

Facies and faunal aspects of the Silurian Read Bay
Formation of northern Somerset Island, District of Franklin, Canada.

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ABSTRACT

The Upper Silurian strata of northern Somerset Island, N.W.T., Canada belong to the Read Bay Formation and an unnamed sequence at Port Leopold.

The Read Bay Formation at Pressure Point, Cunningham Inlet, Garnier Bay and Cape Admiral M'Clintock consists of rubbly limestone and micritic limestone in the subtidal phases; and sandy limestone, dolomitic limestone and minor quantities of sandstone in the intertidal phases. Many of the subtidal rocks contain a rich fauna of brachiopods, corals, stromatoporoids and trilobites while the fauna of the intertidal rocks is restricted to a few genera of gastropods and ostracods.

Markov Chain analysis demonstrates that units of conglomerate, intra-clastic shelly limestone and shelly limestone have a random occurrence within the sections. Such units probably resulted from storm action.

The Leopold succession is apparently restricted to the eastern part of the island. At Port Leopold it comprises intertidal and supratidal dolomitic rocks, sandstone and limestone with detrital material. It contains a restricted fauna of gastropods, ostracods, eurypterids and ostracoderms although stromatolites are common.

Textural relationships between the dolomite and other constituents demonstrates that the dolomite is of diagenetic origin. Its localized

distribution in the Port Leopold sections indicates that it may have been associated with depressions in the tidal flat environment. Markov Chain analysis of these sections was unsuccessful because the states were numerous and the sections too short.

The rubbly limestones are classified into two main groups and five types on the basis of the attitude of the hard lumps of micritic limestone, the composition of the softer groundmass and the textural relationship of the lumps to the groundmass. The heterogeneity of the original sediment was accentuated during diagenesis by addition of dolomite, by compaction and by partial recrystallization of the original calcite.

Although it is difficult to identify exact faunal zones within the individual sections, the faunas suggest that all the sections are of Pridolian age and approximately equivalent to each other. Consequently, the intertidal and subtidal phases in each section could have been related to the same changes in the local paleogeography. The distribution of the subtidal and intertidal rocks and the composition of the rocks with their immature detrital components suggests that there was a low-lying land mass to the north of Somerset Island.

Fluctuations in the elevation of the land mass and the position of the coastline during Pridolian times probably controlled the positions of

the main sedimentary facies.

The distribution of the brachiopod genus Atrypella is primarily a reflection of the distribution of Upper Silurian subtidal rocks rather than an indication of a particular time zone. Computerized statistical analysis of numerous assemblages of Atrypella from northern Somerset Island demonstrates that the length, width, height, absolute deflection of the anterior commissure, relative deflection of the anterior commissure and Side-Circularity Index of Atrypella all varied during ontogeny and with environmental changes while the Plan Circularity Index did not. The apical angle did not vary during ontogeny but varied with environmental conditions. Classification of the genus by statistical methods, which take into account ontogenetic and environmental variation, demonstrates that Atrypella foxi n.sp., A. phoca (Salter) and A. shröcki Cooper are the main species of the genus on northern Somerset Island. Specimens formerly referred to A. scheii are merely varieties of phoca.

Atrypella appears to be restricted to strata immediately below the Siluro-Devonian boundary. Geographically, Atrypella appears to have been restricted to turbid environments in which few other animals could survive, especially in areas bordering geosynclines.

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CHAPTER 1

INTRODUCTION

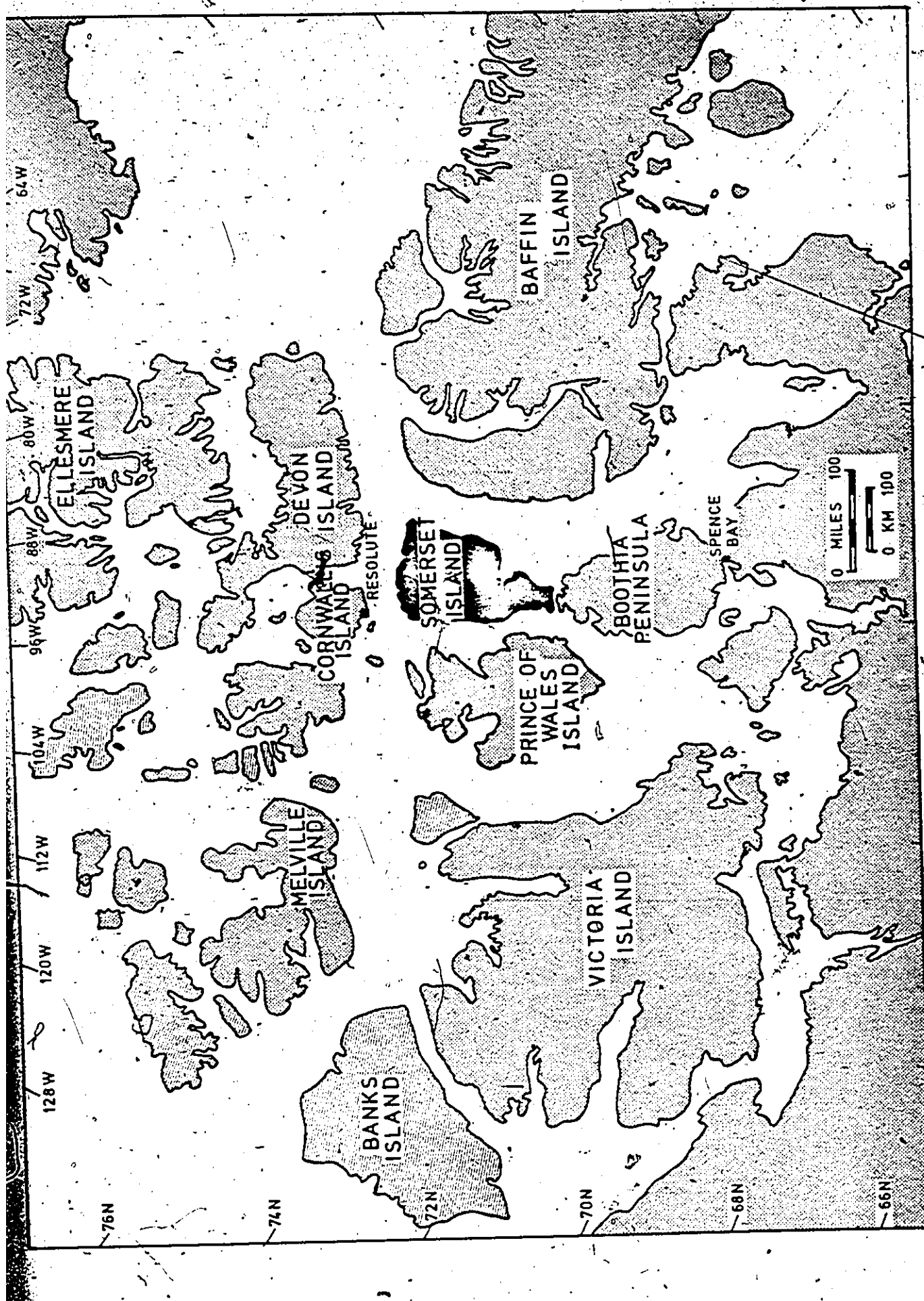
Somerset Island (Text-fig. 1) is situated in the Canadian Arctic between latitudes 72°N and 74°N and longitudes 90°W and 96°W . Field operations were based in Resolute, Cornwallis Island (Text-fig. 1) because Somerset Island is uninhabited except for an Eskimo family. From Resolute, Somerset Island was reached by Otter aircraft.

During the summers of 1971 and 1972, five different localities (Text-fig. 2) were visited along the north coast of Somerset Island. The localities were selected after examination of aerial photographs for areas of good exposure and study of the Geological Survey of Canada's report on Operation Franklin (Fortier *et al.*, 1963). Flying over the localities at low level aided selection of the most complete sections within the chosen localities.

In 1971, five weeks were spent at Port Leopold on the north-east corner of Somerset Island (Text-fig. 2). This locality was revisited in 1973 and a total of 16 sections were measured and one other briefly inspected (Text-fig. 3) during the two visits. Also in 1971, 10 days were spent at Cape Admiral M'Clintock (Text-fig. 2) where one section was studied in detail (Text-fig. 4). In 1972, 2 weeks were spent at a locality about 5 miles (8 kms) west of Cunningham Inlet where 3 sections were documented (Text-fig. 6). Two weeks were

Text-figure 1.

Location of Somerset Island within the Canadian Arctic Islands.



spent at Garnier Bay (Text-fig. 2) where 4 sections were studied

(Text-fig. 5) and 1 week was spent at Pressure Point (Text-fig. 2)

where a composite section was obtained from two sections in the tributary valleys to the main gorge (Text-fig. 7).

The sections were located in river gorges (Pressure Point, Cape Admiral M'Clintock and part of the Cunningham Inlet section) and along sea cliffs (Port Leopold, Garnier Bay and part of the Cunningham Inlet section). The sections measured along the sea cliffs were

started at the top of the scree slopes, most of which are 75-100 m high. The sections that were measured in the river gorges generally started much lower, normally 20-30 m above sea level. Consequently, the sections that were measured in the river gorges are generally thicker than those measured along the sea cliffs. The exceptions to this general pattern are the areas where the strata are dipping.

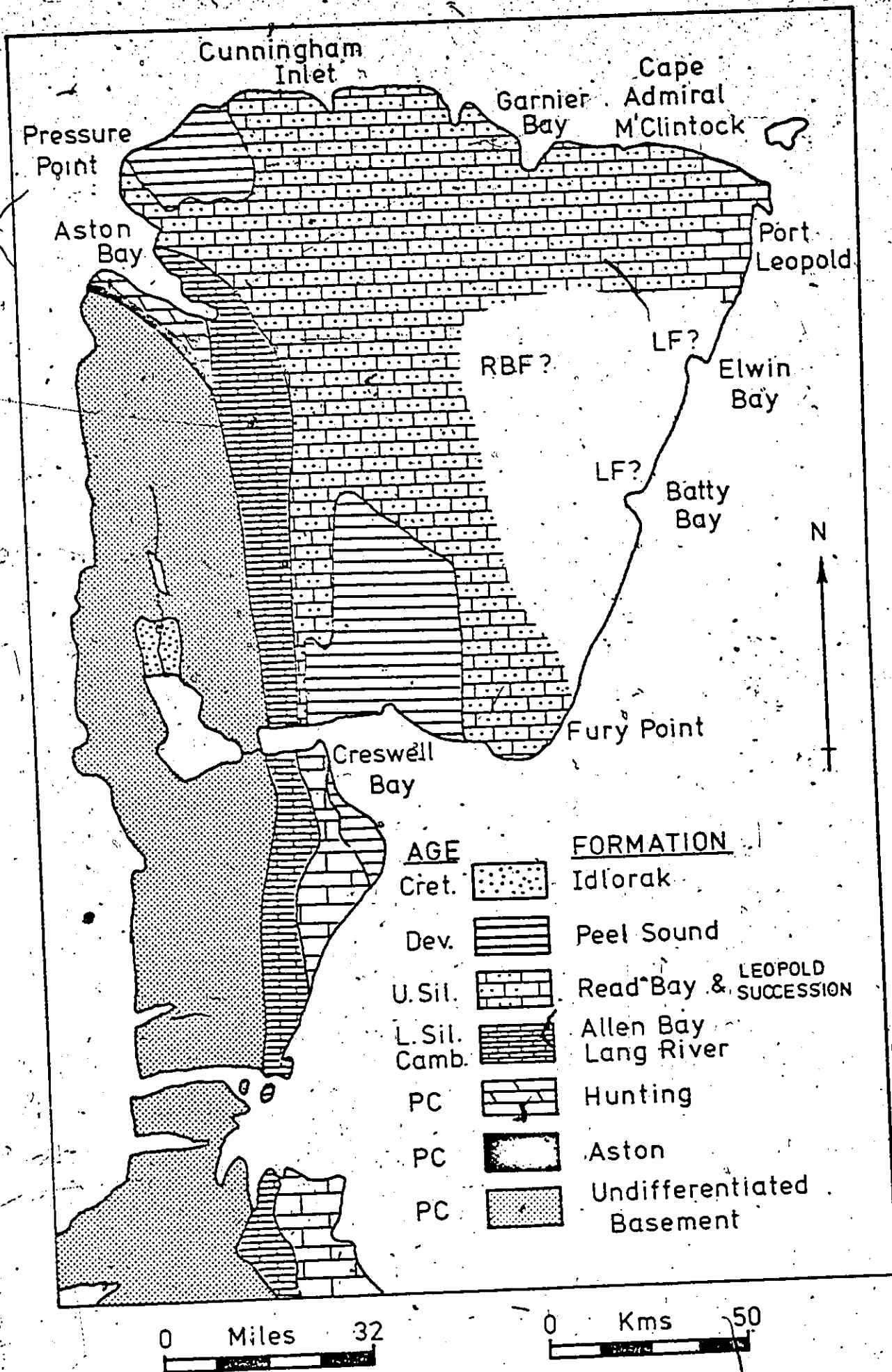
The geomorphological features and the climatology of the island have been adequately described in Fortier et al. (1963, p. 111) and will not be reiterated here. It is sufficient to note that the spring thaw in 1972 was very late (streams did not start to flow until the end of June) and this created many problems in gaining access to some exposures. Inclement weather during that year also caused many problems.

Thicknesses of the successive lithological units were

Text-figure 2.

Geology of Somerset Island and localities cited in this study.

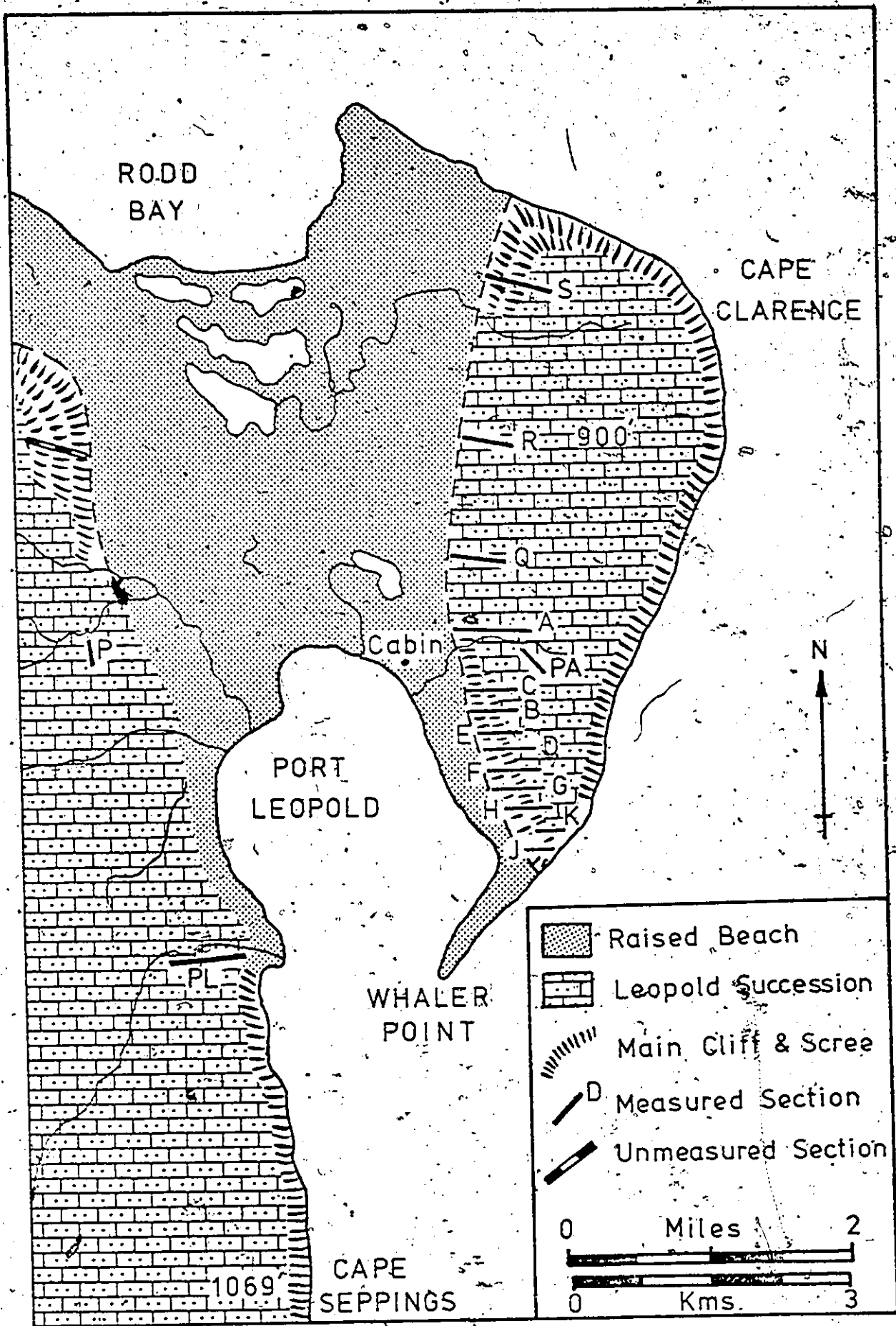
The extent of the Read Bay Formation (RBF) and the Leopold succession is uncertain in the eastern part of the island.



Text-figure 3.

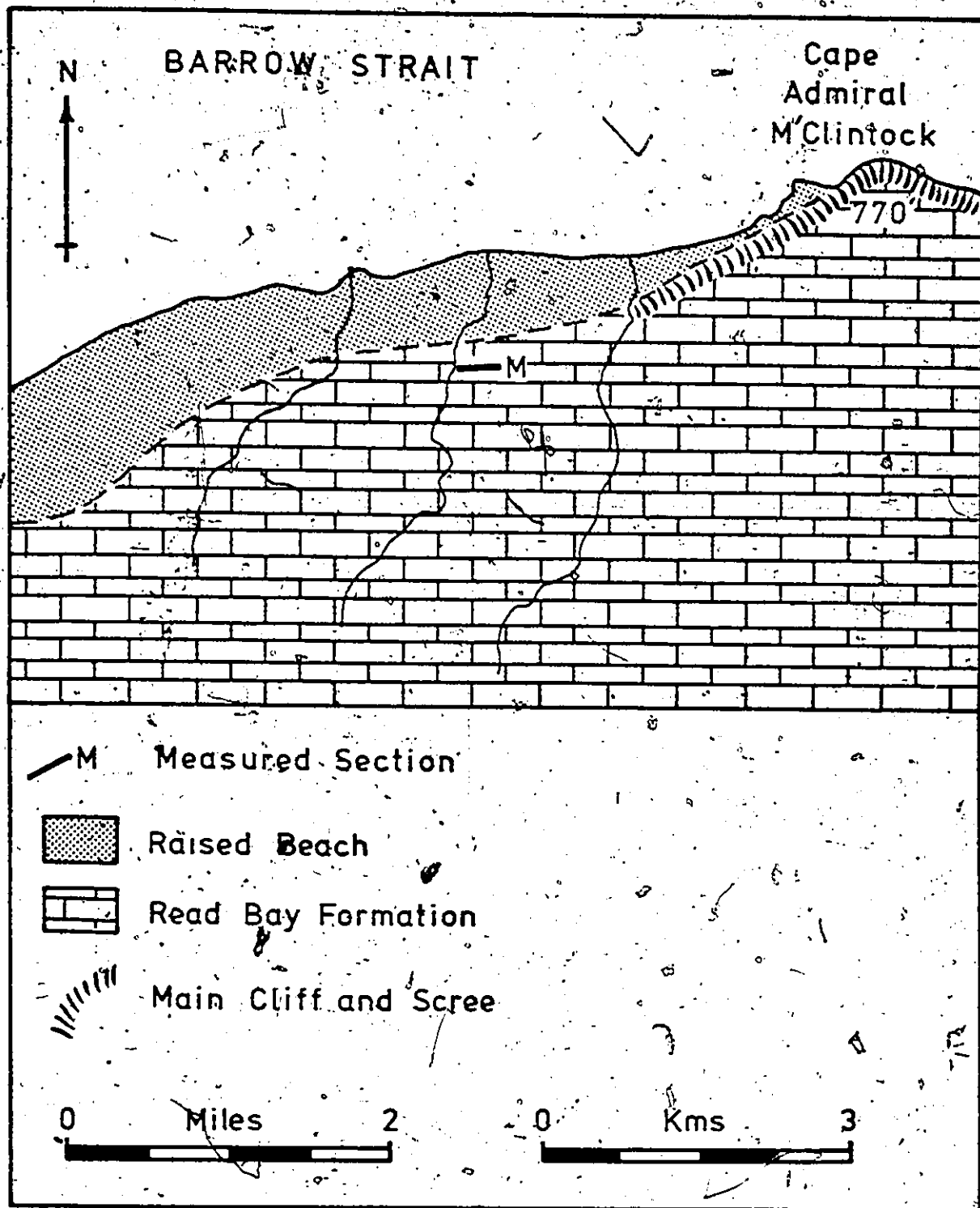
Geology of the Port Leopold area and location of measured sections

A-K, Q, R, S, P, PA and PL.



Text-figure 4.

Geology of the Cape Admiral-McClintock area and location of measured section M.

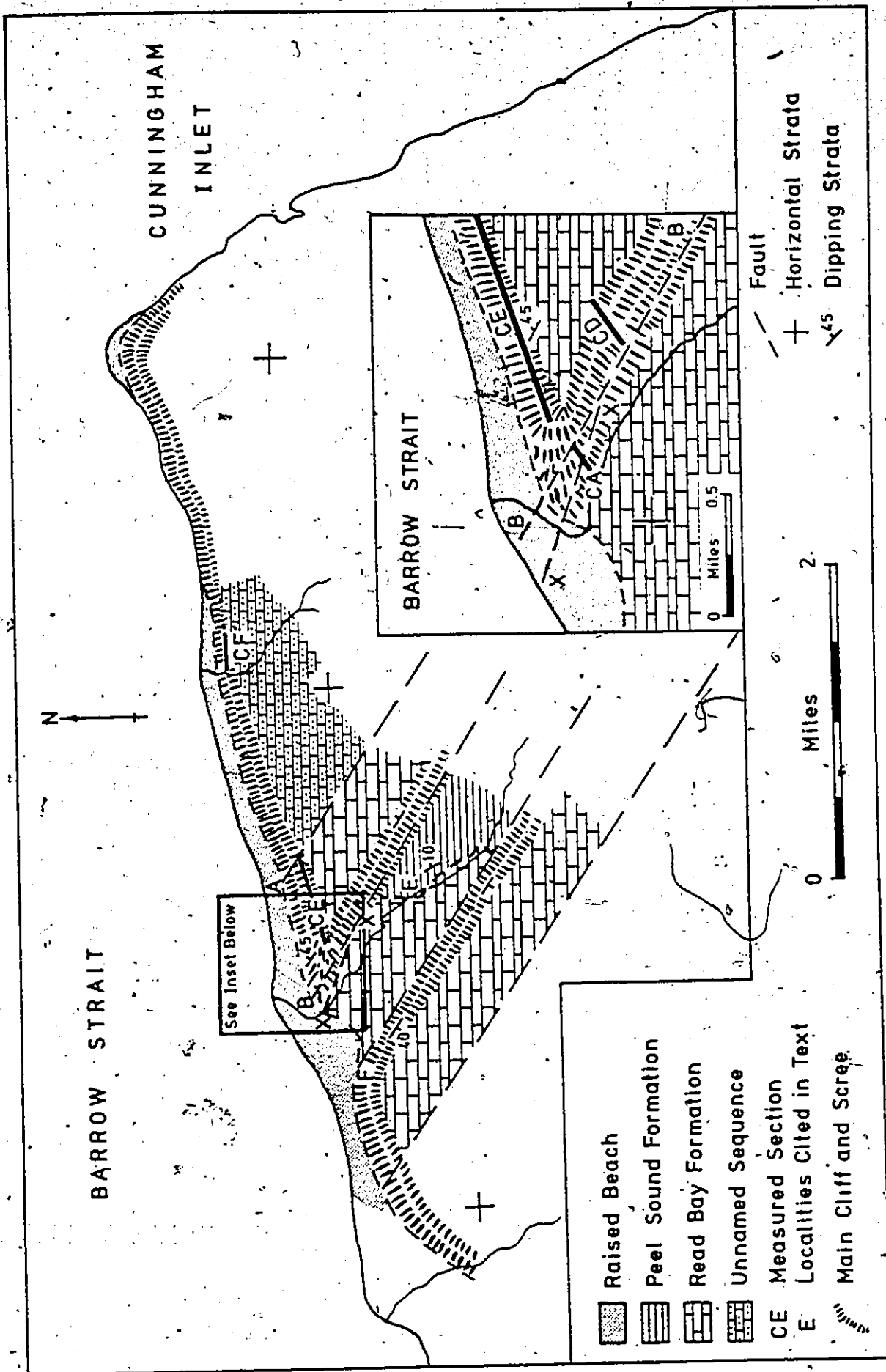


Text-figure 5.

Geology of the Garnier Bay area, location of measured sections GA, GB, GD and GE and location of isolated exposures studied (GC).

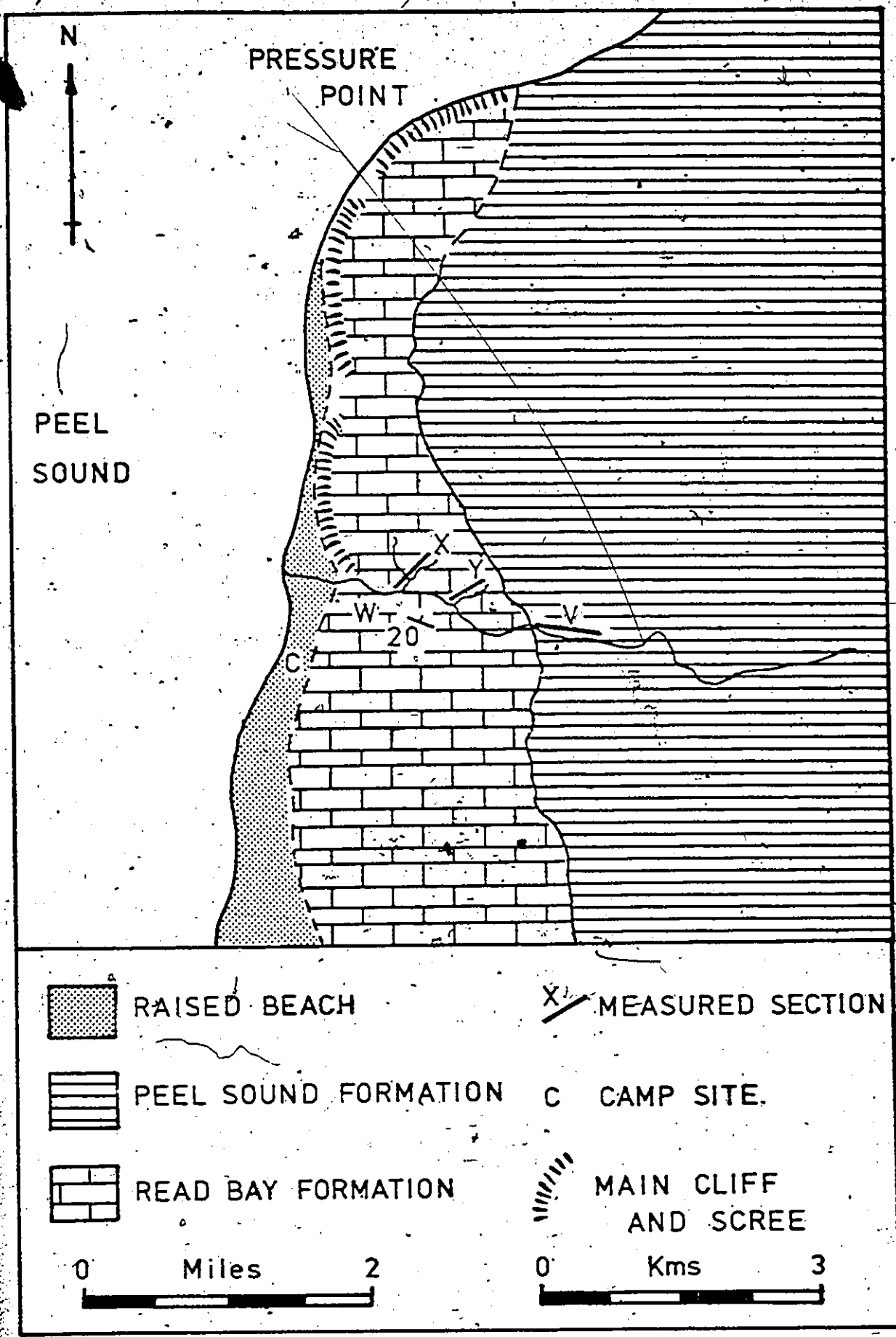
Text-figure 6

Geology of the area to the west of Cunningham Inlet and location
of measured sections CA, CD, CE and CF.



Text-figure 7.

Geology of the Pressure Point area and location of measured sections
X, Y and V and isolated exposure W.



PEEL
SOUND

PRESSURE
POINT

 RAISED BEACH

 PEEL SOUND FORMATION

 READ BAY FORMATION

 MEASURED SECTION

C CAMP SITE.

 MAIN CLIFF
AND SCREE

0 Miles 2

0 Kms 3

recorded in each section. Samples of rock types were taken wherever a new lithology was encountered, whenever the field identification of a particular rock was uncertain or wherever the rock displayed a feature of particular interest. Each rock sample was labelled according to the section code and the unit number. Where fossils were encountered, extensive collections were made. Particular attention was paid to sampling technique to ensure that time-separated assemblages were not mixed.

Previous work

Somerset Island was visited by many of the early explorers including Sir John Ross and F. L. M'Clintock. For a full review of the history of the exploration of this island the reader is referred to Blackadar (in Fortier et al., 1963, p. 105-107) and Blackadar and Christie (1963). Most early reports on the geology of the island emphasized the fossils, which are very abundant in some of the Silurian strata, Salter (1852), Houghton (1857), Etheridge (1878), Foerste (1921) and Teichert (1937) all made brief reference to the Silurian fauna.

The first major work on the stratigraphy and sedimentology of the Paleozoic rocks of Somerset Island was undertaken by the Geological Survey of Canada in 1959 (Operation Franklin). The report on this operation was published in 1963 by Fortier et al. and

constitutes one of the major pieces of research done on the geology of the Canadian Arctic. In 1960 Thorsteinsson and Tozer published a paper on the structural history of the area. Gregory, Bower and Morley (1961) conducted an aeromagnetic survey of the southern Arctic Islands which included Somerset Island. In 1963 Blackadar and Christie produced a detailed map of the geology of Somerset and Prince of Wales Islands. Kerr and Christie (1965) elaborated on Thorsteinsson and Tozer's earlier paper on the structural history of the area. In 1967 Christie produced a compilation of all measured sections from Somerset and Prince of Wales Islands.

In 1964 the University of Ottawa initiated a program of study of Somerset and Prince of Wales Islands. From the early part of this program, which was run by Dr. D. L. Dineley, papers such as those by Dineley (1965a, b and 1968), Tuke, Dineley and Rust (1966); Rust and Coakley (1966) and Brown et al. (1969) resulted. In 1969 A. Miall completed a Ph. D. thesis on the Peel Sound Formation of Prince of Wales Island and later published papers on this topic (Miall, 1970a, b and 1973). In the early part of this program little attention was paid to the lower Paleozoic formations of these islands. However, in 1968 S. R. Williams started work on the Read Bay Formation and in 1969 J. Dixon commenced work on the Allen Bay Formation of the two islands. The present author commenced work on the Read Bay

Formation on the northern coast of Somerset Island in 1971 and in

1973 J. Savelle started research toward an M. Sc. thesis on the Read

Bay Formation of the Creswell Bay area of Somerset Island. The latter

part of the program has been run by Dr. O. A. Dixon who is also

working on the Silurian corals from the Read Bay Formation. In 1973

M. Gibling commenced work on the Peel Sound Formation of Somerset

Island under the supervision of Dr. B. R. Rust. From the latter part

of this program, papers such as those by Dixon, Williams and Dixon

(1971), Turner and Dixon (1971), Dixon, Williams and Turner (1972) and

Dixon, Hopkins and Dixon (1973) have resulted.

Objectives of present study

The basic aim of this thesis is to examine the sedimentology,

stratigraphy and paleontology of the Upper Silurian strata of northern

Somerset Island. Particular attention was paid to the deciphering of

the facies patterns and their associated faunas. From the general

framework of the research project a number of topics were chosen for

detailed study:

- (1) the petrology of the sedimentary rocks and their diagenetic textures,
- (2) determination of the environmental conditions in which the
sediments accumulated,
- (3) reconstruction of the Upper Silurian paleogeography of the area,
- (4) detailed study of brachiopods in the Read Bay Formation. This

involved detailed systematic description and revision of the genus Atrypella,

(5) the relationships between the faunas and the sedimentary facies.

The short field seasons, the difficulty of travel in the region and inclement weather are all obvious limitations on the amount of field work that can be done in the Arctic. Work on the project was also held up when the rock samples collected during the 1971 season were delayed in transit to Ottawa until the summer of 1972.

The north coast of Somerset Island is more than 90 miles long. Consequently, most of the areas studied are 20-30 miles apart and in many places there is no good exposure in the intervening country. In other instances the limited transport facilities prevented examination of the geology in these intervening areas. Consequently, the correlation of successions from one area to another is extremely difficult. The problem is further accentuated by the lack of exposure inland and by the lack of good stratigraphic marker horizons and the scarcity of diagnostic faunas. The paleogeographic conclusions must be viewed in the light of these difficulties. Further investigations of the intervening areas are required to confirm many of the suggestions presented in this thesis.

Geological setting

Structural framework for Silurian sedimentation in the Canadian Arctic.

In Paleozoic times one of the prominent structural features of the Canadian Arctic was the Franklinian Geosyncline (Text-fig. 8) which can be traced for more than 900 miles from northern Ellesmere Island to Victoria Island. Within this structure two subdivisions can be recognized, a miogeosynclinal belt and a eugeosynclinal belt, the latter being exposed only on Ellesmere and Axel Heiberg Islands. Clastic sediments predominated in these areas and of prime importance for dating and correlation are the graptolitic shales. A good example of the sedimentation patterns in the Franklinian Geosyncline during the Silurian Period is the succession in the Hazen Trough (Trettin, 1971).

To the south of the Franklinian Geosyncline was an extensive carbonate platform. The platform consisted of several distinct sedimentary basins separated by arches of the Precambrian basement. As a result the boundary between the Canadian Shield and the Paleozoic sedimentary rocks is highly irregular (Fortier et al., 1954). As shown in Text-figure 8, three main arches were present in the southern Arctic lowlands during the Paleozoic Era:

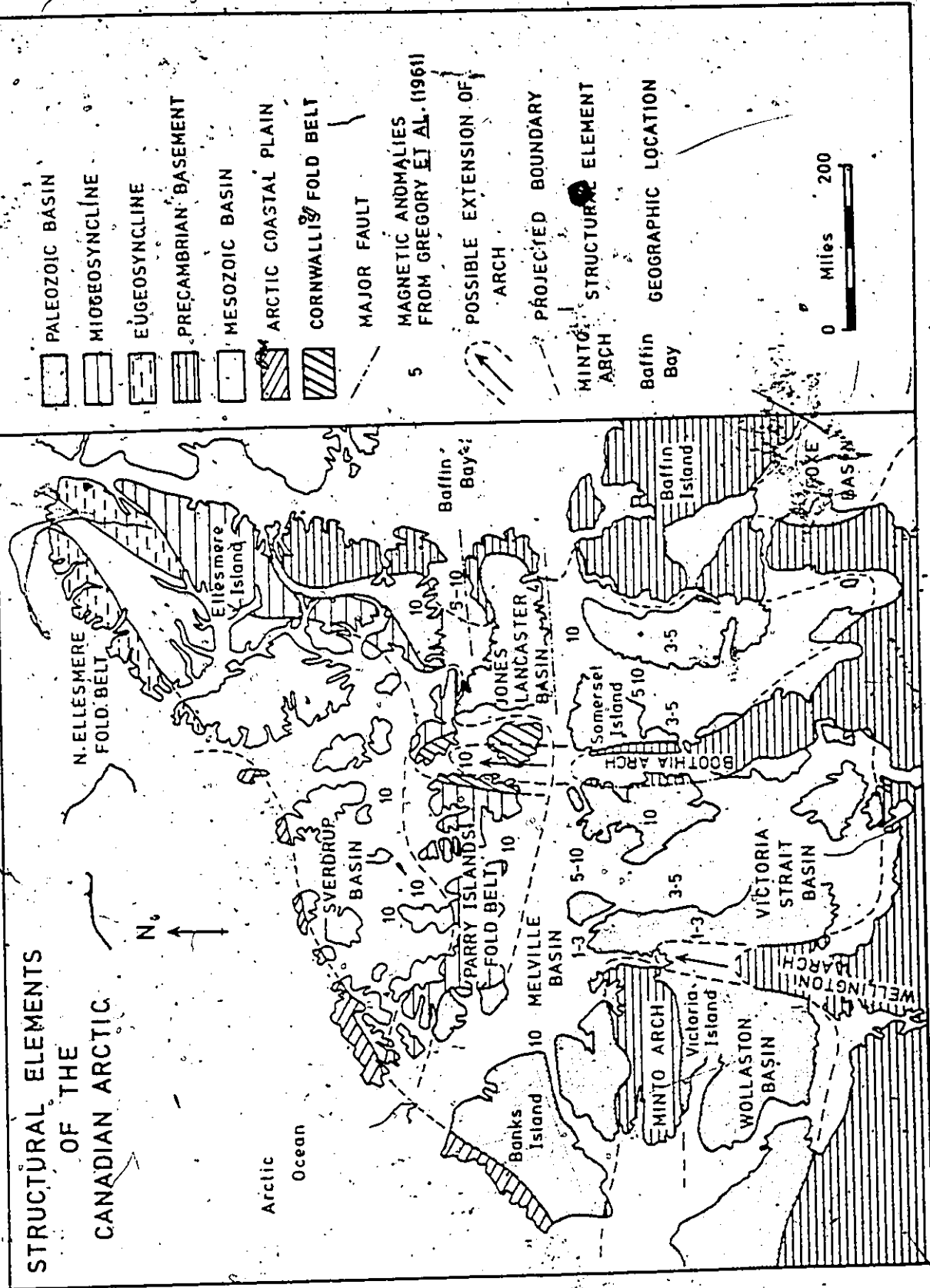
- (1) The Minto Arch is a northeasterly trending arch running through the northwest part of Victoria Island (Text-fig. 8). This arch has poor magnetic expression. Across the northeastern corner

Text-figure 8.

Structural elements of the Canadian Arctic (After Thorsteinsson
and Tozer, 1960, p. 550).

STRUCTURAL ELEMENTS

OF THE CANADIAN ARCTIC



there is a magnetic discontinuity which is thought to indicate a fault.

- (2) The Wellington Arch is a northerly trending arch situated in the southern part of Victoria Island (Text-fig. 8). This is the smallest of the three arches.
- (3) The Boothia Arch is a north-trending arch lying between Somerset Island and Prince of Wales Island. On the basis of aeromagnetic data, Gregory et al. (1961) suggested that the Boothia Arch extends into Bathurst Island where it either terminates or plunges northward. These authors further suggested that the northern portion has been offset 10-20 miles by a fault along Barrow Strait, just south of Devon Island. The presence of a fault is suggested, by a marked magnetic discontinuity in the vicinity of the south coast of Devon Island, by the steep linear nature of the southern coast of Devon Island and by the rapid increase in water depth at the supposed position of the fault.

The western side of the Boothia Arch appears to be bounded by steep faults. The eastern side may also be fault bounded although in the vicinity of Aston Bay (N. W. Somerset Island) the basin appears to slope gradually eastward (Dixon, 1973, unpubl. Ph. D. thesis).

Gregory et al. (1961) suggested that the Boothia Arch was

either an imperfectly developed horst or a faulted anticline.

Walcott (1970) considered that the arch was originally only a mildly positive area developed by isostatic amplification as sediment was deposited in adjacent areas. Once the arch became covered by sediment, such movement ceased.

The Boothia Arch is the most extensively studied of the three arches. Brown *et al.* (1969) showed how this arch influenced the sedimentation patterns of the adjacent basin areas. Miall (1970b) has vividly described the effect the arch had on sedimentation during the Devonian Period. However, as Dineley (1971) pointed out, the arch was not always an emergent feature. During the Ordovician and Silurian periods the arch may have formed a topographic high which influenced local circulation and sedimentation to a certain extent but it supplied little detrital material.

The three arches divided the southern platform area into four distinct sedimentary basins (Text-fig. 8). According to Fortier *et al.* (1954) these basins range in area from about 1,500 square miles (Victoria Strait Basin) to 6,800 square miles (Jones-Lancaster Basin).

While it is not certain how these basins formed, a number of hypotheses have been advanced:

- (1) They are crustal downwarps of pre-Paleozoic age (Fortier *et al.*

1954).

(2) They are crustal depressions with thickened sections (Fortier et al., 1954).

(3) They are 'graben type' structures (Gregory et al., 1961)

The Proterozoic strata in these basins are of considerable thickness. For example, Gregory et al. (1961) estimated that about 10,000 ft of Proterozoic sediments are present in the Melville Basin. However, most of these sediments are horizontal or only gently dipping, which prevents accurate study of the mode of basin formation. All the possibilities previously listed could account for the basins now seen and it is thus difficult to state which was the dominant process.

Earth movements Within the Paleozoic Era two periods of earth movements affected the Canadian Arctic. The first is usually termed the 'early Paleozoic movements' (Thorsteinsson and Tozer, 1960) and occurred at the end of the Silurian Period. These movements produced northward-trending structures such as those present in the Cornwallis Fold Belt. In some areas such as the Driftwood Bay area of eastern Bathurst Island these movements resulted in the development of an angular unconformity between the Silurian and Devonian strata.

The second major period of deformation, which is commonly termed the 'Mid-Paleozoic movements' (Thorsteinsson and Tozer, 1960) occurred in Upper Devonian and Pennsylvanian times. These movements

produced regular folds which have a fold trend as exemplified by the Parry Islands Fold Belt. The intensity of this folding increases northwards.

The fold belts associated with both these periods of movements developed essentially in the miogeosynclinal areas. In the eugeosynclinal areas such movements caused intense metamorphism and produced highly deformed fold belts.

Stratigraphic and sedimentological setting. Within the Jones-Lancaster Basin, sedimentation began with the deposition of sandstone in a shallow marine environment. These detrital rocks constitute the Proterozoic Aston Formation (Tuke, Dineley, and Rust, 1966). The Aston Formation is succeeded by the Proterozoic Hunting Formation which is predominantly carbonate rocks (Dixon, 1973, unpubl. Ph.D. thesis).

Resting unconformably on the Hunting Formation and the basement rocks is a sequence of Paleozoic rocks which Blackadar and Christie (1963) divided into four stratigraphic units, as follows:

- (1) an unnamed Cambrian formation of sandstone and dolostone (map unit 8),
- (2) a sequence of dolostone thought to correlate with the Cornwallis Group and Allen Bay Formation of Cornwallis Island (map unit 9),
- (3) the Read Bay Formation, a fossiliferous limestone sequence of

Silurian age (map unit 11).

- (4) the Peel Sound Formation, containing conglomerate, sandstone, siltstone, dolostone and limestone (map unit 12). An early Devonian age was suggested for this formation (Brown et al., 1969; Miall, 1970a).

On Somerset Island map units 8 and 9 were undifferentiated and mapped as unit 10 (Blackadar and Christie, 1963, Map 36-1963).

The Allen Bay Formation (70th Ord. - M. Sil.) is almost entirely dolostone which Dixon (1974) interpreted as being deposited in supratidal to subtidal environments. The Young Bay Formation, newly defined by Williams (1973, pers. comm. - and cited in Dixon, 1978, unpubl. Ph. D. thesis), contains rocks of intertidal and supratidal origin. In the upper part of the formation subtidal rocks increase in proportion and fossils become more common.

The overlying Read Bay Formation consists primarily of fossiliferous limestone which accumulated in subtidal environments. Intertidal and supratidal rocks are present at some localities.

The Leopold succession, which is best exposed in the Port Leopold area, is probably the lateral equivalent of the Read Bay Formation. It consists almost entirely of dolomite, sandy dolomite, sandy limestone, sandstone and gypsum which collectively display features indicative of intertidal and supratidal environments. It is

distinguishable from the Read Bay Formation by its higher percentage of dolomitic and detrital rocks and its sparse, restricted fauna.

The Young Bay Formation described from exposures in the western part of the island may be equivalent to the basal part of the Leopold succession. Similarly, the transition beds between the Peel Sound Formation (Lower Peel Sound Formation of Miall, 1970a) and the Read Bay Formation appear to thicken towards the east and may be equivalent to the upper portion of the Leopold Formation.

The Peel Sound Formation is usually conformable over the Read Bay Formation except for local discordance (Miall, 1970a). The rocks of this formation are predominantly terrestrial, but away from the Boothia Arch they grade into marine rocks.

Cretaceous-Tertiary rocks are exposed in a block-faulted basin at Stanwell-Fletcher Lake, Somerset Island (the Idlorak Formation of Dineley and Rust, 1968), near Cunningham Inlet (Hopkins, 1971) and north of Creswell Bay (Dixon *et al.*, 1973).

Acknowledgements

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CHAPTER 2

SEDIMENTARY ROCKS OF THE READ BAY AND LEOPOLD FORMATIONS

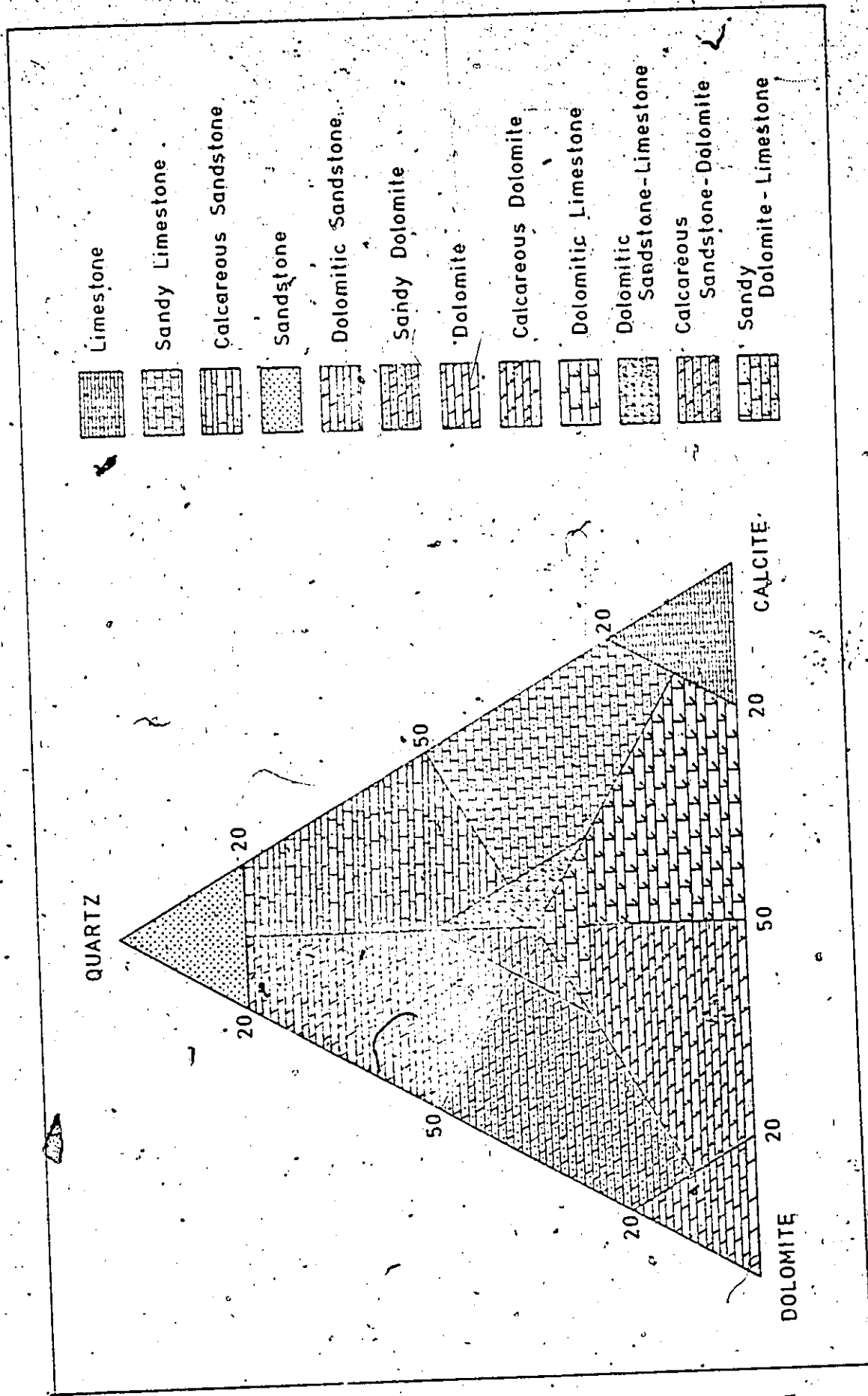
Classification scheme

Most rocks in the Read Bay and Leopold Formations of northern Somerset Island consist of dolomite, quartz and calcite in various proportions. Consequently, the main classification scheme must be one which emphasizes these three end members. The easiest method of classifying rocks that have three main components is to use a triangular diagram such as that shown in Text-figure 9. Twelve categories of rock were established by subdivision of this triangular diagram.

The problem, as with any classification scheme that involves the 'pigeon-holing' of elements, is that of establishing boundaries between adjacent fields. The dolomite, limestone and sandstone in the Read Bay and Leopold Formations can have up to 20-25% of 'foreign' elements without their basic appearance being radically altered. Once this 20-25% level has been passed, the 'foreign' elements become more noticeable and start exerting some control over the overall appearance and texture of the rock. Consequently, on the triangular diagram shown in Text-figure 9, a limestone is defined as a rock composed of at least 80% calcite. Similarly, a dolomite is defined as a rock formed of at least 80% dolomite.

Text-figure 9

Classification of sedimentary rocks in the Leopold succession and the Read Bay Formation - rocks containing quartz, calcite and dolomite on the northern coast of Somerset Island.



Limestones are further classified according to Folk (1959, 1968) who divided limestones into two main groups based on the proportions of micritic and sparry calcite in the groundmass. Further division is based on the types and proportions of allochemical components (Folk, 1968, p. 157).

Clasts, primarily of micritic limestone, are common in some rocks. When the clasts are few in number and constitute less than 50% of the rock, it is termed intraclastic in order to distinguish it from a conglomerate which contains more than 50% of clasts. If the constituent clasts are deemed to have been derived from rocks within the same formation the prefix intraformational is used.

In some of the sections studied the dominant rock type is a micritic limestone in which there is a high content of argillaceous material. This rock occurs in two forms: (1) as a homogeneous rock with no distinct separation of the calcitic and argillaceous components; this type is referred to as argillaceous limestone, and (2) a rock type which on the weathered surface has a rubbly appearance; this type is referred to as rubbly argillaceous limestone. The rubbly appearance of the latter is due to the presence of irregularly shaped masses of hard lithified limestone in a matrix of softer argillaceous material.

Rock types

The following general descriptions of rock types are based on numerous specimens. Features of interest from individual specimens are noted in the detailed discussion of the sections (chapter 3).

The sections were stained with Alizarin Red solution (Friedman, 1959) to distinguish calcite (stains red) from dolomite (no stain). Staining with a potassium ferrocyanide solution (Dickson, 1965, 1966; Neal, 1969) of a number of thin sections did not reveal any difference in the iron content of the various generations of calcite cement.

Sandstone Pure sandstone (i.e. rocks having greater than 80% quartz) is relatively rare in the Read Bay Formation of northern Somerset Island but more common in the Leopold succession. A number of examples were found in the Port Leopold and Garnier Bay areas.

The rock is characterized by angular to subangular quartz grains which are generally less than 0.15 mm (longest axis) in size and commonly show undulose extinction. Minor quantities (generally less than 10%) of muscovite and dolomite are present locally. Micritic calcite occurs interstitially. In some instances, such as unit GB2 of the Garnier Bay section, the sandstone contains minor quantities of shell debris.

Many of the quartz grains are in mutual contact along

planar compromise boundaries.

Dolomitic sandstone Dolomitic sandstone is very rare and is present only as thin laminations in the interlaminated sandy dolomite/dolomitic sandstone of the Port Leopold and Garnier Bay areas. In the Port Leopold area, only one unit (D31) of this rock type was recognized.

The quartz grains are angular to subangular, up to 0.20 mm in size and generally display undulose extinction. Compromise boundaries are commonly developed between adjacent quartz grains.

The dolomite occurs as individual grains which have a similar size and shape to the quartz grains. In some instances, truncated crystal faces of dolomite rhombs are visible, suggesting that some may be abraded dolomite rhombs.

Minor quantities of muscovite and microcline are present locally.

Calcareous sandstone The calcareous sandstone is of two types:

- (1) One type of calcareous sandstone is characterized by quartz grains in a cement of sparry calcite. The quartz grains are angular to subangular, up to 0.20 mm (longest axis) in size and many display undulatory extinction. Minor quantities of muscovite and plagioclase are present. In some units shell debris and pellets are present.

The calcite, which forms the cement of the rock, is of one phase and fills the interparticle spaces. Locally the calcite has

replaced quartz resulting in irregular-shaped quartz grains.

- (2) A second type of calcareous sandstone is characterized by quartz grains in a matrix of micritic calcite. This type commonly occurs as individual laminations in interlaminated rocks (e.g. interlaminated calcareous sandstone/sandy limestone-dolomite of unit B12). This type of calcareous sandstone is characterized by angular to subangular grains of quartz up to 0.15 mm in size.

Minor quantities of plagioclase, muscovite and secondary dolomite are commonly present.

Sandy dolomite Two distinct types of sandy dolomite are present:

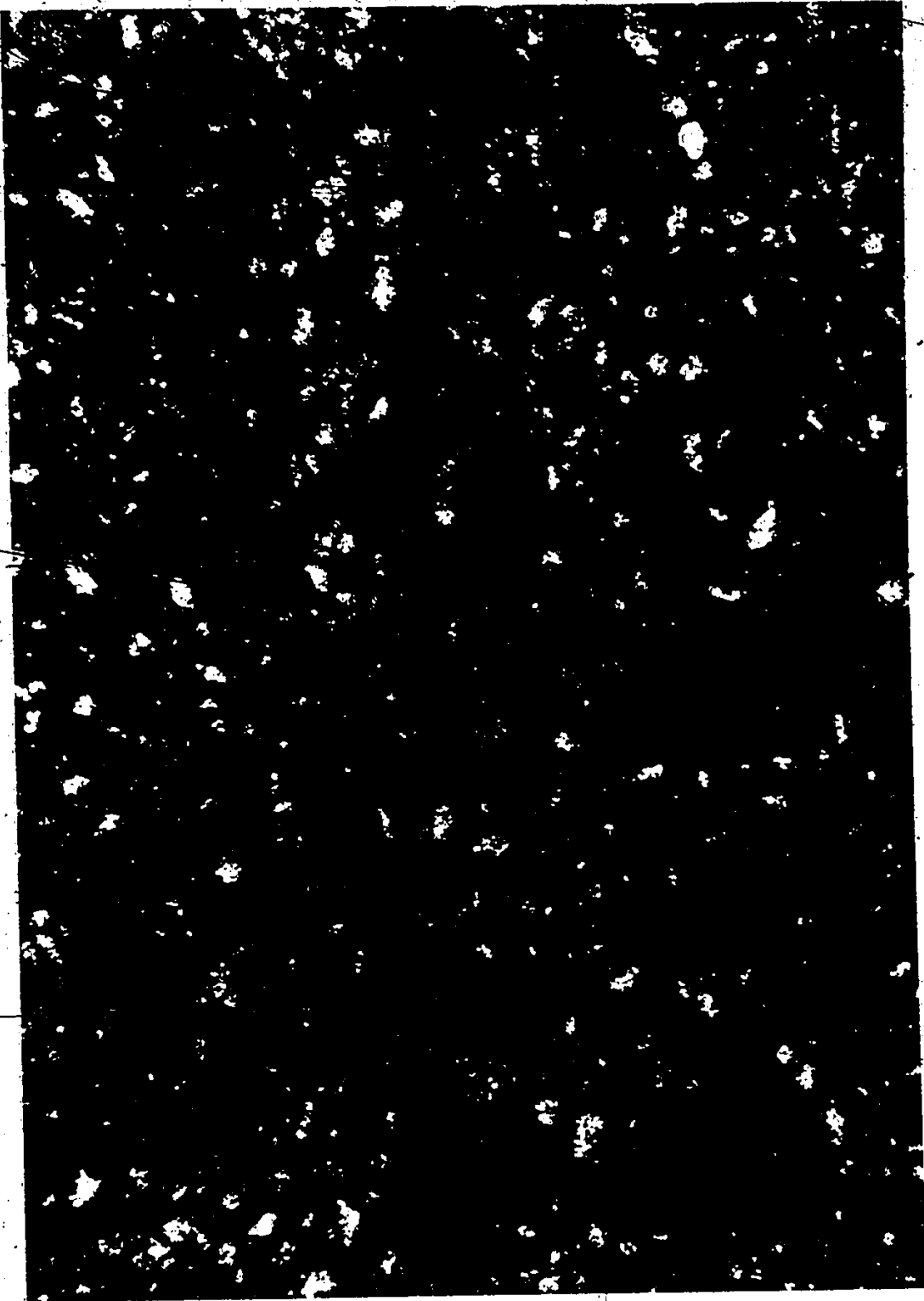
- (1) The first type is relatively rare, occurring only in a few units in the Port Leopold area (e.g. unit F2). The dominant component is mud-sized dolomite in which there are only a few isolated dolomite rhombs (longest axis less than 0.05 mm). Scattered throughout the dolomite are angular to subangular grains of quartz which attain a maximum size of 0.10 mm. Many of the quartz grains display undulatory extinction. Muscovite, micritic calcite and shell fragments occur in minor amounts (Pl. 1).
- (2) A second type of sandy dolomite occurs only as thin laminae alternating with other rock types such as dolomite. The dolomite grains in the two types of laminae contrast sharply. In the dolomitic laminae, the dolomite is mud-sized and contains little

Plate 1.

Dolomite replacing shell fragment

Photomicrograph of thin section stained with Alizarin Red solution showing dolomite (light brown colour) replacing calcite (red) of shell fragment. White grains are quartz, while groundmass is composed of dolomite and calcite (red). Thin section from unit F2 of the Port Leopold area. Textural relationship of dolomite and calcite clearly demonstrates that dolomite is of secondary origin. X100

PLATE 1



other material. The dolomite in the sandy dolomite laminae occurs as irregularly shaped grains which attain a size of 0.25 mm but average about 0.15 mm. They are of a similar size and shape to the quartz grains which occur in the same laminae. In some instances dolomite rhombs are present but they commonly have their corners broken off and some are fractured. Muscovite occurs in the sandy dolomite laminae but not in the dolomitic laminae.

Sandy limestone The sandy limestone is similar to the calcareous sandstone previously described (p. 26) except that calcite is the dominant component. Quartz grains are scattered throughout the rock and only rarely are in contact with each other. Only minor amounts of muscovite are present.

Dolomite This rock type is characterized by fine-grained dolomite in which isolated dolomite rhombs occur. Minor quantities of shell material and quartz grains may be present. The dolomite rhombs are up to 0.10 mm (longest axis) in size. The rhombs are normally isolated and scattered throughout the rock. Within the dolomitic groundmass small, irregularly shaped patches (up to 0.50 mm) of micritic calcite occur locally. The grain size of the calcite is similar to that of the dolomite.

Calcitic shell debris is also present in some of the dolomitic units along with minor quantities of quartz grains. In many examples

the shell debris is partly replaced by dolomite or cut by a single dolomite rhomb.

Calcareous dolomite The calcareous dolomite is texturally very similar to the dolomite described above and differs only in having micritic calcite as a more significant component.

Dolomitic limestone The dolomitic limestone of the Port Leopold, Garnier Bay and Cunningham Inlet sections is texturally very similar to the calcareous dolomite described above. The dominant component is micritic calcite in which some quartz grains occur (angular to sub-angular, up to 0.10 mm). There are a few isolated dolomite rhombs (0.10 mm) but more commonly irregularly shaped patches of fine-grained dolomite occur. These patches are generally less than 0.50 cms in their greatest dimension. The dolomitic patches apparently are randomly distributed throughout the rock. The grain size in the dolomitic patches is the same as that in the surrounding calcitic material. Locally, originally calcitic shell fragments project through the dolomitic patches. The portion of the shell in the calcitic material is calcitic but that in the dolomitic patch is dolomitic.

Dolomitic sandstone-limestone, calcareous sandstone-dolomite and sandy

limestone-dolomite Each of these rock types can be divided into two types according to the texture of the rock.

The first type is characterized by a groundmass of fine-

grained calcitic material. Fine-grained dolomite occurs as irregularly shaped patches similar to those previously described in the dolomitic limestone. The quartz occurs as isolated grains which are angular to subangular grains and up to 0.10 mm in size. Minor quantities of shell debris occur locally.

The second textural type occurs only as thin laminae in some of the interlaminated rocks. The basic difference from the first type is that the dolomite occurs as isolated grains, some of which display crystal faces. The dolomite grains, which are up to 0.20 mm in size, are similar in shape to the quartz grains that occur in the same laminae. The quartz grains are angular to subangular and commonly display undulatory extinction. Minor quantities of muscovite are present in these laminae.

Pelletoidal limestone Pelmicrite and pelsparite are relatively rare in the sections studied and were found mainly in the Port Leopold sections (Pl. 2, fig. 2).

The pellets are elliptical in cross section (although some are flattened due to diagenetic pressures) and up to 0.38 mm in length. They are formed of micritic calcite which is rich in organic matter and locally encases small quartz grains. Clasts of micritic calcite

Plate 2.

Pelletoidal limestones

Figure 1: Photomicrograph of pelmicrite from unit F8 of the Port Leopold area showing clear calcite rims around pellets. Thin section under plane polarized light.

Figure 2: Photomicrograph of pelmicrite from unit B13 of the Port Leopold area. Thin section under plane polarized light.

Figure 3: Photomicrograph of oncopellet in unit B13 of the Port Leopold area showing multiple laminations of clear calcite around pellets. Thin section under plane polarized light.

Figure 4: Photomicrograph of oncopellet in unit B13 of the Port Leopold area showing the combination of three individual oncopellets into a single larger oncopellet. Note that each of the component oncopellets has its own clear calcite rim. Thin section under plane polarized light.

N.B. Scale for figure 2 is incorrect - total bar scale equals 0.50 mm

PLATE 2

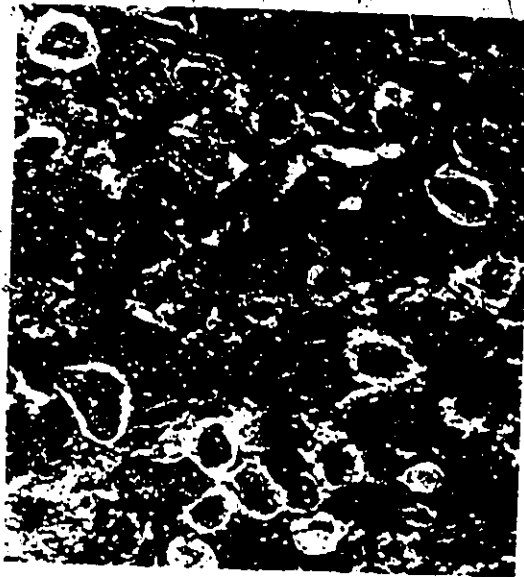


FIGURE 1

0 Mm 1



FIGURE 2

0 Mm 1



FIGURE 3

0 Mm 0.1



FIGURE 4

0 Mm 0.1

(up to 2 cms, longest axis) and some quartz grains occur with the pellets.

The pelsparite is characterized by two generations of interstitial calcite crystals; a first generation of scalenohedra and a second generation of anhedral-sparry calcite.

In some examples, the pelmicrite units are difficult to recognize because diagenetic pressures have crushed the pellets and caused them to merge with the micritic calcite of the groundmass.

Oncopelletal limestone The term oncopelletal is used to describe the structures shown in Plate 2, figures 1 and 3. The ovate bodies in this rock type consist of a central portion of fine-grained calcite and an outer rim of 'clear' calcite (Pl. 2, fig. 1). The central portions are very similar to the pellets in the pelsparite and pelmicrite suggesting that they had a similar origin. Many of the pellets encased by the clear calcite rim contain small quartz grains and are commonly rich on organic matter. The outer rim of 'clear' calcite forms up to 10-15% of the total diameter of the ovate body (0.50 mm maximum). Some of the rims are featureless but others display concentric or asymmetrical laminations (Pl. 2, fig. 3). In some instances two or more ovate bodies have been encased by an additional

calcite rim to form a larger body (Pl. 2, fig. 4).

The groundmass is either micritic calcite (Type II of Folk, 1968) or sparry calcite (Type I of Folk, 1968). The oncopelsparite is commonly very vuggy and this may be due to the absence of a second generation of calcite cement. Lining the vugs are first generation scalenohedra of calcite. Clasts of micritic calcite and small quantities of quartz grains occur in these rock types.

Oncolitic limestone Oncolitic limestone was found at only one locality at Port Leopold in section PA (unit 10). The individual oncolites are up to 3 cms (longest axis) in size. The algal laminae of many of these oncolites have developed around clasts of limestone (Pl. 3, fig. 1). Locally, where the algal laminae have developed around a gastropod shell the resultant oncolite mimics the shape of the enclosed gastropod (Pl. 3, fig. 1). The oncolites are set in a matrix of micritic calcite.

Micritic limestone Micritic limestone is common in the Read Bay Formation and the Leopold succession. It is formed of mud-sized calcite which, by definition, contains only minor quantities of dolomite, quartz, muscovite or shell debris.

Shelly limestone Shelly limestone is common in many of the sections studied. The shell material commonly consists of small fragments (generally less than 1 cm long) of brachiopod shells, ostracod shells

Plate 3

Oncolitic limestone and shelly limestones

Figure 1: Field photograph of oncolitic limestone from unit PA10 of the Port Leopold area showing oncolites mimicing shape of nuclei.

