	(GROUP I) MICRITE	APHANO CRYSTALLINE	
			ALLOCHEM RICH.	ALLOCHEM and SPAR RICH	MIXED ROCKS		ALLO CHEM + MICROCRYSTALLINE CALCITE RICH.	MICROCRYSTALLINE CALCITE RICH.			

SPAR= SPARRY CALCITE CEMENT
MICRO= MICROCRYSTALLINE CALCITE OOZE

Explanation of Plate 46

Figure 1 Micrite showing isolated scattered dolomite euhedra (white rhomb in the centre) in a dark aphanocrystalline (0.004 mm) calcite ground mass. (Unit II, Montreal Street section). X 55.

Figure 2 Micrite with microstylolites and lenses of clear calcite (Unit II, Havelock quarry). Note concentration of dark carbonaceous clayey material along microstylolites. X 22.

PLATE 46.

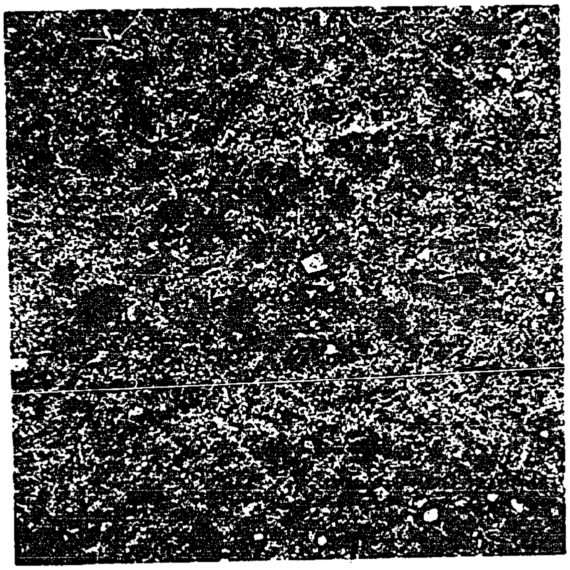


FIG.1

FIG.2

PLATE 47.

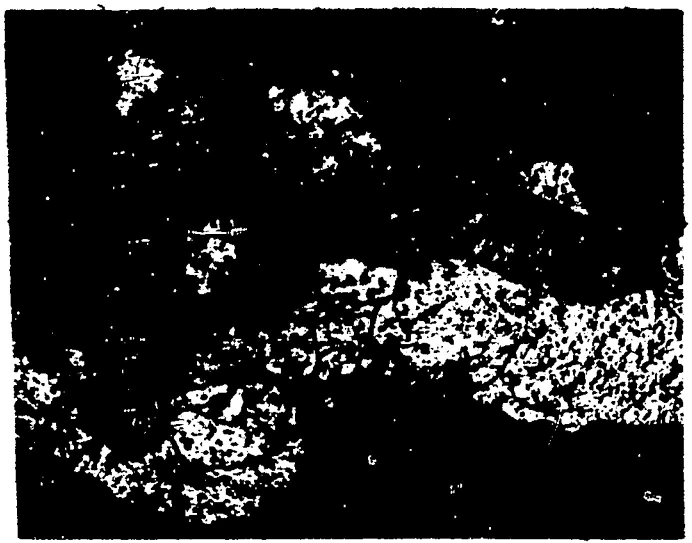


FIG.1

FIG.2

Explanation of Plate 47

Figure 1 Coarse clear calcite filled burrows in micrite (Unit II, Burleigh Falls road section). Note concentration of dark opaque carbonaceous clayey material along the external margin of burrow. X 55.

Figure 2 Fragments of pelmatozoan (c), brachiopod, (B) and ostracod (0) showing irregular distribution of size in a dark grey micritic ground mass (Unit II, Uhthoff quarry). X 22.

matrix respectively. The middle part uses abbreviated form of allochem names. Terms "sparry" or "micritic" are used in the first part to indicate if this rock is low in cement or matrix content. Thus rock with 30% microcrystalline calcite ooze, 15% sparry calcite, 40% intraclasts and 15% shells can be described as "sparry biointramicrite".

A tabular classification showing the distribution of various petrographic types in the Black River rocks is shown in table 3.

Eleven distinct petrographic types have been recognized in the Black River limestones. All these rocks together constitute six major groups of the ternary classification diagram (Fig. 7).

1. Micrite. The rocks represent the chief constituent of Group I carbonate rocks. The rocks are aphanocrystalline in nature with little (10%) or no allochemical constituents (Plate 46, fig. 1). The rocks show frequent association of microstylolites (Plate 47, fig. 2) and burrow structures (Plate 47, fig. 1). In most cases, concentration of dark, carbonaceous clayey material and very fine quartz silt can be seen along microstylolitic contacts (Plate 46, fig. 2) or burrows (Plate 47, fig. 1). Coarse clear calcite occurs in burrows and other irregular lense-like cavities (Plate 46, fig. 2; Plate 47, fig. 1). The rocks are thick bedded, blocky in character, and show straight or gently curved upper and lower contacts. Micrites break with highly conchoidal smooth fractures and are frequently associated with various types of desiccation structures; they show a high content of dolomite, celestite and anhydrite crystals. Skeletal materials are rare in micritic rocks. Occasional broken skeletal fragment or ostracod valves can be seen in some sections. Compositionally the rocks

are pure calcium carbonate, however occasional dolomite-rich types are not uncommon. Extremely dolomite-rich micrites can be described as dolomicrite.

2. Biomicrite. Biomicrites constitute a major portion of Group II limestones. Skeletal materials constitute 10% to 40% of the total volume of the rock. Commonly the shells include fragments of pelmatozoans, brachiopods, ostracods, trilobites and plates. Size of skeletal fragments may range from 0.01 m to 0.5 mm or more (Plate 47, fig. 2). The fragments are irregularly scattered in a dark aphanocrystalline carbonate ground mass. Laminated, filamentous, and crust-forming algae are common in biomicrites (Plate 39, fig. 3; Plate 48, fig. 1). The rocks show effects of intense burrowing. In some cases concentrations of dolomite occur in the burrows. Commonly, biomicrites are thick bedded, blocky in character, and can be traced laterally throughout individual outcrop sections. The rocks show varying amounts of argillaceous intercalation as thin bands or irregular lenses.

3. Pelmicrite. Pelmicrite forms the second important carbonate lithology of group II rocks. Pellets constitute 20% to 40% of the rock and range in size from 0.06 mm to 0.2 mm . Concentrations of pellets occur as irregular lenses or uniformly distributed widely scattered grains within aphanocrystalline, dark, micritic matrix. Commonly, the micritic matrix is recrystallized into clear, coarse calcite grains varying in size from 0.006 mm to 0.02 mm. or more. Pellets also show varying

Explanation of Plate 48

Figure 1 Dark micrite grading upward into grey biomicrite. (Unit III, Coboconk quarry). Note growth of crust forming ring-like, or irregular algal structure in upper biomicrite. X 22.

Figure 2 Recrystallised peloomicrite. (Unit III, Roblindale quarry). Note various stages of obliteration of allochem structures by recrystallisation. X 22.

PLATE 48.

FIG. I

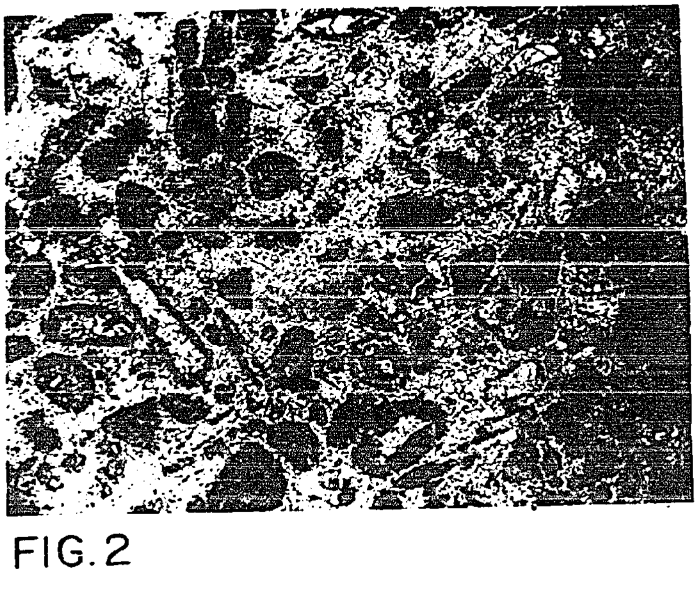


FIG. 2

degrees of recrystallisation. Two distinct types of pellets occur in the Black River rocks: (1) light grey, uniformly sized, (2) black, carbonaceous, pellets of irregular shape and size (Plate 26, fig. 2). Pellet-rich micrites occur as persistent, thick to thin bedded units, and show frequent alternate intercalation with very thin shale. Occasional symmetrical ripples are noted in pelmicrites.

4. Intramicrite. Intramicrites are common in group II carbonate rocks. The rocks are easily recognized in the field by the presence of flat, rounded, poorly sorted, coarse (0.06 mm to .4 mm), light coloured intraclasts in dark coloured micritic matrix (Plate 42, fig. 3). Intraclasts constitute 30% to 40% of the rock, while micrite forms the remainder. The rocks are thin bedded, and occur as persistent bands or lenses. Commonly these rocks are associated with mud cracks and other desiccation structures. Absence of pellets or skeletal material is a rule rather than an exception. In some cases the micritic matrix exhibits irregular development of dolomite. Intraclasts also show evidence of minor deformation and weak imbrication.

5. Oömicrite. Oömicrites are rare in group II carbonate rocks. Oölites are perfectly spherical to irregular in shape and have black, thick carbonaceous envelopes. Oölites constitute 20% to 50% of the rock and are closely packed (Plate 31, fig. 1) or widely scattered (Plate 31, fig. 3) in a dark micritic matrix. Oölites also show a variable thickness of the outer envelopes. The presence of a lace-like network of algal mat (Plate 31, fig. 3) in the matrix and algal borings in the outer envelopes suggest an organic origin for some oölites. Oölites

are invariably affected by recrystallisation. The recrystallisation process usually starts within the oölites and gradually spreads into the micritic matrix. Rare occurrence of isolated widely scattered normal spherical oölites, in micritic matrix has also been noted in some thin sections. It is thought that such rare isolated oölites represent derivation of allochems from an adjacent higher energy environment, to a low energy environment. Oömicrites occur as thin bedded, irregular lense-like units in the Black River rocks.

Some group II rocks contain two or more different types of allochems (Plate 31, fig. 3).

The group III carbonate rocks are similar to the various rock types of group II. The only differencesare in the distribution of allochems in group III carbonate rocks. Allochems constitute 50% to 75% of the rock, while micritic matrix forms 20-40%. These rocks frequently contain two or more types of allochems. The most common petrographic types are as follows: (1) Pellet-rich micrite or micritic pelletite, (2) Intraclast-rich micrite or micritic intraclastite, (3) Bioclast-rich micrite or micritic bioclastite. Commonly micritic bioclastite contains abundant delicately branching algae, bryozoa, and isolated corals.

6. <u>Biosparite</u>. Biosparites form a minor portion of group IV carbonate types. Skeletal materials constitute 50-75% of the total volume of the rock, while sparry calcite cement forms the remaining 25-50%. Commonly, shells are fragmented, and range in size from 0.01 mm to 1 mm or more. Corals, pelmatozoans,(crinoids) brachiopods, ostracods and plates constitute the chief skeletal material.

Explanation of Plate 49

Figure 1 Oösparite grading upward into a biosparite. (Unit III, Roblindale quarry). Note recrystallization of shells and development of micritic envelope along the outer margin. X 22.

Figure 2 Pelsparite. (Unit IV, Marmora quarry). Note uniform size and shape of pellets in a clear crystalline, white sparry calcite cement. X 55.

PLATE 49.

FIG. I

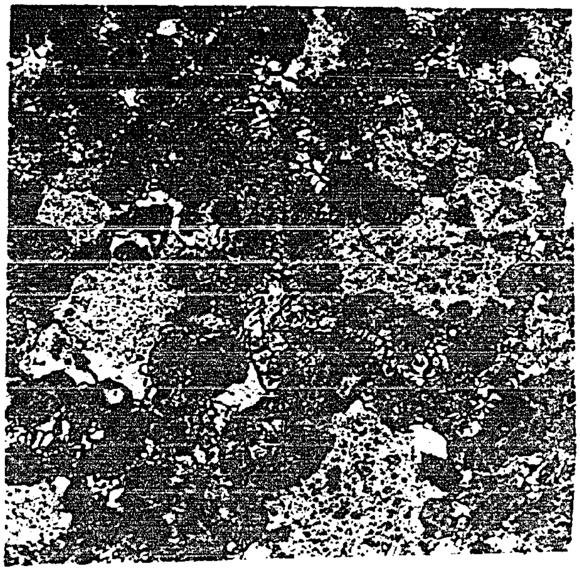


FIG. 2

Most of the shell fragments show recrystallisation (Plate 49, fig. 1), or filling of internal cavities by clear coarse calcite. Dark micritic envelopes are present on some coral and brachiopod shells (Plate 49, fig. 1). These micritic envelopes indicate algal boring (Bathurst 1966). Fragments of ostracods and plates do not show any evidence of textural change as the result of recrystallisation or algal boring. The shell fragments are cemented by an irregular interlocking mosaic of clear calcite crystals ranging from 0.008 mm to 0.4 mm in size. Biosparites show a common association with oölite and pellet-rich rocks. The rocks are thick to thin bedded, and usually show a sharp contact with under and overlying rocks. Cylindrical massive bryozoa, and algae, are very characteristic of most biosparites.

7. **Pelsparite.** Pelsparites constitute a major part of group IV carbonate rocks. Pellets form 40 to 60% of the rock, while clear crystalline sparry calcite cement makes up the remainder. Pellets range from 0.03 mm to 0.15 mm in size, and are embedded in a clear crystalline mosaic of calcite crystals (0.02 mm, to 0.1 mm., (Plate 49, fig. 2). The pellet-rich rock shows a common association with intraclast-rich limestones. The intraclasts lack any perceptible internal structures, e.g. laminations etc. and like pellets, they are composed of microcrystalline calcite. Pellet-bearing rocks commonly contain composite grains. The most common skeletal fragments are pelmatozoan. Development of secondary calcite rims in optical continuity with the original pelmatozoan fragments are not uncommon (Plate 50, fig. 1). Occasionally the micrite of pellets

Explanation of Plate 50

Figure 1 Biopelsparite (Unit IV, Point Ann quarry). Pelmatozoan fragments show development of clear calcite rims. Some pellets show evidence of recrystallization. Recrystallized calcite aggregates also maintain the original outline of the allochems (marked X). X 55.

Figure 2 Intrasparite with elliptical intraclasts in clear mosaic of calcite grains (Unit III, Port McNicol quarry). Note development of fine calcite crusts around intraclasts. The crusts show a gradual transition to coarser equant calcite mosaics of pore filling cement. X 55.

PLATE 50.

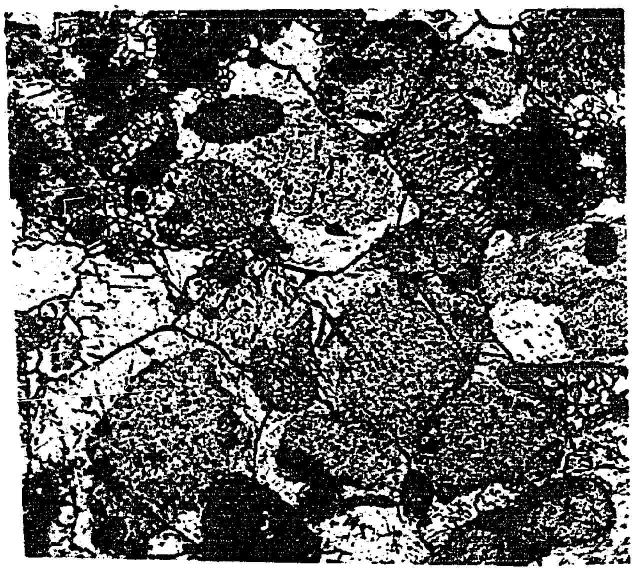


FIG.1

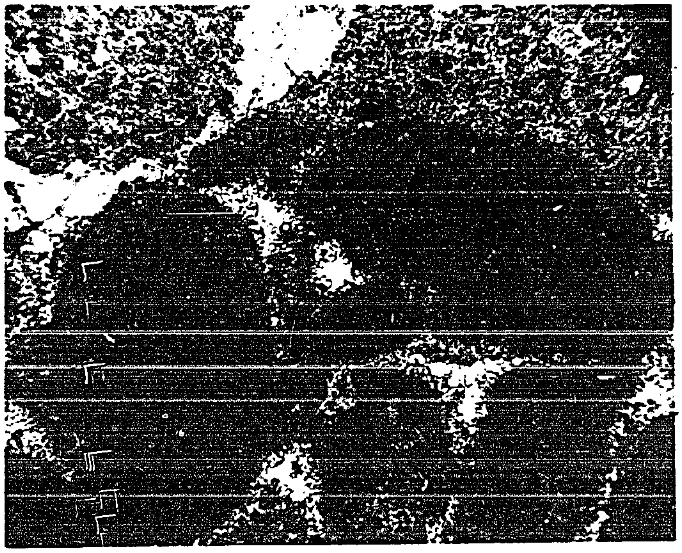


FIG.2

appears to have undergone recrystallisation. In extremely recrystallised rock, a granular mosaic of clear calcite, replaces the original micritic material of pellets. However in most cases the pellets can be recognised because coarse, recrystallised calcite grains show the outline of the original allochem (Plate 50, fig. 1). Ripple marks, and crust-forming algae, are common associates in pelsparites. Locally pelsparites show development of hemispherical stromatolites. The rock occurs as uniformly thick, thick to thin bedded units and shows frequent lateral transition to other rocks of different lithology.

8. Intrasparites. These rocks comprise a minor part of the group IV limestones. Rounded, elliptical, elongate, intraclasts ranging from 0.3 mm to 5 mm or more are cemented in a clear coarse interlocking mosaic of calcite (0.01 mm to 0.3 mm). Commonly intraclasts form 40% to 60% of the rock while sparry cement constitutes the rest. The intraclastic grains are made of microcrystalline calcite ooze. Unlike intraclasts of group II these completely lack internal sedimentary structures. Intrasparites show a gradual transition to pelsparites. Intraclasts do not show any evidence of obvious recrystallisation. Common skeletal fragments include massive cylindrical bryozoa, algae and pelmatozoans (crinoid). Micritic intraclasts show development of finely bladed calcite crusts (Folk 1965) around the outer margin. The fine crust grades into a coarser mosaic of equant calcite (Plate 50, fig. 2). Allochems in intrasparite, show a great uniformity of size.

9. Oösparites. The rocks form a major part of group IV carbonate

Explanation of Plate 51

Figure 1 Oösparites with allochems of uniform size and shape in clear sparry calcite cement (Unit III, Hwy. 401 section, 5 miles east of Napanee). X 55.

Figure 2 Coarse bioclastite with clear sparry calcite cement (Unit III, Hwy. 401 section, 5 miles east of Napanee). Skeletal fragments (corals) show recrystallization of internal material. Dark, thin micritic algal envelopes mark the outline of organic shells. Also note around the external margin a fibrous overgrowth of calcite which grades into a coarse equant mosaic of pore-filling calcite cement. X 55.

Figure 3 Coarse bioclastite with dark micritic matrix (Unit III, Roblindale quarry). Crinoids show algal micritic envelopes. Note presence of some partly recrystallized pellets. X 55.

PLATE 51.

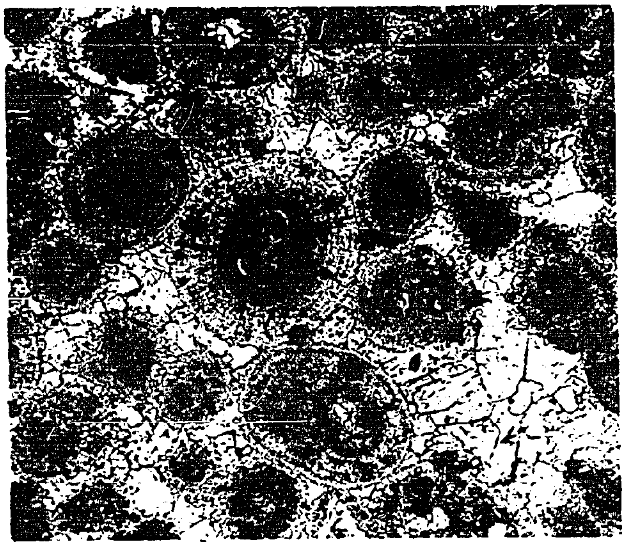


FIG.1

FIG.2

FIG.3

petrographic type, oölites form 40% to 65% of the total rock. Oösparites are typically thick bedded, coarse, and dark grey in colour. The rocks occur as irregular thick, lenticular units, showing frequent cross-bedding. Composite oölitic grains and crust forming algae are also present. Oölitic grains range from [illegible] inch (0.2 mm to [illegible] 0.7 mm in size and are cemented in a clear crystalline mosaic of calcite. Oölites show development of finely bladed crusts (Folk 1965) around their external margins. The crusts grade into fine to medium crystalline equant mosaic of pore filling calcite. Pellets, broken coral and brachiopod fragments are common in oösparites. The rocks are marked by uniformity in size and shape of allochems (Plate 51, fig. 1). Oölites show both radial and concentric structures. Most oölites contain a pellet-rich nucleus. In some cases allochems in oösparite show the effect of pronounced recrystallisation.

10. <u>Allochemical types:- (Bioclastite)</u>. These rocks are a minor portion of the group V carbonate lithology. Only skeletal fragment rich rocks are observed in the Black River sequence. Allochems (skeletal material) range from [illegible] 0.3 mm to [illegible] (1 mm) or more in size and constitute more than 80% of the total volume of the rock. Sparry calcite cement and micritic matrix do not exceed more than 35%. Sparry calcite cemented bioclastites show a uniform distribution of allochem size in the rocks. Bioclastites, with micritic matrix, exhibit irregular distribution of size in allochems. Sparry calcite cemented bioclastites contain chiefly corals, brachiopods, massive bryozoa, algae, and trilobite fragments and plates. In most cases coral and brachiopod

Explanation of Plate 52

Figure 1 Micritic pelbiosparite showing rounded, spherical light grey pellets and pelmatozoan fragments (marked X) in clear sparry calcite cement. (Unit IV, Point Ann quarry). Isolated irregular dark black patches represent micritic matrix. Pelmatozoans in sparry cement rich areas show secondary overgrowth. X 55.

Figure 2 Recrystallised micrite (Unit III, Uhthoff quarry). Fine anhedral mosaic of clear calcite spars replacing the original aphanocrystalline micrite. Patches of coarse porphyrotopic calcite crystals are also present (marked X). Recrystallised sparry calcite cuts across the microstylolite and obliterates original microstructure. X 55.

Figure 3 Recrystallised biomicrite showing a partial to complete obliteration of stromatolite structure (Unit IV Bobcaygeon road section). Note the presence of original dark micrite and organic material as inclusions in some clear spars. X 55.

PLATE 52.

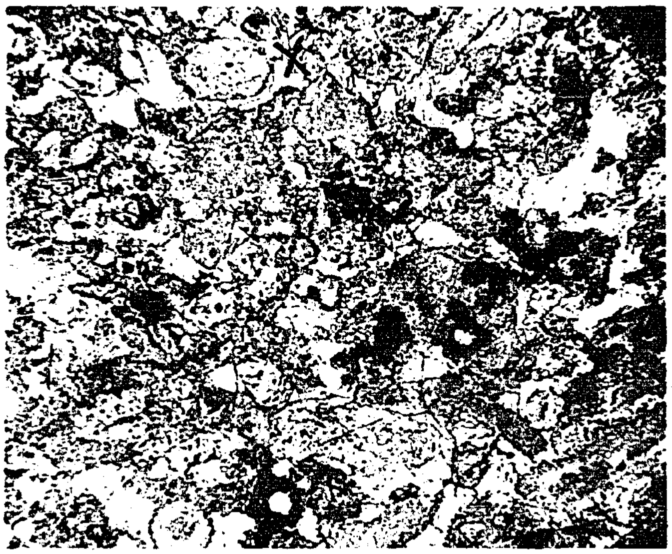


FIG. 1

FIG. 2

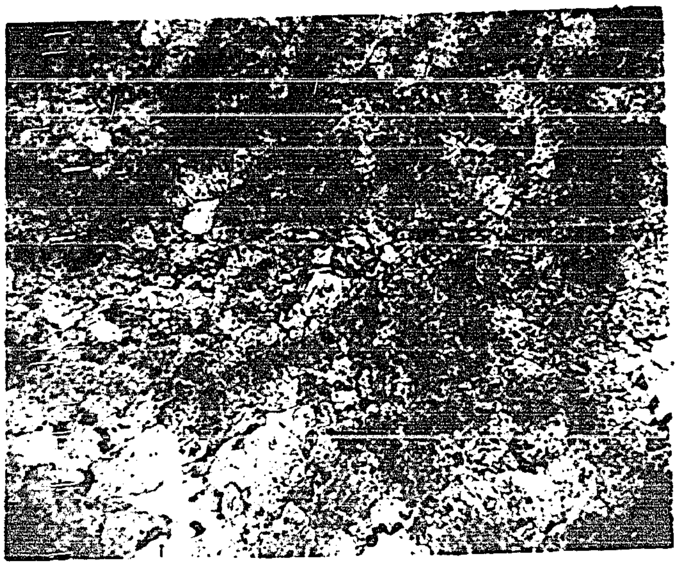


FIG. 3

shells are recrystallised. Infilling of shell cavities by coarse, clear calcite is common. Dark algal micrite envelopes (Bathurst 1966) surround the outer margins of most shell fragments. Fine (0.016 mm) to medium (0.021 mm) fibrous overgrowths of calcite (Folk 1965) are developed around the outer margin of allochems, (Plate 51, fig. 1). Ostracods and pelmatozoan debris form the chief allochems of micritic bioclastites. Commonly, the allochems do not exhibit regularity of size and shape. Micrite envelopes occur around some pelmatozoan fragments. Allochems lack recrystallisation. The rocks may contain minor amounts of pellets. Often, pellets are recrystallised (Plate 51, fig. 3). Sparry bioclastites are thick to thin bedded, lenticular in nature and grade laterally into oösparites or pelsparites. Micritic bioclastites are also irregularly bedded, lenticular in nature and show lateral transition to pelmicrites.

11. <u>Mixed types</u>. Rocks of mixed lithology include the following important types: (1) Sparry pelbiomicrite, (2) Micritic pelbiosparite, (3) Sparry biointrapelmicrite, (4) Micritic biointrapelsparite, and (5) Micritic biopelintrasparite etc. The rocks of mixed lithology constitute group VI carbonate petrographic types. Allochems include intraclasts, pellets, and skeletal materials and range in size from 0.01 mm to 2 mm. Allochems constitute 20% to 75% of the total volume of rocks. Both micritic matrix and sparry calcite cement form the chief binding material of allochems. Sparry calcite cement ranges from 12% to 50% in amount while micritic matrix may constitute 10% to 65% of the rock (Plate 34, fig. 1 and Plate 52, fig. 1).

In some cases allochems and micritic matrix show recrystallisation and the distinction between true sparry calcite cement and recrystallised spar becomes less obvious. The rocks of mixed type occur as thick to thin bedded lenticular units.

12. Recrystallised types. The rocks include various petrographic types as described in the present section. Recrystallisation causes partial or complete obliteration of original sedimentary textures (Plate 52, fig. 2) and therefore statements regarding the genesis of the original sediment cannot be made. In order to achieve a simplified workable classification of the present carbonate rocks, recrystallised petrographic types are excluded. Recrystallised rocks are characterised by the following features:

(1) Extremely irregular development of fine (0.02 mm) to very coarse (2 mm) sparry calcite (Plate 61, fig. 1).

(2) Partial to complete obliteration of original texture of rocks (Plate 52, fig. 3).

(3) Common presence of inclusions of original sediment in coarse crystalline calcite.