Figure 2: Photomicrograph of biosparite from unit D38 of the Port Leopold area showing sparry calcite in place of shell material.

Figure 3: Photomicrograph of biosparite from unit GB7 of the Garnier Bay area showing two phases of calcite cement.

N.B. Scale for figure 1 is incorrect - total bar scale equals 2 cms

PLATE 3

FIGURE 1



FIGURE 2



FIGURE 3



trilobites and less commonly coral or bryozoan debris. The original shell structure is commonly preserved but locally, as in unit D38, the shells have been replaced by more coarsely crystalline calcite (Pl. 3, fig. 2).



The matrix of this rock type is either micritic (Type II of Folk, 1968) or sparry calcite (Type I of Folk, 1968) giving rise to the classes biomicrite and biosparite. Much of the sparry calcite in the biosparite shows two generations of crystal growth (Pl. 3, fig. 3).

Rubbly limestone Rubbly limestone derives its name from its field appearance. This rock type commonly occurs as thick units (up to 12 m) and on the weathered surface has a characteristic rubbly appearance caused by the occurrence of hard lithified lumps of limestone in a softer matrix which is more easily eroded. Five different types have been recognized, as follows:

- (1) The first type of rubbly argillaceous limestone consists of hard, irregularly shaped lumps of micritic limestone in a matrix of argillaceous material. The lumps, which are rarely greater than 20 cms in their longest dimension, apparently have a random orientation. Locally, one lump may be in contact with another, but more commonly they are separated by zones of argillaceous material;

The limestone lumps are formed of micritic calcite and microspar. The micrite (Pl. 4) encloses shell debris which shows

Plate 4/

Type I rubbly limestone

Photomicrograph of Type I rubbly limestone from unit GD2 of the Garnier Bay area. Thin section under plane polarized light shows zonation of limestone lumps from micritic limestone (ML) at centre to crystalline calcite (CC) at edges. The argillaceous groundmass (AGM) contains dolomite rhombs (LR) and shell debris (SD).

PLATE 4

AGM

SD

DR

CC

ML

1

2

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

little or no diagenetic alteration. Zones of crystalline calcite with crystals about 0.04 mm in size surround the areas of micritic calcite and enclose shell material which shows some degree of diagenetic alteration. These zones in turn are enclosed by outer zones of coarsely crystalline calcite (up to 0.10 mm in size). The concentration of the crystals per unit area shows a tendency to decrease towards the outer part of the zone (Pl. 4). Shell fragments in the outer zone are extensively replaced by spar, commonly to such an extent that only 'ghost' structures remain.

Between the limestone lumps are zones of mud-sized material which has a high content of organic matter. Numerous isolated dolomite rhombs (longest axis up to 0.15 mm) occur in this zone and commonly penetrate the shell debris. The shell fragments in this portion of the rock are generally small (0.10 mm compared to 0.75 mm in other parts of the rock) and highly altered.

(2) A second type of rubbly limestone, very common on northern Somerset Island consists of hard, irregularly shaped lumps of micritic limestone (longest axis up to 20 cms) in a matrix of argillaceous material. The lumps apparently are randomly distributed and locally in contact with another but more commonly they are separated by zones of argillaceous material.

X-ray diffraction analysis showed that the argillaceous

material has clay, quartz, muscovite, some dolomite and calcite as its main constituents. The quartz is mainly silt- to clay-sized grains but a few grains up to 0.10 mm (longest axis) occur. Muscovite flakes up to 0.35 mm long also occur,

In unit M32 of the Cape Admiral M'Clintock section the long axes of the muscovite flakes show a distinct tendency to be parallel to the margin of the nearest carbonate body. Other large bodies of dark-coloured material also display a similar tendency (Pl. 5, fig. 2).

These units of rubbly argillaceous limestone, especially the thicker ones, are commonly rich in fossils (especially brachiopods). The brachiopods occur in clusters or less commonly evenly distributed throughout the rock. In either type of distribution complete shells are confined to the zones of argillaceous material. This may be a function of poor collecting, but in numerous carbonate lumps split and examined, no complete shells were found.

(3) A third type of rubbly argillaceous limestone is similar to type II in having hard lumps of micritic limestone embedded in a matrix of argillaceous material. However, this type differs from Type II in having semi-continuous beds of micritic limestone. The lumps of hard micritic limestone are usually aligned in the same plane as the semi-continuous beds (Text-fig. 10). This type is relatively rare

Plate 5

Type II rubbly limestone

Figure 1: Hand specimen of Type II rubbly limestone from unit 32
of the Cape Admiral M'Clintock section.

Figure 2: Photomicrograph of Type II rubbly limestone from unit 32
of the Cape Admiral M'Clintock section.

PLATE 5

FIGURE 1

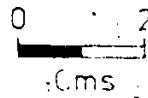
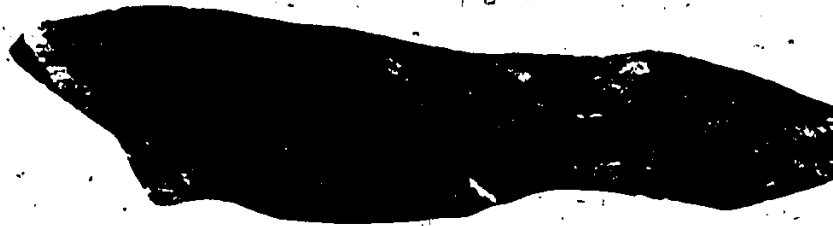
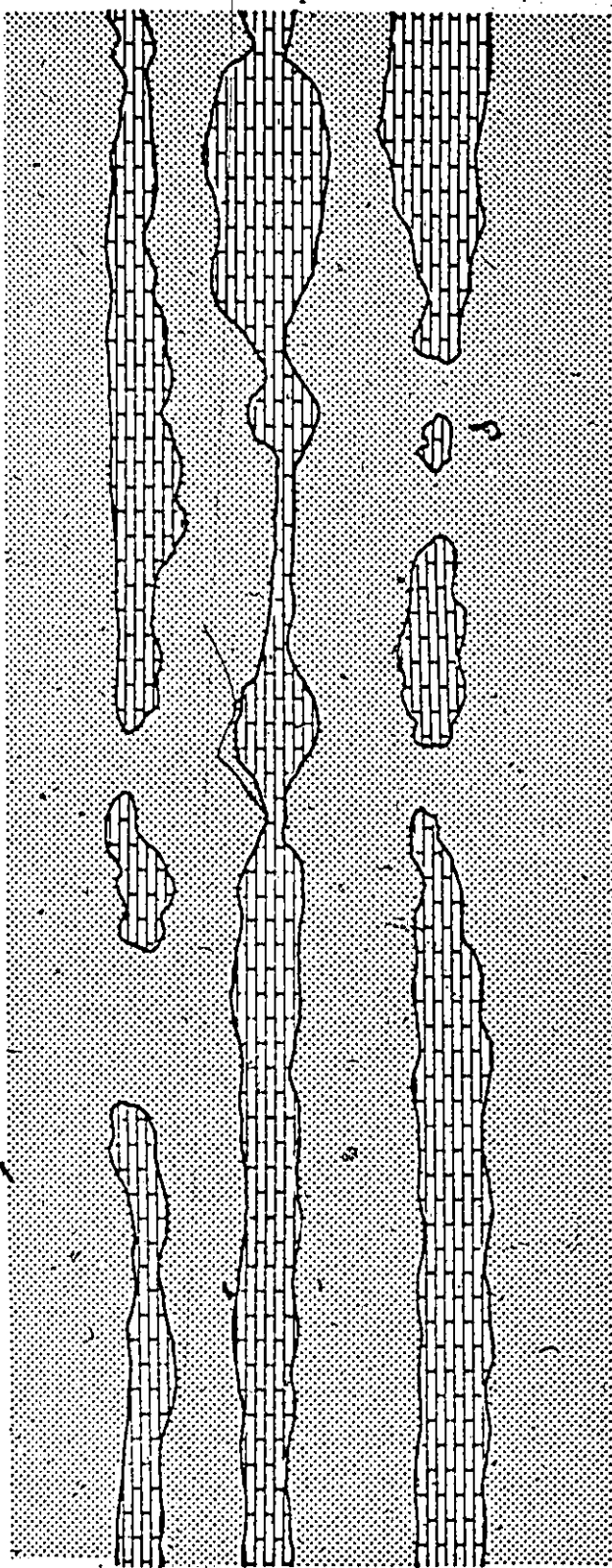


FIGURE 2



Text-figure 10

Limestone lumps in Type III rubbly limestone from units GE6 at
Garnier Bay.



0 cm s⁻²

Argillaceous Material

Micritic Limestone

and is best represented by unit GE6 of the Garnier Bay area.

(4) A fourth type of rubbly limestone, which is common in the Pressure Point section, consists of numerous lumps of micritic limestone embedded in a matrix of dolomitic material. The lumps are of variable size (up to 10 X 6 X 4 cms) and their light grey colour contrasts sharply with the yellowish-orange colour of the dolomitic groundmass. The shape of the lumps is highly variable and commonly angular shapes have developed because of invasion of the micritic limestone by the dolomite (Pl. 6, figs. 1 and 2). Brachiopods (Atrypella foxi n. sp.) occur in unit Y18 and are restricted to the dolomitic matrix. Numerous lumps were split but no whole shells were found in the lumps.

The lumps of micritic limestone appear to be randomly distributed throughout the rock (Pl. 6, Figs. 1 and 2; Text-figs. 11a-f) but in some examples there appears to be some concentration of the dolomitic material in laminations parallel to the bedding planes of the unit (Text-figs. 11a and 11b). However, the pattern of dolomitization is so irregular that this apparent lamination may simply be due to dolomitization and not because of any previous structure.

In thin section the dolomite usually displays some degree of zonation. On either side of the central crystalline dolomite

Plate 6

Type IV rubbly limestone

Hand specimen of Type IV rubbly limestone from units Y10 (Fig. 1) and Y18 (Fig. 2) of the Pressure Point area. Specimens stained with alizarin red solution. Note variable size and irregular shape of the limestone lumps.

FIGURE 1

PLATE 6

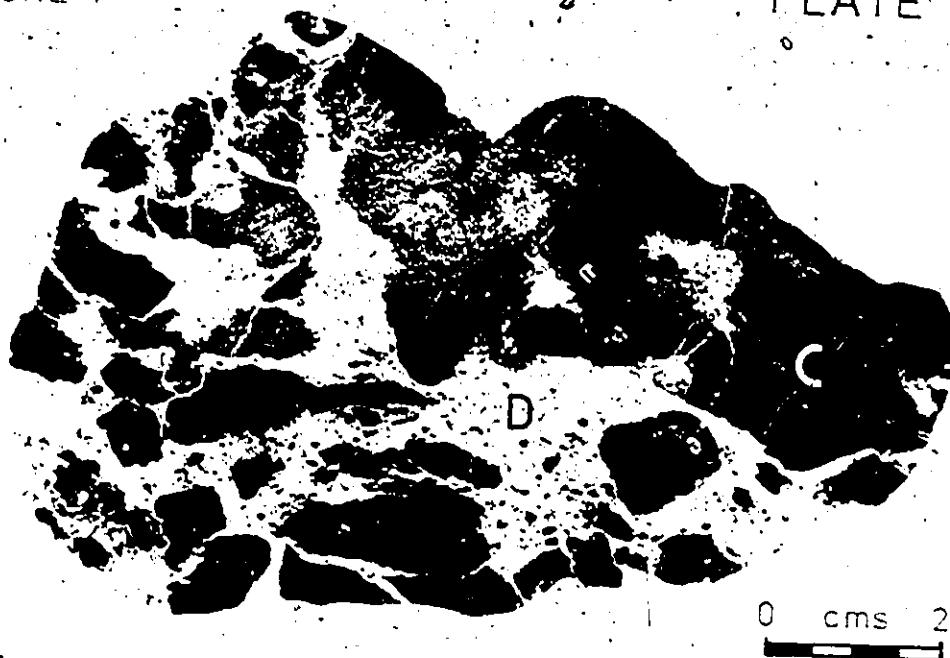
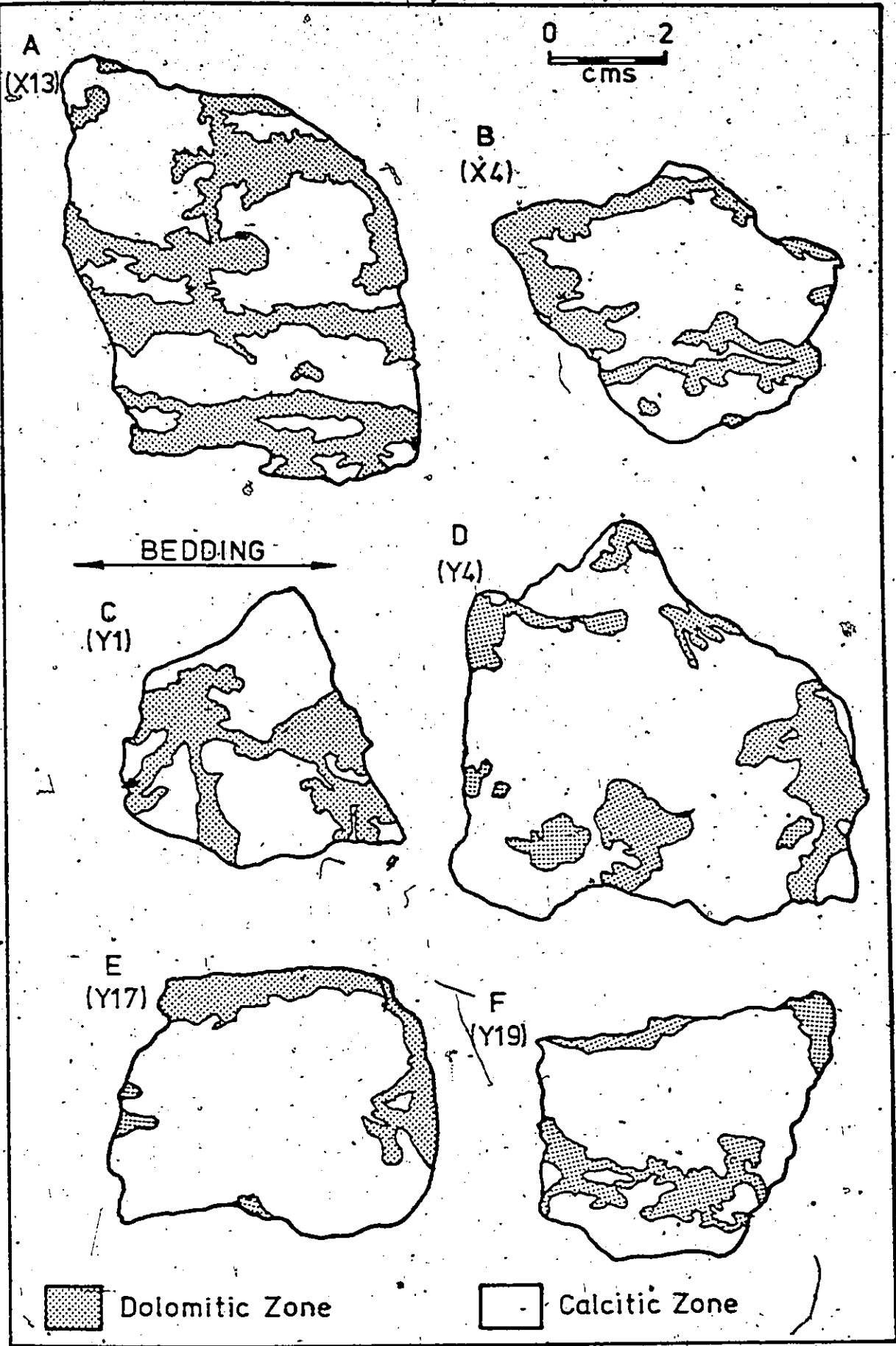


FIGURE 2



Text-figure 11

Limestone lumps in Type IV rubbly limestone of the Pressure Point sections. Code number in parentheses, (e.g. X14) refers to unit from which samples came.



zone there are the following zones: (1) a zone in which the dolomite occurs as isolated rhombs (longest axis up to 0.02 mm) in a groundmass of micritic calcite. The density of dolomite rhombs per unit area tends to decrease away from the central crystalline dolomite zone. (2) a zone of calcite spar, although this zone is not as persistent as the other zones since it commonly thins out and disappears. (3) an outer zone of micritic calcite which forms the limestone lumps (Pl. 7). In some examples the lumps contain fragments of crinoids, brachiopods or bryozoans which are rarely greater than 1 cm in length.

The zones previously described generally have irregular boundaries and in some instances the boundary is transitional and difficult to place exactly. The boundary between zones 2 and 3 tends to be the most irregular and transitional of all the boundaries.

In many of the rocks of this type secondary silica is common as cavity fillings. Many of the brachiopods in unit Y18 are partly silicified. The presence of secondary dolomite and silica in the same rock commonly results in complex textures.

(5) A fifth type of rubbly limestone consists of dolomite and calcite which are arranged in well-defined zones that are parallel to bedding. The micritic limestone occurs as thin layers (usually less than $1\frac{1}{2}$ cm thick) which have hummocky surfaces and are laterally persistent (Pl. 7, fig. 2). The dolomitic material occurs as layers of

Plate 7

Type IV rubbly limestone

Photomicrograph of Type IV rubbly limestone from unit X13 of the Pressure Point section. Thin section under plane polarized light shows zonation from dolomite rhomb-calcite zone (DR-C Zone) around lumps of micritic limestone (ML). Centrally placed between limestone lumps are dolomite zones (D Zone) which are formed entirely of dolomite. Dolomite rhombs (DR) occur between the lumps but not in the lumps.

PLATE 7

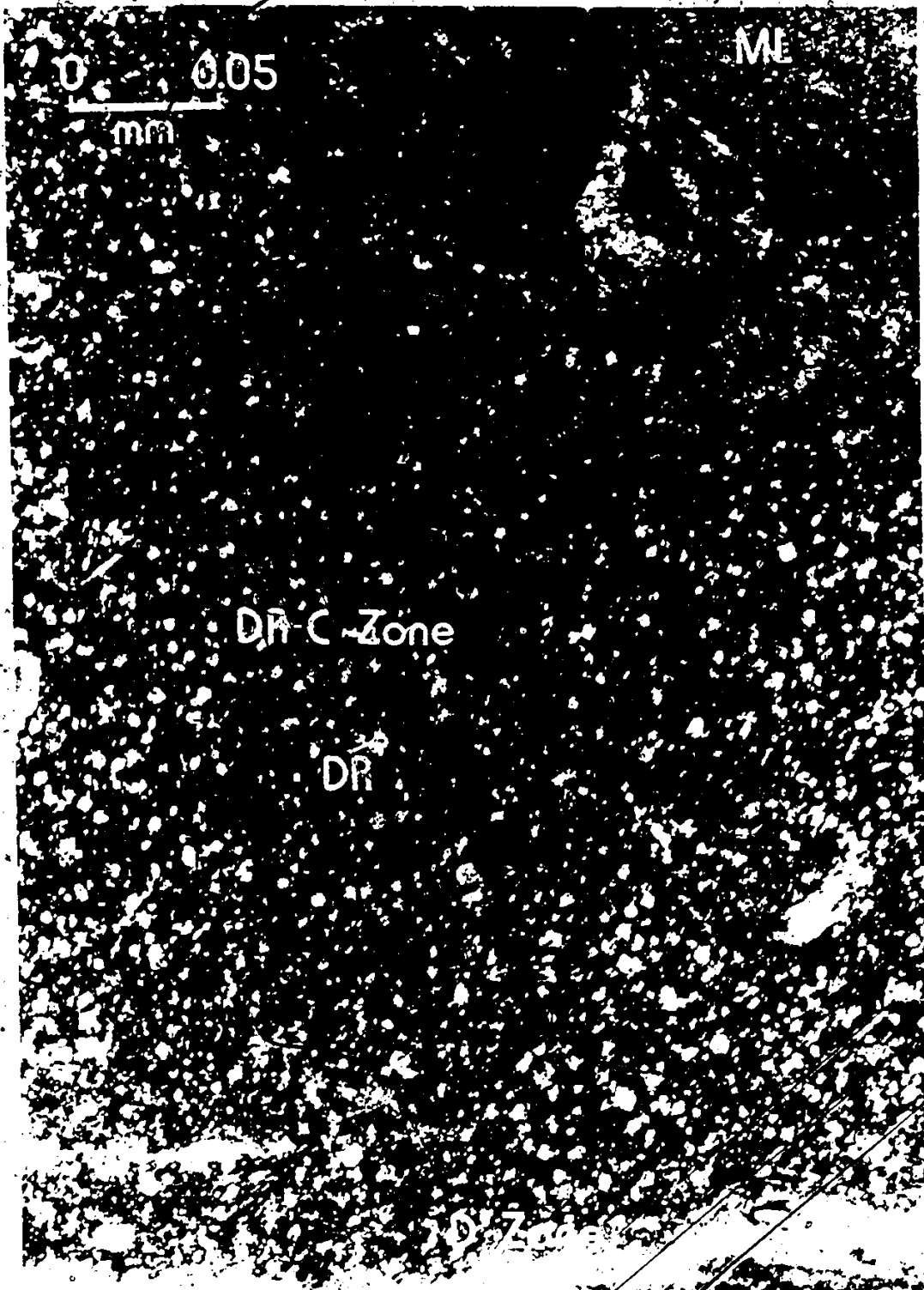


Plate 8

Type IV and type V rubbly limestone

Figure 1: Hand specimen of Type IV rubbly limestone from unit X18 of the Pressure Point area.

Figure 2: Field photograph of Type V rubbly limestone from a locality on the south bank of the West Creswell River, approximately 9 miles north of Creswell Bay.

PLATE 8

FIGURE 1

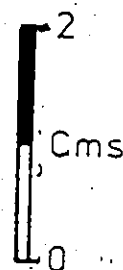
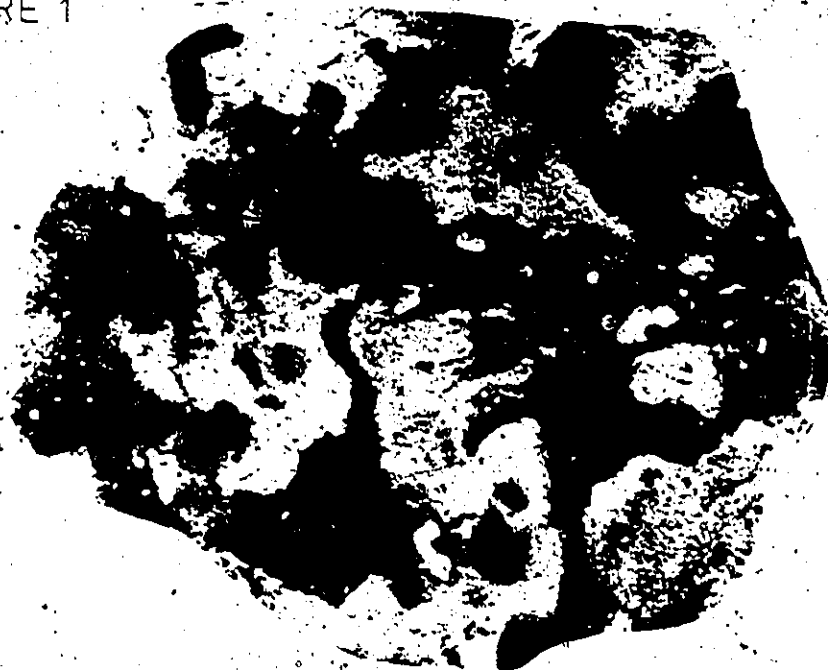
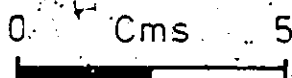
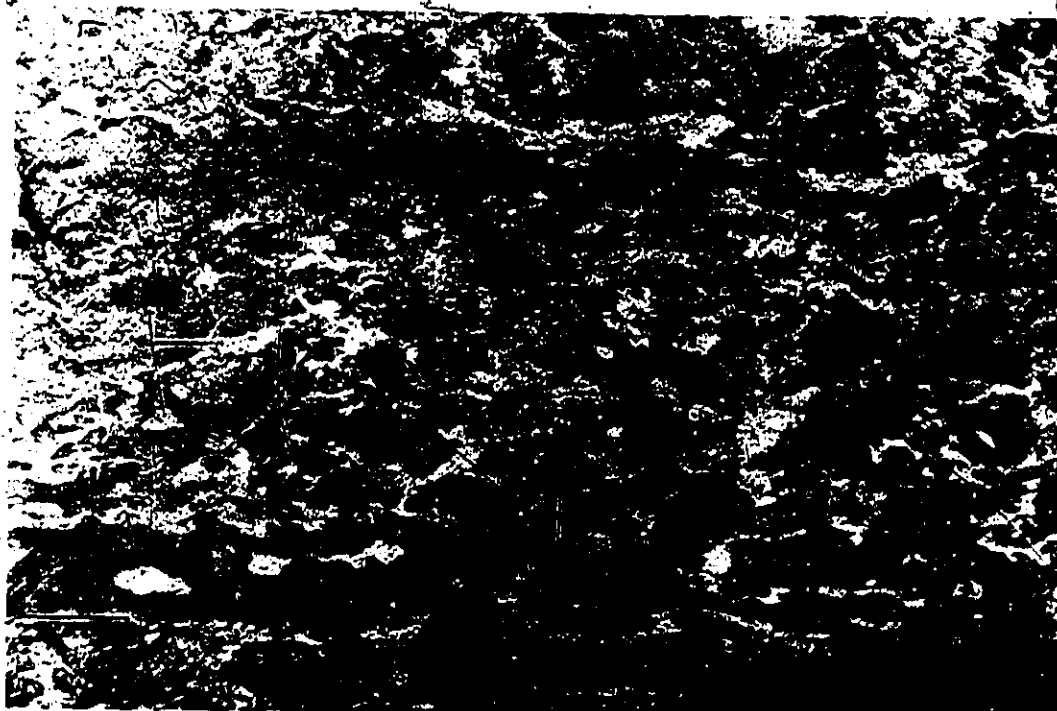


FIGURE 2



irregular thickness between the micritic limestone layers (Pl. 8, fig. 2). The boundary between the dolomitic and calcitic layers is always sharp (Pl. 8, fig. 2).

The dolomitic layers commonly contain numerous complete brachiopods apparently in life position. In striking contrast the micritic limestone layers contain no shells.

Several units of this rock type occur at a locality on the West Creswell River, where the micritic limestone layers are generally less than 2 cms thick and commonly persist laterally for as much as 40 cms. However, these layers pass laterally into a rock consisting of lumps of micritic limestone encased by dolomitic material (Pl. 8, fig. 2). It is apparent from this lateral relationship in horizon and thickness that the lumps were once part of the continuous layers of micritic limestone.

There is little reference to the classification of rubbly limestone in the literature. In 1956 Osmond proposed the classification scheme outlined in Table 1 for the dolomitic group of rubbly limestones. Apart from the fact that this classification scheme only refers to the dolomitic group of rubbly limestones the classification is based on knowledge of the rock's genesis. In most cases this classification scheme cannot be used because as Beales (1953) pointed out, "...the completeness of alteration has obliterated

Table 1.- Osmond's (1956) classification scheme of mottled dolomites

(1) Organic control	(3) Intrastratal deformation control
(a) Tabular	(a) Rolled
(b) Fucoidal (Reticular)	(b) Uneven lamination
(c) Corals and bryozoans	(c) Anhydrite origin
(d) Burrow filling	
(e) Algal origin	(4) Depositional and diagenetic control
(f) Worm tubes	(a) Laminae relics
(2) Depositional control	(5) Diagenetic control
(a) Shrinkage cracks	(a) Permeative
(b) Solution-hole filling	(b) Pseudobreccia
(c) Evaporite blebs	(c) Concretionary
(d) Flocculated masses	(d) Metamorphic

the original texture of these structures, making identification doubtful." Consequently, Osmond's classification is rejected and replaced by the one given in Table 2. This classification scheme, which includes the rubbly argillaceous limestones and the mottled dolomite-limestones, is based solely on field appearance and the petrological character of the rock. The classification scheme is arranged on two levels so that the initial classification, which is made in the field, can later be refined following thin-section analysis.

Intraclastic shelly limestone The intraclastic shelly limestone typically contains abundant shell material and a few intraclasts in a groundmass of micritic and/or sparry calcite (Pl. 9, fig. 2). The shell fragments are rarely greater than 1 cm in length. In the rocks at Cape Admiral M'Clintock the shell material was derived from brachiopods, trilobites, crinoids and bryozoans. In the Port Leopold sections gastropod fragments are abundant. Although the original shell structure is usually well preserved, locally (as in unit 79 of the Cape Admiral M'Clintock section) the shell material has been removed and one generation of drusy calcite now represents the shell. In unit 79 of the Cape Admiral M'Clintock section some of the shell material has not been affected in the manner described above. Indeed, although most of the gastropod shells have been affected, few of the crinoid ossicles or

Table 2.

New classification of rubbly limestones based on material from
Somerset Island.

TYPE OF RUBBLY LIMESTONE						
LEVEL OF OBSERVATION	GROUP 1		GROUP 2			
	RUBBLY ARGILLACEOUS LIMESTONE		MOTTLED LIMESTONE-DOLOMITE			
	TYPE I	TYPE II	TYPE III	TYPE IV	TYPE V	
COMPONENTS	LIMESTONE LUMPS		LIMESTONE LUMPS			
	ARGILLACEOUS GROUNDMASS		DOLOMITIC GROUNDMASS			
DISTRIBUTION OF LUMPS	RANDOM NO CONTINUOUS LAYERS		LONG AXES OF LUMPS PARALLEL TO BEDDING PLANES SOME CONTINUOUS LAYERS	RANDOM NO CONTINUOUS LAYERS	LONG AXES OF LUMPS PARALLEL TO BEDDING PLANES SOME CONTINUOUS LAYERS	
GROUNDMASS	DIFFUSE BOUNDARIES SCATTERED DOLOMITE RHOMBS SHELL MATERIAL EXTENSIVELY ALTERED	SHARP BOUNDARIES NO DOLOMITE RHOMBS MUSCOVITE FLAKES COMMON	SHARP BOUNDARIES NO DOLOMITE RHOMBS	DIFFUSE BOUNDARIES DOLOMITE RHOMBS DISTINCT ZONAL ARRANGEMENT OF DOLOMITE ABUNDANCE	SHARP BOUNDARIES DOLOMITE MUD	
'LUMPS'	ZONATION FROM MICRITE AT CENTRE TO CRYSTALLINE CALCITE AT EDGES		NO ZONATION OF MICRITIC CALCITE	MICRITE OR BIOMICRITE LOCALLY BOUNDED BY CRYSTALLINE CALCITE	NO ZONATION OF MICRITIC CALCITE	
MEGASCOPIC (Field Observations)						
MICROSCOPIC (Thin Section Analysis)						

Plate 9

Intraformational conglomerate and Intraclastic shelly
limestone

Figure 1: Hand specimen of intraformational conglomerate from unit M69 of the Cape Admiral M'Clintock section. Blade-shaped clasts of micritic limestone are held in a groundmass of micritic and sparry calcite.

Figure 2: Hand specimen of intraclastic shelly limestone from unit M105 of the Cape Admiral M'Clintock section. White fragments are crinoid ossicles. Note fragments of sponge in central part of the specimen.

FIGURE 1



0 cms 2

FIGURE 2



0 cms 2

ostracod shells have been modified.

According to Zingg's classification (Krumbein and Sloss, 1963, p. 107) the clasts have a blade shape. They are up to $6.0 \times 4.0 \times 0.75$ cms in size but most are less than $3.0 \times 2.0 \times 0.50$ cms. Some clasts less than 0.50 cm in size are spherical. Although most of the clasts have a smooth surface, some are irregular in outline either because of original irregularity or because of secondary calcite invading and replacing the original clast. The clasts invariably consist of micritic limestone and some have a high content of muscovite.

Intraformational conglomerate The intraformational conglomerate is characterized by clasts derived from within the formation embedded in a groundmass of micritic and/or sparry calcite. Minor quantities of shell debris are present in some units.

According to Zingg's classification (Krumbein and Sloss, 1963, p. 107) the clasts have a blade shape. The clasts are up to $7.0 \times 4.0 \times 0.75$ cm in size but are commonly less than $4.0 \times 2.0 \times 0.50$ cm (Pl. 9, fig. 1). Some spherical clasts are in the size range 0 - 0.50 cm. Most of the clasts are formed of micritic limestone and some contain muscovite and shell debris. The groundmass is micritic calcite and/or sparry calcite.

Sedimentary structures

In most of the sections studied, few sedimentary structures other than bedding were apparent. The classification of bedding characteristics used (Table 3) is that of McKee and Weir (1953--cited in Krumbein and Sloss, 1963, p. 126) with some additional terms defined below.

The term interlaminated is applied to a unit containing two rock types in alternating laminae. The laminae by definition are less than 1 cm thick. The term interbedded has the same connotation as the term interlaminated except that each rock type occurs in beds thicker than 1 cm.

The term unlaminated denotes a rock which lacks bedding planes and appears homogeneous.

Dolomitic rocks described as mottled contain small irregularly shaped patches of dark-grey carbonate which contrast sharply with the lighter coloured carbonate forming the bulk of the rock.

Desiccation cracks (Pl. 10, fig. 1) are common in the dolomitic and sandy units. Such structures are evident in some thin-sections. In the interlaminated dolomite/calcareous dolomite of unit G7 (Port Leopold) the fine-grained laminae of dolomite are commonly disrupted by vertical cracks which are filled with coarser grained calcareous dolomite. The calcareous dolomite also contains some quartz and muscovite (Pl. 10, fig. 2). In examples where sandy limestone

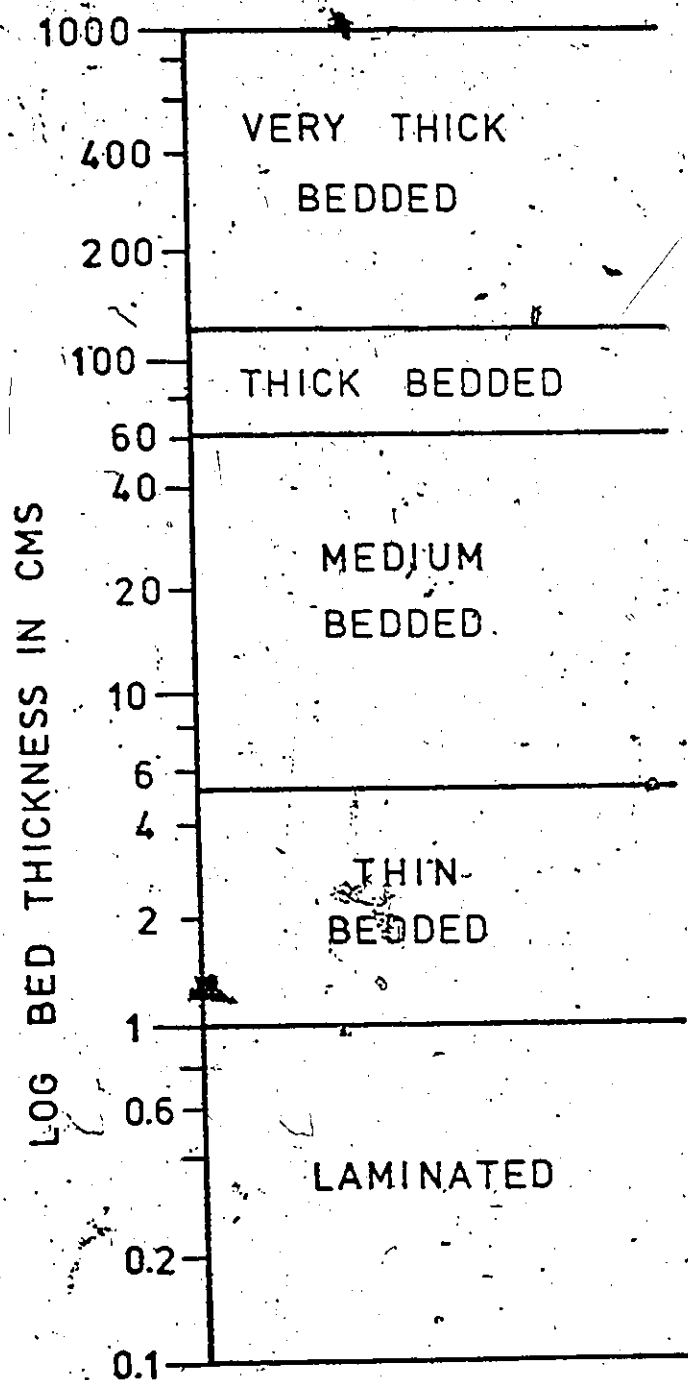


Table 3.- Classification of bed thickness after McKee and Weir

(1953 - cited in Krumbein and Sloss, 1963, p. 126).

Plate 10

Desiccation cracks

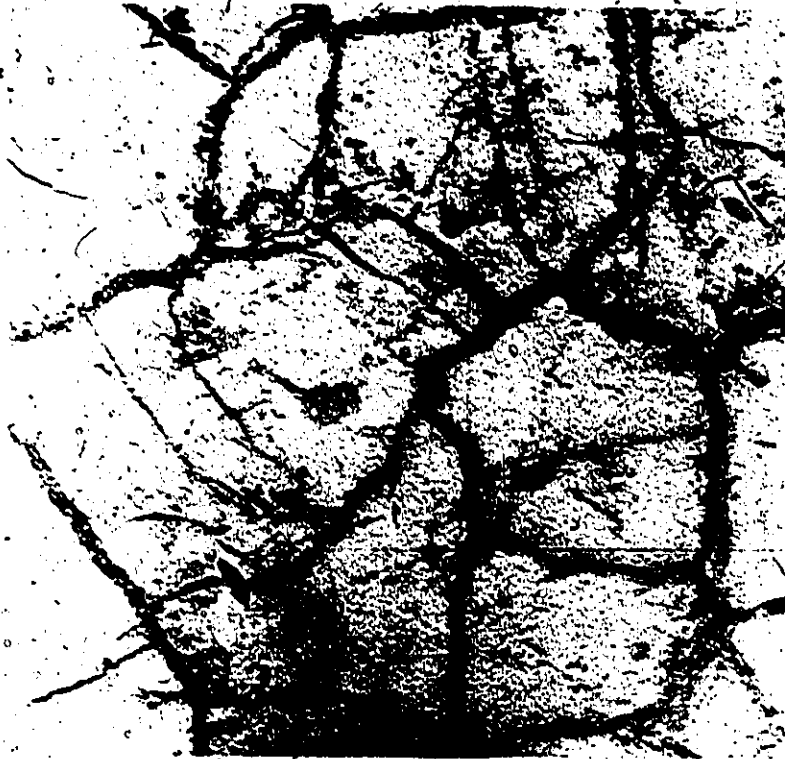
Figure 1: Field photograph of desiccation cracks on a scree block from the Port Leopold area in the vicinity of section A.

Figure 2: Photomicrograph of vertical section through desiccation cracks in unit G7 of the Port Leopold area. Coarse-grained sediment filling cracks and in horizontal laminae is detrital quartz and dolomite in a groundmass of micritic calcite.

Thin section under plane polarized light.

FIGURE 1

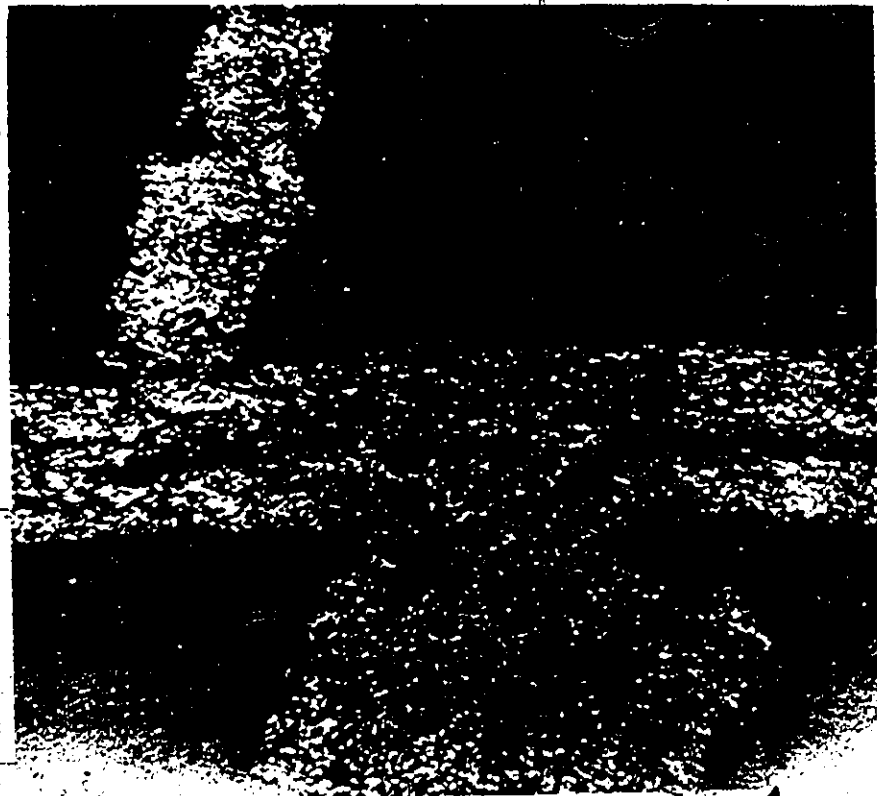
PLATE 10



10
Cms
0

FIGURE 2

3
Mm.
0



is interbedded with dolomite a similar relationship can be seen.

Channels are apparent only in the Port Leopold sections.

The best example is a complete cross-section of a channel in unit J20.

The channel is deep centrally and shallower towards the margins. It is cut into limestone and is filled with intraformational conglomerate.

Unit F11 contains several channels such as those depicted in Text-figure

12. The interesting feature of these channels is the nature of the overhanging sides which suggest that when the channel was cut the sediment had sufficient rigidity to prevent bank collapse. The channel fill is interlaminated limestone and sandy limestone. The trend of these channels could not be determined from the two dimensional exposure.

Clast imbrication is a common feature in many of the conglomeratic units of the Port Leopold area. In unit H41 the clasts dip towards the west.

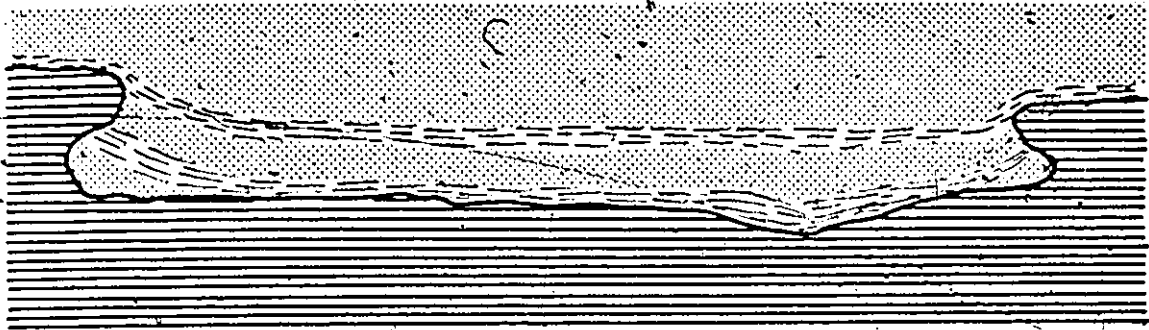
Current bedding is most evident in the units that have a high content of detrital material. Commonly it was difficult to measure the orientation of the cross beds because they were only exposed on two dimensional faces.

The best examples of rippled surfaces are in units GB1 and GB2 of the Garnier Bay area (Pl. 11, fig. 2). The ripples are generally of low amplitude (less than 1.50 cms) and wavelength (up to

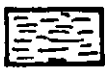
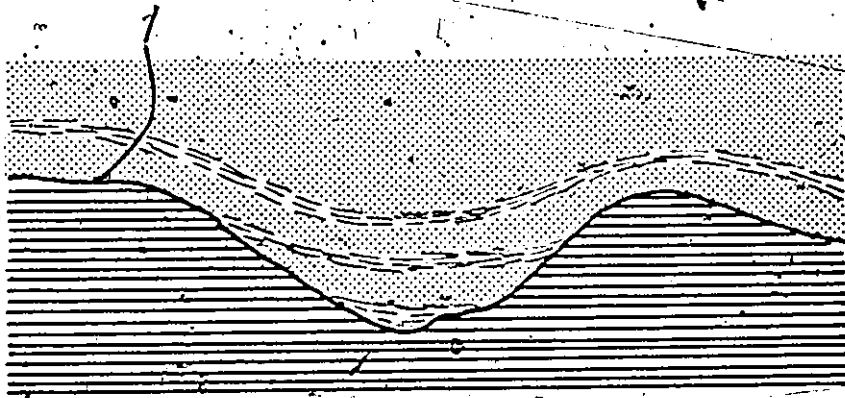
Text-figure 12.

Morphology of channels in unit F11 of the Port Leopold area.

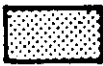
A



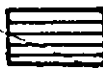
B



SANDY LIMESTONE



UNLAMINATED LIMESTONE



LAMINATED LIMESTONE

0 Cms 4

Plate 11

Megaripples and ripples

Figure 1: Field photograph of megaripples in unit 65 of the Cape Admiral W'Clintock section. Megaripples are in intraclastic shelly limestone interbedded with rubbly argillaceous limestone.

Figure 2: Plan view of ripples in unit GB2 of the Garnier Bay area. Troughs are filled with shell debris.

PLATE 11



FIGURE 1

0 Cms 12

FIGURE 2

4
Cms
0



Plate 12

Erosion surface and load structures

Figure 1: Hand specimen of shelly limestone and micritic limestone showing erosion surface in unit 8 of the Cape Admiral M'Clintock section.

Figures 2 and 3: Hand specimen of load structure from unit A14 of the Port Leopold area. Section shown in Figure 2 is at right angles to that shown in Figure 3.

61.
6 cms). In unit G51 the ripple orientation on any one surface tends to be unidirectional. However, many different orientations are present on successive layers and no predominant orientation was evident in outcrop. In unit G52 the amplitude of the current ripples is 2.0-2.5 cms and the wavelength up to 7 cms. The troughs of these ripples are filled with shell debris (Pl. 11, fig. 2). In the Fort Leopold sections ripples are well developed in the sandstone of the upper part of the sections. Where 3-dimensional exposures occur the ripples indicate water movement towards the west.

Megaripples in units 57 and 64 of the Cape Admiral M'Clintock section (Pl. 11, fig. 1) are usually symmetrical with a wavelength of about 2 m and amplitude of 10-15 cms. The lower boundaries of these units are sharp and even.

Erosional surfaces occur at several horizons in the Read Bay Formation and Leopold succession. The best examples are in units M8 and M31 of the Cape Admiral M'Clintock section (Pl. 12, fig. 1). In unit M8 the shell material in the lower shelly limestone is truncated at the erosion surface. A second, higher erosional surface is exposed in the field as a smooth surface on which the cross-sections of gastropods and other shells are present. The erosion surface in M31 displays similar features to the ones in unit M8.

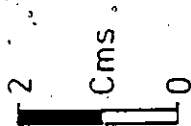


FIGURE 1

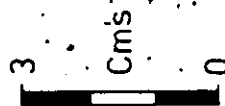


FIGURE 2



FIGURE 3

load structures (Pl. 12, figs. 2 and 3) occur in unit A14 of the Port Leopold area where a micritic limestone overlies a coarser more porous carbonate rock. Individual load structures attain maximum dimensions of 25 X 12 X 6 cms (length, width and thickness respectively). The unit containing the load structures can be traced laterally for about 200 m.

Stylolites occur in many of the rocks in the Port Leopold area. The stylolite seams, which consist of clay minerals, quartz and other insoluble substances, have a maximum amplitude of about 10 mm. In unit B21 a stylolite seam oblique to bedding is unusual in that the displacements of the seam have a triangular profile (Pl. 13) as opposed to the normal parallel-sided displacement. Of additional interest are the small veins of calcite radiating from the apices of the triangular displacements (Pl. 13).

Plate 13

Stylolites

Photomicrograph of stylolites in unit B21 of the Port. Leopold area.

The stylolite seams (SS) which are formed of clay minerals and quartz isolate a layer of sandy limestone (SL) within the micritic limestone (ML). Cracks extending from the apices of the triangular displacements are filled with one phase of crystalline calcite (CC). Note fan-shaped arrangement of cracks associated with the largest displacement.

CHAPTER 3

STRATIGRAPHIC SECTIONS

Port Leopold

Location of sections In the Port Leopold area sections suitable for study and documentation are unevenly distributed. Eleven good sections were studied on the southern part of the Leopold peninsula but only three were suitable for study on the northern part. On the western side of the bay one section (section P on Text-fig. 3, p. 5) was measured during the summer of 1971 and another during the summer of 1973 (section PI on Text-fig. 3, p. 5). An additional section was briefly inspected in 1971 but ice conditions in 1973 prevented further detailed documentation (Text-fig. 3, p. 5). Of the 17 sections studied, 7 were studied in considerable detail (Text-figs. 13-19).

Wherever possible sections were measured in gullies because these tend to have the most complete sections. All sections on the southern part of the peninsula at Port Leopold were measured on cliff buttresses (Pl. 14) and were spaced at 150-250 metre intervals.

Correlation of sections Correlation of the various sections in the Port Leopold area is difficult owing to the lack of fossil-rich beds other than stromatolitic layers. Lithological correlation was attempted but was prone to many errors owing to the rapid horizontal and vertical

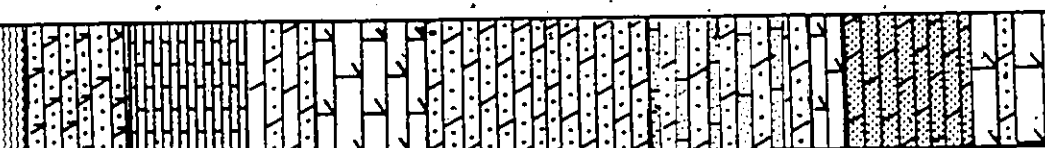
Text-figures 13-19: Lithology, sedimentary structures and faunal elements of sections A, B, C, D, E, F and G of the Port Leopold area.

ROCK TYPES	BEDDING TYPE	SEDIMENTARY STRUCTURES
MICRITIC LIMESTONE		
DOLOMITIC LIMESTONE		
CALCAREOUS DOLOMITE		
DOLOMITE		
SANDY DOLOMITE		
DOLOMITIC SANDSTONE		
SANDSTONE		
CALCAREOUS SANDSTONE		
SANDY LIMESTONE		
INTRACLASTIC SHELLY LIMESTONE		
CONGLOMERATE		
ARGILLACEOUS LIMESTONE		
ONCOPHELLET LIMESTONE		
SANDY DOLOMITE-LIMESTONE		
CALCAREOUS SANDSTONE-DOLOMITE		
DOLOMITIC SANDSTONE-LIMESTONE		
GYPSUM & ANHYDRITE		
STROMATOLITE		
SHELLY LIMESTONE		
REEF LIMESTONE		
RUBBLY ARGILLACEOUS LIMESTONE		
MOTTLED DOLOMITE-LIMESTONE		
NO EXPOSURE		
POOR EXPOSURE		
BEDDING TYPE	UNLAMINATED LAMINATED INTERLAMINATED THIN BEDDED MEDIUM BEDDED MOTTLED	IN SITU FAUNA
IF UNIT IS INTERLAMINATED OR INTERBEDDED IT IS DENOTED BY COMBINATION OF ROCK TYPE SYMBOLS. THUS:		SOLITARY CORALS (4) INDICATES NUMBER OF INDETERMINATE GENERA INCLUDED IN GENERIC DIVERSITY
UL	UNLAMINATED	DENOTES GENUS PRESENT
IL	INTERLAMINATED	DENOTES DOMINANT ELEMENT IN UNIT, IF MORE THAN ONE GENUS PRESENT
TB	THIN BEDDED	
MB	MEDIUM BEDDED	
M	MOTTLED	

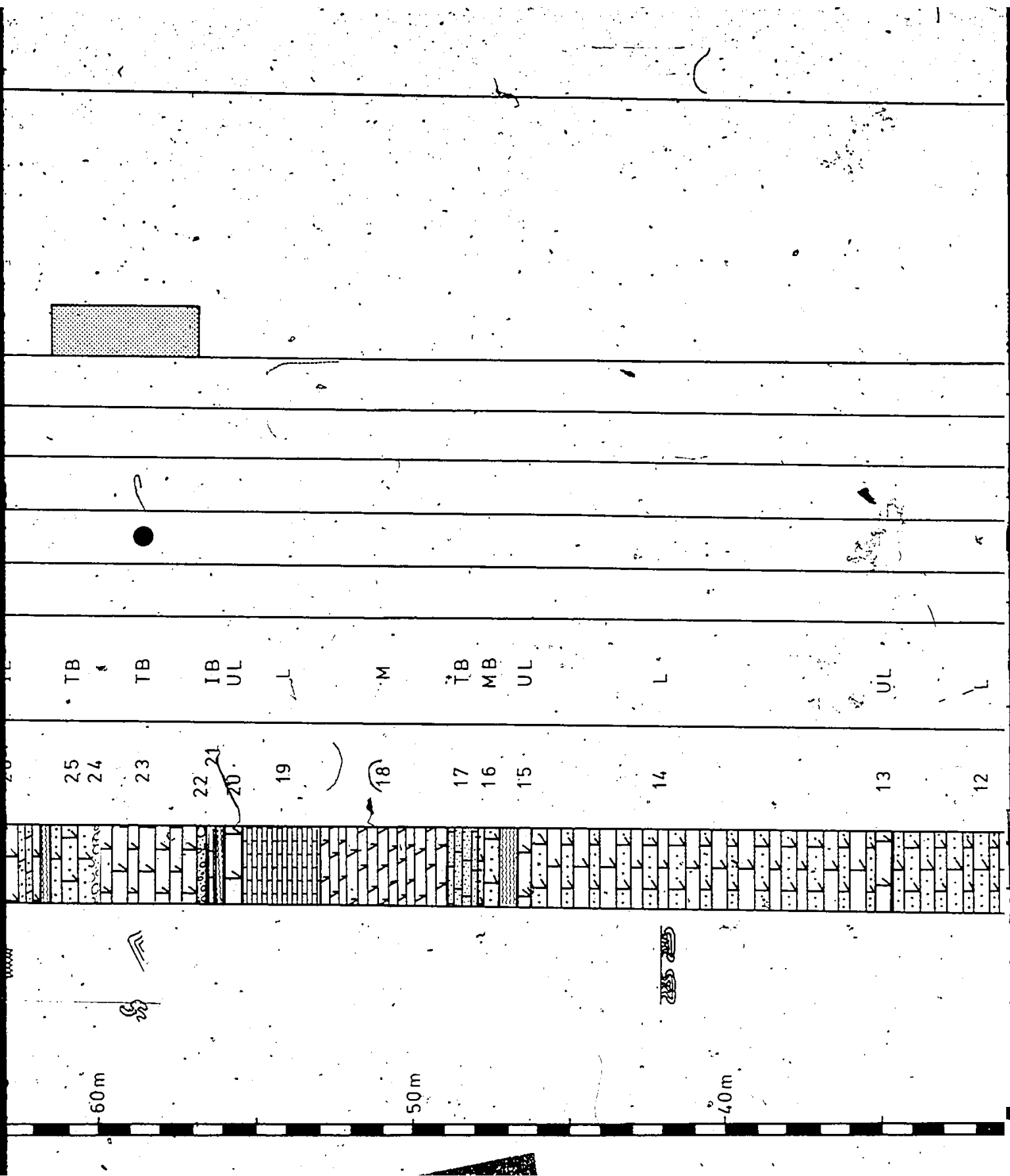
Text-figure 13.

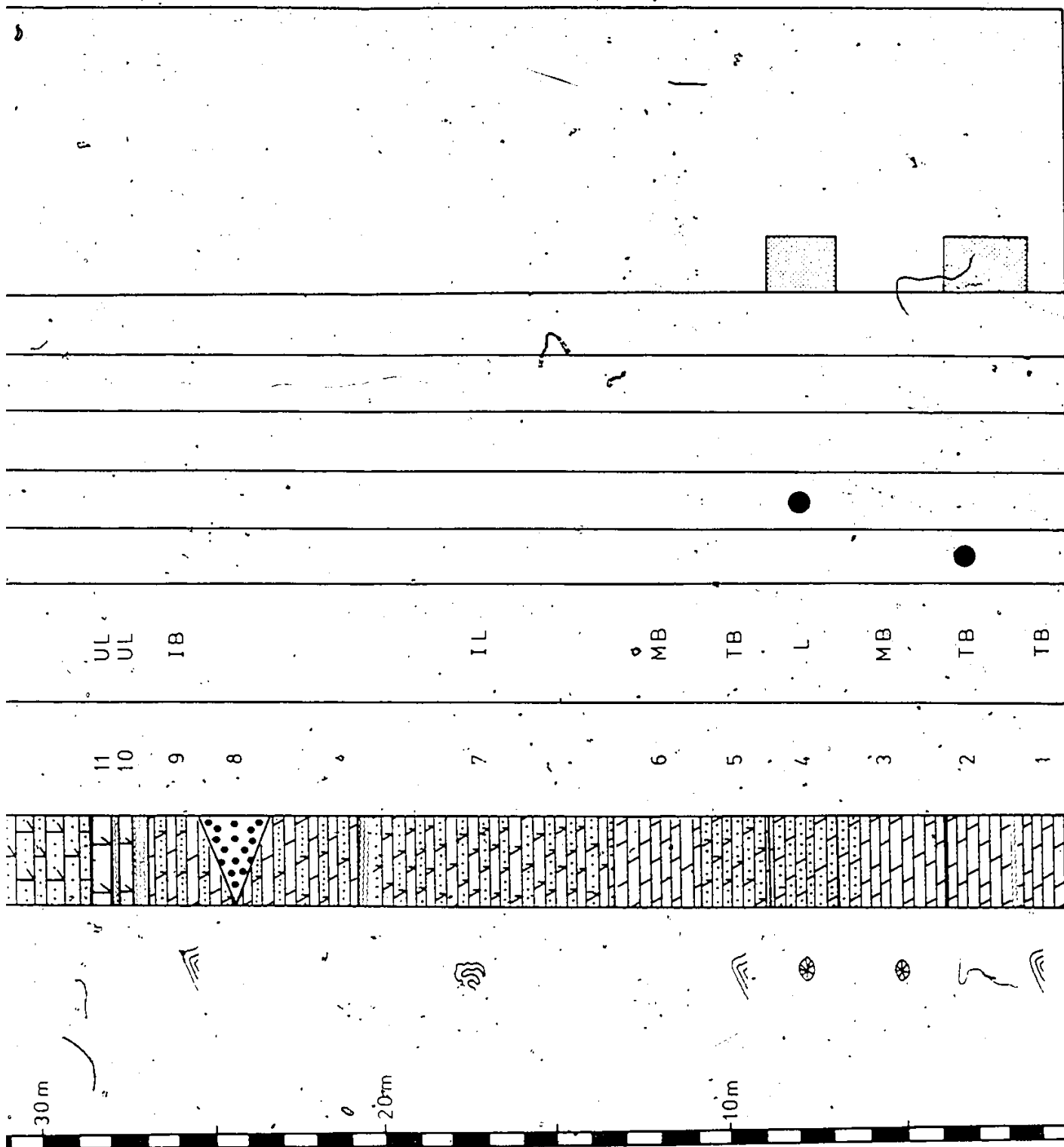
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OTTAWA, ONTARIO, CANADA

PORT LEOPOLD SECTION A

Scale	Sedimentary Structures	Rock Type	Unit	Bedding Type	In Situ Fauna				Generic Diversity
					Howellia	Ostracod indet.	Homotoma	Eurypterus	
			34	UL					
			33	TB					
			32	IL					
			31	TB					
			30	UL					
			29	IL					
			28	UL					
			27	TB					
			26	IL					

1 of

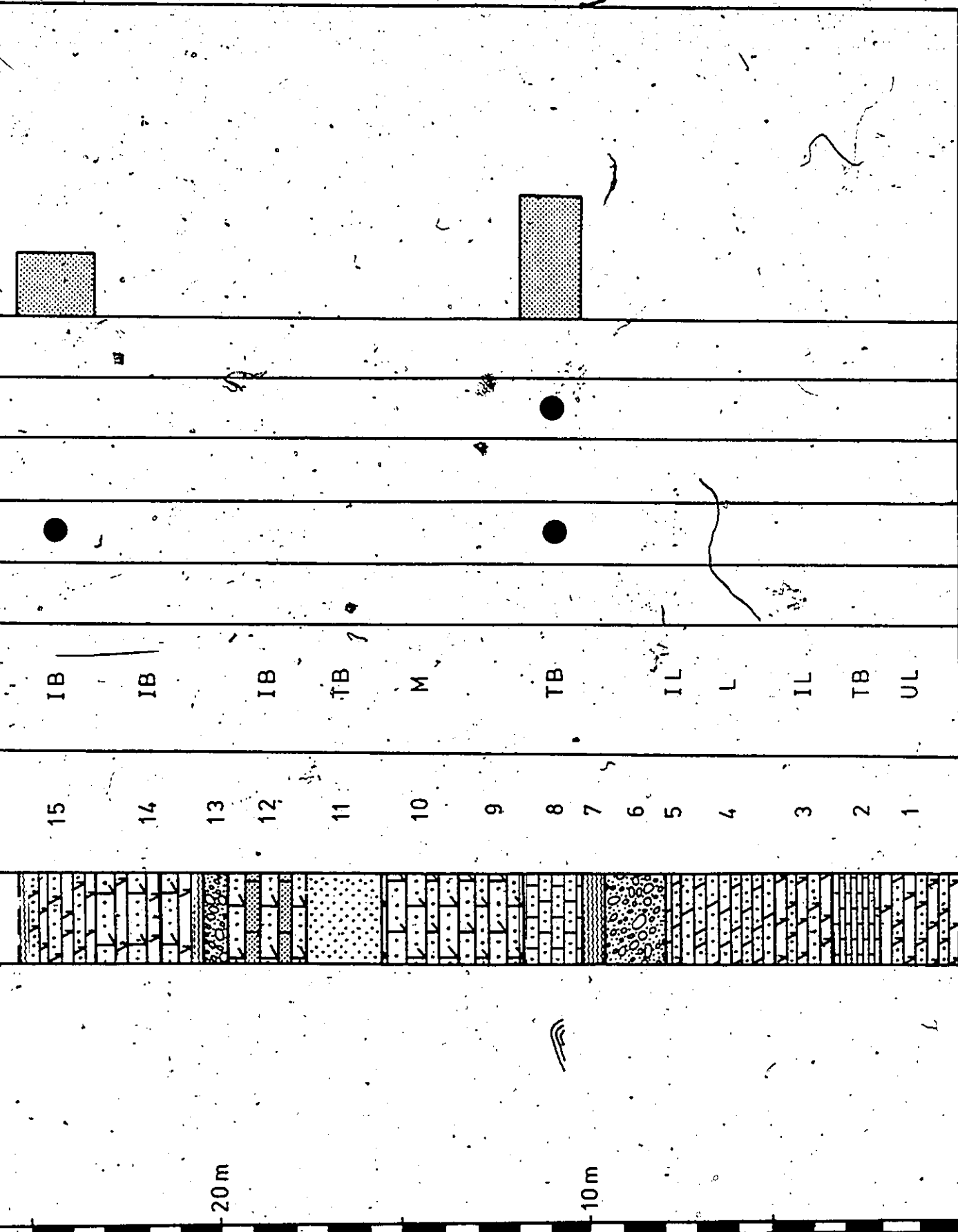




PORT LEOPOLD SECTION B

Scale	Sedimentary Structures	Rock Type	Unit	Bedding Type	In Situ Fauna				Generic Diversity			
					Howellia	Ostracod indet	Hormotoma	Eurypterus				
40m			23	M								
			22									
30m			21	UL								
			20	IB								
			19	UL								
			18	UL								
			17									
			16	TB								
		NE										

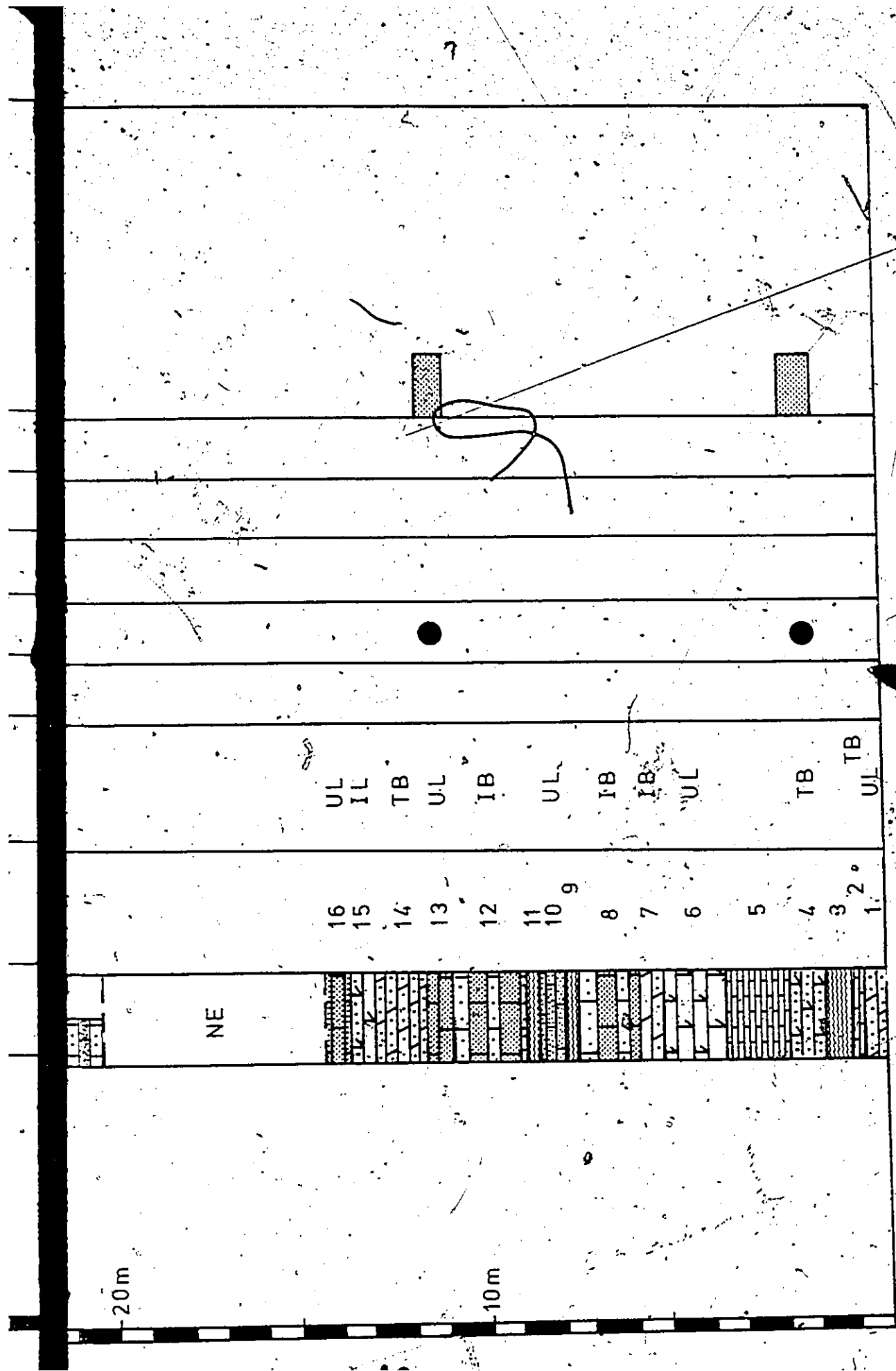
Text-figure 14.



Text-figure 15.

PORT LEOPOLD SECTION C

Scale	Sedimentary Structures	Rock Type	Unit	Bedding Type	In Situ Fauna				Generic Diversity
					Howellella	Ostracod indet.	Hormotoma	Eurypterus	
 30m 20m									Number of Genera 1 2 3 4
			19	UL					
			18						
		NE	17						



Text-figure 16.

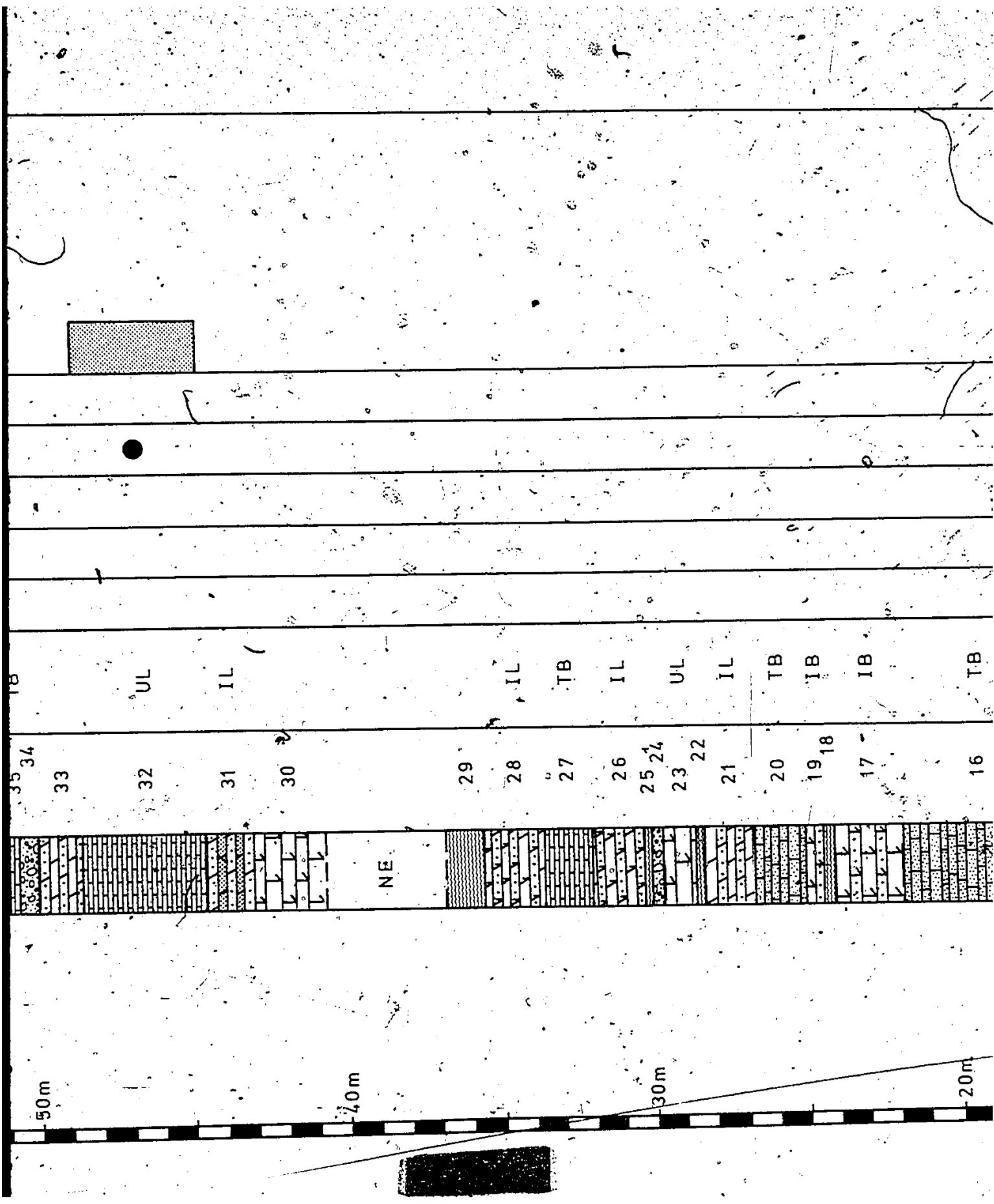
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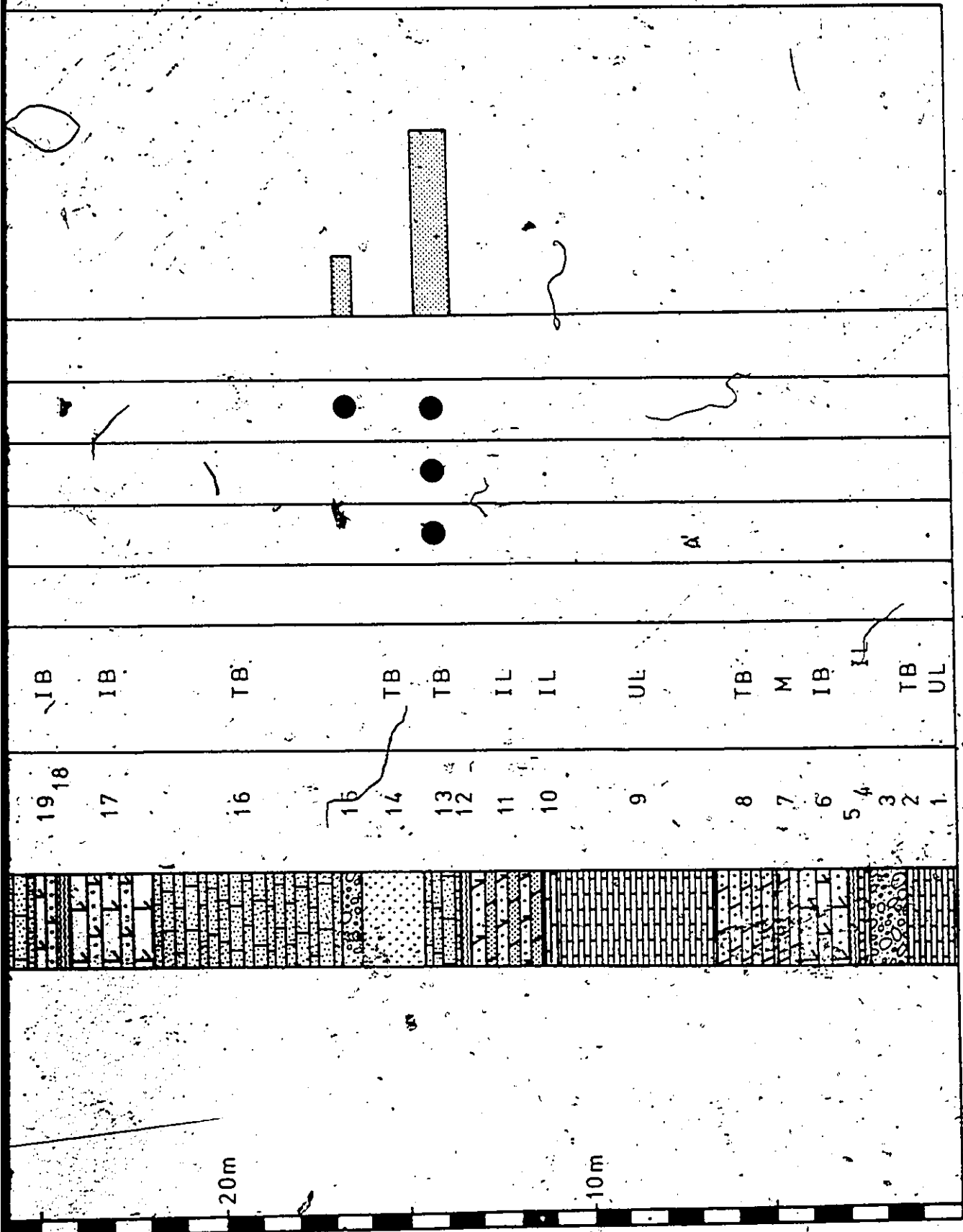
PORT LEOPOLD SECTION D

Scale	Sedimentary Structures	Rock Type	Unit	Bedding Type	In Situ Fauna				Generic Diversity
					Howellia	Ostracod indet.	Hormotoma	Eurypiterus	
60m.			41	UL					Number of Genera 1 2 3 4
50m			40	IL					
			39	IB					
			37						
			36	IL					
			35	TB					
			34						
			33						
			32	UL					

60m.

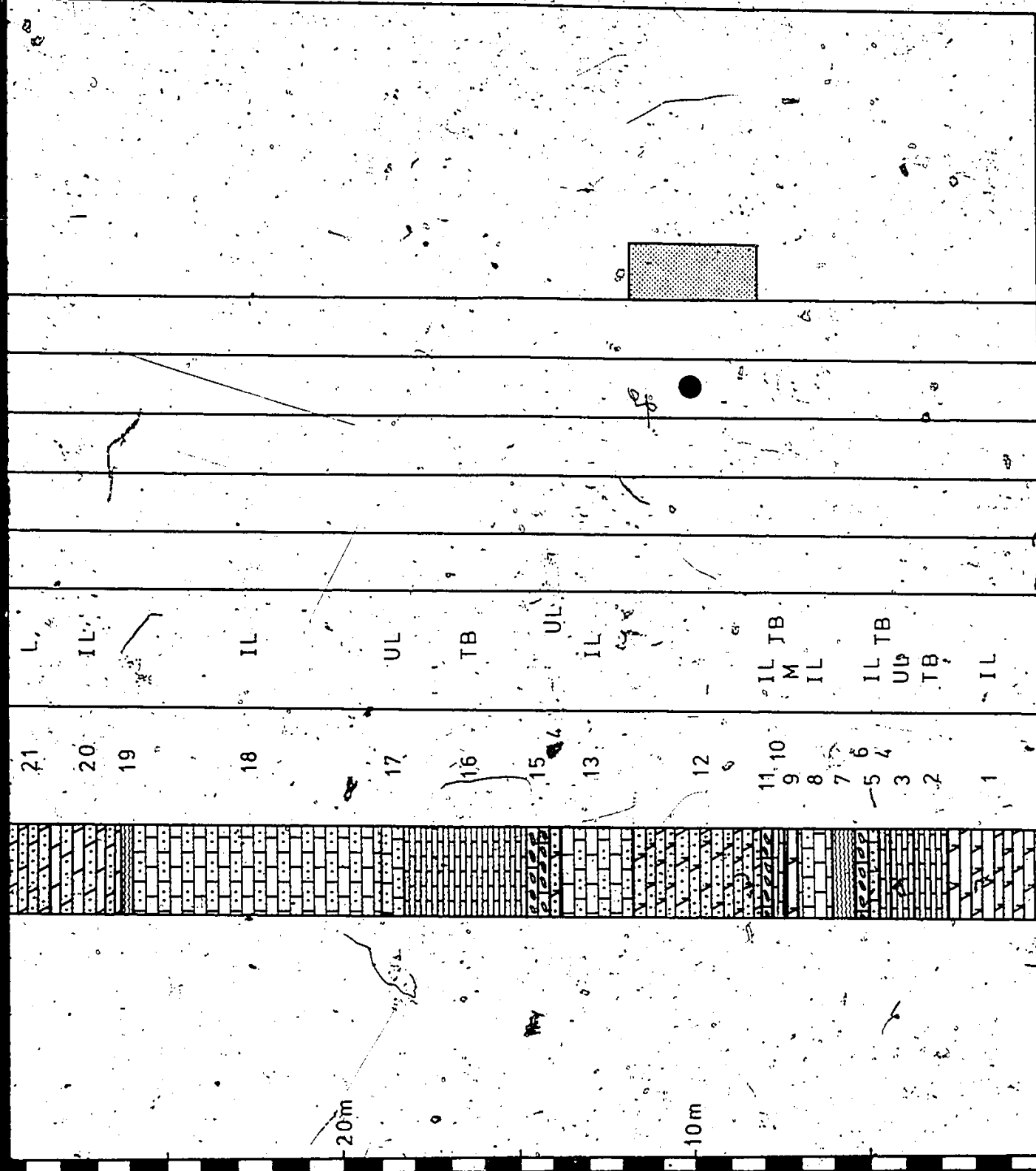
50m





PORT LEOPOLD SECTION E

Scale	Sedimentary Structures	Rock Type	Unit	Bedding Type	In Situ Fauna				Generic Diversity			
					Howellia	Ostracod indet.	Hormotoma	Eurypterus	Number of Genera			
			36									
			35	IL								
			34									
			33	UL								
			32	IL								
			31	TB								
			30									
			29	TB								
			28	UL								
			27	IL								
			26	M								
			25	UL								
			24	IL								
			23	TB								
			22	UL								
			21	L								



Text-figure 18.

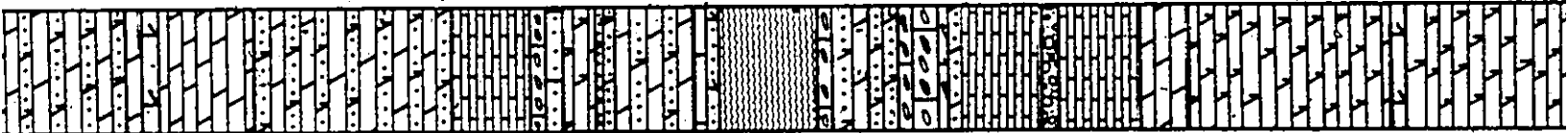
PORT LEOPOLD SECTION F

Scale	Sedimentary Structures	Rock Type	Unit	Bedding Type	In Situ Fauna				Generic Diversity			
					Howellella	Ostracod indet.	Hormotoma	Eurypterus				
60m			42	IL								
			40									
50m			39	IB								
			38									
			37	TB								
			36									
				IB								

60m

50m

1.26



35 34
33

UL
TB

32

IB

31

TB

30

IB

29

UL

28

L

27

IB

26

UL

25

UL

24

UL

23

L

22

TB

21

L

20

M

19

UL

18

UL

17

IB

16

UL

15

UL

14

IB

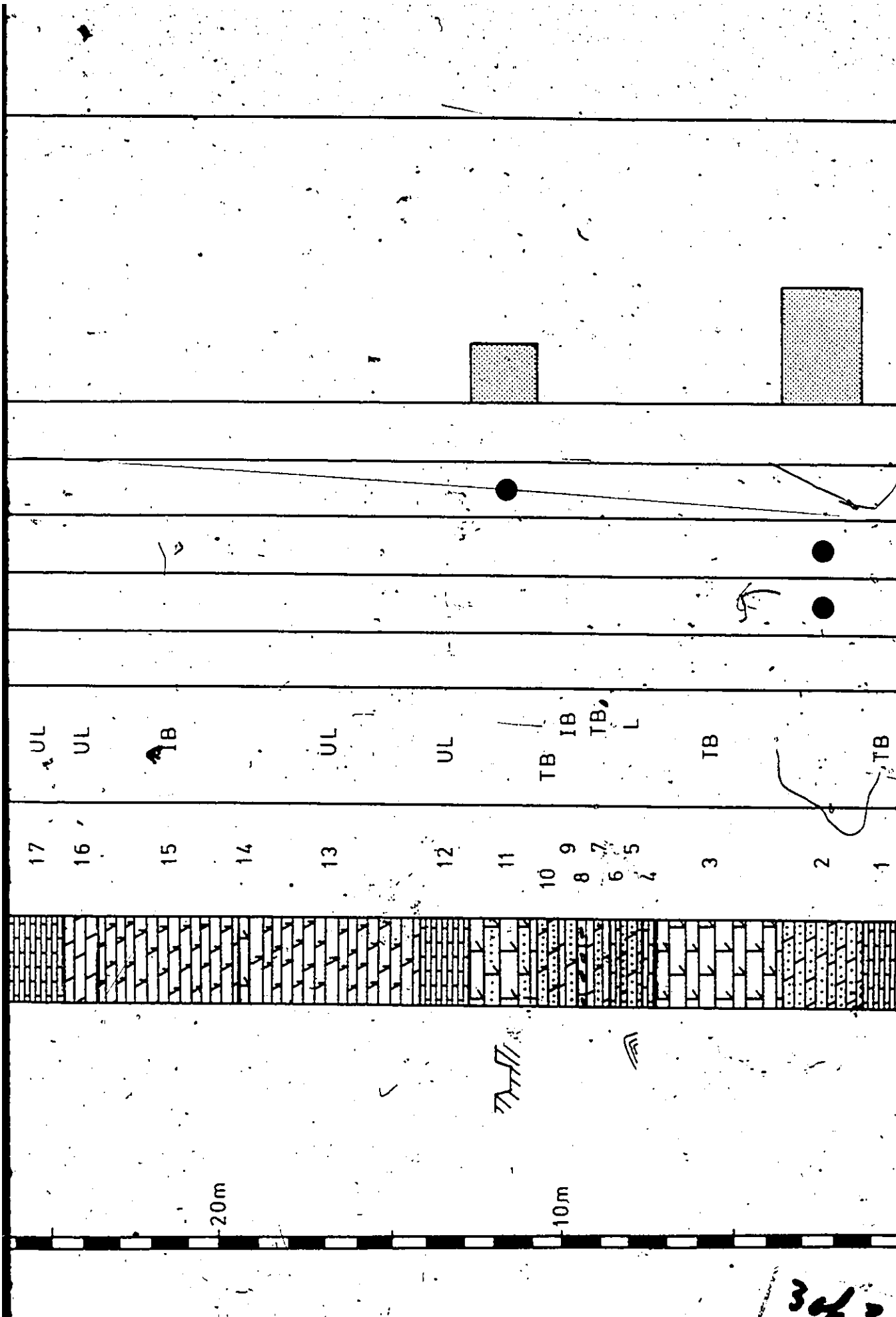
13

UL

40m

30m

20m

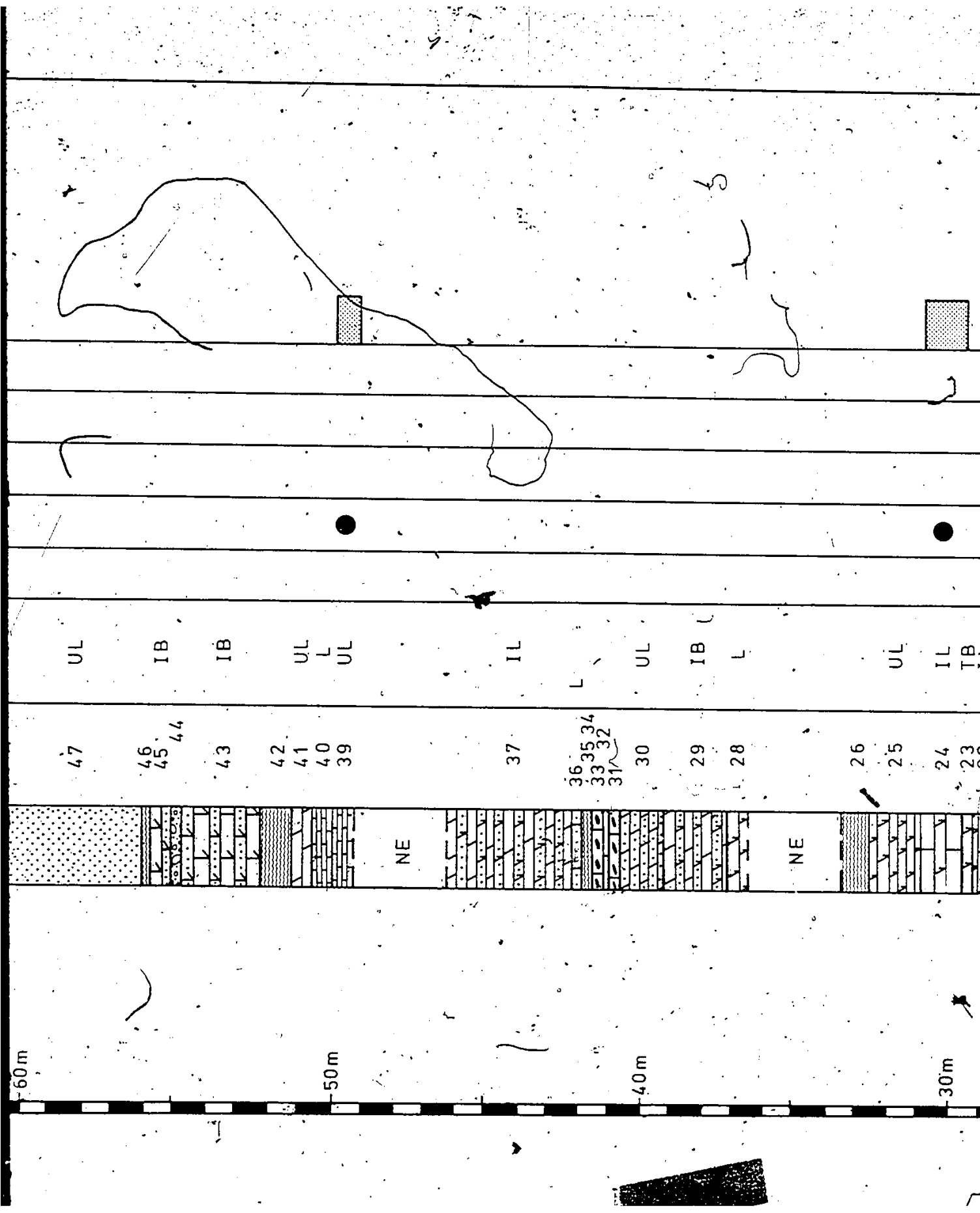


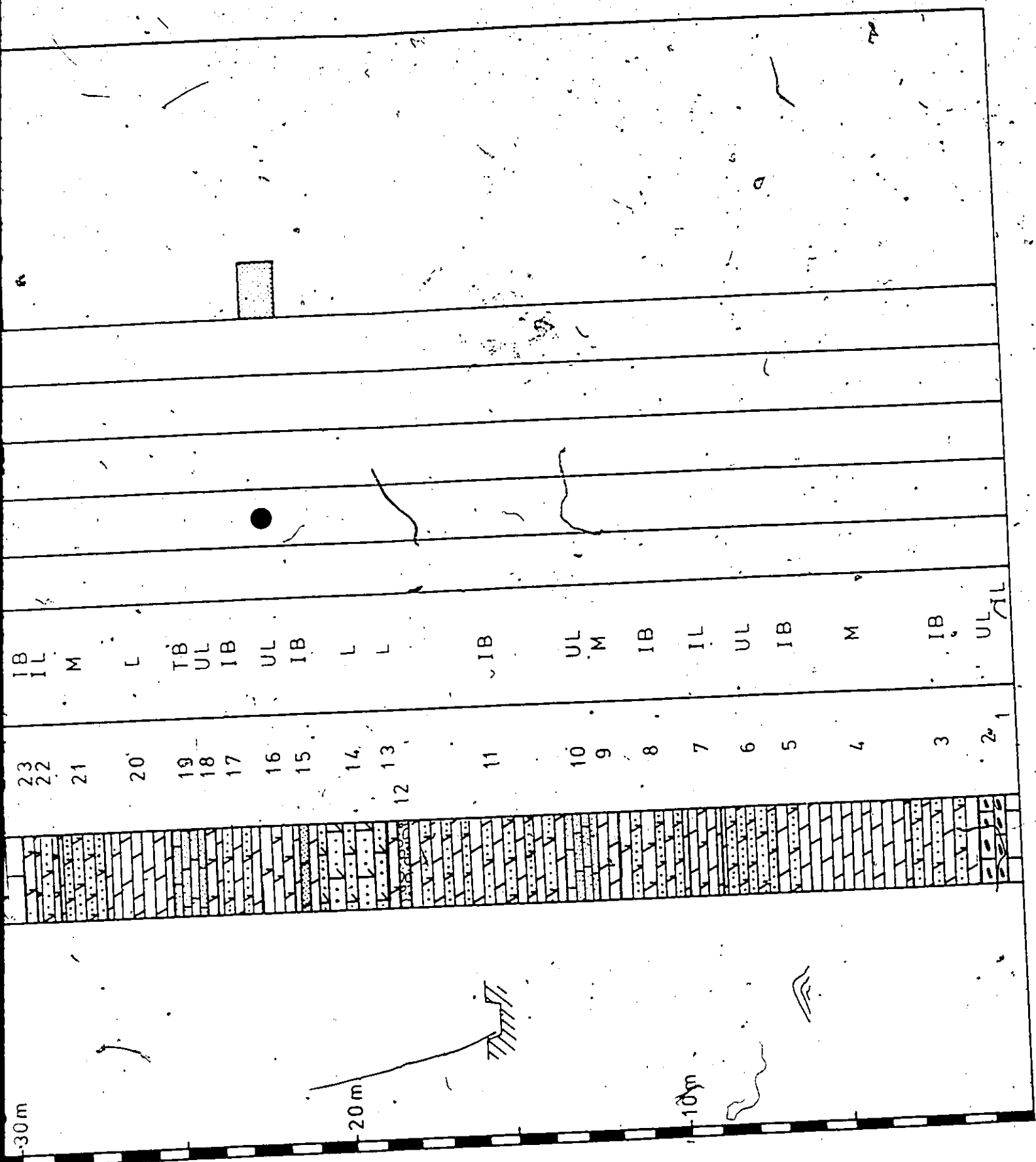
Text-figure 19.

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PORT LEOPOLD SECTION G

Scale	Sedimentary Structures	Rock Type	Unit	Bedding Type	In-Situ Fauna				Generic Diversity
					Howellia	Ostracod indet.	Hormotoma	Eurypterus	Number of Genera
									1 2 3 4





343

Plate 14

Peninsula at Port Leopold

Field photograph of the peninsula at Port Leopold showing the location of sections C, B, E, D, F, G, H, J and K. Section of peninsula shown in photograph is approximately 2,820 yards (approx. 2,500 m) long and a maximum height of about 1,000 ft. (approx. 307 m) above sea level.

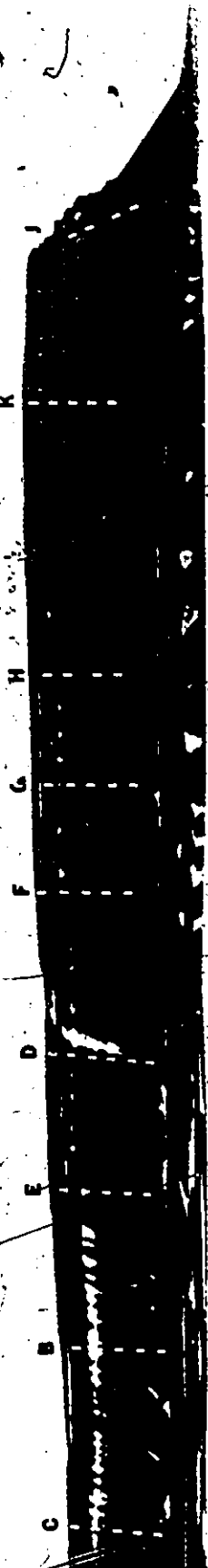
4

PLATE 16

8.

END

PLATE 14



74.
changes in these rocks (Pl. 15).

Fortunately a few of the stromatolitic units are of sufficient lateral extent that they can be used as marker beds in the manner described by Hoffman (1967) and Donaldson (1963). The main stromatolitic unit (units A35, B23, C20, D29, F25, G26 and H29) is referred to as marker bed 1 and is used as the datum for Text-figure 20. Other stromatolitic marker beds occur at lower levels in the section and place further constraints on the possible lithological correlations (Text-fig. 20).

Marker beds 1, 2 and 3 do not extend into sections J and K (Text-fig. 20) making it difficult to correlate the lower portions of these sections with other sections. However, other laterally continuous beds above marker bed 1 allow correlation of the upper part of sections J and K with other sections (Text-fig. 20). Marker bed 4 is a conglomerate with a distinctive erosional surface (Text-fig. 20).

Rock types The sections at Port Leopold are predominantly formed of dolomitic rocks and rocks which have a high content of detrital material. A complete sequence of rocks ranging from micritic limestone, through dolomitic limestone and calcareous dolomite to dolomite can be identified. The textural relationship of the dolomite and the micritic calcite (p. 31) suggest that this is a sequence which shows

Plate 15

Cliff exposure on peninsula at Port Leopold

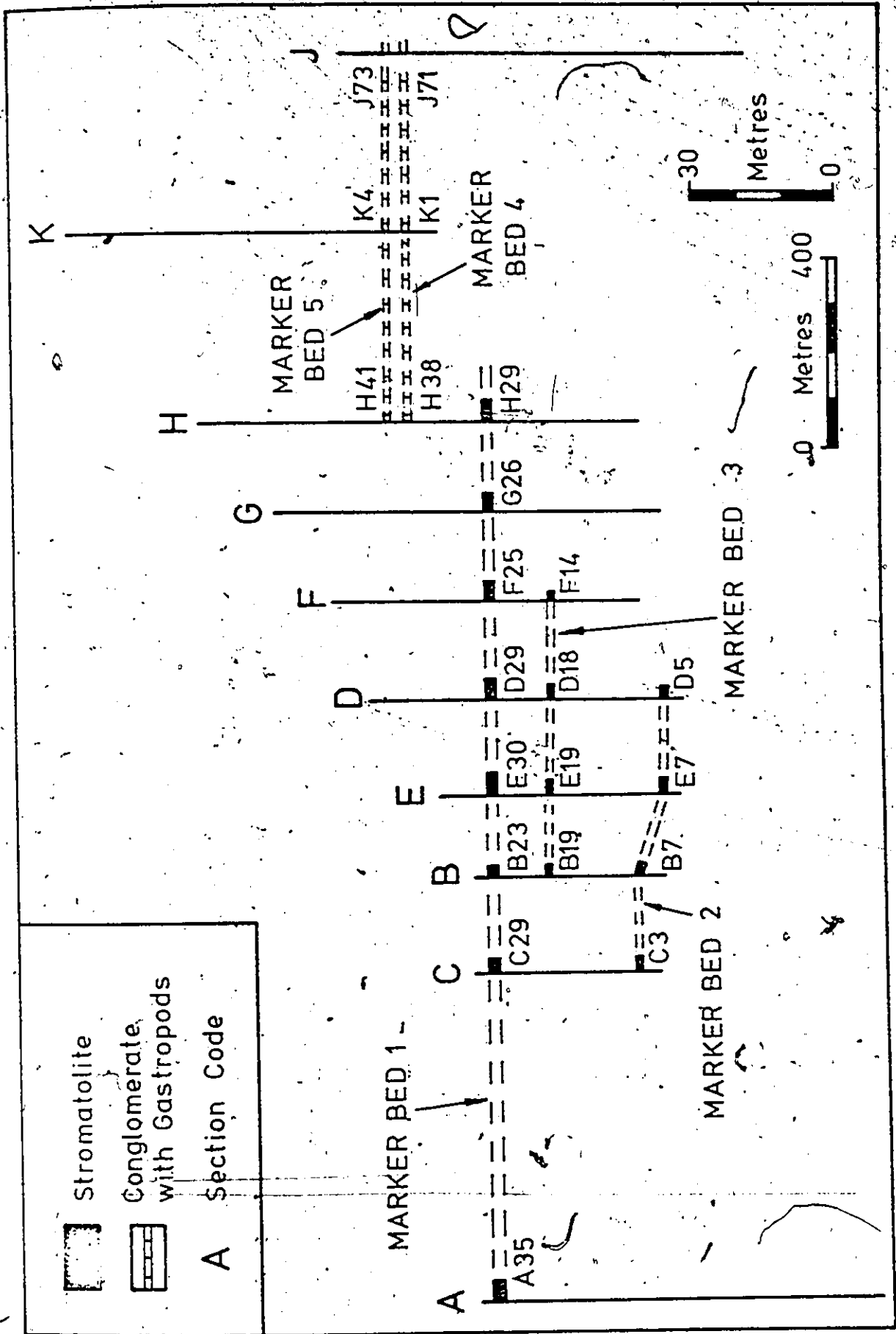
Field photograph of sea cliffs at southern end of the peninsula at Port Leopold showing the horizontal layering of the strata and the numerous vertical facies changes. The lighter coloured beds are the dolomitic rocks. (Photograph courtesy of Dr. O. A. Dixon).

PLATE 15



Text-figure. 20

Marker beds in the Port Leopold area -- their location and extent in sections A to K inclusive. Marker beds are numbered in order of importance for correlation purposes.



varied degrees of dolomitization of original micritic limestone.

The detrital material in these rocks is predominantly angular to subangular grains of quartz (longest axis up to 0.25 mm, but more commonly less than 0.15 mm) which commonly display undulatory extinction. Muscovite and minor quantities of plagioclase and microcline are present in many of the rocks. In some instances the quartz occurs in sufficient quantity to form sandstone (e.g. unit F42). On top of the peninsula at Port Leopold are isolated exposures of yellowish-brown sandstone. This sandstone is formed of subrounded to subangular grains of quartz and shows interference ripples (Pl.16, fig. 2) and current bedding (Pl.16, fig. 1).

Pelletoidal limestone is relatively rare in these sections; the common form is oncopelletoidal limestone.

Dolomitic sandstone, sandy dolomite, sandy limestone and the calcareous sandy dolomite commonly occur as thin laminae (or thin beds) interlaminated (or interbedded) with dolomite or limestone.

Of the 17 sections studied in the Port Leopold area 7 were studied in considerable detail to see whether any systematic variations in the rock types occur. Most rocks in these 7 sections were studied in thin section to permit a more accurate analysis of the rock types. The 7 sections (A, B, C, D, E, F and G) are depicted in Text-figures 13 to 19 respectively. For each section the relative percentages

Plate 16

Cross-bedding and interference ripples in sandstone;

gypsum-filled cavity in dolomite.

Figure 1: Field photograph of cross-bedding in the sandstone on the top of the peninsula at Port Leopold.

Figure 2: Field photograph of interference ripples in the sandstone on the top of the peninsula at Port Leopold.

Figure 3: Field photograph of selenite crystals (S) and amorphous gypsum (A) filling cavity in the dolomite (D) of unit PL43 of the Port Leopold area.

PLATE 16

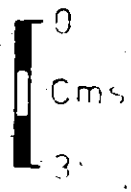
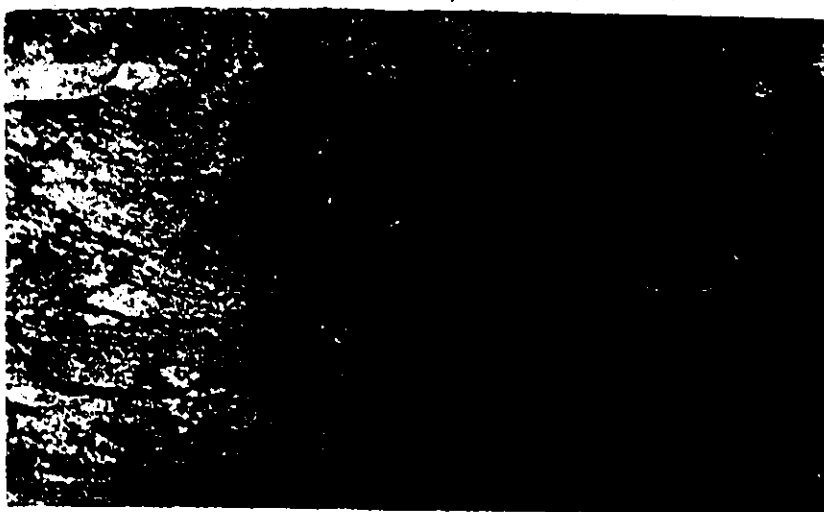


FIGURE 1

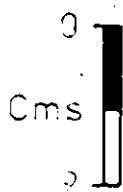


FIGURE 2

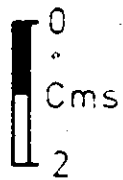


FIGURE 3

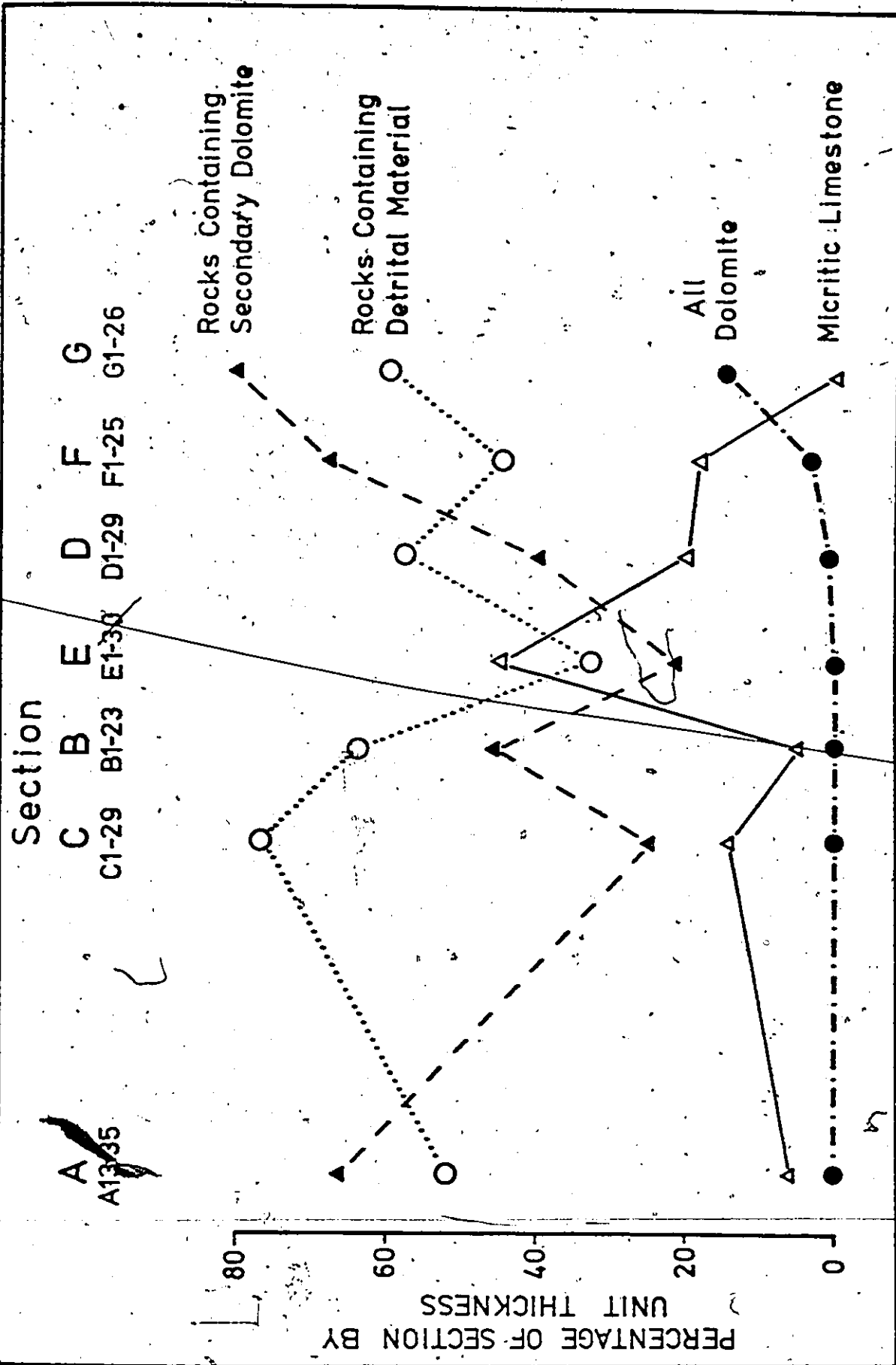


(based on unit thickness) of each type was determined. Some distinct differences in distribution are apparent from this analysis (Text-fig. 21):

- (1) The percentage of conglomerate in each section remains relatively constant (approximately 4-5%).
- (2) The percentage of stromatolitic rock in each sections remains relatively constant (approximately 4-5%).
- (3) Dolomite is absent from sections A, C, B and E but is present in sections D, G and F and shows a gradual increase to 15% in section G (Text-fig. 21). Thus, the amount of dolomite increases towards the south.
- (4) The quantity of rocks containing secondary dolomite is at a minimum in section E (Text-fig. 21). This quantity increases to the south until 78% of the rocks in section G contain secondary dolomite (Text-fig. 21). A similar increase occurs towards section A (Text-fig. 21). Section C is the exception to the general trend.
- (5) Micritic limestone is most common in section E (Text-fig. 21). It decreases gradually towards the south but more rapidly to the north.
- (6) The quantity of rocks containing detrital material is at a minimum in section E and increases to the south and to the

Text-figure 21

Lateral variation in the quantity of rocks containing secondary dolomite and detrital material, and in the quantity of dolomite and micritic limestone in sections A, B, C, D, E, F and G of the Port Leopold area. Percentages are based on unit thickness and calculated only for the units denoted on the Text-figure.



north (Text-fig. 21).

Sedimentary structures Many of the rocks at Port Leopold contain abundant sedimentary structures such as desiccation cracks, channel cuts, load structures and current bedding. The distribution of the various sedimentary structures is shown in Text-figures 13 to 19.

In unit PL43, the dolomite contains irregularly shaped cavities (up to 3 X 2 cms) filled by two generations of gypsum. A first generation of ~~ethedral~~ crystals of selenite with their long axes perpendicular to the cavity wall (Pl. 16, fig. 3) was followed by a second generation of white, amorphous gypsum filling the central part of the cavities (Pl. 16, fig. 3).

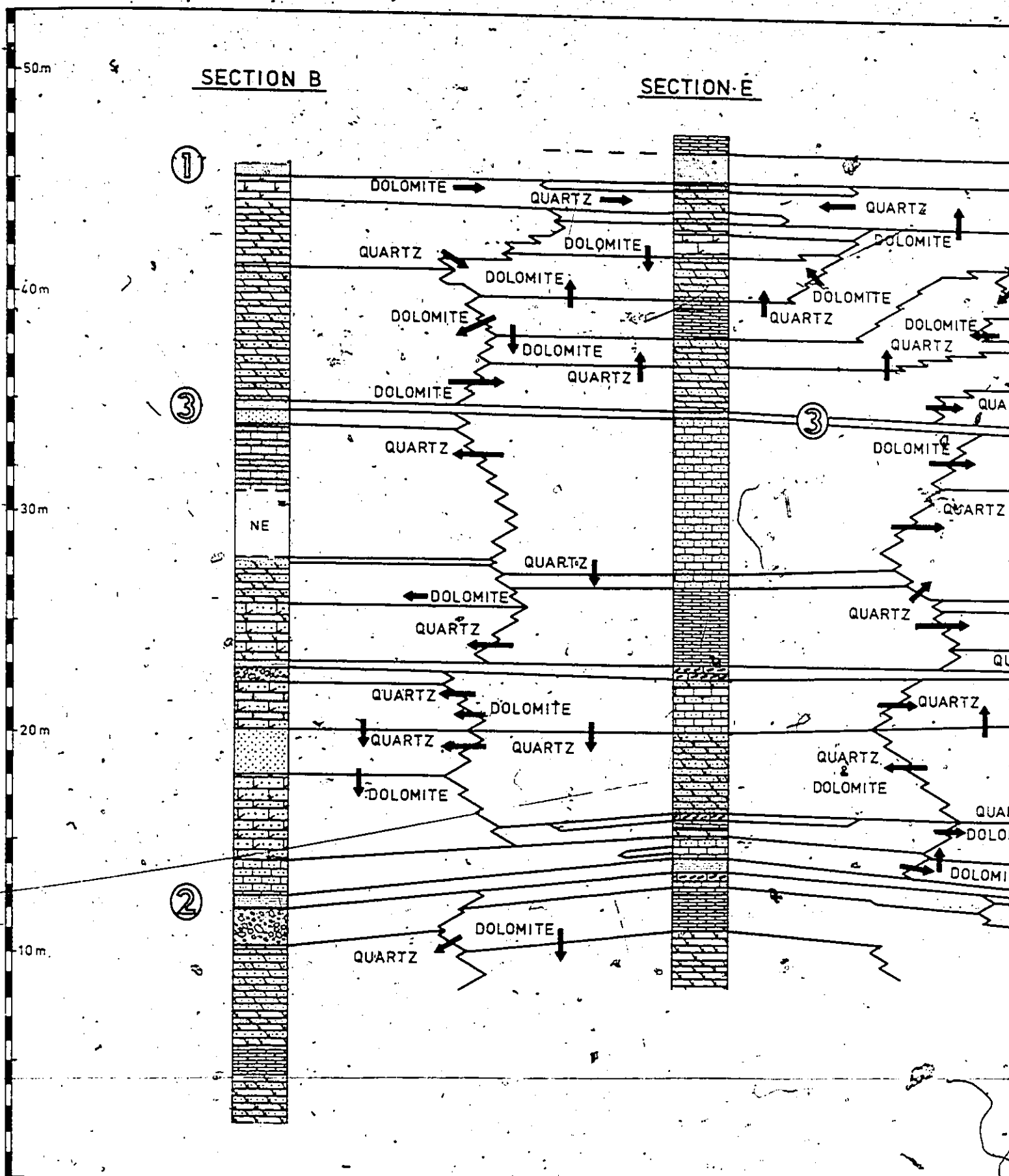
Faunal distribution One of the distinctive features of the sections in the Port Leopold area is their very sparse in situ fauna. Only 6 in situ genera of invertebrate fossils have been recognized although there are a few fragments of corals, bryozoans and brachiopods in several units.

Although there are very few genera of ostracods, eurypterids, brachiopods and gastropods, the number of individuals of each genus is usually large. Thus, where ostracods are found they normally occur in sufficient quantities to cover bedding planes. The ostracods are commonly, but not always, associated with eurypterids.

Isolated body segments, head shields and telsons of

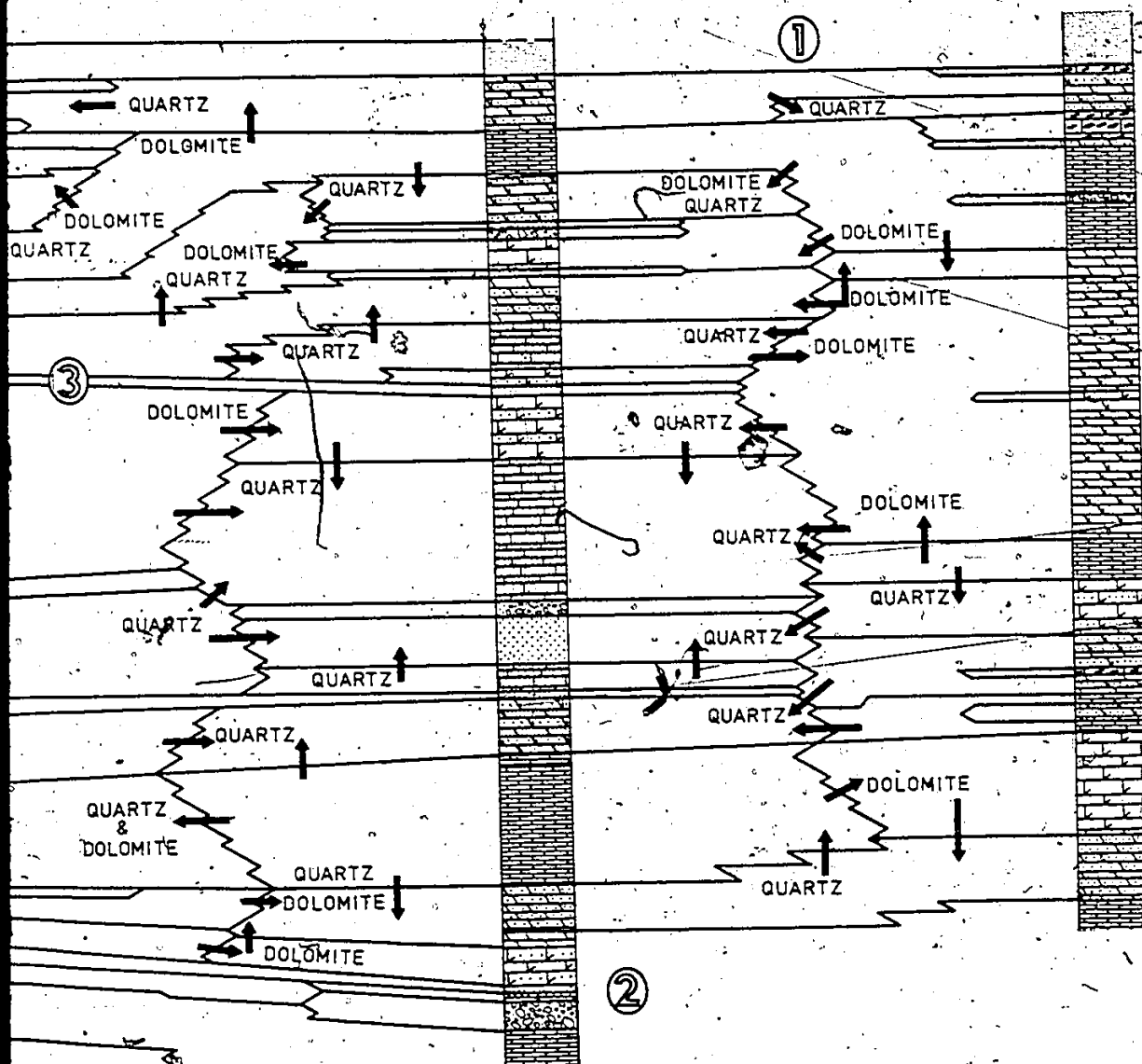
Text-figure 22

Correlation of Port Leopold sections, B, D, E and F. Although only the parts of the sections below marker Bed 1 are shown, they illustrate the nature and degree of facies variation typical of all sections on the peninsula. Facies boundaries are not positioned on field evidence but are arbitrarily placed to denote the lateral and vertical facies changes.

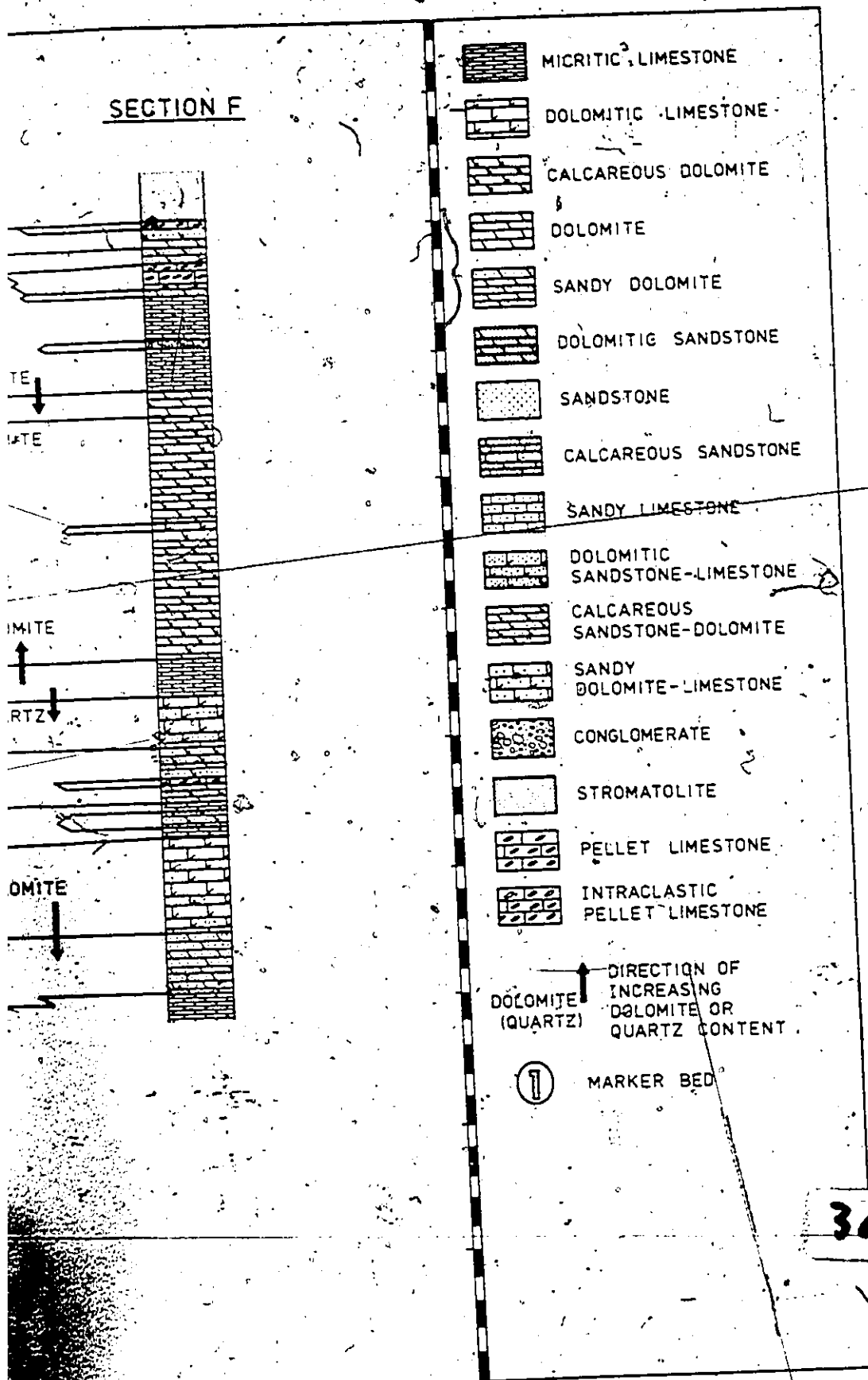


SECTION D

SECTION F



0 METRES 60



euryppterids are common in units D38 and B8 (Pl.17, fig. 2, and 3).

Specimens with up to 5 articulated body segments have been found.

rarely (Pl.17, fig. 3).

Brachiopods are extremely rare in the Port Leopold sections and were found in only three units (A2, K49 and H44). Unit A2

contains numerous complete and articulated specimens of Howellella.

Their occurrence and articulation suggests that this is a life

assemblage. In unit H44 a few incomplete and damaged specimens of

Conchidium occur in a conglomerate situated between the stromatolitic

domes of that unit. Lingula occurs in unit K49.

Unit K49 and its equivalents contain the dorsal shields, ventral shields and scales of ostracoderms. E. Loeffler (1973, pers.

comm.) has identified the following forms: Archegonaspis cf. A. schmidtii,

Homaspis cf. H. borealis, Cyathaspis indet. and

Heterostraci indet. Ostracoderms are preserved in unit PL51 in a

bituminous limestone which emits a petroliferous odour when broken.

E. Loeffler has identified the following forms from this unit:

Corvaspis cf. C. kingi, Kallostrakon ? sp., Ptomaspis leopoldensis n. sp.

and Ptomaspis indet.

McMillan (1963) reported Atrypella (?) from this area but

the genus was not found in any of the sections examined in this study.

Plate 17

Eurypterids

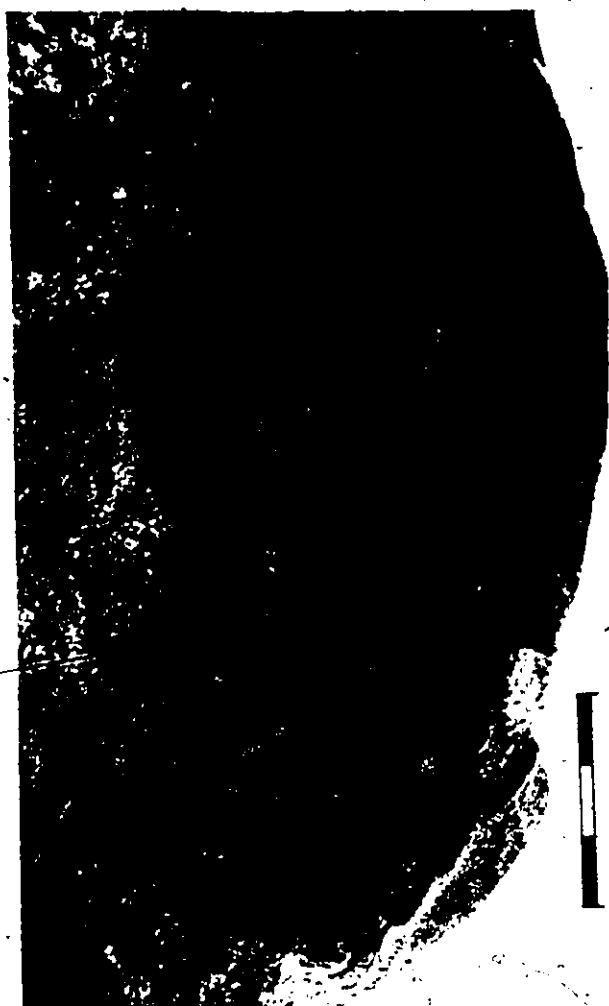
Eurypterids of the Eurypterus remipes group from units E31 and D14 of the Port Leopold area. Figure 1 - Head shield, Figure 2 - Telson, Figure 3 - Articulated body segments and Figure 4 - Body segment.

FIGURE 1



0 Cms 1

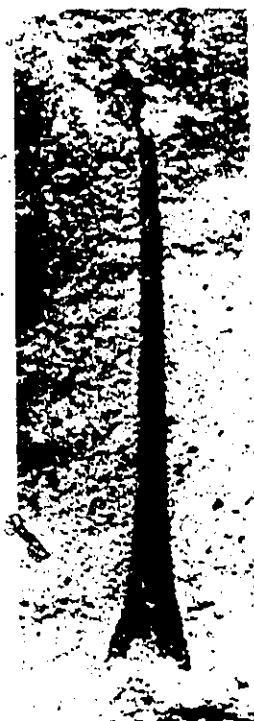
FIGURE 3



3
Cms
0

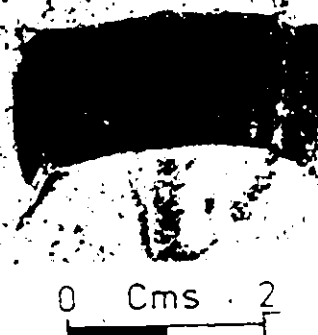
PLATE 17

FIGURE 2



3
Cms
0

FIGURE 4



0 Cms 2

Stromatolites Stromatolites are extremely common in the Port Leopold sections (Text-figs. 13-19) and warrant special consideration. In the following discussion only those forms which have been used as marker beds or which display features of particular interest are described.

In unit A9 the stromatolites are undulatory bodies which truncate the laminae of the underlying rock (Pl. 18, fig. 1). The stromatolite is of variable thickness but attains a maximum thickness of 5 cms at the highest point of the underlying rock surface. Probably, the undulatory surface of unit A8 is an erosional surface on which the stromatolite grew. The agent of erosion was sufficiently powerful to transport any debris away from the area as none occurs in depressions on the erosion surface.

The stromatolites of marker unit 2 have a distinctive large domal form (Pl. 18, fig. 2). The domes are up to 0.50 m high and 0.33-0.50 m in diameter. The spacing of the domes is variable: some are isolated but others are close together and linked. Each dome has two distinctive portions (Pl. 18, fig. 2). In vertical section the inner, semicircular portion, consists of massive, generally vuggy, micritic limestone. Locally, the long axes of the vugs are in a semi-circular arrangement which mimics the shape of the stromatolite. Surrounding the inner massive portion is an outer

Plate 18

Stromatolites of the Port Leopold area

Figure 1: Field photograph of stromatolite on erosional surface in unit A9 of the Port Leopold area. Note how the stromatolite truncates laminae of underlying limestone.

Figure 2: Field photograph of large domal stromatolites from marker bed 2 of the Port Leopold area.

Figure 3: Field photograph of stromatolites in conglomerate of unit D38 of the Port Leopold area. Individual stromatolites initially developed as oncolites around limestone clasts before commencing their upward growth.

PLATE 18

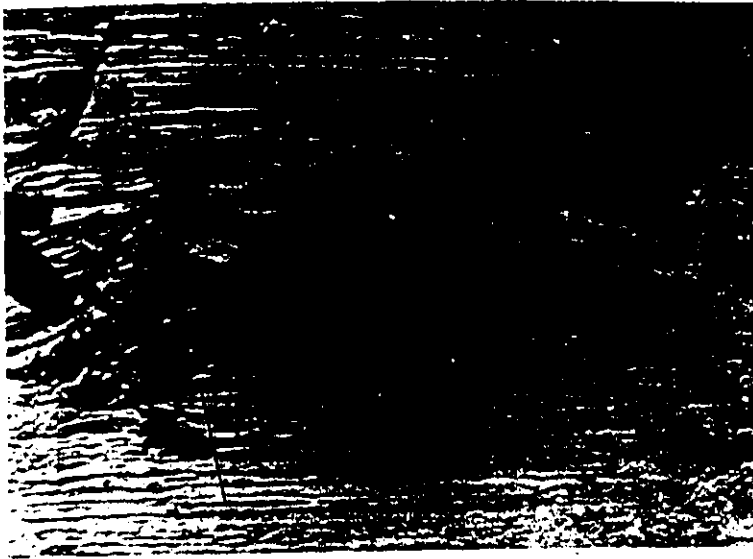


FIGURE 1

0 cms 6

FIGURE 2

0 cms 12



FIGURE 3

0 cms 6

portion of laminated micritic limestone. The laminae are parallel to the external form of the stromatolite (Pl. 18, fig.2). Successive laminae were added with their outer edges partly or completely overlapping the preceding laminae. This form is similar to the SH-V form of Logan et al. (1964). The form of the stromatolitic domes is constant throughout the marker bed.

Marker unit 3 contains two contrasting forms of stromatolites. In units such as B13 and D12 the stromatolites are small domal features which have a height of 5-10 cms and a diameter of 15-20 cms; they are the LLH type of Logan et al. (1964). Unit E15 which is equivalent to units B13 and D12 (Text-fig. 20) is oncopelmicrite (see p. 34 for description). According to Logan et al. (1964) oncolites are indicative of submerged zones, thus it is possible that the oncolitic structures in unit E15 formed in a subtidal environment. They may have formed in a channel flanked by the stromatolites of units B13 and D12.

Marker unit 1 is the main stromatolitic unit (1.50-2.00 m thick) in the area and contains 2 types of stromatolites. The lower part of the unit contains columnar stromatolites which are club shaped (Pl. 19, fig.2). The columns, which have an irregular outline, consist of fine-grained, dark-grey micritic limestone and display laminae which mimic the external form of the stromatolite.

Plate 19

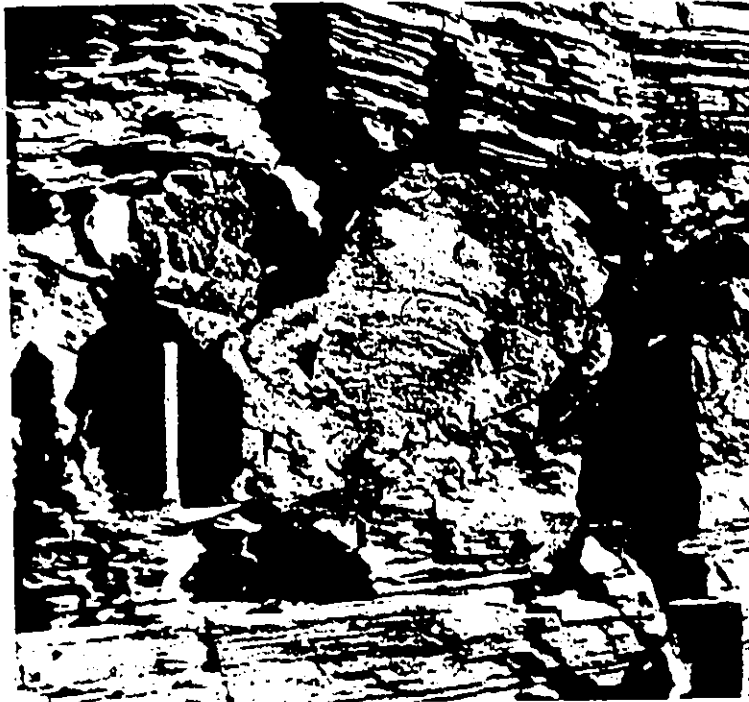
Stromatolites of the Port Leopold area

Figure 1: Field photograph of expanding stromatolite column in unit J75 of the Port Leopold area. Interdomal areas filled with intraformational conglomerate.

Figure 2: Field photograph of columnar stromatolite in marker bed 1 of the Port Leopold area.