CHAPTER 7

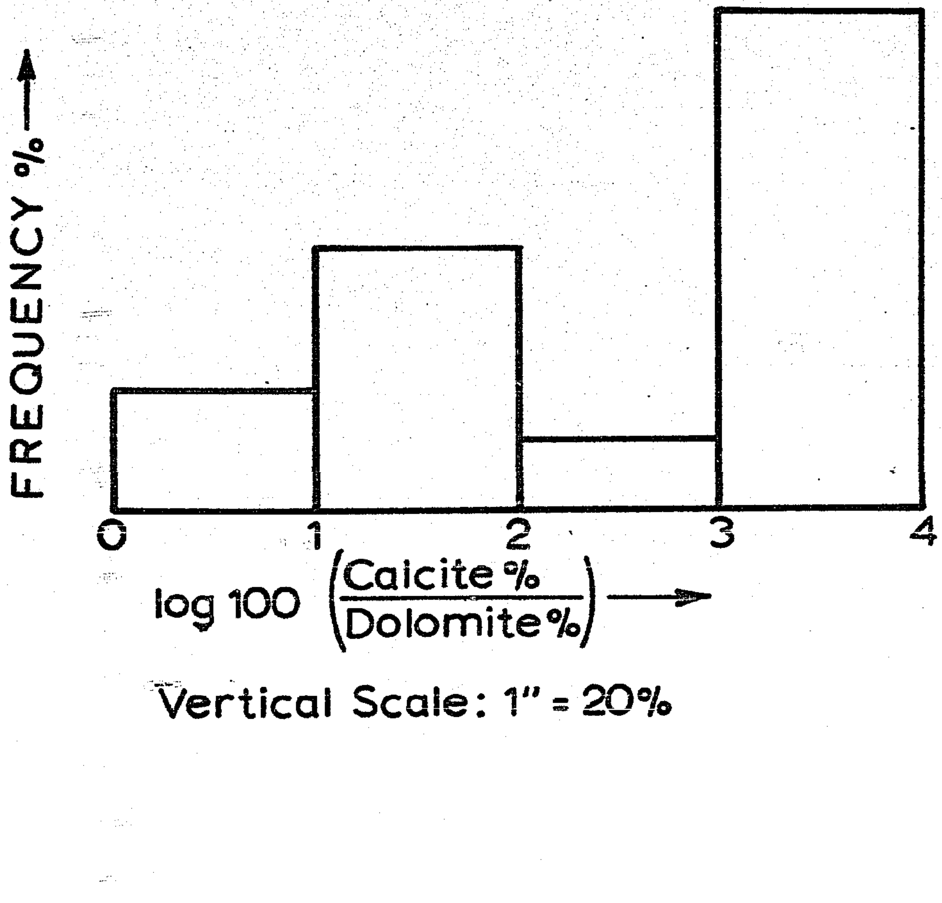
CHEMICAL COMPOSITION

Chemically, the Black River limestones constitute a rather simple group of carbonate rocks with very high (>80%) content of calcite and, or dolomite. In rare cases, minor amounts of ankeritic dolomite has been detected. The original non-carbonate minerals are sulphates including celestite, anhydrite and gypsum. The silicate minerals are clay minerals, quartz, and feldspar and various heavy minerals. Appreciable amounts of iron oxides and sulphides minerals are present. The amount of non-carbonate material is generally extremely low (Beales 1958) and rarely exceeds more than 5% to 10% by weight. Regionally, the composition of carbonate rocks shows minor variation, but the total bulk composition of the carbonate minerals is more or less constant (Hewitt 1960). A chemical classification based on the relative distributions of the two principal carbonate phases is presented. Such a classification has the advantage of easy utility, both in the field and laboratory.

Three different methods were used in the present investigation:

1. Acid Test: A rough percentage determination of calcite and dolomite content was made in the field by noting the reaction rate of dilute HCl (2 drops of 10%) on a fresh rock surface.
2. Stain Test: Approximate percentage of calcite and dolomite in

Fig. 7. CHEMICAL COMPOSITION of 565 BLACK RIVER LIMESTONE



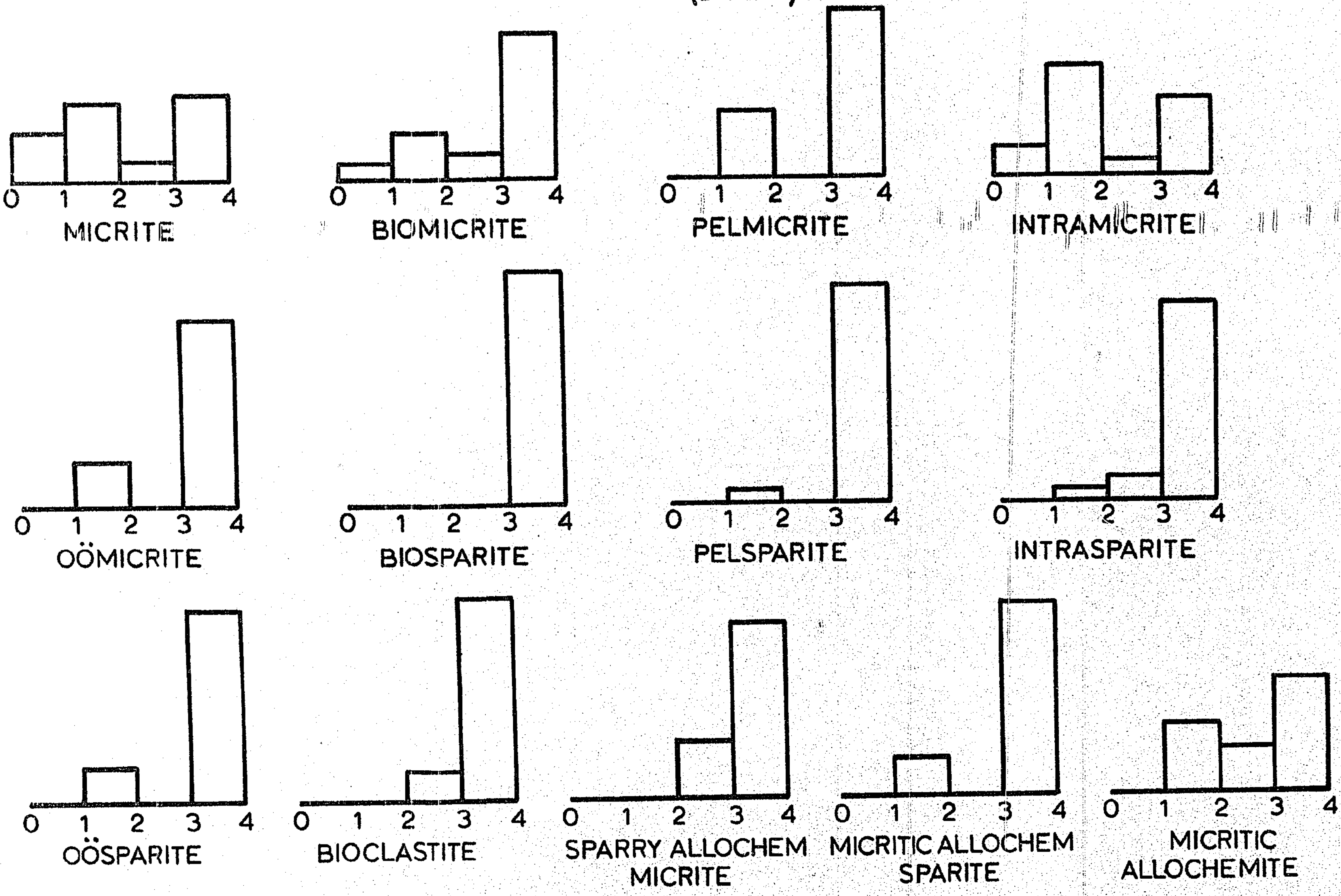
Vertical Scale: 1" = 20%

each sample was determined by using stained hand specimens following Katz and Friedman's method (1964). In some cases stained thin and plastic peel sections were also used (details in appendix).

3. X-ray diffraction method: Relative proportions of the two chief carbonate phases in each sample were determined by using the X-ray diffractometer (Tennant and Berger 1957, Gulbrandsen 1960). About 800 samples were analyzed. Only ratios of integrated peak areas could be obtained and no direct attempt was made to relate peak area to weight-percent for each carbonate mineral is made (details in appendix). However, a semi-quantitative estimate of weight percent of calcite and dolomite was made from the combined results of all three methods. Results of X-ray and staining analyses showed a fair degree of correlation within ± 5% error limits. On the basis of carbonate composition, the Black River rocks can be classed into four distinct types showing the following calcite/dolomite ratios: 1, 2, 3, and 4, (Figure 7). Weight percentages of calcite and dolomite corresponding to each of the above four calcite/dolomite ratio groupings are given in the table below.

	Methods			
X-Ray	Stain Test		Acid Test	Classification of Limestones Pettijohn 1957
Peak intensity $\frac{\text{Calcite}}{\text{Dolomite}}$	Dolomite % ± 5%	Calcite % ± 5%		
1	90%	10%	very slow or none	Dolostone (Shrock 1948)
2	50%	50%	slow	Calcitic dolostone
3	20%	80%	immediate	Dolomitic limestone
4	0% - 10%	10% - 90%	immediate, vigorous	Limestone

FIG.8. DISTRIBUTION of CALC/DOL. RATIOS in VARIOUS PETROGRAPHIC TYPES. VERTICAL SCALE 1" to 50%, SHOWS FREQUENCY DISTRIBUTION of CALC/DOL RATIOS. HORIZONTAL AXIS REPRESENTS $\log 100 \left(\frac{\text{CAL\%}}{\text{DOL\%}}\right)$.



Ancient Study	Recent Study				
Black River of SW.Ontario (PRESENT STUDY)	Bahamas SHINN, GINSBURG and LLOYD 1965	Florida GINSBURG 1957, BERNER 1966	Bonaire, Netherland Antilles DEFFEYS, LUCIA and WEYL 1965	Persian Gulf ILLING, WELLS and TAYLOR 1965	S.Australia SKINNER 1963
1 SEDIMENT: MICRITE PELMICRITE, BIOMICRITE, INTRAMICRITE		1. CARBONATE MUD. (BERNER, 1966, P.3),	1. PELLETED MUD, SILT, ALGAL MAT. (P. 74)		
2. COLOUR: ALTERNATE BROWN to TAN and LIGHT MEDIUM GRAY (PLATE.53, FIG. 1.).				2. DARK BROWN to TAN at the SURFACE GRADING to LIGHT MEDIUM GRAY (P.97).	
3. STRUCTURE: ALTERNATE WHITE and GRAY LAMINATIONS 1mm to 2cm THICK.			3. FINELY LAMINATED NATURE of DOLOMITE CRUST 2 cm to 3cm. THICK		
4. ALLOCHEM: VARYING AMOUNTS of CRINOID, PELLET, OSTRACOD, TRILOBITE, BRACHIOPOD, and INTRACLAST (FLAT, ELONGATED).	4. PELLETS, DOLOMITE CRUSTS (P. 117).		4. SHELLS of MOLLUSK ALGAE (P. 74).		4. VARYING AMOUNTS of SHELLS, and PLANT DEBRIS (P452)
5. BEDDING PLANE STRUCTURE: MUD CRACKS and POLYGONS, HIGHLY CARBONACEOUS LAMINATED NET LIKE NATURE of MICRITE and BURROWS.	5. COMMON ASSOCIATION of MUD CRACKED POLYGONS and ALGAL LAMINATIONS and BURROWS (P 117)				
6 INTERNAL CHARACTER: COMMON ASSOCIATION of COARSE CALCITE FILLED SHELL and OTHER CAVITIES.	6. INFILLING of VUGS by PORE FILLING CEMENT.			6. LEACHING of SKELETAL MATERIAL CAUSING VUGS (P 101).	
7. COMPOSITION: DOLOMITE >50%.	7. DOLOMITE 20% to 80% (P.117).		7. DOLOMITE 80% to 95% (P. 74).		
8. NON CARBONATE VARYING AMOUNTS of MINOR QUARTZ, CLAY, CELESTITE, ANHYDRITE and GYPSUM.			8. GYPSUM, CLAY (P.87).	8. CELESTITE, GYPSUM ANHYDRITE, QUARTZ (P.95 to 99).	8 VARYING AMOUNTS of QUARTZ, CLAY, HALITE, CELESTITE (P.452).
9. SELECTIVE GROWTH of DOLOMITE and ALGAE ALONG MUD CRACKS BORINGS and GRADUAL SPREADING to SURROUNDING MATRIX		9. SELECTIVE GROWTH of ALGAE and DOLOMITE ALONG MUD-CRACKS and BORINGS (P.93 and SHINN 1966, P.65).			
10. DOLOMITES with EXCESS of CALCITE in the STRUCTURE (GILLOT 1963).	10. DOLOMITES with EXCESS of CALCITE in the STRUCTURE (P. 118).		10. DOLOMITE with EXCESS of CALCITE in the STRUCTURE (P.74).	10. NORMAL DOLOMITE with NO EXCESS of CALCITE in the STRUCTURE (P. 97).	10. DOLOMITE with EXCESS of CALCITE in the STRUCTURE (P. 449).
11. DOLOMITE GROWING as 1μ to 10μ ISOLATED RHOMBS.	11. DOLOMITE OCCURS as TINY RHOMBS 1μ to 2μ in SIZE. IT DEVELOPS FIRST in the ARAGONITE MATRIX and then SPREADS INTO the FRAME WORK (ALSO ILLING et al. P.99).				

TABLE.4. COMPARISON of BLACK RIVER DOLOMICRITE with SIMILAR SEDIMENTS in RECENT CARBONATE ENVIRONMENTS.

Explanation of Plate 53

Figure 1 Alternate dark tan to grey dolomicrite with finely laminated net like carbonaceous algal material (Unit I, McGinnis and O'Conner quarry). Note presence of minute, clear, calcite filled patches and some clear rhombs in upper clear band. X 22.

PLATE 53.

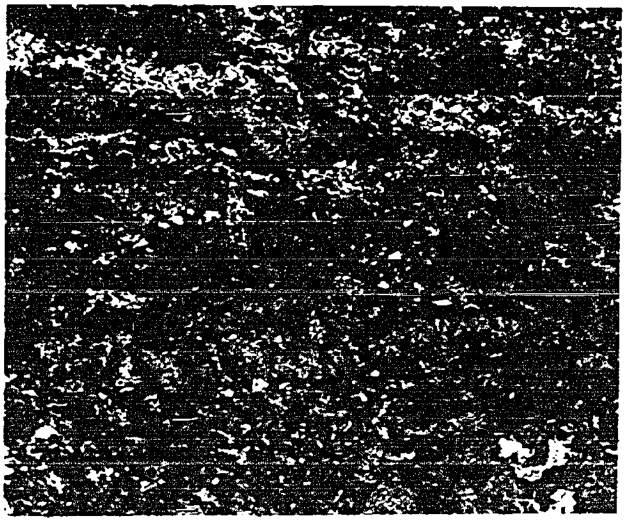


FIG.1

The table shows a comparative chemical grouping based on three methods and classifications of limestones. Shrock's (1948) terminology of dolostone is supplemented in Pettijohn's classification.

The Black River carbonates can be grouped into four chief chemical types: dolostone, calcitic dolostone, dolomitic limestone and limestone (Pettijohn 1944, 1957; Shrock 1948).

In order to investigate the relative chemical composition of various petrographic types, the frequency percentage distributions of four chemical types are plotted against each petrographic member (Fig. 8). Commonly micrites and intramicrites show a higher content of dolomite. Occasional dolomite-rich rocks occur in biomicrites and pelmicrites. Rocks of other petrographic types (sparry calcite-rich) are exceptionally high in calcite content. Both celestite and anhydrite are common in the insoluble residues of dolomite-rich micritic rocks. Thus the distribution of dolomite would seem to be controlled by the microlithology of these carbonate rocks. It is evident that dolomite has a common genesis with the deposition of original micritic carbonate rocks. A detailed account of textural character of the carbonate rocks will be given in a subsequent section on diagenesis. A broad comparative study of Black River dolostones and similar sediments of recent carbonate environments is given in table 4. Studies of recent carbonate environments suggest a penecontemporaneous growth (primary) of dolomite in supratidal, calcium carbonate mud-rich lagoon condition. Normal marine waters entering supratidal lagoon are enriched in magnesium due to evaporation and withdrawal of calcium in the form of gypsum and anhydrite (Deffeyes _et al_., 1965; Shinn _et al_. 1965). These waters dissolve carbonate mud (aragonite) and form dolomite until the calcium magnesium equilibrium is attained. Occurrence of leached shells and pellets indicate dissolution of allochems to provide carbonate ions for the growth of dolomite (Murray 1960; Weyl 1960). The presence of various allochems in dolomite-rich sediments indicates transportation of such materials from adjacent environments, by strong currents, storm waves and/or high tides (Illing *et al*. 1965).

CHAPTER 8

DIAGENESIS

Diagenesis of carbonate rocks embraces a large number of factors and mechanisms that tend to alter the original content of major and minor trace elements, texture, and structure of the individual carbonate particle as well as the whole rock unit (Wolf et al. 1967, p. 99). Diagenetic changes take place at low temperature and pressure and result in partial to complete lithification of unconsolidated sediments into indurated rock (Pettijohn, 1957). The details of various diagenetic processes, textures and mineralogical and structure alteration can be obtained from the recent works of Bathurst (1958, 1964, 1966), Beales 1958, 1965), Folk (1965), Orme and Brown (1963), Shearman et al. (1961), Wolf (1965b, c), Friedman (1964, 1965), Stehli and Hower (1961).

Studies of modern carbonate environments have shown that present day limestones are composed of three principal carbonate phases. Namely, high magnesium calcite, aragonite, and low-magnesium calcite or calcite (Friedman 1964; Stehli and Hower 1961; Skinner 1963; Mathews 1966). Deep sea carbonate sediments contain high-magnesium calcite and low-magnesium calcite with or without minor amounts of aragonite. Under shallow water conditions, aragonite and high-magnesium calcite form the major bulk of the carbonate minerals with minor amounts of low-magnesium calcite (Friedman 1965). The study of stability relations of various shallow water (subaerially exposed) carbonate mineral assemblages shows the following sequence in descending order: low-magnesium calcite, aragonite, and high-magnesium calcite. High-magnesium calcite readily changes to low-magnesium calcite by preferential removal of magnesium involving leaching (recrystallisation, Folk 1965, p. 21) or solution deposition on a microscale, without affecting the original texture of the sediment (Friedman 1964). Aragonite changes to stable low-magnesium calcite by leaching (solution) to form molds which are subsequently filled with calcite (Friedman 1964, Bathurst 1966). The conversion of aragonite to calcite can also be attained by inversion in the solid state without involving an intermediate solution and reprecipitation stage (Folk 1965, p. 21; Friedman 1964, Land 1967).

Various compositional, petrographic and structural evidence support a shallow water origin for the Black River limestones. The present mineralogical assemblages of the Black River rocks do not reflect the original composition of the sediments. However, a careful study of various textural characters may greatly aid in reconstruction of the physicochemical nature of ancient depositional environments.

Sparry Calcite Cement

Sparry calcite cementation consists of chemical deposition of calcium carbonate from supersaturated solution on the free surfaces of intergranular pore spaces in unconsolidated sediments. The term is synonymous with granular cementation (Bathurst 1958, p. 14; Orme and Brown 1963, p. 52). Several distinct types of textures have been

Explanation of Plate 54

Figure 1 Pelsparite with rounded, elliptical elongate pellets in a granular mosaic of clear, equant to irregular, uniformly sized calcite, with straight to gently curved intergranular contact (Unit III, Coboconk quarry). (Black spots are due to faulty peel preparation). X 55.

Figure 2 Oösparites showing development of fine fibrous thin calcite crust at right angles to outer surface of oöliths (Unit III, Roblindale quarry). Central coarse, equant to irregular calcite mosaic represents secondary cement. X 55.

Figure 3 Oösparite showing partial solution of oöliths and deposition of coarse equant, calcite mosaic in the voids. Skeletal fragments at the bottom show presence of weak thin fibrous calcite crust (Unit III, Roblindale quarry). Dark spots represent organic material (?) X 55.

PLATE 54.

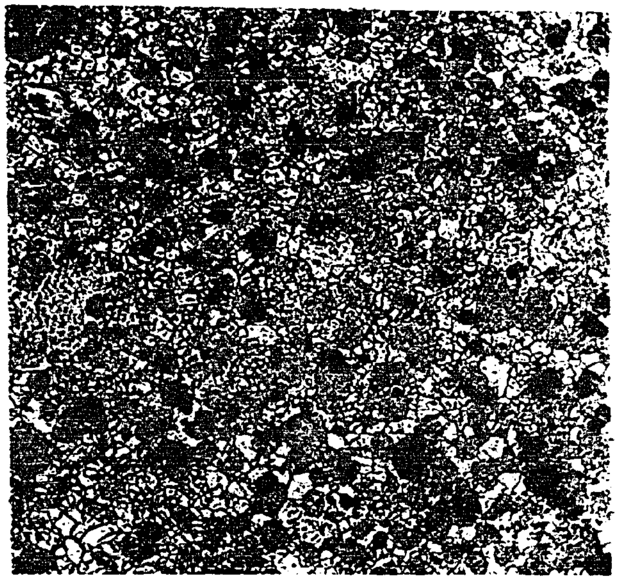


FIG.1

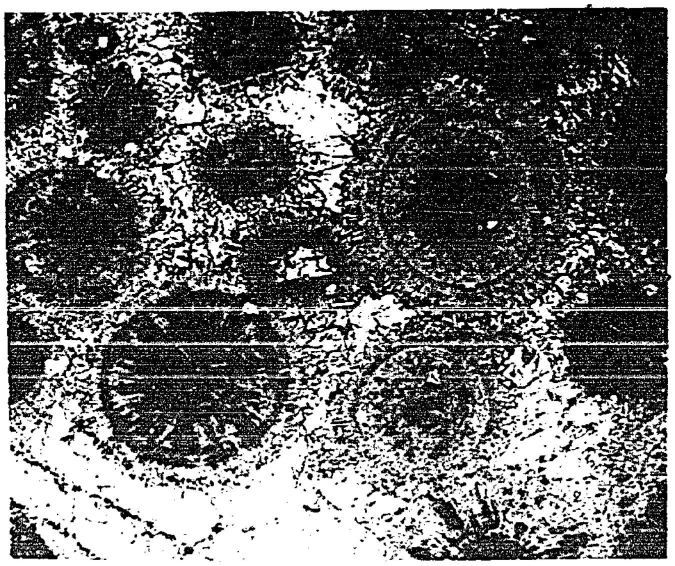


FIG.2

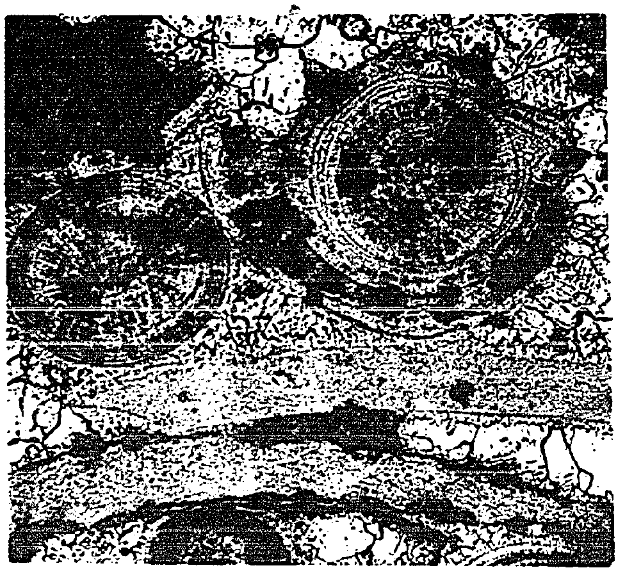


FIG.3

recognized in allochem-rich rocks with sparry calcite cement filling interallochemical pores.

1. <u>Interallochemical pores infilled with granular mosaic</u>.

This type of texture is particularly common in pelsparite and intrasparite type of rocks. The allochems are cemented in a fine (10 μ or 0.01 mm) to coarse (80 μ or 0.08 mm), clear, equant, to irregular, uniformly sized mosaic of calcite showing straight to gently curved intergranular boundaries (Plate 54, fig. 1; Plate 55, fig. 2). Commonly, sparry calcite shows a simple random growth of crystals in pore spaces around the allochems.

In pelsparite, it is not possible to recognize the mode of formation of the sparry calcite. Beales (1965) gave an excellent review of the problem of diagenesis of pelletal limestones and clearly brought out the complexity of spar genesis. The decay of organic material induces precipitation of aragonitic material from the entrapped interstitial water within the sediments. This represents the initial stage of lithification (Beales 1965, p. 54). The second stage of lithification is marked by the development of stable calcite from unstable aragonite. The generation of stable calcite from unstable aragonite can be achieved by direct alteration in the solid state, with or without interstitial fluids (Folk 1965, p. 24; Friedman 1964). The stable calcite may also evolve by the solution of original aragonite, and redeposition of calcite in the voids (Friedman 1964). However, lack of any typical cavity filling drusy mosaic or encrustation textures in the present rocks clearly negates such a possibility.

Studies of recent Bahaman pellet-rich sediments suggest that materials constituting the cement represent precipitation of aragonite, locally induced by organic decay. Skeletal grains associated with pellets do not show any evidence of development of carbonate encrustation (Purdy 1963). Thus, the cementation of pellet-rich sediments does not involve any intermediate void stage of growth by solution. The stable calcite is formed by simple recrystallisation (Purdy 1963a; Illing 1954) or neomorphic inversion (Folk, 1965, p. 21). Like their present day counterpart, the pellet-rich Black River rocks are marked by an abundance of various composite grains. The origin of cement is dependent on two factors, (1) the supersaturated nature of water with respect to calcium carbonate, and (2) lowering of calcium carbonate solubility in the immediate micro-environment through organic decay. The decay of organic materials by sulphate-reducing or ammonifying bacteria causes precipitation of calcium carbonate. The exact nature of such bacterial activity cannot be determined in the Black River rocks. The precipitation of calcium carbonate can be initiated in the following ways,

(a) $NH_3+H_2O=NH_4OH, NH_4(OH)+Ca(HCO_3)_2=(NH_4)_2CO_3+2H_2O+CaCo_3$

(b) $NH_3+H_2O=NH_4OH, 2NH_4OH+OH+Co_2=(NH_4)_2Co_3+H_2O, (NH_4)_2Co_3+CaSo_4=(NH_4)_2So_4+CaCo_3$

(c) $CaSo_4+8H=CaS+4H_2o$, $CaS+Co_2+H_2O=H_2S+CaCo_3$

2. <u>Rocks with interallochem areas filled with fibrous encrustation and coarse granular mosaic.</u>

Oösparite, biosparite, intrasparite (rare), and other skeletal-rich rocks are characterized by the following textural features:

a) Most allochems show a thin overgrowth of fibrous or bladed calcite crystals around the outer periphery. The crystals grow perpendicular to the free encrusted surface and range in size from 0.009 mm (9µ) to

Explanation of Plate 55

Figure 1 Bioösparite with thin, dark envelopes of micrite around skeletal fragments. (Unit III, Roblindale quarry). Note collapse of dark micrite envelopes and partial to complete leaching of oöliths and shell. There is no evidence of inclusions of original materials in clear spars. X 22.

Figure 2 Micrite (lower) grading sharply into intrapelsparite (upper) (Unit III, Roblindale quarry). Coarse, clear, irregularly sized calcite represents granular cement in interallochem pores. X 22.

PLATE 55.

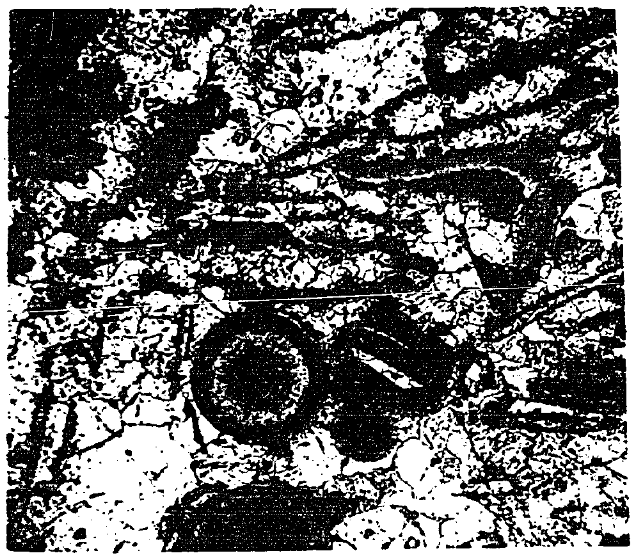


FIG. I

FIG. 2

0.01 mm (1μ) in size, (Plate 54, fig. 2; Plate 29, fig. 2).

The fibrous calcite crystals grow in optical continuity with the original allochem nucleus e.g. oölith (Plate 54, fig. 2), and fibrous skeletal material such as brachiopods, ostracods, trilobites, etc. (Plate 51, fig. 2; Plate 54, fig. 3). The polycrystalline nature of the original nucleus causes development of a multitude of parallel fibrous or bladed calcite crystals (Folk 1965).

b) A coarse mosaic of calcite crystals usually fills the central part of interallochem pores. Calcite crystals are equant to irregular in shape, and range in size from 0.007 mm (7μ) to 0.12 mm (120μ). Intergrain boundaries may be straight or slightly curved. A weak grain enlargement of calcite can be seen from the wall towards the centre of the cavity (Plate 54, fig. 2).

c) Allochems such as oöliths, corals, brachiopods and algal fragments show good evidence of partial to complete solution (leaching) of structures (Plate 54, fig. 3; Plate 55, fig. 1).

d) A thin dark micrite envelope (Bathurst, 1964, 1966) of finely divided crystalline material develops along the outermost margin of skeletal allochems (Plate 51, fig. 2) or oöliths (Plate 55, fig. 1). Micrite envelopes are thought to be of organic origin. Repeated algal boring, decay and infilling of aragonite micrite around the outer shell wall cause the development of micrite envelopes (Bathurst 1966, p. 19). Bathurst (1966) reported similar micrite envelopes around various skeletal fragments from the sediments of Bimini lagoon in the Bahamas.

e) Outer micrite layers also show evidence of collapse (Plate 55, fig. 1).

f) Micritic matrix is completely lacking in rocks. No evidence of grain welding is observed.

Explanation of Plate 56

Figure 1 Intrapelbiosparite with syntaxial cement rims around pelmatozoan fragments (Unit IV, Point Ann quarry). Rims are composed of calcite with straight outer margins and continuity of cleavage from the central dusty core to the clear outer areas. The outer margins of the rims are in contact with other rims or allochems. Intraclasts and pellets show neomorphism of internal material. Some rims also include isolated intraclast and pellet fragments. There is weak development of sparry cement (equant) encrustation around one allochem (marked X). X 55.

Figure 2 Micrite with elliptical cavity filled with coarse clear, drusy calcite mosaic (Unit II, McGinnis and O'Conner quarry). Sparry calcite has develeped perpendicular to the cavity wall and shows a sharp contact with micrite. Sparry calcite crystals show gradual increase in size from the wall towards the centre. They also show straight intergrain boundaries. Irregular fragments of micrite along the base of the cavity represent intraclasts formed during growth of gypsum crystals. X 22.