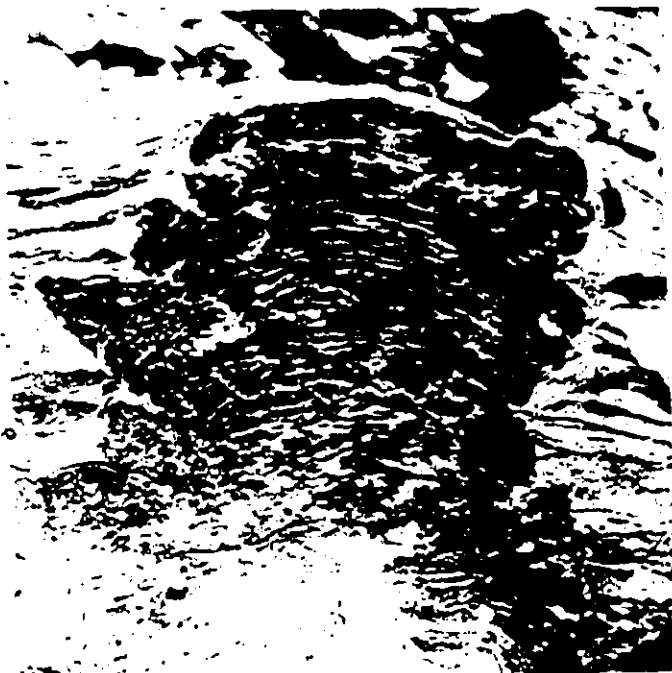
PLATE 19

FIGURE 1



12
cms
0

FIGURE 2



10
cms
0

(Pl. 19, fig. 2). Local patches of light-grey micritic limestone 'trapped' within the stromatolite (Pl. 19, fig. 2) mark periods when the upward growth of the stromatolite was interrupted. During such periods of interrupted growth, sediment the same as that in the intercolumn spaces was deposited on top of the stromatolite, filling the central depression. Subsequent growth of the stromatolite proceeded from the outer margins inwards and eventually covered the sediment in the hollow on top of the stromatolite. The individual columns of the unit are linked laterally by flat-lying, laminated stromatolite (Pl. 19, fig. 2). Although there are some differences in the morphology of the stromatolites of this horizon, no systematic lateral change in a N-S or E-W direction could be detected.

The upper part of marker unit 1 consists of undulatory continuous to semi-continuous laminae, contrasting sharply with the lower part of the unit. The upper surface of this unit displays a series of closely packed domes (Pl. 20, fig. 1) which have a diameter between 2 m and 3 m and an amplitude of up to $\frac{1}{2}$ m. The sediment between the columns of the lower part of the unit is interlaminated micritic limestone and sandy limestone. The laminae are convex-up (Pl. 20, fig. 1), a profile which probably resulted because the central portion of the intercolumn area was the site of maximum water movement.

Plate 20 .

Stromatolites of the Port Leopold area

Figure 1: Field photograph of upper portion of stromatolite in marker bed 1 of the Port Leopold area. Hammer handle is $1/3$ m.

(Photograph courtesy of Dr. O. A. Dixon).

Figure 2: Hand specimen of stromatolite on conglomerate in unit D38 of the Port Leopold area.

PLATE 20

FIGURE 1

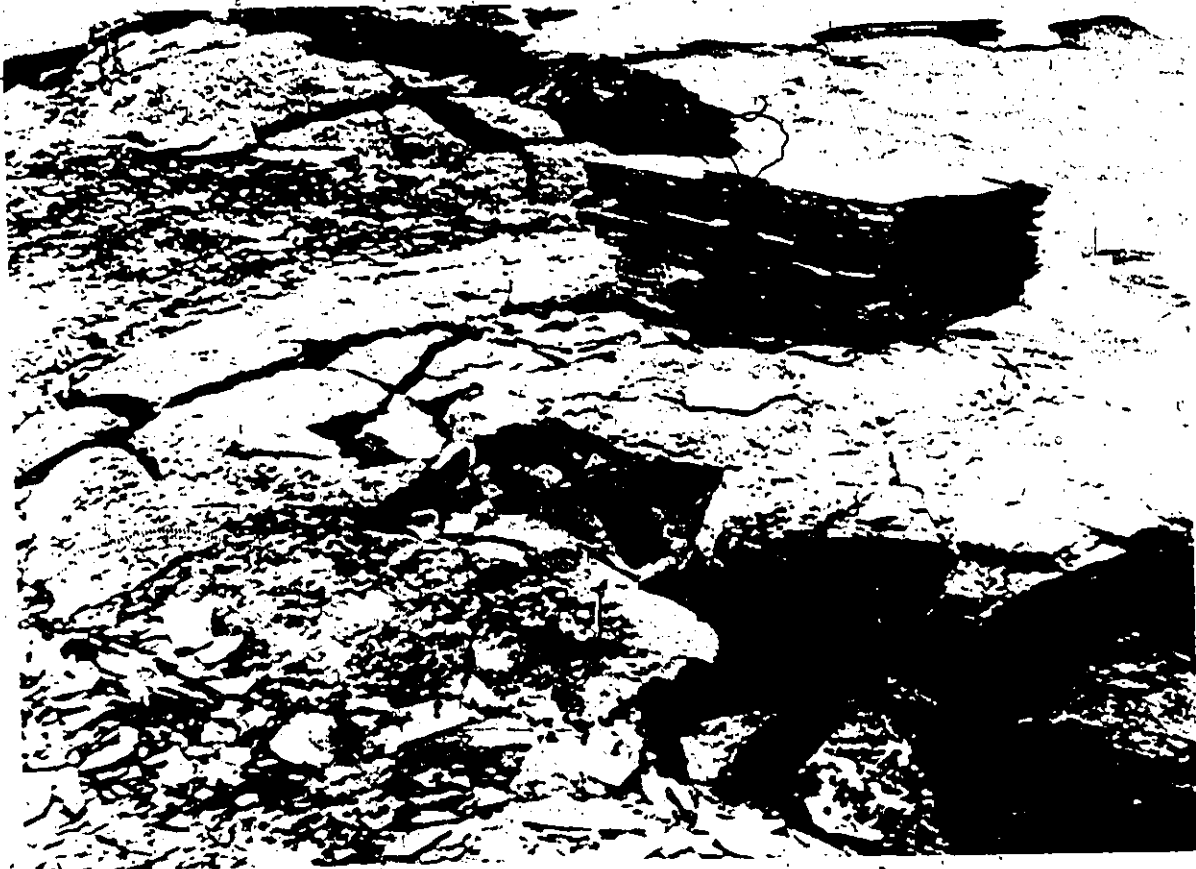


FIGURE 2



The conglomerate in unit D38 contains many stromatolites which are up to 10 cms high and up to 5 cms in diameter. These stromatolites show several distinct stages in their development.

The lower portions of the stromatolite grew around nuclei of single pebbles or groups of small pebbles (Pl. 18, fig. 3). Concentric laminae produced an oncolitic structure around these nuclei. The oncolitic structures probably formed in a submerged area under high energy conditions. Subsequent to this period of agitation, the oncrites became anchored and growth proceeded in an upward direction only.

The stromatolites of unit G46 and its equivalents have diameters of 0.6 to 1.0 m and heights of 10-15 cms. Smaller domes are present on the upper surface of the stromatolite (Pl. 21, fig. 3). At the same stratigraphic level along the peninsula, other stromatolites of this form are present but apparently are not linked together.

In unit J75 the dome-shaped stromatolites (Pl. 19, fig. 1) are up to 0.6 m high and have a base diameter of 0.3 to 0.5 m which increases upwards to 0.9-1.0 m. The interdome areas are filled with conglomerate (clasts up to 10 X 5 X 3 cms) which contains Kirkidium (?) and some fragmentary orthoconic nautiloids.

In an isolated exposure near sea level (approximately 100-150 m to the NE of the cabin -- Text-fig. 3, p. 5) many stromatolites are exposed on a bedding plane (Pl. 21, fig. 2). These

Plate 21

Stromatolites of the Port Leopold area

Figure 1: Field photograph of conical stromatolites from locality 100 metres north-east of cabin at Port Leopold.

Figure 2: Field photograph of stromatolites on bedding plane at locality 100 metres north-east of the cabin at Port Leopold. Individual stromatolites approximately the same height as the form shown in Figure 1.

Figure 3: Field photograph of upper surface of isolated stromatolite lens in unit G46 of the Port Leopold area.

Figure 4: Field photograph of vertical section through a stromatolite in unit D38 of the Port Leopold area.

FIGURE 1



0 cms 8



PLATE 21



FIGURE 2

FIGURE 3



FIGURE 4



0 cms 6



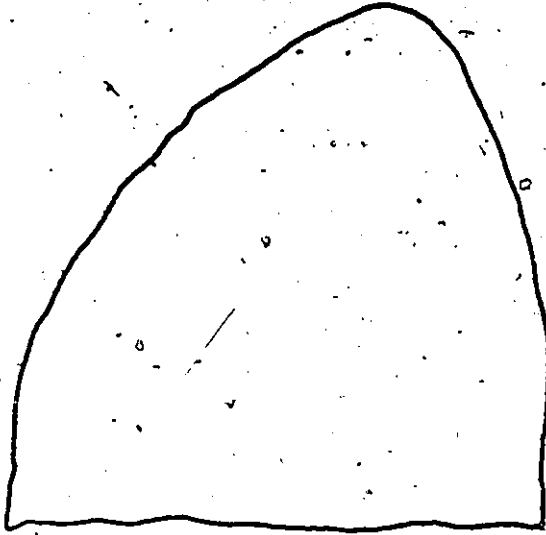
stromatolites have a variable shape in plan view but all are characterized by steep, straight sides. In their simplest form they are conical (Pl. 21, fig. 1) but in some examples growth was more rapid on one side than the other, producing an asymmetrical form (Text-fig. 23). If the asymmetrical forms continued to grow in the same manner it is possible that they could join with other stromatolites and produce elongate forms such as that shown in Plate 21, figure 2. In extreme cases, growth has produced forms which are 'V'-shaped in plan view (Text-fig. 23).

Internally the conical stromatolites have conical laminae stacked one on another (Text-fig. 23). The central portion of the stromatolite has a 'columnar' structure which produces a depression in the internal laminae (Text-fig. 23). The internal laminae indicate that the stromatolite originally had a wide base and low amplitude. During life the base diameter remained relatively constant while the height of the stromatolite increased greatly. The increase in height of the stromatolite eventually resulted in the conical form now seen. The conical form appears to resemble closely the form Conophyton, which Soviet geologists consider to be an index fossil of Precambrian rocks. However, they also have a profile similar to forms in the Persian Gulf (Shinn, 1972). Shinn (1972) considered that the axial structure in the Recent Persian Gulf forms was due to worm burrowing.

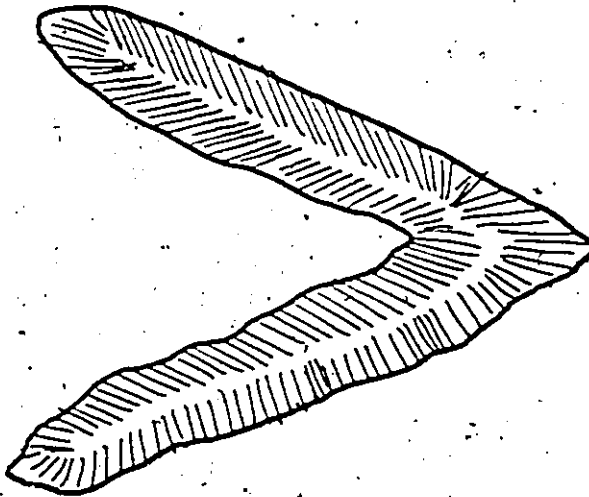
Text-figure 23.

Morphology of stromatolites from isolated exposure northeast of the cabin at Port Leopold. A- Asymmetrical form in side view, B- Plan view of V-shaped stromatolite and C- Vertical section through conical stromatolite showing internal laminae.

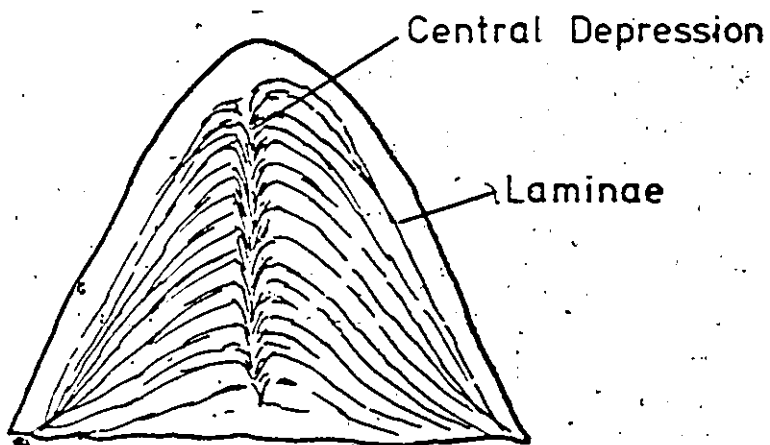
A



B



C



Cape Admiral M'Clintock

Location of section Three suitable sections for study are present in the gullies and sea cliffs at Cape Admiral M'Clintock. However, during the brief visit, inclement weather prevented the study of two of these.

In the western gully (Text-fig. 4) about 100 m (320 ft) of section were measured beginning at 18 m above sea level. The stream flowing from this gully cut through the raised beach revealing additional portions of the section. However, much of the rock in these lower exposures is apparently in a slump block and their relationship to the main part of the section is uncertain.

Rock types The dominant rock type of this section is rubbly argillaceous limestone (Text-figs. 24 to 27). Within the section there are units of intraformational conglomerate, intraclastic shelly limestone, shelly limestone and micritic limestone. Such units are generally less than 1m thick compared with units of rubbly argillaceous limestone up to 7 m thick. The rock types conform to the basic descriptions previously given (chapter 2, p. 23).

Sedimentary structures Apart from stratification the only sedimentary structures present in the Cape Admiral M'Clintock section are erosional surfaces and megaripples (Text-figs. 24, 25 and 26).

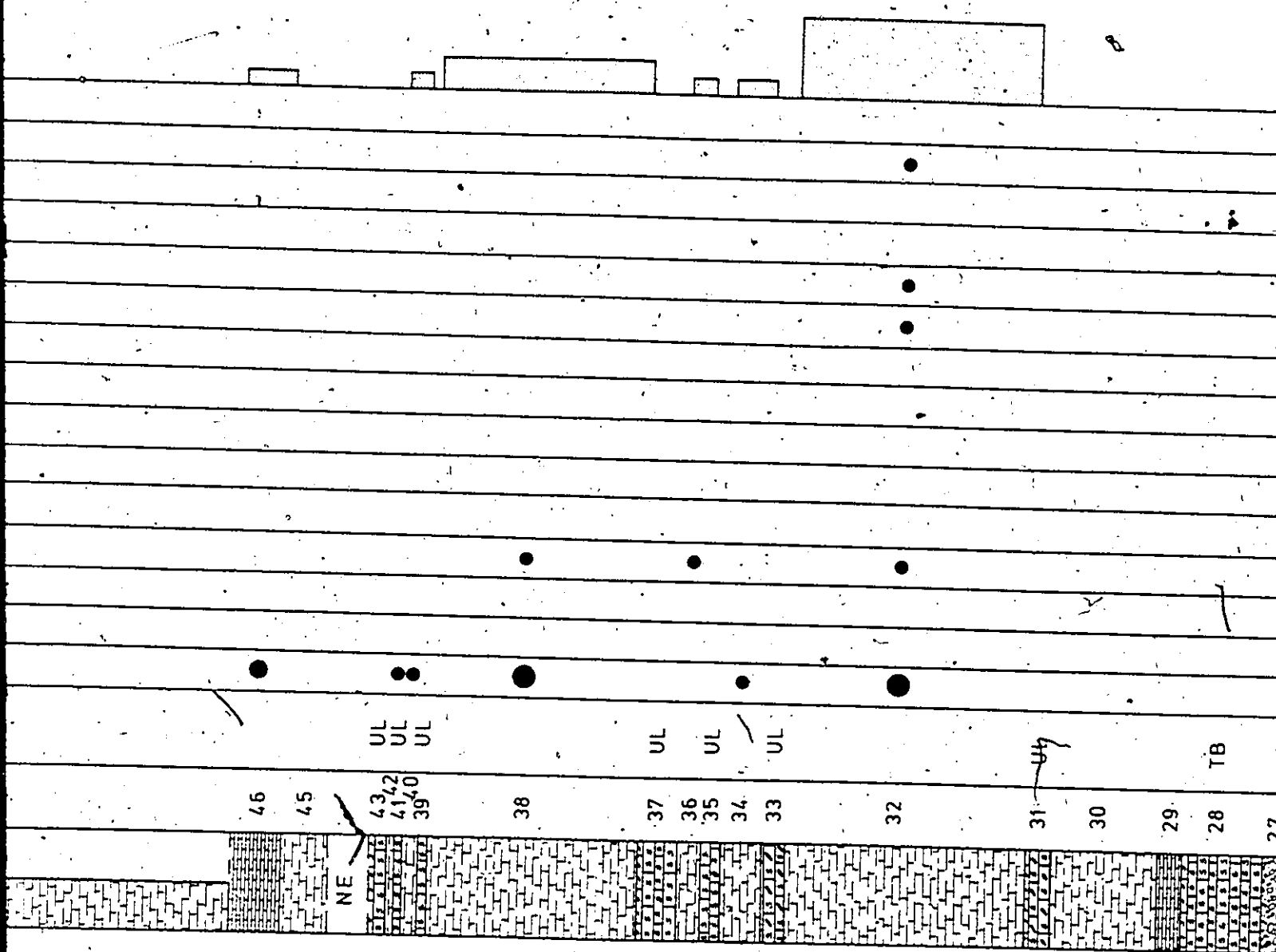
Text-figures 24-26: Lithology, sedimentary structures and faunal elements of section K of the Cape Admiral M'Clintock area.

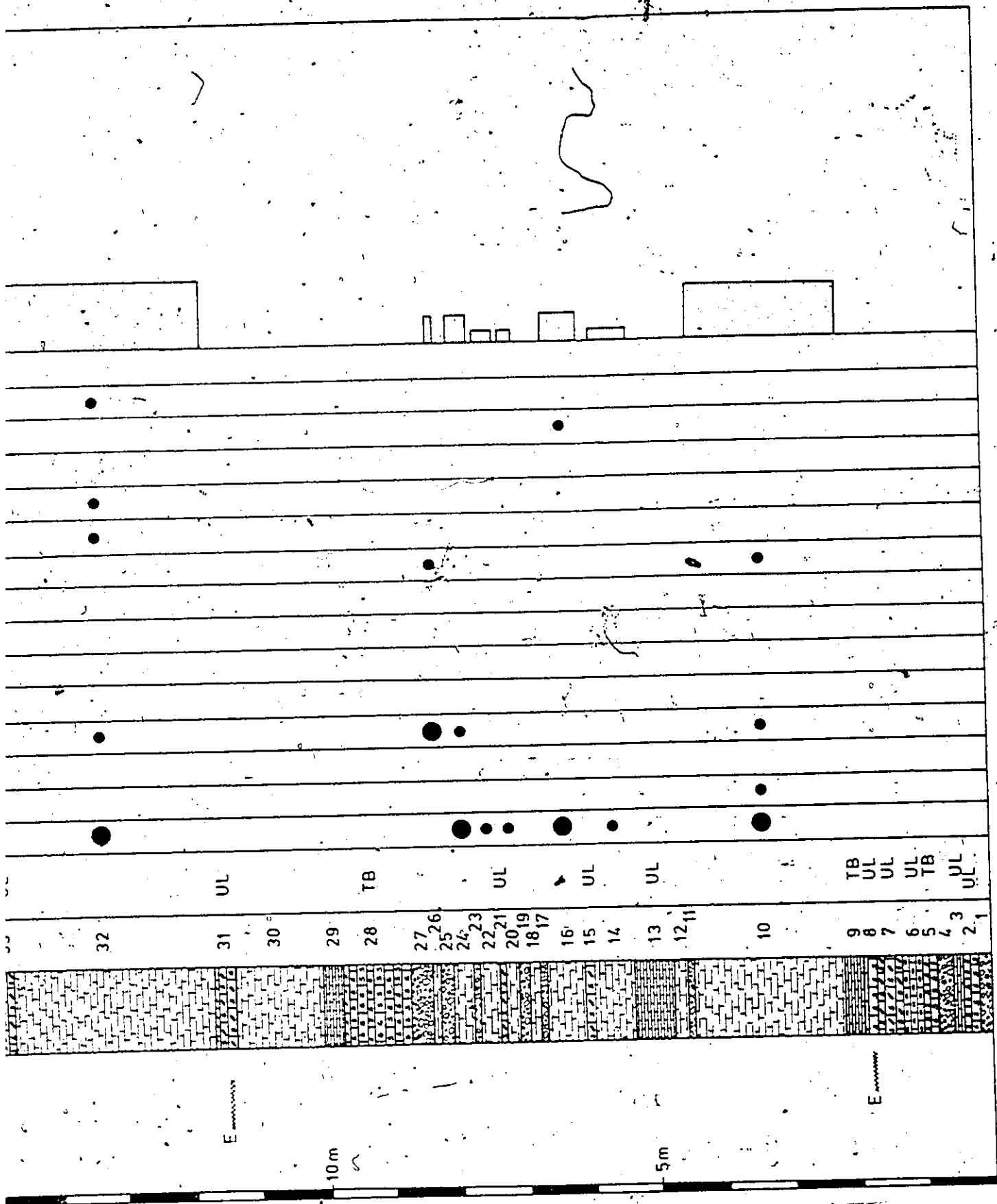
ROCK TYPES	SEDIMENTARY STRUCTURES	BEDDING TYPE
 MICRITIC LIMESTONE  DOLOMITIC LIMESTONE  CALCAREOUS DOLOMITE  DOLOMITE  SANDY DOLOMITE  DOLOMITIC SANDSTONE  SANDSTONE  CALCAREOUS SANDSTONE  SANDY LIMESTONE  INTRACLASTIC SHELLY LIMESTONE  CONGLOMERATE  ARGILLACEOUS LIMESTONE  ONCOPELLET LIMESTONE  SANDY DOLOMITE-LIMESTONE  CALCAREOUS SANDSTONE-DOLOMITE  DOLOMITIC SANDSTONE-LIMESTONE  GYPSUM & ANHYDRITE	 STROMATOLITE  SHELLY LIMESTONE  REEF LIMESTONE  RUBBLY ARGILLACEOUS LIMESTONE  MOTTLED DOLOMITE-LIMESTONE  NO EXPOSURE  POOR EXPOSURE	SEDIMENTARY STRUCTURES  RIPPLES  DESICCATION CRACKS  BIRD'S EYE STRUCTURE  CHANNEL  STYLOLITE  EROSION SURFACE  TRACE FOSSILS  TRACE FOSSILS (?)
BEDDING TYPE UL UNLAMINATED L LAMINATED IL INTERLAMINATED TB THIN BEDDED MB MEDIUM BEDDED H MOTTLED IF UNIT IS INTERLAMINATED OR INTERBEDDED IT IS DENOTED BY COMBINATION OF ROCK TYPE SYMBOLS. THUS:  1L OR 1B DOLOMITE AND SANDY DOLOMITE	IN SITU FAUNA ● DENOTES GENUS PRESENT ● DENOTES DOMINANT ELEMENT IN UNIT IF MORE THAN ONE GENUS PRESENT SOLITARY CORALS (4) NUMBER IN BRACKETS INDICATES NUMBER OF INDETERMINATE GENERA INCLUDED IN GENERIC DIVERSITY	SEDIMENTARY STRUCTURES ● DENOTES GENUS PRESENT ● DENOTES DOMINANT ELEMENT IN UNIT IF MORE THAN ONE GENUS PRESENT SOLITARY CORALS (4) NUMBER IN BRACKETS INDICATES NUMBER OF INDETERMINATE GENERA INCLUDED IN GENERIC DIVERSITY

Text-figure 24.

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OF NEW YORK

Sedimentary Structures	Rock Type	Unit	Bedding Type	In Situ Fauna												Generic Diversity																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
				Atrypella	Ferganella	Stegorhynchus	Protolhyris	Gypidula	Fardenia	Howellia	Cyrtina (?)	Hormotoma	Encrinurus	Favosites	Nautiloid indet.	Sponges indet.	Ostracod indet.	Number of Genera																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
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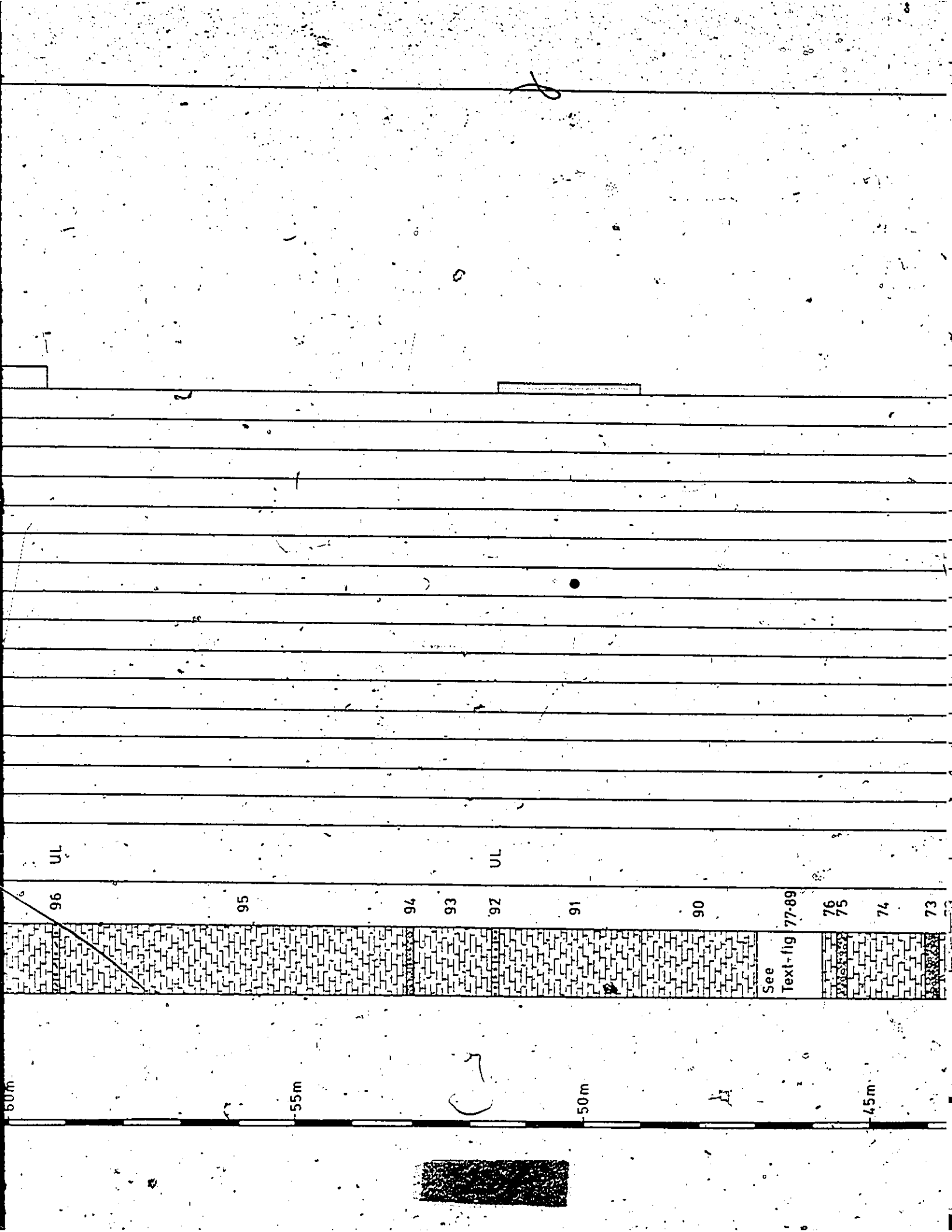
343

Text-figure 25.

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2

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90

See
Text-fig 77-89

76
75

74

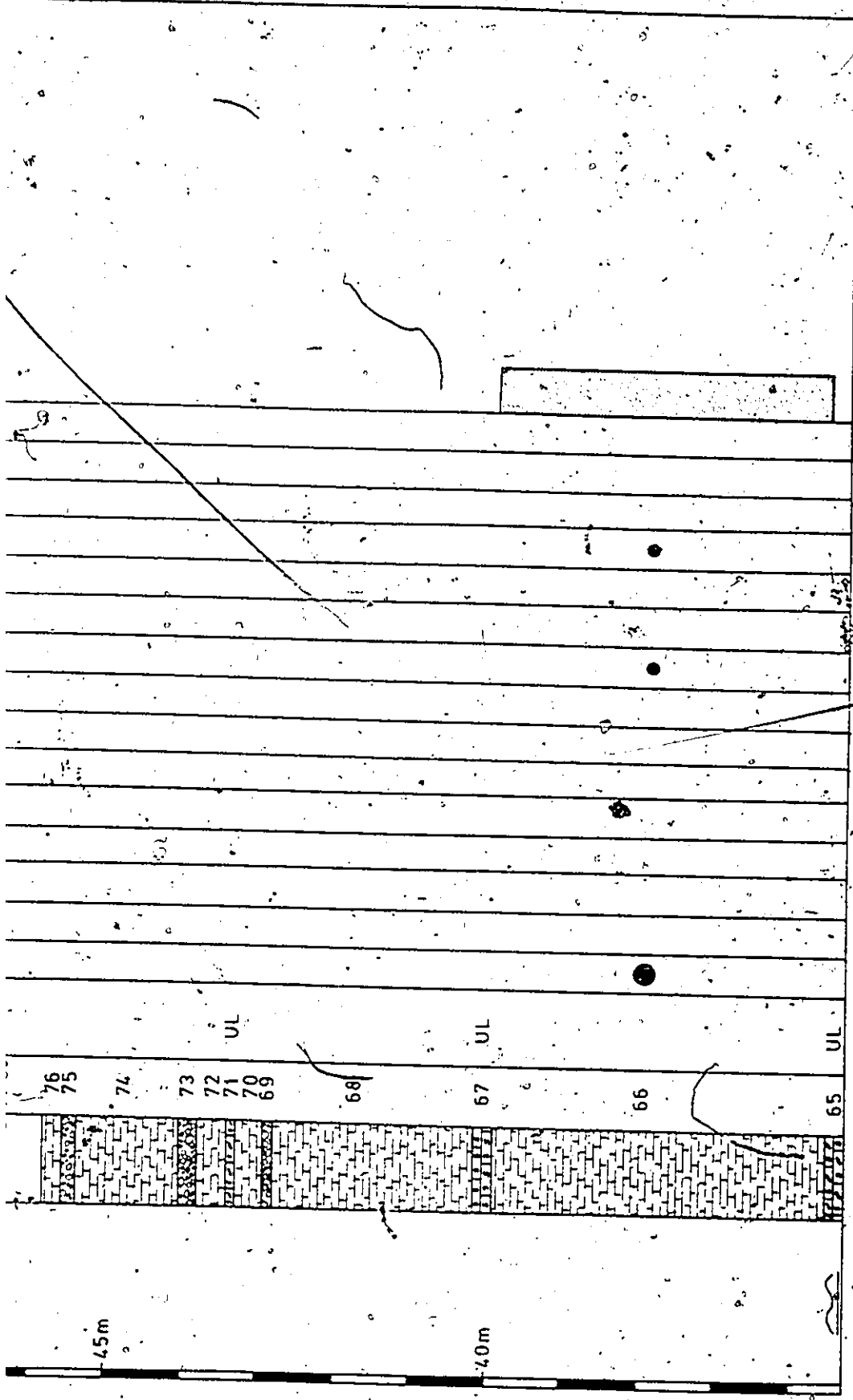
73

50m

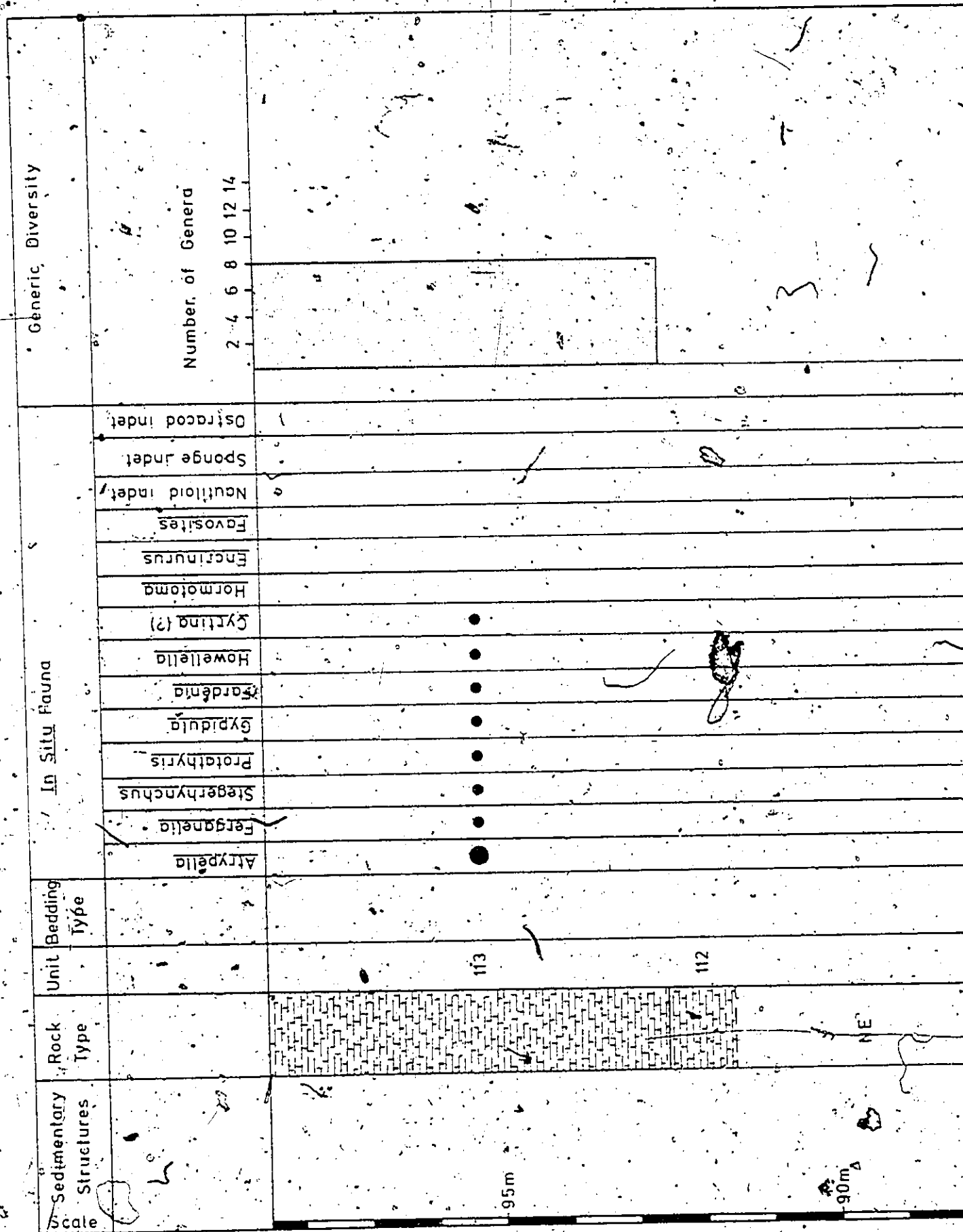
55m

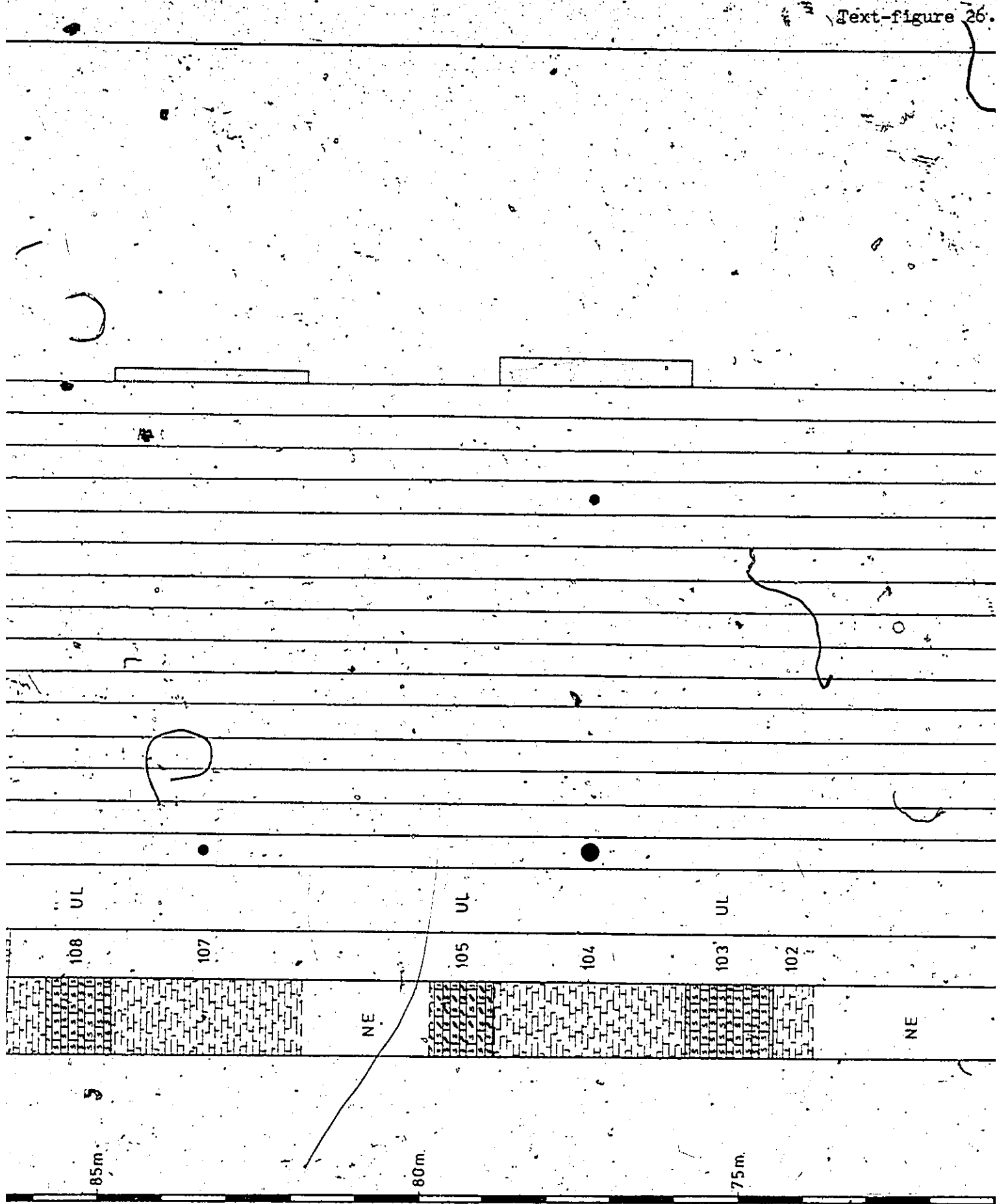
50m

45m



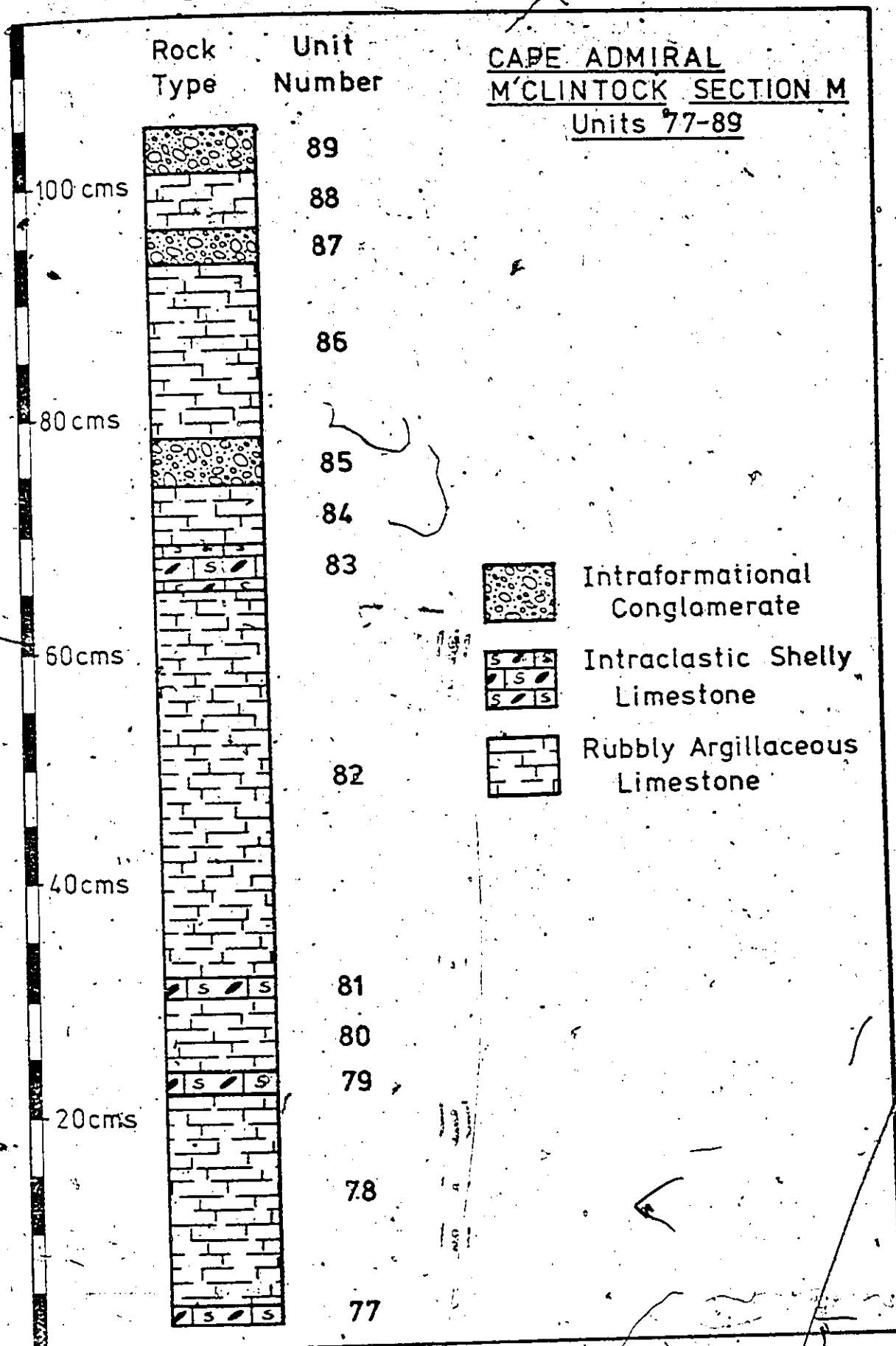
CAPE ADMIRAL M'CLINTOCK SECTION M UNITS 100-113





Text-figure 27

Succession of rock types between units 77 and 89 of the section
at Cape Admiral M'Clintock. See Text-figure 25 for position
within section.



Faunal distribution. The distribution of in situ genera is shown in Text-figures 24, 25 and 26. Identification of in situ fauna is based on the state of articulation (high numbers of articulated forms), the ratio of undamaged to damaged shells (few damaged forms in in situ fauna) and the size-frequency histograms of the shells (normal distribution for in situ fauna).

The main peaks of generic diversity generally coincide with the units of maximum thickness (Text-figs. 24, 25 and 26) and maximum faunal abundance. In striking contrast, the thin units (e.g. units 75-88) generally contain no in situ fauna.

Between units M8 and M31 there is a gradual change in the fauna (Text-fig. 24). In the lower part of the sequence (units 10 to 24) Atrypella occurs along with some crinoids and sponges. In higher units (units 24 to 26) only Protathyris occurs, while in the units immediately below unit M31 only Hormotoma-type gastropods are present.

The pattern described above is a generalization and there are exceptions. For example, unit M60 which is a rubbly argillaceous limestone has a thickness of two and one-third metres but apparently no fauna.

Garnier Bay

Location of sections and structural setting Four sections were measured in the Garnier Bay area (Text-fig. 5 and Table 4) and several isolated exposures were also examined (localities GC on Text-fig. 5).

The structure of the Garnier Bay area is controlled by several faults (Text-fig. 5). Some of these faults are detectable on air photographs (Pl. 22) and others are evident in the field from the abrupt changes in attitude of beds on either side of a fault. Faults A-A and B-B (Text-fig. 5) are readily apparent in the field because of the contrasting dips of strata on either side of the fault (Text-fig. 5). Plate 22 shows how fault E-E has truncated beds in the eastern area (position E-E on Pl. 22). The fault E-E apparently also exerts some control over the morphology of the Garnier River. If the fault line is projected eastward, the river to the south of it is strongly braided while to the north of the fault line all the water is contained within one main channel in a broad valley. The boundary between the two fluvial patterns is sharp and distinct (Text-fig. 5). Faults C-C and D-D are conjectural for there is little direct evidence of displacement. The alignment of the cliffs in both fault blocks is the same (Text-fig. 5) and the

Table 1: Location of sections measured in the Garnier Bay area.

Section Code	Location of Section Base		Height of section Base above sea Level	Thickness of section
	Lat.	Long.		
GA	73°57'	92°17'	10 - 15 m	186 m
GB	73°57'	92°05'	5 m	17.5 m
GD	73°56'	92°10'	175 - 200 m	59.5 m
GE	73°57'	92°08'	175 - 200 m	approx. 170 m

Plate 22

Air-photomark of the Garnier Bay area

Air photograph of Garnier Bay area showing location of sections (CA, CB, CD and CE) and position of faults a-a, b-b, c-c and d-d.

Scale 1" = 1 mile.

Garnier Bay

PLATE 22

GA

CD

CB

e

N

PLATE 22

trend of both faults is approximately the same as that for fault E-E.

At the base of section GA the beds are nearly horizontal but at the top of the section the beds dip about 15° to the south.

Rock types The rock types in these sections generally correspond to those previously described (chapter 2, p. 23). However, in some of these rocks particular features warrant brief additional discussion.

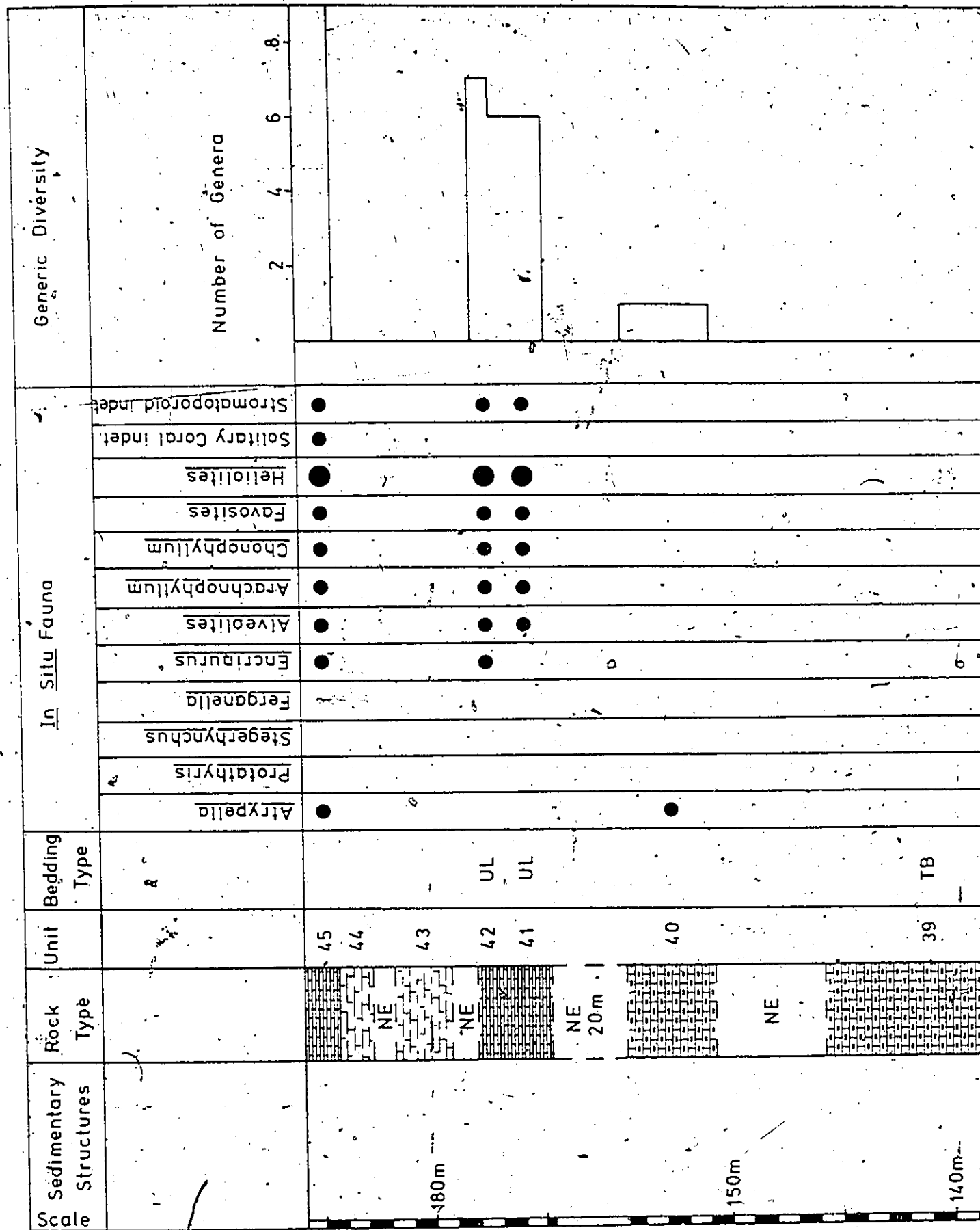
The content of detrital plagioclase in the basal part of section GA (units GA1-GA14 - Text-fig. 28) is relatively high (up to 10%, e.g. unit GA10) compared to rocks in other parts of the Read Bay Formation. The plagioclase grains are of similar size and shape to the quartz grains (angular to subangular and up to 0.20 mm) and show strain features. Muscovite generally constitutes only 2-5% of the rocks, but exceptionally (e.g. unit GA12) there is as much as 20%. Commonly, the long axes of the muscovite flakes are orientated parallel to bedding. Lenses and thin laminae (less than 1 cm thick) of conglomerate occur in the limestone of unit GA11. The distinctive feature of the clasts, which are up to 2.0 X 1.0 X 0.5 cms in size, is their red colour. Sectioning demonstrates that this is a ferrous oxide coating around the clasts of grey, micritic limestone.

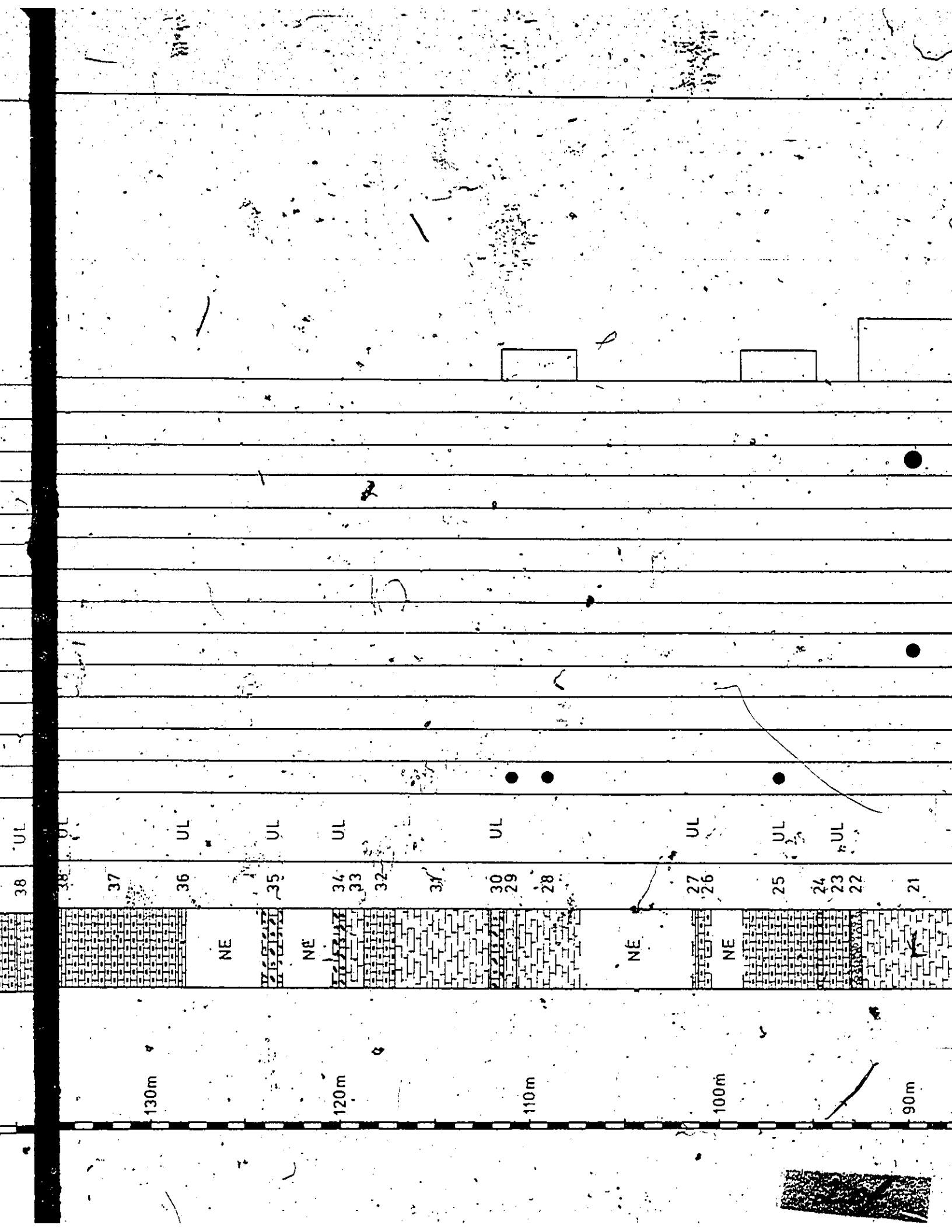
Many of the rocks in section GB also have a high content of angular to subangular grains of detrital quartz and plagioclase (up to 0.12 mm in size) and some muscovite flakes. The quartz is

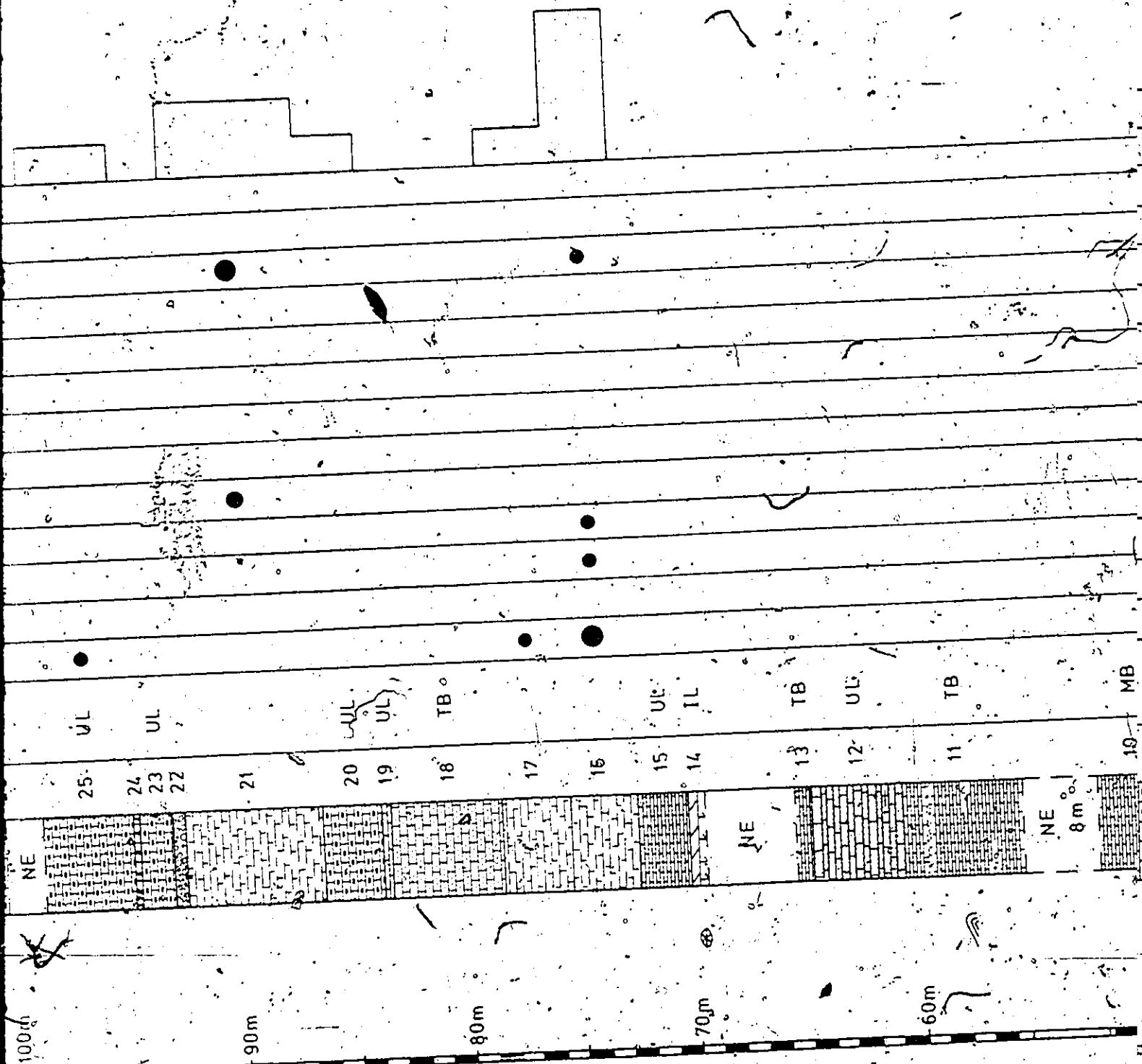
Text-figures 28-30: Lithology, sedimentary structures and faunal elements of sections GA, GB and GD of the Garner Bay area.

ROCK TYPES	SEDIMENTARY STRUCTURES	IN SITU FAUNA
HICRITIC LIMESTONE DOLOMITIC LIMESTONE CALCAREOUS DOLOMITE DOLOMITE SANDY DOLOMITE DOLOMITIC SANDSTONE SANDSTONE CALCAREOUS SANDSTONE SANDY LIMESTONE INTRACLASTIC SHELLY LIMESTONE CONGLOMERATE ARGILLACEOUS LIMESTONE ONCOPHELLET LIMESTONE SANDY DOLOMITE-LIMESTONE CALCAREOUS SANDSTONE-DOLOMITE DOLOMITIC SANDSTONE-LIMESTONE GYP SUM & ANHYDRITE	STROMATOLITE SHELLY LIMESTONE REEF LIMESTONE RUBBLY ARGILLACEOUS LIMESTONE MOTTLED DOLOMITE-LIMESTONE NO EXPOSURE POOR EXPOSURE NE STYLOLITE EROSION SURFACE TRACE FOSSILS TRACE FOSSILS (?)	• DENOTES GENUS PRESENT • DENOTES DOMINANT ELEMENT IN UNIT IF MORE THAN ONE GENUS PRESENT 1. SOLITARY CORALS (4) NUMBER IN BRACKETS INDICATES NUMBER OF INDETERMINATE GENERA INCLUDED IN GENERIC DIVERSITY
BEDDING TYPE UL UNLAMINATED L LAMINATED IL INTERLAMINATED TB THIN BEDDED MB MEDIUM BEDDED M MOTTLED IF UNIT IS INTERLAMINATED OR INTERBEDDED IT IS DENOTED BY COMBINATION OF ROCK TYPE SYMBOLS. THUS: IL OR IB DOLOMITE AND SANDY DOLOMITE	• RIPPLES • DESICCATION CRACKS • BIRD'S EYE STRUCTURE • CHANNEL • STYLOLITE • EROSION SURFACE • TRACE FOSSILS • TRACE FOSSILS (?)	• DENOTES GENUS PRESENT • DENOTES DOMINANT ELEMENT IN UNIT IF MORE THAN ONE GENUS PRESENT 1. SOLITARY CORALS (4) NUMBER IN BRACKETS INDICATES NUMBER OF INDETERMINATE GENERA INCLUDED IN GENERIC DIVERSITY

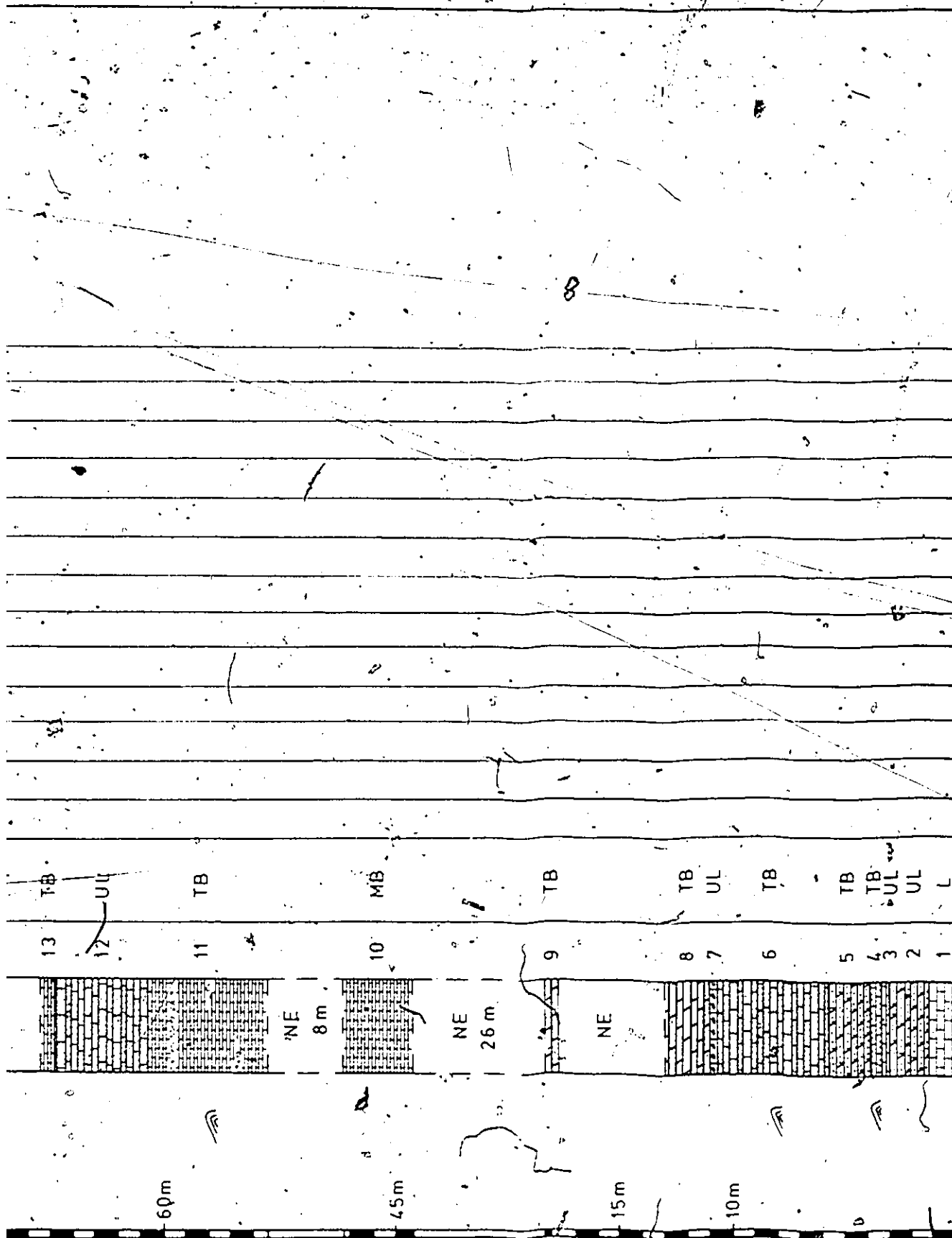
GARNIER BAY SECTION GA







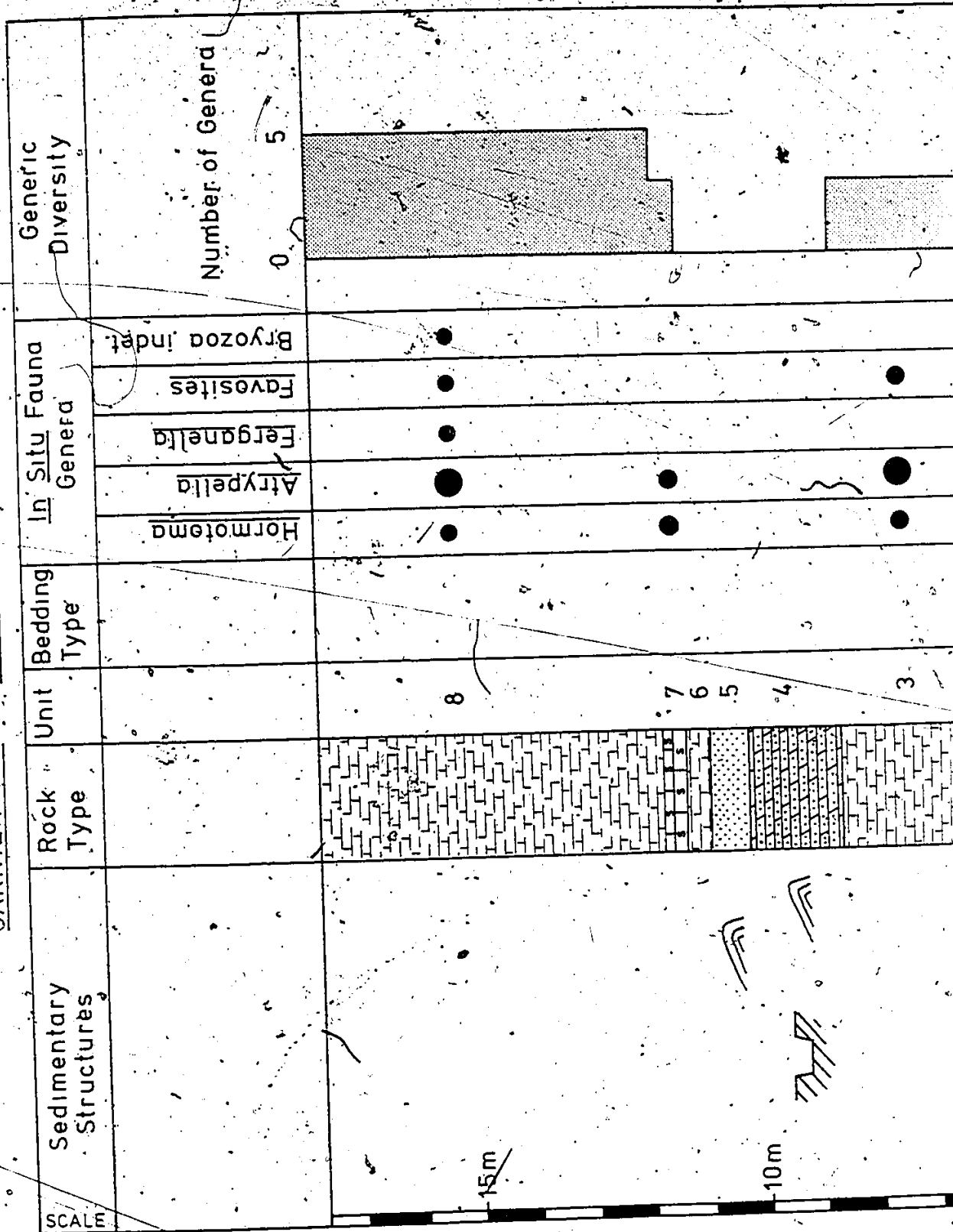
Text-figure 28.