PLATE 56.

FIG. I

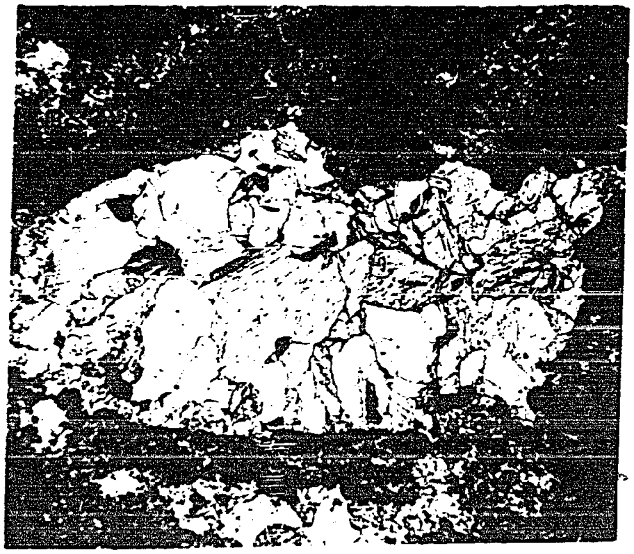


FIG. 2

The development of fine, thin fibrous crust-like overgrowths around various allochems represents precipitation of calcite from supersaturated solution. This marks the initial stage of cementation causing early lithification of sediments. The coarse granular mosaic indicates later infilling of pore spaces. The materials for the later infilling may be supplied by the solution of allochems. Friedman (1964) described similar modes of lithification in oölitic sediments of the Bahama Bank areas. The absence of any evidence of welding of allochemical materials in the Black River rocks suggests that the lithification has taken place under little or no overburden.

3. Rim cementation.

The phenomenon of rim cementation is best illustrated in rocks with pelmatozoan fragments, and sparry calcite cement. The clear sparry calcite is deposited syntaxially on the outer surface of pelmatozoan (crinoid) fragments (Bathurst 1958, p. 21). The process is similar to Pettijohn's (1957) "secondary enlargement" and the "syntaxial cement rim" of Orme and Brown (1963). The following characteristic textural features of rim cementation are recognized in the Black River rocks.

a) A detrital core composed of a single crystal of calcite, and usually marked by a high density of inclusions in the centre (Plate 56, fig. 1).

b) A more or less clear outer syntaxial rim with occasional presence of other allochem inclusions (Plate 56, fig. 1).

c) Host and rim are syntaxial as is shown by continuity of cleavage traces (Plate 56, fig. 1).

d) Outer boundaries of the rims are commonly in contact with other rims, allochems or granular cement, but never against micritic matrix (Plate 56, fig. 1).

e) Plane outer boundaries of rims (Plate 56, fig. 1).

f) Syntaxially grown spars range from 0.18 mm (180µ) to 0.36 mm (360µ) in size. The size of weakly developed encrusting equant (overgrowth) spars around some allochems ranges from 0.01 mm (10µ) to 0.03 (30µ), (Plate 56, fig. 1).

g) Allochems such as pellets or intraclasts may show various stages of neomorphism (Plate 56, fig. 1). The precise time of internal neomorphism of allochem cannot be determined (Plate 56, fig. 1).

The texture consisting of syntaxial growth of calcite rims around pelmatozoan fragments has been described by various workers e.g. Lucia (1962), Evamy and Shearman (1965) and others. The lack of any irregularly sutured grain boundaries, and the widely scattered nature of allochems suggest, 1) fragments have sufficient contact to form a self supporting framework, 2) lithification has taken place under very light or no compaction.

4. Drusy mosaic.

The process consists of deposition of sparry calcite from solution into cavities and not in intergranular pores (Bathurst 1958, p. 14; Orme and Brown, 1963). The sparry calcite may vary in form from bladed to equant with size ranging from 0.008 mm (8µ) to 0.18 mm (180µ). Drusy mosaic textures are frequently observed in micrites, and biomicrites. Granular mosaic can be identified by the following characters:

a) The granular mosaic develops on free surfaces of cavities e.g. shell chambers etc. (Plate 56, fig. 2).

b) An abrupt contact between the mosaic and cavity wall (Plate 56, fig. 2) is common.

c) The calcite mosaic filled area may exhibit the obvious shape of a cavity (Plate 56, fig. 2).

d) The grain size increases from the cavity wall to the centre (Plate 56, fig. 2).

e) The long axes of crystals are oriented normal to the cavity wall (Plate 56, fig. 2). In an equant drusy mosaic calcite crystals also grow perpendicular to the cavity wall.

f) Sparry calcite crystals show plane to curved intergrain boundaries (Plate 56, fig. 2).

The cavities may originate in various ways, e.g. solution of unstable material under subaerial condition, removal of materials by connate or percolating ground water, cavities formed by burrowing organisms, or entrapped gases. In some cases, the time of cavity formation and infilling of such molds cannot be easily determined. Lack of any deformation or collapse features around the outer margins of drusy calcite filled cavities suggest that most of the drusy mosaic textures probably developed after considerable consolidation of carbonate sediments. Elliptical, circular, elongate, coarse, drusy calcite filled cavities are commonly encountered in the lower dolomicrite beds of unit II of the Black River sequence. Most of the cavities probably represent solution molds of gypsum nodules. The cavities probably formed after partial consolidation of the sediments, and were later infilled by secondary calcite. Isolated elliptical hollow cavities are seen on the exposed weathered surface of the sediments. Stained samples show a high iron content in coarse crystalline calcite thus lending further support to a theory of secondary origin for the drusy mosaic (Oldershaw and Scoffin, 1967).

Neomorphism

The term was first proposed by Folk (1965, p. 21), to include various processes of recrystallisation, inversion, and replacement in a restricted sense. As the original mineralogy and chemistry of ancient limestones are difficult to ascertain, the comprehensive term "neomorphism" is appropriate. It signifies a change in form with the composition of the original material remaining constant. The original mineralogy of ancient carbonate rocks may be partly inferred from detailed textural analysis. If the clear calcite resulted from solid state inversion of original aragonitic material, the term neomorphic inversion may be used to describe such a mechanism. If it is known that recrystallisation of original calcitic material resulted in the existing coarse sparry mosaic the term neomorphic recrystallisation may be applied. Neomorphic calcite can be divided into two groups, chiefly on the basis of arbitrary size limits. Microspar represents the first group with size ranging from 0.005mm(5 μ) to 0.04 mm (40 μ). Microspar may show a gradational or sharp contact with coarser neomorphic pseudospar of the second group. The size of pseudospar crystals ranges from 0.04 mm (40 μ) to 0.10 mm (100 μ) or more. Pseudospar may completely obliterate the original texture of rocks or it can mimic the appearance of true pore filling sparry calcite cement mosaic (Folk 1965).

1. Neomorphic microspar

The development of microspar is more or less restricted within micrite rich carbonate rocks. Microspar can be easily distinguished

Explanation of Plate 57

Figure 1 Neomorphic biomicrite showing recrystallization of dark micrite into uniformly sized clear sparry areas (Unit II, Napanee quarry). Irregular patches of original dark micrite remains as inclusions coarse clear calcite crystals (inside the bryozoan zooarium). X 22.

Figure 2 Neomorphic micrite showing porphyrotopic nature of recrystallization in anaphanocrystalline carbonate matrix (Unit II, Port McNicol quarry). Clear calcite crystals are equant and of uniform size with plane to curved intergrain boundaries. X 22.

Figure 3 Neomorphic pelmicrite showing intense recrystaliization of allochem and micritic matrix (Unit III, Point Ann quarry). Phosphatic skeletal fragment (centre) does not show any alteration. Irregular patches of dark micrite are present in clear calcite crystals and also around the outer margins. X 22.

PLATE 57.

FIG. 1

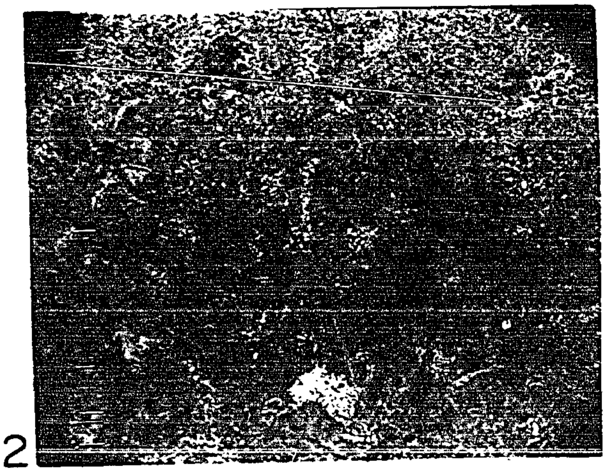


FIG. 2

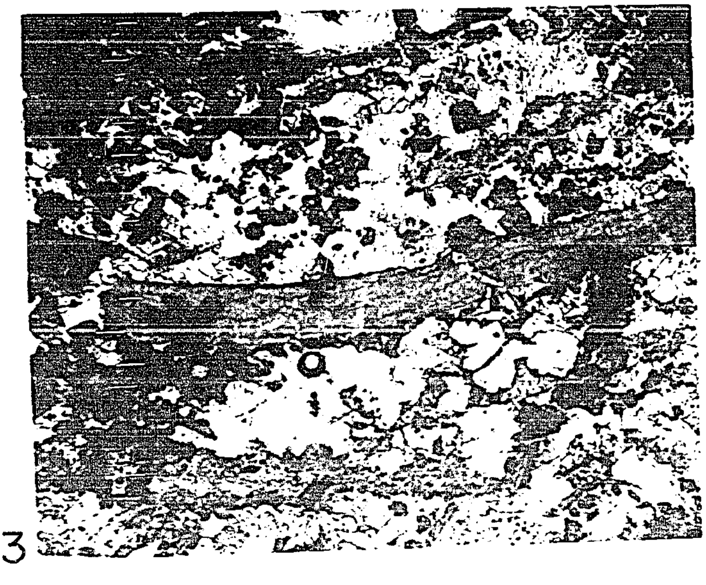


FIG. 3

Explanation of Plate 58

Figure 1 Neomorphic intrabiomicrite showing passage of microspar into coarse pseudospar (Unit III, Napanee quarry). Recrystallization has spread irregularly in allochems and matrix. Pelmatzoans shows replacement rim with dark inclusions of original micrite matrix. Recrystallization is more intense in the matrix (as evident from complete removal of micrite) and spreads into the allochems (small size of spars). X 55.

Figure 2 Neomorphic pelsparite showing intense recrystallization of allochems and original carbonate matrix (Unit IV, Point Ann quarry). Allochems show partial to complete obliteration of original character. Sparry calcite shows more or less uniform size. Irregular patches of undigested impurities occur as dark inclusions along contacts of sparry calcite crystals. X 22.

Figure 3 Biopelmicrite showing recrystallization of allochems and micritic matrix (Unit III, Point Ann quarry). Pellets are less affected by microspars than skeletal material. Bryozoan fragments are intensely affected by recrystallization. X 22.

PLATE 58.

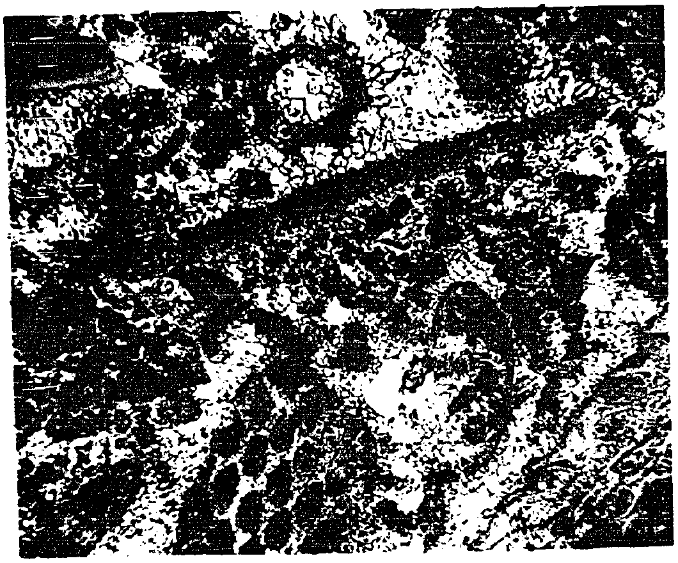


FIG. 1

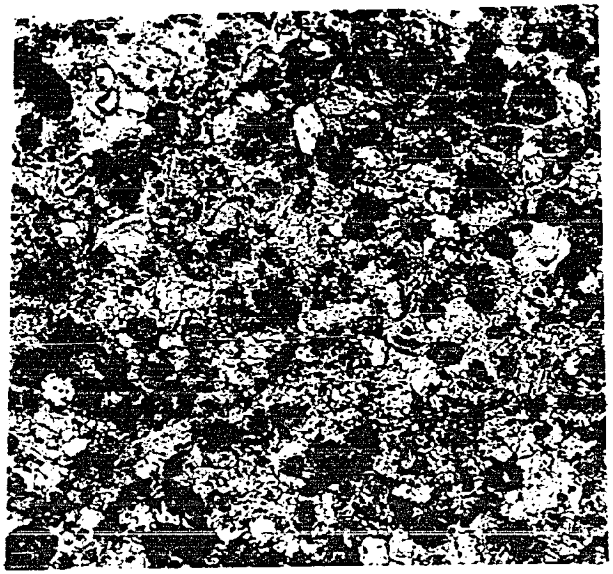


FIG. 2

FIG 3

Explanation of Plate 59

Figure 1 Neomorphic biopelmicrite (Unit III, Coboconk road section). Note irregular inclusions of micritic mud in clear sparry calcite (marked X). Irregular syntaxial cement rims are developed around pelmatozoans. Pellets show irregular growth of microsparry calcite crystals.

Figure 2 Biomicrite showing recrystallisation of skeletal material (bryozoa) and micritic matrix (Unit III, Coboconk quarry). Clear sparry calcite crystals contain inclusions of original material (dark patches). X 55.

Figure 3 Neomorphic biopelintramicrite with partial recrystallisation of allochems and complete recrystallisation of matrix (Unit IV, Hwy. 401 section, 5 miles east of Napanee). Note development of neomorphic microsparry fibrous crust around the large intraclast(at left)which spreads irregularly into the allochem. Pelmatozoa fragments show development of irregular rims. Dark irregular patches of inclusions are also seen within and around clear calcite crystals. Curved fragments of ostracods do not show any evidence of alteration. X 55.

PLATE 59.

FIG. 1

FIG. 2

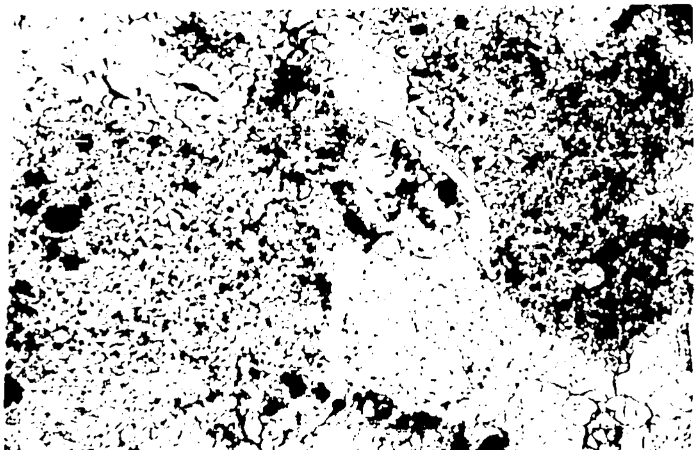


FIG. 3

from similarly sized pore filling sparry calcite by the following features:

a) Microspar shows an uniform grain size (Plate 5, figs 1 and 2).

b) Commonly, microspar shows equant shape with straight to slightly sutured intergrain boundaries (Plate 57, figs. 2 and 3).

c) Microspar may contain frequent inclusions of original micrite (Plate 57, fig. 1; Plate 59, figs. 2 and 3). Clay or other organic material may be concentrated along the outer margins of sparry calcite crystals (Plate 57, fig. 3; Plate 59, fig. 3). Pellet-rich rocks show irregular concentration of dark undigested impurities along the intergranular contacts of clear calcite spars (Plate 58, fig. 2).

d) The growth of microspar in micrite is marked by a porphyrotopic fabric (Plate 57, fig. 2). As the process of neomorphic recrystallisation continues, the porphyrotopic nature of growth is replaced by a xenotopic fabric due to the coalescive nature of formation of microspar (Plate 57, fig. 2).

e) Fibrous microsparry calcite or crust shows irregular cross-cutting relation with the allochems (Plate 59, fig. 3).

f) Pelmatozoan fragments show development of syntaxial rims with highly irregular outer margins). The rims may or may not contain irregular dark inclusions of micrite (Plate 59, figs. 1 and 3).

g) In allochem-rich rocks microspar commonly spreads from the micritic matrix into the allochemical grains (Plate 58, fig. 1; Plate 60, fig. 1). Microspar shows coarser nature in micrite and finer size in allochems (Plate 58, figs. 1 and 3).

Explanation of Plate 60

Figure 1 Pelmicrite showing spread of recrystallised microspar from matrix to pellets (unit III, Coboconk quarry). Micrite matrix is completely recrystallised while pellets show various stages of irregular, recrystallization of internal material. X 55.

PLATE 60.

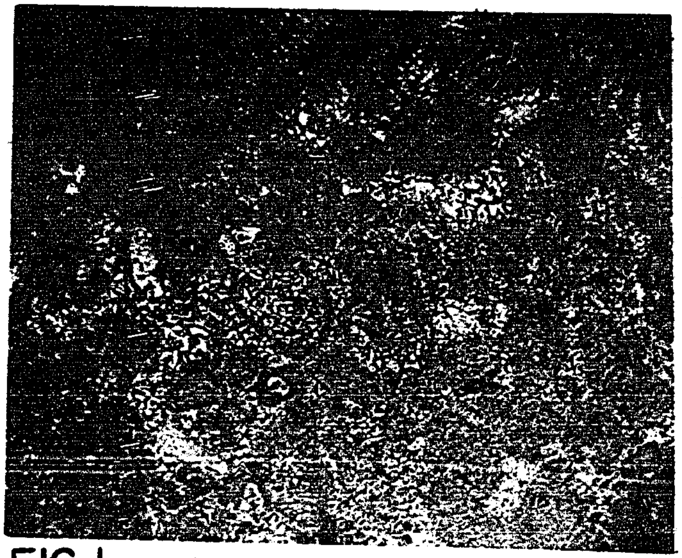


FIG. I

Explanation of Plate 61

Figure 1 Extremely coarse to fine, elongate, equant to fibrous pseudospar with straight to slightly curved intergrain contacts. (Unit III, Point Ann quarry). Pseudospar contains relict traces of original pellets, (left central corner) and micrite (as irregular dark patches in clear calcite). Pseudospar obliterates the original fabric of the rocks. X 55.

Figure 2 White coarse pseudospar showing irregular shape, size and straight to sutured outer margin. (Unit IV, Point Ann quarry). Allochems are loosely scattered in sparry calcite crystals and an ostracod (centre) valve shows the growth of fine fibrous to equant clear calcite within the skeleton. Irregular patches of micrite occur as inclusions within and around clear calcite spars. X 55.

Figure 3 White coarse equant pseudospar with straight outer intergrain boundaries. Fibrous crust-like neomorphic calcite grows around the inner margin of ostracod shell (lower right corner). (Unit IV, Point Ann quarry). Dark irregular patches represent inclusions of micrite in pseudospar. Ostracods can be easily recognized while other allochems are completely obliterated by pseudosparry calcite crystals. X 55.

PLATE 61.

FIG. 1

FIG. 2

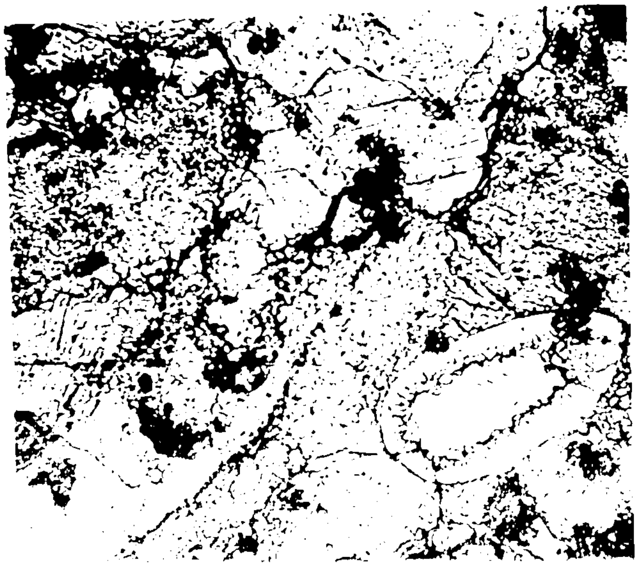


FIG. 3

Explanation of Plate 62

Figure 1 Equant pseudosparry calcite crystals replacing corals and showing straight outer boundaries. (Unit IV, Roblindale quarry). Note inclusions of outer shell wall (dark patches) within spars. Fracturing of shells may have taken place before the formation of pseudospar. X 55.

Figure 2 Extremely coarse equant pseudospar with straight outer margin (Unit IV, Coboconk quarry). Traces of organic skeleton can be recognized as thin dark resistant micritic lines. Inclusions of micrite are present as dark irregular patches, within and around pseudosparry calcite crystals. The presence of unaffected oöliths showing micrite rings may be due to algal activity. X 55.

PLATE 62.

FIG.1

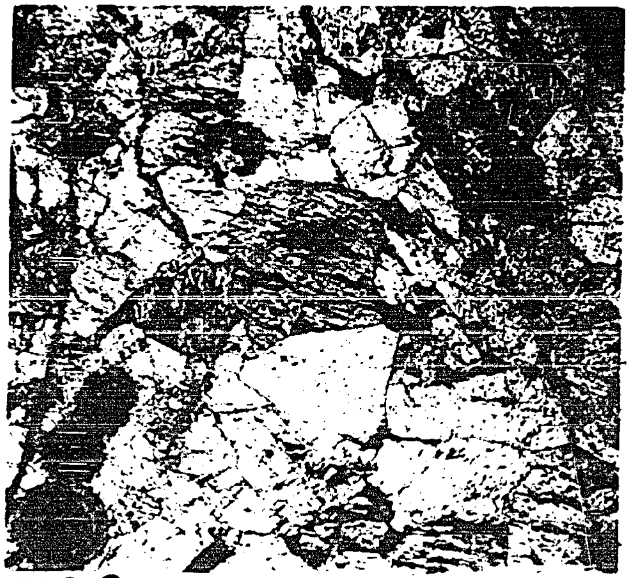


FIG.2

Explanation of Plate 63

Figure 1 Coarse clear pseudosparry rock with widely scattered dark pellets (Unit III, Point Ann quarry). Structures of allochems are obliterated in most cases, even the resistant pelmatozoa are difficult to recognize. Pseudospar has a length several times greater than its width (in the centre). Inclusions of micrite also show development of small irregular pseudosparry crystals (upper left). Pseudosparry calcite crystals around allochems are coarser in size. X 55.

Figure 2 Clear white pseudospar showing extremely irregular size (Unit IV, Point Ann quarry). Pelmatozoa fragments show syntaxial replacement rims with highly irregular rim margins. Note extremely elongate nature of the replacement rim (upper left corner). Pseudosparry calcite crystals contain dark irregular inclusions of micrite. X 55.

Figure 3 Large pseudospar (clear white) with inclusions of original dark micrite (Unit III, Marmora quarry). A pelmatozoan shows development of replacement rim (upper left corner). Outer margin of the rim shows irregular extensions in the surrounding micrite. Patches of coarse finer clear pseudospar grows irregularly in the micritic matrix. X 55.

PLATE 63.

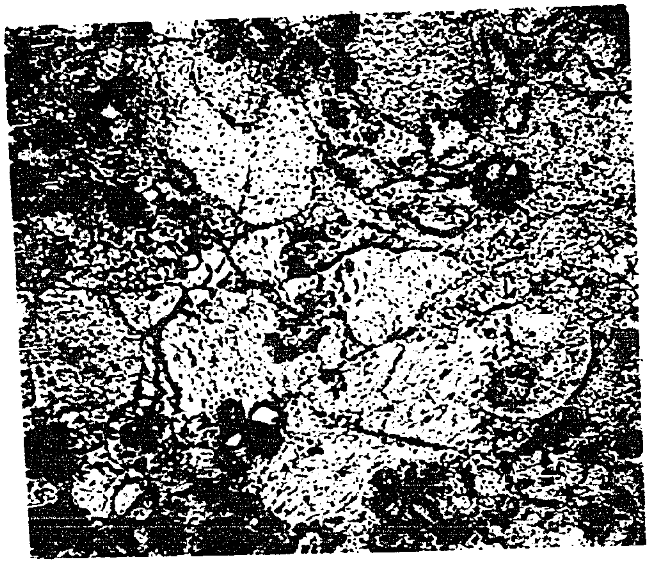


FIG.1

FIG.2

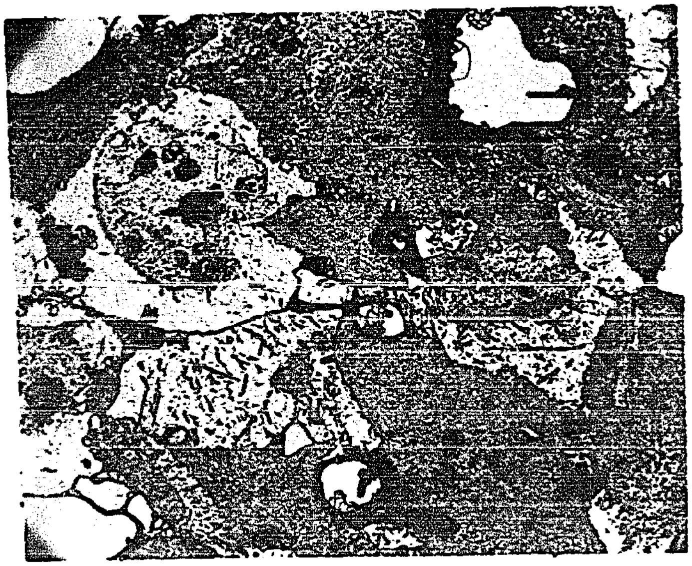


FIG.3

The development of microspar (neomorphic) is not yet fully understood. The salinity of the depositional environment and the nature of clay minerals in the sediment may play an important role in the selective growth of microspar in micritic rocks (Folk 1965, p. 42). The initial process of microspar formation may be triggered by neomorphic recrystallization or inversion of original aragonitic material. It is also interesting to note that micrites associated with dolomicrites in units I and II do not show any evidence of microspar formation and thus bears further support to Folk's (1965) idea of salinity control in the selective growth of microspar.

2. Neomorphic pseudosparry calcite

Pseudosparry calcite ranges from 0.03 mm (30 µ) to 0.8 mm (800 µ) or more in size (Plate 61, fig. 1). The texture is fibrous (Plate 61, fig. 1), equant (Plate 62, figs. 2 and 3) to irregular (Plate 61, fig. 2).

Pseudospar commonly shows straight intergrain contacts (Plate 62, figs. 2 and 3; Plate 61, figs. 1, 2 and 3). In most cases textures of pseudospar mimic primary pore filling calcite spars, and the differentiation of two types of spar is extremely difficult. The following textural criteria have been used in the identification of pseudospar from the pore filling spars:

a) Highly irregular distribution of size of pseudospar (Plate 61, figs. 1 and 2; Plate 63, fig. 2).

b) Frequent inclusions of micrite or clayey material within or around clear pseudospar (Plate 63, fig. 3; Plate 62, figs. 1 and 3; Plate 65, fig. 3).

c) Presence of relict traces of original allochem structures in pseudo-

Explanation of Plate 64

Figure 1 Pelmatozoa (crinoids) show growth of clear syntaxial replacement rims with extremely irregular outer margins. The outer margins of rims rest directly against micrite (centre). Inclusions of pellets and micrite are common within the outer rims. Pseudospar shows straight intergrain boundaries. X 55.

Figure 2 Pelmatozoa (dark, dusty areas in the centre of clear coarse rims) show growth of syntaxial replacement rims with straight to curved intergrain contacts (Unit IV, Buckhorn Road section). Patches of dark micrite remain as inclusions in coarse calcite spars. Stable phosphatic and ostracod (curved) shells show development of fine neomorphic fibrous crusts around outer margins (marked X). X 55.

Figure 3 Coarse, clear, pseudospar transecting across a large intraclast (Unit II, Roblindale quarry). Note presence of large irregular micrite patch as inclusions in clear crystalline calcite spar. X 55.

PLATE 64.

FIG. 1

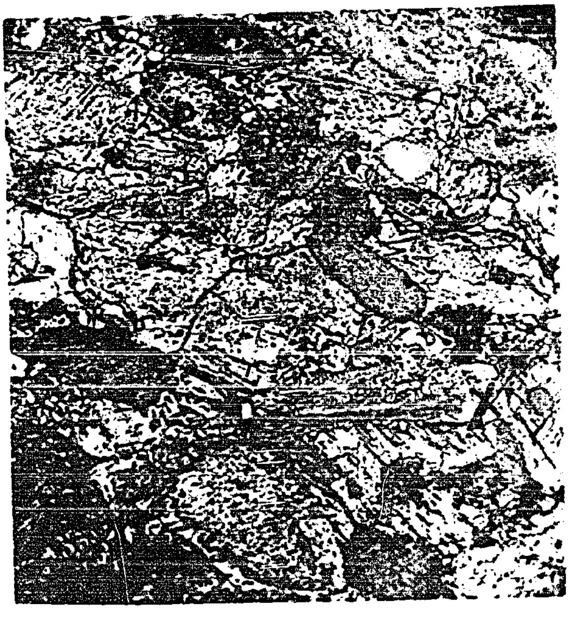


FIG. 2

FIG. 3

Explanation of Plate 65

Figure 1 Pseudospar with straight to curved intergrain boundaries. (Unit II, Hwy. 401 section at Hwy 15 exit). Traces of pellets (?) are present as relict structures within pseudosparry calcite crystals (clear, white areas with broken fragments at the base represent fracturing of thin section during staining). Syntaxial growth of calcite spar around zoned, ring like nucleus may be due to the presence of pelmatozoan (crinoid) fragment. X 55.