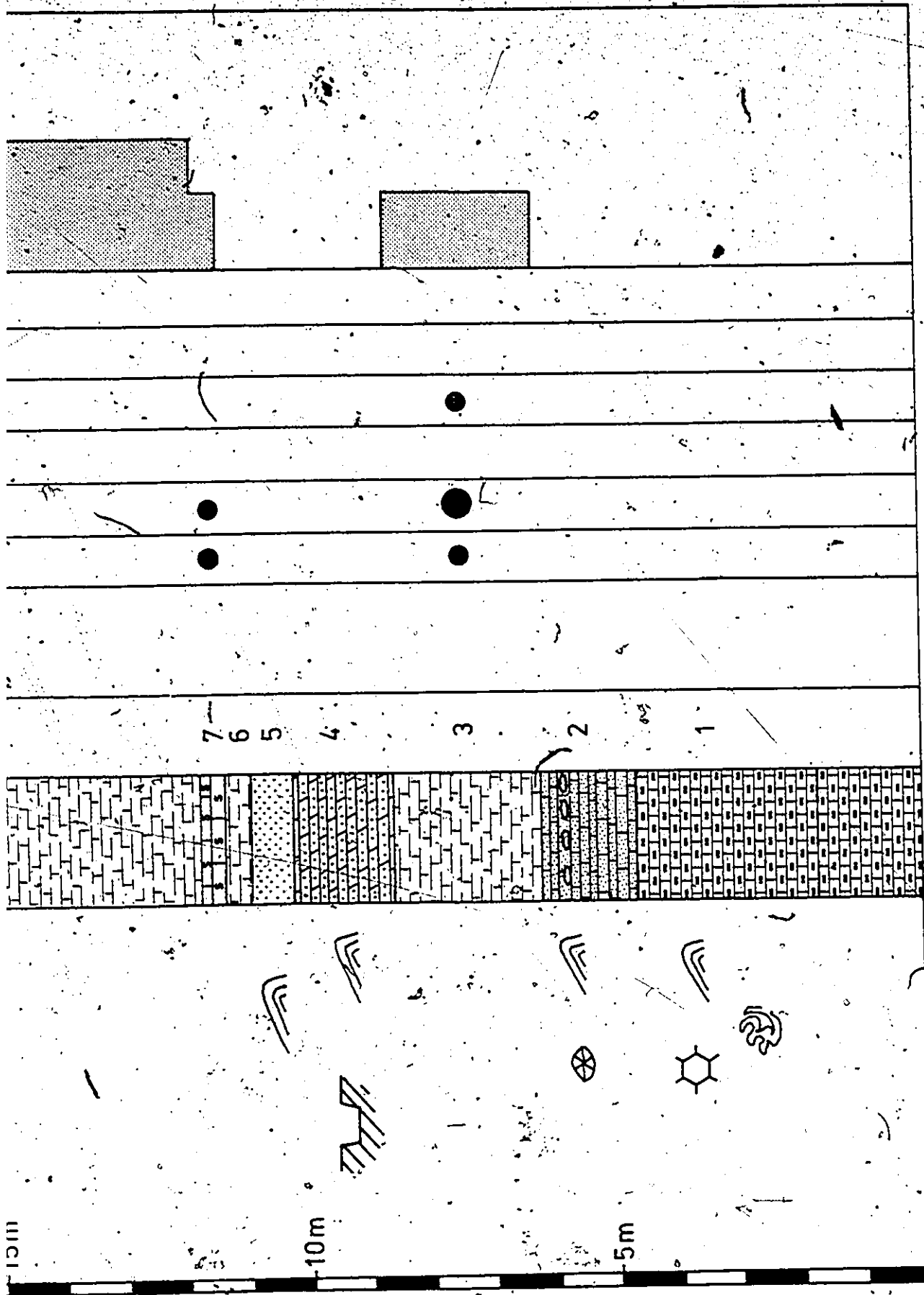


Text-figure 29.



GARNIER BAY SECTION GB



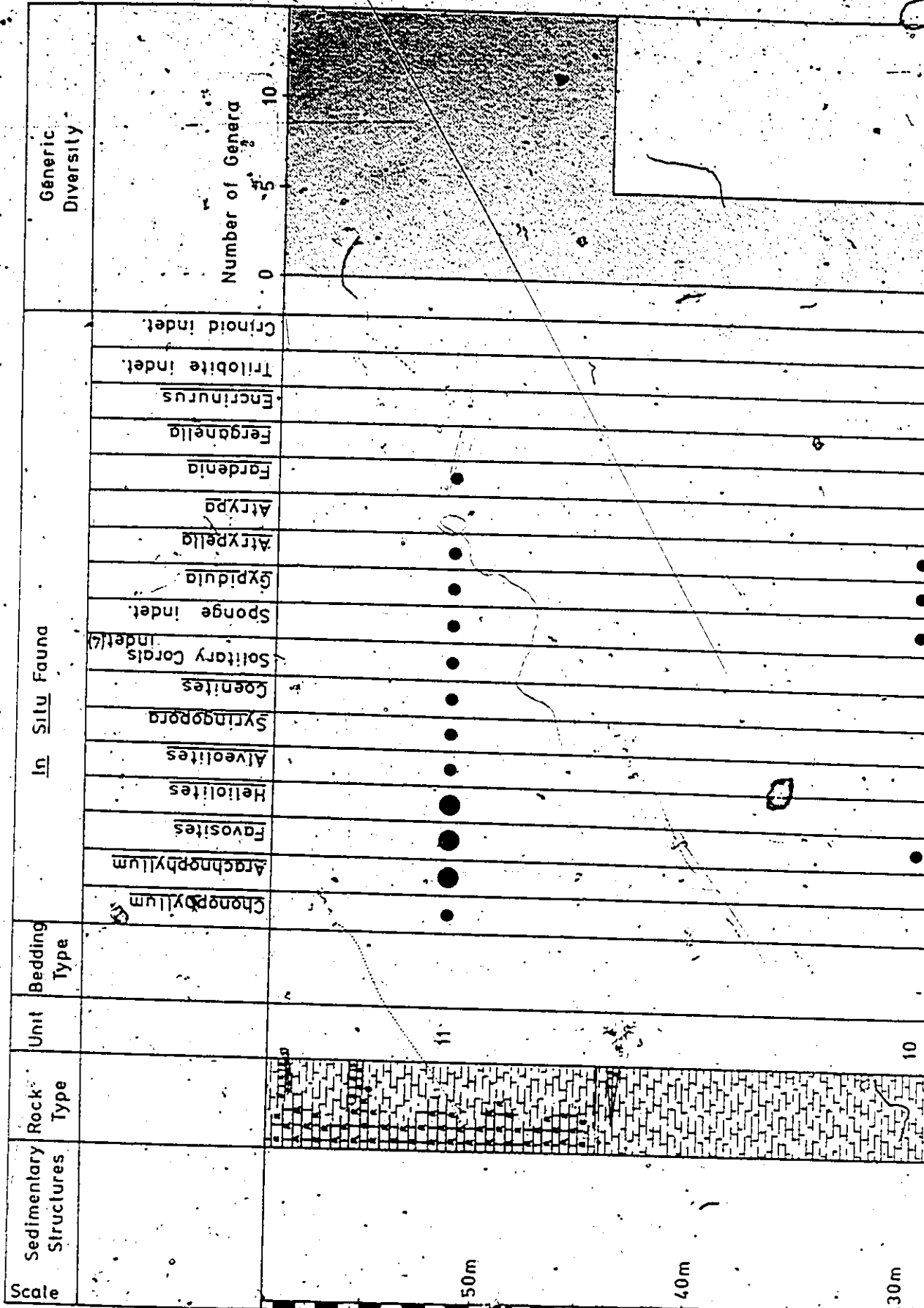


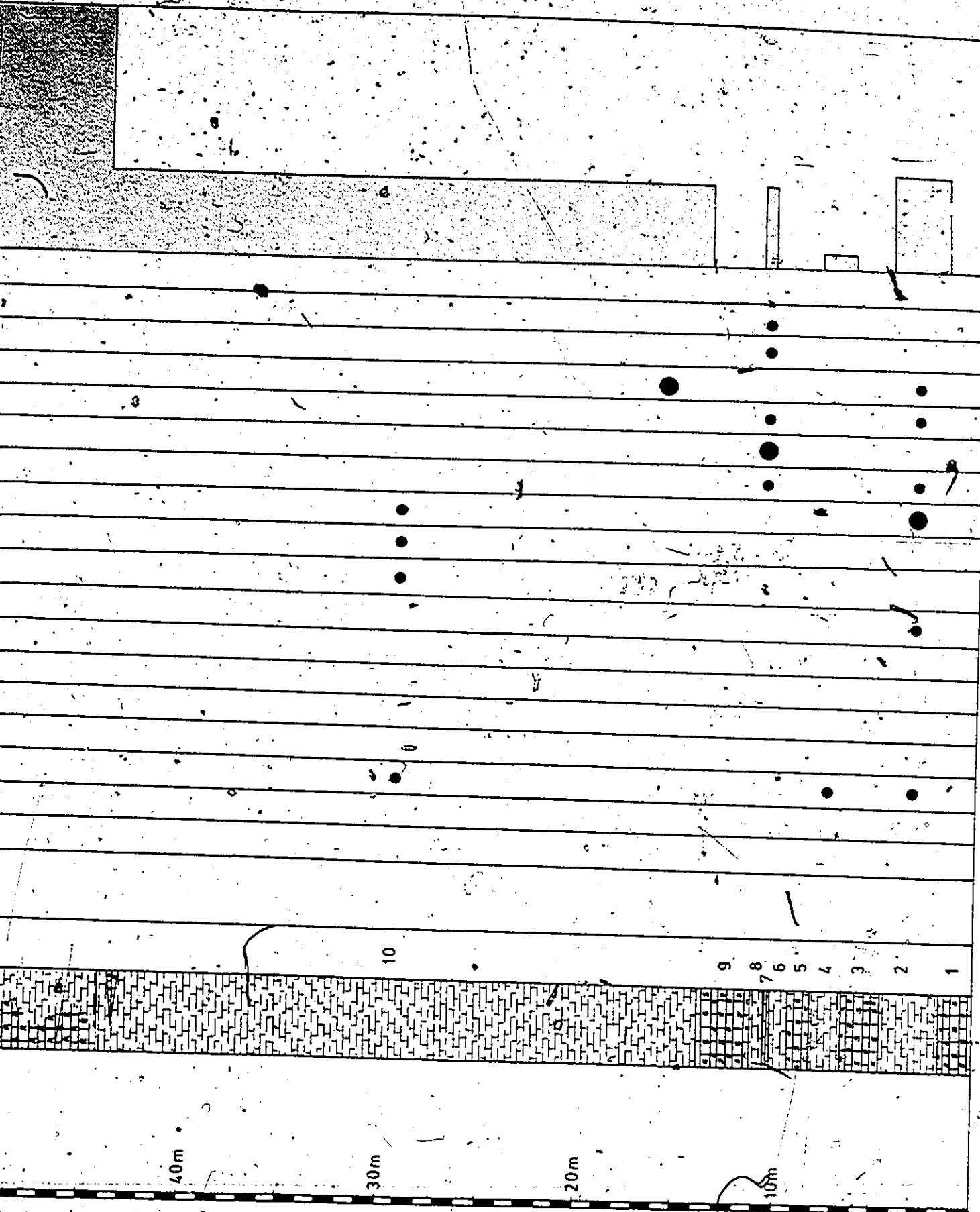
2 of 2

Text-figure 30.

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GARNIER BAY SECTION 61 GO





2 of 2

present in sufficient quantities to form sandstone (Text-fig. 29 - unit GB5). Many of the rocks containing detrital material also contain shell fragments (less than 5 cms long) some of which have been dolomitized. In the sandstone of unit GB5, pressure solution has formed planar boundaries between adjacent quartz grains.

The predominant rock type in Section GD and GE is rubbly argillaceous limestone (Text-fig. 30). Interbedded with it are micritic limestone and shelly limestone. Unit GD11 consists of reefoidal limestone flanked by rubbly argillaceous limestone containing thin beds (less than 0.50 m thick) of crinoidal limestone (Text-fig. 30).

Sedimentary structures The most common sedimentary structure in section GB are ripples (Text-fig. 29 - see p. 58 for description of their form). A series of elliptical, calcareous concretions occur in a sandy limestone in the upper part of unit GB2 (Text-fig. 29). The concretions, which are up to 2.0 X 0.75 cms in size, have their long axes parallel to bedding. Unit GB2 contains a few irregularly shaped patches of crystalline calcite up to 1 cm in size (longest axis) suggestive of 'bird's eye' structure.

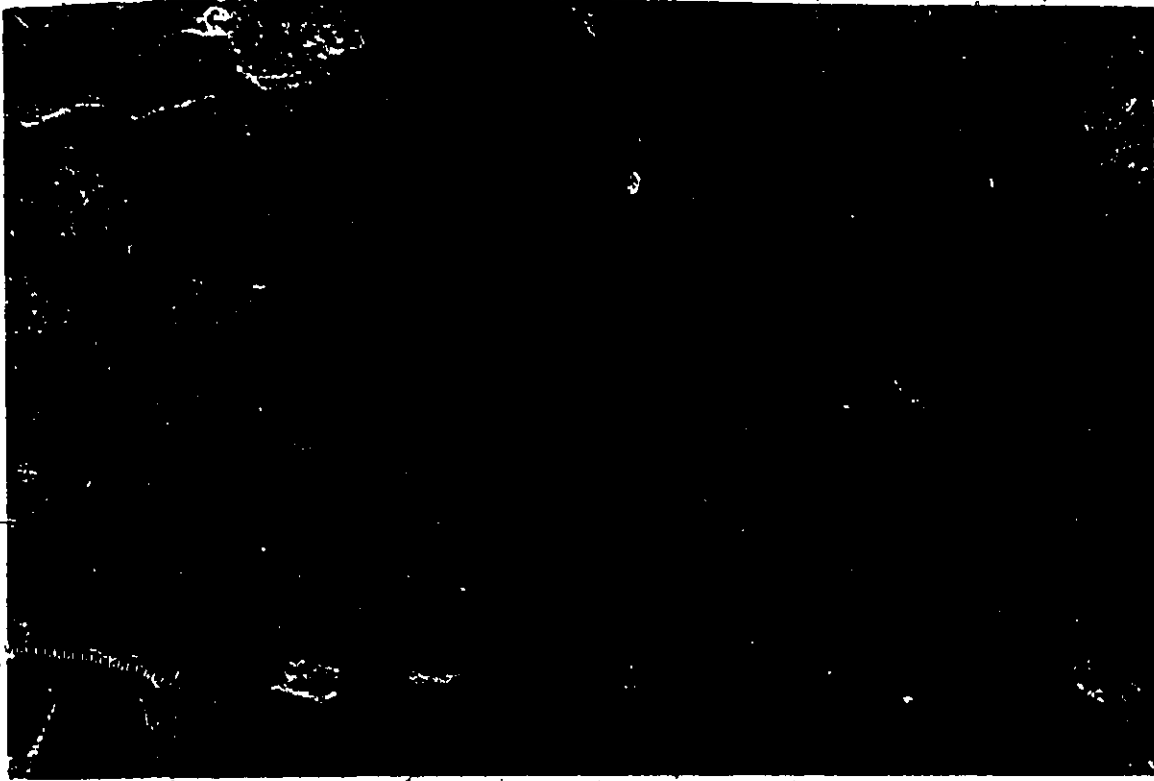
A number of trace fossils of unknown origin occur on the bedding surfaces of unit GB1. These elongate structures (Pl. 23) generally have parallel sides and slightly rounded ends. They are of

Plate 23.

Problematical trace-fossils

Field photographs of 'trace fossils' from unit GB1 of the Garnier Bay area (Figure 1) and from the Young Bay Formation north of Creswell Bay (Figure 2).

FIGURE 1



0 Cms 6

FIGURE 2



0 Cms 5

also, ranging from 1 X 2 cms to 10 X 50 cms and appear to have no fixed length/width-ratio. The laminae are concentric about the mid-point of the structure. The same structures are present in the Peel Sound and Young Bay Formations at a locality to the south of the West Greswell River. M. Gibling (1973, pers. comm.) has observed them in the Peel Sound Formation of Prince of Wales Island (Arctic coast). The specimens at the Creswell River locality are much smaller than those at Garnier Bay. One specimen from the Peel Sound Formation is 10 cms wide and about 50 cms long (Pl. 23, fig. 2). Other specimens from the Young Bay Formation measured 25 X 10 cms, 17 X 10 cms and 4 X 2 cms.

Faunal distribution The distribution of the in situ genera is shown in Text-figures 28, 29 and 30.

Section GA can be divided into four distinct portions on the basis of faunal distribution and generic diversity of the various units:

(1) Units GA1-GA14 have a restricted fauna which consists of few genera (Text-fig. 28) but many individual specimens.

Fragments of orthoconic nautiloids occur in unit GA3 and appear to have been transported prior to their deposition.

(2) Units GA15-GA31 are characterized by higher generic diversity and more profuse fauna than units GA1-GA14. Atrypella rhoca

and A. foxi are the dominant elements of the fauna. Separate valves of Megalomus occur in a convex-up position in unit GA16.

(3) Units GA32-GA39 appear to be devoid of fauna.

(4) Units GA40-GA45, and in particular unit GA45, are characterized by high generic diversity (Text-fig. 28) and numerous individuals. The colonial corals (Text-fig. 28) all have a 'pancake' shape being up to 35 cms in diameter but only 4-5 cms high (Pl. 24).

Section GB, with the exception of units GB3, GB7 and GB8 has a very sparse fauna. The units which contain ripple marks and bird's eye structure have only fragmentary shell material..

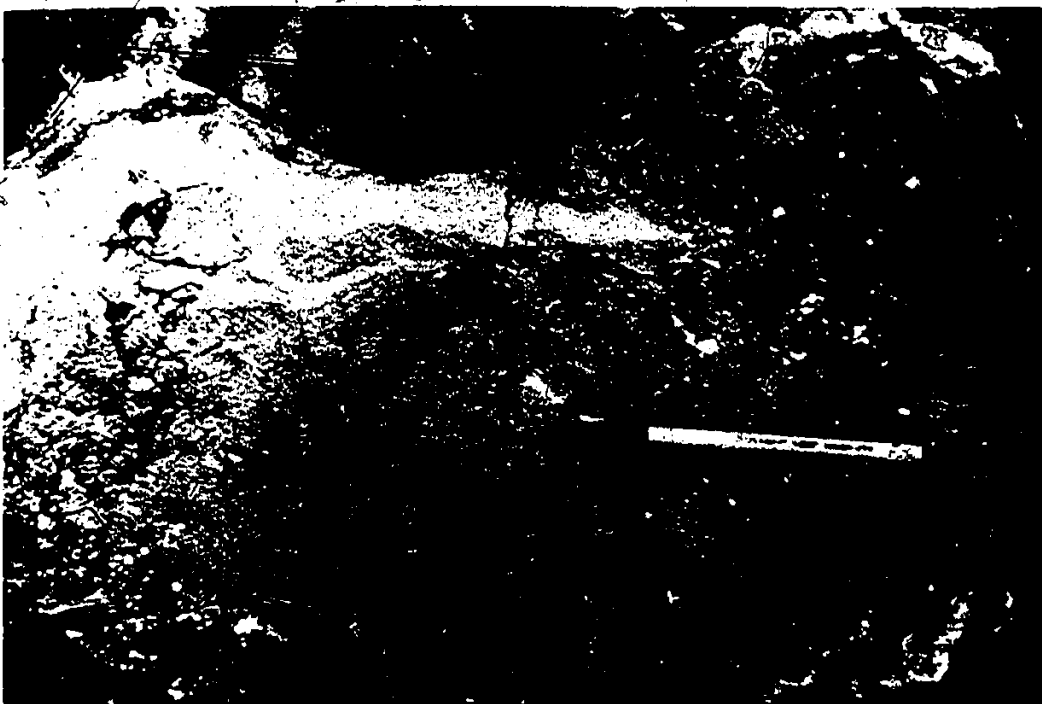
Section GD has a profuse in situ fauna of corals and brachiopods. In the lower part of the section (units GD1-GD9) brachiopods dominate the fauna (Text-fig. 30) whereas the upper part of the section (Units GD10 and GD11) has a rich and diverse coral fauna. All the colonial corals (Text-fig. 30) in unit GD11, other than those from the bioherm, have a 'pancake' shape (diameter, 30-40 cms and height, 4-5 cms). The units with no in situ fauna have a high content of shell debris.

Plate 24

'Pancake'-shaped favositid coral

Field photograph of colonial coral from bioherm in unit GD11 of the Garnier Bay area. Vertical section through coral is in upper left-hand corner of block (white-coloured material). (Photograph courtesy of Dr. O. A. Dixon).

PLATE 24



0 Cms 9

Cunningham Inlet area

Location of sections and structural setting. The measured sections are situated on the north coast of Somerset Island approximately 5 miles west of Cunningham Inlet (Text-fig. 6, p. 8). Four sections (CA, CD, CE and CF) were measured in this area (Text-fig. 6) and a few isolated exposures were examined (Localities E and F on Text-fig. 6).

The dominant structures of the area are major northwest-to southeast-trending faults. The striking feature of the area is the mirror image of the structures about the central line of the main valley (Text-fig. 6, p. 8). Only the strata to the east of this line were examined in detail.

Fault A-A, which dips $60-70^{\circ}$ to the southwest (Text-fig. 6, p. 8) separates horizontal strata from dipping strata (Pl. 25, fig. 1). Unlike other faults in the area, no fault breccia is associated with this fault. The dipping beds adjacent to this fault exhibit a series of small drag folds (Read and Watson, 1962, p. 490).

Faults B-B, E-E and F-F (Text-fig. 6, p. 8) are all marked by zones of breccia up to 6 m wide. The zones of fault breccia contain large (up to $2.5 \times 2.0 \times 1.0$ m), randomly distributed blocks of unaltered limestone embedded in a matrix of smaller blocks and fine-grained carbonate material. One such limestone block in the

Plate 25

Faulted strata and fault breccia near

Cunningham Inlet

Figure 1: Field photograph of the fault (A-A) to the west of Cunningham Inlet which separates the horizontal strata (left hand side of photograph) of the unnamed carbonate sequence from the dipping strata of the Read Bay Formation (right hand side of photograph). Oblique view towards the east.

Figure 2: Field photograph of cliff face showing breccia associated with fault X-X of the Cunningham Inlet area. Note undisturbed strata in the upper right hand corner of the photograph.

PLATE 25

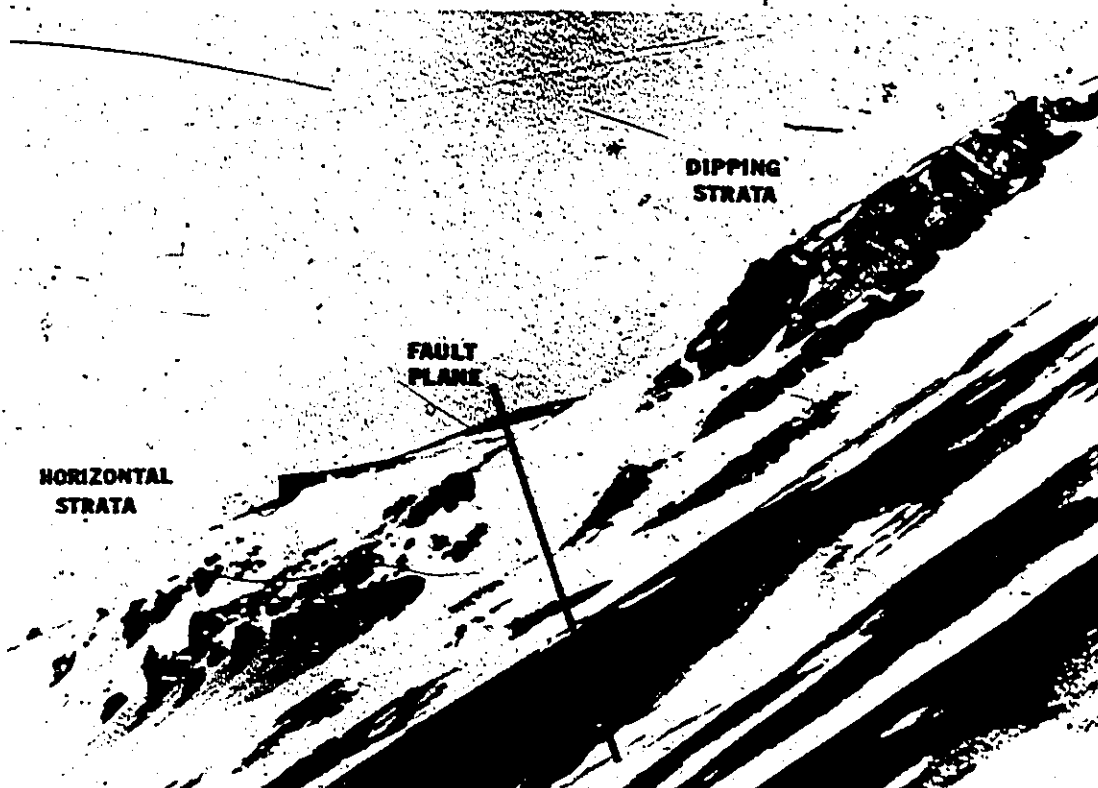


FIGURE 1

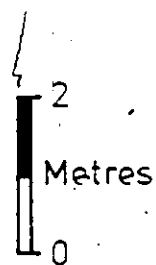


FIGURE 2

breccia associated with fault B-B contained Atrypella phoca (Salter).

The breccia occurs as vertical to sub-vertical sheets suggesting that the associated faults are vertical to sub-vertical (Pl. 25, fig. 2).

Rock types The rock types in these sections are generally the same as those previously described (chapter 2, p. 23).

Micritic limestone, dolomitic limestone, calcareous dolomite and dolomite predominate in section CA (Text-fig. 31). These rocks contain considerable quantities of shell debris (ostracods and bryozoans) with fragments generally less than 1 cm long. In unit CA16, as in many of the other units that contain large amounts of shell debris, many of the shell fragments have been enlarged by syntaxial overgrowths of calcite. In other units (e.g. unit CA16) the shell fragments have dark coloured rims which strongly resemble micritic envelopes. The rocks of section CA contain angular to subangular grains of quartz (up to 0.20 mm) and flakes of muscovite.

Section CD (Text-fig. 32) is predominantly rubbly argillaceous limestone and micritic limestone. Chalcedony spherulites up to 2 mm in size (longest axis) occur in unit CD2. They are rounded, but the centre of the extinction does not coincide with the centre of the spherulite.

Micritic limestone, dolomitic limestone, calcareous dolomite

ROCK TYPES

	MICRITIC LIMESTONE
	DOLOMITIC LIMESTONE
	CALCAREOUS DOLOMITE
	DOLOMITE
	SANDY DOLOMITE
	DOLOMITIC SANDSTONE
	SANDSTONE
	CALCAREOUS SANDSTONE
	SANDY LIMESTONE
	INTRACLASTIC SHELLY LIMESTONE
	CONGLOMERATE
	ARGILLACEOUS LIMESTONE
	ONCOPELLET LIMESTONE
	SANDY DOLOMITE-LIMESTONE
	CALCAREOUS SANDSTONE-DOLOMITE
	DOLOMITIC SANDSTONE-LIMESTONE
	GYPSUM & ANHYDRITE

SEDIMENTARY STRUCTURES

	RIPPLES		MEGARIPPLES
	DESICCATION CRACKS		
	BIRD'S EYE STRUCTURE		
	CHANNEL		
	STYLOLITE		
	EROSION SURFACE		
	TRACE FOSSILS		
	TRACE FOSSILS (?)		

BEDDING TYPE

UL	UNLAMINATED
L	LAMINATED
IL	INTERLAMINATED
TB	THIN BEDDED
MB	MEDIUM BEDDED
M	MOTTLED

IF UNIT IS INTERLAMINATED OR INTERBEDDED IT IS DENOTED BY COMBINATION OF ROCK TYPE SYMBOLS. THUS:

	IL OR IB DOLOMITE AND SANDY DOLOMITE

IN SITU FAUNA

•	DENOTES GENUS PRESENT
•	DENOTES DOMINANT ELEMENT IN UNIT IF MORE THAN ONE GENUS PRESENT
	SOLITARY CORALS (4) NUMBER IN BRACKETS INDICATES NUMBER OF INDETERMINATE GENERA INCLUDED IN 'GENERIC DIVERSITY'

Text-figure 31.

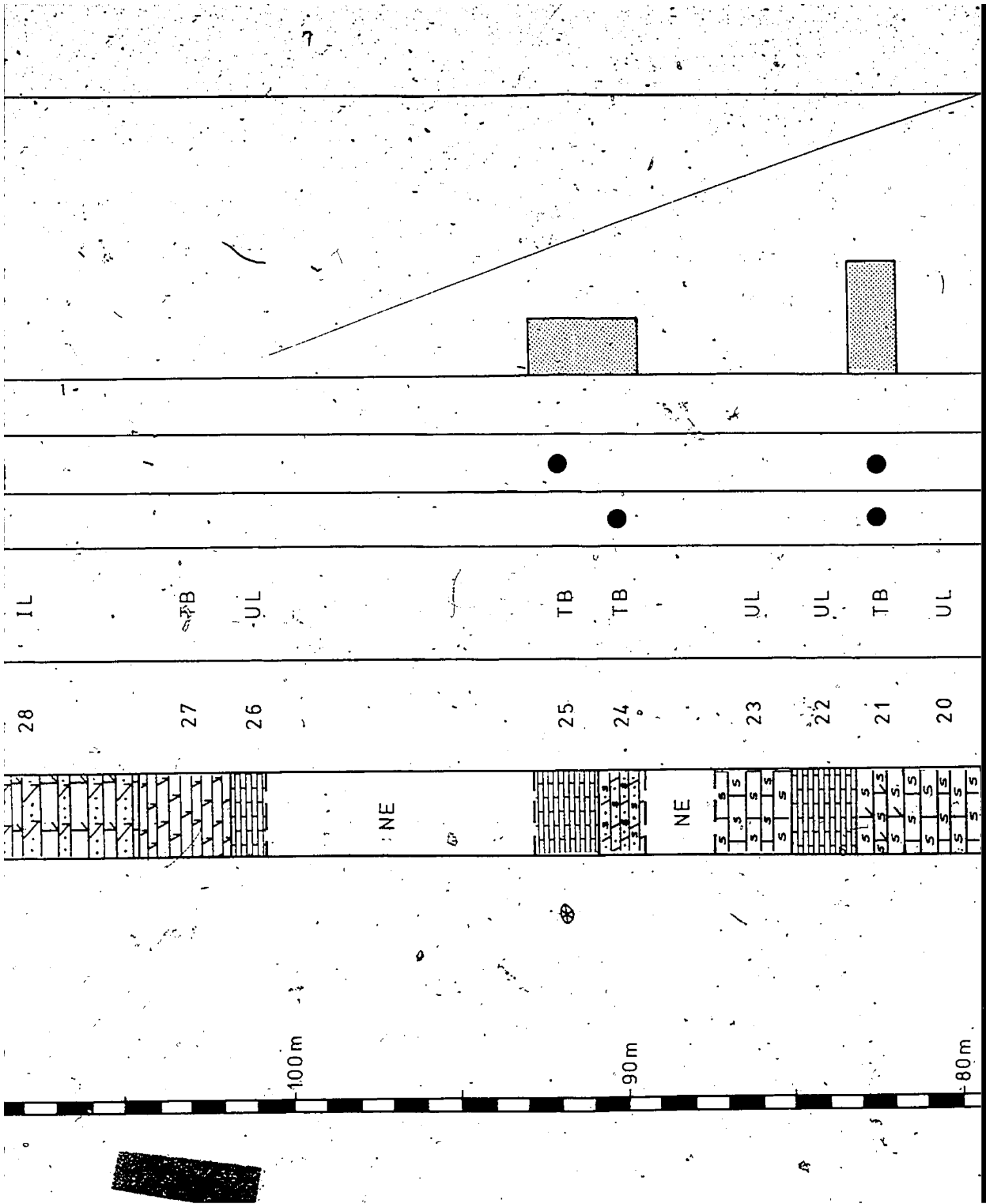
0.00010

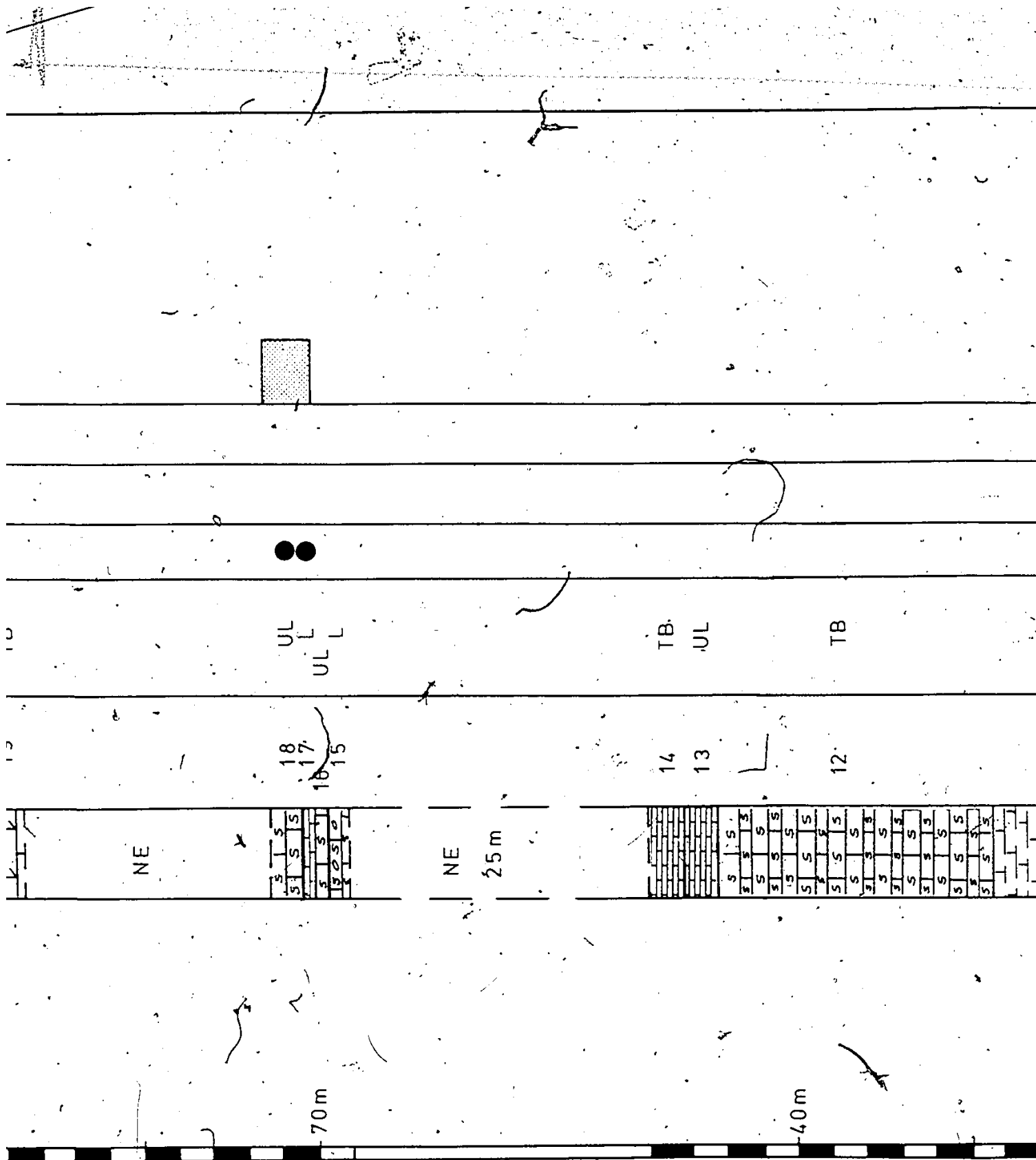
0.00010

0.00010

CUNNINGHAM INLET SECTION CA

Scale	SEDIMENTARY STRUCTURES	ROCK TYPE	UNIT	BEDDING TYPE	IN SITU FAUNA		GENERIC DIVERSITY
					Gastropod Indet.	Ostracod Indet.	
							Number of Genera 1 2 3 4
			32	TB			
			31				
			30	TB			
			29	TB			





TB

UL

TB

TB

UL

L

UL

UL

14

13

12

11

10

9

8

7

6

5

FAULT

BRECCIA

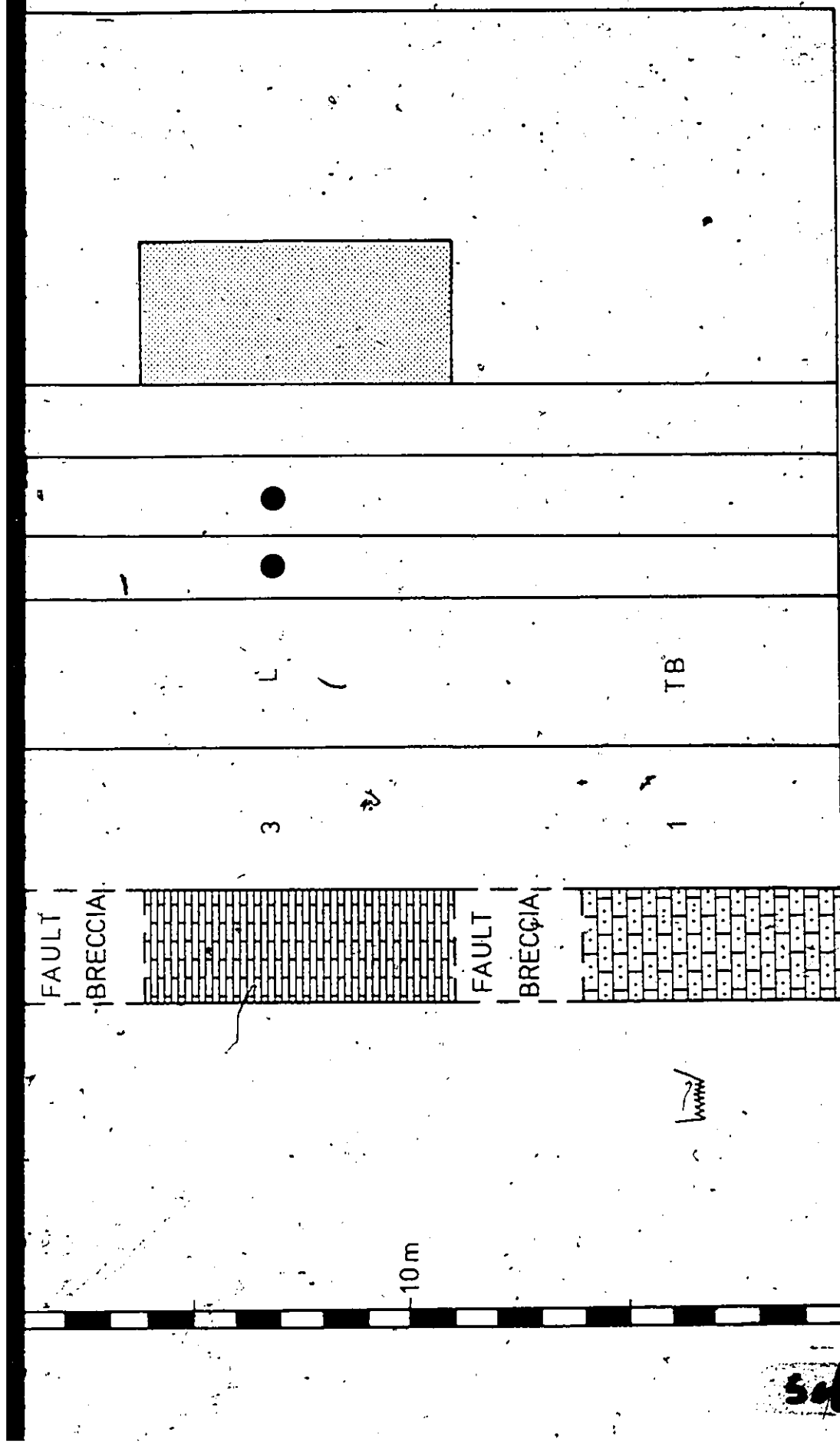
40m

30m

20m

E

4 OF

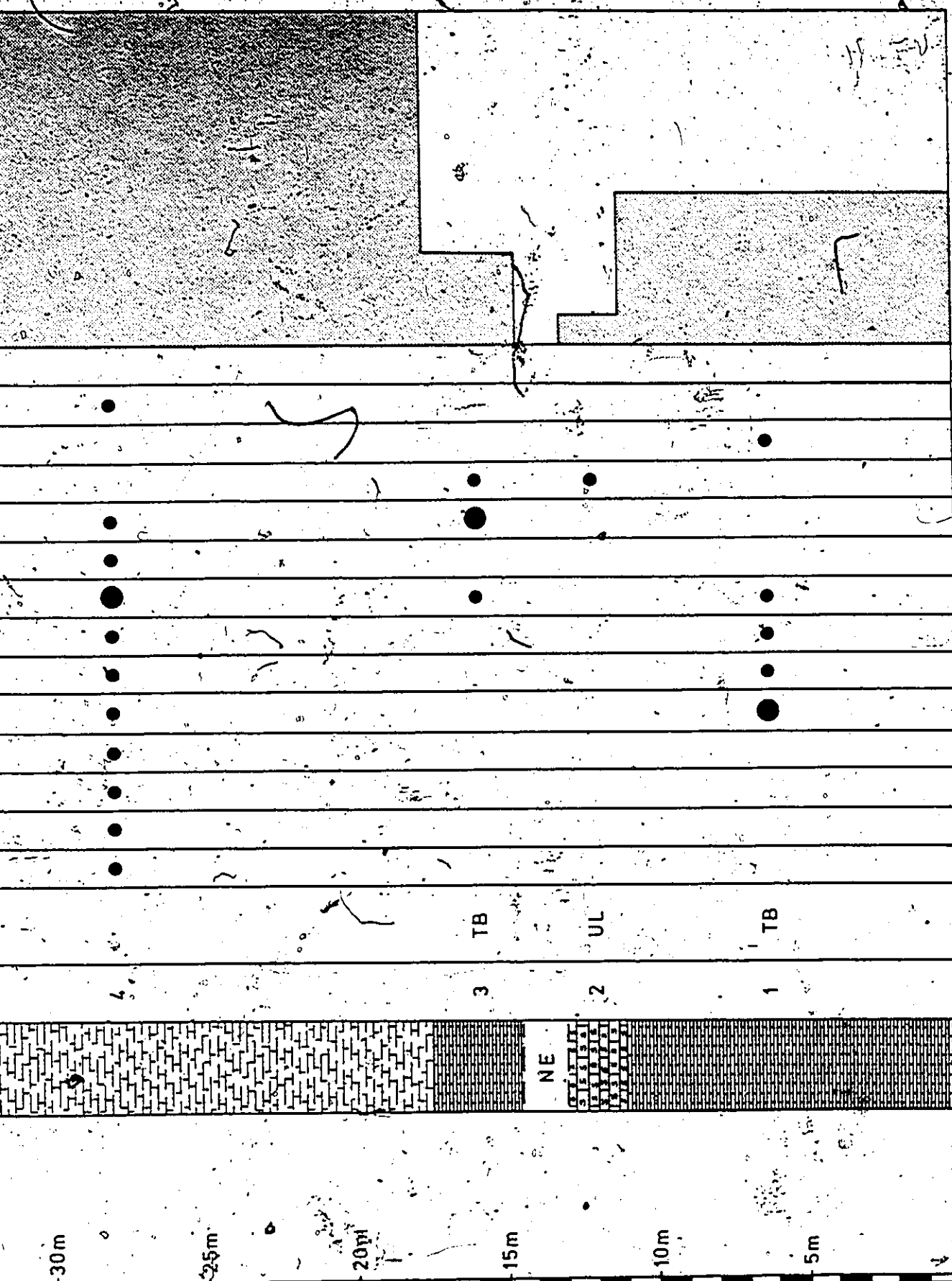


5063

CUNNINGHAM INLET SECTION CD

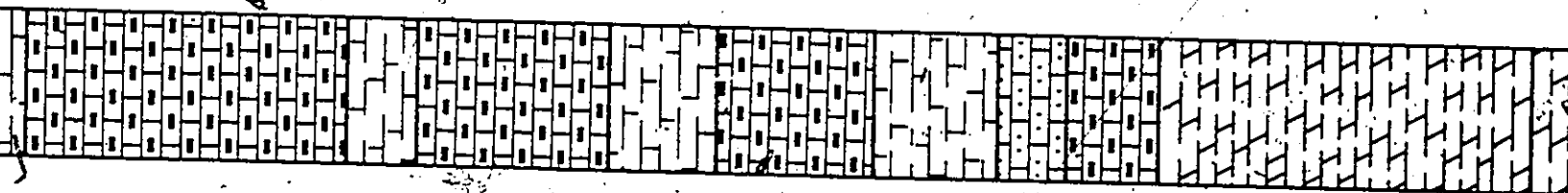
Scale	Sedimentary Structures	Rock Type	Unit	Bedding Type	In Situ Fauna											Generic Diversity				
					Coenites (?)	Arachnophyllum	Alveolites	Favosites	Syringopora	Heliolites	Solitary Coral	Stromatopora indet.	Favosites	Protolithys	Encrinurus	Number of Genera				
60m			6	TB												2	4	6	8	10
45m																				
40m			5																	
35m																				

Text-figure 32.



1 of

2



34

33

32

31

30

29

28

27

26

25

WL

TB

TB

L

TB

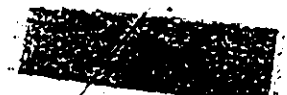
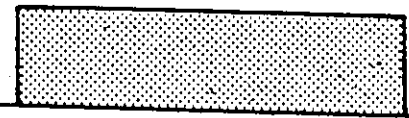
110 m

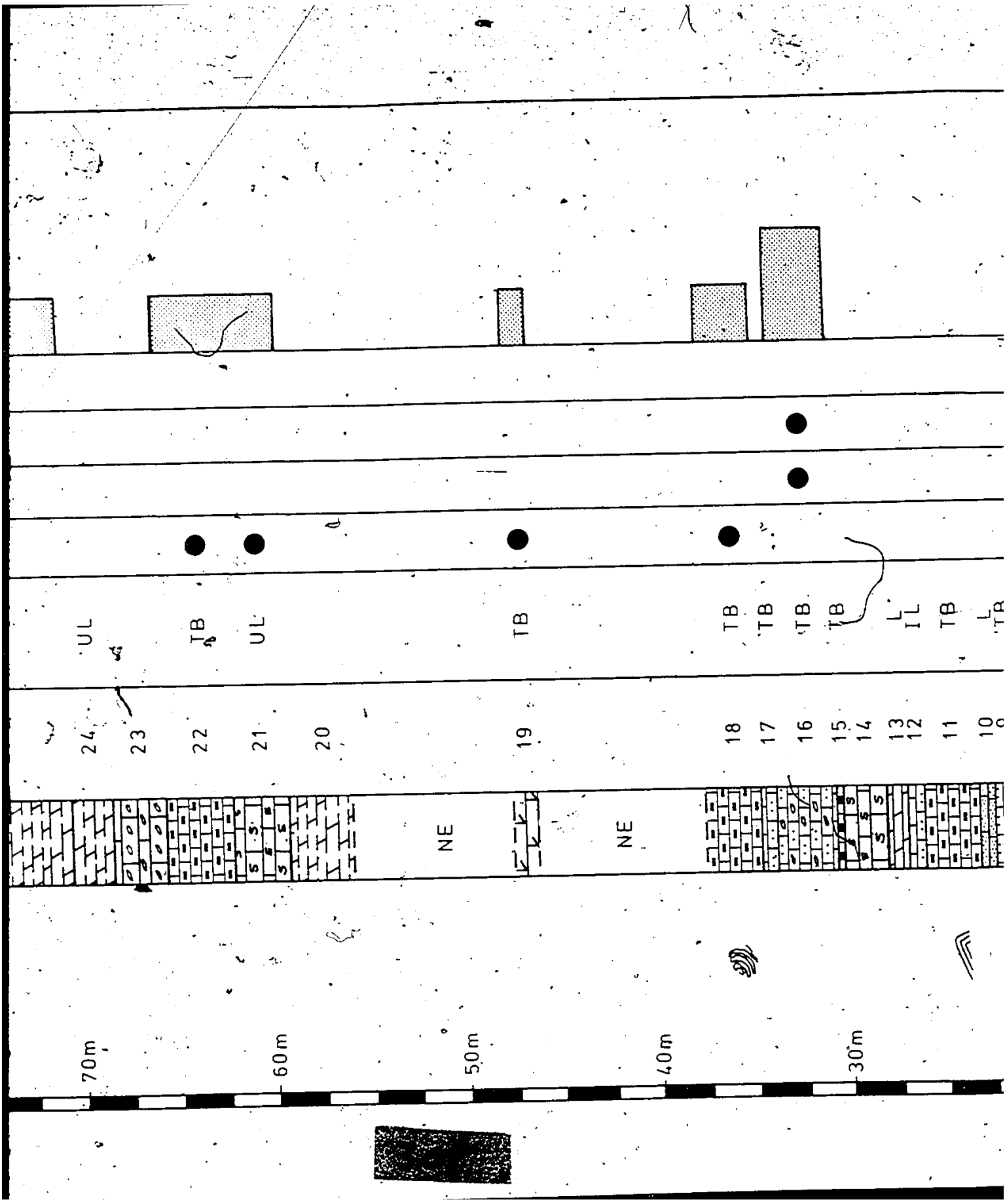
100 m

90 m

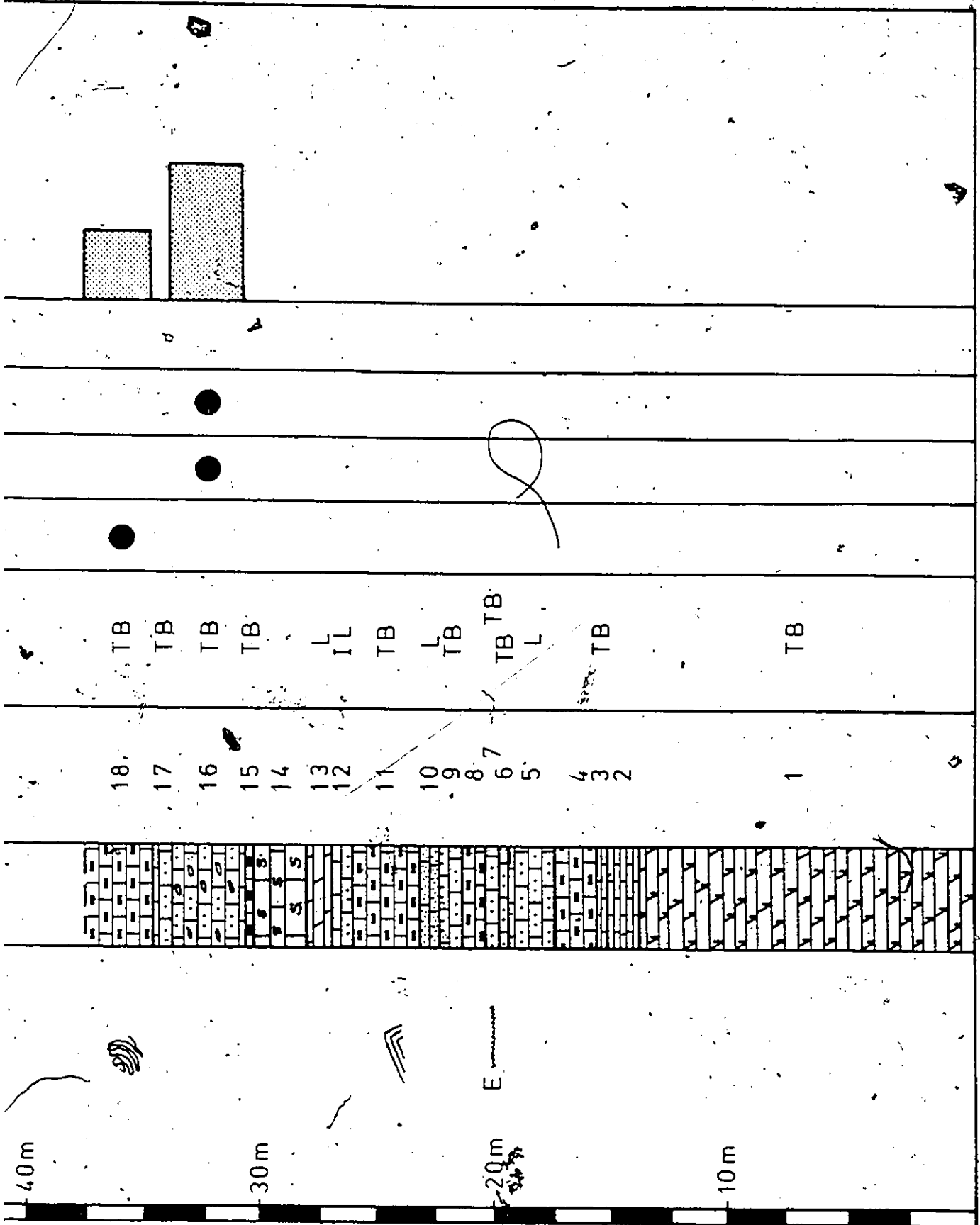
80 m

70 m

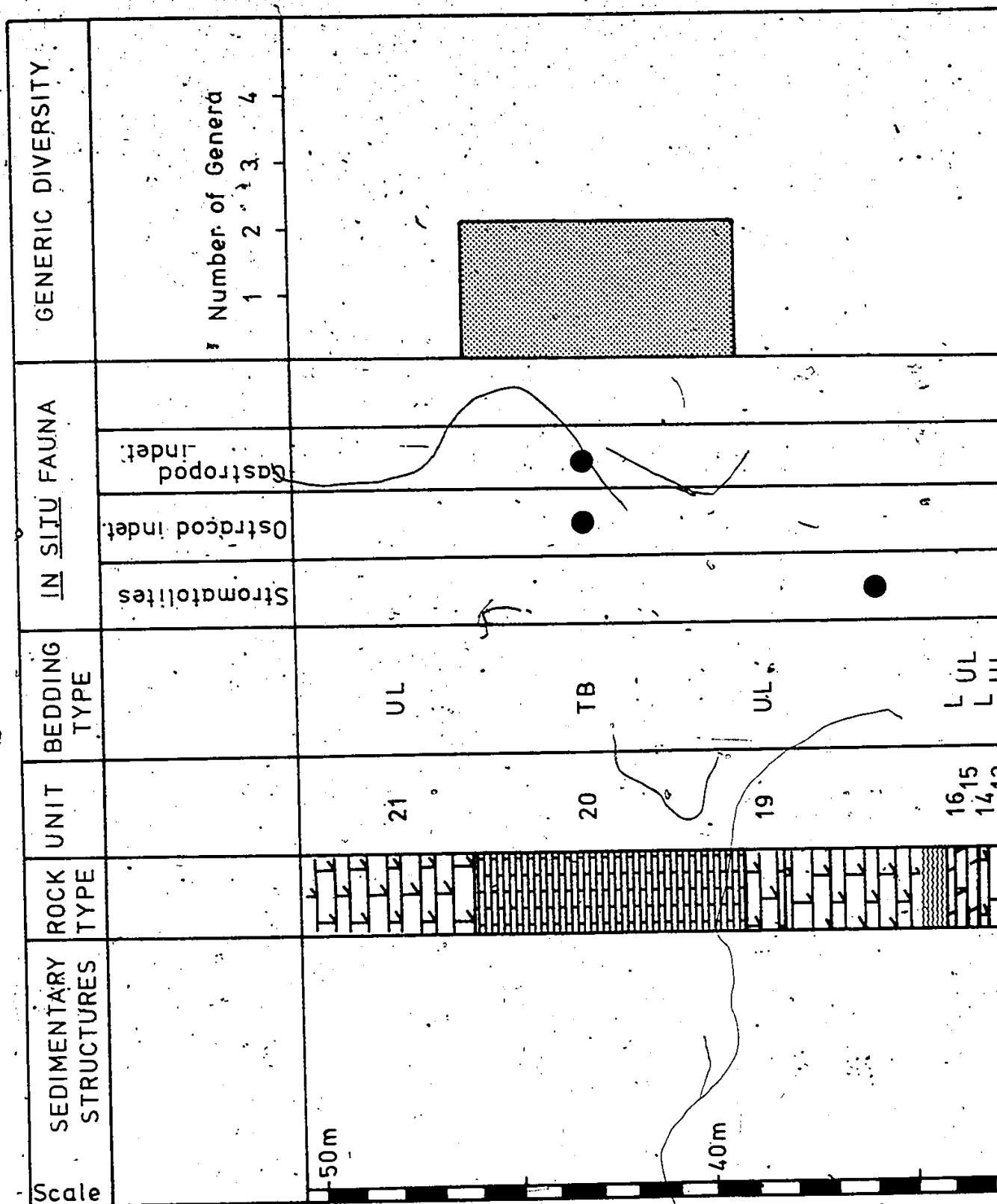


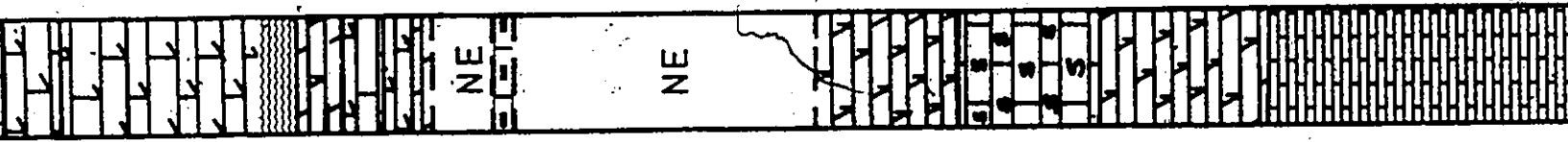


Text-figure 33.



CUNNINGHAM INLET SECTION CF

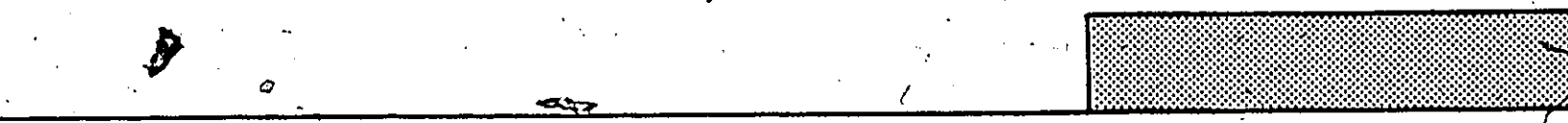
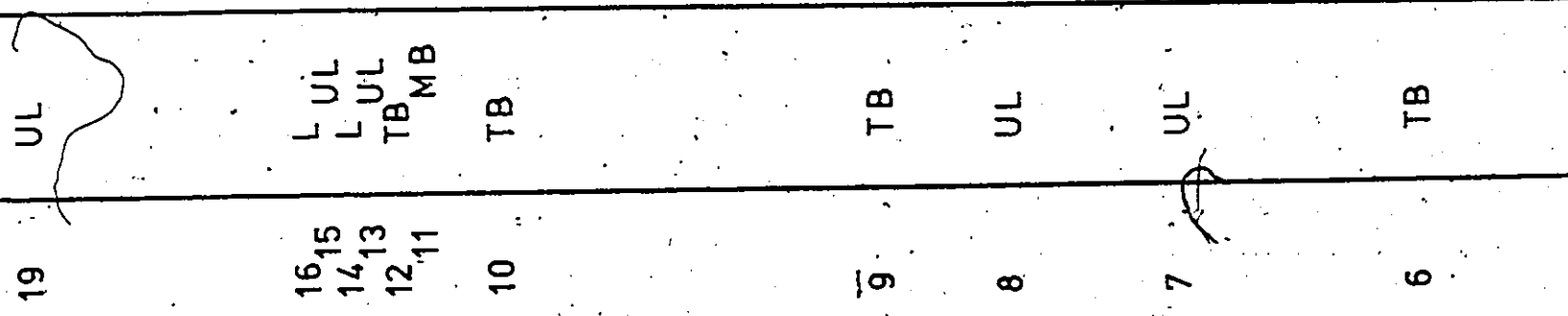




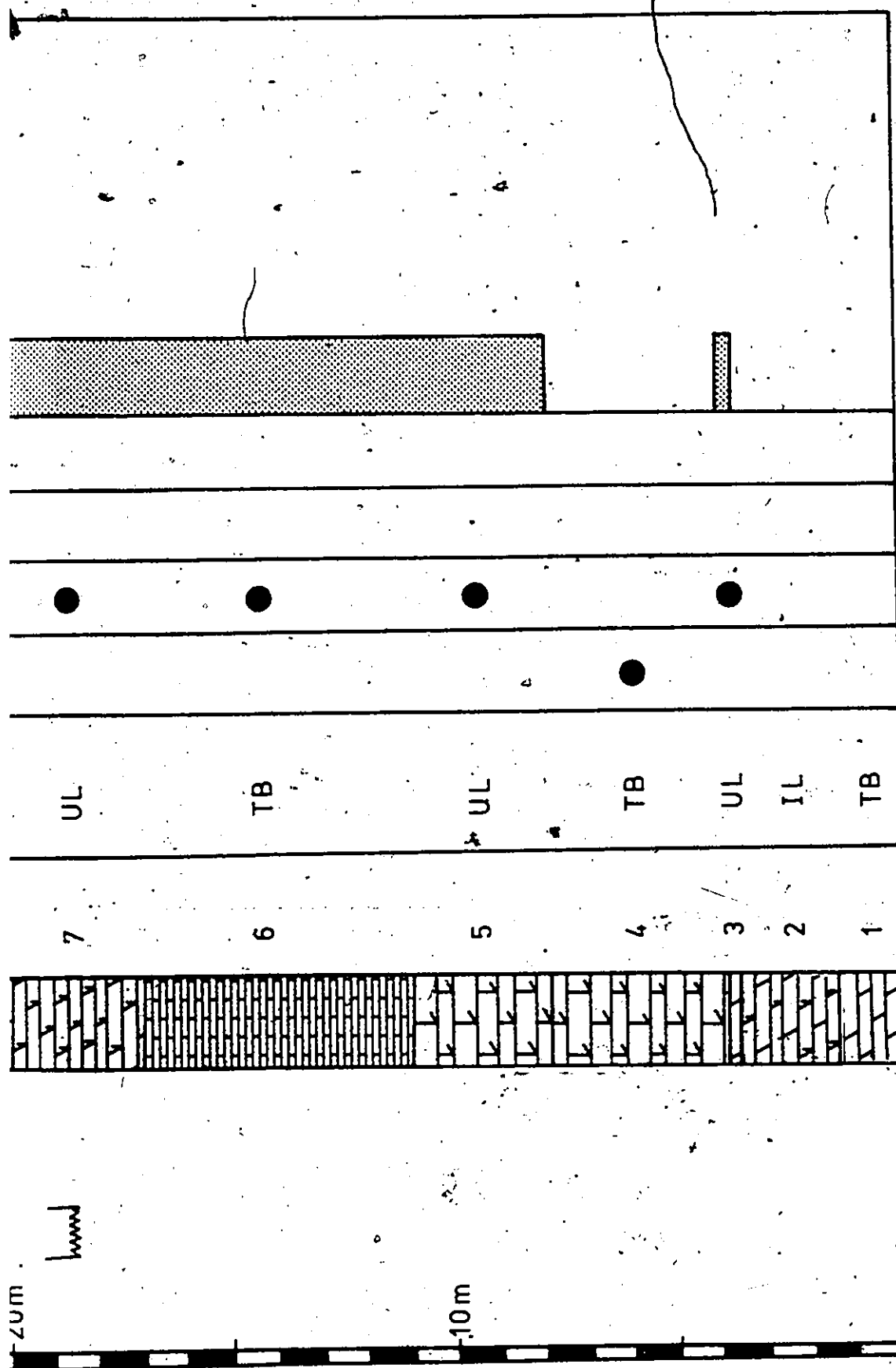
30m

20m

hand



Text-figure 34.



343

and dolomite are the principal rock types in the basal part of section CE (Text-fig. 33). They contain a relatively high content of detrital material (up to 60% as in unit CE10) consisting of quartz and plagioclase (angular to subangular with longest axis up to 0.20 mm) and some muscovite flakes. The plagioclase never constitutes more than 5% and the muscovite never more than 10% of the total rock. The middle part of the section (units CE15-CE26) is predominantly shelly limestone and micritic limestone which has little dolomitization. Some units (e.g., unit CE22) are rubbly limestone with a dolomitic matrix (Type V - see p. 46). The upper part of the section (units CE27-CE42) is predominantly micritic limestone and argillaceous limestone, which generally have a low content of sand-sized detrital material.

In sharp contrast with sections CA, CD and CE, most rocks in section CF are dolomitic (Text-fig. 34) and some contain detrital quartz (longest axis up to 0.20 mm) and minor amounts of muscovite. In unit CF8 the shelly limestone contains fragments of bryozoans, stromatoporoids and ostracods. The cavities in the Bryozoa are filled with one generation of calcite crystals.

Sedimentary structures Many units in section CA contain bird's eye structures and low-amplitude ripples (Text-fig. 31). In section CE, sedimentary structures such as asymmetrical ripples and erosional

Plate 26

Stromatoporoids

Field photographs of stromatoporoids in growth position in strata of the Cunningham Inlet area. Unit is equivalent to unit CD4. Section through Hexalonus (N) visible along with the brachiopod Kirkidium (?) (cf. Figure 2 shows close-up view of stromatoporoid in lower left hand corner of Figure 1. (Photographs courtesy of Dr. O. A. Dixon).

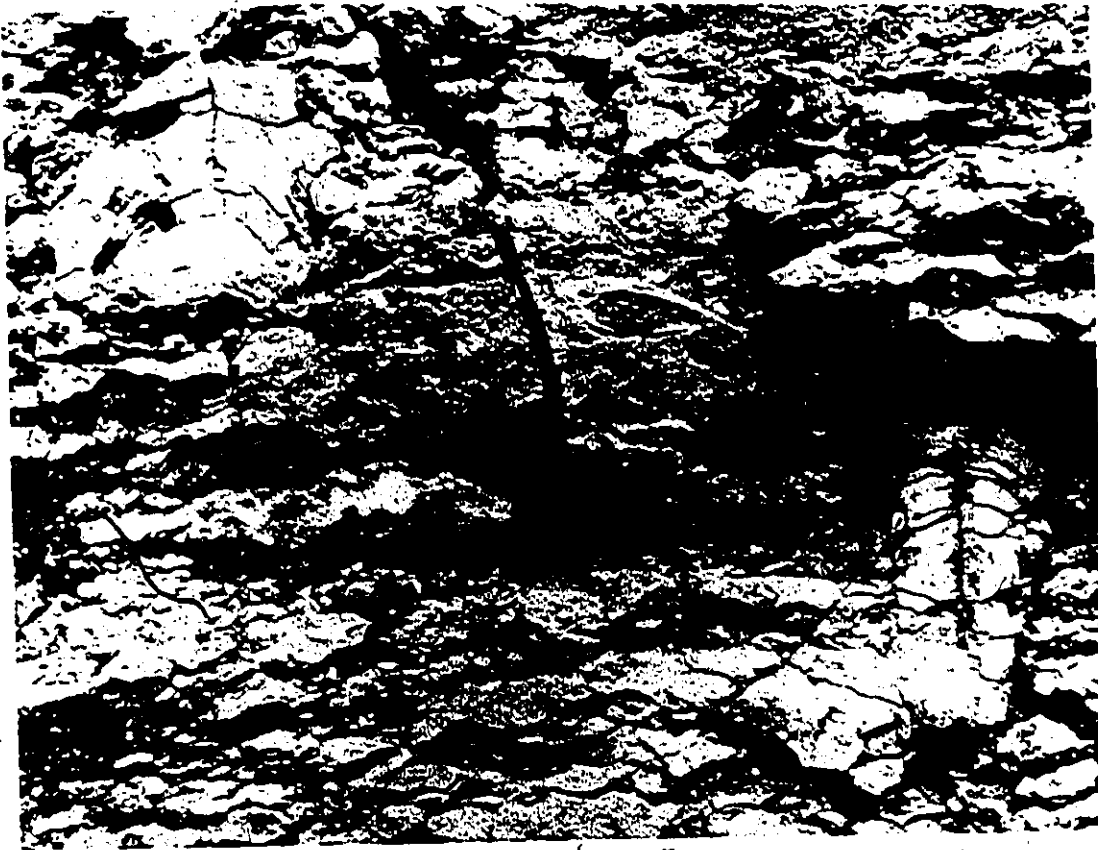
surfaces are confined to units CE1-CE14. The current ripples indicate that the prevailing water movement was towards the north. The muscovite flakes above the erosion surface in unit CE7 have long axes aligned parallel to the erosional surface.

Although few sedimentary structures were found in place in section CF, some specimens indicate that channels, desiccation cracks and ripples are common.

Faunal distribution Section CA contains a restricted in situ fauna. Apart from shell debris the fauna consists only of ostracods and gastropods, which are locally very common, as in units CA7 and CA8. (Text-fig. 31).

Section CD has a profuse fauna of stromatoporoids, corals, brachiopods, ostracods and crinoids. Specimens of Kirkidiur are extremely abundant in unit CD1 and apparently very close to their life position as many of them occur with their pedicle valve down. Unit CD6 contains a profuse fauna of stromatoporoids and colonial corals, many of which are still in life positions (Pl. 26, figs. 1 and 2). The corals and stromatoporoids in these units are relatively high forms which generally have small basal diameters (less than 10 cm) contrasting sharply with the 'pancake' forms which are typical in the Carnier Bay sections. The specimens of Atrypella in these units are small, immature forms.

FIGURE 1



0 Cms 4

FIGURE 2

2
Cms
0



Numerous specimens of ostracoderms were found on scree slabs from an 8 m thick covered interval between units CD4 and CD6.

The distribution of the slabs in the scree suggests that they originated in a layer approximately 2 m below the top of the covered interval.

Anglaspis sp., Pionaspis sp. and Corvaspis (?) sp. occur in this unit along with a few unidentified forms.

The lower and upper parts of section CE apparently are devoid of in situ fauna but fossils are present in the middle part of the section (units CE15-CE26). Unit CE16 contains ostracods and gastropods while other units typically contain small specimens of Atrypella sp. (Text-fig. 33). A few corals in the scree apparently originated in the covered interval between units CE18 and CE19.

Section CF is characterized by a very limited biota (Text-fig. 34) of gastropods, ostracods and stromatolites. The stromatolites are generally small domal forms. In unit CF4 they have circular to elliptical outlines (diameters of about 5 cms) and low amplitudes (less than 3 cms) while in unit CF17 the stromatolites are up to 10 cms high and have diameters of about 33 cms. Small fragments and local complete head shields of ostracoderms are present in unit CF21.

Pressure Point area

Location of sections and structural setting The section at Pressure Point was measured in two parts. Sections X and Y were measured in the tributary valleys of the main gorge as the latter was inaccessible because of ice conditions. The basal unit of section Y immediately overlies the top unit of section X. Section V is a sequence from the 'transitional beds' (Lower Peel Sound Formation of Miall, 1970a) between the Read Bay and Peel Sound Formations.

The Pressure Point area is situated on the western limb of the Cape Anne Syncline where the strata dip $20-25^{\circ}$ northeast.

Rock types Sections X and Y contain a large proportion of mottled dolomite-limestone (Text-figs. 35 and 36) which exhibit various degrees of dolomitization (Text-figs. 35 and 36). The degree of weathering, which is a reflection of the degree of dolomitization in the mottled dolomite-limestone, and the faunal distribution were used to delineate many of the units shown in Text-figures 35 and 36. The basal part of the section has a relatively high content of argillaceous material compared to the rest of the section.

Large quantities (20-25%) of detrital quartz and muscovite are present only in units X21 and Y13. The quartz grains are angular to subangular and up to 0.12 mm in size (longest axis).

Text-figures 15 and 361 Lithology, sedimentary structures and faunal elements of sections X and Y of the Pressure Point area.

ROCK TYPES

	MICRITIC LIMESTONE		DOLOMITIC LIMESTONE		CALCAREOUS DOLOMITE		DOLOMITE		SANDY DOLOMITE		DOLOMITIC SANDSTONE		SANDSTONE		CALCAREOUS SANDSTONE		SANDY LIMESTONE		INTRACLASTIC SHELL LIMESTONE		CONDOLMITE		ARGILLACEOUS LIMESTONE		ONCOPELLET LIMESTONE		SANDY DOLOMITE-LIMESTONE		CALCAREOUS SANDSTONE-DOLOMITE		DOLOMITIC SANDSTONE-LIMESTONE		GYPSUM & ANHYDRITE

SEDIMENTARY STRUCTURES

	STROMATOLITE		RIPPLES		MEGARIPPLES
	SHELLY LIMESTONE		DESICCATION CRACKS		BIRD'S EYE STRUCTURE
	REEF LIMESTONE		CHANNEL		STYLOLITE
	RUBBY ARGILLACEOUS LIMESTONE		EROSION SURFACE		TRACE FOSSILS
	MOTTLED DOLOMITE-LIMESTONE		NO EXPOSURE		TRACE FOSSILS (?)
	POOR EXPOSURE				

IN SITU FAUNA

	SOLITARY CORALS (1)		NUMBER IN BRACKETS
	INDICATES NUMBER OF INDETERMINATE GENERA INCLUDED IN GENERIC DIVERSITY		ONE GENUS PRESENT
	DENOTES GENUS PRESENT		DENOTES DOMINANT ELEMENT IN UNIT IF MORE THAN ONE GENUS PRESENT

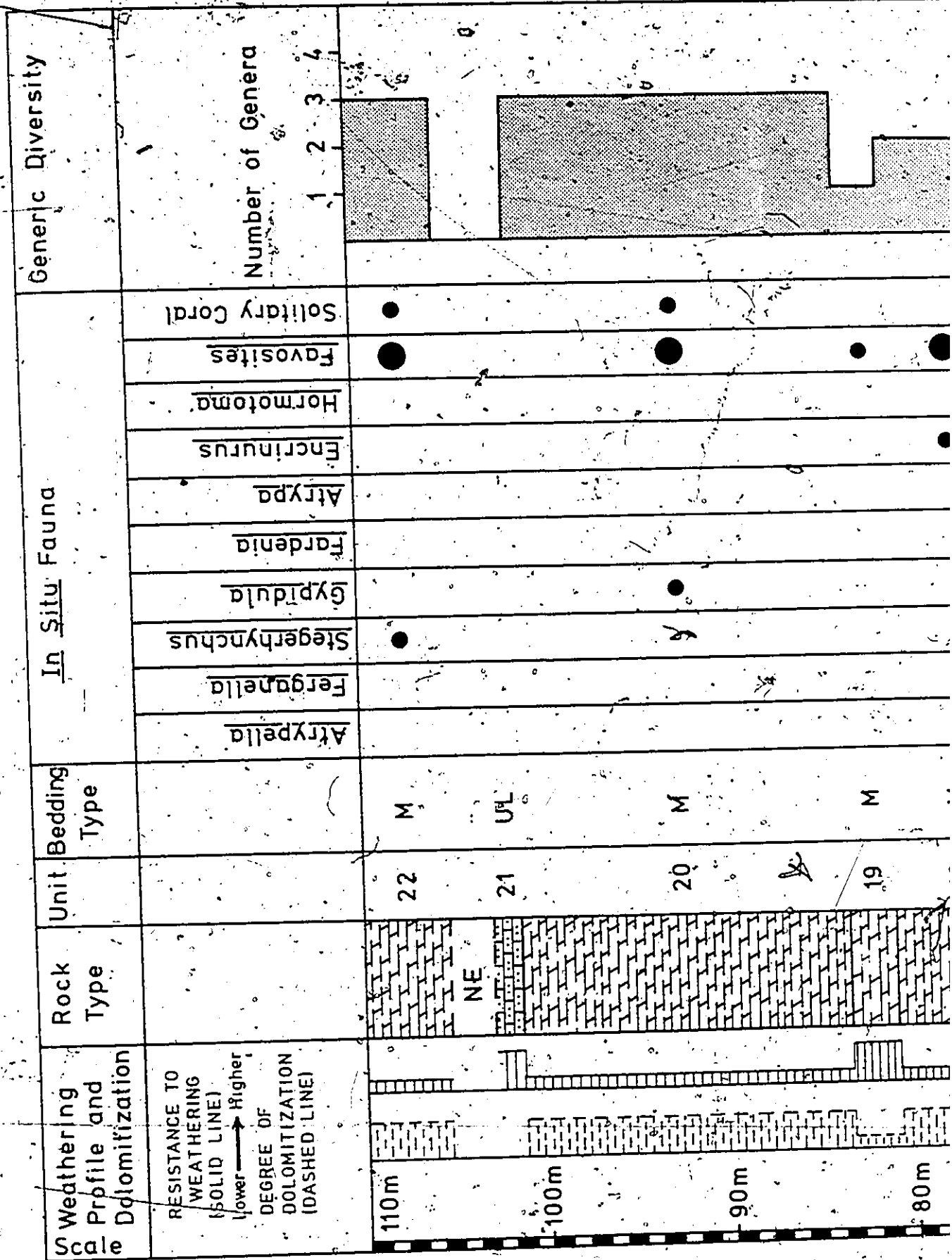
BEDDING TYPE

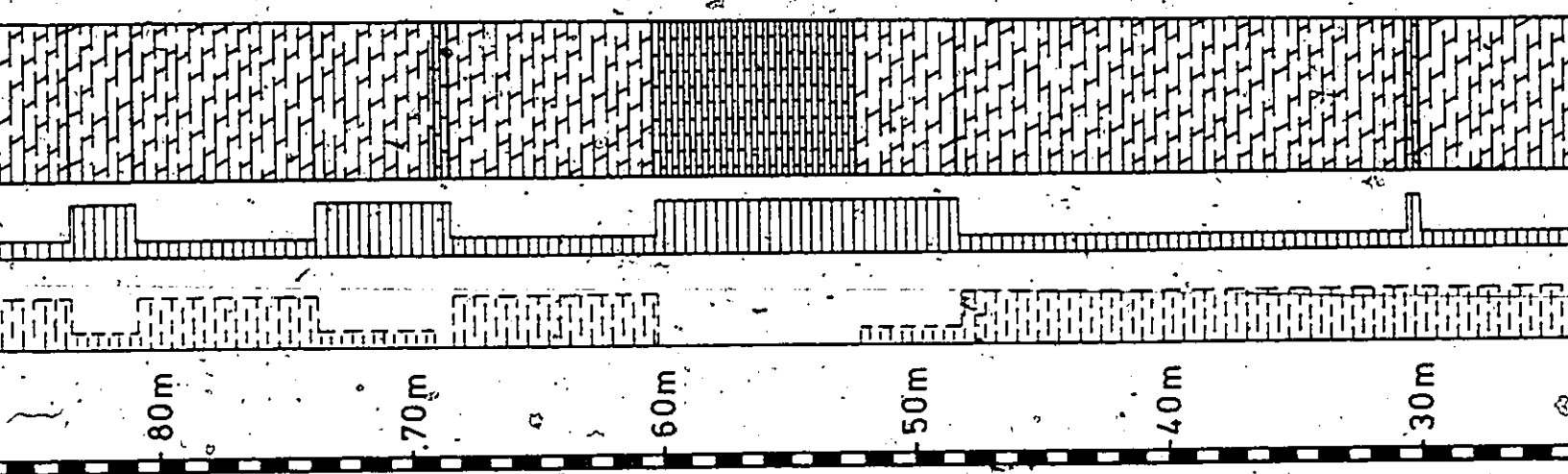
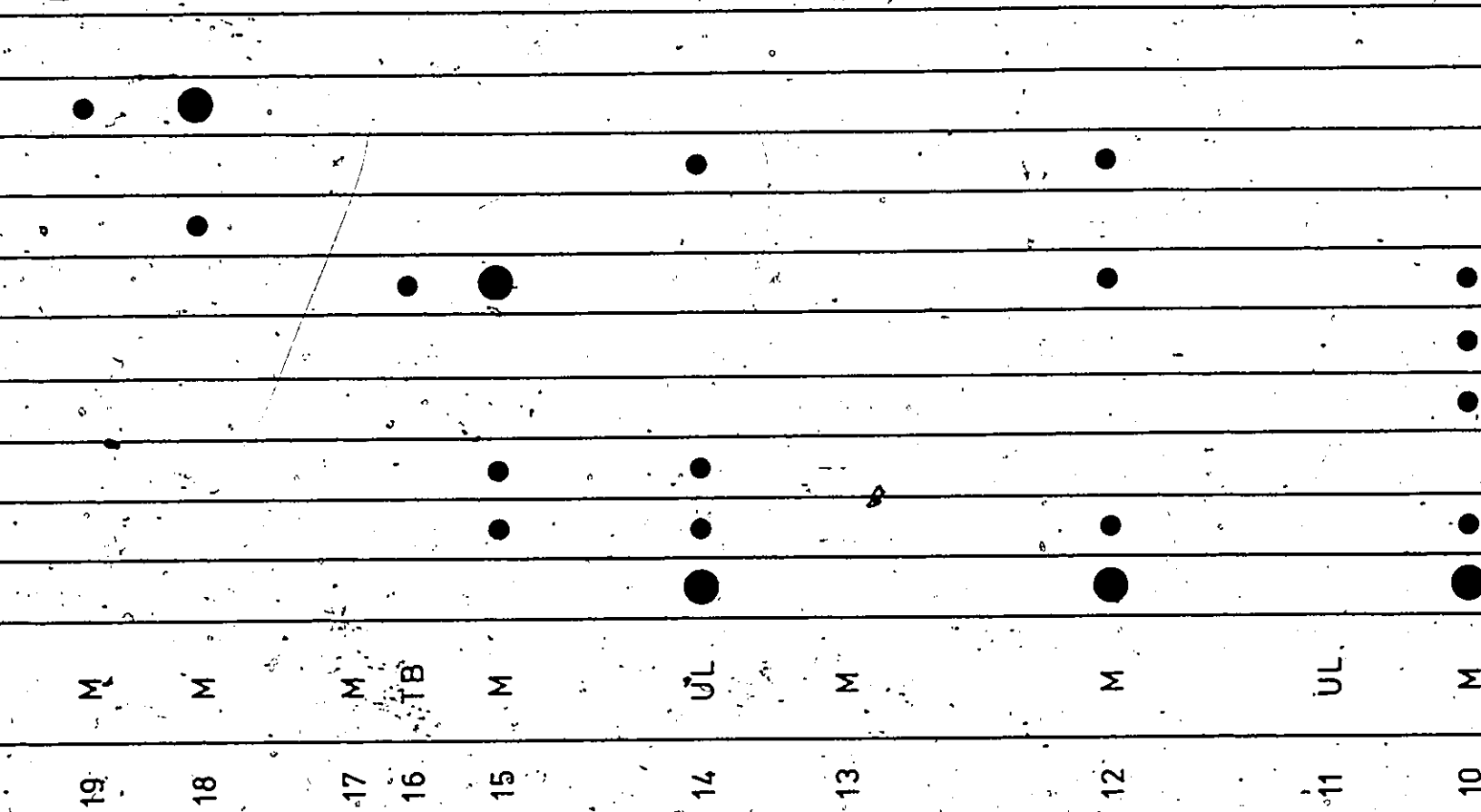
	UNLAMINATED		INTERBEDDED
	LAMINATED		THIN BEDDED
	MEDIUM BEDDED		MOTTLED
	INTERBEDDED		INTERBEDDED
	INTERBEDDED		INTERBEDDED
	INTERBEDDED		INTERBEDDED
	INTERBEDDED		INTERBEDDED
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	INTERBEDDED		INTERBEDDED
	INTERBEDDED		INTERBEDDED

IF UNIT IS INTERBEDDED OR INTERBEDDED IT IS DENOTED BY COMBINATION OF ROCK TYPE SYMBOLS. THUS:

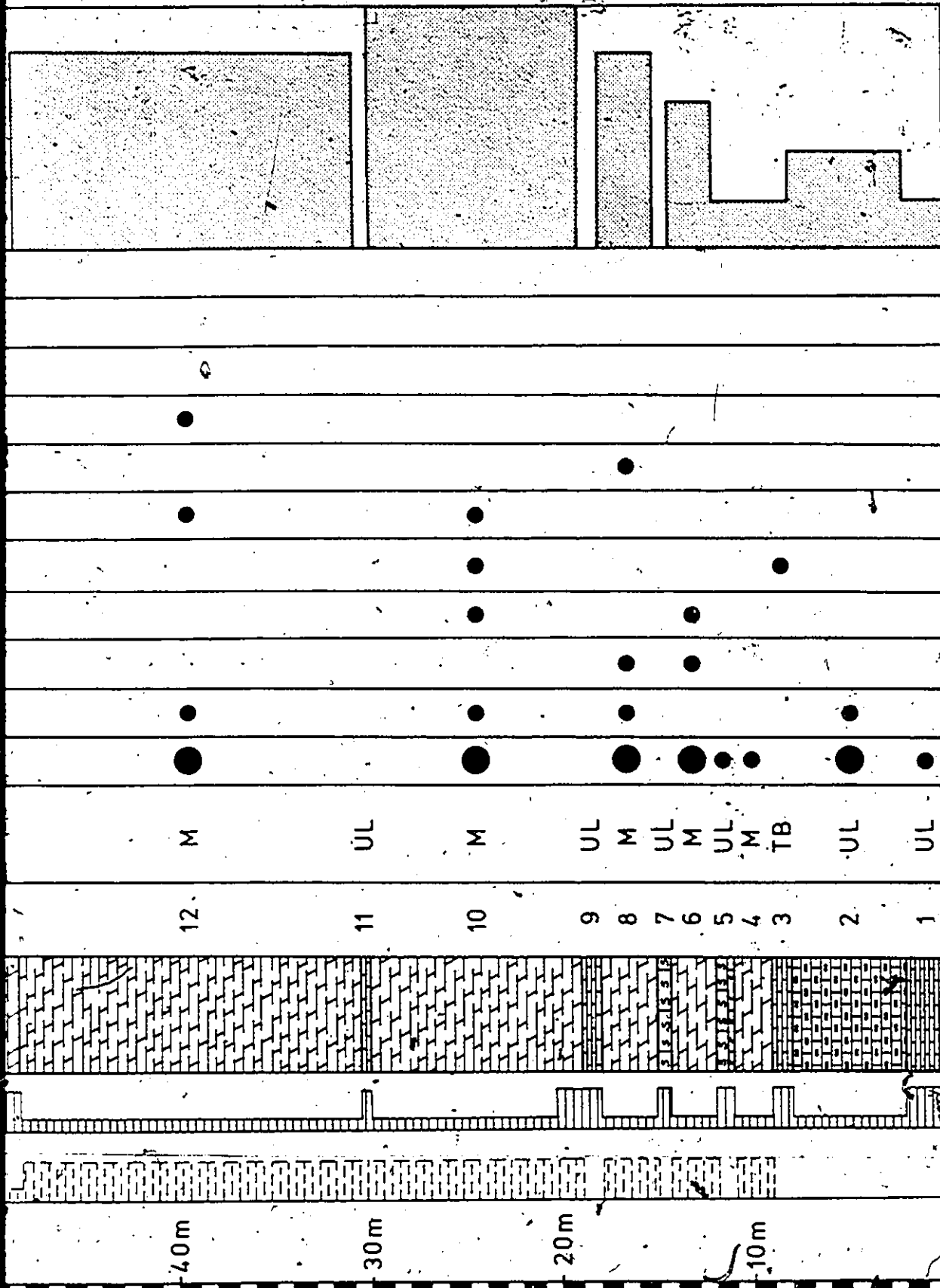
	IL OR IB DOLOMITE AND SANDY DOLOMITE

PRESSURE POINT SECTION X





Text-figure 35.

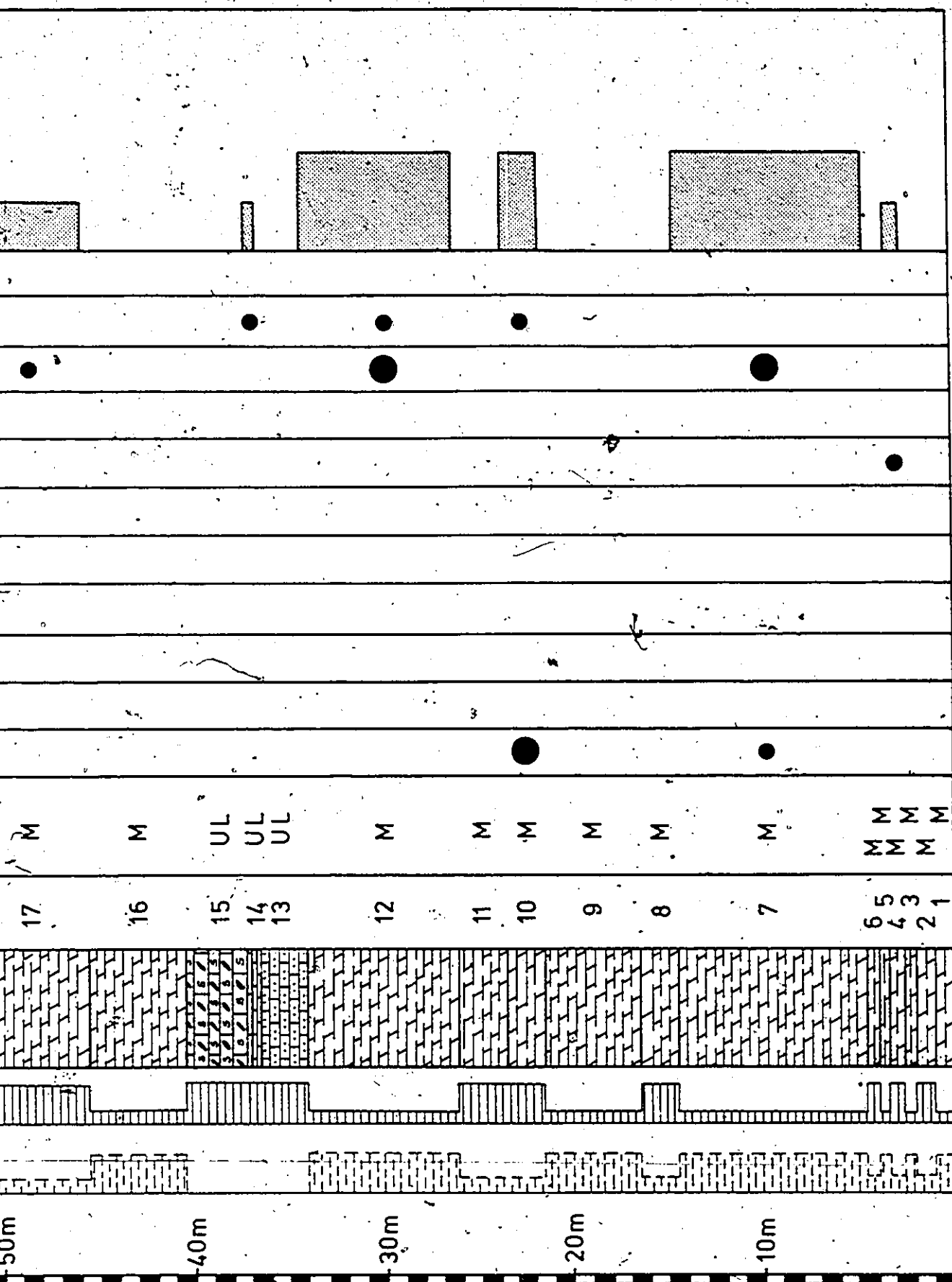


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PRESSURE POINT SECTION Y

Weathering Profile and Dolomitization	Rock Type	Unit	Bedding Type	In Situ Fauna										Generic Diversity																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							
				Atrypella	Ferganella	Stegorhynchus	Gypidula	Fardenia	Atrypa	Encrinurus	Hormotoma	Favosites	Solitary Coral																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
RESISTANCE TO WEATHERING (SOLID LINE) Lower → Higher DEGREE OF DOLOMITIZATION (DASHED LINE)	PEEL SOUND FORMATION	19	M																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		

Text-figure 36.



Crinoidal limestones are present in the lower part of the section (Text-fig. 35).

Faunal distribution The fauna of this succession is dominated by brachiopods and corals (Text-figs. 35 and 36). The fauna of the basal units of section X (units X1-X16) is dominated by brachiopods while the upper part of the section (units X17-X22 and section Y) is dominated by corals (Favosites and solitary corals). The Favosites have a 'pancake' form (up to 30 cms. diameter and up to 10 cms high) similar to the colonial corals of units GD11 and GA45 of the Garnier Bay area (p. 111).

The specimens of Atrypella in units X14 and Y18 are of the 'large' variety (see p. 326) while the specimens of Atrypella in the argillaceous limestone of unit X2 are the 'small' variety (see p. 326).

CHAPTER 4

MARKOV CHAIN ANALYSIS OF MEASURED STRATIGRAPHIC SECTIONS

Introduction

A Markov process is one "...in which the probability of the process being in a given state at a particular time may be deduced from knowledge of the immediately preceding state" (Harbaugh and Bonham-Carter, 1970, p. 98). The prime example of Markovian successions are the Carboniferous coal cyclothems of the British Isles (Doveton, 1971). Gingerich (1969) also successfully applied Markov Chain analysis to deciphering cycles within the Polecat Formation (U. Cret.) of Wyoming. Miall (1973) further demonstrated the usefulness of this type of analysis in his investigation of the Devonian continental succession of Prince of Wales Island in the Canadian Arctic.

In some instances the cyclic nature of a succession can be recognized without using Markov Chain analysis. For example, the coal measure cyclothems were known long before Doveton (1971) statistically analyzed them. However, as Miall (1973) demonstrated, Markov Chain analysis can reveal cycles not previously recognized by visual examination.

Markov Chain analysis in its simplest form can be done in one of two ways. The first order Markov Chain ('embedded Markov Chain' of Krumbein and Dacey, 1969) investigates the relationship between any given bed and the bed immediately succeeding it. In this case a transition is counted only where the lithology changes (e.g. a limestone on a limestone is not counted as a transition). An alternative method of investigation is to record the bed type at fixed intervals throughout the section. In this method a transition from a limestone to a limestone is possible.

The philosophy behind the two methods is essentially different (Miall, 1973). The 'embedded Markov Chain' emphasizes the changes that occur and does not take into account the frequency of occurrence of any particular rock type. Conversely, the second method, by virtue of its fixed interval of sampling gives a more accurate measure of the proportions of each lithology, but poses a problem in choice of sampling interval. Too large a sampling interval may lead to certain units being omitted from the analysis. Too small a sampling interval will produce numerous transitions of the limestone to limestone type which will tend to mask any Markovian tendencies that may be present. Miall (1973) recommended that the sample interval should be slightly less than the average bed thickness.

Once a cycle has been established it is necessary to interpret it in the context of geological processes. If this is possible then a more accurate knowledge of the evolution of the geological setting of an area can be studied.

As Potter and Blakely (1968) pointed out, there is a continuous spectrum between a 'regular' distribution (Text-fig. 37a) and a 'crazy quilt' distribution of facies (Text-fig. 37b). If a transgression occurred in the direction indicated in the diagrams, then according to Walther's principle the succession would be as shown in Text-figures 37a and 37b. In Text-figure 37a the succession is regular and a cyclic process would be readily detectable. Conversely, in Text-figure 37b the succession is irregular and apparently non-cyclic. The difficulties in such a situation are enhanced if a second section on Text-figure 37b is constructed since this makes it even more difficult to detect Markovian processes.

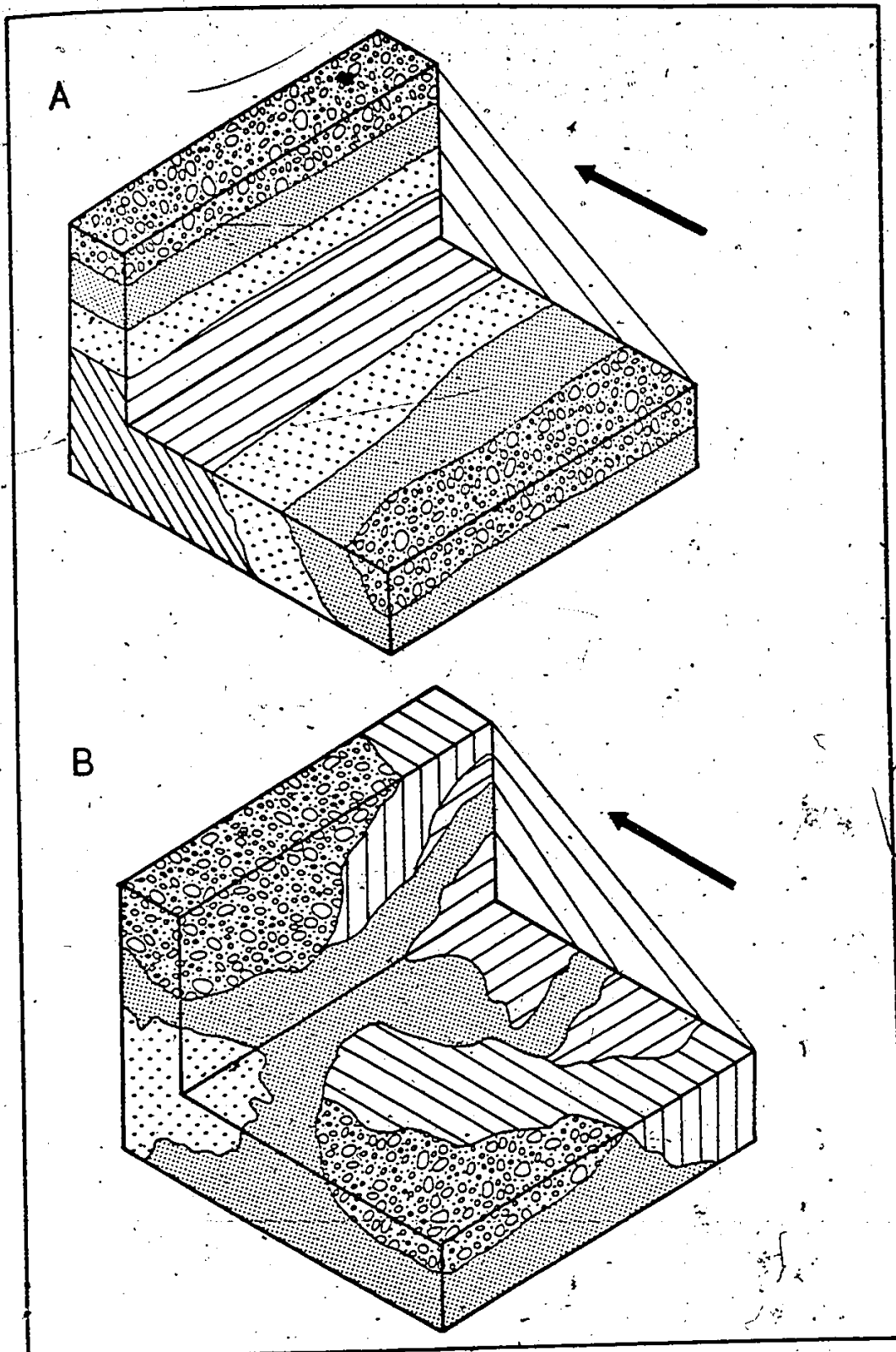
Further consideration of the first case (i.e. regular distribution of facies) is useful for it demonstrates another possible use of Markov Chain analysis. As Miall (1973) pointed out, certain states within a sequence may have resulted from the occurrence of random processes which bear no relationship to the preceding state.

If this is the case then another process must be invoked to account for the presence of that unit. Good examples of random states in

Text-figure 37

'Regular' and 'crazy quilt' facies distribution (A and B respectively)
and the different successions that could result from transgression.

Direction of transgression shown by arrows.



geological terms are hurricanes, flash-floods and landslides, all of which are usually non-cyclic but capable of producing abrupt changes in the geological record of an area.

If a stratigraphic section is tested against the theoretical Markovian cycle then it may be possible to demonstrate breaks or omissions from the ideal cycle. For example, the theoretical cycle might be A-B-C-D whereas the actual succession may go directly from A to D. The implication in such a case is that states B and C were either bypassed or were removed prior to the deposition of D.

Method of analysis

The analysis is done in the following stages:

(1) Transition Count Matrix This matrix represents the raw data that is derived from the original stratigraphic section. A matrix is set up in which the number of transitions from rock type 1 to rock type 2 in the stratigraphic section are recorded. The lowest bed in the succession is represented by the row while the succeeding bed in the succession is represented by the column. Following the connotation of Miall (1973) each element of this matrix is referred to by the symbol f_{ij} (i = row, j = column).

(2) Probability Matrices From the transition count matrix two probability matrices are derived. The independent trials probability

matrix (r_{ij}) represents the probability of a given transition occurring randomly while the transition probability matrix (p_{ij}) gives the actual probabilities of a given transition occurring in a given section.

The values r_{ij} and p_{ij} are derived by the following formulae:

(a) For fixed sampling interval:

$$r_{ij} = s_j / t$$

where

$$t = \sum_{ij}^n f_{ij} \quad (\text{total number of beds})$$

n = rank of matrix (number of columns)

s_j = sum of f_{ij} for j th. column of f matrix.

(b) For the bed to bed method:

$$r_{ij} = s_j / (t - s_i)$$

(c) For both methods

$$p_{ij} = f_{ij} / s_i$$

(3) Difference Matrix The values in the p matrix may reflect any cyclicity that may be present in the stratigraphic section under consideration. The construction of a difference matrix (d_{ij}) is useful since it helps to 'highlight' the cyclic transitions. d_{ij}

is obtained from the following formulae:

$$d_{ij} = p_{ij} - r_{ij}$$

(4) Tests of significance. Although positive values in the d matrix indicate transitions which have occurred with a greater than random frequency, these values themselves may be due to random chance.

Consequently, a Chi-squared test is used to test their significance.

Two formulae can be used for the embedded Markov Chain analysis:

(a) After Billingsley (1961, p. 17) and Gingerich (1969, p. 331):

$$\chi^2 = \sum_{ij}^n (f_{ij} - s_i r_{ij})^2 / s_i r_{ij}$$

Degrees of freedom = $n^2 - 2n$

(b) After Anderson and Goodman (1957) and Harbaugh and Bonhas-Carter (1970, p. 121):

$$\chi^2 = 2 \sum_{ij} f_{ij} \cdot \log_e (p_{ij} / (s_j / f_{ij}))$$

For embedded Markov Chain analysis:

Degrees of freedom = $(n-1)^2 - n$

For type 2 analysis:

Degrees of freedom = $(n-1)^2$

For both equations the Null Hypothesis is that the vertical succession of strata was derived by random variation of the depositional mechanisms.

The application of the two different formulae for obtaining the Chi-squared value results in two different values which may indicate two different results. Thus, the problem arises as to which

formula should be used. With reference to the formula derived by Billingsley (1961, p. 17) and Gingerich (1969, p. 331), Miall (1973) stated, "F. P. Agterberg (1972, pers. comm.) recommends using the equation only where each value of f_{ij} exceeds 5."

Since most of the sections examined in this study are relatively thin and at the same time embody a large number of rock types, the chances of having each value of f_{ij} exceeding 5 is very remote. Consequently, while Chi-squared values derived from both tests are given, more emphasis is placed on the value obtained from the formula derived by Anderson and Goodman (1957).

For the sections studied in this thesis, analysis was done by the computer program 'Embedded Markov Chain Analysis' which was adapted from a program written by A. D. Miall.

Application of Markov Chain analysis to measured sections

The embedded Markov Chain analysis was applied to each section measured on northern Somerset Island. The results of these analyses demonstrated that there are other problems in addition to the theoretical ones previously outlined. These problems are discussed below.

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Application of Markov Chain analysis to measured sections

The embedded Markov Chain analysis was applied to each section measured on northern Somerset Island. The results of these analyses demonstrated that there are other problems in addition to the theoretical ones previously outlined. These problems are discussed below.

Port Leopold sections The sections at Port Leopold are characterized by numerous different rock types. In addition to the units consisting only of one rock type there are units in which pairs of rock types are interlaminated or interbedded. Consequently, the number of states that can be recognized for the purpose of Markov Chain analysis is large (as many as 25). This fact, together with the shortness of the stratigraphic sections (generally less than 100 m) makes the initial transition count matrix invalid as any Markovian tendencies that may exist are masked in the large matrix that is required to represent all the states.

The dolomitic rocks could have formed by early diagenetic or late diagenetic alteration of the original sediment. The purpose of Markov Chain analysis is to determine whether any cyclicity existed in the primary depositional conditions. Thus, the question arises as to how the dolomitic rocks should be treated in this type of analysis. If the dolomite formed before the next unit was deposited then it should be included in the transition count matrix because it represents a distinct stage in the development of the succession. However, if the dolomite formed at a late stage in the history of the sediment it should not be included in the analysis.

At the present day dolomitization follows complex patterns

which generally bear no relation to the facies patterns of an area. In such an area the dolomitizing fluids commonly penetrate and dolomitize sediments to considerable depths.

In an effort to resolve the problem, two analyses were done for each of the Port Leopold sections. The first analysis included the dolomitic rocks as a distinct state in the transition count matrix. While this indicated some cyclicity, problems arose because of the combination of too many individual states in a thin succession. From all these analyses no cycle could be derived that would fit all the sections. The second analysis was conducted under the assumption that the dolomite was of late diagenetic origin; thus each dolomitic rock was reverted to its presumed original state. The reversion of dolomitic limestone to limestone was advantageous since it automatically reduced the number of states in the transition count matrix. However, it also created some additional problems. In some sections at Port Leopold the difference between successive units is the amount of dolomite. With the removal of dolomite from the analysis many of the units identified in the measured section were combined with the underlying units (for example, a unit of limestone overlain by a unit of dolomitic limestone became a single unit of limestone) thereby reducing the number of possible transitions

that could be included in the transition count matrix. Even using this method of analysis, no satisfactory cycles could be recognized in the Port Leopold sections. This undoubtedly is a result of the many analytical problems (Table 9) but it may, to a certain extent, reflect the nature of the original facies patterns of the area and the patterns of subsequent dolomitization.

An additional problem was encountered with analysis of sections containing units of interlaminated or interbedded rock types. The large number of possible combinations of rock types means that the inclusion of all possible pairs would make the analysis invalid. Each of the laminae or beds in an interlaminated or interbedded unit represents a separate stage in the evolution of the environmental conditions of the area. These conditions were undoubtedly of short duration as indicated by the thinness of each of the layers. Such units can be treated as homogeneous states and registered as one which contains the same components (i.e. an interlaminated sandy limestone and limestone would be registered as sandy limestone). This has the effect of reducing the number of states in the transition count matrix but ignores the fact that each of the laminae represents a stage in the development of the environment. Alternatively, each of the transitions in the

interlaminated or interbedded unit can be included in the transition count matrix. This takes into account the successive changes in environmental conditions but it causes problems in the analysis since the number of transitions involved in one unit would far outnumber all the other transitions recorded from the section. Any Markovian tendencies in the section would be masked. In reality the only method of resolving this problem is to use sections which are thick enough to allow the inclusion of all these states in the transition count matrix.

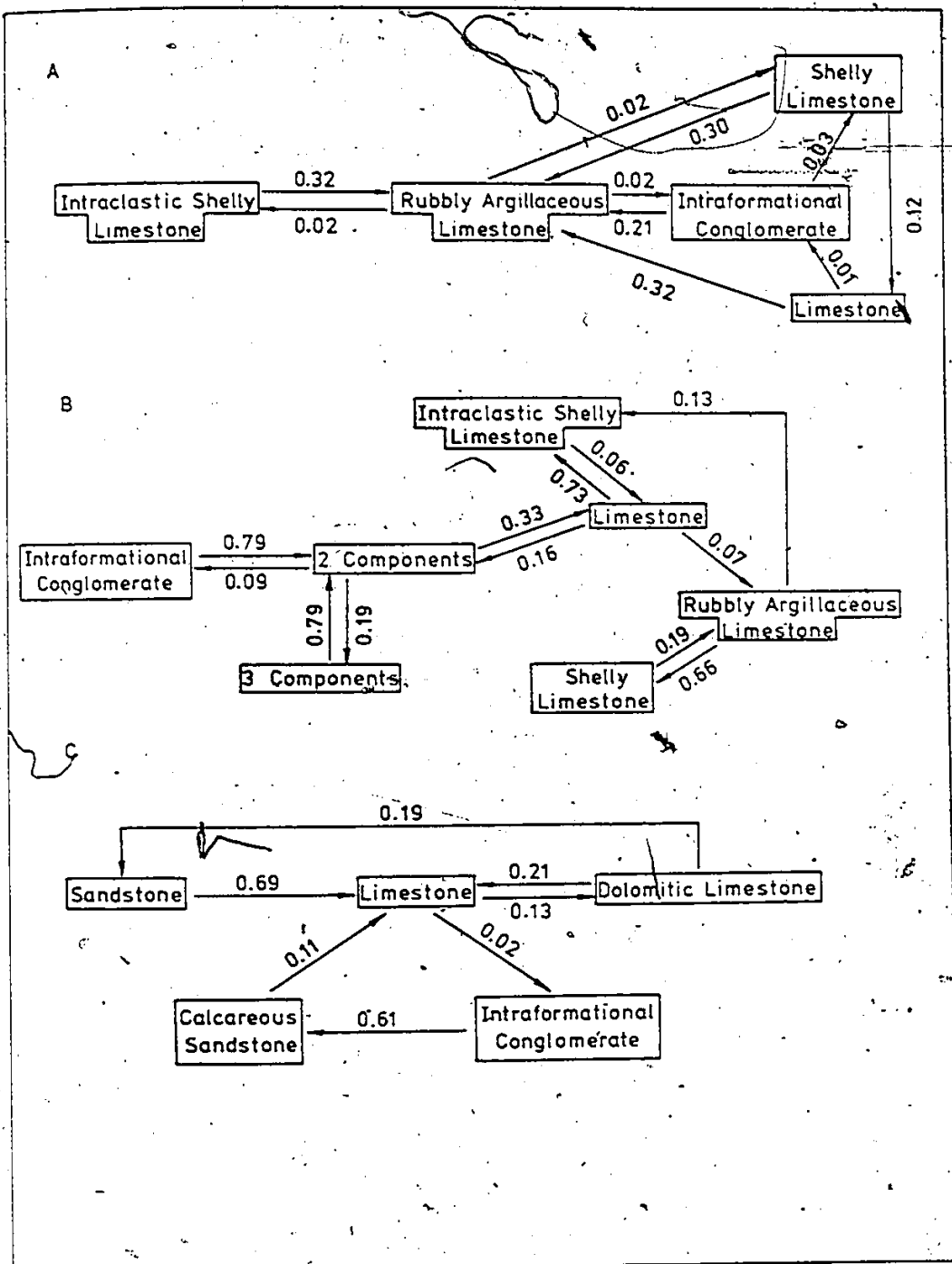
Cape Admiral M'Clintock section The section at Cape Admiral M'Clintock provided an excellent example of the successful application of Markov Chain analysis to the interpretation of a sequence of rocks. In the cycle derived from this analysis (Text-fig. 38a) the dominant state of the section is rubbly argillaceous limestone. From the theoretical Markovian cycle it is apparent that rubbly argillaceous limestone can follow any other state. Conversely, all the other states have a weak linkage with rubbly argillaceous limestone. The shelly limestone, intraclastic shelly limestone and intraformational conglomerate all have a low probability ($d = 0.02$) of following from a rubbly argillaceous limestone other than by random chance. The low transition probabilities involved indicate

Text-figure 38

Markovian cycles at Cape Admiral M'Clintock and Garnier Bay:

- (A) Section at Cape Admiral M'Clintock.
- (B) Sections GA, GB, GD and GE at Garnier Bay. See text for explanation of states termed '2 components' and '3 components'.
- (C) Section GB and basal part of section GA at Garnier Bay.

Transitions are for rocks that accumulated in intertidal environments. Limestone state includes micritic limestone, rubbly argillaceous limestone and shelly limestone. Dolomitic limestone includes dolomitic limestone and calcareous dolomite.



that such transitions were probably controlled by independent factors.

The Chi-squared tests of significance (Table 5.) indicate that the Null Hypothesis (p.134) can be rejected and that some cyclicity exists within the succession.

Garnier Bay sections Two separate analyses were conducted on the sections of the Garnier Bay area. The first analysis involved the transitions from all the sections irrespective of the facies. The second analysis included only the transitions in section GB and the basal part of section GA (units GA1-GA14). The second analysis was conducted in an attempt to recognize cyclicity in the sedimentary rocks that contained large amounts of sand-sized detrital material.

In the first analysis the 'two component state' included any rock that had two of the following components: quartz, dolomite or limestone. Thus, a sandy dolomite would be included in this state. The 'three component state' included any rock that contained all three of the above components. Thus, a sandy dolomite-limestone was included in this state.

From the cycle obtained by this analysis (Text-fig. 38b) it is apparent that the conglomerate shows no strong linkage with

Table 5.- Tests of significance for Markov Chain analysis of the section at Cape, Admiral, M'Clintock.

Test equation	χ^2	D.F.	Limiting Value *
Billingsley (1961)	26.20	15	14.98
Anderson and Goodman (1957)	106.67	11	19.88

* 95% confidence limit

Table 6.- Tests of significance for Markov Chain analysis of section CF of the Cunningham Inlet area.

Test equation	χ^2	D.F.	Limiting Value *
Billingsley (1961)	4.15	8	15.49
Anderson and Goodman (1957)	23.52	5	11.04

* 95% confidence limit

N.B. χ^2 value must exceed limiting value to be significant.

any other state, although there is some indication that it had the greatest chance of occurring after a 'two component state'. The occurrence of conglomerate after any other state must be viewed as a random occurrence.

The Chi-squared tests of significance (Table 7) indicate that the Null Hypothesis (p.134) can be rejected and that some cyclicity exists within the sections.

The 'two component state' includes six different rock types. While they are similar in containing two components they may in fact represent different depositional environments. To investigate the effect that this might have had, and to aid in the understanding of the succession of sediments the 'two component state' was divided into three separate states: (1) those rocks containing dolomite and limestone, (2) those rocks containing dolomite and quartz, and (3) those rocks containing limestone and quartz. Since these rock types are confined to the basal part of section GA and to section GB a separate analysis was done on the transitions within these sections. In this analysis, the shelly limestone, the argillaceous limestone and the micritic limestone were included in one state. The resultant cycle (Text-fig. 38c) indicates a strong linkage between most of the states. The

Table 7.- Tests of significance for Markov Chain analysis of the
Garnier Bay sections (GA, GB, GD and GE) -- all facies.

Test equation	χ^2	D.F.	Limiting Value *
Billingsley (1961)	60.94	35	49.80
Anderson and Goodman (1957)	81.44	29	42.55

* 95% confidence limit

Table 8.- Tests of significance for Markov Chain analysis of the
Garnier Bay sections --- intertidal facies only for
section GB and basal part of section GA.

Test equation	χ^2	D.F.	Limiting Value *
Billingsley (1961)	11.04	15	24.99
Anderson and Goodman (1957)	24.82	11	24.75

* 95% confidence limit

N.B. χ^2 value must exceed limiting value to be significant.

exception to this is the linkage between limestone and conglomerate ($d = 0.02$). The low probability of conglomerate occurring after limestone indicates that the conglomerate occurred randomly.

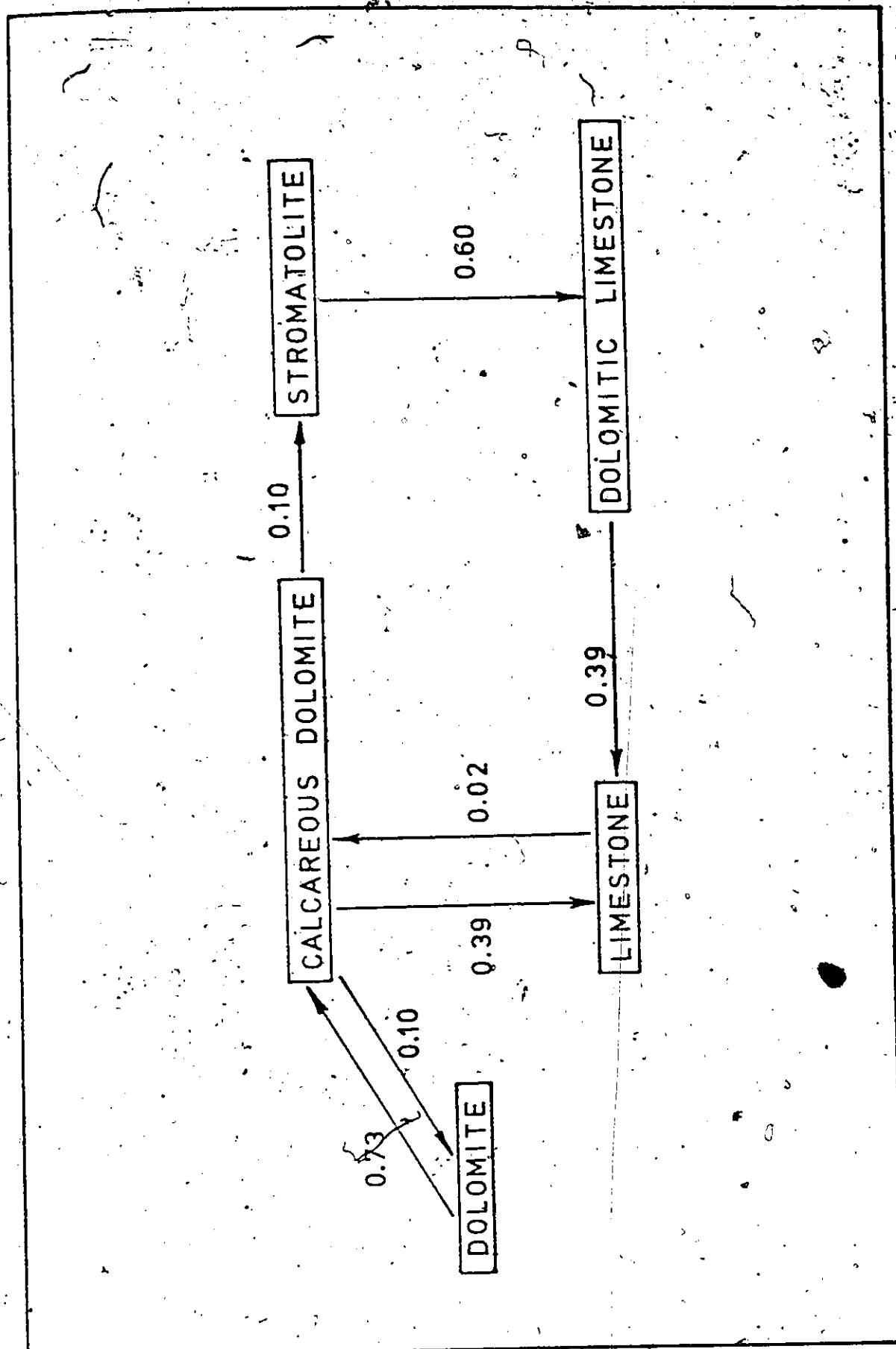
The Chi-squared tests of significance in themselves pose a problem. According to the value obtained from the Billingsley formula the Null Hypothesis cannot be rejected and no cyclicity exists within the succession. However, according to the formula of Anderson and Goodman there is cyclicity within the succession. For reasons previously outlined (p.135) more reliance is given to the result from the Anderson and Goodman formula (Table 8).

Cunningham Inlet sections Section CF of the Cunningham Inlet area is slightly anomalous in comparison to other sections of similar lithology. In the sections at Port Leopold the presence of dolomite had the effect of complicating the analysis (p.136) but in section CF this problem was not encountered. It is apparent from the cycle derived by this analysis (Text-fig. 39) that there is linkage between the different states.

The Chi-squared significance tests (Table 6) display a similar pattern to that for section GA and GB at Garnier Bay. As in the previous case the result of the Anderson and Goodman formula is followed. Consequently, the Null Hypothesis (p.134)

Text-figure 39

Markovian cycle for section CF of the Cunningham Inlet area.



is rejected, indicating that Markovian tendencies exist within this succession.

Other successions Sections CA and CE of Cunningham Inlet and the Pressure Point section could not be analyzed for reasons previously outlined. The problems associated with each section are summarized in Table 9.

Table 9.- Summary of reasons for failure of Markov Chain analysis
for sections at Port Leopold, Cunningham Inlet and
Pressure Point.

Section	Reason for failure of Markov Chain analysis
Port Leopold sections	(1) Short sections (generally less than 100 m) (2) Numerous different states (3) Numerous units of interlamiated or interbedded rock types (4) The presence of secondary dolomite in many units
Cunningham Inlet-Sections CA and CE	(1) Covered intervals in short sections (2) The presence of secondary dolomite in many units
Pressure Point	(1) A thick succession of mottled dolomite-limestone in which differences reflect the degree of dolomitization (2) Few transitions between the various states

CHAPTER 5

INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS

Introduction

The interpretation of sedimentary environments on the basis of evidence preserved in ancient rocks has many limitations. One of the main problems is that physical parameters, so readily discernable in modern environments, cannot be measured directly. The evidence for them recorded in lithology, sedimentary structures and associated faunas, is generally incomplete. The interpretation of ancient depositional environments depends substantially on the principle of uniformitarianism, but even this is limited in application because the origin of some modern sediments is commonly not fully understood.

The following discussion examines the theories advanced for the formation of various sediment types and sedimentary structures in modern environments. The concepts are examined as they relate to the depositional environments of the Read Bay Formation and Leopold succession of northern Somerset Island. The main objectives are to distinguish subtidal environments from intertidal and supratidal environments, and to distinguish the various types of subtidal environment. The interpretation of the principal depositional environments takes into consideration all the criteria discussed. The conclusions outlined in this chapter

are used to determine the succession of environments described in chapter 6.

Subtidal Environments

Micritic limestone The origin of micritic limestone even in modern environments has been variously interpreted. Essentially four possible origins have been proposed although only two are generally accepted at present. Purdy (1963b, p. 485) summarized the four possibilities as follows:

- (1) Bacterial origin (Drew, 1914; Smith, 1926)
- (2) Bacterial origin with redistribution (Bavendamm, 1932)
- (3) Physiochemical origin (Gee et al., 1933; Black, 1933)
- (4) Skeletal origin (Sorby, 1879)

Drew (1914) advanced the theory that the aragonite muds of the Bahama Bank originated through the activity of ammonifying and denitrifying bacteria. While there is some evidence to show that this can occur, it has been shown that the scale of production is insufficient for the amount of mud found on the Bahama Bank. Consequently, this process is generally discounted. Bavendamm (1932) concluded that most of the mud formed by bacterial action in mangrove swamps, is transported and redistributed over the Bahama Bank. Newell et al. (1959) demonstrated that this process will provide insignificant amounts of mud.

Consequently, the majority of recent studies have advanced either physiochemical or skeletal origins for the muds. Gee et al. (1933) produced aragonite crystals from seawater by passing carbon dioxide through it. Subsequently, Black (1933), Smith (1940) and Cloud (1962) all suggested that the aragonitic muds of the Bahama Bank were formed by inorganic processes (i.e. precipitation from seawater). Milliman (1967) suggested that the high Sr content (greater than 0.95%) of the aragonitic muds of Hogsty Reef (a Bahamian atoll) can only be explained if an inorganic process is involved.

In contrast, workers such as Sorby (1879), Lowenstam (1954), Matthews (1966), Hoskin (1966), Folk and Robles (1964), Jindrich (1969) and Stockman et al. (1967) have suggested that the aragonitic muds are formed from skeletal material that has been reduced to its smallest possible size. Lowenstam and Epstein (1957), demonstrated that the $\delta^{18}\text{O}$ values of the muds on the Bahama Bank showed most similarity to the $\delta^{18}\text{O}$ values of the algae of the area. The disintegration of algae such as Penicillus would provide more than sufficient quantities of aragonite needles to account for the mud found on the Bahama Bank (Stockman et al., 1967, p. 645).

It is clear that the original aragonite needles of the mud can be derived either by skeletal breakdown or by physiochemical processes.

In the Bahama Bank area probably both processes are operative.

However, only the aragonitic muds of the Abu Dhabi Lagoon in the Persian Gulf appear to be solely of inorganic origin (Bathurst, 1971, p. 204).

In this area organic controls are insignificant because the climate of the area is unsuitable for the algae and corals which provide the skeletal debris for the Bahamian muds.

As diagenesis proceeds aragonite will revert to the more stable form of low magnesian calcite (Friedman, 1964, p. 732). Consequently, ancient micritic limestone probably originated from mud similar to modern aragonitic mud.

In modern environments most aragonitic mud forms in shallow marginal conditions. However, as on the Bahama Bank, mud will accumulate anywhere that the current velocity is insufficient to allow transportation. Baffles, such as those created by marine grasses and mangroves, will also create conditions where mud can accumulate. Thus, while the area of formation of aragonite mud may be fairly limited, the sediment can be extensively redistributed. The interpretation of micrite as being originally quiet water sediment may be misleading, as algae can stabilize mud even in high energy environments (Bathurst, 1971, p. 122).

It is apparent that calcite mud can form and accumulate in many different modern environments. Thus, ancient micritic limestone cannot be used as an indicator of a particular environment.

Rubbly limestone - Group I Within this group of rubbly limestones,

which is collectively referred to as rubbly argillaceous limestone, three main types (designated Types I, II and III) are recognized.

The Type I rubbly argillaceous limestone is distinctive because of the textural zonation within the limestone lumps (p. 39). The groundmass consists mainly of argillaceous material but in contrast to the argillaceous material of Type II it contains dolomite rhombs (p. 39). The dolomite rhombs are of secondary origin as they commonly cut previous textures. Shell material in the argillaceous groundmass is commonly highly altered and usually represented by ghost structures. Thus, within the zone of argillaceous material, fluid movement may have been responsible for the introduction of dolomite and the alteration of the shell material.

Fluid movement along the zones of argillaceous material was probably also responsible for the zonation of the limestone lumps. The outer parts of the lumps are the most altered (p. 39) and there is a gradual decrease in the degree of alteration towards their centre. The central parts of the lumps are composed of micritic limestone which locally contains unaltered shell material and probably is the original component of the limestone lumps.

In this type of rubbly argillaceous limestone there appears to have been some original heterogeneity in the sediment. This

heterogeneity allowed free post-depositional passage of fluids through the sediment and resulted in the alteration patterns now present in the rock.

The main problem in explaining the origin of this rock type is that of accounting for the original heterogeneity of the sediment. Some of the lumps possibly were originally calcareous sponges, algae or stromatoporoids. This rock type commonly contains a fauna of corals, brachiopods and trilobites which suggests that the sediment accumulated in a subtidal environment. In section GD of the Garnier Bay area this rock type flanks biohermal limestones. The form of the corals in these units (e.g. unit GD10) suggests that the environment was one of strong water turbulence.

Type II has been recognized mainly in the Cape Admiral M'Clintock section. The draping of the muscovite flakes around the limestone lumps (p. 40) suggests that the rock underwent considerable diagenetic pressure which resulted in the re-orientation of the flakes. The fact that the orientation of the muscovite flakes is related to the form of the limestone lumps suggests that the lumps were rigid prior to the onset of diagenetic pressures. The low degree of alteration of shell material in the argillaceous material indicates that there was little or no post-depositional movement of fluids through the sediment.

The nature of the rock suggests that the original sediment

was heterogeneous. If in fact the original sediment was homogeneous it would be difficult to explain the process of segregation which produced the present heterogeneous rock. The limestone lumps possibly are entirely of diagenetic origin and resulted from concretionary growth below the sediment-water interface. If they formed in this manner the calcite would have needed centres of nucleation. However, the calcareous brachiopod shells, which would be obvious centres of nucleation, have no crystalline calcite adhering to them. The fact that the lumps neither contain complete shells nor exhibit concentric growth further illustrates that the shells were not centres of nucleation.

The original sediment was possibly extensively bioturbated causing some heterogeneity which was subsequently accentuated by various diagenetic processes. However, it is difficult to visualize how such processes could give rise to units of rubbly limestone which are up to 12 m thick and uniform in character throughout.

A few of the limestone lumps were found to be stromatoporoids or calcareous sponges and many others originally may have been calcareous sponges. Siliceous sponge spicules occur in some units of rubbly argillaceous limestone and their occurrence indicates that the environment was suitable for the growth of sponges. If the limestone lumps were originally calcareous sponges it would explain why no shells are found in them. It would also explain the rigidity of the lumps prior to

diagenetic pressures.

The fauna of corals, brachiopods and trilobites in this rock type suggests that the original sediment accumulated in subtidal environments.

Evidence for the origin of Type III rubbly argillaceous limestone is relatively rare since it is present only in unit GE6 of the study area. The striking feature of this type is the lateral relationship between the isolated limestone lumps and the semi-continuous layers (Text-fig. 10, p. 42). This, and the irregular profile of the individual layers suggests that progressive growth and coalescence of the lumps formed the semi-continuous layers. It seems probable that the lumps formed below the sediment-water interface at an early stage in the sediment's history. Although this unit contains no fauna, the general sequence in which the unit occurs suggests that the original sediment accumulated in a subtidal environment.

Rubbly limestone - Group II Within this group of rubbly limestones, which are collectively referred to as mottled dolomite or mottled limestone, two main types (designated Types IV and V) have been recognized. The literature on mottled dolomite is sparse. Apart from brief reference to its occurrence by authors such as Van Tuyl (1914), Wallace (1913), Birse (1928), Griffin (1942) and Fisher (1954), only Osmond (1956) and Beales (1953) have made any attempt at explaining its origin.

Osmond (1956, p. 32) stated: "A spotty or patchy colour pattern referred to as mottling is created by the presence of contrasting matrix and enclosed bodies." Most commonly the mottling is created by the occurrence of micritic calcite lumps in a matrix of dolomitic material.

A survey of the literature indicates that this rock type is common in many North American Paleozoic formations. Griffin (1942, p. 67) reported its occurrence in the Middle Ordovician Platteville Limestone of Minneapolis while Wallace (1913, p. 402) and Birse (1928, p. 217) noted its occurrence in Ordovician strata of Manitoba. Osborn (1956, p. 34) noted its presence in Cambrian limestones of the Cordilleran miogeosyncline. Nolan (1935, p. 20) and Osmond described mottled dolomite from the Upper Devonian strata of Utah. Beales (1953, p. 2281) documented the mottled dolomite of the Upper Devonian Palliser Formation of Alberta.

On the basis of the literature, this rock type appears to be confined to pre-Permian times. This may be a reflection of the conditions necessary for its development.

Many different hypotheses have been advanced for the origin of mottled dolomites. Van Tuyl (1914, p. 356) suggested that the magnesia was introduced post-depositionally and in some instances selectively replaced fucoids and in other instances the alteration

spread out from certain favourable centres. Wallace (1913, p. 414) and Birse (1928, p. 217) considered that the dolomitization was localized by the presence of tubes of organic origin which extended through the original sediment. Beales (1953, p. 2288) suggested that the dolomite was of diagenetic origin and that the magnesium carbonate was introduced from sea water. Beales also advanced the idea that decaying organic matter in the sediment maintained a low alkalinity so that $MgCO_3$ was precipitated, while $CaCO_3$ remained in solution.