Figure 2 Transection of original allochem (coral) by extremely coarse clear, pseudospar. (Unit IV, Havelock road section). The outline of allochem is marked by traces of dark micritic material along the outer margin. (Marked X). Relatively stable pellets are unaffected. Inclusions of micrite are present within or around pseudosparry calcite crystals. Smaller size of spars (upper left corner) indicates recrystallization of micrite to microspar. X 55.

PLATE 65.

FIG. I

FIG. 2

spar (Plate 65, fig. 2; Plate 61, fig. 1).

d) Transection of allochems by pseudospar (Plate 64, fig. 3; Plate 65, fig. 2).

e) Abnormally loose packing of allochems (Plate 61, fig. 2; Plate 63 fig. 1).

f) Presence of overgrowths in optical continuity, around crinoids (pelmatozoans) with highly irregular outer rims (Plate 63, figs. 2 and 3; Plate 64, fig. 1). Syntaxial rims rest against micrite (Plate 63, figs. 2 and 3; Plate 64, fig. 1). These rims have been described as syntaxial replacement rims by Bathurst (1958) and Orme and Brown (1963).

g) Development of fibrous crusts within or around shells which are resistant to diagenesis such as ostracods (Plate 61, figs. 2 and 3), phospatic plates (Plate 64, fig. 2).

h) In some cases pseudosparry calcite crystals may be several times as long as wide (Plate 63, figs. 1 and 2).

Pseudospar is believed to have developed by inversion of organic skeleton or recrystallization of micrite. Commonly, the effect of pseudospar growth leads to the partial or complete obliteration of all original structural and textural features of the rock (Plate 61, fig. 1; Plate 63, fig. 1). Only allochem-rich rocks, with minor amounts of interstitial matrix show development of pseudosparry calcite crystals. Traces of micritic matrix can be recognized as irregular isolated small dark patches around the intergranular margins of pseudospar (Plate 61, fig. 3).

Diagenetic studies of recent carbonate sediments reveal that non-skeletal aragonite undergoes very slow inversion to calcite as compared to their skeletal counterparts. According to Land (1967) the presence of water catalyzes the inversion process, regardless of the nature of original aragonite. No evidence is yet available to account for the difference between diagenetic fabrics of microsparry calcite and pseudosparry calcite-rich rocks. Berner (1966) has demonstrated that the concentration of Mg^{++} in sea or interstitial water prevents recrystallisation of inhibits nucleation and crystal growth. The association of magnesium-rich clayey material and other impurities in micrite may probably account for the observed difference in crystallinity between microspar and pseudospar. The presence of strontium carbonate in the aragonite lattice can also inhibit the inversion process (Siegel, 1960). The observed high values of celestite in the micrites of Black River units suggest that high strontium contents of the initial aragonitic mud would probably control the inversion or recrystallisation process.

Diagenetic minerals (Authigenesis)

As defined by Pettijohn (1957, p. 661) "authigenic processes are largely processes attempting to establish an equilibrium assemblage, or facies by elimination of the unstable species, growth of stable species, and the production of new and stable species by appropriate chemical reactions". Most of the reactions pertaining to authigenesis take place during diagenetic alteration of deposited sediments and therefore the term <u>diagenetic minerals</u> could also be applied for authigenesis. Truly authigenic minerals form at a very early stage of

Explanation of Plate 66

Figure 1 Micrite with isolated, widely scattered, clear uniformly sized, euhedral rhombs of dolomite and rounded to prismatic crystals of quartz. (Unit II, Montreal Street section). Dark opaque areas represent spherical nodules of pyrite which tend to replace dolomite in places. X 22.

Figure 2 Slender needle-like molds of celestite and isolated small rhombic dolomite in micrite (Unit II, Marmora quarry). The coarse calcite filled areas cut across celestite molds. Spar filled areas in most cases show smooth outer margins. Minor inclusions of dark carbonate material can be seen in clear coarse spars.

Figure 3 Doubly terminated prismatic crystals of quartz (Unit II, McGinnis and O'Conner quarry). Dusty irregular inclusions within quartz represent micrite. (Dark spots are due to faulty peel preparation). X 55.

PLATE 66.

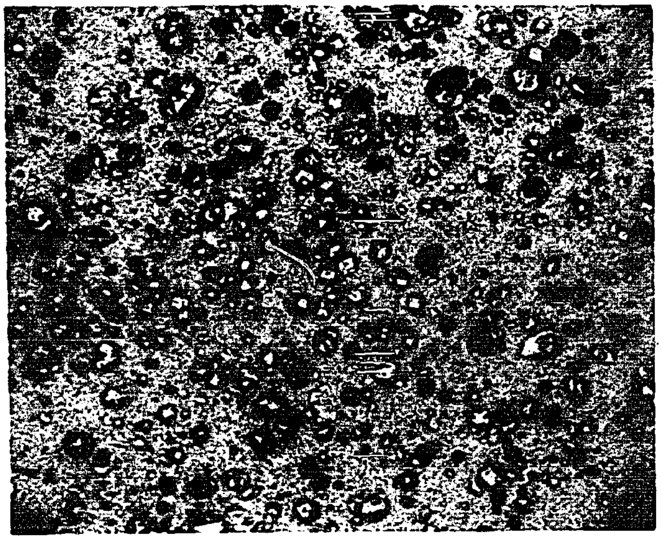


FIG. 1

FIG. 2

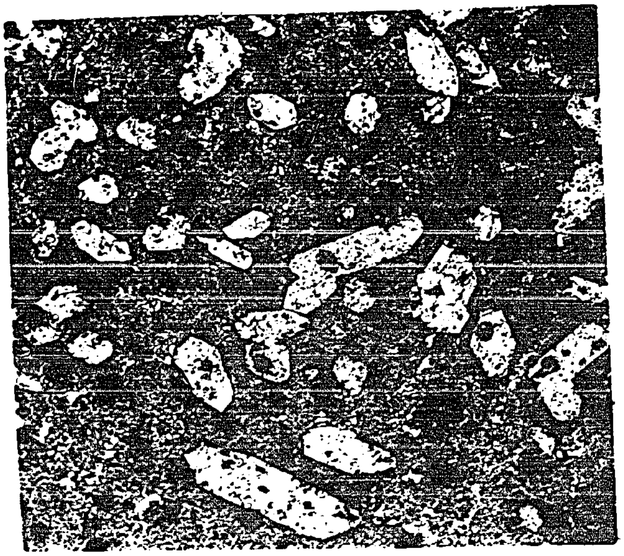


FIG. 3

Explanation of Plate 67

Figure 1 Dolomicrite showing hypidiotopic to idiotopic fabric with irregularly sized subhedral to euhedral rhombs of dolomite (Unit II, Burleigh Falls road section). Dolomite shows fine dusty inclusions of dark micrite or organic materials. Note the extreme stability of central phosphatic shell, while most of the original structures are obliterated by dolomite rhombs. Few dolomite crystals cut across the shell fragment. X 22.

Figure 2 Clear, coarse calcite spar-filled irregular areas in micrite (Unit II, Marmora quarry). Late microstylolites do not cut across spar-filled areas and tend to follow the outlines of sparry-areas. X 55.

Figure 3 Coarse tabular, rhombic to prismatic euhedra of celestite and dolomite showing poikilotopic texture. (Unit II, Marmora road section). Patches of dark micrite are enclosed by euhedra. Some euhedra contain irregular inclusions of dark micrite. X 55.

PLATE 67.

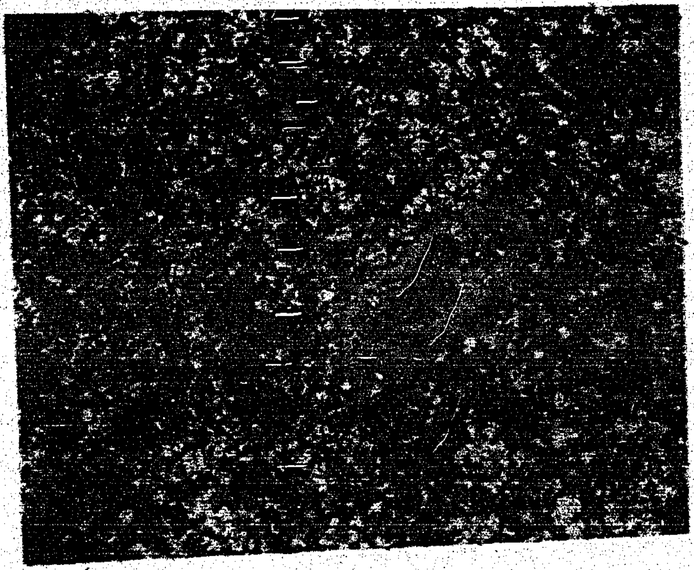


FIG. I

FIG. 2

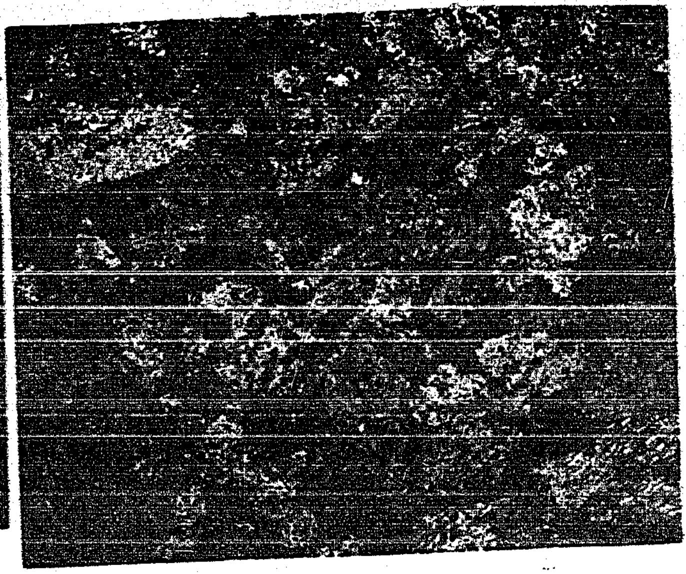


FIG. 3

diagenesis. These do not tend to disrupt the original textural features of the deposited sediments. Late diagenetic minerals are of replacive nature. They tend to destroy the initial textures of deposited sediments. Evidences of early and late diagenetic growth of various minerals can only be seen and established in micrites.

1. Early (penecontemporaneous) diagenetic dolomite

Dolomite occurs in aphanocrystalline micrite of uniform texture, ranging from 0.005 mm (5 μ) to 0.01 mm (10 μ) in size and shows perfect euhedral rhombic nature. The crystals are widely scattered as isolated clear rhombs (Plate 66, fig. 1). In places, rhombs may contain dark irregular dusty or bubble like inclusions. No evidence of grain coarsening can be observed in the dark micrite. Often, doubly terminated prismatic quartz crystals also occur in the micrite (Plate 66, fig. 1). The frequent association of algal material is marked by the presence of very finely laminated, alternate, dark carbonaceous micrite and dolomite rhomb bearing micrite (Plate 45, fig. 1). The dolomite-bearing micrites invariably lack skeletal materials excepting some occasional scattered broken fragments. The micrite beds adjacent to dolomitic micrite units show abundant, irregularly sized, and shaped, coarse sparry-calcite filled cavities (Plate 66, fig. 2; Plate 67, fig. 2). Dolomite-bearing micrites also show common association of celestite, burrows and other structures (Plate 66, fig. 2).

Kepper (1966, p. 555) ascribed the uniform-size, isolated, rhomb-shaped nature of dolomite euhedra to primary or early diagenetic precipitation. Carozzi (1960, p. 436) recognized similar textural features of dolomite in various evaporitic lithologies, e.g. gypsum, anhydrite, halite-beds etc. and suggested a theory of chemical precipitation. Shinn et al. (1965), Illing et al. (1965) and Friedman (1964, p. 811) also reported the occurrences of isolated, loosely scattered rhombs of dolomite (4 u to 5 u) from various recent supratidal carbonate environments and suggested penecontemporaneous or early diagenetic nature of formation for the crystals.

Aragonite and high-magnesium calcite represent two important minerals which are precipitated from the supersaturated solution of sea water. Under higher saline condition, with a high Mg/Ca ratio aragonite is more soluble than high-magnesium calcite. Occurrence of the calcium sulphate phase (e.g. gypsum) is also common in the supratidal environment. The formation of sulphate mineral or minerals may cause a rapid depletion of Ca^{++} and enrichment of Mg/Ca ratio in the interstitial or surrounding sea water. The common association of various spar-filled cavities in dolomite-bearing micrites or other adjacent micrites suggests solution of unstable calcium carbonate to provide the necessary carbonate for the growth of dolomite (Murray 1960, p. 73). According to Illing et al. (1965), the formation of magnesium-rich brine is one of the most important factors in causing early dolomitization of the sebkba sediments of Persian gulf. High pH values may not be essential to the formation of dolomite.

2. Early diagenetic (authigenic) quartz

Quartz occurs in various petrographic types, but commonly it has a close association with micrite. Quartz occurs as isolated doubly terminated prismatic crystals ranging from 0.005 mm (5 μ) to 0.20 mm (200 μ) in length, and 0.02 mm (20 μ) to 0.05 mm (50 μ) in width. Euhedra are irregularly scattered in dark to light grey micrite with or without isolated dolomite rhombs (Plate 67, fig. 3). Micrite may or may not exhibit the evidence of neomorphic alteration. Commonly quartz crystals seem to contain dark inclusion of original carbonate material.

The precise time of quartz formation is difficult to determine. Schimdt (1965, p. 155) reported a similar occurrence of quartz in the shallow water Jurassic carbonate rocks of Germany. The presently observed association of quartz euhedra with the dolomite-rich micrites tends to suggest an early authigenic growth, probably contemporaneous with the dolomite formation.

The original source of silica could be derived from siliceous organisms in the sediments, or fine detrital silt particles. The study of solubility of silica and calcium carbonate in water under varying pH conditions suggests that the solubility of silica and calcium carbonate has an inverse relation with respect to pH, i.e. a rise of pH will cause a decrease in solubility of calcium carbonate and increase insolubility of silica (Correns, 1950). The two solubility curves also intersect at pH value of 7. Therefore water in contact with both minerals will become saturated with both phases at the existing pH level. Any change in pH value will cause increase solubility of the one and decrease solubility or precipitation of the other. Dapple's (1959, p. 50) work clearly indicates that the solubility of silica is independent of pH at values below 8, and perhaps temperature dependent. Considering the various possibilities it seems reasonable to assume that both dolomite and quartz euhedra represent an early authigenic growth.

3. Early (?) diagenetic celestite

Celestite occurs in micrites with or without dolomite rhombs. Celestite forms slender, elongated needlelike, tabular or prismatic euhedra (Plate 67, fig. 2; Plate 69, figs. 1 and 2). Tabular crystals of celestite grow irregularly around micritic matrix (Plate 69, figs. 1 and 2). Often, celestite crystals show random truncation of grain boundaries by irregularly sized, isolated dolomite euhedra. The dolomite euhedra are coarser in size ($>10 \mu$) and contain a high percentage of dark inclusions (Plate 69, figs. 1 and 2). In most cases stained thin sections indicate the presence of iron in dolomite crystals. These iron-rich dolomite rhombs are thought to be of secondary or late diagenetic origin.

The origin of celestite is considered to be of early authigenic nature. Strontium is supplied during the breakdown of unstable aragonite in an extremely saline Mg/Ca rich environment. The presence of gypsum and anhydrite also contributes to the formation of celestite. Maycock (1959) suggested that strontium was derived from diagenetic alterations of gypsum and anhydrite. It is a well established fact that aragonite and anhydrite can incorporate strontium within their crystal structures. Stoontium is more readily substituted in aragonite lattice than in any other phase. Strontium can be coprecipitated with aragonite from sea water (Kinsman, 1966a, p. 19). In dolomitized carbonates of Persian Gulf sebkha areas, celestite is produced as a byproduct of replacement of high strontium-bearing initial aragonite (up to 7000 PPMSr) by low strontium bearing dolomite (1000 PPMSr) (Kinsman 1966a, p. 12). It seems likely that celestite is formed during neomorphic inversion, recrystallisation, or dolomitization of unstable aragonite at an early diagenetic stage. In some Black River rocks celestite crystals are truncated by neomorphic coarse sparry calcite-filled areas. These spar filled areas show extremely circular, elliptical, shape, with perfectly smooth, outer margin and very closely resemble organic structure (Plate 67, fig. 2; Plate 56, fig. 2). It is possible that late diagenetic neomorphism of original organic materials may have resulted in the development of such spar-filled cavities. Perhaps a concentration of Mg^{++} in the interstitial pore water inhibited recrystallisation of organic aragonitic material. Neomorphism of organic material may have taken place at a very late stage of final lithification, because the removal of porosity would cause a reduction of Mg^{++} from pore water of sediment interstices. Concentration of excess Mg^{++} may cause dolomitization of the sediments.

2. Late diagenetic minerals

Late diagenetic minerals include those phases which are formed at a very late stage of sediment induration. The most common late diagenetic minerals in the Black River limestones include dolomite, celestite (rare) and pyrite.

Dolomite:- Dolomite is the most common mineral of late diagenetic origin in the Black River rocks, especially in the rocks of units I and II. Dolomite ranges from 0.01 mm (10 μ) to 0.04 mm (40 μ) in size with

Explanation of Plate 68

Figure 1 Micrite showing concentrations of dolomite (white) in dark carbonaceous clay rich mud crack. (Unit I, Burleigh Falls road section). X 55.

Figure 2 Irregular lenses or patches showing xenotopic mosaic of dolomite. Dolomite causes a partial replacement of original microsparry micrite. (Unit II, McGinnis O'Conner quarry). X 55.

Figure 3 Irregularly sized, coarse, isolated or aggregates of dolomite cutting across bedding laminations. Dolomite causes partial replacement of original alternate, interlaminated dolomicrite and dark, organic rich carbonate layers. (Unit II, Montreal Street section). X 55.

PLATE 68.

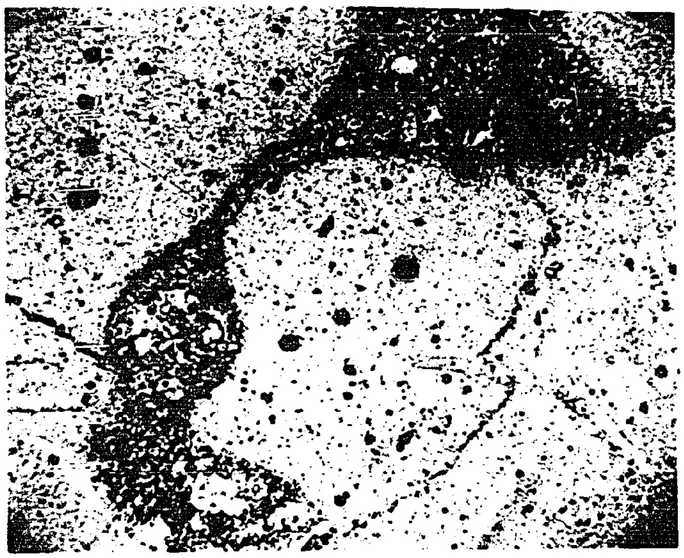


FIG. 1

FIG. 2

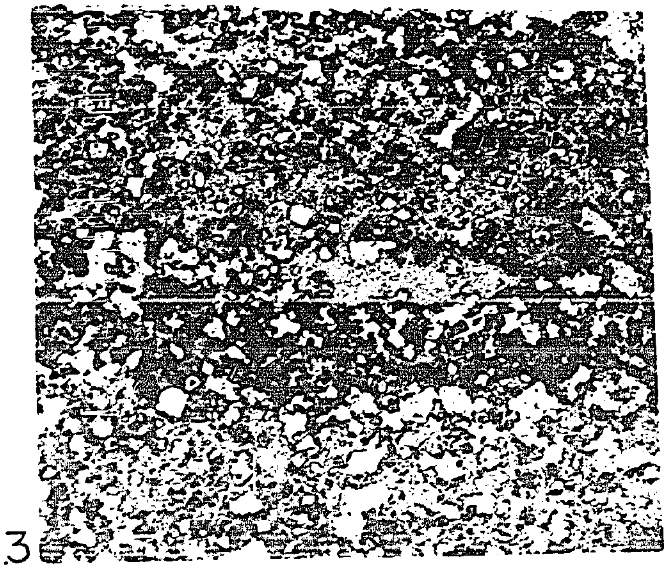


FIG 3

Explanation of Plate 69

Figure 1 Growth of tabular, clear euhedra of celestite (lower part) in a micrite with isolated scattered small, clear dolomite (upper part) rhombs. (Unit II, Marmora quarry). Celestite crystals show irregular margins and grow around micritic patches. Dark patches with coarse, irregularly sized, isolated or aggregates of dolomite represent later replacement. Note irregular spreading of dark dolomite-rich areas into the isolated dolomite, celestite-bearing micrite. X 55.

Figure 2 Coarse late dolomite indiscriminately cuts across celestite and micrite (Unit II, Uhthoff quarry). Note presence of iron rich inclusions in large late diagenetic dolomite rhombs. Irregular shape of celestite is due to the growth of mineral in fine interstitial pore spaces. X 55.

PLATE 69.

FIG.1

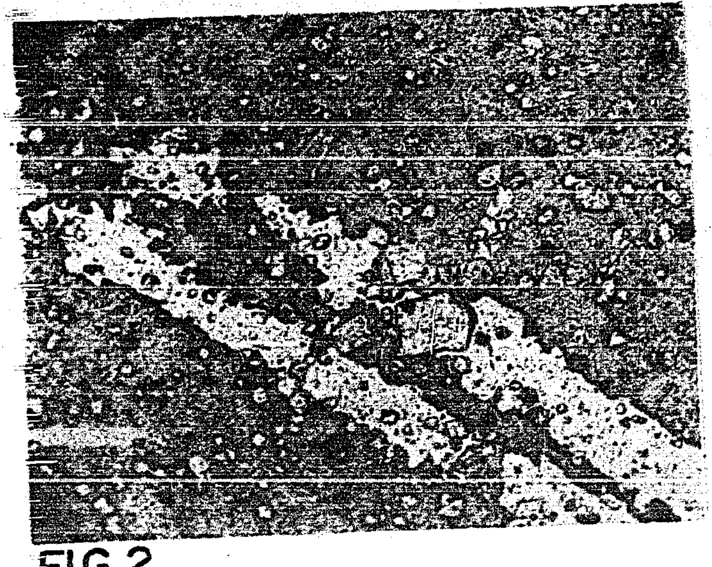


FIG.2

euhedral to subhedral crystals. Dolomite occurs as aggregate-forming irregular lenses or continuous bands and causes partial to complete replacement of original host materials (Plate 68, fig. 1; Plate 69, figs. 1 and 2).

The growth of dolomite would seem to be associated with desiccation cracks and rare stylolites (Plate 69, fig. 1). Dolomite shows gradual spreading into the host material, along irregular extensions or patches (Plate 70, fig. 1). Commonly, dolomite exhibits truncation of sedimentary structures e.g. laminations... (Plate 69, fig. 2). The fabric is typically xenotopic or hypidiotopic with anhedral to subhedral mosaic of dolomite crystals. Most of the dolomite crystals contain dark carbonaceous, or carbonate inclusions (Plate 68, fig. 1). The association of highly laminated alternate micrite and black carbonaceous material (algal?) is also common. The dolomite-rich rocks may contain scattered fragments of intraclasts. Rare fragments of phosphatic materials and ostracods are characteristic of the rocks. Phosphatic fragments or ostracods rarely show any effect of alterations and thus suggest a stable nature even under the most intense diagenetic alteration (Plate 67, fig. 1). Irregular dolomitization imparts colour mottling to the rocks in outcrop sections.

Extensive dolimitization of supratidal sediments inrrecent carbonate environments has been reported by Shinn et al. (1965, Illing et al. (1965), Deffeyes et al. (1965) and Shinn (1965). Interstitial saline waters of the supratidal environment have salinities 5 to 6 times higher than normal sea water. The interstitial water has also an unusually high Mg/Ca ratio of 40:1 as compared with about 5:1 for normal water (Shinn, 1966). Evaporation at the surface combined with upward capillary movement of saline water from below may cause concentration of sea salts in the upper few feet of sediment surface (Shinn 1966, p. 65). Variations in permeability and porosity of the sediments also determine the distribution of dolomite. The highly porous and permeable nature of sediments infilling mud cracks, and worm burrows form easy channelways for the upward migrating fluid and thus may cause selective dolomitization (Shinn, 1966). A sufficient concentration of Mg^{++} can also be achieved by warming and evaporation of sea water in the restricted lagoons (Beales, 1953, 1958). Magnesium-rich sea water may cause selective dolomitization of sediments depending on the initial porosity and permeability. Deffeyes et al. (1965) consider that the evaporation of sea water may cause dense heavy brine to flow downward into the permeable sediments, causing selective dolomitization. This type of dolomitization will show cross-cutting relationship with the adjacent beds.

The Black River rocks do not reveal any large scale cross-cutting relation between dolomitized beds and the adjacent unaffected limestone beds. The extreme selective nature of dolomite formation suggests a restricted and local nature of dolomitization probably following the mechanism as suggested by Shinn (1966).

Celestite:- The rocks with replacing celestite are rare in the present area. Only one thin bed of unit II in the Marmora road section (at 4' 8" level) shows evidences of late diagenetic celestite formation.

Celestite forms elongated rhombic to tabular euhedra with dark inclusions of carbonate material (Plate 68, fig. 3). Occasional euhedral crystals of dolomite and anhydrite can also be observed. Crystals of celestite also enclose irregular patches of dark micrite. Beales (1965, p. 68, 69, figs. 5-7, 5-8) described similar coarse celestite-rich rocks from the Black River rocks. He implied that celestite was formed at an early stage of diagenesis. Schmidt (1965, p. 152) also reported clear prismatic, tabular, coarse crystalline mosaic of celestite from the upper Jurassic beds of northwestern Germany. The celestite replaced calcite, dolomite, anhydrite, and iron silicate. According to Schmidt (1965, p. 153) "most of the replacement celestite is clearly of late diagenetic origin". The high concentration of strontium necessary for celestite formation was supplied by various late diagenetic reorganization of aragonite, and anhydrite material of adjacent beds.

It is interesting to note that micrite beds underlying the celestite-rich horizon show high concentration of anhydrite in the insoluble fractions. The immediate overlying, coarse allochem-rich beds contain a high percentage of oölith's and coral fragments. Most of the allochems show evidences of intense neomorphism, and leaching. Aragonitic oölites contain appreciable amounts (10,080 PPM) of strontium (Kahle 1965b). A major part of strontium is lost during early diagenesis of oölitic sediments (Kahle 1965b, p. 855). Recent corals and various types of algae also have a high strontium content in their skeletons (Lowenstam 1966). It seems reasonable to assume that diagenetic reconstitution of various organic and inorganic materials contributed to the concentration of strontium, which subsequently replaced the original

Explanation of Plate 70

Figure 1 Euhedral, cubic pyrite (light area with dark heavy outline) cutting across allochems (intraclasts) and microspar, indicates a very late stage of formation (Unit III, Port McNicol quarry). Pyrite seems to grow from interallochem pore spaces. X 55.

Figure 2 Irregular pyrite (light area with dark high outline) replacing crinoid fragments. (Unit IV, Point Ann quarry). X 55.

Figure 3 Calcite pseudomorphs after dolomite. Coarse euhedral rhombic calcite forms idiotopic fabric. (Unit II, McGinnis and O'Conner quarry). Rhombs of calcite contain abundant dusty inclusions. Note the aggregate of small rhombs (dark) growing irregularly within large clear dolomite rhomb (marked X). X 55.

PLATE 70.

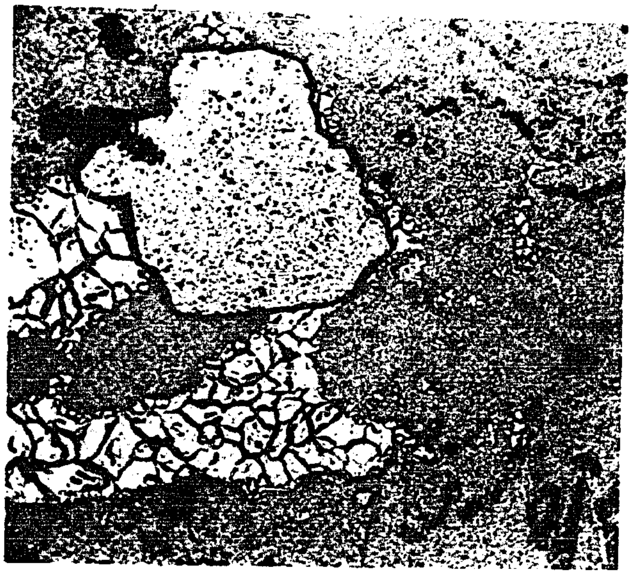


FIG. 1

FIG. 2

FIG. 3

Explanation of Plate 71

Figure 1 Thin dark microstylolites growing across allochems (pellet) and clear sparry calcite ground mass suggest a late stage of development (Unit III, Point Ann quarry). Note oblique branching of microstylolite. X 55.

Figure 2 Microstylolites cutting across both allochems (oöliths) and sparry ground mass (Unit III, Roblindale quarry). Note lateral displacement and interpenetration of individual oöliths along microstylolites. X 55.

Figure 3 Microstylolites cutting across micrite (Unit II, Port McNicol quarry). Note stylolites follow the spar filled organic molds. Spars filled cavities do not show drusy mosaic texture and contain inclusions of dark micrite indicating neomorphism of original material (organic?) Sparry calcite filled areas also show uniform smooth outlines. Dark opaque spots represent pyrite. X 55.

PLATE 71.

FIG.1

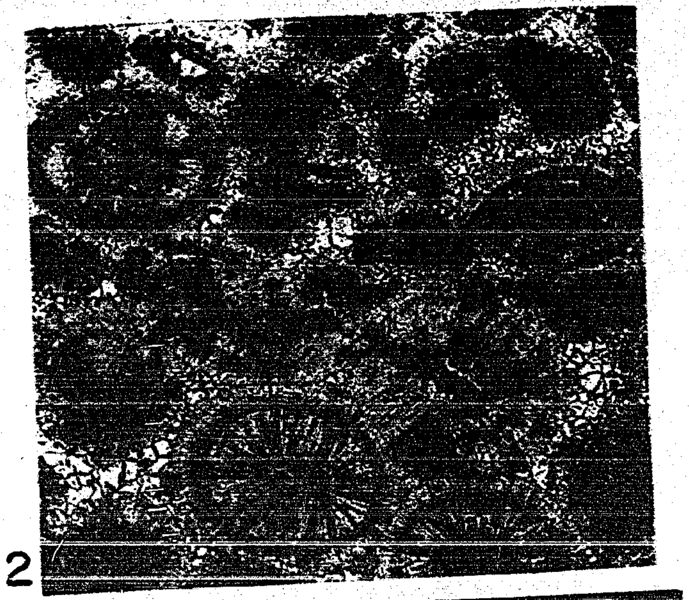


FIG.2

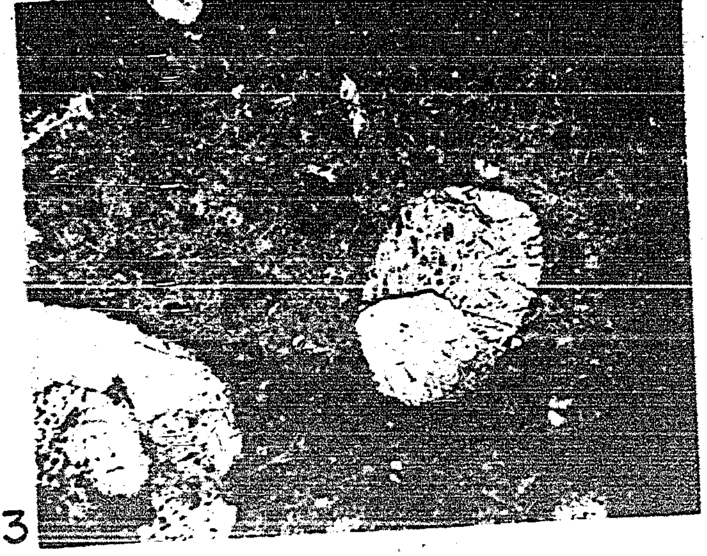


FIG.3

micrite as celestite.

Pyrite:- Pyrite is frequently observed in skeleton-rich rocks. In most cases pyrite shows irregular replacement of pelmatozoan fragment (Plate 70, fig. 2). In allochem rich rocks pyrite usually grows outward from the interallochem areas (Plate 70, fig. 1). Pyrite exhibits a variety of shapes, ranging from euhedral, cubes (Plate 70, fig. 1) pyritohedrans to irregular anhedral nodular grains. The combined action of decay of organic detritus, and sulphate reducing bacteria probably caused the formation of pyrite. The ~~exact~~ process of pyrite formation can be represented by the following chemical equation:

$$CaSo_4 + 8H \text{ (obtained from organic decay)} = CaS + 4H_2O;$$

$$CaS + Co_2 + H_2O = H_2S + CaCo_3$$

The liberated H_2S combines with iron to form iron disulphide.

Pressure Solution

The effects of pressure solution is most evident in micrite as microstylolitic contacts. Microstylolites are rarely noted in coarse allochem-rich sparry calcite cemented rocks. The effect of pressure solution reveals the following characteristic features:-

a) Presence of microstylolitic contact (Plates 71, figs. 1 to 3; Plate 72, figs. 1 and 2).

b) Microstylolites develop parallel to bedding planes with occasional oblique bifurcations (Plate 72, fig. 2).

c) Microstylolites transect allochems and the surrounding groundmass. These also cause lateral displacements in allochems (Plate 71, figs. 1 and 2).

Explanation of Plate 72

Figure 1 Microstylolites bending around prismatic quartz crystal. (Unit II, Hwy. 401 section at Hwy. 15 exit). (Irregular thin dark bubble like areas are due to faulty peel preparation). X 55.

Figure 2 Microstylolites developing parallel to the bedding in micrite. Resistant phosphatic curved fragment of conodont remains upright against bedding plane (Unit III, Havelock quarry). Microstylolites stop against conodont or follow along its outer margin. Dark materials in microstylolites represent concentration of clay. Note the termination of stylolites against the irregular coarse sparry lenses. (Dark spots are due to faulty peel preparation). X 55.

Figure 3 Thin curved fragments of brachiopod (recrystallized) extending upright across bedding lamination from the lower dark micrite into microsparry micrite (Unit II, Hwy. 401 section, 5 miles east of Napanee). X 55.

PLATE 72.

FIG. 1

FIG. 2

FIG. 3

Explanation of Plate 73

Figure 1 Micrite with fine weakly defined microstylolites. Microstylolites show abrupt termination into irregular clear (iron rich) coarse sparry calcite areas (unit II, Marmora quarry). X 22.

PLATE 73.

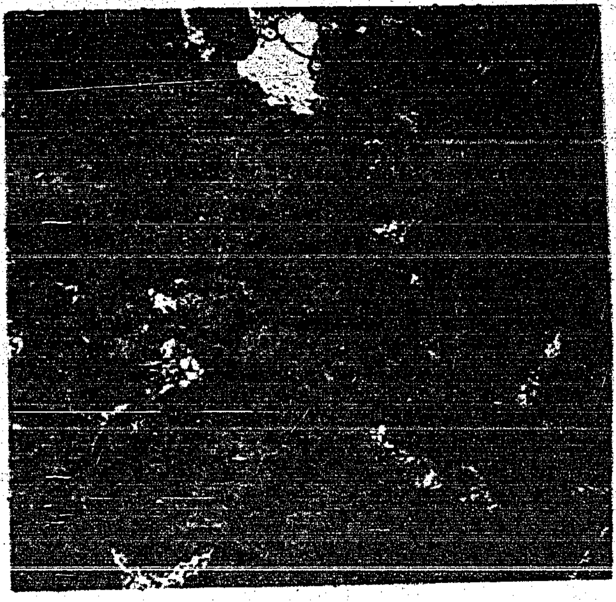


FIG.1

d) Microstylolites do not cut across quartz or other stable noncarbonate allochems (Plate 72, figs. 1 and 2).

e) Clay, dolomite and other in soluble materials are concentrated within microstylolitic contacts (Plate 72, fig. 2).

f) Commonly microstylolites show abrupt termination against the irregular coarse sparry calcite-filled areas (Plate 72, fig. 2; Plate 73, fig. 1). Staining of coarse calcite shows enrichment of iron.

g) Surfaces away from the microstylolites do not show any evidence of pressure solution.

h) The presence of upright, curved, brachiopod, and conodont fragments across bedding planes indicates at least a partial induration of the sediments with little or no compaction before microstylolitisation (Plate 72, fig. 2).

i) Microstylolites in micrites occasionally bend around coarse calcite filled cavity structures. The cavities have smooth rounded margins resembling infilled organic molds (Plate 71, fig. 3).

j) Coarse spars contain inclusions of dark micritic material and do not display any penetration by microstylolites (Plate 71, fig. 3).

The evidences as listed above clearly support a late diagenetic evolution of microstylolites in the partially lithified carbonate sediments. Stockdale (1922, 1943) suggested stylolites resulted from the differential solution of materials in hardened rocks under pressure on both sides of the bedding plane or lamination. The various evidences as mentioned under heading c to e can be easily explained by Stockdale's process. Shaub (1939, 1949) proposed that stylolites were formed by alternate deposition of clay and lime mud. Connate water expelled from lime mud would tend to migrate upward and find its way blocked by imperneable clay layer. The lime mud lying above the clay layer would be dried up due to exposure. Thus a tension could be generated between the dried up upper lime mud and the wet lower mud layer separated by an intermediate clay layer. Finally the tension would be released by the upward pushing of soft wet underlying sediments into the overlying dry lime mud. This will result in interpenetration of two layers as stylolites. The criteria as listed under heading a to e can be explained by Shaub's tension release method of stylolite formation. However, the impracticability of contraction pressure process can be clearly explained by the following facts:-

A) No microstylolite can be seen in rocks where finely laminated, alternate micrite and carbonaceous clayey layers are present.

B) Complete lack of any deformation in the layers above and below microstylolites.

C) Lateral shifting and interpenetration of allochems (Plate 71, figs. 1 and 2).

Prokopovich (1952) suggested stylolitisation could originate by solution of sedimentary layers. The solution causes irregular pinnacles and depression, while the insoluble (clay) would cover the irregular surface. Redeposition of new carbonate sediment on the clay covered irregular surface will assume stylolitic nature. The partial validity of this process in carbonate rocks cannot be overlooked. Frequent presence of very fine microstylolite like laminations parallel to the bedding planes in a sequence of alternate clay and carbonate-rich layer can be explained by Prokopovich's mechanism.

Similar features have been noticed in the Black River limestones. Jaanusson (1961) and Lindström (1963) also described similar features as "discontinuity surface" from the Ordovician limestones of Scandinavia. However, other features such as the bifurcating nature of microstylolites, truncation of bedding planes, displacement and interpenetration of individual allochem etc. indicate that the process of simple solution of carbonates under subaerial condition would not result in microstylolites.

In conclusion, it is suggested that the pressure solution process as defined by Stockdale represents strictly a post-depositional or late diagenetic phenomenon in the Black River limestones. The process involves solution of material along strained intergrain contacts and deposition of dissolved material in areas of less pressure (Bathurst 1958, p. 22). The presence of irregular calcite spar-filled areas causing abrupt termination of microstylolites represents deposition of calcium carbonate which was derived from pressure solution.

Compaction

Compaction of sediments results from the weight of overlying strata. Compaction of sediments may cause decrease in porosity, closer packing of grains, deformation of sedimentary structures and fabrics and recrystallisation. The various compaction effects may be of early or late diagenetic origin, and depend on the following factors: 1) the rate of sediment accumulation and supply, 2) tectonic stability of the depositional area. The study of various textural features of the Black River limestones clearly reveals, that most of the diagenetic changes of sediments have taken place under little or no compaction. The evidences strongly supporting the above idea are given below:

1). A complete lack of deformation structures.

2). The presence of delicate, thin curved shell fragments resting straight across the bedding planes (Plate 72, figs. 2 and 3).

Dedolomitization

The replacement of calcite by dolomite is a common feature while the reverse process of replacement is rarely known in limestones. Von Morlot~~e~~ (1948) first stated the possibility of replacement of dolomite by calcite and used the term dedolomitization (Shearman <u>et</u> <u>al</u>. 1961, p. 13). Calcite pseudomorphs after dolomite have been observed locally in Kingston and Georgian Bay areas. Dedolomitization is entirely restricted within the limits of unit II, especially in the basal parts. The rocks are characterised by the presence of high percentage of celestite and anhydrite. Commonly, the rocks display yellowish buff colours, and a coarse (0.03 mm to 0.11mm) mosaic of idiotopic fabric, with interlocking euhedral rhombs of calcite. The rocks exhibit the following important textural characters:-

a) Euhedral rhombic calcite forming idiotopic fabric (Plate 70, fig. 3).

b) Crystals with a high content of inclusions (Plate 70, fig. 3).

c) Presence of small rhombic crystals of calcite within large clear rhombs of dolomite (Plate 70, fig. 3).

d) Stained thin sections showed irregular distribution of dolomite within calcite pseudomorphs. Commonly, the rhombs contain dolomite around the central calcite nuclei. The presence of dolomite in the central nuclei can also be observed.

e) Preliminary electron probe analysis of four selected dolomite rhombs indicated a marked increase of magnesium and iron contents around the periphery while calcium showed high values in the centre. All estimates are qualitative.

f) Some rhombic euhedra also display relict crystal boundaries of original dolomite as dark, fine dusty inclusions within large rhombic calcite. Shearman *et al.* (1961, p. 7) described similar zoning as due to ferric oxide staining. It is interesting to note that electron probe analysis of crystals showing zonal structure, also reveals high magnesium and iron content corresponding to such dusty zones. Goldberg (1967, p. 765, fig. 12) recognized a similar zoning in the dedolomitized Jurassic limestones of Hamakhtesh Haqatan, areas of Isreal.

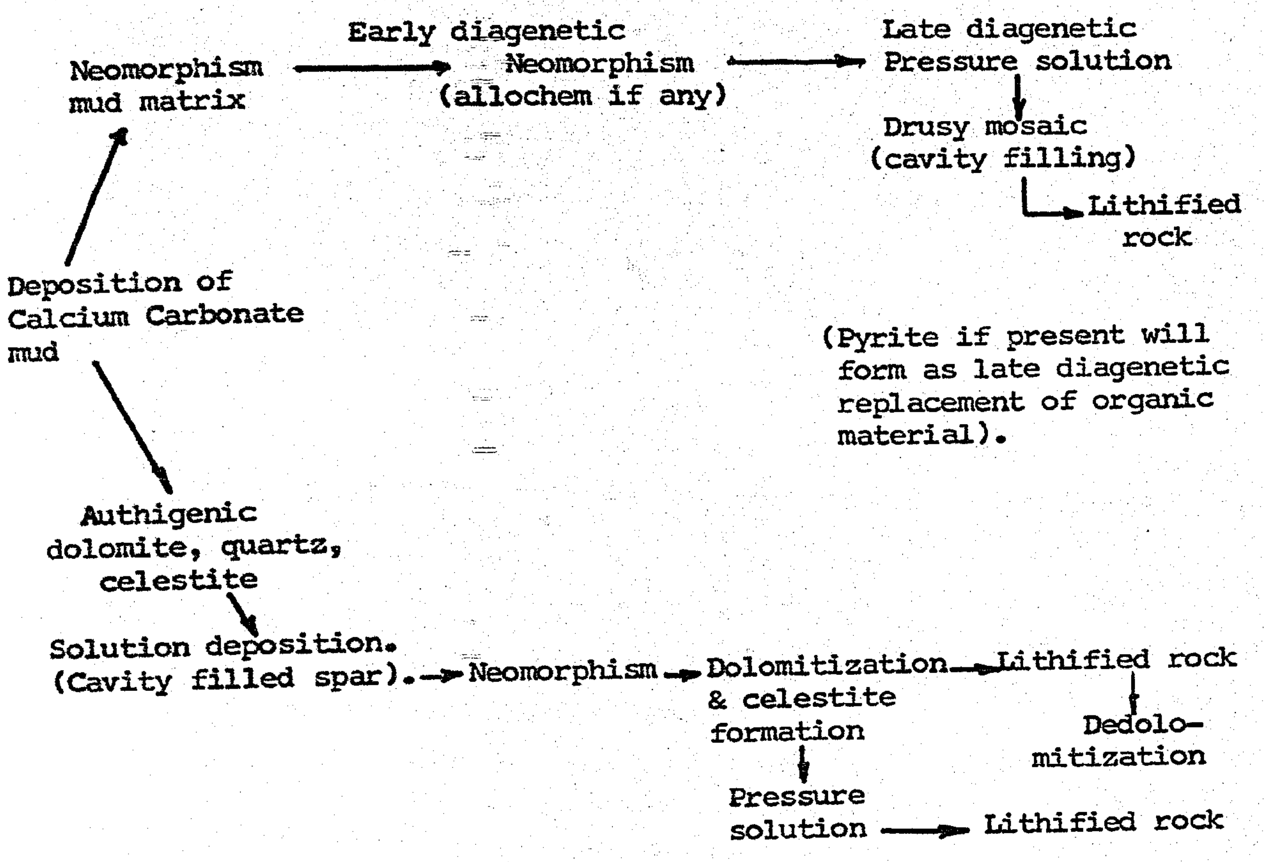
According to Goldberg (1967), Von Morlot's (1848) process of the gypsum-dolomite reaction may cause dedolomitization by the following chemical equation: $CaMg(Co_3)_2+CaSo_4 2H_2O = CaCo_3+MgSo_4+2H_2O$. "The sulphate ions are supplied by the solution leaching of gypsum and or anhydrite" (Goldberg 1967, p. 771). Yanateva (1955) examined the solubility of dolomite in sulphate solutions under varying PCo_2 and suggested that under low PCo_2 dedolomitization was a common process. The oxidation of pyrite may also produce sulphate ions required for the dedolomitization process. Both fresh and oxidized pyrite have been noted in the insoluble residues of various Black River limestones.

The distribution of pyrite seems to have an inverse relation with the dolomite content of rocks, while the other sulphate minerals show a direct relation i.e. high dolomite content is associated with high amounts sulphate minerals (e.g. gypsum, anhydrite, celestite etc.) and low pyrite distribution. It is suggested that the distribution of sulphate minerals probably controls the local nature of late diagenetic dedolomitization in parts of the Black River units.

Sequence of Diagenesis

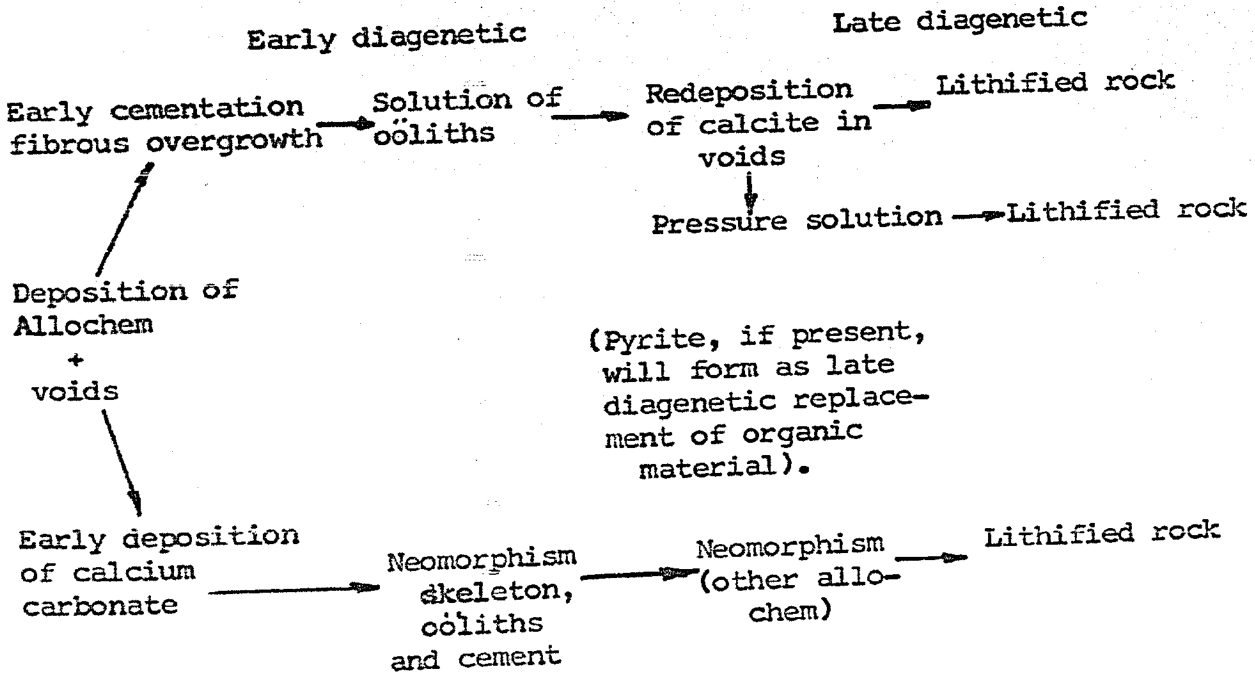
The ancient carbonate rocks have extremely complex diagenetic history. The nature of original skeletal and non-skeletal compositions can play a major role in the evolution of final lithified limestone. No one diagenetic process can explain the mode of lithification of various petrographic types, as observed in the Black River units. A careful consideration of various textural evidences as discussed in the preceding section may greatly aid, in establishing approximate sequences of diagenesis for several broad lithologic groups. Diagenetic trends of three major limestone groups are schematically shown below.

1. Carbonate mud (allochem absent or rare).



(Pyrite if present will form as late diagenetic replacement of organic material).

2. Allochem rich sparry calcite rock.



(Pyrite, if present, will form as late diagenetic replacement of organic material).

3. Allochem-rich micrite rock. The diagenetic sequence of this group is extremely complex and cannot be represented in a simplified scheme. The rocks may show various combination of diagenetic processes as shown in the first two preceding schemes. Some of the important diagenetic features are summarized below.

a) Micritic matrix-rich rocks invariably show the development of microspar. In rare instances, a gradation of microspar to pseudospar can be noticed.

b) Allochem-rich micrites with abundant, skeletal material are characterized by the dominant growth of pseudspar.

c) No evidence of pressure solution is observed in rocks showing pseudosparry calcite growth.

d) Late diagenetic dolomitization can only be seen in micritic matrix-rich lithologies. Commonly, dolomite is restricted within the matrix. Rare presence of isolated dolomite can be seen in pellets or intraclasts.

CHAPTER 9

ORIENTATION FABRIC OF CONSTITUENTS

Pettijohn (1957, p. 72) defined the fabric of sedimentary rock as "the orientation or lack of it, of the elements, of which a rock is composed". Two types of fabric can be defined namely, deformation and apposition. The former is caused by external stress on the rock, and occurs in metamorphic rocks and therefore is not applicable in the present investigation. The apposition fabric is formed at the time of sedimentation. The compaction of sediments accompanied by reduction in porosity, may modify the original primary character of sedimentary fabrics. The fabric element of a sedimentary rock may be a single crystal, a detrital fragment, a fossil or any other particle which exhibits dimensional inequalities and behaves as a single unit with respect to the applied force (Pettijohn 1957, p. 53; Potter and Pettijohn 1963, p. 23). The fabric may have no orientation (isotropic) or it may exhibit a preferred pattern (anisotropic). The anistropic fabric results from alignment of particles in a force field. In sedimentary rocks, such a force field is chiefly controlled by the depositing fluid, (Pettijohn 1957, p. 73; Potter and Pettijohn 1963, p. 23). Like all other physical forces, the fluid force field can be defined by both magnitude (current strength) and direction (direction of applied force or azimuth). In practice, primary directional fabrics or structures are described with reference to the transport direction or current direction and the bedding or the depositional surface.

During deposition, elongate particles tend to attain a stable position with their long dimensions parallel to the direction of current flow. Other factors, such as bed roughness and their associated turbulent flow, secondary currents, etc., may or may not increase the overall dispersion of original stable fabric of sediments, but the original symmetry of fabric remains more or less constant (Potter and Pettijohn 1963, p. 28).

The principal aim of the study of sedimentary (primary) fabrics has been the reconstruction of current direction during the deposition of ancient sediments. Sorby (1859) realized the importance of paleocurrent studies for the understanding of ancient physical geography. The fundamental principle of paleocurrent study chiefly involves measurement of direction of mega- or micro-features with reference to the known depositional surface or bedding plane.

In recent years, the orientation of detrital grains in coarse clastic rock has become the subject of intensive research, and a large amount of fabric information can be obtained from the works of Dapples and Rominger (1945), Schwarzacher (1951), Curray (1956), Rusnak (1957), Nairn (1958), Ganguly (1960), McBride (1960), Bouma (1962), and Potter and Mast (1963).

The limestones have been almost completely neglected for systematic study of directional fabrics. It is well established that the majority of shallow water carbonate environments closely resemble the depositional models of their terrestrial counterpart. The particulate materials in carbonate rocks respond in exactly the same way as noncarbonate detrital grains, and exhibit primary directional fabrics and structures (Potter and Pettijohn 1963, p. 245). The studies of orientation fabrics in carbonate rocks are entirely restricted within large scale sedimentary structures or very coarse to coarse particles of skeletal or non skeletal origin. In this connection, references can be made to a few scattered early observations of James Hall (1843, p. 52-54), Ruedemann(1897), Kindle (1914) and some detailed studies by later workers like King (1948), Chenoweth (1952), Schwarzacher (1961, 1963), Imbrie and Buchanan (1965), Klein (1965), Hoffman (1966), and Selley (1967b).

Detailed research on limestone microfabrics is rare. Bruno Sander (1936) studied the Triassic limestones in Austria, and first demonstrated the importance of microfabric as a paleocurrent indicator, which has been adopted increasingly for basin analysis of clastic rocks. Since Sander's (1936) pioneer work, references can only be made to the works of Stauffer (1962), Schwarzacher (1963) and Lee and Winder (1967).

The undeformed nature, wide regional extent, and the presence of a complete spectrum of carbonate lithology of Black River rocks provided an ideal situation for microfabric analysis. About 268 oriented peel sections with a total measurement of orientation of 21,732 grains were studied. The results of each individual sample were grouped into 20° class intervals, and plotted in current rose diagram. The number of principal modes in each current rose diagram can be determined approximately by noting the total number of strongest maxima trends or most commonly occurring values. A composite current histogram showing the

FIG. 9. HISTOGRAM SHOWING THE DISTRIBUTION OF FABRIC ORIENTATION MODES IN THE BLACK RIVER ROCKS.

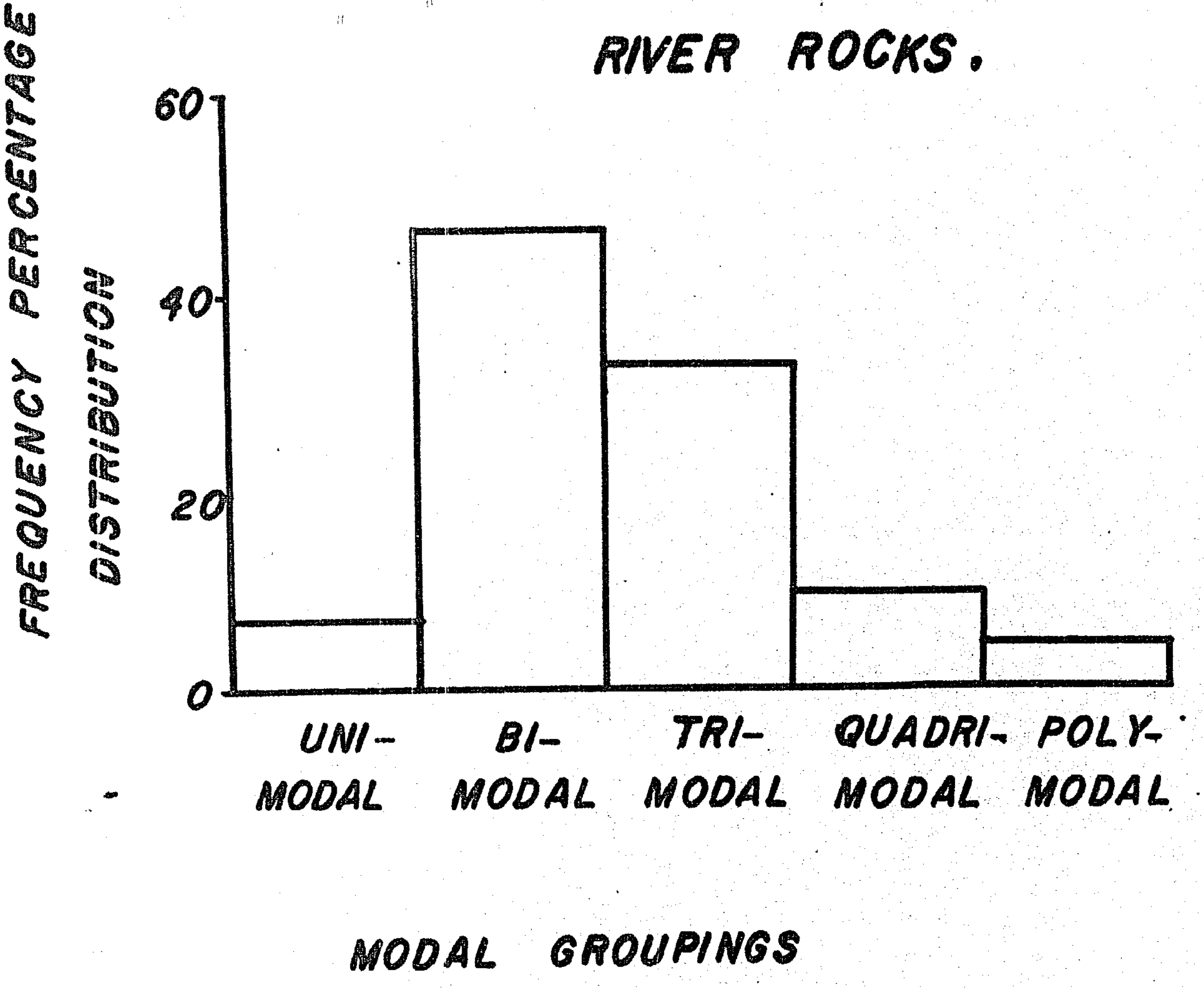
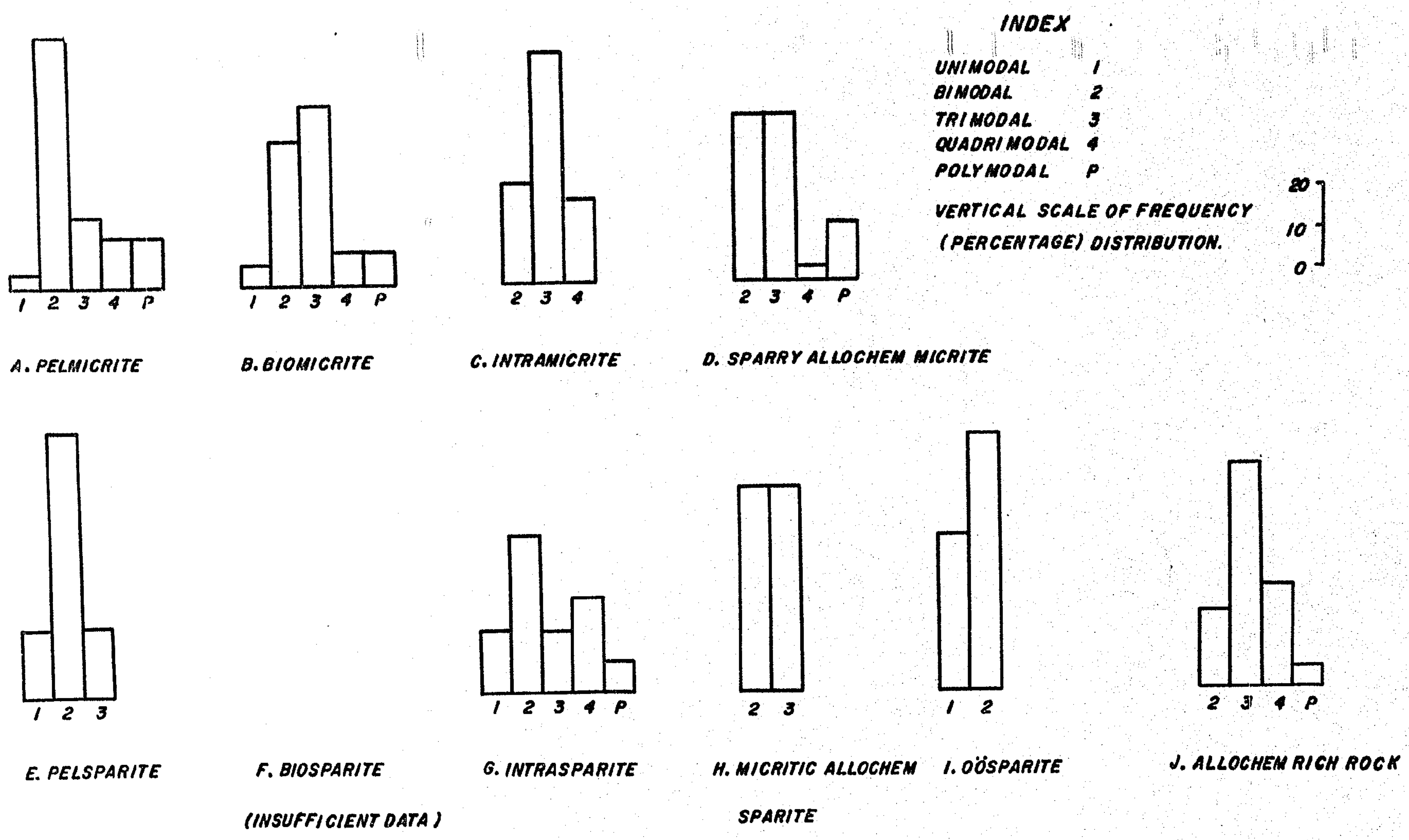


FIG. 10. DISTRIBUTION OF FABRIC ORIENTATION PATTERN (MODAL) IN DIFFERENT PETROGRAPHIC TYPES.