The main difficulty is in accounting for the $MgCO_3$. Fisher (1954, p. 82) suggested that seaweed provided the $MgCO_3$, while Beales (1953, p. 2288) considered that the $MgCO_3$ was derived from sea water, algal action or from shell material that had a high Mg content.

Study of the mottled dolomite and mottled limestone of the Read Bay Formation at Pressure Point has provided some evidence which assists in the understanding of the genesis of these rocks.

The dolomite is of diagenetic origin as demonstrated by the following:

- (1) The dolomite rhombs in some instances penetrate small fragments of calcitic shell material.
- (2) The irregular shape of the limestone lumps (Pl. 6, figs. 1 and 2 and Text-figs. 11a-f) is created by the dolomite 'invading' and replacing the original micritic calcite.

The dolomite, in the Type IV rubbly limestone, is generally concentrated in distinct areas of the rock and these commonly have diffuse borders (Pl. 7). The zonation of the dolomitic areas suggests that the dolomitizing agent was most effective in certain zones where practically all the micritic calcite was replaced by dolomite. Away from these zones the dolomitizing agent was less effective, resulting in less of the original micritic calcite being replaced. The zonation is probably a reflection of the ease of movement of the dolomitizing agent through the rock.

The dolomitizing process may have been one of two types. The first possibility is that the fluid moved through more permeable zones in the sediment bringing in MgCO_3 from an external source. The second possibility is that the dolomitization pattern is due to redistribution of Mg^{++} that was already in the sediment. This would have involved only interstitial movement of fluid.

If the dolomitization was due to redistribution of original MgCO_3 , then the form of the dolomitic areas is difficult to explain. Usually, where redistribution of a mineral occurs, it recrystallizes in cavities or tends to accumulate about nucleation centres forming ellipsoidal or spherical concretions. In such instances the original material is almost totally excluded.

In the examples in the Read Bay Formation, the dolomite occurs in distinct zones between the limestone lumps; it does not occur in ellipsoidal or spherical concretions. There is no indication of concentration of the dolomite about nucleation centres. The zonation of the dolomite in the dolomitic areas suggests that the dolomitizing agent was most effective in zones between limestone lumps. Thus, the dolomite appears to have been introduced by fluid movement along narrow zones within the sediment. The fluid permeated adjacent zones of sediment less effectively and caused less complete dolomitization. This may have been due to a decrease of MgCO_3 in the fluid once some dolomite had been precipitated in the central zone of the dolomitic area. Thus, at any particular time there would have been a concentration gradient across the zone that was being dolomitized since the quantity of Mg^{++} in solution would have been the greatest in the central zone and would have decreased gradually outward. Ultimately, a stage would be reached where fluids may have penetrated a zone, but because of their lack of Mg^{++} , no dolomitization would have occurred. These fluids may have caused the recrystallization of the micritic limestone, or deposited the crystalline calcite zone that has been observed in some specimens adjacent to the dolomite rhomb-calcite zone.

If the dolomitizing agent was a fluid passing through the sediment then the reason for it penetrating particular zones would

probably be permeability differences between the various parts of the sediment. Thin-section analysis suggests that the main component of the original sediment was micritic calcite. The only difference between the lumps and the matrix (apart from the dolomite content) is that the lumps tend to have a higher concentration of shell debris. In the dolomitic areas, shell debris constitutes less than 5% of the sediment. This figure possibly was originally much higher as some shell debris could have been totally replaced by dolomite. However, shell debris in these zones is rarely extensively altered. Shell debris constitutes up to 30% of the limestone lumps. Thus, the dolomitizing fluid apparently followed zones where there was little shell debris. However, in some units (e.g. unit Y18) whole shells occur only in the dolomitic areas. These whole shells possibly affected the permeability of sediment in their immediate vicinity.

In the Pressure Point section the various rock units with differing proportions of dolomitic and calcitic material show that dolomitization has proceeded to various degrees. Ultimately, total dolomitization is possible. The process of dolomitization could have been terminated either because the source of the Mg^{++} was cut off, or because the crystallization of dolomite in these zones decreased the porosity of the sediment until ultimately fluids were prevented from

passing through the sediment.

An important aspect of this problem is the possible source of the additional Mg^{++} that was necessary for the dolomitization of the sediment. The dolomitization probably occurred at an early stage in the diagenetic history of the rock for this would have been the time when porosity differences would have been the greatest. The source of the Mg^{++} must have been large to produce such vast areas of the same sediment. Similarly, the thickness of the units (up to 12 m) indicates that the source must have persisted for a long time.

Another additional feature that must be explained is the textural uniformity throughout such large bodies of rock. The presence of a fauna of corals, brachiopods and crinoids in many of these rocks suggests that they originally accumulated in subtidal environments, and this is supported by the lack of shallow-water sedimentary structures.

The most obvious source of Mg^{++} , which would explain the features described above, is seawater. This suggests that the seafloor which covered the Pressure Point area during Silurian times had a high salinity. If the seawater was the source of the Mg^{++} it would explain the lateral and vertical uniformity of the rock.

It is apparent from the nature of the sediment that calcite or aragonite was formed first, as it is at the present day, and that dolomitization subsequently took place. This suggests that the dolomite could only crystallize out of seawater in sub-surface sediment and that special conditions existed within the sediment. Decaying organic matter in the sediment could have affected the pH level of the pore water in the manner suggested by Beales (1953).

If seawater was the source of the Mg^{++} then it is possible to suggest why dolomitization at any particular level in the sediment did not proceed to completion. Probably the dolomitization would proceed downwards to only a certain depth and once the fluids reached this depth, the Mg^{++} content of the fluid would have decreased to a level that precluded further dolomitization. If additional sediment was being deposited as the dolomitization proceeded, then the zone in which dolomitization occurred would progressively move upwards. Thus, the degree to which a particular sediment was dolomitized would be a function of the rate of deposition of sediment on the seafloor.

As previously suggested an alternative method of terminating dolomitization would be to decrease the porosity of the sediment. This, too, may well have had an effect on the degree of dolomitization of a particular sediment.

In summary, the degree of dolomitization of a particular sediment may be a function of:

- (1) The rate of penetration of the dolomitizing fluids through the sediment; this would depend on the permeability of the sediment.
- (2) The amount of Mg ions in the fluid.
- (3) The rate of sedimentation, as this would control the time that the sediment was in the zone of potential dolomitization.

In some of these units, secondary silica has formed in cavities and has resulted in complex textures. It is difficult to state with certainty whether the deposition of silica preceded or followed dolomitization.

Rubbly limestone of Type V, which is considered to have formed predominantly in intertidal environments is discussed in a later part of this chapter.

Intraformational conglomerate, intraclastic shelly limestone and shelly

limestone. Good examples of these three rock types are present in the

Cape Admiral McClintock section. Markov Chain analysis demonstrated that they occur as random states within the succession (p. 139).

Consequently, their origin was due to factors independent of the prevailing depositional mechanisms in the sedimentary basin at that time.

The breakdown of shell material can occur because of:

- (1) Continuous abrasion and breakage of shelly material in a high energy regime.
- (2) The tritulating action of organisms such as parrot fish, boring sponges and algae (Bathurst, 1971, p. 113).
- (3) The separation of skeletal plates of organisms such as crinoids after death and decay of the soft tissues (Cain, 1968, p. 196).

If the shell material was broken solely by organisms then it should be randomly distributed rather than confined mostly to the thin units of shelly limestone, intraclastic shelly limestone and intraformational conglomerate. The latter implies that the agent which caused the fragmentation was of short duration. Similarly, the process of skeletal separation after death cannot always be invoked since this would imply a random occurrence of the phenomenon. Consequently, the fragmentation of the shell material apparently was caused primarily by high energy conditions.

The presence of large clasts in the units of intraformational conglomerate and intraclastic shelly limestone and megaripples in units 57 and 64 also imply that high energy conditions were responsible for their formation.

The thick units of rubbly argillaceous limestone in the Cape Admiral M'Clintock section apparently accumulated in quiet sub-tidal conditions (p. 156). Thus, the thin units of shelly limestone, intraclastic shelly limestone and intraformational conglomerate represent drastic but short-lived changes in energy regimes.

Storm activity can radically affect the sediments that are accumulating in shallow seas. Bathurst (1971, p. 149) stated:

"Hurricanes have an influence on erosion and deposition out of all proportion to their short duration." Such phenomena as storms and hurricanes are normally of random occurrence. They are capable of producing energy levels in a shallow body of water that under normal circumstances would never occur. Hobday and Reading (1972, p. 323) suggested that storms were responsible for the high energy conditions that produced symmetrical ripples in some of the Pre-Cambrian siltstones of Finnmark.

Random storm activity would readily explain the following features:

- (1) The increased energy necessary to derive and transport the clasts that form the conglomerate and intraclastic shelly limestone and the shell debris in the shelly limestone and intraclastic shelly limestone.

(2) The random occurrence of the conglomeratic units within the succession of rocks.

(3) The repeated occurrence of thin units (less than 1/3 m) of conglomeratic material within a section that is dominated by rubbly argillaceous limestone of quiet water, subtidal origin.

The most probable cause of the intraformational conglomerate, intraclastic shelly limestone and shelly limestone units such as those in the Cape Admiral McClintock section is storm activity.

Although the three rock types represent higher energy conditions than does the rubbly argillaceous limestone, the sequence intraformational conglomerate - intraclastic shelly limestone - shelly limestone represents a gradation from higher to lower energy conditions. This sequence may represent varying strengths of storms.

In other sections the intraformational conglomerate, intraclastic shelly limestone and shelly limestone occur within predominantly.

intertidal and supratidal facies, for example, in the Leopold Formation of the Port Leopold area and in parts of the Read Bay Formation at Garnier Bay. In this type of environment these rock types probably represent storm activity, high tides or floods.

Fauna The fauna of most subtidal environments commonly has a high generic diversity and occurs in profusion.

Modern scleractinian corals can be divided into two main

groups, the hermatypic and the ahermatypic corals. Since the tissues of the hermatypic corals contain symbiotic zooxanthellae the corals are restricted to water depths where light can penetrate. The salinity and temperature of the water; the availability of food and turbidity are further controls over their distribution. Ahermatypic corals are not dependent on symbiotic zooxanthellae and can therefore live down to depths of 6,000 m (Wells, 1967, p. 353). Consequently, unlike the hermatypic corals, they cannot be considered good depth indicators.

It is relatively easy to relate many modern corals to particular water depths. However, the scleractinian corals did not appear until the Mesozoic Era and their Paleozoic predecessors, the tabulate and rugose corals, have no modern equivalents. Although it is unknown whether the Paleozoic corals had requirements similar to those of the modern corals the tabulate and rugose corals apparently were confined almost entirely to subtidal environments. However, they do not show any clear patterns of depth distribution.

According to Heckel (1972, p. 283) the sessile, suspension-feeding stromatoporoids probably required attachment to a firm substrate, low turbidity levels and slow deposition of sediment. They are of little use for determining the absolute water depth of any ancient environment although they were probably confined to subtidal environments.

Although the corals and stromatoporoids are of little use in determining the absolute water depth of ancient environments, they can be used as indicators of the degree of water turbulence. In units GD11 and GA45 of the Garnier Bay area the distinctive 'pancake' shape of all the colonial corals suggests that environmental conditions rather than genetic controls determined the colony form. These corals probably lived in very turbulent environments that inhibited the vertical growth but not the lateral growth of the colonies. In striking contrast to the 'pancake' forms are the high forms in unit CD4 of the Cunningham Inlet area. These forms, which have a small base diameter (p. 121) probably developed in an environment which was relatively quiet compared to the turbulent waters of the Garnier Bay area.

Recent brachiopods form a very insignificant group which have a fairly restricted range of habitats. Most modern brachiopods are confined to a zone in and just below the intertidal environment but exceptional types such as Chlidonophora occur at depths down to 4,000 m in the Indian Ocean (Rudwick, 1961, p. 475).

Ager (1967, p. 158) suggested that all modern brachiopods with the exception of Lingula require well-oxygenated marine waters with normal salinity. Only Lingula can withstand occasional influxes of freshwater. Craig (1952) briefly reviewed the literature on the subject

and concluded that Lingula is essentially a shallow-water marine animal which occurs at depths of less than 30 m.

It is evident from the literature that the brachiopods of the Paleozoic Era inhabited a far greater range of habitats. Since no direct analogy can be made with modern brachiopods (except for Lingula) evidence of depth control on brachiopod distribution must be inferred from sedimentological evidence.

Intertidal and supratidal environments

Detrital rocks Included in this discussion are all the rocks that contain some detrital material. The detrital fraction in the Read Bay and Leopold Formations only rarely occurs in such quantities that the rock can be classified as a sandstone.

The Persian Gulf is a fine example of an area of carbonate formation with an influx of detrital material. The detrital material is mainly silt- to clay-sized grains of clay minerals (Bathurst, 1971, p. 183) along with quartz grains of eolian origin. These grains, and other detrital fragments of Mesozoic carbonate rocks are brought to the lagoonal areas by northeasterly winds which sweep the area. The fragments of Mesozoic carbonate rocks, which have already undergone diagenesis,

can be distinguished from the Recent dolomite by the degree of ordering of the lattice (unordered in the Recent dolomite but ordered in the old

dolomite). The ancient limestone also has a low magnesian composition while the more recent limestones have either an aragonitic or a high magnesian composition.

In the lagoon off the coast of British Honduras the content (maximum 30% by weight) of terrigenous material in the carbonate lutites increases westwards towards the landmass which is the source area (Matthews, 1966). The terrigenous material is introduced both by the action of off-shore winds and by streams flowing into the lagoon from the mainland.

The detrital material in the Read Bay Formation and Leopold succession is mainly in the silt- to clay-size range and could have been wind blown. However, all the dolomite has undergone diagenesis and thus has an ordered lattice. Consequently, the criteria of ordering cannot be used to identify ancient detrital dolomite. Many of the dolomite grains display rhomb faces but have their corners broken off, and some grains are fractured (p. 30). These features and the occurrence of quartz grains of similar size and shape to the dolomite grains suggest that the grains have undergone transportation prior their burial.

Some of the detrital material in the Leopold succession may have been brought in by winds, but probably was subsequently reworked subaqueously.

Most of the detrital fraction of the sedimentary rocks consists of poorly sorted angular to subangular grains. The common mixture of relatively unstable minerals such as plagioclase and microcline with the more stable minerals such as quartz and muscovite suggests that the sediments in which they are found underwent little current transportation. The nature of the sediments, their low degree of sorting and the angularity of the grains suggests that the sediment accumulated relatively quickly.

Dolomitic and evaporitic rocks Since most of the dolomite is of secondary origin (p. 31) the following paragraphs primarily concern the possible mechanisms of formation and environmental interpretation of these rock types.

The controversy over the formation of dolomite in modern environments has gained considerable attention for the last two decades. Many different theories have been advanced, each with its own merits and faults. It seems probable that all the suggested processes could be effective depending upon local conditions.

In the Persian Gulf area there is extensive dolomitization of the surface sediment of the sabkha. Illing et al. (1965, p. 100.)

suggested that the formation of dolomite is closely linked to the precipitation of gypsum in the algal flat zone. With the

precipitation of gypsum, the Mg/Ca ratio of the pore waters increases until dolomitization of the surrounding sediment is possible. Landward of the algal flat zone the Mg/Ca ratio of the pore waters gradually decreases due to the formation of dolomite. The dolomite of the sabkha shows a distinct tendency to replace aragonite mud preferentially (Illing et al., 1965, p. 102). Kinsman (1966), Butler (1969) and Illing et al. (1965) all assumed that pore waters are derived from the lagoon and move landward through the sediment below the water table.

The model proposed above is simplified. Further work by Kinsman and others in the Abu Dhabi lagoon shows that other factors are more important (Bathurst, 1971, p. 530). This research shows that the pore waters of the sabkha need not be replenished solely by landward movement of the lagoonal waters through the sediment. Lagoonal waters driven over the algal mat during periods of high winds tend to collect in old channels on the sabkha surface (Bathurst, 1971, p. 530). Evaporation of this water increases its density and causes it to sink into the sediment (R. J. Patterson, 1973, lecture at Carleton University). As sinking occurs, dolomitization of the underlying sediment takes place. It is obvious that such a process will lead to extremely complex patterns of dolomitization for it will be dependent on the pattern of the old.

channels. There will be no regularity of the dolomitization as might be expected with the model proposed by Illing et al. (1965).

The unconsolidated sediments of Bonaire Island in the southern Caribbean contain large quantities of dolomite. The dolomite in shell debris indicates that the dolomitization originated by diagenetic processes. Workers such as Deffeyes et al. (1964, 1965), Lucia (1968), have documented evidence for the process of dolomitization.

Deffeyes et al. (1965) investigated the relationship between evaporation, salinities of lake waters and seawater and concluded that there is net movement of water from the lake to the sea. The increase in lake water density, caused by evaporation, results in sinking of the lake water into the underlying sediment. As the water moves seaward, the sediment through which it passes is dolomitized. However, with precipitation of dolomite in the lakeward sediments, the Mg/Ca ratio of the porewater will gradually decrease until there is little or no dolomitization. Consequently, the degree of dolomitization of the sediment will decrease seaward.

According to Deffeyes et al. (1965), dolomite should be present in the lake sediments and the pore waters should have a high salinity.

However, Lucia (1968) who drilled through the lake sediment found no

dolomite and found pore waters of normal salinity. The low permeability of a volcanic ash layer 0.50 - 1.00 m below the sediment-water interface restricted the vertical movement of the pore waters thereby preventing the full development of the cycle proposed by Deffeyes et al. (1965).

Hsu and Siegenthaler (1969) suggested that a process which they termed evaporative pumping was responsible for dolomitization. Their theory was based on laboratory experiments in which they introduced freshwater into the land sediment and NaCl into the seawater. Evaporation over the land caused loss of freshwater and replenishment by seawater. The seawater thus moved landward because of the evaporation of the freshwater. If the evaporation ceased, the landward movement of seawater ceased. During the landward movement of seawater, dolomitization occurred.

Muller and Tietz (1966) described the process of dolomitization of supratidal marine calcarenite in the Canary Islands. Occasionally these sediment are subjected to high waves or spray. This water accumulates in pools and evaporates causing precipitation of gypsum and halite. As the water sinks through the underlying sediment, dolomitization occurs.

The origin of secondary dolomite in modern environments is still not fully understood. It is apparent that local conditions are

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The origin of secondary dolomite in modern environments is still not fully understood. It is apparent that local conditions are

extremely important in controlling the manner of dolomitization and it may well be that all the processes described above could lead to the formation of dolomite. Despite the diversity of possible mechanisms for the formation of the secondary dolomite, they all have one feature in common (in that all the dolomite forms in supratidal or high intertidal environments. However, this does not necessarily mean that they are formed without the aid of standing water, for dolomite may form beneath small lakes in the supratidal environment (Deffeyes et al., 1965).

Evaporite beds are confined to the Leopold succession and have been examined in the Port Leopold area where the main evaporite minerals are gypsum and anhydrite. Evaporite precipitation is commonly a prerequisite for dolomite formation. In the Persian Gulf area minute crystals of gypsum occur in aragonitic muds beneath the 'cinder zone' of stromatolites (Kendall and Skipworth, 1968; p. 1052). Bathurst (1971 p. 207) noted that gypsum may constitute up to 50% of the top metre of sediment on the sabkha.

It is apparent that the association of dolomite and evaporite is a common feature of modern supratidal and high intertidal environments. Consequently, this association in the Leopold Formation is interpreted in a similar manner. The occurrence of dolomite without evaporitic material is also suggestive of these environments; however, other

supportive evidence must be used before a definite conclusion can be made, since dolomite does occur in the subtidal mottled limestone-dolomite of the Read Bay Formation.

Limestones In general limestones are of little use for environmental interpretation since they occur in a wide range of Recent environments.

However, some types may be useful, if considered with other data.

The pellets in pelletoidal limestone can be produced by many different animals and yet display similar form (Bathurst, 1971, p. 137).

While most of the pellets in Recent environments are produced by fish and gastropods they can also be formed by polychaetes (Cloud, 1962, p. 28) and by burrowing crabs (Bathurst, 1971, p. 197).

Since most of these animals are mobile and not closely restricted by environmental boundaries, pellets can be found in almost any environment. This is further complicated by the fact that some may be redistributed.

Pellets initially consist of soft mud, bound by a mucus sheath produced by the animal. Consequently, before it can be preserved in a sedimentary rock the pellet must be hardened, or diagenetic pressures will crush it and destroy its original form. If the matrix is also calcareous mud the pellet will tend to merge with it and become difficult to recognize in sedimentary rocks. In some pelletoidal

limestones of the Port Leopold sections the pellets have been crushed, some to such an extent that they are barely recognizable. Possibly they were crushed because they were not sufficiently rigid prior to diagenesis. Conversely, pellets in other units within the Port Leopold sections maintained their form despite diagenetic pressures and appear to have been rigid bodies prior to diagenesis.

The pellet content, alone, in the rocks is not indicative of any particular sedimentary environment. In the Port Leopold sections the gastropod Hormotoma commonly occurs in great abundance and is the most likely source of the pellets. Ostracoderms could have produced the pellets but only disarticulated plates have been found in these sections, and were probably transported prior to burial. Consequently, they probably were not responsible for the pellets. The pelletoidal limestones of Port Leopold are most analogous with the modern pelletoidal sediments of the Abu Dhabi lagoon where pellets commonly are formed by gastropods and accumulate in the intertidal zone. The pellets probably accumulated in sheltered areas away from the effects of strong current action. As Bathurst (1971, p. 197) noted, pellets produced by the crab Scopimera can be easily destroyed by strong currents soon after their formation.

The pellets in the oncopelletoidal limestone are enclosed by

rims of clear calcite (p. 34). The nature of the rims, commonly with asymmetrical laminae (p. 34), suggests that they could have formed by algal action similar to that described by Logan et al. (1964) for the formation of oncolites. The occurrence of composite oncolitic bodies containing several pellets, each with its own rim also suggests an algal origin.

A uniform algal coating on a pellet would have required continuous movement of the body in a manner similar to that necessary for the formation of ooids (Bathurst, 1971, p. 302) or oncolites (Logan et al., 1964, p. 81). If algae were responsible for the clear calcite rims on the pellets, then the pellets possibly were semilithified prior to algal growth. Alternatively, the initial algal coating may have acted as a protective sheath which prevented the break-up of the pellet.

In the Port Leopold sections the oncopelmicrite commonly occurs in beds of short lateral extent. Thus, in unit E15 the oncopelmicrite occurs at the same stratigraphic level as an algal mat horizon. The oncopellets possibly mark the position of a channel through the algal mat zone. A channel environment would have provided the current necessary to form the oncopellets and there would have been an abundance of algae in the area to coat the pellets.

The occurrence of oncolitic limestone in unit PA10 of the Port Leopold area is interpreted as representing a subtidal environment that was subjected to strong current action. However, its association with rock types indicative of intertidal and supratidal environments suggests that it was a localized subtidal area, possibly in a channel which cut the intertidal and supratidal zones.

Type V rubbly limestone is characterized by the presence of semi-continuous layers of micritic limestone in a groundmass of dolomitic material. In some instances the rock containing the continuous layers passes laterally into a rock containing lumps of micritic limestone in a dolomitic groundmass but no continuous layers (p.49). The lumps of micritic limestone were presumably part of the continuous layers.

Shinn (1968b) described a process of selective dolomitization in the supratidal sediments of Sugar Loaf Key (Lower Florida Key) which produces a pattern closely akin to that found in this type of rubbly limestone. Shinn (1968b, p. 618) noted that the lime mud, deposited very rapidly in the supratidal zones during storms (especially hurricanes), dried out once conditions returned to normal. Shrinkage cracks which developed in the lime mud commonly were subsequently filled by more porous and permeable sediment. Seawater which found its way onto the surface of the supratidal sediments evaporated rapidly, causing an

increase in the Mg/Ca ratio (up to 40:1 compared to 5:1 for the interstitial water in the intertidal sediments). With the high Mg/Ca ratio, dolomitization of the subsurface sediment occurred. The pattern of dolomitization was controlled by the distribution of the more permeable sediment along the desiccation cracks.

It is possible that the mechanism of selective dolomitization outlined by Shinn (1968b) could explain this type of rubbly limestone. If the process described by Shinn was repeated many times it could produce a thick unit of rock with a dolomitization pattern similar to that present in Type V rubbly limestone.

The critical factors in this process of selective dolomitization are (1) a period of rapid sedimentation, (2) a period of exposure to the atmosphere and formation of shrinkage cracks, (3) the filling of the cracks with a sediment more porous and permeable than the lime mud, and (4) a period during which surface water evaporated causing an increase in the Mg/Ca ratio of the interstitial water.

The process may well explain the nature of the rock observed at a locality on the West Creswell River (p. 49 and Pl. 8, Fig. 2). However, units of this rock type from section CE of the Cunningham Inlet area commonly contain Atrypella, apparently in, or near their life position for they display no evidence of transport. The layers of

micritic limestone are more continuous laterally than in the example from the West Creswell River locality. The presence of Atrypella in these layers suggests that the environment of deposition was not supratidal with periods of exposure. The lateral persistence of the limestone layers tends to support this suggestion since there was obviously no development of desiccation cracks. It is possible that the original sediment accumulated in a low intertidal or shallow subtidal environment. However, the pattern of dolomitization still may have been controlled by the occurrence of layers of sediment more porous and permeable than the micritic limestone. The limestone layers, which are devoid of fossils, possibly accumulated very rapidly during storms. The analogy with Shinn's (1968a) pattern of selective dolomitization is very strong. The only difference is the lack of the broken layers and the presence of fossils. Thus, the sediment that was deposited after the storm-deposited limestone was probably more porous and permeable than the limestone, thereby allowing selective dolomitization of certain parts of the sediment.

Sedimentary structures Since intertidal and supratidal zones are amongst the most unstable environments they commonly display numerous and varied sedimentary structures.

Desiccation cracks occur in sediments that have been exposed

to the atmosphere. Laporte (1971, p. 728) in his analysis of the Paleozoic carbonate facies of the central Appalachian shelf suggested that mud cracks most commonly occur in tidal flat areas.

Bird's eye structure can originate in a number of different ways. Shinn (1968a) proposed the following possible origins: (1) they were originally water droplets, (2) they are due to algal action, (3) they were originally filled with anhydrite, (4) they are due to shrinkage of the sediment and (5) they are due to diagenetic recrystallization. Illing (1959) suggested that shrinkage or inclusion of gas bubbles in the original sediment were the most probable causes of bird's eye structure. However, despite the argument about their origin, most authors agree that they formed mainly in supratidal and intertidal environments (Laporte, 1967, p. 80, 1971, p. 728; Shinn, 1968a, p. 215). Where this structure is found in the Leopold and Read Bay Formations it is interpreted as being the result of exposure of the original sediment to the atmosphere in the supratidal or high intertidal environment.

Large cavities filled with selenite and gypsum are common in the dolomite of unit PL43. The form of the selenite crystals indicates that they grew into an empty cavity. Apparently these cavities were formed at an early stage in the rock's history and may be a large form of bird's eye structure. In the Persian Gulf area, gypsum is restricted

to the sabkha zone, although some does form beneath the algal mat zone.

It is concluded that this structure with the gypsum is indicative of high intertidal or supratidal environments.

Channels of the form previously described (p. 58), are most commonly associated with the tidal zone in modern environments. Laporte (1971, p. 728) considered scouring and the subsequent filling with conglomerate as indicating a tidal flat zone. Such a zone would have the high energy levels needed to cut the channels and transport the conglomeratic material into the area. The channels in various units of the Port Leopold sections are interpreted in this manner.

Ripples represent conditions in which the energy level was high enough to transport considerable amounts of sediment. Although ripples and cross-bedding are not necessarily restricted to any one environment they are most common in the intertidal zone. Most of the ripples and cross-bedding in the Read Bay Formation and Leopold succession are considered to be of intertidal origin, particularly as they are commonly associated with other features suggestive of intertidal environments.

Fossils The fauna of intertidal and supratidal environments commonly has a low generic diversity but numerous individuals.

The gastropods are unusual in having representatives in fresh water, brackish water and salt water. Commonly they occur in profusion

in environments unsuitable for most other animals. Modern gastropods occupy a wide variety of marine environments. They occur in intertidal zones of Bimini Lagoon (Newell et al., 1959, p. 206) and the Abu Dhabi lagoon (Bathurst, 1971, p. 136) and in association with Thalassia banks of the subtidal environments (Bathurst, 1971, p. 113). Although gastropods are most common in waters less than 600 feet (180 m) deep, some can live down to depths of 4,500 ft (1400 m) (Heckel, 1972, p. 282).

Large numbers of fossil gastropods found with little other associated fauna suggest intertidal or supratidal environments with abnormal salinities.

Ostracods, like the gastropods have the ability to survive in a wide range of aqueous habitats and consequently are commonly abundant in environments where most other animals cannot survive. They are known to be abundant in areas of abnormally high or low salinity, such as intertidal areas.

In contrast to most of the Paleozoic arthropods; eurypterids are not confined solely to marine environments (Clarke and Ruedemann, 1912, p. 300). They commonly occur in rocks of transitional environments which were characterized by highly fluctuating salinity levels (Heckel, 1972, p. 284).

Algae obtain food by photosynthesis and are thus restricted

to the photic zone in the sea. The amount of light reaching the algae will be controlled by the depth and clarity of the water. Consequently, the greatest amount of algal growth generally occurs in tropical intertidal waters, in shallow lagoons and on coral reefs (Table 10). The terms algal mat and laminated stromatolite are often used without any apparent distinction (Table 10). Kalkowski (1968) defined stromatolites as "...laminated structures of problematical origin...", whereas the term algal mat refers to laminated stromatolites in which there are definite algal structures, indicating their algal origin.

Stromatolites occur predominantly in intertidal and supratidal areas. Laminated stromatolites (possibly equivalent to algal mats in modern environments) may occur in shallow subtidal environments (Bathurst, 1967, p. 736).

Hoffman (1967), Donaldson (1963), Kruger (1969) and Elloy and Tixier (1970) all considered the ancient stromatolites that they studied to be indicative of intertidal and/or supratidal environments. Such conclusions were based on comparisons with recent stromatolites and consideration of the sedimentological evidence.

The notable exception to the general intertidal-supratidal occurrence are the stromatolites in the Devonian of the Canning Basin.

Table 10. Distribution of algae in modern environments, according to various authors.

Location	Reference	Algal Type	Depth of water
Bahamas	Shinn <u>et al.</u> (1969)	Algal mat	Intertidal
Bimini Lagoon	Scoffin (1970)	<u>Penicillus</u> <u>Halimeda</u> <u>Batrophora</u> <u>Rhipocephalus</u>	Absent in water above low water mark. Common down to 3 m.
Great Bahama Bank	Bathurst (1967)	Algal mat	Deeper than the low water mark Common down to 3 m
Shark Bay (Australia)	Logan <u>et al.</u> (1964)	Stromatolites	Intertidal
Persian Gulf - Trucial coast	Butler (1969)	Algal mat	Upper Intertidal Zone
Bermuda	Gebelein (1969)	Stromatolites	Intertidal, Subtidal

(Playford and Cockburn, 1969) and in the Cretaceous of the James Reef Complex (Achauer and Johnson, 1969). There the occurrence of stromatolites with hydrozoans and other subtidal organisms on the fore-reef slopes provides a means for distinguishing them from forms that grew in intertidal and supratidal environments.

Some stromatolites, besides being useful for indicating the general environment can also be used to determine levels within the intertidal zone since local conditions within these broad environments can affect their form (Logan, 1961, p. 523; Gebelein, 1969, p. 47; Gebelein and Hoffman, 1968, p. 109). Logan (1961) noted that the form of the stromatolites in Shark Bay (Australia) was controlled by four factors: (1) upward growth of the mat, (2) doming over irregularities, (3) preferential growth on highs and (4) inhibition of growth in depressions. Gebelein (1969, p. 47) considered that five factors were important in determining the form of Bermudan stromatolites: (1) the quantity of sediment brought to the site, (2) the rate of bottom traction and consequent erosion, (3) grain size, as only the finer grained material was incorporated, (4) current velocity, which influences both the sediment supply and the rate of erosion, and (5) wave turbulence, which inhibits growth. It follows that if these factors control the shape of stromatolites then the form of ancient stromatolites should reflect

the conditions in which they developed.

In Shark Bay, Australia, the club-shaped stromatolites have resulted partly because of undercutting and scouring of the bases during tidal runs (Bathurst, 1971, p. 220). Thus growth is confined to the upper surfaces, which are normally at about water surface, where there is a moist, relatively flat, micro-environment. Consequently, the height of the stromatolites can be used as a guide to approximate water depth.

It is apparent that the external form of stromatolites is controlled by many environmental factors. In the intertidal and supratidal environments in which most stromatolites occur, physical conditions can change radically over short distances, and the stromatolite form will be a reflection of the local physical environment. The form of stromatolites may be completely different in a channel, on a bank, or a few metres away from the channel. Local variations in physical conditions are responsible for the zonal arrangement of stromatolites in the Khor al Bazar (Kendall and Skipworth, 1968, p. 1047). In general terms the amplitude of the stromatolites tends to decrease towards the supratidal zone.

The stromatolites in the Port Leopold sections have been studied in this context in an effort to determine more accurately the

local and regional environments. In some instances the forms of the Port Leopold stromatolites are directly analogous to some of the forms described in modern environments. Thus, the club-shaped forms in marker bed 1 can be compared directly with the intertidal forms described by Bathurst (1971). In contrast, the high domal forms of marker bed 2 (Pl. 20, fig. 2) probably grew below low-water mark and maintained their growth surface in the surface waters.

Other stromatolites cannot be compared directly to modern examples and their form may be explained by analysis of the stromatolites themselves and the environmental conditions as indicated by the sedimentary rocks. Thus, the stromatolites in unit A9 of the Port Leopold area are interpreted as forms which developed preferentially on the highs of an erosion surface.

The examples from the Port Leopold area summarized above illustrate the manner in which these structures are used in the analysis of ancient environments.

Summary

The most reliable interpretation of sedimentary environments is one based on ALL the criteria available.

The intertidal and supratidal environments are characterized by unstable energy levels and variable salinities which create numerous local microenvironments. Consequently, the sediments which accumulate

in these environments reflect the complex system of physical parameters by abundant lateral and vertical facies changes (Table 11). The complex facies patterns preserved in the sections at Port Leopold (p. 82) are probably indicative of such environments. Since subtidal environments tend to be more stable than the intertidal and supratidal environments they commonly display less lateral and vertical variation. Thus, in ancient successions, subtidal rocks tend to be much more extensive geographically. The subtidal environments also tend to be more persistent in time, thereby creating thicker accumulations of individual rock types. This contrast in facies extent and distribution between different depositional environments is exemplified by the Port Leopold sections (Text-fig. 22, p. 82) and the Pressure Point sections (Text-figs. 35 and 36, p. 125 and 126).

The unstable intertidal and supratidal environments impose severe restrictions upon the fauna and flora which can inhabit such zones. Thus, apart from abundant stromatolites the only common in situ fossils in such intertidal and supratidal rocks are gastropods, ostracods and eurypterids (Table 11). In striking contrast, the subtidal rocks commonly contain a profuse, diverse fauna of brachiopods, corals, trilobites and stromatoporoids. The comparison of faunal composition and diversity provides an excellent basis for the interpretation of ancient depositional

Table 11. Summary of criteria used for environmental interpretation.

Parameter	Environment		Supratidal	Intertidal	Shallow Subtidal
Rock types:					
Intraformational conglomerate			Random Occurrence		
Intraclastic shelly limestone			Random Occurrence		
Shelly limestone			Random Occurrence		
Micritic limestone			Redistributed		
Dolomitic rocks					
Mottled dolomite-limestone			Type V	Type IV	
Pelletoidal limestone					
Detrital material			Coarser grained	Finer grained	
Rubby argillaceous limestone					
Sedimentary structures:					
Desiccation Cracks					
Bird's eye structure					
Ripples			More common	Mega-ripples	
Cross-bedding					
Channels					
Fossils:					
Algae			Stromatolites	Oncolites	
Corals					
Brachiopods			Lingula common		
Gastropods			Common		
Eurypterids			Common		
Ostracods			Common		

Table 11 (contd.).- Summary of criteria used for environmental interpretation.

Parameter	Environment	Supratidal	Intertidal	Shallow Subtidal
Number of taxa		Low	Increasing	High
Ratio of low salinity forms to high salinity forms		Abundant	abnormal salinity forms	abundant normal salinity forms
Facies patterns:				
Vertical		Numerous		less numerous
Areal facies distribution		Outcrop scale		Areally persistent

environments (Table 11).

Sedimentary structures can also be useful for interpretation of ancient environments. Structures such as desiccation cracks and bird's eye structure clearly indicate subaerial exposure of the sediment, thereby implying an intertidal or supratidal origin. Although other structures are not as useful for identifying depositional environments they can be used as supporting evidence along with other indicators (Table 11).

A rock type, by itself, is rarely indicative of a particular environment since most can commonly form in subtidal, intertidal or supratidal environments. Dolomite, especially where associated with evaporites, suggests a high intertidal or supratidal environment (Table 11) whereas micritic limestone is indicative of no particular environment (Table 11).

The conclusions outlined in this chapter, and more significantly the comparisons, are used in the following chapter to determine the succession of environments in the Read Bay Formation and the Leopold succession.

CHAPTER 6

SUCCESSION OF ENVIRONMENTS IN THE SILURIAN STRATA OF
NORTHERN SOMERSET ISLAND.Port Leopold area

The low generic diversity, the high numbers of individuals of any one taxon and the composition of the in situ fauna suggest that adverse marine conditions prevailed during deposition of the rocks of the Leopold succession. Some Silurian eurypterids occur in rocks containing marine fauna while others occur in rocks containing a restricted fauna indicating that they could survive in many different environments (Heckel, 1972). Commonly, they occur with ostracods, linguloid brachiopods and gastropods and apparently record transitional environments with highly fluctuating salinities trending towards the hypersaline side (Heckel, 1972, p. 284).

The fact that the in situ fauna (except for Howellella in unit A2) comprises forms which can survive in environments where fluctuating salinities are the norm suggests that the depositional environments in the Port Leopold area were ones of variable salinity. However, the presence of fragmentary corals and bryozoans in some units and Kirkidium (?) and nautiloids in unit J75 suggests that normal marine conditions existed nearby.

Most Recent linguloid brachiopods inhabit shallow water areas and are most common in tidal flat and intertidal environments (Craig, 1952; Chuang, 1962). Thus, the presence of Lingula in unit K49 suggests that the depositional environment was a shallow-water one.

The fauna suggests that the rocks of the Port Leopold area accumulated in transitional environments close to a normal marine environment. This would have required some off-shore feature which restricted circulation of the shoreward waters.

From the evidence available the nature of the topographic high is uncertain. However, stromatolites, which are so common in these sections, possibly were responsible for the restricted circulation in the landward environments. Stromatolites, such as those in marker bed 2, had sufficient lateral extent and amplitude to have acted as a shoal area which restricted circulation. In other stromatolitic units the individual stromatolites are not as high as those in marker bed 2 and probably did not have such a marked effect on the landward environment. However, if the original gradient of the sediment surface was low and the water depth minimal, the shoal area would not have had to be very high in order to restrict water circulation in the landward environments. Thus,

it is possible that the stromatolites in marker bed 1, which are only 0.33 m high, acted as a shoal area.

With the exception of oncolites and possibly some of the high domal forms the stromatolites of the Port Leopold area are taken to indicate intertidal environments. The stromatolite beds in the sections on the peninsula at Port Leopold are distinctive for three reasons: (1) the marker beds have a wide lateral extent in a north-south direction (Text-fig. 20), (2) each bed contains a distinctive stromatolitic form (p. 89) which is relatively constant throughout the lateral extent of the bed and (3) the base of each stromatolite bed, which is sharp, distinct and apparently horizontal, transects numerous facies (Text-fig. 20).

Probably each different form of stromatolite represents a slightly different response to environmental conditions. The amplitude of the stromatolites is indicative of the water depth or tidal range of an area. Thus, the stromatolites of differing amplitudes in these sections possibly represent differing positions in the tidal zone or varying water depths. The high domal stromatolites of marker bed 2 probably grew in a shallow subtidal environment. In contrast to these forms are the smaller stromatolites of marker bed 1 which probably grew in a low intertidal environment.

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Many stromatolites in the Port Leopold area grew on a conglomerate (p. 91). In some examples, the stromatolite initially developed as an oncolite around limestone clasts but subsequently became anchored on the subsurface and grew upward. In other examples the stromatolites grew on an erosional surface (e.g. unit A9, see p. 85) or possibly on a surface of non-deposition. In unit A9 the evidence for the presence of an erosional surface prior to the growth of the stromatolites is quite clear (p. 85).

However, at other localities the evidence is less clear. The sharp, distinct and apparently horizontal surfaces at the base of each stromatolite unit may be an erosional surface. This would explain the manner in which the stromatolitic units transect numerous different facies. Once the stromatolites became established, subsequent sedimentation rates were commonly very low, allowing the structure to grow upwards.

The association of stromatolites with erosional surfaces, surfaces of non-deposition or conglomerate suggests that these structures developed during periods when the environmental conditions were changing rapidly. Possibly, they represent phases of transgression.

Within the sections at Port Leopold there are indications

of periodic atmospheric exposure. The most obvious consequence of subaerial exposure is the development of desiccation cracks (p. 55). In some units of the Port Leopold sections the desiccation cracks which were initially developed in micritic limestone or dolomite were filled with coarser grained sediment (Pl. 10, fig. 2, p. 57) which commonly contains detrital quartz and dolomite. This coarse-grained sediment also formed thin laminae above the micritic limestone or dolomite. Thus, it would seem that the periods of subaerial exposure were periodically and temporarily interrupted by influxes of detrital material. Although it is difficult to determine whether the detrital material was wind- or water-borne the uniformity of lamina thickness suggests that it was related to the periodic influx of water. This may represent a regular tidal influx or may mark periods of exceptionally high tides which allowed the water to reach areas normally above the high tide mark.

In unit F11 the channels are distinctive because of their overhanging banks (Text-fig. 12). It is possible that subaerial exposure hardened the sediment sufficiently to allow the development of the overhanging banks as the channels were cut. As the fauna suggests that the area was in an intertidal environment, it is possible that many of the periods of exposure to the

atmosphere occurred between tides.

Many of the rocks in the Port Leopold area contain a large amount of detrital quartz, muscovite, plagioclase and microcline and many have been extensively dolomitized. The angular to subangular shape of the detrital grains, the poor degree of sorting and the presence of feldspar suggest that these sediments are immature and underwent little movement once the material had been introduced into the environment. The nature of the detrital material suggests that it was derived from a land mass relatively close to the environment of deposition.

Detrital material occurs scattered throughout the rock, concentrated as laminae (or beds) in interlaminated (or interbedded) units, or as distinct units of sandstone. The first two modes of occurrence suggest that the detrital material was constantly being introduced into the environment while the third mode of occurrence suggests that there were certain periods when large amounts of material was introduced. The concentration of the detrital material in the individual laminae or thin beds may mark periods of high winds, high tides, storms or flood conditions of rivers from nearby land masses. The thicker units of detrital material probably mark periods of sustained influx of detrital material and may

indicate periods of regression. Alternatively, the local concentrations of detrital material may indicate positions of old channels.

Once the detrital material was introduced into the environment its distribution was probably controlled by local current directions and the sites of local depressions. The material was probably subject to some degree of reworking but the immaturity of the sediment suggests that this was not extensive.

The textural relationship of the dolomite with the other components in the rock clearly point to it being of secondary origin. The uneven and local concentrations of the dolomite suggests that the dolomite distribution reflects an early diagenetic dolomitization. If the dolomitization was of late diagenetic origin then a more complete and even dolomitization of the original sediment might be expected. The reason for the localization of the dolomite is not readily apparent and there is no readily discernable pattern in terms of increasing or decreasing dolomite content (Text-fig. 22). However, in view of the distribution of dolomite in Recent environments this is to be expected. In many Recent environments the dolomitizing fluids are confined to old channels (p. 173) or to other minor depressions in the high intertidal and supratidal zones. Thus, the

dolomite in the rocks on the peninsula at Port Leopold can be interpreted as marking the sites of old channels or depressions. The degree of dolomitization is probably a reflection of the length of time the sediment was subjected to the dolomitizing fluids and the quantity of Mg ions in the dolomitizing fluids available for dolomite formation. Alternatively, the dolomitization phases during the evolution of the sedimentary environments may have been relatively few in number and the varying degrees of dolomitization may reflect the depth of penetration of the dolomitizing fluid. At any given stage in the dolomitization phase there was probably a decrease in the dolomite content at greater depths in the sediment. If this was the situation then, theoretically, the upward sequence would be limestone-dolomitic limestone-calcareous dolomite-dolomite. Although this sequence can be recognized in some instances, it is not always present. Indeed, in some instances the vertical sequence is the opposite in upward succession.

The conglomerate generally has a local distribution and probably occurs in the sites of old channels. In some examples the channel is small and evident in a single exposure, while in other examples the channel structure containing the conglomerate must be inferred.

The accurate interpretation of the paleogeography of the area is largely dependent upon determining the position of the contemporary shoreline. The Read Bay Formation which lies to the west of the Port Leopold area (Text-fig. 2, p. 4) may be the lateral equivalent of the Leopold Formation (see chapter 7 for further discussion). Most of the strata in the Read Bay Formation accumulated in subtidal environments, and consequently an off-shore subtidal area lay generally to the west separated by the 'transitional' environments of the Leopold succession from a shoreline generally to the east. This suggests that the shoreline may have had an approximate north-south orientation. Some local evidence at Port Leopold supports this suggestion. The stromatolite beds on the peninsula at Port Leopold display no north-south variation in form over a distance of 2,200 m although marker bed 1 disappears south of section H (Text-fig. 20, p. 76). If the shoreline lay to the north or to the south then some degree of variation would be expected, reflecting different positions in the intertidal zone.

The distribution of the various rock types also conflicts with an interpretation placing a shoreline to the south or north. There is no apparent increase in the quantity of detrital

material in either direction. Indeed, the greatest concentration of calcareous sandstone is in section D (Text-fig. 22, p. 82).

Dolomitic rocks are present in all the sections but are common in sections G and F suggesting that the southern part of the area was more favourable for dolomitization. Since dolomitization most commonly occurs in shoreward environments, the southern sections appear to contain rocks of high intertidal and supratidal origin. This suggests that local irregularities in the coastline may have complicated the situation. It is possible that local embayments or promontories may explain the more abundant dolomite in the more southerly sections and the disappearance of many of the stromatolite beds.

Although paleocurrent data is sparse there is some evidence that the prevailing paleocurrent direction was generally toward the south or south west. In some modern examples, the long axes of elongate stromatolites are oriented perpendicular to the shoreline although locally this may vary slightly due to varying directions of onshore currents. Evidence such as channel trends, current bedding and imbricated conglomerate also suggests paleocurrents toward the south or south-west. Thus, the north-south trend of the shoreline is supported by the east-west elongation of the stromatolites in unit G46 and the sedimentary structures.

If the shoreline was aligned north-south there is still a problem in explaining the lateral variation displayed in the strata on the peninsula at Port Leopold. Superimposed on the lateral variation at any one level within the section are the vertical variations that are primarily a response to the lateral migration of the various environments, which is controlled by varying positions of the shoreline and changes in sea level. The rock types show distinct differences in distribution. The most noticeable difference is between section E and sections to the north and south. Section E contains a higher percentage of micritic limestone than any other section (Text-fig. 21, p. 80). Within the section, dolomite occurs as a minor constituent in 23% of the rocks while detrital material occurs in 33% of the rocks, usually as a minor constituent.

The problem is therefore one of explaining the lateral variations in the rock types in a series of sections parallel or sub-parallel to the ancient shoreline. Section E possibly marks the position of a topographic high and the sections on either side may represent depressions or channels. Such an arrangement would explain the low content of detrital material in section E as it would probably have been concentrated in the depressions.

Similarly, if the dolomitization pattern was controlled by the distribution of the old channels (p.173) then the low dolomite content in section E is also explained.

The unit immediately below marker bed 2 in section E is micritic limestone but in sections B and D is intraformational conglomerate (Text-fig. 22). Similarly, at the 25 m level in section E there is micritic limestone while at the same level in sections B and D there is sandstone and conglomerate. Thus, the gross changes reflected in Text-figure 21 are supported by local comparisons.

It is possible that the conglomerate and sandstone units accumulated in channels on either side of section E.

Section C is slightly anomalous as a high percentage of its rocks contain detrital material but only 25% contain secondary dolomite. However, this may be an effect of the fact that major parts of the section are unexposed (Text-fig. 15).

The discussion so far has been based on the assumption that the shoreline was aligned in a generally north-south direction.

However, in most Recent carbonate environments (e.g. Persian Gulf) the distribution of islands, channels and shoal areas and an extremely irregular coastline result in extremely complicated facies patterns.

It is probable that the paleogeography of the Port Leopold area was

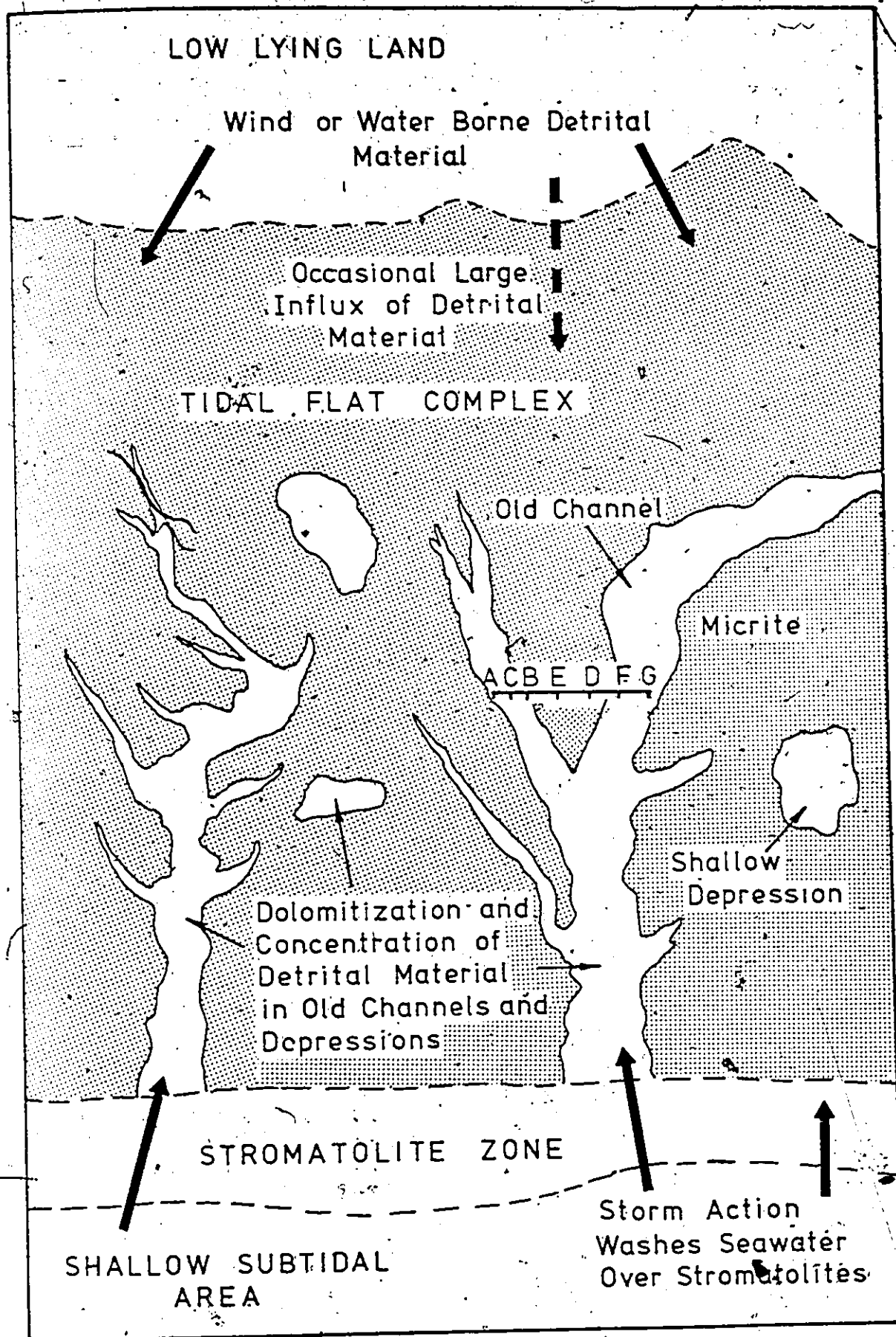
equally complex and that the rapid facies changes of the area are a reflection of that complexity.

The stromatolites probably played an important role since they had the ability to restrict circulation of waters in landward environments. The landward environments which probably occupied a tidal flat complex had an uneven surface due to the presence of numerous channels and depressions (Text-fig. 40). The channels were probably the sites of the most vigorous water movement and consequently concentrated most of the detrital material (Text-fig. 40). At the same time the channels and depressions provided areas where water could settle. Subsequent evaporation led to an increase in the Mg/Ca ratio of the water. Consequently, dolomitization of the original sediment was common in the local channels and depressions (Text-fig. 40).

The local channels and depressions were gradually filled due to higher rates of deposition at these localities. Each continuous stromatolite bed may mark a transgressive phase during the evolution of the area.

Text-figure 40

Depositional model for Silurian rocks of the Port Leopold area. Shaded areas of tidal flat denotes area least susceptible to dolomitization and accumulation of detrital material. Distance from stromatolite zone to low-lying land mass was probably of the order of 3-5 miles while the water depth was minimal. Stromatolite zone was probably a shoal area which came to water surface. Line marked A-C-B-E-D-F-G indicates possible position of sections A, B, C, D, E, F and G of the Port Leopold area.



Cape Admiral M'Clintock

The section at Cape Admiral-M'Clintock can be divided into 2 portions on the basis of rock types, sedimentary structures, generic diversity and faunal composition (Text-fig. 41a).

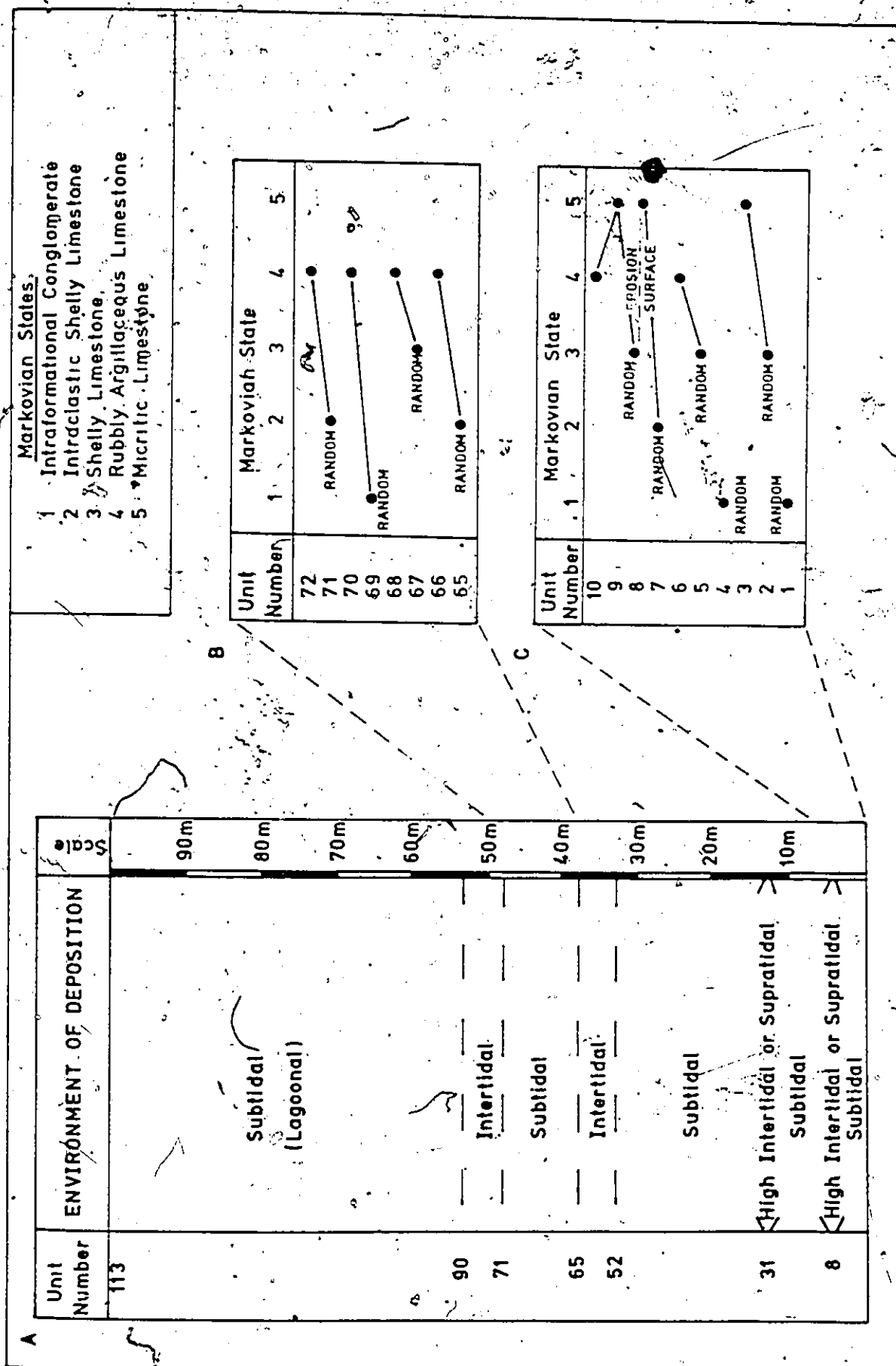
Units M1-M8 The basal units represent sediments which accumulated in subtidal environments. Progressive shallowing eventually resulted in the formation of the erosion surface above unit M8.

Units M9-M31 Subsequent to the formation of the erosion surface there was a return to subtidal environments in which the rubbly argillaceous limestone with Atrypella (unit M10) accumulated. The subsequent shallowing of the water caused a progressive change in the composition of the fauna (p.100) and eventually led to the formation of the erosion surface of unit M31.

Markov Chain analysis has demonstrated that the intraformational conglomerate, intraclastic shelly limestone and shelly limestone had a low probability of succeeding any of the other Markovian states (p.139). Thus, a trace of the succession of these parts of the section (M1-M8 and M9-M31) shows a series of 'breaks' in the succession where the intraformational conglomerate, intraclastic shelly limestone or shelly limestone occur. This type of sequence is typified by the trace for unit M1-M10 shown in Text-figure 41.

Text-figure 41

- (A) Succession of environments represented by the rocks in section M of the Cape Admiral M'Clintock area.
- (B) Trace of succession from unit 65 to 72 of section M. Solid lines indicate that transition is compatible with transitions predicted by the Markovian cycle depicted in Text-figure 38a.
- (C) Trace of succession from units 1 to 10 of section M. Solid lines indicate that transition is compatible with transitions predicted by the Markovian cycle depicted in Text-figure 38a.



Units M32-M52, M66-M71, M91-M113 These parts of the section are characterized by thick units of rubbly argillaceous limestone which commonly contain a profuse fauna (especially Atrypa) and thin units of intraformational conglomerate, intraclastic shelly limestone and shelly limestone. Such features, as well as the lack of shallow water sedimentary structures, suggest that the original sediment accumulated in tectonically and hydrodynamically stable environments. The detrital material (quartz, muscovite and possibly dolomite) is clay- to silt-sized, suggesting that water movement was minimal. Consequently, it is suggested that the units of rubbly argillaceous limestone represent sediments that accumulated in a quiet water, subtidal environment in which the water was 'murky' due to the presence of the fine-grained detrital material.

Markov Chain analysis demonstrated that the intraformational conglomerate, the intraclastic shelly limestone and the shelly limestone had a low probability of succeeding any other state, suggesting that their occurrence was random (p.139). These rocks are probably storm deposits. If the water depth in the subtidal environment was too great then storms would not have affected the sediment on the sea floor. Thus, the environment of deposition was probably a calm, shallow-water lagoon that was periodically affected by storm action.

Units M53-M65 and M72-90 These parts of the section are characterized by a rapidly alternating sequence of thin units of rubbly argillaceous limestone (devoid of fauna), intraformational conglomerate, intraclastic shelly limestone and shelly limestone. It is possible that these parts of the section represent intertidal conditions. However, the lack of shallow-water sedimentary structures and dolomitization suggests that these rocks represent low intertidal rather than high intertidal or supratidal environments.

Garnier Bay - Section GA

Section GA can be divided into four distinct portions on the basis of rock types, sedimentary structures and faunal distribution (Text-fig. 42a).

Units GA1-GA14 The restricted nature of the fauna, the presence of large amounts of sand-sized detrital material, the extensive dolomitization of many of the rocks and the sedimentary structures (p.108 and Text-fig. 28) all suggest that the rocks of units GA1 to GA14 accumulated in an intertidal environment. The sedimentary structures suggest that the area was periodically subjected to more vigorous water movement (forming the ripples) and periods of subaerial exposure (forming the bird's eye structure). Unit GA7 (pelletoidal limestone) is the exception to the general environmental

Text-figure 42

- (A) Succession of environments represented by the rocks in section GA of the Garnier Bay area.
- (B) Comparison of transitions from units GA38 to GA45 with transitions predicted by the Markovian cycle depicted in Text-figure 38b. Solid lines indicate that transitions are compatible with that cycle.
- (C) Comparison of transitions from units GA1 to GA14 with transitions predicted by the Markovian cycles depicted in Text-figures 38b (cycle 1) and 38c (cycle 2). Solid lines indicate that transitions are compatible with those predicted by the cycles.

Unit Number	Environment of Deposition	Scale
45	Subtidal HIGH ENERGY	180m 160m
38	Intertidal	140m
31	Subtidal	120m 100m
14	Intertidal	80m 60m 40m 20m

A

Unit Number	Cycle 1		
	Markovian State 1	2	3
45	●		
44		●	
43		●	
42		●	●
41			●
40		●	
39			●
38			●

Cycle 1		Cycle 2	
Unit Number	Markovian State	Markovian State	
14	1	1	
13	4	6	
12	5	7	
11	6	8	
10	1	9	
9	4		
8	5		
7	6		
6	1		
5	4		
4	5		
3	6		
2	1		
1	4		

6

Markovian State

- 1 Limestone
- 2 Rubbly Argillaceous Limestone
- 3 Shelly Limestone
- 4 2 Components
- 5 3 Components
- 6 Intraformational Conglomerate
- 7 Sandstone
- 8 Calcareous Sandstone
- 9 Dolomitic Limestone

Cycle 1 is Text-figure b

character of the section since it appears to have formed in a subtidal zone. This thin unit (0.10 m) may represent a local channel or slight encroachment of subtidal conditions onto the lower intertidal areas.

The trace of the succession of rock types in this part of the succession according to either Markovian cycle (Text-figs. 38b and 38c) demonstrates that the only major break in the sequence is the occurrence of the intraformational conglomerate in unit GA11. The conglomerate probably represents the product of a storm or an exceptionally high tide.

Units GA15-GA31 Units GA15-GA31 contrast sharply to the previous units in having: (1) a lower content of detrital material, (2) a lower degree of dolomitization and (3) a higher generic diversity (Text-fig. 28 and p. 108). The scarcity of sand-sized detrital material, the relatively high generic diversity and the composition of the fauna all suggest that these rocks accumulated in subtidal environments.

In unit GA16 Megalomus valves occur in a convex-up position suggesting that there was some water movement.

Units GA32-GA38 These units are similar to units GA15-GA31 except that they appear to be devoid of fossils (Text-fig. 28). With the exception of unit GA36 which is 6 m thick, the units in this part

of the section are relatively thin and rapidly alternating. The rock types, the lack of fauna and the rapid alternation of the rock types suggests that these rocks accumulated in low intertidal or high intertidal environments. The lack of shallow-water sedimentary structures and the low degree of dolomitization suggests the former.

Units GA39-GA45 Units GA39-GA45 are similar to units GA15-GA31 in having a relatively high generic diversity and similar rock types.

Consequently, it is possible that these rocks accumulated in subtidal environments. However, a richer coral fauna in units GA39-GA45 suggests that there were some differences in the type of subtidal environment. The fact that all the colonial corals in unit GA45, irrespective of genera, have a flat 'pancake' form suggests that they lived in very turbulent water which curtailed their vertical growth but encouraged their lateral growth. The water turbulence attained a maximum development during accumulation of unit GA45.

The trace of this part of the succession according to the theoretical Markovian cycle (cycle 1 - Text-fig. 42b) demonstrates that there are no major breaks from the sequence predicted by cycle 1 (Text-fig. 38b).

Garnier Bay - Section GB.