A. PELMICRITE B. BIOMICRITE C. INTRAMICRITE D. SPARRY ALLOCHEM MICRITE

E. PELSPARITE F. BIOSPARITE (INSUFFICIENT DATA) G. INTRASPARITE H. MICRITIC ALLOCHEM SPARITE I. OÖSPARITE J. ALLOCHEM RICH ROCK results of all fabric measurements suggests a five fold classification of the Black River carbonates (Figure 9) specifically unimodal, bimodal, trimodal, quadrimodal and polymodal fabric patterns. However, the bimodal fabric trend seems most frequently developed in these rocks.

Recent works of Potter (1967, p. 348-350), Klein (1967, p. 370-372) and Selley (1967b, p. 215-223) provide information on the nature of primary fabric of the sediments of various environments. Though most of the recent studies by these authors are based on cross-bedding data, the gross character or the nature of fabric pattern can be compared with the results of the fabric analysis of the Black River. Unlike cross-bedding data, no definite current direction or paleoslope can be established from the microfabric study of Black River limestones. A predominently bimodal fabric pattern of these rocks with minor associations of trimodal, quadrimodal and polymodal trends (Figure 9) suggest a shallow water tidal environment of deposition (Potter 1967; Klein 1967; Selley 1967a). Other structural, petrographic, chemical and mineralogical characters as discussed earlier, would also seem to corroborate this environmental interpretations.

A plot of the chief maxima trends against their frequency percentage distributions (Figure 10) suggests that a relationship exists between the nature of petrographic types and the number of developed preferred maxima. The following features can be seen in this figure.

a) A bimodal pattern of fabric occurs in most rocks.

b) The fabric variability is pronounced in micrite rich rocks (A to D).

c) Sparry calcite cement-rich rocks (E, G, H, and I) commonly have a strong development of bimodal maxima.

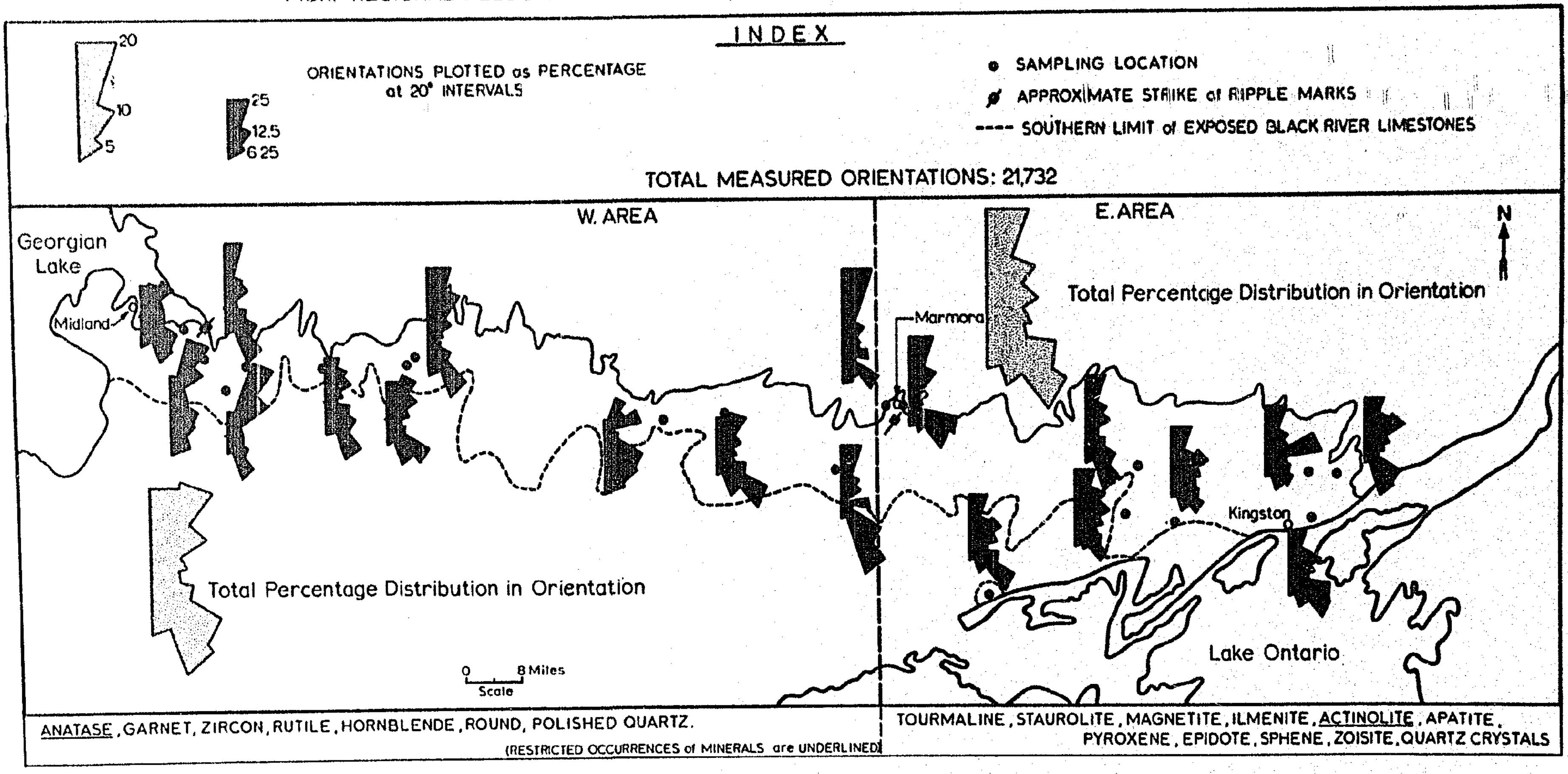
d) Rocks with skeletal-rich materials display a more variable orientation pattern irrespective of the presence or absence of micritic matrix and sparry calcite cement (B, F, and J).

e) The rocks of mixed lithology show dominantly bimodal orientations with a strong association of trimodal trends (D and H).

The extreme fabric variability in micritic rocks may be related to the degree of current agitation.

Micrites are usually considered to indicate quiet water weak current activities (Folk, 1958, 1962). The strongly bimodal nature of sparry calcite cement-rich rocks may be due to greater current agitation in the original environment. The marked fabric variability of micritic matrix and sparry calcite cement-rich rocks may also be dependent on the nature of original depositional surface. Flume experiments (Schwarzacher 1963, p. 583) have revealed that during transportation, a bottom composed of sand sized particles offers greater resistance to the rotation of deposited particles than a smooth mud bottom surface. The flume study also showed "if more than one test body was placed in the flume, a much more complex orientation patterns developed as the particles interferred with each other". The fabric variability of skeletal rich lithologies may reflect extensive scavenging activity of burrowing organisms. The evidences of burrowing which would modify and obliterate original structural and textural features of the carbonate particles are common in both recent and ancient carbonate environments. The extreme bimodal maxima trends of mixed lithologies with a strong development of trimodal nature may also result from the interaction of various particles during transportation. Finally the variability of the fabric may not necessarily display the

FIG. II REGIONAL ALLOCHEM ORIENTATION, and DISTRIBUTION of HEAVY and LIGHT MINERALS



existence of shifting current systems in the depositional environment. All experimental studies showed the development of submaxima as a result of the friction of particles on the floors or their different hydraulic behavior (Schawarzacher 1963, p. 584).

Composite rose diagrams including all fabric measurements at each stratigraphic section of the Black River are shown in figure 11. In most areas strong bimodal fabric trends are evident with some exceptional polymodal trends. Commonly the major fabric trends show an angular dispersion of 90° to 120° or more. The sediments of tidal flat areas are characterized by the development of two prominent current trends at angles of 90° and 180° (Klein 1967, p. 373; Selley 1967b, p. 220, fig. 4).

According to Klein (1967), Potter (1967) and Selley (1967a), bimodal fabric patterns are caused by the influence of tidal currents during ebb and flood tides. In the absence of sufficient cross-bedding data, a definite recognition of the offshore and inshore transport directions cannot be established for the Black River rocks. Near shore sediment movement has also been studied by Johnson (1956) and Curray (1956). In a nearshore region, the sediment transport is chiefly determined by the littoral drift along the shore and the backwash component of waves acting perpendicular to normal littoral drift (Johnson, 1956, p. 2221). The direction of longshore current controls the direction of littoral drift (Johnson, 1956). According to Curray (1956, p. 2447) the effect of backwash is reflected by the development of a strong preferred fabric of elongated particles in a direction at right angles to the beach or shore trend (Curray 1956, p. 2447,

FIG. 12. A PROVISIONAL CLASSIFICATION OF SHORELINE PALEOCURRENT MODELS (AFTER SELLEY 1967).

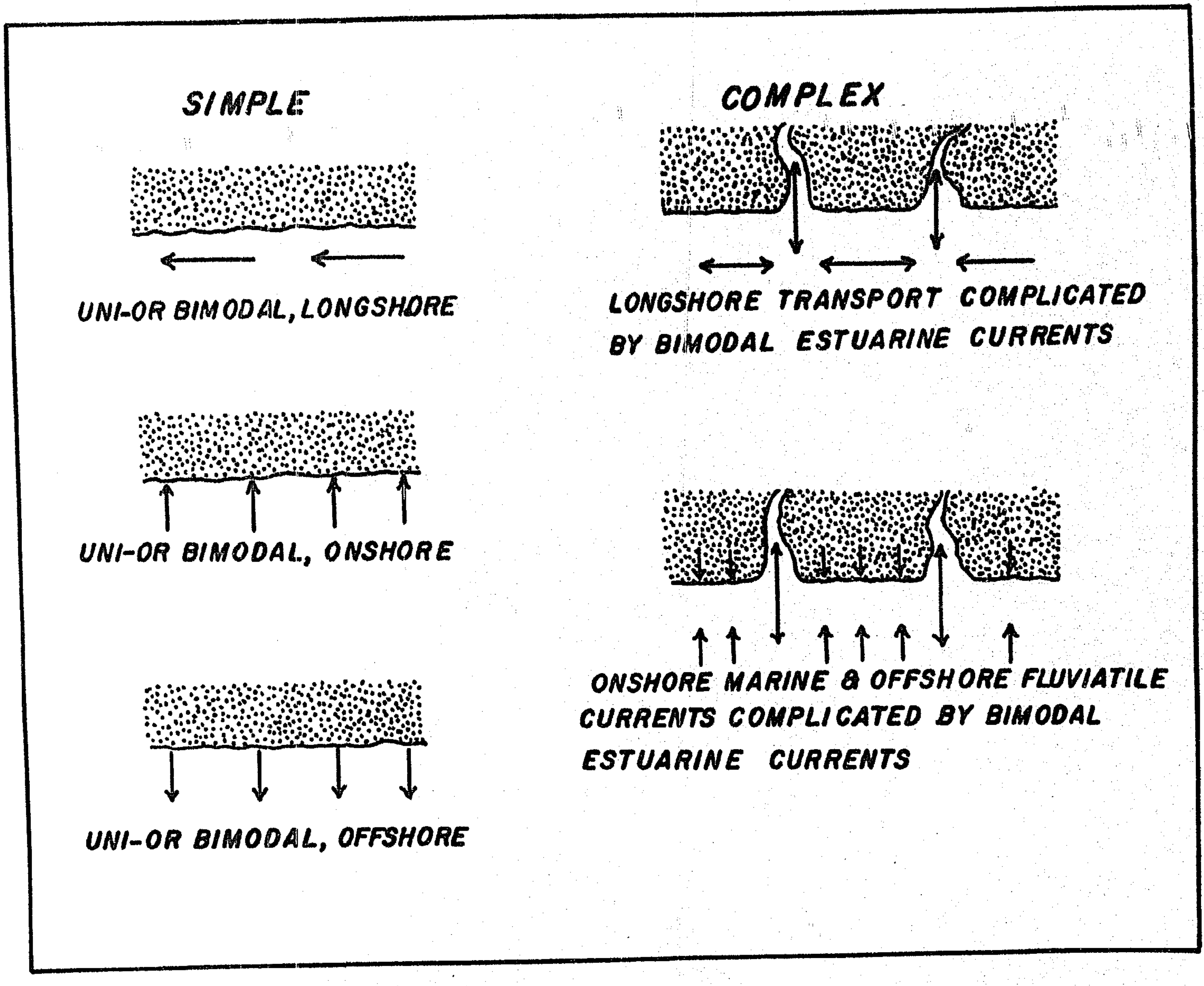


Figure 3). Thus the bimodal nature of the present fabrics may have resulted from the combined action of a longshore littoral drift and backwash effect. Selley (1967a) reported that the bimodal fabric pattern could originate in several possible ways (Figure 12): a) seasonal change of longshore current directions, b) longshore transport complicated by estuarine currents, c) tidal inshore and offshore currents complicated by estuarine currents and d) tidal inshore and offshore currents.

The lack of bimodal maxima trends showing the angular dispersion of 180° perhaps removes the possibility of Selley's model as stated in (a). The second and third possibilities of Selley are not applicable due to the remarkable lack of insoluble terrestrial materials in the Black River carbonates except at the base of the section. The low relief of the Precambrian surface also raises doubt about the possibility of an estuarine model. The effect of inshore and offshore tidal currents cannot be easily denied. On the other hand can it be easily determined? The occurrence of a few cross-bedding and channel filling structures near Kingston area seems to indicate the possibility of tidal currents in NE-SW directions. The presence of occasional symmetrical ripple marks striking in a NE-SW direction at Marmora and Medonte Quarry also strongly suggeststhe possibility of ebb currents (inshore tidal effect). Klein (1967) illustrated mega ripples, the crest lines of which were oriented at right angles to the coast line; he stated that they were formed by ebb currents. A strong persistency of SE-NW trend maxima throughout the present area and constant minor fluctuations of NE-SW trends may suggest the possibility of a combined influence of longshore and tidal currents (Figure 11). The early middle Ordovician paleogeography of Ontario as proposed by Kay (1937, p. 288, Plate 6) may explain the workable nature of the depositional model as proposed in the present section.

The composite current rose diagrams of areas east and west of Marmora (Figure 11) show recognizable trend differences of the two maxima. In the eastern part, both NE and SE trends show a more northerly shift than the similar trends in western regions. Heavy mineral distributions also reflect a notable differences in both areas. The western part has restricted occurrences of anatase, abundant garnet, zircon, tourmaline, hornblende and rounded polished quartz, whereas the eastern area has abundance of staurolite, actinolite, apatite, pyroxene, and doubly terminated prismatic quartz crystals. No definite criteria can be established to explain such differences between the eastern and western areas (Figure 11).

Frequent occurrence of Precambrian inliers in the eastern areas may have had a local influence on the current patterns. Preliminary statistical studies on the results of composite diagrams of eastern and western areas (Figure 11) also suggest the possibility of existence of trend differences in the two areas. However no definite conclusions can be drawn without doing further detail statistical analyses of all individual observations.

CHAPTER 10

INTERPRETATION

The various structural, mineralogical, chemical, textural, and petrographic characters of the Black River carbonates allow certain generalizations to be made regarding their depositional history. Studies of modern carbonate environments clearly provides the evidence that deposition is primarily controlled by physical, chemical and biologic parameters within the depositional realm. In the case of ancient limestones precise determination of such parameters is not always satisfactorily achieved. However, some pertinent inferences can be made by comparing different observed features of the Black River rocks with those of the recent ones.

The association of ripple marks, mud cracks, oöliths, algal stromatolites, pellets and other features strongly fabours the possibility of a shallow water deposition for the Black River rocks. A major part of the Black River is composed of microcrystalline calcite ooze, which could have resulted from chemical and/or biochemical precipitation of calcium carbonate in the form of aragonite. The notable abundance of pure micrite with minor amounts, or complete lack, of organic material would seem to indicate the importance of inorganic precipitation, at least in the lower units (I and II). Similar areas of chemical precipitation of calcium carbonate have been recognized in the Bahama Bank (Illing, 1954; Newell and Rigby, 1957; Cloud, 1962) and the Gulf of Batabano (Daetwyler and Kedwell, 1959). Most of the recent carbonate environments have an average annual temperature range of 28° to 33°C. The presence of dolomite, celestite, anhydrite, and corals in the Black River rocks may also indicate a warm temperature condition similar to the present day area. Ma (1956) postulated that Middle Ordovician depositional areas were near the equator and thereby suggesting the existence of a warm climate. Abundance of well-rounded, (possibly wind blown) frosted quartz grains in the insoluble residues, freshness of feldspars in the basal clastic units of the Black River rocks, suggest the possibility of very low rainfall in the exposed Precambrian continent.

The normal salinity of sea water is about 35‰, but this can be raised to 40‰ or more if the water is evaporated by low humid and high temperatures. Such high salinities have been reported in various present day shallow lagoons or other areas with restricted circulation. Illing <u>et al</u>. (1965), and Kinsman (1966, p. 5) reported salinities of 40‰ to more than 60‰ from the present day supratidal (Sebkha) penecontemporaneous dolomite-forming areas of Persian Gulf. The presence of supratidal dolomite deposits in units I and II of Black River rocks suggests at least similar or higher salinities during the deposition of sediments in the restricted lagoons. A complete lack of skeletal material, except for rare ostracods and algae, perhaps indicates the environment was not favourable for the growth of organisms less tolerant to such highly saline condition. The common salinity in areas of relatively free water circulation ranges between 36‰ and

43‰ e.g. Bahama Banks, and Persian Gulf. It is reasonable to assume that the Black River rocks of unit III and IV are formed in areas with salinities ranging from 36‰ to 43‰ or little more.

The high temperatures of 25°C to 33°C can only be found in sea water in the low latitudes and at depths less than 50 m (Kuenen 1950, p. 18, 25). In recent shallow water carbonate environments the depth of water ranges down to 45 feet. It seems reasonable to assume that a similar water depth existed during the deposition of most of the Black River carbonates. The percentage of incident light energy decreases sharply within the first 3 to 7 feet approximately, and at a depth of about 40 feet it is only 7‰ to 25‰ (Holmes 1957, p. 119). The organisms which rely on light to produce food by photosynthesis will be restricted in the upper few feet of water. The presence of algae, corals, stromatolites, mud cracks etc. suggests frequent subaerial exposures and therefore very shallow depth of water. In various recent supratidal lagoons water depth ranges from a few inches to a couple of feet. It is therefore suggested that in areas of supratidal dolomite-bearing sediments of the Black River rocks, water depth was extremely shallow.

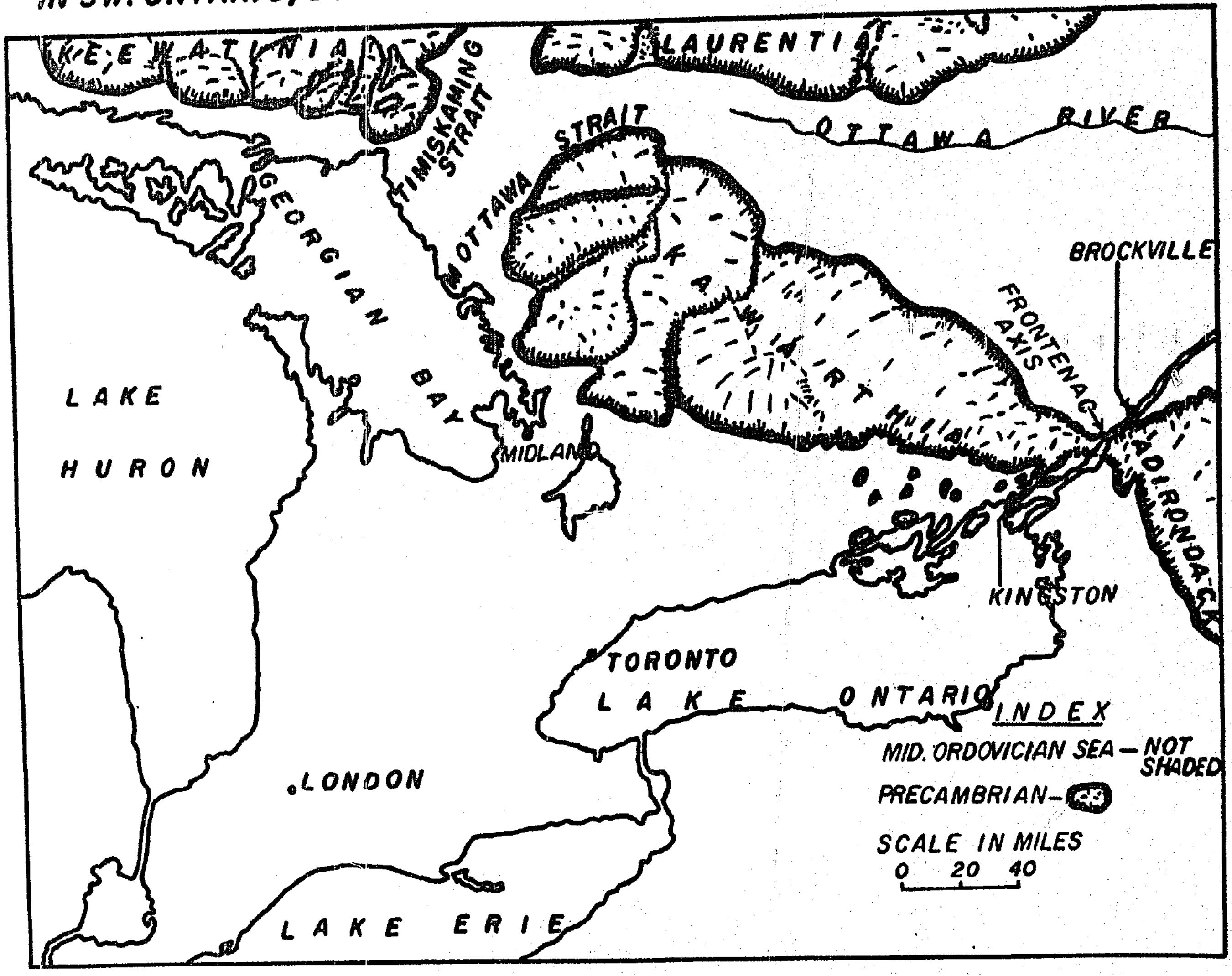
Differences between the eastern and western areas along the outcrop belt of Black River rocks can be easily understood if it is assumed that a more special, restricted circulation existed toward the east.

Areas west of Marmora show minor amounts or complete lack of anhydrite in the rocks of unitsI and II. Rocks of the same unit in areas east of Marmora exhibit an increasing abundance of anhydrite. It is thought that a more restricted nature of environment in the east could result in such mineralogical differences. The Kingston and Napanee areas show evidences of intense dolomitization in rocks of unit III and IV. Release or migration of Mg^{++} rich brine from an extremely saline supratidal condition to the adjacent more open water environment could have resulted in the dolomitization. Similar refluxing of dolomitizing fluid is reported from recent Bonaire Antilles carbonate environments (Deffeyes et al., 1965).

Rocks east of Marmora show an abundance of doubly terminated quartz crystals in the insoluble residues. Extremely rounded wind blown quartz grains are abundant in the Black River rocks of areas to the west of Marmora. A relatively high saline environment in the east could cause the solution of very fine detrital quartz silt and reprecipition of silica as euhedral crystals. Orientation of allochems in eastern areas also showed frequent shifting of NE-SW maxima trends. This variation of maxima trends can be explained as due to irregular trends of tidal inlets in eastern areas.

Hewitt (1964) summarized the occurrance of a large number of irregularly trending isolated Precambrian inliers in areas east of Marmora. A sudden southeasterly swing of the Precambrian along the Frontenac axis near Kingston toward the Adirondacks could have contributed to restricted circulation during the deposition of Black River limestones. The absence of Lower Ordovician units in southwestern Ontario suggeststhe possibility of a continuous barrier like extension of Precambrian continent (Kawarthia of Kay 1937) from southwestern Ontario to Adirondack (Adirondackia, of

FIG. 13. A MODIFIED PALEOGEOGRAPHIC MAP (AFTER KAY, 1937) SHOWING THE DISTRIBUTION OF PRECAMBRIAN CONTINENTS AND ISLANDS (HEWITT, 1964) IN SW. ONTARIO, DURING THE FORMATION OF BLACK RIVER LIMESTONES.



Kay 1937) or very constricted nature of the outlet separating the Ottawa Valley basin from southwestern Ontario. In either case an extremely saline environment would have developed in areas east of Marmora due to major Precambrian blocks bordering the northern and eastern limits and isolated islands in the south (Figure 13).

The general, highly saline, environment could result from the spreading of vast shallow seas on the peneplained flat, great expanse of Precambrian continents. The areas which do not have complete tidal exchange will be marked by hypersaline condition even in the absence of a physical barrier (Shaw, 1964, p. 10). The salinity gradient will be maintained by geographic separation and an extremely gentle slope of the bottom surface. The presence of small topographic irregularities on shallow seas can disproportionately affect environments for hundreds of miles (Shaw 1964, p. 12). Thus it is suggested that hypersaline condition of deposits in the rocks of units I and II may be due merely to the shallow nature of the sea. The occurrence of isolated Precambrian inliers in the east provided additional restriction and thereby further modified the local chemical environments.

An extremely high concentration of isolated celestite crystals molds, and calcite-filled molds of original anhydrite or gypsum nodules in rocks of unit II suggests the formation of minerals during the deposition of carbonate sediments. Similar concentrations and occurrences have been observed in the sebkha areas of Persian Gulf (Illing et al., 1965, p. 95, 97). The presence of celestite as irregular patches in the rocks of unit III and IV can be due to diagenetic alteration of strontium-bearing oöliths and other aragonite-rich skeleton materials. During diagenesis, strontium can also be derived from aragonite-rich carbonate mud. The increased distribution of neomorphic sparry calcite (recrystallised) in units containing high amounts of corals, bryozoa and brachiopod, reflects the original unstable composition of organic skeletons.

Exceedingly high abundance of pyrite in units III and IV indicate the possible role of bacterial activity due to decay of various organic materials. Such extensive organic growth is more prevalent in areas of normal marine condition. A complete lack or very minor amounts of pyrite in rocks of unit I and II also leads further support to the organic origin of pyrite. Units affected by late diagenetic dolomitization show irregular distribution of pyrite.

High concentration of heavy minerals at Coboconk, Burleigh Falls, and Hwy. 401 and Hwy. 15 exit may be due to various local causes, e.g. stream activities, or erosion. The possibility of any major trunk rivers discharging sediments into the Middle Ordovician sea is not likely as indicated by the remarkable low content of insoluble materials in Black River rocks. According to Ambrose (1964, p.817) the drainage pattern as exposed to-day in the Precambrian shield is at least as old as Pre-Ordovician time.

It is interesting to mention that an isopach map of Sanford (1961, fig. 4) shows a distinct NW-SE trending thicker area passing through Burleigh Falls and Coboconk areas. The sharp rise of heavy minerals in areas east of Marmora may probably be related to this regional feature. Remarkably low concentration of heavies in the rocks of unit I and II is possibly due to the unstable nature of various silicates under highly saline environment of the supratidal lagoons. A general common occurrence of most heavy minerals throughout the rocks of four major units indicates derivation of material from a common source and also the differential stability of silicate minerals under varying environments. The differences of heavy mineral compositions in areas to the east and west of Marmora reflect the original differences in composition of Precambrian source areas.

Frequent local, lateral and vertical mixing of different petrographic constituents in the rocks of various units of Black River rocks suggests the possibility of repeated migration of adjacent facies or environments due to the fluctuation of mean sea levels. Similar complex nature of lithofacies is also observed in the present day carbonate areas. The general trend of increasing calcite/dolomite ratio, association of oöliths, composite grains, corals, brachiopods, bryozoa and other fossil fragments in rocks of units III and IV of Black River rocks explain the gradual migration of highly saline supratidal environments as indicated by dolomite, celestite anhydrite-rich and deficiency of skeleton fragments (units I and II) to relatively higher energy, normal free circulating shelf lagoon conditions.

Presence of more or less persistent NW-SE maxima trends of allochems represents a longshore drift of sediment. Occasional cross-bedding and channel marks in the oosparites near Kingston indicate NE-SW trend of tidal inlets.

Thus the present strike of the Black River outcrop may coincide with the original depositional area parallel to the Precambrian shore;

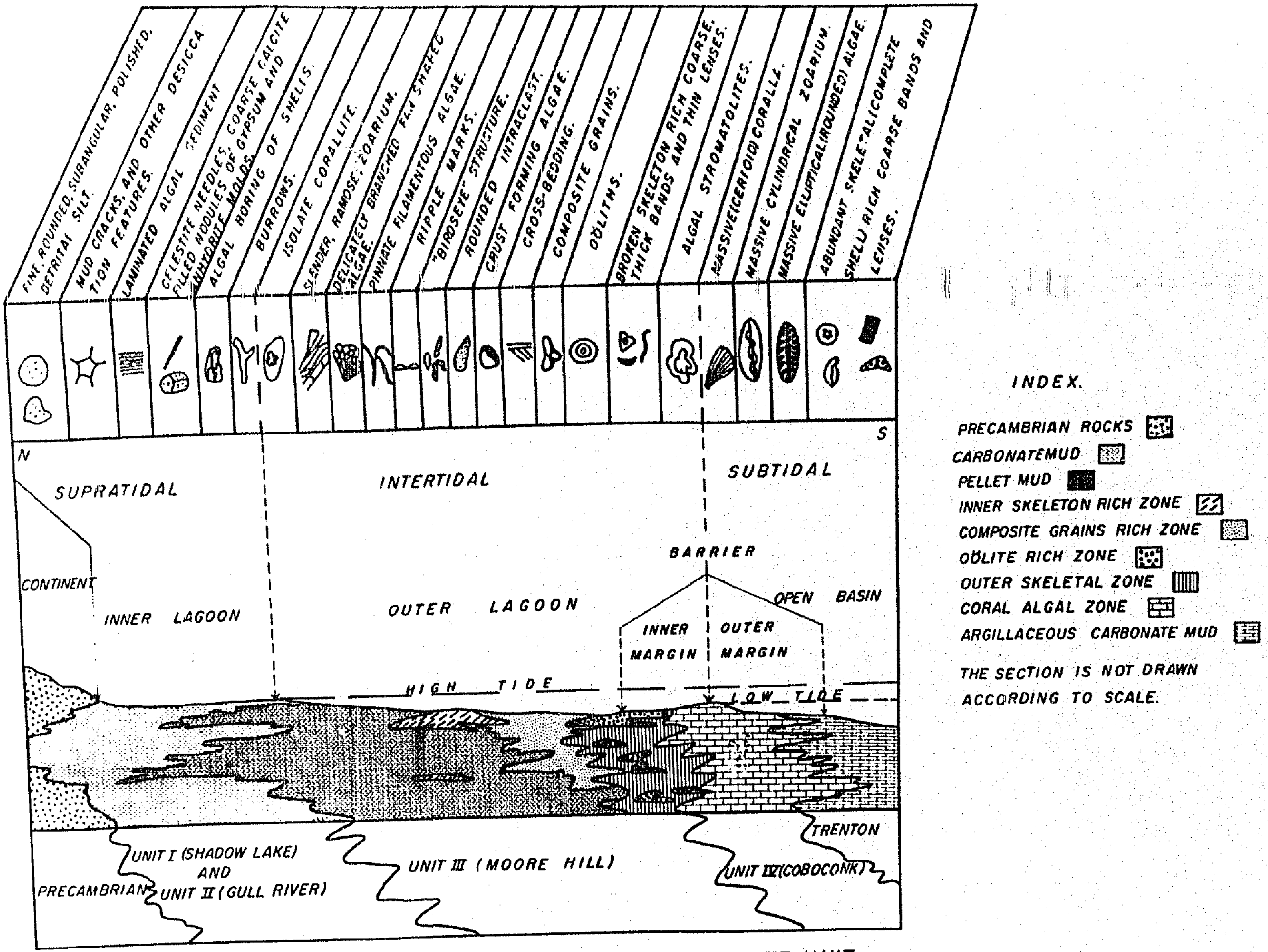


FIG. 14. ENVIRONMENTS OF THE BLACK RIVER CARBONATE UNIT AND DEVELOPMENT OF LITHOFACIES.

oösparites represent the development of shoals margining the outer edge of shelf lagoons. Similar shoals margining the outer edge of Bahama Bank or Florida Bay are known in modern carbonate environments.

The formations of the Black River Group are interpreted as a sequence simultaneously deposited in coexisting environments (Fig. 14). Micrite-rich basal rocks of unit I and II are formed in a supratidal lagoonal environment as indicated by frequent abundance of mud polygons, selective growth of algae, dolomitization around desiccation cracks, highly laminated nature of sediments with burrow structures, intraclast, celestite crystals and molds, algal boring and extremely high dolomite content. The association of pellets and occasional oöliths can also be recognized in the upper parts of unit II, representing a transitional passage to the adjacent environments. The rocks of supratidal inner lagoon mark a relatively calm low energy environment with occasional inflow of marine waters from adjacent areas during the periods of storm or very high tides.

Rocks of unit III are characterised by pellet mud deposits of the shelf lagoon type environment. Other characters include frequent ripple marks, delicately branched slender bryozoa, fan shaped algae, filamentous algae, and crust forming algae. These show frequent association of irregular composite grain "grapestone" type deposits immediately adjacent to the oölith-rich rocks. Oölith-rich rocks show some cross-bedding. The occurrence of shell-rich horizons in unit III probably reflects local concentrations of organic communities upon raised substrate. Oöliths mark the development of shallow shoals along tidal inlets bordering the outer seaward edge of shelf lagoon. The

Explanation of Plate 74

Figure 1 Coral (Stromatocerium) rich biostromal nature of unit IV rocks. This outcrop is exposed on the Crowe River, east of Crowe Bridge, near Campbellford, Ontario. G.S.C. 134332.

PLATE 74.

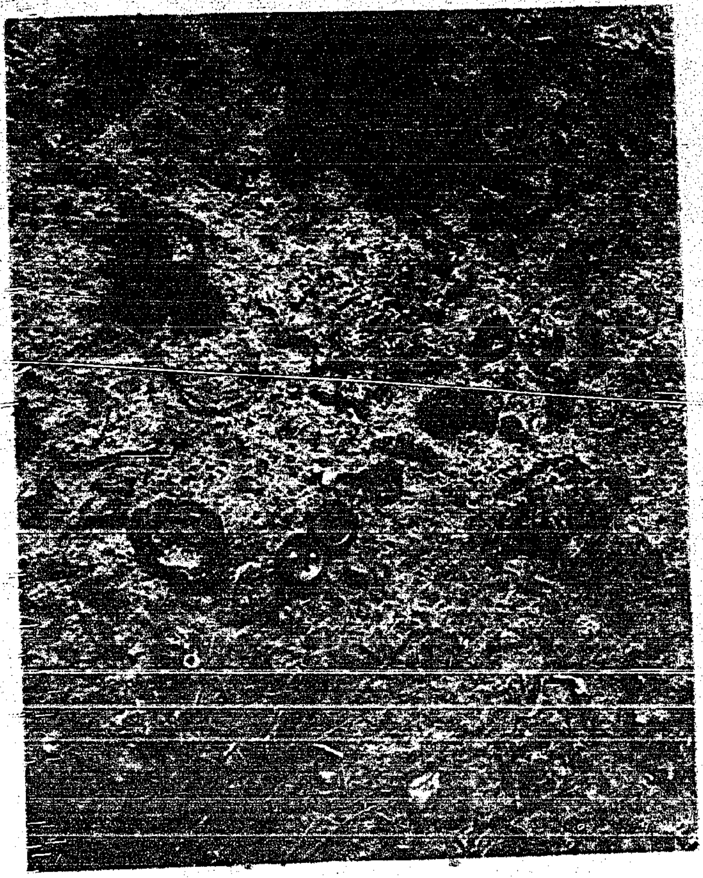


FIG. 1

deposits of intertidal shelf lagoon exhibit a gradational passage of high to low energy areas from the outer edge of oölitic shoals to inland margin respectively. The area is characterised by frequent in and out flow of marine waters during tides. Growth of isolated, irregular organic-rich areas on raised bottom surface may locally act as barriers and give rise to quiet water lagoon type sediments. Similar local isolated low energy areas can be seen in the Bimini Lagoon (Bahama Banks) and Florida Keys (Florida Bay). Development of large oölitic shoals along the seaward outer edge also contributes greatly in reducing energy of water movement within the shelf lagoon.

Rocks of unit IV are characterised by an abundance of pellets, linked hemispherical and discrete hemispherical algal stromatolites in the lower part which grade upward into pelmatozoan, massive coral (Plate 74, fig. 1) bryozoa, algae-rich zones. Oölith also occurs in the lower most part of the unit. Thus the basal part of unit IV is transitional between the adjacent shelf lagoon environment of unit III and the shell-rich outer marginal patchy biostromal barrier. The notable fragmentation of skeletal materials and lack of any organically build raised structure in unit IV suggest the possibility of both shelf and open seaward transportation of skeletal fragments derived from the break down of a barrier structure at the outer most seaward edge of the shelf lagoon. In the adjacent deep water environment, i.e. in higher units of Middle Ordovician, the Trenton rocks were laid down. Alternatively, the present skeletal-rich units could also represent isolated small biostromal structure seaward from the outer margin of oölitic shoals. The sediments of subtidal outer shelf undergo strong mechanical actions due to wave action. This is evident from extreme fragmentation of skeleton material, and lack of oöliths... etc. The paleogeographic configurations as suggested in the present sections are very similar to the Florida Bay and Persian Gulf areas. Both areas show development of various environments adjacent to large continental blocks, bordered by isolated islands along the outer open seaward side.

CHAPTER 11

PROPOSED STRATIGRAPHIC NOMENCLATURE

The stratigraphic classification and nomenclature of the Black River Group is in a state of flux, both in the Mohawk Valley area of northwestern New York, and Ontario. The history and complexity of terminology has already been discussed in a previous section. In the last 20 years interests have been directed towards the Black River rocks of southwestern Ontario, but the classifications of Kay (1937) and Young (1943) included a duality which cannot be rationalized within the standard of the American Stratigraphic code (A.A.P.G. 1961, articles 4 and 6). Perhaps a major part of the controversy arose due to the strong belief by most earlier workers that lithologies are essentially chronostratigraphic (time parallel) units. Kay and Colbert (1965, p. 90) defined "the smaller lithologic divisions of rocks as formations, thus a formation might represent a stage". It is further stated "Formations are rock units normally laid through time of the duration of a stage".

In recent years, Winder (1953, 1960), Cooper (1956), Fisher (1962) and Barnes (1967) have suggested that the Black River rocks are purely lithostratigraphic units.

Most of the faunal assemblages would seem to be ecologically controlled and long ranging, as opposed to the assumption of earlier workers that the diverse faunal assemblages are time controlled. Fisher (1962) recognized a similar relation in New York type areas, and suggested "Within the Black River Group, Chaumont, Lowville, and Pamelia lithology are both laterally and vertically transitional. Rockland lithologies demonstrably interfinger with those of the Black River Group. Thus parts of the Black River Group and Trenton Group are contemporaneous. Cursory study suggests that the Black River Group represent six or seven contemporaneous carbonate facies, each representing a distinct ecological niche". Thus it is perhaps justified to emphasize here that Black River rocks, as developed in southwestern Ontario, can be treated as a purely lithologic sequence, until detail information regarding the morphological and distribution characters of various fossil groups are more adequately known.

Okulitch (1939) recognized the lithostratigraphic nature of Black River rocks in southwestern Ontario and suggested a four fold classification. The formations in ascending order were named as follows: Shadow Lake, Gull River, Moore Hill, and Coboconk. Liberty (1953, 1955, 1967) restudied the stratigraphy of Black River rocks in Ontario and proposed a new classification. Liberty's (1967) classification includes the following formations in ascending order: Shadow Lake, Gull River (including Moore Hill) and Bobcaygeon. The term Gull River includes in ascending order the upper impure carbonate rocks of Shadow Lake, Gull River, Moore Hill and Chaumont units (New York state). The new term Bobcaygeon Formation includes the Coboconk unit of Okulitch (1937) in the lower part, and the upper part includes the lower Trenton Group. The faunal list of Liberty's (1967, p. 175) "D Member or Chaumont limestones" of the

Gull River is not much different from the original faunal list of the Coboconk Unit as proposed by Okulitch (1939, p. 336). Faunal lists of Chaumont as given by Young (1943, p. 219 to 232) from various localities in New York and Ontario also have a close similarity to the fauna of Okulitch's (1939) Coboconk Unit.

According to Okulitch (1939), the Coboconk is equivalent to the Chaumont Formation. Sanford (1961, p. 2) and Beards (1967) recognized Shadow Lake, Gull River and Coboconk Formations in the Middle Ordovician subsurface rocks of southwestern Ontario.

The present investigation clearly demonstrates that four lithologic units can be traced laterally across the outcrop belt of the Black River. Furthermore, each of the four units reflects easily recognisable distinct lithological characters. All four units should be treated as separate lithologic units instead of grouping them together under one unit e.g. "Gull River" of Liberty (1967). The lithologic units, I, II, III, and IV, as established in the present investigation correspond closely to Okulitch's (1939) Shadow Lake, Gull River, Moore Hill and Coboconk formations respectively. It is proposed that these names be used for the outcrop area from Georgian Bay to the eastern end of Lake Ontario. The units would occur within the Wilderness Stage as defined by Fisher (1962).

PROPOSED REFERENCE SECTIONS

Shadow Lake (Unit I)

The type section of the Shadow Lake as described by Okulitch (1939) on Hwy. 35, is four miles north of Coboconk, Ontario. The lower contact of the unit with the Precambrian rock is not exposed. According to Okulitch (1939, p. 321) "the actual gap in the section is probably not more than 5 feet and possibly only about 3 or 4 feet". The total thickness in the type area is about 18 feet (Okulitch 1939, p. 324). It is proposed that Marmora quarry section should be used as a reference section, chiefly because of the following reasons:

1. Well defined upper and lower limits of the unit are distinctly exposed in the section. The lower contact is distinctly unconformable with the underlying Precambrian rocks.
2. Thickest (45 feet) development in the area.

Gull River (Unit II)

The type section of the Gull River as described by Okulitch (1939, p. 325) from the road cut on Hwy. 35, is 2.2 miles north of Coboconk. The lower contact of this unit with the underlying Shadow Lake is not seen. According to Okulitch (1939, p. 326) "the section exposed is 45 feet minus 4 feet, or 41 feet plus the 9.5 feet at the Shadow Lake or a total of some 50 feet. This is probably the maximum possible thickness, and is correct only if our assumption is true that the lowest beds at the road side section immediately follow the uppermost bed at the Shadow Lake section".

From the present investigation it is felt that Marmora quarry section should be used as a reference section because of the following inherent advantages:

1. Clearly visible, upper shale bed marking a sharp contact with the Moore Hill. The lower boundary is distinctly marked by green clastic marker beds.
2. Easily determinable total thickness of 43 feet 10 inches.

Moore Hill (Unit III)

Okulitch (1939, p. 329) described the type section of the Moore Hill from the road cut, 0.9 miles north of Coboconk. According to Okulitch (1939, p. 329) the total thickness of the unit is about 20 feet. The rock is marked by characteristic "birdseye" structure and abundant *Tetradium*. The rocks of the Moore Hill are developed in most outcrop sections in the region. However the Marmora quarry section should be used as a reference section due to the following reasons:

1. Clearly recognisable both upper and lower contacts of the unit.
2. The thickness of the unit is approximately 31 feet and 5 inches.
3. The rocks show all characteristics as mentioned earlier.

Coboconk (Unit IV)

The type section for the Coboconk is described by Okulitch (1939, p. 331) from the east quarry of Canada Lime, Coboconk. The total thickness of this unit is about 20 feet (Okulitch 1939, p. 335). Furthermore Okulitch (1939, p. 335) stated "it is however questionable whether all of the twenty feet can be retained in the Coboconk and whether it will not be necessary to restrict this formation to beds 14 and 15". The transition from Moore Hill to Coboconk is not sharp and established on the basis of the upper range of certain <u>Tetradium</u> sp. The present study shows the Coboconk has a maximum developed thickness of 38 feet 9 inches in Marmora quarry. The lower contact with the Moore Hill is also marked sharply by the presence of a thin calcareous shaly bed, while the lowest beds of the Coboconk show characteristic wavy bedding. However, inspite of having all the requisite criteria of a reference section, Marmora section of Coboconk does not reveal the clear uppermost limit. It is therefore suggested that the section of the Coboconk as exposed in the Point Ann quarry should be used as a reference section. The uppermost limit is marked by thin bedded, argillaceous carbonate unit of the Trenton Group, while the lower boundary is sharply defined by argillaceous thin limestone bed 1 foot thick. The total developed thickness is about 28 feet 6 inches.

CHAPTER 12

CONCLUSIONS

The present investigation of the Black River Group suggests the following conclusions:

1. The Black River rocks are persistently exposed along a 10 to 30 miles wide belt extending from Midland on Georgian Bay to Kingston on Lake Ontario. Composite sections of the Black River rocks suggest the total thickness varies from approximately 90 feet at Coboconk to about 156 feet at Marmora.
2. Four distinct stratigraphic units designated I, II, III and IV in ascending order, can be traced in the area. Various sub-units within each major unit are probably parastratigraphic. The lowest major unit (I) is principally shale and sandstone with some dolomicrite and micrite, grading upward into biomicrite. The rocks of unit I are underlain by the Precambrian and the upper limit is marked by a distinct green, dolomitic clastic unit ranging in thickness from 7 feet to 6 inches. The second unit (II) has a lower micrite and dolomicrite association and an upper biomicrite. The rocks of unit I and II show thick bedded to finely laminated nature with frequent occurrences of desiccation features, fucoid marks and burrows. Celestite needles, molds and various

kinds of calcite of gypsum-filled nodules, solution breccia and intraclastic bands are characteristic in the rocks of unit II. The upper limit of unit II is a regionally persistent thick to thin bedded, brown, carbonate-rich clastic or extremely argillaceous limestone bed, weathering yellowish brown, and ranging in thicknees from 6 feet 6 inches to 6 inches. The upper limit of unit III is sharply defined by the lowermost wavy bedded rocks of unit IV.

The third unit (III) is a highly variable carbonate in the lower part and an upper oösparite, biomicrite or other mixed types. "Birdseye" structures are characteristically developed in the rocks of unit III. The lower part of the uppermost unit (IV) has an abundance of micrite with frequent intraclasts and chert. The middle and upper parts show highly variable carbonate lithology. The rocks of unit III and IV are marked by an irregular alternation of thick to thin bedded units. In places, the rocks may contain lenses and bands of corase skeletal -rich materials. Ripple mark, cross-bedding or cross-lamination are common in the rocks. Irregular shaly bands and lenses, and hemispherical algal stromatolites mark the carbonate rocks of unit IV. The upper limit of the Black River is a change to thin bedded argillaceous, shell-rich rocks of the Trenton Group.

Intraclasts of desiccation origin are frequent in the rocks of unit I and II. Pellets are observed in the rocks of unit II, III and IV, however, they become a characteristic feature of unit III and IV rocks. Various composite grains can only be observed in the rocks of unit II (upper parts) and III. Oöliths are an important constituent of unit III.

3. The detrital heavy minerals include the following: amphiboles, apatite, epidote, garnet, ilmenite, magnetite, pyroxenes, staurolite, sphene, tourmaline, zircon and zoisite. Authigenic heavy minerals include anatase, anhydrite, celestite, dolomite, and pyrite. Pyrite shows an extremely high concentration in the rocks of units III and IV. Anatase is restricted to areas west of Marmora and pyroxene shows a restricted distribution in the areas east of Marmora. Garnet, zircon, and hornblende have a higher abundance in areas west of Marmora whereas ilmenite, magnetite, tourmaline and apatite have increasing abundance in the eastern parts. Staurolite, actinolite, epidote and sphene are also characteristic minerals of the eastern areas. Dolomite, celestite and anhydrite have common association in the Black River rocks, more particularly in units I and II. Areas east of Marmora have a higher concentration of anhydrite and celestite than the western parts.

4. Fine slender branching algae, bryozoa, and corals, specifically <u>Tetradium</u> sp. are characteristic fossils of units II (locally) and III. Massive, branching-type algae, bryozoa, corals, algal stromatolites, and abundant brachiopods and pelmatozoan debris are the types of fossils in the rocks of unit IV.

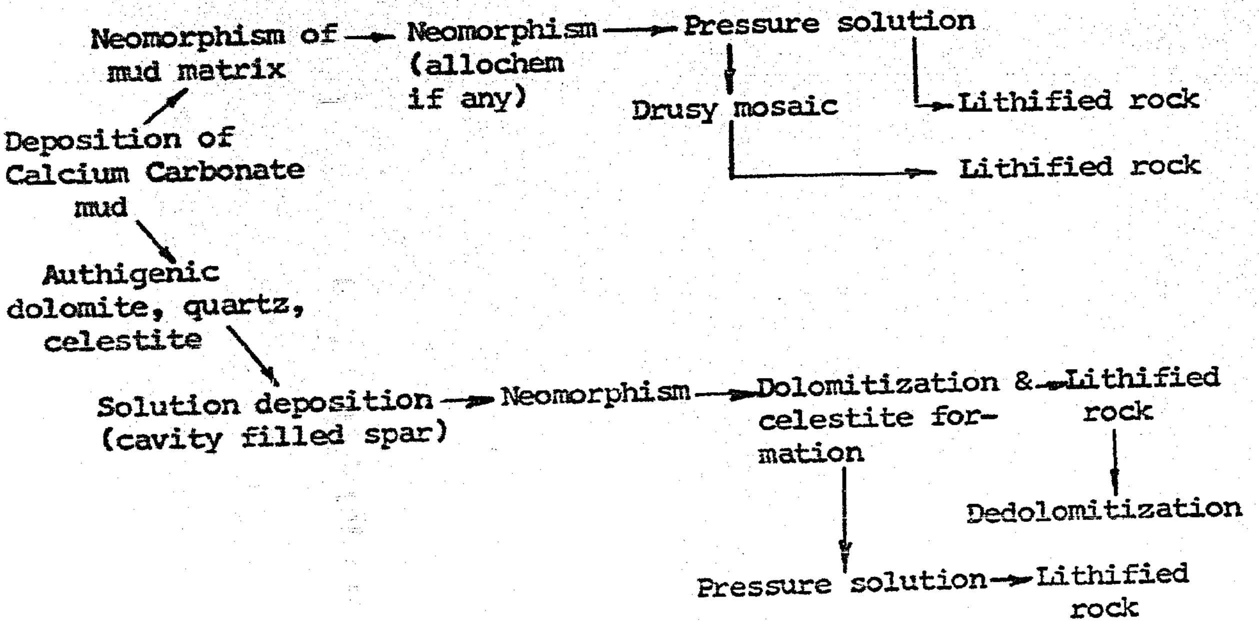
5. Petrographically, the rocks are divided into the following carbonate types: micrite, biomicrite, pelmicrite, intramicrite,

allochem-rich variety (e.g. bioclastite), mixed rock, (e.g. micritic pelbiosparite) and recrystallised (neomorphic) rock.

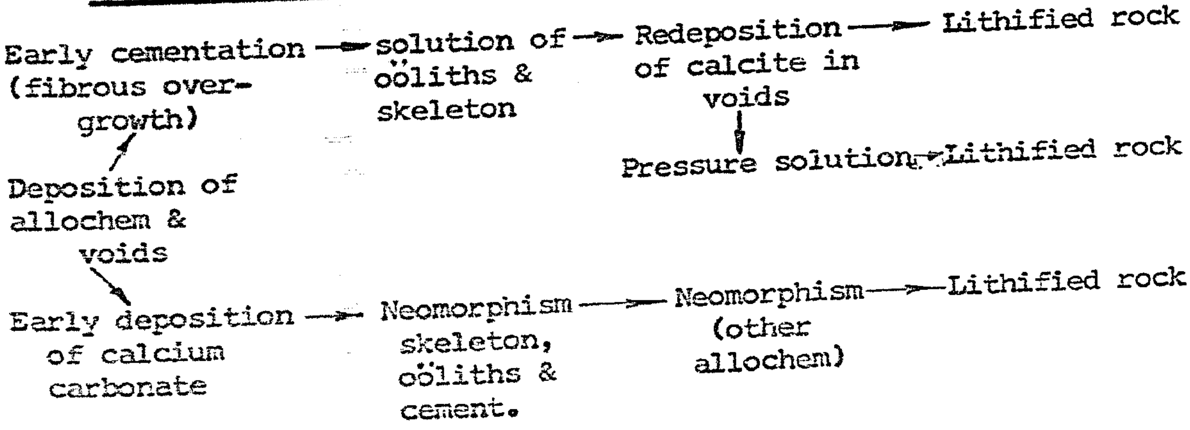
6. Chemically the rocks are grouped into four distinct varieties, dolostone, calcitic dolostone, dolomitic limestone and limestone. The rocks of units I and II are dolostone or calcitic dolostone and dolomitic limestone and pure limestone occur in units III and IV.

7. Interpretation of the diagenesis suggests the following important trends:

A. <u>Carbonate mud-rich rocks</u>



B. <u>Allochem-rich sparry calcite cemented rocks</u>



C. Diagenetic trends of mixed carbonate rocks are complex and cannot be represented by a simple scheme.

8. Allochem orientations have NE-SW and SW-NE trend maxima.

9. The Black River rocks can be interpreted as an ancient analogue of present day carbonate environments. Most features can be compared with the existing carbonate sediments of Florida Bay and Persian Gulf areas. The rocks of major and minor units may be interpreted as contemporaneous deposition in co-existing adjacent niches.

10. Various sedimentary structural features, abundance of dolomite, celestite, anhydrite, laminated algal structures and lack of organisms in rocks of units I and II are indicative of a supra-tidal lagoon environment. Frequent associations of oöliths, corals, pelmatozoan fragments, brachiopod, bryozoa and algal stramatolites in the rocks of unit III and IV suggest a gradual transition to a more or less free water circulating condition i.e. intertidal to subtidal shelf lagoon. Various types of algae, bryozoa, corals and their association with distinct carbonate lithologies suggest ecological control rather than an evolutionary change of morphology.

11 Orientation maxima showing NE-SW and SW-NE trends probably correspond to tidal and long shore currents respectively.

12. The differences in distribution of heavy minerals between the areas east and west of Marmora could have resulted from the original mineralogical differnces of adjacent Precambrian source areas.

13. The rocks of unit I and II exhibit development of penecontemporaneous dolomite. Dolomite crystals in rocks of unit III and IV are the result of late diagenetic dolomitization due to influx of brine from the adjacent supratidal environment. More intense dolomitization of units III and IV in areas east of Marmora is thought to be due to increased salinity of supratidal environment (units I and II) causing frequent discharge of brine in the adjacent seaward environments. Brachiopod, bryozoa, coral and broken skeletal rich rocks show increased effect of neomorphism as compared to other lithologies. Mg^{++} rich supratidal environments greatly inhibited neomorphic processes.

14. Pellets are of polygenetic nature. However a notable amount are thought to have been formed by mechanical attrition. Both inorganic and organic processes contributed in the deposition of microcrystalline calcite. Inorganic precipitation played a major role at least in forming the rocks of units I and II.

15. The high content of pyrite in the organic-rich, dolomite deficient rocks of units III and IV is due to the increased organic growth and bacterial activity.

16. A warm (23° to 33°C) climate with very shallow (1 foot) to shallow (30 feet) depth of water, characterized the depositional environments.

17. Extremely low content of the insoluble residues reflects the low relief of Precambrian surface and the lack of effluent streams. Distribution of Precambrian inliers contributed greatly in modifying the local environments, e.g. areas east of Marmora show

appreciably higher content of celestite, anhydrite etc. in the rocks of unit I and II than the same units of western areas. Areas west of Marmora show a more persistent nature of orientation maxima (NE-SW) than the eastern areas.

18. The present outcrop belt represents the original depositional strike of sediments deposited adjacent to the Precambrian shore.

19. Lastly, the four fold classification of the Black River Group - Shadow Lake, Gull River, Moore Hill and Coboconk as suggested by Okulitch (1939) - should be retained as formational names, corresponding to units I, II, III and IV of this study.

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APPENDIX

I Measurement of Stratigraphic Section and Collection of Sample.

The thickness of a section was measured directly across a vertical exposed rock face. As the Black River rocks are flat lying, the measured vertical thickness will represent a more or less accurate total thickness of horizontally bedded rocks. The thickness was first measured by means of a tape and the heights at each one foot level was marked on the rock face by marker. Attempt was made to measure section along one vertical line, however in places a lateral shift of 10 to 20 feet was made due to hanging nature of exposed rock faces.

Samples were collected from marked one foot intervals. Any lithologically dissimilar units within the regular one foot interval was also collected and the heights noted. The geographic orientation was marked on the bedding surface of each sample. Most sections were measured from the base towards the top. Sections on Hwy. 401, 5 miles east of Napanee, and at Montreal Stteet exit were measured from the top towards the base. Each sample was numbered with height value as marked previously. All samples from a particular section was given an identifying reference number. A total of 767 carbonate samples were collected.

II Preparation of Samples For Analysis.

All samples, except shales, were cut into 5 parts. The first three portions were sliced at right angle to the bedding. The first part was kept for making peel, thin sections and staining. The second block was used for carbonate analysis and the third piece was used for insoluble study. A fourth slab was made parallel to the bedding and used for making oriented peel section while the remaining piece was stored as a reference sample. After sawing, each piece was numbered according to the original individual sample number.

Methods

III Peel Preparation

Two types of peel section were made following the methods of Lane (1962, p. 870) and Frank (1964, p. 499). In most cases Frank's (1964) improved method on acrylic plexiglass was used because of the following advantages: 1) peel sections can be studied upto magnification of about 800, and thus revealed greater details of constituents. 2) peels do not wrinkle or curl due to the rigidity of the slide, 3) no mounting of peel between glass slides is required, 4) peel are rigid and resistant to surface damage.

Method:

The sawed specimen of carbonate rocks is polished with #600 grit until all saw marks are removed and the surface is smooth. The polished surface is then etched in 10% dil Hcl. for 8 seconds (limestones) to 15 seconds (dolostones). The etched surface is gently washed with water and dried. The dry etched surface of the sample is flooded with ethylene dichloride. A piece (2 inches x 2 inches) of 1/16 inch thick acrylic plexiglass is gently placed on one edge of the flooded sample and allowed to fall. All air bubbles can be removed if the plexiglass is allowed to fall in such a way that a meniscus of solvent precedes it. After 45 minutes to 1 hour the peel is dry and removed.

The samples with high content of shaly or silty materials and porosity do not show good results with Frank's technique and Lane's (1962) method of acetate peel is used. The principle of Lane's peel preparation is similar to the one as described previously. Fine grade (0.002 inch) cellulose acetate film and commercial grade acetone are used. Acetate peels dry within 15 minutes and should be removed immediately and mounted between glass slides in order to avoid wrinkles.

IV . Staining

The staining technique as suggested by Katz and Friedman (1964) was used in the present investigation. The method of combined stain was followed, as this easily distinguises calcite, dolomite, ferrous calcite and ferrous dolomite.

Preparation of stain:

The staining solution is made by dissolving 1 gm of alizarine red-S, and 5 gms of potassium ferricyanide in 2 cc of concentrated hydrochloric acid. The solution is made upto 1 litre mark by adding distilled water. In order to facilitate quick dissolving of chemicals, the solution is warmed for 30 minutes over a hot plate.

Staining of hand specimen:

After making peel sections, the samplesare repolished with #600 grade grit, washed and dried. The polished surface is then etched for 10 seconds (limestone) to 15 seconds (dolostone) in 10% dilute Hcl (1 part acid and 9 parts water). The etched surface is gently washed with distilled water and dried. A large deep porcelain dish containing the staining reagentis kept warm at 40°C. The samples are placed into the warm solution with the etched surface pointing upward. The solution is kept active by frequent swirling with a glass rod. After 5 minutes the sample is taken out of the solution, washed with distilled water and allowed to dry. The stained surface is then coated with a fine even spray of colourless plastic to prevent fading of the stain. The carbonate minerals show the following characteristic colours.

a) calcite - red or purple

b) dolomite - unstained

c) ferrous calcite - bluish red

d) ferrous dolomite - blue to indigo blue

Used stain solution should be thrown away if the colour turns brownish green and turbid. A liter of the staining reagent can be used to stain 40 samples.

Staining of Thin Section:

The method is similar to the previous process. Before putting on a glass coverslip, the thin section is etched in 10% dilute HCl for 5 seconds (limestone) to 10 seconds (dolostone). The etched surface is washed in distilled water and dried. The dry etched section is then kept in the staining reagent for 5 minutes and again washed with distilled water. After the section is dry, a thin glass cover slip is placed on the stained section.

Staining of acetate peel:

The stained etched surface of the handspecimen is dried. The dry stained area is flooded with acetone and a thin acetate film is emplaced. After 15 minutes the film is removed for mounting between glass slides. Stained thin and peel sections are only used for selected samples showing mineralogical peculiarities.

V Insoluble Residues

About 400 gms of sample is used for obtaining insoluble residues. The sample is kept in 1000 cc of dilute acetic acid (1 part commercial grade acetic acid and 5 parts water), for 7 days. During this period, the used acid is changed for fresh acid every 24 hours. After seven days, undissolved sample and insoluble residue are carefully washed several times. Finally, the undissolved sample and insoluble residue are placed on a set of three sieves - 45 mesh (0.35 mm), 150 mesh (0.1 mm), and 250 mesh (0.06 mm) arranged in descending order. The undissolved mass of the bulk sample is washed through the sieves. The sample from each is taken out and kept in a plastic dish for drying. The fine insoluble material collected in the lowermost screen is thoroughly cleaned, transferred to a plastic dish and allowed to dry. The dry, undissolved original portion of the rock is weighed. The difference in weights of the sample before and after acid digestion represents the total weight of lost material. The 250 mesh insoluble residue is also weighed.

Heavy mineral separation:

The insoluble fraction is treated to the standard method of heavy mineral separation using tetrabromoethane (specific gravity 2.96).

Insoluble residues are gently poured into the separating funnel containing heavy liquid. The mixture is stirred gently 5 times at 15 to 20 minutes interval and then allowed to stand for 4 hours after which the heavy and light fractions are collected, thoroughly washed with alcohol and dried in an oven. Each fraction is examined under the stereomicroscope to determine if the separation is complete. In case of incomplete separation, the fraction containing mixed residues is again treated to heavy liquid separation. Thus a complete separation of light and heavy fraction is obtained. The separated heavy and light fractions are stored in properly marked glass bottles. The fraction of light residue is weighed. The total percentage of light residue in the 250 mesh fraction of the sample is calculated by the following expression:

$$\frac{\text{Total light insoluble fraction in 250 mesh}}{\text{Total weight of original dissolved bulk sample X 100}}$$

The heavy fraction is splitted into two parts using a sample splitter. One half is stored in bottles for reference and the other half is used for mounting of heavy mineral in glass slides. Before mounting the heavy minerals in glass slide, a strong magnet is held outside the glass bottle in order to determine any magnetite in the sample. All samples with magnetite are marked by the letter "M" in the reference bottle as well as on the slide. Heavy minerals are mounted permanently on glass slide following the standard method of the Krumbein and Pettijohn (1938, p. 359).

VI Chemical Composition

A qualitative estimate of composition of carbonate sample was made at three different stages.

1. Acid testing:

This simple rapid method of field classifying carbonate rocks was developed independently in the present investigation. Recently Wolf *et al.* (1967, p. 256) have described a similar method for rapid identification of carbonate rocks.

About 5 drops of cold dilute Hcl (10%) is put on a clean, flat surface of the specimens. The acid should be dropped in areas showing no intercalation of clastic materials. The nature of reaction is carefully observed in the field under a magnifying lense. The characteristics of four chief types of carbonate rocks are as follows.

a) Limestones - immediate violent, frothy audible reaction.

b) Dolomitic limestones - immediate, quiet reactions.

c) Calcite dolostone - slow reaction.

d) Dolostone - no or very slow reaction.

2. Stain test:

Stained hand specimens on the etched surface are examined under the binocular microscope. The relative percentages of calcite and dolomite in a sample are determined visually. Thus the rocks are again grouped into four chemical types.. The composition characteristics of each carbonate type are as follows:

a) Limestone - coloured entirely red or bluish red.

b) dolomitic limestone - 15% to 20% of the area is unstained while the remaining 80% to 85% shows red stain.

c) Calcitic dolostone - about 55% to 45% of the area does not appear stained, whereas the rest shows a red or bluish red colour.

d) Dolostone - in most cases 85% to 90% of the area does not show stain while the rest shows a purplish colour. In some cases, samples turn blue, due to the presence of iron.

3. X-ray diffraction method:

For a more refined method of determining the relative distribution of calcite and dolomite in the sample, an X-ray diffraction technique is used, as described by Tenant and Berger (1957, p. 23) and modified by Gulbrandsen (1960, p. 71). The X-ray diffraction method is extensively used for determining calcite/dolomite ratios in carbonate rocks (Sarin 1962; Diebold et al. 1963; Friedman, 1964; Borst, 1966; Behrens, 1966; Mathews, 1966; Textoris, 1966; and Asquith, 1967).

The method is based on the fact that X-ray diffraction intensities (peak heights) are proportional to the amount of calcite and dolomite present in the sample. The ratio of peak intensity of calcite/dolomite is used as a measure of dolomite content of the rock. The method consists of two parts, 1) construction of a standard curve by running a series of mixtures containing known weights of calcite and dolomite, 2) determination of calcite/dolomite ratio of unknown samples from the standard curve.

Pure calcite (iceland spar) supplied by Semi Elements Inc., (Saxonburg, Penn) and pure dolomite obtained from Southwest Scientific Company, (Sedona, Arizona) are used as standards. The dolomite was tested with staining reagent and did not show any ferrous iron. Chemical analysis of carefully separated white dolomite crystals contained 56.92% calcium carbonate and 41.95% magnesium carbonate. A survey of composition of natural sedimentary dolomite also reveals that the mineral contains excess of calcium carbonate upto the range of 56.2% mole percent (Goldsmith and Graf 1958, p. 682). A study of available chemical analyses of various Black River dolostone also showed the presence of varying degree of excess calcium carbonate in the dolomites. Gillot's (1963) study of dolomites from Kingston area also showed the presence of excess calcite in the range of 53.97 to 55.6%. The dolomite standard used in this study is very similar in composition to the natural Black River dolomites.

The samples of standard calcite and dolomite are finely ground in an impact grinder separately and sieved through 400 mesh screen. A series of 20 mixtures are prepared by taking finely ground calcite and dolomite in different proportions in order to represent a complete series of composition between 100% pure calcite to 100% pure dolomite. Each mixture is then thoroughly mixed in an agate mortar using acetone and gently stirring the mixture for one hour in order to ensure absolute mixing of two carbonate phases. After mixing the samples are dried and kept in glass bottles.

The powdered sample is then placed in a glass sample holder with a square cavity (8 mm^3) in the centre. The base of the cavity is sealed by a piece of aluminium foil. The cavity is filled with powdered material by using the thin edge of a small spatula. The excess powder is scraped out with a razor blade. Thus the amount of sample taken for analysis in each run is kept more or less constant.

CuK_{α} radiation is used in the Phillips Norelco diffractometer, with settings at voltage 35 kv, and current 20 M.A. The recorder chart speed is fixed at one degree per minute and the scanning of each sample is done between 24° to 33° degrees of 2θ. The strongest peaks of calcite (104 reflection) and dolomite (112 reflection) appear at 2θ values of 29.43 degrees and 30.99 degrees respectively. The total intensity

FIG. 15. RELATION OF PEAK INTENSITY RATIO OF $\frac{\text{CALCITE}}{\text{DOLOMITE}}$ TO THE RATIO OF $\frac{\text{CALCITE\%}}{\text{DOLOMITE\%}}$

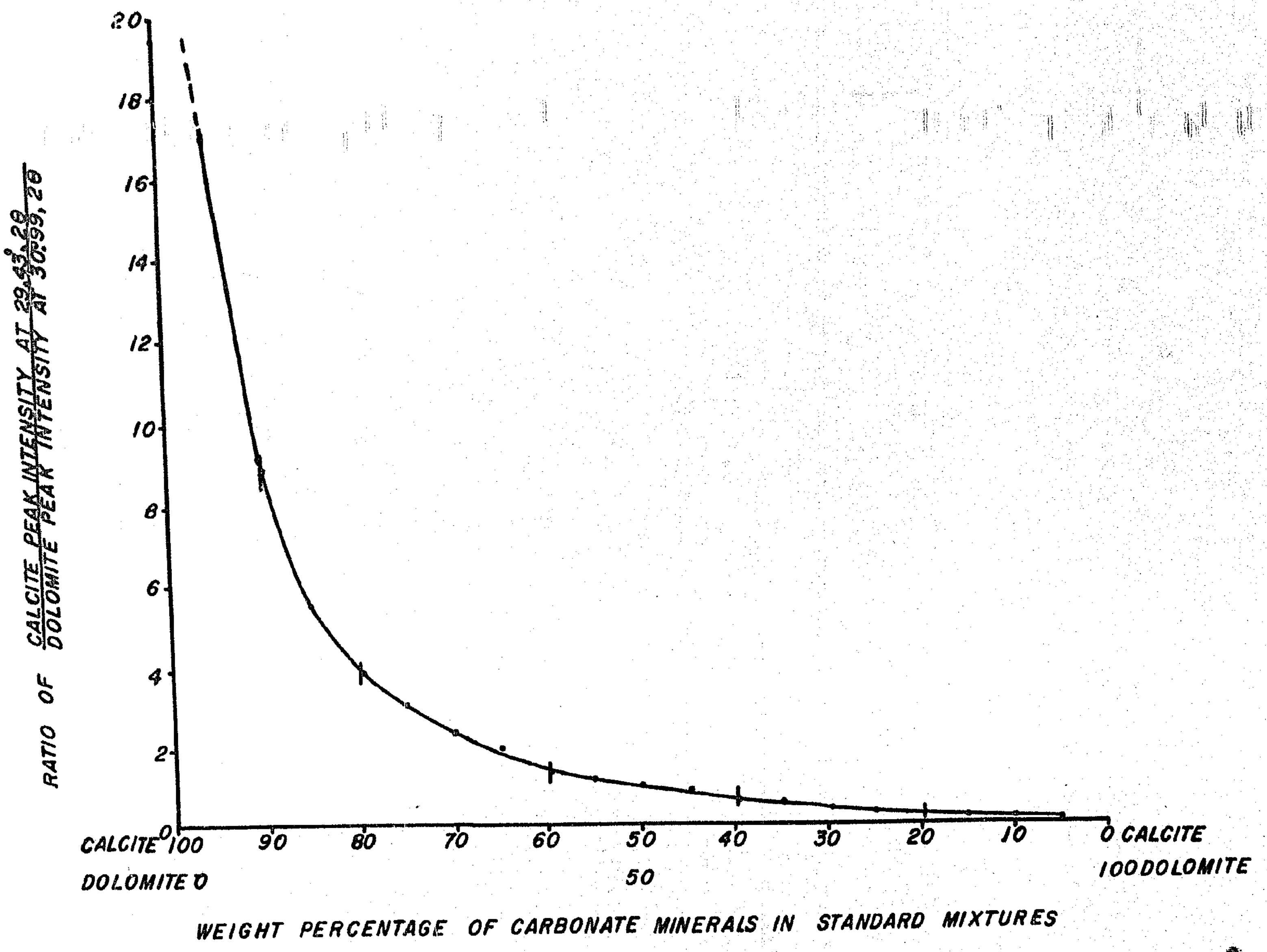
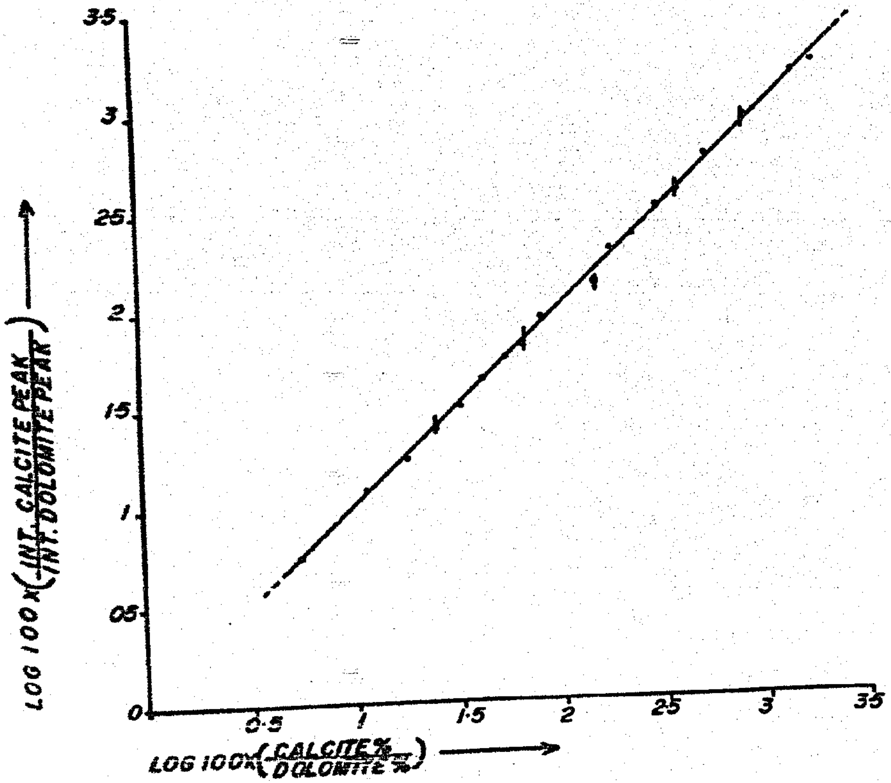


FIG. 16. X-RAY DIFFRACTOMETER METHOD FOR THE DETERMINATION OF THE RATIO OF $\frac{\text{CALCITE}}{\text{DOLOMITE}}$ IN CARBONATE ROCK (CALIBRATION MADE WITH Cu K_α)



PEAK AREA RATIOS OF $\frac{\text{CALCITE (29·43°)}}{\text{DOLOMITE (30·99°)}}$ PLOTTED AGAINST THE RATIOS OF $\frac{\text{CALCITE \%}}{\text{DOLOMITE \%}}$

area of each of the strongest peak is measured by planimeter with reference to the background value. The intensity ratio of calcite/dolomite is thus determined corresponding to particular mixtures. The results of intensity ratios are plotted against the corresponding percentage compositionsof each mixture (Figure 15). In order to check the nature of constancy of intensity ratio values, five mixtures with calcite content of 90%, 80%, 60%, 40%, and 20% are run three times in the diffractometer at different hours. The results of intensity variation at each composition point are plotted in the previous diagram (Figure 15). The maximum range of variation is not more than 5%. The larger variation is observed towards the dolomite rich compositions due to flattening out of the curve (Figure 15). However, as the present classification of Black River carbonates is chiefly designed to identify broad chemical groups, this error is considered to be insignificant. The compositions of carbonates as determined by X-ray technique also showed fair agreement with the results obtained by two other previous methods.

Following Gulbrandsen (1960), logarithim values of peak height ratios are plotted against the percentages and a line of best fit is drawn through the observed points (Figure 16). The correlation co-efficient analysis of intensity ratios and composition of different mixture, showed a high value of about 0.9. All values of composition are also expressed in terms of logarithim. The characteristic percentage composition ratio of calcite/dolomite in four types of carbonate rocks shows the following values.

a) Limestone - values of ratio 3 or above.

b) Dolomitic limestone - values of ratio between 2 and 3.

c) Calcitic dolostone - values of ratio between 1 and 2.

d) Dolostone - values of ratio 1 or less.

In the case of pure calcite bearing rock, no carbonate ratio is plotted in the stratigraphic section.

VII Petrographic Analysis

Petrographic analyses of peel and thin sections are made by point counting various constituents over a constant area. A survey of literature showed wide divergence of opinion regarding the total number of counts to be made in a section. The total number of count varies between 100 to 500. Carozzi and his co-workers use 100 counts. Lee and Winder (1967) used 200 counts. Stauffer (1962) suggested 400 counts and Behrens (1965) observed 500 grains. Because there is variation between different thin or peel sections from the same hand specimen, the contribution to the analytical error from this source cannot be decreased by increasing the total number of counts. The composition of sedimentary rocks more particularly carbonate rocks involves a number of independent variables which will affect composition. The inorganic or organic constituents may not be uniformly distributed throughout a single bed. Therefore a precise determination of composition cannot be made as the area immediate to the studied slide may vary more than the probable sampling error.

The Black River rocks are essentially rich in microcrystalline calcite with minor amounts of coarse allochems. Within the limits of studied slide area the analytical error will also depend on the size of grid spacing. A number of peel sections containing allochems

Table 1. Table shows the variation of lithologic composition corresponding to 40, 100, 200, 300, 800 and 2500 point counts.

Sample No.	No. Counts	Mic.	Sparry Cal.	Brach.	Bry.	Cri.	Plate	Int	Pellet	Rec	Rim	Others
F 47	2500	1.69	17.12	29.77	13.72	23.73	4.85	3.04	2.62	1.56	0.15	1.35
	800	1.47	16.99	30.19	14.30	22.61	4.40	4.26	1.7	1.83	0.12	1.34
	300	0.95	17.51	29.93	13.38	23.50	4.01	4.82	2.87	1.91	0.31	0.96
	200	0.92	16.51	29.34	13.30	24.77	3.67	5.50	2.75	1.31	0.46	1.83
	100	0.96	16.79	29.01	12.98	24.01	3.05	3.05	3.82	0.76		0.76
	40	1.70	17.22	29.77	12.41	24.39	3.70	5.55	3.41	0.02		1.85

Table 2. Table shows the variation of lithologic composition corresponding to 40, 100, 200, 300, 800 and 2500 point counts.

Sample No.	No. Counts	Mic	Algae	Brachiopod	Bryozoa	Burrows	Ter.	Rec.	Drusy	Dol.	Second.	Other	Py.
54	2500	84.84	0.16	0.12	0.52	2.76	3.96	1.40	0.56	3.16	0.04	0.28	2.2
	800	83.34	0.38	0.38	0.63	2.63	3.63	2.00	0.25	3.25	0.13	0.30	3.00
	300	81.72	0.27	0.27		2.42	3.49	32.3	0.81	4.03		0.27	3.49
	200	83.25	0.45	0.45	0.45	2.26	3.61	2.71	0.45	3.61			2.71
	100	83.00		1.00		3.00	3.00	3.00		3.00			3.00
	40	68.42		0.02	2.63	5.26	7.89	2.63		7.89			5.26

Table 3. Table shows the variation of lithologic composition corresponding to 40, 100, 300, 800, and 2500 point counts.

Sample No.	No. Count	Spy. Calcite	Brachiopod	Bryozoa	Crinoid	Other (Skeleton)	Intraclast	Pellet	Oolith	P.oolith	Accr.	Ter.	Other	Rec.	Drusy	Rim	Sec	Other
E25°1	2500	33.47	0.52	0.40	0.12	0.60	4.21	2.78	39.39	5.24	2.85	0.08		1.67	0.24	8.25	0.12	0.08
	800	33.25	0.61	0.25	0.12	0.25	5.77	2.48	39.88	4.94	1.96			1.72		8.47		0.25
	300	33.55	0.95	0.32	0.32		5.48	2.90	38.70	5.81	0.95			2.90		8.39		0.32
	200	33.49	0.94				5.66	3.77	37.26	5.66	1.42			3.30		8.49		
	100	33.33					5.41	2.70	38.79	5.41	0.90		0.90	2.70		9.90		
	40	42.22			2.22			6.66	29.44	8.88	2.22			6.66		6.66		

of various sizes are randomly selected. The slides are examined on a Reichert visopan under magnification of X125 to estimate the average size of coarse particles. The most frequent size of the longest particle is found to be about 2 mm. A grid spacing of 3 mm is used for all petrographic analysis. Even particles coarser than average 2 mm size would be covered within this selected grid spacing. Thus the chance of repeated counting of one coarse allochem is greatly reduced. In each section, an area of 900 mm^2 was traversed counting 300 grains. In one traverse length 10 grains are counted at a regular interval of 3 mm. An increase of the total number of counts may introduce a considerable error due to over an estimation of micrite and other fine constituents. Several peels containing varying amount of allochems were randomly selected to test the accuracy of estimated percentages of each constituent of the limestones. The slides were studied by counting 40, 60, 100, 200, 300, 800, and 2500 grain (Tables 1, 2 and 3). The studied area for each section was kept constant. For each section a count of about 300 points was found satisfactory. The variation in composition ranges within ±5%. 766 samples were pointed counted during the present investigation of Black River rocks. All microlithologic variations in different stratigraphic sections represent percentage distributions (calculated by taking moving average of three samples at a time).

VIII Heavy Mineral Analysis

The mounted heavy minerals are studied under ordinary petrographic microscope fitted with a mechanical stage. In each slide heavy mineral residues are mounted within an area of 4 cm^2. Each slide area is then divided into eight equal small square grids. All grains within each small area are counted. In general the total distribution of heavy minerals ranged from 50 to about 600. In sections with only one or two types of heavy mineral, about 200 points are counted. Commonly sections with large number of grains, show only one or two dominant types of heavies. The results of heavy mineral distribution are not calculated in terms of the original bulk rock compositions.

IX Orientation Measurement

With the general absence of large scale mega-sedimentary features and a limited number of widely scattered geologic sections, paleogeographic reconstruction can be aided greatly by the study of long axes orientation of allochems. Oriented peel sections were analysed on mechanical stage of Reichert visopan by a circular acetate film graduated at 20° interval with north at 0°. The viewing screen with graduated acetate film is rotated so that the N mark of the peel coincides with the direction of N on the screen.

An area of 600 mm^2 is studied in each peel section using a magnification of X125 and a grid spacing of 2mm. The orientation of lying particle in or close to the centre of the field is measured. Only orientations of elongated intraclasts, pellets, oöliths, and detrital fragments are measured. The total number of measured grains ranged from 100 to 200 as suggested by Potter & Pettijohn (1963, p. 42). Few slides contained less than 100 measurable grains. The result of orientation measurement

Table 4. Actual total (observed number) distribution of allochem orientation in each 20° grouped interval.

Section	0°-20°	20°-40°	40°-60°	60°-80°	80°-100°	100°-120°	120°-140°	140°-160°	160°-180°
McGinnis & O'Conner Quarry	187	125	127	93	68	165	187	124	42
Hwy. 401 & Hwy. 15 exit section	200	162	175	94	56	63	187	207	62
Hwy. 401 & Montreal St. exit section	180	105	85	190	74	82	113	103	54
Hwy. 401 section, 5 miles E. of Napanee	431	274	315	220	157	226	294	217	109
Napanee Quarry	165	112	97	72	50	60	100	49	85
Roblindale Quarry	533	330	315	178	154	280	438	184	44
Point Ann Quarry	436	283	322	224	149	257	456	237	99
Marmora Quarry	1277	745	372	213	266	931	851	426	319
Marmora Road Section	362	153	97	70	84	111	251	125	139
Havelock Quarry and road section	10	7	4		5	2	9	13	3
Burleigh Falls and sections	91	112	67	44	41	71	146	95	37

Table 4 (contd). Actual total (observed number) distribution of allochem orientation in each 20° grouped interval.

Section	0°-20°	20°-40°	40°-60°	60°-80°	80°-100°	100°-120°	120°-140°	140°-160°	160°-180°
Buckhorn road section	2	7	5	8	2	3	10	11	14
Cobo-conk east Q.	171	123	66	28	13	20	58	133	75
Cobo-conk road section	130	160	119	77	43	66	174	139	69
Long-ford Quarry	115	100	91	45	31	68	104	171	98
Hampshire Mills Section	3	9	6	2	2	2	3	5	2
Unthoff Quarry	126	72	57	26	25	42	74	121	58
Medonte Quarry	6	16	10	4	4	4	8	10	14
Port McNicol Quarry	33	36	48	30	29	29	55	59	42

is shown in table 4.

There are three sources of probable error.

1. The plane of the peel may not be absolutely parallel to the bedding. Therefore elongate grains will be affected by the direction in which the bedding is truncated. Increased number of observation will not improve the result. Only careful sawing of sample parallel to the bedding can reduce this error. Great care is taken to saw samples parallel to the bedding (Stauffer 1962, p. 324).

2. When bedding is cut by the plane of the peel section, the orientation of grains show alignments parallel to the bedding rather than along the current direction. These will reflect the orientation of the line of intersection of the peel and the bedding plane at that point. Study of large peel areas covering several undulating surface can reduce this error (Stauffer 1962, p. 324). The Black River rocks in general do not show such irregular bedding plane irregularities.

3. The measured orientation of long axes of grains might possibly represent the apparent elongation of the cross section of grains in the plane of the peel rather than true elongation. The error is minimized by selecting only clearly observable elongated non-skeleton allochems. Moreover measurement of 100 grains and the grouping of aximuth of long axis into class interval of 20° reduces the error to a minimum (Potter and Pettijohn, 1964, p. 42; Stauffer 1962, p. 364).