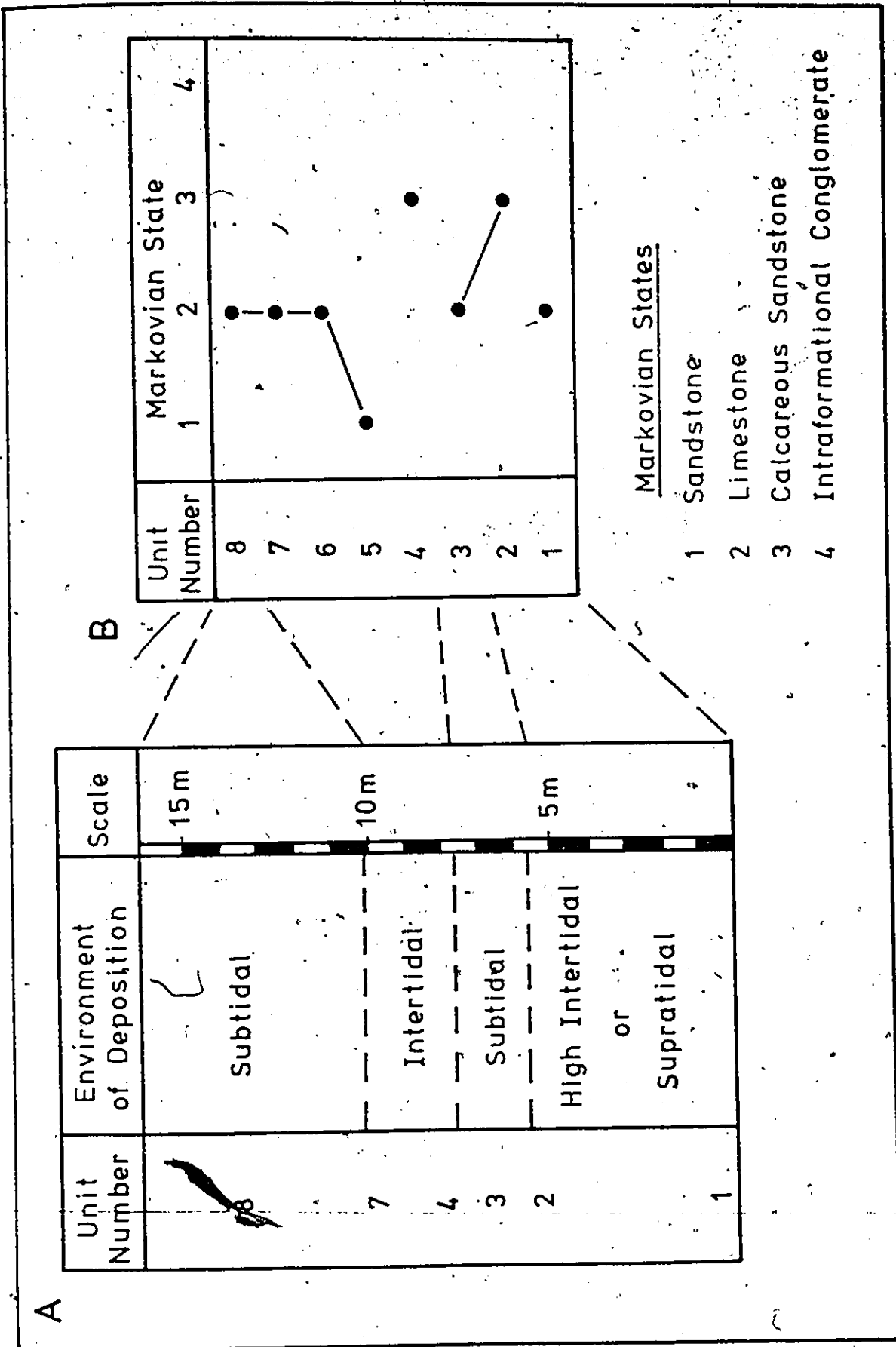
The rock types, the sedimentary structures, the generic diversity of the various units and the faunal composition suggest that most of the rocks in section GB accumulated in intertidal environments (Text-fig. 43). The presence of ripples on many of the bedding surfaces suggests that there was considerable water movement during the period of deposition. Probably the high degree of water movement also brought the detrital material into the environment. The lack of macrofossils suggests that conditions were inhospitable for animal life. The presence of desiccation cracks in unit GB1 indicates that the original sediments were periodically exposed to the atmosphere.

The rubbly argillaceous limestones of units GB3 and GB8 which contain small (less than 1.25 cms long) Atrypella, probably accumulated in subtidal environments. The absence of shallow-water sedimentary structures in these units tends to support this assessment.

Comparison of the actual transitions and the transitions predicted by Markov Chain analysis (Text-fig. 38b) demonstrates that the sandstone and calcareous sandstone of units GB1, GB3 and GB5 occur out of sequence. Possibly these sandstones represent periods

Text-figure 43

- (A) Succession of environments represented by the rocks in section GB of the Garnier Bay area.
- (B) Comparison of transitions from units GB1 to GB8 with transitions predicted by Markovian cycle depicted in Text-figure 38c.
Solid lines indicate that transitions are compatible with that cycle.



of high energy which were associated with storm action or unusually high tides.

Garnier Bay - Sections GD and GE

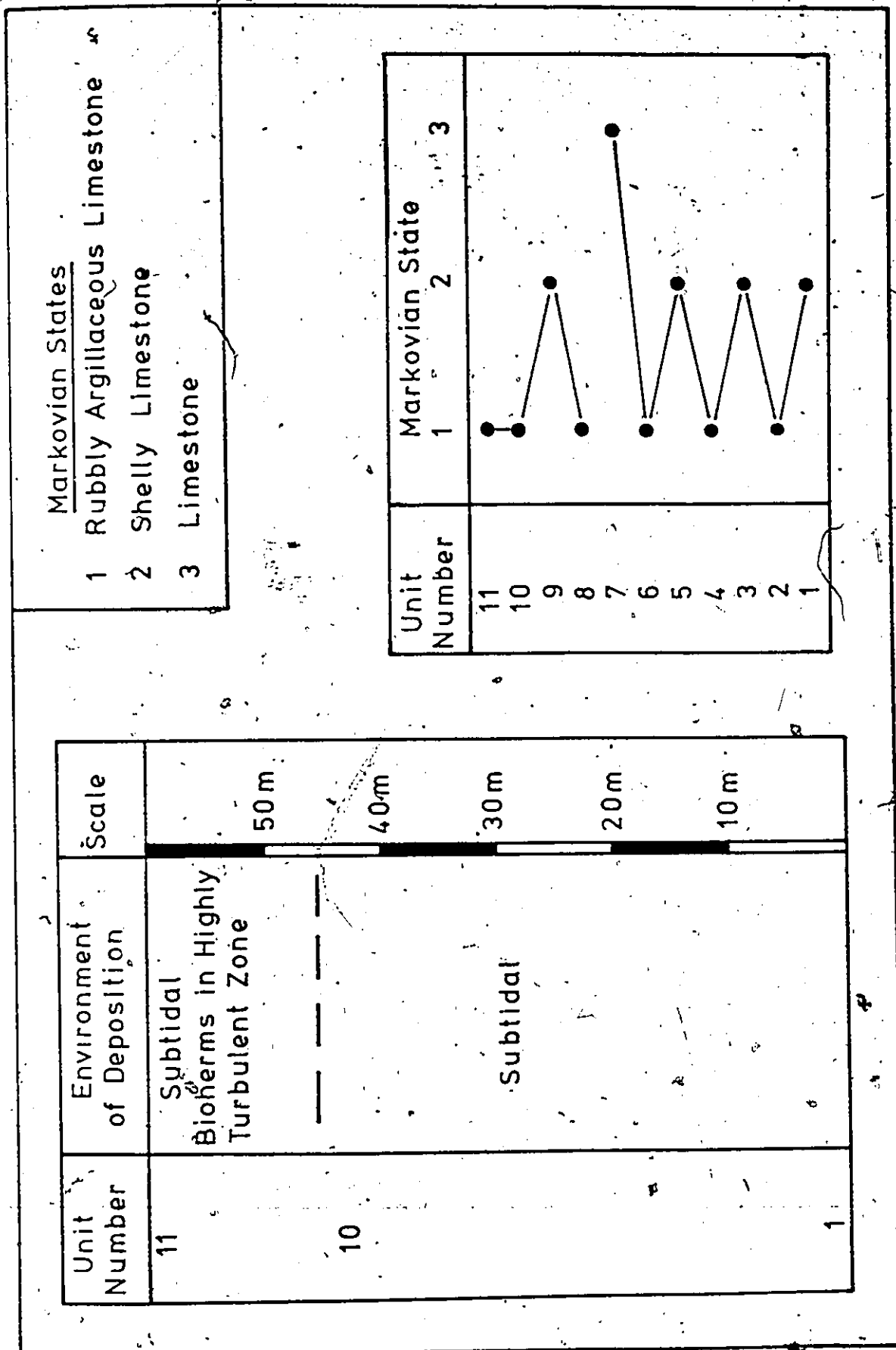
The presence of an abundant, diverse fauna in most of the units of these sections suggests that the rocks in these sections accumulated in subtidal environments. In section GD two parts can be recognized (Text-fig. 44).

Units GD1-GD10 Brachiopods are the dominant element of the in situ fauna of this part of the section, although locally, as in the basal part of unit GD10, trilobites predominate. The units of rubbly argillaceous limestone with the fauna of brachiopods and trilobites probably represent sediments that accumulated in subtidal environments. The general succession of rubbly argillaceous limestone is interrupted by the occurrence of shelly limestone units (Text-fig. 30) which probably represent periods of higher energy conditions than those associated with the units of rubbly argillaceous limestone.

Unit GD11 Unit GD11 consists of two distinct rock types, the reefoidal limestone of the bioherms and the rubbly argillaceous limestone flanking the bioherms. This unit is characterized by a profuse fauna of pancake-shaped colonial corals suggesting that the original environment of deposition was very turbulent. The reason

Text-figure 44

- (A) Succession of environments represented by the rocks in section GD of the Garnier Bay area.
- (B) Comparison of transitions from units from units GD1 to GD11 with transitions predicted by Markovian cycle depicted in Text-figure 38b. Solid lines indicate that transitions are compatible with that cycle.



for the dominance of corals in unit GD11 compared to the dominance of brachiopods and trilobites in the lower part of the section is unclear but it may be related to more favourable salinity levels, a higher content of oxygen in the water or more abundant food supply. The only evidence of change in the environmental conditions is of more turbulent waters during the time when unit GD11 was forming. The higher degree of turbulence would have created a more even distribution of oxygen through the water thereby creating more favourable conditions for coral growth.

If the actual transitions in section GD are compared to the transitions predicted by the Markov Chain it is apparent that there is no major break in the succession (Text-fig. 44b).

Section GE has a succession of rock types comparable to that in section GD and is thus considered to represent a similar succession of environmental conditions. However, there are no bioherms in the upper part of the section.

Correlation of sections in the Garnier Bay area

Correlation of the various sections in the Garnier Bay area is difficult because of faulting and lack of good stratigraphic controls. However, while reliable correlation between the sections cannot be made on the basis of available paleontological evidence

certain lithological correlations can be suggested.

Section GA, which is the most complete in the area, can be divided into four distinct environmental portions (p. 212). The basal portion contains rocks that accumulated in intertidal and supratidal conditions, a succession that is very similar to that in section GB (Text-fig. 29). The basal part of the G.S.C. section number 10 (McMillan, 1963) contains rocks which indicate a similar type of environment.

The central two portions of section GA are difficult to correlate with the other sections which are not as continuous. However, these parts of the section are possibly correlatable with the basal parts of sections GD and GE.

The upper portion of section GA and section GD are both characterized by a diverse coral-dominated fauna. The sections differ in that the upper part of section GD is characterized by bioherms while the upper part of section GA is not. The individual colonies of corals in the upper part of sections GD and GA are all pancake-shaped and therefore probably lived in highly turbulent environments.

Cunningham Inlet area - Section CA

The lithologies, sedimentary structures and the restricted fauna (Text-fig. 31) suggest that most of the rocks in section CA accumulated in intertidal and/or supratidal environments.

Several features in units CA1-CA14, namely the dolomitic and sandy nature of the rocks (Text-fig. 31), the erosion surface in unit CA5 and the absence of fauna, all suggest that the sediments accumulated in high intertidal and/or supratidal environments. The adverse conditions of such environments probably prevented habitation by animals. The units of shelly limestone probably represent periods of high energy during which shelly material was washed into these environments from elsewhere.

The lithology of units above CA14 is very similar to the lithology of units CA1-CA14 (Text-fig. 31), but the rocks commonly contain ostracods and/or gastropods. The presence of some in situ fauna suggests that the environmental conditions during the formation of these units were not quite as severe as during the accumulation of units CA1-CA14.

Cunningham Inlet area - section CD

The lithologies and profuse fauna in the rubbly argillaceous limestone suggests that these rocks accumulated in subtidal conditions.

The presence of many small Atrypella in some units suggests that conditions were fluctuating rapidly enough to kill the populations before they reached maturity. The stromatoporoids from unit CD4, which are very high compared to their base diameter, contrast sharply with the pancake-shaped corals in units GD11 and GA45 at Garnier Bay. Their relatively high form suggests that growth was primarily upward. Probably, the reason for the immaturity of the Atrypella populations and the high form of the stromatoporoids was a high sedimentation rate. This would have buried and killed the brachiopods and prevented the stromatoporoids from extending laterally. The nature of the rocks and the form of the stromatoporoids suggests that the majority of the rocks in this section accumulated in quiet water subtidal environments with high sedimentation rates.

The presence of dolomite between units CD4 and CD6 is anomalous since it has been suggested previously (p.176) that dolomite is probably representative of intertidal or supratidal conditions. However, the covered interval between units CD4 and CD6 possibly contains a succession that is indicative of this type of environment.

Cunningham Inlet area - Section CE

Section CE can be divided into three portions on the basis of the rock types, sedimentary structures and faunal distribution.

(Text-fig. 45).

Units CE1-CE14 The dolomitic and sandy nature of the rocks, the presence of ripples in some units, the erosional surface in unit CE5 and the apparent absence of fauna suggests that the rocks in this part of the succession accumulated in high intertidal and/or supratidal environments. The presence of ripples in some of the units suggests that there was considerable water movement in the original environment. The absence of fauna from these units indicates that the environmental conditions prevented habitation by animals.

Units CE15-CE26 Units CE15-CE26 contain a fauna dominated by small Atrypella suggesting that the depositional environments were more favourable for animal life than they were during the formation of units CE1-CE14. However, the mottled dolomite-limestone (Type V) and the small size of the Atrypella suggests that the environment was probably low intertidal and/or shallow subtidal. The scree specimens of corals which presumably came from the covered interval between units CE18 and CE19 tend to confirm that subtidal conditions were established at this stage in the evolution of the area.

Text-figure 45

Succession of environments represented by the rocks in section CE
of the Cunningham Inlet area.

Unit Number	Environment of Deposition	Scale
42	Low (?) Intertidal	140m 120m 100m
27	Shallow Subtidal	80m 60m 40m
15	High Intertidal and/or Supratidal	20m
1		

Units CE27-CE42 Units CE27-CE42 are similar to units CE1-CE14 in that they are apparently devoid of fauna. However, in contrast to units CE1-CE14 they have a lower degree of dolomitization, a lower content of sand-sized detrital material and no ^Esedimentary structures such as ripples or erosion surfaces. Consequently, it is suggested that this succession of argillaceous limestone, rubbly argillaceous limestone and micritic limestone (Text-fig. 33) accumulated in low intertidal and/or shallow subtidal environments which were unsuitable for colonization by animals and in which dolomite would not form.

The reason for the lack of fauna in these units is not readily apparent.

Cunningham Inlet - Section CF

The in situ fauna of this section is restricted to ostracods and gastropods suggesting that most of the rocks in this section accumulated in intertidal and/or supratidal environments. This assessment is supported by the occurrence of dolomite, calcareous dolomite and dolomitic limestone.

Markov Chain analysis demonstrated that there is a marked cyclicity in the succession of rocks in this section. The sequence dolomite-calcareous dolomite-stromatolite-dolomitic limestone, limestone is present from unit CF3 to CF6, from unit CF15 to CF20

and in part from unit CF11 to CF13. The in situ fauna of ostracods and gastropods occur only in the dolomitic limestone and the limestone.

The dolomite probably represents sediment that accumulated in high intertidal and/or supratidal environments in which conditions were suitable for dolomitization (Text-fig. 46). The limestone and dolomitic limestone probably accumulated in low intertidal or shallow subtidal environments which were unsuitable for extensive dolomitization (Text-fig. 46). This environment was inhabited by ostracods and gastropods. The low amplitude stromatolites which appear to separate the two contrasting environments suggests that the environments were characterized by a low tidal amplitude.

With the progressive subsidence of the area the facies migrated laterally, eventually resulting in the sequence now seen (Text-fig. 33). The sequence of events was repeated three times during the period of time it took for the sediments of this section to accumulate. There is some indication that the cycle could also operate in a reverse direction (i.e. during regression) as evident by the succession of dolomitic limestone above limestone. However, the return to the high intertidal/supratidal environment was in some cases quite rapid as shown by the major break in the succession between units CF14 and CF15 (Text-fig. 46b).

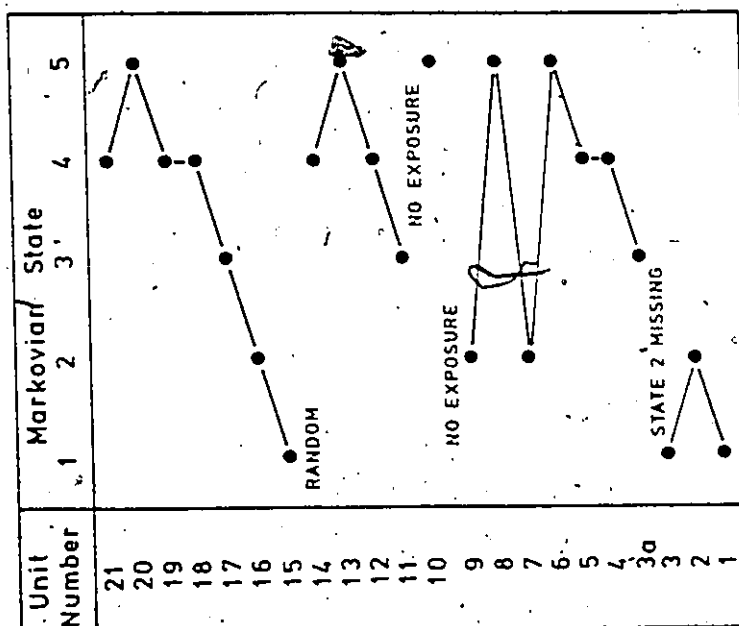
Text-figure 46

- (A) Succession of environments represented by the rocks in section CF of the Cunningham Inlet area.
- (B) Comparison of transitions from units CF1 to CF21 with transitions predicted by Markovian cycle in Text-figure 39. Solid lines indicate that transitions are compatible with that cycle.

Markovian States

- 1 Dolomite
- 2 Calcareous Dolomite
- 3 Stromatolite
- 4 Dolomitic Limestone
- 5 Limestone

Unit Number	Environment of Deposition	Scale
21	Low Intertidal	40m
16	High Intertidal	30m
10	Low Intertidal	20m
1	High Intertidal	10m



Pressure Point area

The nature of the fauna, the rock types and the lack of shallow-water sedimentary structures suggests that the rocks in this section accumulated in subtidal environments.

There is little argillaceous material in the rocks except in the basal units of section X. Sand-sized detrital quartz which occurs with some muscovite in units X21 and Y13 probably represent minor changes in the environmental conditions. They probably represent the increased energy levels that were created by storm action.

The conditions were such that dolomitization of the original micritic limestone and biomicrite occurred at an early stage in the diagenetic history of the sediment (p.163).

CHAPTER 7

SILURIAN STRATIGRAPHY AND PALEOGEOGRAPHY OF THE CANADIAN ARCTIC

Basis of Silurian stratigraphy

While the main purpose of this chapter is to examine the correlation of Silurian strata in the Canadian Arctic, it is necessary to first understand the stratigraphic subdivision of Silurian strata in other better known areas.

During the Silurian Period two major sedimentary environments developed, namely the geosynclinal environment (or 'Rhenish facies' of Bouček, 1965) characterized by graptolitic shales and the shelf or platform environment characterized by carbonate sediments and a shelly fauna. Murchison (1854 and 1859) first delineated the Silurian Period in the British Isles on the basis of the geosynclinal graptolitic beds. Lapworth (1879-1880) initially defined 11 graptolitic zones in the Silurian whereas Elles and Woods (1901-1918) further divided the strata and defined 21 graptolite zones. Berry and Boucot (1970) confirmed such a figure. The highest graptolite zone in the British Isles is that of Monograptus leintwardinensis. As a result of such work it was often assumed that any monograptid graptolite automatically indicated a Silurian age.

The Silurian period was originally divided into three main subdivisions, from oldest to youngest, the Llandoveryan, the Wenlockian and the Ludlovian. These subdivisions contain their own characteristic graptolite zones and were initially defined in type areas such as Dobbs Lynn in the Southern Uplands of Scotland (Lapworth's classical area). However, such a system poses many problems (Strachan, 1960). The most notable example is that of the Cyrtograptus murchisoni zone which Lapworth originally defined as being the basal zone of the Wenlockian, but outside the type area the species is rarely found and the base of the Wenlockian more commonly has been defined by the base of the Cyrtograptus centrifugus zone.

Following the early work of the British geologists, others studied the graptolite sequences from other parts of the world. The most notable sections in this respect are those of the Barrandian areas of Czechoslovakia, the German sequences and the Russian sequences including those in the Zeravshanskii Khrebets range of Middle Asia and those in the Kazakhstan area (Obut, 1968; Obut et al., 1968). In North America Jackson and Lenz (1962) described the Road River Formation in the Yukon Territory. All these areas have graptolite zones which are younger than the Monograptus leintwardinensis zone of the

British Isles. Tomczyk (1968) has shown that there is a marked facies change in the Polish succession at about the time of the Monograptus leintwardinensis zone.

The immediate reaction of many workers was to include these higher graptolite zones within the Silurian Period. However, many of the higher graptolite zones occur in beds which either contain, or are near beds which contain, a brachiopod fauna that is of Devonian form (Boucot and Pankiwskyj, 1962). Thus, it was demonstrated that some of the younger graptolites must be of Devonian age. Such a hypothesis has been confirmed many times since 1960 and at present there is little doubt as to the existence of Devonian monograptid graptolites.

The number of Devonian graptolites is largely a function of the position of the Silurian-Devonian boundary. Since the Silurian Period was first defined in 1834 the position of the upper boundary has fluctuated greatly. Murchison himself set the stage for such fluctuations by varying the position of the boundary in his various publications. For further information on the varying position of the Silurian-Devonian boundary the reader is referred to White (1950). After giving an excellent review of previous literature on the

subject White placed the Siluro-Devonian boundary at the base of the Ludlow Bone Bed. Subsequently, many workers agreed with such a position (including Holland, 1962, 1965; Shaw, 1969). However, other workers have shown that the Ludlow Bone Bed does not everywhere mark the most notable faunal change. For example, Allen and Tarlo (1963) have shown that the most notable expansion in the vertebrate fauna occurred at the beginning of the Dittonian and that the Downtonian forms are very similar to the Ludlovian forms. Shaw (1969) considered the ostracod fauna of the Ludlow area and showed that no faunal breaks could be detected in areas where the Ludlow Bone Bed was not developed.

The Caledonian earth movements which started at the end of the Silurian were responsible for the change from ~~granitic~~ facies to continental facies in many areas. Although the continental facies are commonly associated with the Devonian Period, it seems to be generally forgotten that some of the continental facies may be Silurian and the facies equivalent to the ~~geosynclinal~~ deposits.

An important aspect of Silurian geology which many people ignored for many years is that of the stratigraphy and fauna of the carbonate shelf facies. The geosynclinal facies were of small areal extent compared with the carbonate shelf facies (Perry and Boucot, 1967). Yet, despite this, work on stratigraphic zonation of such areas has only been

carried out within the last two decades. The most important areas in this respect are the Podolian sections of Russia (Obruchev and Karatayute, 1968; Boucot and Pankiowskyj, 1962; Abushik, 1967; Nikiforova et al., 1967), the reefal areas of Götland (Martinsson, 1967), the shelf area of Czechoslovakia (Boucek et al., 1967) and the Ludlow area of the British Isles (Holland et al., 1959; Holland, 1962; Lawson, 1960; Straw, 1962; Shaw, 1969). These studies are cited as an indication of the amount of evidence compiled, upon which the following general conclusions are made.

Boucot and Pankiowskyj (1962) considered the faunal lists of the Podolian area of Russia and placed the Siluro-Devonian boundary in the Skalian strata (this unit being post-Ludlovian but pre-Gedinnian in age). Thus, a situation arose whereby a group of strata existed which was neither Ludlovian nor Gedinnian in age.

As a result of Boucot and Pankiowskyj's work other areas were studied and the existence of post-Ludlovian, pre-Gedinnian strata became increasingly obvious. It became apparent that these beds are characterized by a fauna which is predominantly of Silurian elements but unlike the Ludlovian fauna it has forms which are of Devonian aspect. The problem thus becomes a philosophical one, for the question of what constitutes a stratigraphic boundary and on what grounds it

should be delineated becomes pertinent.

Is the lower boundary of a period to be drawn on the basis of the incoming of new, important faunal elements or is it to be drawn where a marked change in the total fauna occurs? Such considerations are of vital importance for they will affect the faunal composition of the Silurian and Devonian Periods. Many authors consider that the incoming of new faunal elements is sufficient to constitute the beginning of a new period. However, if the lower Devonian boundary is to coincide with the first appearance of fauna of Devonian aspect then no consideration is given to the overall composition of the fauna which may still be predominantly Silurian in character. The most satisfactory solution must be one which considers the composition of the whole fauna and not only one aspect of the fauna.

Thus, the post-Ludlovian, pre-Gedinnian strata which contain a mixed fauna of Silurian and Devonian elements should be included in the Silurian (Berry and Boucot, 1970).

If such a division exists in the shelf deposits then it must also exist in the geosynclinal deposits. Furthermore, this post-Ludlovian, pre-Gedinnian stage must be characterized by some particular monograptid graptolite zones. Of the monograptid graptolite

zones which occur above the Monograptus leintwardinensis zone only the Sactograptus fritschi linearis, Pristograptus fragmentalis and M. formosus zones can be considered of Ludlovian age (Sokolov and Polenova, 1968). Thus, any zones above that of M. formosus can be considered post-Ludlovian in age.

In an effort to solve the problem of where the Siluro-Devonian boundary should be placed two conferences have been held, one in Bonn and Brussels in 1960 and the other in Prague in 1961. The consensus from the later of these conferences is one which was emphasized by McLaren (1969), namely that the base of the Monograptus uniformis zone should mark the base of the Devonian strata. As McLaren pointed out, this zone marks a distinctive stage in the evolution of the graptolites. The monograptids above the M. uniformis zone are entirely biform and uniform species with hooked thecae of a type similar to those of Monograptus uncinatus. In addition, this zone marks important changes in other groups as summarized below (McLaren, 1969, p. 27):

Conodonts: Iseriodus woschmidtii appears for the first time in the Monograptus uniformis zone.

Corals: Some taxa become extinct, e.g. the families Halysitidae and Proporida, the subfamily Kodonophyllidae and some

Cystiphyllidae. Squamulate Favosites are widely associated with the Monograptus uniformis zone. Thamnopora and Pleurodictium make their first appearance. Among the rugose corals Pseudoplasmodora and Grypophyllum increase in abundance.

Brachiopods: Taxa appearing for the first time include Terebratulida along with the genera Ivdelinia, Cymostrophia and Schizophoria.

Trilobites: Encrinuridae and Raphiophoridae become extinct near this level.

Ostracods: Many genera become extinct while many new genera appear, as documented by Abushik (1967).

Crinoids: Scyphocrinites elegans is widespread and is found commonly at the base of the M. uniformis zone.

Vertebrates: Fossil fish are difficult to evaluate due to the incomplete knowledge of their age range.

The post-Ludlovian, pre-Gedinnian division is thus becoming widely accepted and has been identified at many localities. Many names have been suggested for it. Boucot and Pankiwskyj (1962) suggested the name Skalian. Khalfin (1968) endorsed such a procedure and suggested that it was valid since it has a definite and 'manysided' paleontological character in both marine and lagoonal facies and it

is a proven gap in the International Stratigraphic Sequence.

Khalifin (1968) considered that it merited a separate rank or stage because the fauna of the strata is significantly different from that found in Ludlovian and Gedinian strata. He suggested that the name Skalian was suitable but acknowledged that its inclusion within the Silurian or Devonian Period should be decided by the International Stratigraphic Commission.

Berry and Boucot (1970) in their consideration of the Silurian rocks of North America included this stage in the Silurian sequence to the opinion expressed by Boucot and Parkhurst (1970) and Khalifin (1968) they termed it the Podolian stage. They defined the base of the Podolian as coinciding with the first appearance of Parthyris quadrispinus.

The Skalian stage is the equivalent of the Podolian beds of the Bohemian sequence, the Podlaissian beds of Poland, the upper Ordovician beds of the Barrandian section and possibly the Downtonian of the British Isles.

Read Bay Formation at its type locality

The Read Bay Formation derives its name from its type locality along the shores of Read Bay on the east coast of Cornwallis Island. This formation was established by Thorsteinsson (1956) who

defined it to include all the strata which occur with conformable and gradational contacts between the underlying Allen Bay Formation and the overlying Snowblind Bay Formation. The strata are essentially calcareous with the dominant rock types being limestone and argillaceous limestone along with minor amounts of dolomite, sandstone, calcareous sandstone and shale.

Thorsteinsson (1958) on the basis of map measurements suggested that the Read Bay Formation at the type locality has a thickness of 8,500 ft (approx. 2,600 m). Within this thickness Thorsteinsson (1958, p. 48) delineated 4 subdivisions (A, B, C and D) to which he gave member status while acknowledging that further study might show that these members should be elevated to formation status and the Read Bay Formation to group status. Up to the present time the status of these divisions has remained unchanged.

According to Thorsteinsson (1958) the Read Bay Formation covers a time span from the Middle or Upper Wenlockian to the Upper Ludlovian. Thorsteinsson, while agreeing that the upper age limit of the Read Bay Formation must remain in doubt, considered that none of it is younger than Upper Ludlovian in age. Such an assumption is based upon the assignment of an Upper Silurian or Lower Devonian age to the overlying Snowblind Bay Formation. However, Thorsteinsson and Tozer (1970) considered that the Read Bay Formation extended into the Gedinian.

The dating of the individual members is based largely on the occurrence of rare graptolites. Unit 57 of member A contains graptolites of the Monograptus bohemicus zone, which Thorsteinsson took to indicate a lower Ludlovian age. At Snowblind Creek the M. ultimus zone occurs in strata which Thorsteinsson considered to belong to member G. This was taken to indicate a lower Middle Ludlovian age. Following these conclusions Thorsteinsson tentatively assigned member B a Lower Ludlovian age and member D an Upper Ludlovian age.

Douglas et al., (1963) and Kerr (1967) followed Thorsteinsson in assigning a Middle or Upper Wenlockian to Upper Ludlovian age to the Read Bay Formation.

However, Thorsteinsson's conclusions were reached at a time when the existence of a Pridolian stage was not anticipated. Now the presence of this stage is generally acknowledged it is necessary to review the data and the dating of the type section of the Read Bay Formation.

The Russian (Obut et al., 1968), the Polish (Tomczyk, 1968) and the Czechoslovakian sequences (Boucek, 1965) all suggest that the Monograptus bohemicus zone should be assigned a Lower Ludlovian age as previously suggested by Thorsteinsson (1958).

However, the same sequences suggest that the Monograptus ultimus zone should be assigned a Pridolian age and likewise member C of the Read Bay Formation (Berry and Boucot, 1970). If such an age assignment is correct, the problem remains of assigning an age to members B and D.

Berry and Boucot (1970) suggested that member B started at the base of the Pridolian and continued through the Lower Pridolian. The dating of member B is difficult because the fauna is sparse and lacks diagnostic forms. However, a Lower Pridolian age for member B may be incorrect for the following reasons:

- (1) The Monograptus bohemicus zone occurs in units 57 and 58 of member A which is about 300 ft (approx. 92 m) below the base of member B. Since the M. bohemicus zone indicates a Lower Ludlovian age it suggests that the rest of the Ludlovian period was represented by only 300 ft (approx. 92 m) of strata.
- (2) The M. ultimus zone according to Berry and Boucot (1970) should be taken as the base of the Pridolian. This zone occurs within member C of the Read Bay Formation.

Thus, if the definition of the Pridolian is to be strictly followed, its base should be placed within member C thereby including all of member B and part of member C in the Ludlovian.

Berry and Boucot (1970) suggested that member C does not extend beyond the middle of the Fridolian. The accurate dating of members C and D is very difficult and will not be satisfactorily resolved until more faunal data is available. Consideration of the overlying Snowblind Bay Formation is useful since the dating of the lower part of this formation can greatly assist in the dating of the upper part of the Read Bay Formation.

Thorsteinsson (1958) reported the following heterostracan ostracoderm fauna within 200 ft (approx. 60 m) of the base of the Snowblind Bay Formation (the contact between the two formations, which is conformable and gradational, is drawn at the first appearance of laterally persistent limestone conglomerate beds): Ctenaspis n. sp. aff. C. dentatus, Anglaspis n. sp., Pteraspis sp. indet. cf. P. podolica (Zych) and Cyathaspididae n. gen. and sp. indet. In the British Isles Ctenaspis, Anglaspis and Pteraspis all indicate a Dittonian age (White, 1950; Allen and Tarlo, 1963).

Such an age assignment may suggest that member D of the Read Bay Formation is Downtonian. Whether the Downtonian is of Silurian or Devonian age is a matter of much discussion as shown in the review on Silurian stratigraphy (p. 234). However, in the light of the Russian and European sections it seems possible

that it is equivalent to the Pridolian. Thus, it would seem that member D extended throughout the Pridolian. Whether it terminated at the top of the Pridolian or continued into the Lower Devonian (Gedinnian) as suggested by Berry and Boucot (1970) is a matter of debate. However, the Siluro-Devonian boundary probably lies near or at the top of member D of the Read Bay Formation.

In all these studies dating and zoning has been made on the basis of isolated graptolites. No attempt has been made to consider the zonation of the shelly faunas which are more important on the islands away from the Franklin Geosyncline. If this is to be regarded as the type section it should at least have the potential of being recognized elsewhere. The type section should be zoned according to its shelly fauna; the graptolites should be used as a framework for dating the zones so delineated.

Information regarding the shelly fauna is sparse and this creates many problems. Indeed, Thorsteinsson (1958) designated an unnamed creek entering the south-west side of Read Bay as the type section for member C, yet no faunal data is available (Thorsteinsson stated that no fossils were collected due to inclement weather). Presumably, he designated this the type section in the hope that it would be revisited and studied in more detail.

However, this has not yet occurred, and member C has been little studied.

A similar problem exists with member B. To the author's knowledge this member has not been reported from any other island. Although a type section may reasonably have a unit not present elsewhere, in this instance it creates a special problem. Member C is very similar to member A and is distinguished largely on the basis of the presence of member B. If member B is missing it is very difficult to separate member A from member C.

Where faunal evidence is available the fossils have commonly been inadequately identified. Thorsteinsson, instead of assigning species names, frequently followed the practice of distinguishing two different species by designating them species A and species B. While such a procedure is valid for an individual, the species are of little use to other workers for correlation.

There is obviously a need to establish a type section for the formation and in many respects the section at Read Bay fulfills the need. It is well exposed and thick (8,500 ft, approx. 2,600 m) and it is well placed with regards to the areal distribution of the Read Bay Formation.

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11. The first step in the process of the formation of a new business is the selection of a business idea.

It is evident from Table 12 that the Cape Phillips Formation and its equivalents have extremely variable thicknesses on different islands. Similarly, it is apparent that the graptolitic shales represent shorter time spans on some islands than on others. For example, on Melville Island the Ibbett Bay Formation thins from 2,000 ft (approx. 615 m) in the Carrobert Hills area (Foxer, 1954, p. 13) to 300 ft (approx. 92 m) in the Kidson Formation at the western end of the Raglan Range (Foxer and Thorsteinsson, 1964, p. 63). In this example the age range of the graptolitic shales is considerably shorter for the Kidson Formation (Table 12).

The relationship between the geosyncline and the margin of the carbonate platform is not fully understood but work by Mayr (1974) suggests that it was quite complex.

South of the geosyncline lay vast expanses of platform seas in which considerable thicknesses of carbonate rocks were formed. Early work on these platform areas suggested simple patterns of sedimentation but subsequent detailed work, such as that being done on Somerset Island by the Ottawa University group, shows that the facies patterns were more complex.

The Read Bay Formation shows considerable variation

Table 12.

Correlation Table

Correlation of late Ordovician to Early Devonian strata of selected Arctic Islands. Information from following sources: stratigraphy and ages for Melville, Devon, Ellesmere, Victoria and northern Cornwallis Islands from Berry and Boucot (1970); stratigraphy and ages for Southern Cornwallis Island modified from information given by Berry and Boucot (1970); stratigraphy and ages for Northwest Baffin Island modified from Berry and Boucot (1970) and Trethin (1969); stratigraphy and ages for eastern Prince of Wales and western Somerset Islands from C. Dixon (1973, Unpubl. Ph. D. thesis) and stratigraphy and ages for eastern Somerset Island, this study. The abbreviations S.R. and S.B. are for the Sutherland River and Snowblind Bay Formations respectively.

in thickness. For example, from the type section on Cornwallis Island, where the formation is 8,500 ft (approx. 2,600 m) thick, it thins to 2,100 ft (approx. 640 m) on northwestern Somerset Island (S. R. Williams, pers. comm., 1973) and to 1,000 ft (approx. 300 m) on southern Somerset and Prince of Wales Islands (S. R. Williams, pers. comm., 1973). The formation is difficult to date owing to the scarcity of good diagnostic faunas. However, it probably ranges from the Middle Wenlockian to the Upper Pridolian on Somerset Island and possibly into the Gedinian on Cornwallis Island.

On Banks, Victoria and Stefansson Islands the thickness of the Read Bay Formation is unknown (Thorsteinsson and Tozer, 1961, p. 6). Like the Read Bay Formation on other islands it consists of carbonates which contain a rich shelly fauna.

On north-west Baffin Island Silurian strata are exposed on the Brodeur and Borden Peninsulas. In these areas Trettin (1969, p. 6) identified the Brodeur Group which he subdivided into the Baillarge Formation (late Middle Ordovician to Middle Silurian) and the Cape Crauford Formation (Middle Silurian or younger).

Norris (1963, p. 152) termed part of the Cape Crauford Formation "...the lower limestone unit of the Read Bay Formation." However,

Trettin (1969, p. 55) considered that the succession could not be included in the Read Bay Formation because it contains solution breccias and a high proportion of dolomite, which is significantly different from the Read Bay Formation, and because "...the index fossil Atrypella does not seem to be present." Trettin (1969) also concluded that the Cape Crauford Formation was older than the Read Bay Formation because Atrypella was absent. Although Norris (1963, p. 152) reported the presence of Atrypella from these strata, Bolton (in Trettin, 1969, p. 55) doubted whether these forms were correctly identified. Consequently, Trettin (1969, p. 55) considered that the Silurian strata were no younger than Lower Wenlockian. However, Atrypella is probably absent from these rocks because the depositional environments were unsuitable for their existence. The rocks of the northwest Baffin Island successions are representative of high intertidal or supratidal environments. Thus, the Cape Crauford Formation may be younger than anticipated by Trettin and may be as young as the Pridolian.

Carbonate rocks of the Read Bay Formation are present on southern Devon Island (Glenister and Thorsteinsson, 1963, p. 195)

while the Douro Formation occurs on the northern part of the island in the vicinity of Prince Alfred Bay. The fauna of the

Douro Formation suggests that it correlates with member A of the Read Bay Formation on Cornwallis Island (Berry and Boucot, 1970).

On southern Ellesmere Island the Read Bay and Douro Formations have been recognized at many localities. Greiner (1963, p. 294) noted that the Douro Formation (1,340 ft - 410 m) of the Goose Fiord area consists of reefoidal limestones. In the Vendom Fiord area, 3,600-3,700 ft (1,100-1,128 m) of carbonate overlies the Cornwallis Formation (Norris, 1963, p. 340) and contain a probable Ludlovian and/or Pridolian fauna indicating that the rocks may be equivalent to the Read Bay Formation.

The carbonates of the platform areas are extremely variable and represent many different environments. The strata of Ludlovian and Pridolian age tend to thicken towards the Franklinian Geosyncline. The dating of the carbonate sequences from the platform areas is extremely difficult as there are few diagnostic fossils. In the literature the brachiopod Atrypella has often been used as an index fossil of the Read Bay Formation. However, while its presence may indicate Read Bay strata, its absence does not necessarily mean that the strata are not equivalent to the Read Bay

Formation because the distribution of Atrypella was controlled by environmental conditions (p. 411). Rocks which accumulated in

intertidal and supratidal environments will not usually contain Atrypella.

Silurian strata of Somerset Island

Comparison of measured sections with previous work Silurian strata cover most of Somerset Island (Text-fig. 2, p. 4) north and east of a line joining Aston Bay and Creswell Bay. The only major published work on the Silurian strata of Somerset Island is that by Fortier et al., (1963 - Operation Franklin). The localities described in this study were initially documented by various workers on Operation Franklin. However, as will be demonstrated there are many discrepancies between their work and the present study.

In the area around Pressure Point Thorsteinsson and Tozer (1963, p. 119) recognized a conformable sequence of the Allen Bay, Read Bay and Peel Sound Formations. Thorsteinsson and Tozer (1963, p. 122) reported the occurrence of the ostracoderms Anglaspis and Corvaspis in the Peel Sound Formation of this area. In addition to these forms, Dynesley (1965a, p. 12) reported the occurrence of traquairaspids, cephalaspids, cyathaspids and

acanthodians in the Peel Sound Formation. Thorsteinsson and Tozer

(1963, p. 124) concluded that Peel Sound sedimentation started in Lower Devonian times. From a locality 10 miles to the south of

Limestone Island these authors noted the presence of Atrypella scheil, Fardenia sp., Stegerhynchus sp., Howellella sp. and Hormotoma sp. in strata which they assigned to the Read Bay Formation.

The present study demonstrates that the stratigraphic description provided by Thorsteinsson and Tozer (1963, p. 119) is oversimplified. Immediately overlying the Peel Sound Formation is a sequence of units which should be assigned to the lower Peel Sound Formation (Miall, 1970a, p. 127). The sequence comprises interbedded limestone and red beds and probably represent the transitional period between the subtidal environments of Pridolian times and the terrestrial environments of the Gedinnian. This transitional series should possibly be designated a new formation.

However, further detailed study of the regional distribution of the strata is required before the validity of a new formation can be judged. The Read Bay Formation of this area comprises a succession of mottled dolomite-limestone, micritic limestone, shelly limestone and argillaceous limestone which contains a rich fauna of corals and brachiopods (text-figs. 35 and 36, p. 125 and 126):

The argillaceous limestone forms only a minor part of the sequence.

S. R. Williams (1973, pers. comm.) reported a total thickness of

2,100 ft (620 m) of Read Bay strata. On the basis of conodont evidence he has placed the boundary between the Read Bay and Peel Sound Formations in the Upper Fridolian.

Thus, the Read Bay strata in the measured section at Pressure Point are probably of Fridolian age. This section is probably correlatable with member C and part of member D of the type section on Cornwallis Island.

Near Cunningham Inlet McMillan (1963, p. 131) reported the occurrence of 2,000 ft (approx. 600 m) of flaggy and argillaceous limestone that contained a fauna indicative of the Read Bay Formation. However, sections CA, CD and CE which comprise the section measured by McMillan (1972, pers. comm.) total only 1,100 ft (336 m). It is also apparent from the previous description of these sections (chapter 3; p. 65) that the succession of rock types is more complex than that described by McMillan (1963, p. 131). The strata of sections CE and CD contain a fauna indicative of the Read Bay Formation. Section CA, which is separated from section CD by a fault, contains a restricted fauna (Text-fig. 31, p. 116) but the rock types in this section suggest that it should be assigned to the Read Bay Formation. Section CF (Text-fig. 34, p. 119), by virtue of its restricted fauna and distinctive rock types, should not be assigned

to the Read Bay Formation. The sequence is very similar to those found in the Port Leopold area. Although this section may be equivalent to the Leopold succession it is referred to as an unnamed sequence until its exact age or relationship to the Read Bay Formation can be determined.

In this area the Peel Sound Formation is present only in the central part of the valley. (locality E on Text-fig. 6, p. 8). Although the actual boundary with the Read Bay Formation is not exposed the distribution of the Peel Sound and Read Bay strata suggests the boundary position depicted in Text-fig. 6. The age of the boundary at this locality is not known.

The dating of sections CA, CE and CF is uncertain owing to the lack of diagnostic fossils. The presence of Kirkidium (?) in units CD2 and CD3 indicates that the strata of section CD are of Ludlovian or Pridolian age (Berry and Boucot, 1970, p. 30). The coral fauna contains genera such as Coenites and Alveolites, which are most commonly associated with Devonian strata, along with genera such as Favosites, Heliolites and Arachnophyllum, which are more indicative of a Silurian age.

In unit CD5 the fossil ostracoderms Pionaspis, Anglaspis and Corvaspis. (?) occur in dolomite. The genus Pionaspis was

originally described by Denison (1964) on the basis of specimens from Early Devonian strata near Muncho Lake, British Columbia. At this locality Pionaspis was found with Traquairaspis which Broad and Dineley (1973) consider to be of Pridolian or Gedinnian age.

Anglaspis has been reported from Early Devonian strata near Keele River (Denison, 1964) and from the Snowblind Bay Formation on Cornwallis Island (Thorsteinsson, 1958). Allen and Tarlo (1963) reported the occurrence of Anglaspis and Corvaspis in Dittonian strata of the Welsh Borderlands, England. Obruchev and Karatayute-Talimaa (1968) reported the occurrence of Anglaspis and Corvaspis in association with the Traquairaspis zone of the Yuraskie level (Downtonian) in the Polish-Luturan Synocclis area. Thus, the vertebrate fauna strongly suggests that the strata in section CD are of Pridolian age, possibly uppermost Pridolian.

Section CD of the Cunningham Inlet area is probably correlatable with member C and the lower part of member D of the type section on Cornwallis Island. Section CE which occurs directly above section CD is probably of Upper Pridolian or possibly of Lower Gedinnian age. It may be equivalent to member D of the type section.

In unit CF7 Leperditia gibbera occurs while Leperditia

cf. L. gibbera occurs in unit CF20. On Somerset and Prince of Wales Islands this ostracod occurs in the upper part of the Read Bay Formation and the lower member of the Peel Sound Formation (Copeland, 1973, pers. comm.). Thus, this section may be the equivalent of the lower member of the Peel Sound Formation and the upper part of the Leopold Formation.

The information given by McMillan (1963, p. 131) on the Read Bay Formation of the Garnier Bay area is very sparse. He noted that the strata were mainly argillaceous limestone but that the argillaceous content was less than that in the Cape Admiral M'Clintock sections. The age of the Garnier Bay sections is difficult to determine accurately. However, the presence of corals such as Favosites, Heliolites, Arachnophyllum, Chonophyllum, Syringopora, Alveolites and Coenites in the upper part of sections GD and GA suggests that they are of Pridolian age.

In the Cape Admiral M'Clintock area McMillan (1963, p. 131) noted the presence of 520 ft (approx. 160 m) of argillaceous limestone overlain by 175 ft (approx. 53 m) of massive limestone. According to McMillan the fauna in these strata is indicative of the Read Bay Formation.

The section measured in the gully in the west of this

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The section measured in the gully in the west of this

area is 325 ft (100 m) thick. At this locality the massive, chocolate-coloured limestone which McMillan (1963, p. 131) noted is missing. However, McMillan probably measured his section on the sea cliffs to the east where the massive limestone is present. It is evident from Text-figures 24-26 that the section at Cape Admiral M'Clintock is far more complex than that reported by McMillan (1963). The fauna in the section at Cape Admiral M'Clintock (Text-figs. 24-26) indicates that it should be assigned to the Read Bay Formation as he suggested but the fauna lacks taxa which are useful for dating purposes. The strata may be of Fridolian age.

In the Port Leopold area McMillan (1963, p. 130) reported the occurrence of flat-lying beds, exposed on cliffs which rise up to 1,100 ft (approx. 340 m) above sea level. He divided the sequence into three main units based on a composite section derived from several small sections measured at various localities in the area.

These units are as follows:

- (1) a lower unit about 180 ft (approx. 55 m) thick comprising grey limestones which are dolomitic. Gypsum occurs as lenses and continuous layers.
- (2) a middle unit 250 ft (approx. 76 m) thick comprising thick bedded grey limestone.

- (3) an upper unit 700 ft (approx. 210 m) thick comprising thin-bedded, ostracod-bearing argillaceous limestone and partly sandy limestones.

Detailed study of the Fort Leopold area demonstrates that the stratigraphic succession is more complex than that reported by McMillan (1963, p. 130). The nature of the composite section proposed by McMillan (1963) is largely dependent on the location of the individual sections measured. As shown previously (p. 82) there is great lateral variation of rock types on the peninsula at Fort Leopold. For this reason McMillan's scheme of subdivision is inadequate as it is not representative of the area.

The presence of Kirkidium (?) in the conglomerate of unit 175 suggests that the strata are of Ludlovian or Pridolian age (Bégin and Boucot, 1979).

South of Fort Leopold, at Cape Seppings, McMillan (1963, p. 131) reported the occurrence of a fauna which included Atrypa, Conchidium, Hermotoma and Lepordilla from the upper part of the section.

In the Elwin Bay area Morris (1963, p. 137) divided the strata into two members, as follows:

- (1) a lower evaporitic member which is 70 ft (approx. 21 m) thick and comprises anhydrite, gypsum, limestone and chert.

(2) an upper member which is 800 ft (approx. 244 m) and contains "thin irregular-bedded 'stromatolitic' limestone" (Norris, 1963, p.138) and intraformational conglomerate. Many of these rocks display sedimentary structures such as mud-cracks, ripple marks and cross-bedding. In the upper part of the sequence the following poorly preserved fossils were found: Atrypella scheil (Holtedahl), A. phoca (Salter), Clorinda sp., Stegerrhynchus sp., Merista obesa (Poulsen), Hormotoma sp. and ostracods.

In 1971 Panarctic Oils Ltd. drilled a well (Panarctic Deminex, Garnier 0-21) about 6 miles southwest of Port Leopold (latitude $73^{\circ} 41' N$, longitude $90^{\circ} 37' W$ - Text-fig. 2). The drill site was at a height of 1,209 ft (approx. 370 m) above sea level and the borehole terminated at a depth of 6,515 ft (approx. 1,987 m). The well log records the strata as being undifferentiated Allen Bay and Reed Bay Formations for the full depth of the well. The predominant rock type recorded was dolomite although sandy limestone is common in the upper part of the section. The limestone which occurs at various levels in the succession is commonly sandy or contains anhydrite and gypsum. The quartz in the sandstone and the sandy limestone units is recorded as being subangular, poorly sorted and generally immature (Panarctic Deminex, Garnier 0-21, Well Report).

In the area around Creswell Bay the Read Bay Formation is up to 1,000 ft (approx. 300m) thick and comprises mottled dolomite-limestone and micritic limestone with little detrital material compared to the Read Bay strata of the northern coast.

It is evident from the previous discussion that the sections on the north coast of Somerset Island can be assigned to one of the two groups below:

- (1) those sections which are predominantly limestone and rubbly limestone and contain a rich fauna of corals and brachiopods. Detrital material occurs in some rocks giving rise to minor quantities of sandstone, sandy limestone and calcareous sandstone. Dolomite forms only a minor part of the total rock type. The rocks in these sections are generally grey to dark grey in colour. Sections M, GA, GB, GD, GE, CA, CD, CE, X and Y all fall into this category.
- (2) those sections which are predominantly dolomite, sandy dolomite, dolomitic limestone and calcareous dolomite and contain a restricted fauna of ostracods, gastropods, eurypterids and stromatolites. Detrital, sand-sized grains of quartz, feldspar and muscovite are common in many of the rocks. Limestone and argillaceous limestone form only a minor part of the total

rock type. The rocks in these sections are generally buff or yellowish-brown in colour. The sections at Port Leopold and section CF fall into this group.

The sections that fall into group 1 are within the definition of the Read Bay Formation. However, the sections of group 2 contrast sharply with those in group 1 and cannot be included in the Read Bay Formation. Consequently, the sections at Port Leopold are included in a sequence which is called the Leopold succession. The isolated section of this type at Cunningham Inlet must at present remain unnamed as its relationship to the Read Bay Formation is unknown. The section may be part of the 'transition beds' between the Read Bay and Peel Sound Formations.

The Leopold succession The Leopold succession, which is at least 340 m (approx. 1,100 ft) thick in the type area at Port Leopold, consists predominantly of buff or yellowish-brown dolomite, sandy dolomite, dolomitic limestone and calcareous dolomite. Minor quantities of sandstone, limestone, intraformational conglomerate, pelletoidal limestone, oncolitic limestone and evaporites also occur. Sand-sized detrital material is common in many of these rocks.

The Leopold succession, which is probably the lateral equivalent of the late Silurian Read Bay Formation, consists predominantly

of dolomitic rocks whereas the Read Bay Formation is mainly argillaceous limestone and micritic limestone. Sand-sized detrital material is common in the rocks of the Leopold succession but rare in the subtidal rocks of the Read Bay Formation. Compared to the abundant and diverse fauna of brachiopods, corals, stromatoporoids and trilobites of the Read Bay Formation the Leopold succession has a very restricted fauna of ostracods, gastropods, eurypterids, ostracoderms and brachiopods (including Lingula). Stromatolites are common in the Leopold succession but rare in the Read Bay Formation.

Numerous facies of short lateral and horizontal extent, the distinctive lithologies and the restricted fauna suggest that the rocks of the Leopold succession accumulated in intertidal and supratidal environments. Most of the Read Bay Formation comprises subtidal rocks.

The Leopold succession is probably worthy of formational status but has not been so designated because of the difficulty of mapping its extent on eastern Somerset Island. It is evident from the borehole data from southwest of Port Leopold that the lithological types associated with the Leopold succession continue for many thousands of feet below ground level and are not significantly different from the rock types associated with the underlying Young Bay and Allen

Bay Formations. The upper boundary is not exposed in the Port Leopold area as the Leopold succession is the highest sequence exposed.

The numerous facies changes mean that any section chosen to represent the Leopold succession will probably be a unique section in that it will have a distinct succession of rock types which will not be repeated elsewhere. However, this section should be representative of the Leopold succession. Consequently, a composite section formed of section A and the part of section G above marker bed 1 (see Text-figs. 13 and 19, p. 66 and 72 respectively) is considered typical of the Leopold succession.

Since dating of the Leopold succession cannot be achieved by consideration of its upper and lower boundaries it must be done on the basis of fauna in the strata of the area and its relationship to the Read Bay Formation. While this is difficult because of the sparse fauna present, certain pieces of evidence, considered together, give some indication of the age of the succession. This evidence is as follows:

- (1) The brachiopod Kirkidium (?) is present in the conglomerate of unit J75. Berry and Boucot (1970, p. 30) suggested that Kirkidium is indicative of a Ludlovian or Pridolian age. These brachiopods have also been found in the Read Bay Formation.

- (2) The brachiopod Howellella is present in unit A2. Howellella has been found in unit M113 of the Cape Admiral M'Clintock section and in the Read Bay Formation (or its equivalents) on other Arctic Islands.
- (3) The gastropod Hormotoma is present in many of the units of the Leopold succession. This gastropod has been found in many of the sections of the Read Bay Formation.
- (4) Fragments of the corals Coenites and Favosites are present in some units of the Leopold succession at Port Leopold. These genera occur at several localities along the northern coast of Somerset Island in strata belonging to the Read Bay Formation.
- (5) Eurypterids of the Eurypterus remipes group occur in many of the units of the Leopold succession. According to Copeland (1973, pers. comm.) these eurypterids are indicative of Upper Silurian strata.
- (6) In unit PL43 on the west side of the bay at Port Leopold an ostracoderm fauna comprising Corvaspis cf. C. kingi, Ptomaspis leopoldensis, Ptomaspis indet. and Kallostrakon (?) indet. occurs. Although Denison (1963) originally assigned a Middle Ludlovian age to specimens of P. canadensis from the Beaver

River area of southeastern Yukon he later (Denison, 1964) considered it to be of Lower Devonian age since they occurred with Traquairaspis. However, Traquairaspis is not necessarily indicative of Devonian strata since it occurred earlier in northern Canada than elsewhere (Broad and Dineley, 1973).

A carapace resembling Ptomaspis has been reported from the Early Ludlovian strata of the Cape Phillips Formation on Cornwallis Island in association with Homalaspidella and Vernonaspis and Archegonaspis (Thorsteinsson, 1967).

Kallostrakon podura, the type species was originally described from the Downtonian of England (Lankester, 1870) but has also been reported from the upper part of the Read Bay Formation on Somerset Island (Tarlo, in Dineley, 1965a; Tarlo, 1965). Other species, K. macanuffi, K. grundrodi and K. alleni occur in the Downtonian of the Welsh Borderlands, England (Tarlo, 1964, 1965). Thus, there is strong evidence that this fauna is of Pridolian or Gedinian age.

In unit K49 another ostracoderm fauna comprising Archegonaspis cf. A. schmidtii, Homalaspidella cf. H. borealis, indeterminate Cyathaspidae and indeterminate Heterostraci was found. The type species of Archegonaspis schmidtii was

found in an erratic from the Graptolithengestein of Germany (Geinitz, 1884) and is of Early Ludlovian age (Denison, 1964, p. 365). Thorsteinsson (1967, p. 46) also reported the genus from the late Wenlockian and Early Ludlovian strata of the Cape Phillips Formation on Cornwallis Island.

Archegonaspis bimar occurs in the Middle Ludlovian part of the Greben Horizon on Vaygach Island (Novitskaya, 1970).

Homalaspidella borealis Denison occurred with Ptomaspis canadensis and thus has a similar age. Using graptolites

for dating purposes, Thorsteinsson (1967) denoted five separate faunas in the Cape Phillips Formation on Cornwallis Island. His Late Wenlockian fauna "...includes cyathaspids, one or more species of which may be referred to Vernonaspis or Archegonaspis and another possibly to Homalaspidella".

(op. cit., p. 46) while the two Early Ludlovian faunas include "...Cyathaspids, two forms of which may be included either in the genus Vernonaspis or Archegonaspis, a third that is referable to Homalaspidella and a fourth represented by a unique, incomplete carapace that resembles Ptomaspis".

Thus, according to the literature Archegonaspis indicates a late Wenlockian, Lower Ludlovian or Middle Ludlovian age.

However, this may simply be a reflection of the material that has been found so far. It is possible that this represents the youngest occurrence of Archegonaspis yet reported.

- (7) The strata of the Port Leopold area are all horizontal or sub-horizontal and there is no evidence of a major structural discontinuity between the Port Leopold area and the Cape Admiral M'Clintock area where Read Bay strata occurs. This suggests that the Leopold succession is the lateral equivalent of the Read Bay Formation.

McMillan (1963, p.132) reported the occurrence of Atrypella and Conchidium in beds of the Port Leopold area. The Text-figures accompanying McMillan's work suggest that these specimens occurred in a conglomerate in the upper part of the section at the southern end of the peninsula at Port Leopold. It is possible that they were found in the same unit in which the present author found the specimens of Kirkidium (?) (unit J75). If Atrypella does occur in these sections then there is additional evidence that the Leopold succession is laterally equivalent to the Read Bay Formation.

Thus, while the paleontological evidence is sparse there is a cumulative indication that the Leopold succession is of uppermost Pridolian or Gedinnian age and the lateral equivalent of the Read

Bay Formation or the lower member of the Peel Sound Formation.

Paleogeography of Somerset Island during Upper Silurian times

Interpretation of the Upper Silurian paleogeography of the Somerset Island area is difficult because the Silurian strata have not yet been adequately studied. The sections measured to date are distributed along the north coast of Somerset Island and along the western limb of the Creswell syncline. However, these sections do reveal some of the major features of the Silurian strata of Somerset Island and certain aspects must be explained in any proposed paleogeographic reconstruction. The following facts are vital to any paleogeographic interpretation of the area:

- (1) The Leopold succession of north-eastern Somerset Island, which appears to be the lateral equivalent of the Read Bay Formation, comprises a thick series of rocks of intertidal and supratidal origin. The well drilled southwest of Port Leopold penetrated more than 6,000 ft (approx. 1,800 m) of dolomite, evaporites, rocks with a high content of detrital material and some limestone.

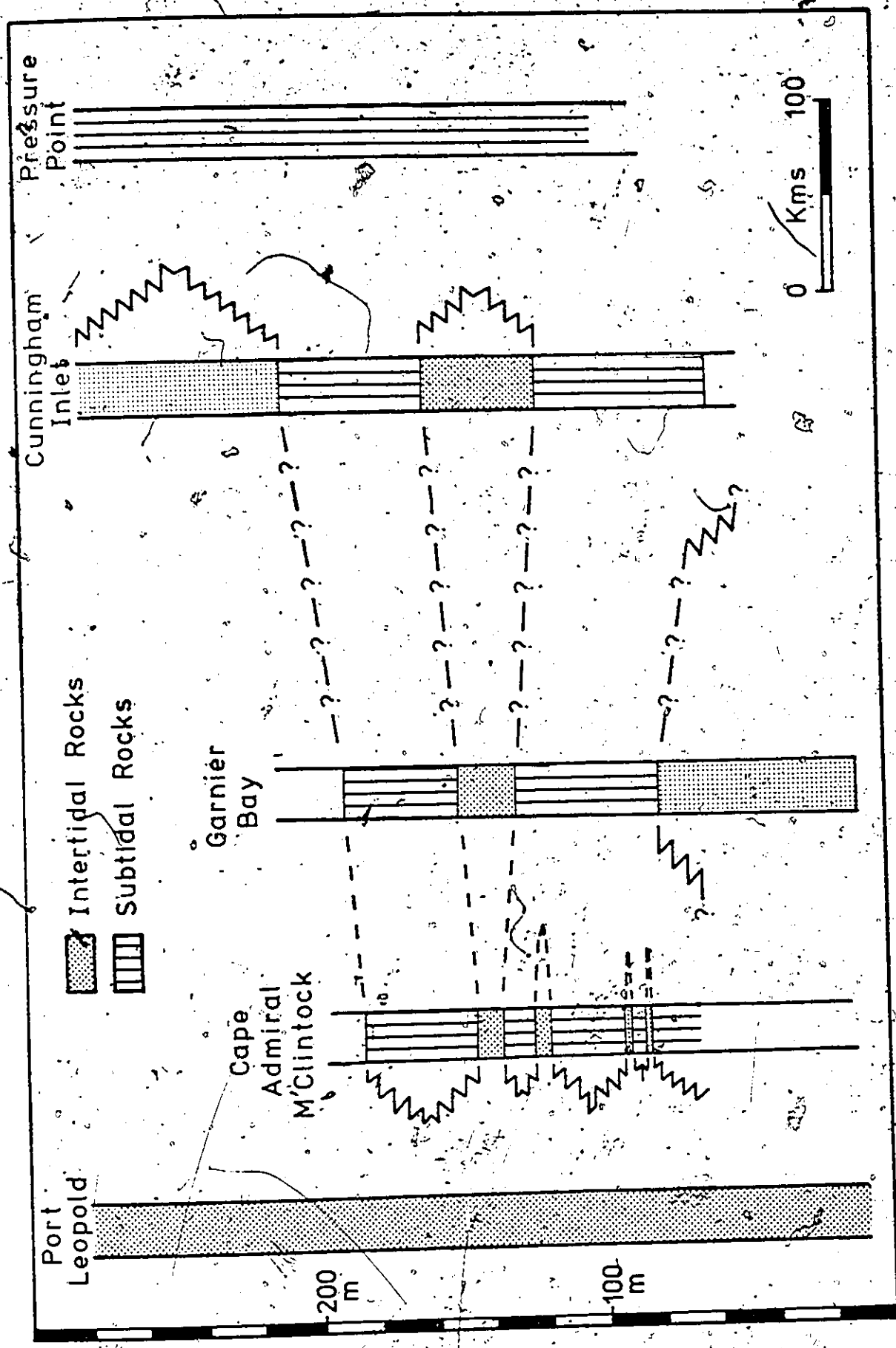
- (2) In the Pressure Point area there are about 2,100 ft (approx. 640 m) of Read Bay strata. The rocks in the upper 600 ft (180 m) of the section are completely subtidal in origin.

- (3) The sections between Port Leopold and Pressure Point comprise rock units which accumulated in alternating intertidal and subtidal environments. Distinct intertidal phases are recognizable in the sections at Garnier Bay, Cunningham Inlet and Cape Admiral M'Clintock (Text-fig. 47 and chp. 6 for full description).
- (4) Large quantities of detrital material (quartz, plagioclase, microcline and muscovite) are present in many of the rocks. In general terms the amount of sand-sized detrital material decreases towards the west, although locally there are exceptions. The quartz grains are commonly angular and subangular and generally display undulatory extinction. The detrital sedimentary rocks are immature as evident from the presence of feldspar and the angular nature of the detrital grains.
- (5) On northwestern Baffin Island, Trettin (1969) reported the occurrence of an Ordovician-Silurian rock succession of intertidal and supratidal origin. The sedimentary rocks of the Baillarge Formation were deposited on an erosional surface which probably resulted from a period of subaerial erosion (Trettin, 1969, p. 6). Many of the rocks in the Baillarge and Cape Crauford Formations contain mica, quartz, plagioclase,

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Text-figure 47

Correlation of Silurian strata on northern Somerset Island. The tentative correlation of the strata at the localities is based on the succession of environmental phases, and the fact that all the sections appear to be approximately equivalent in age. The scarcity of diagnostic faunas in these sections prevents the establishment of accurate time zones. Consequently, time lines cannot be established for these sections.



K-feldspar and clay minerals (Trettin, 1969, p. 44).

One of the severe restrictions in interpreting the paleogeography of the area is the difficulty of correlating the various measured sections on northern Somerset Island. The common elements in the invertebrate faunas suggest that the sections of the Port Leopold area, Cape Admiral M'Clintock, the Garnier Bay area, some of the sections at Cunningham Inlet and the Pressure Point section are of roughly equivalent age and can be correlated as shown in Text-figure 47. It must be emphasized that this particular correlation (Text-figure 47) is based on the succession of environmental phases and there is no accurate evidence on which time lines can be based. Thus, the correlations must remain tentative until more accurate dating of the sections is possible. However, even if the correlations suggested in Text-figure 47 prove to be invalid, there still remains the problem of explaining the intertidal phases of the various sections.

The distribution of Read Bay and equivalent strata containing sand-sized detrital grains clearly demonstrates that the Boothia Arch was not the source area. The Pressure Point section contains only small quantities of quartz (p. 124) near the top of the Formation, and they probably reflect the first effects of the late Silurian-Devonian uplift of the Boothia Arch. Similarly, the section of the

Read Bay Formation at Kanguk Gorge (6 miles north of Creswell Bay) contains little detrital material. Thus, the land mass which supplied the detrital material to northern Somerset Island must have been situated elsewhere.

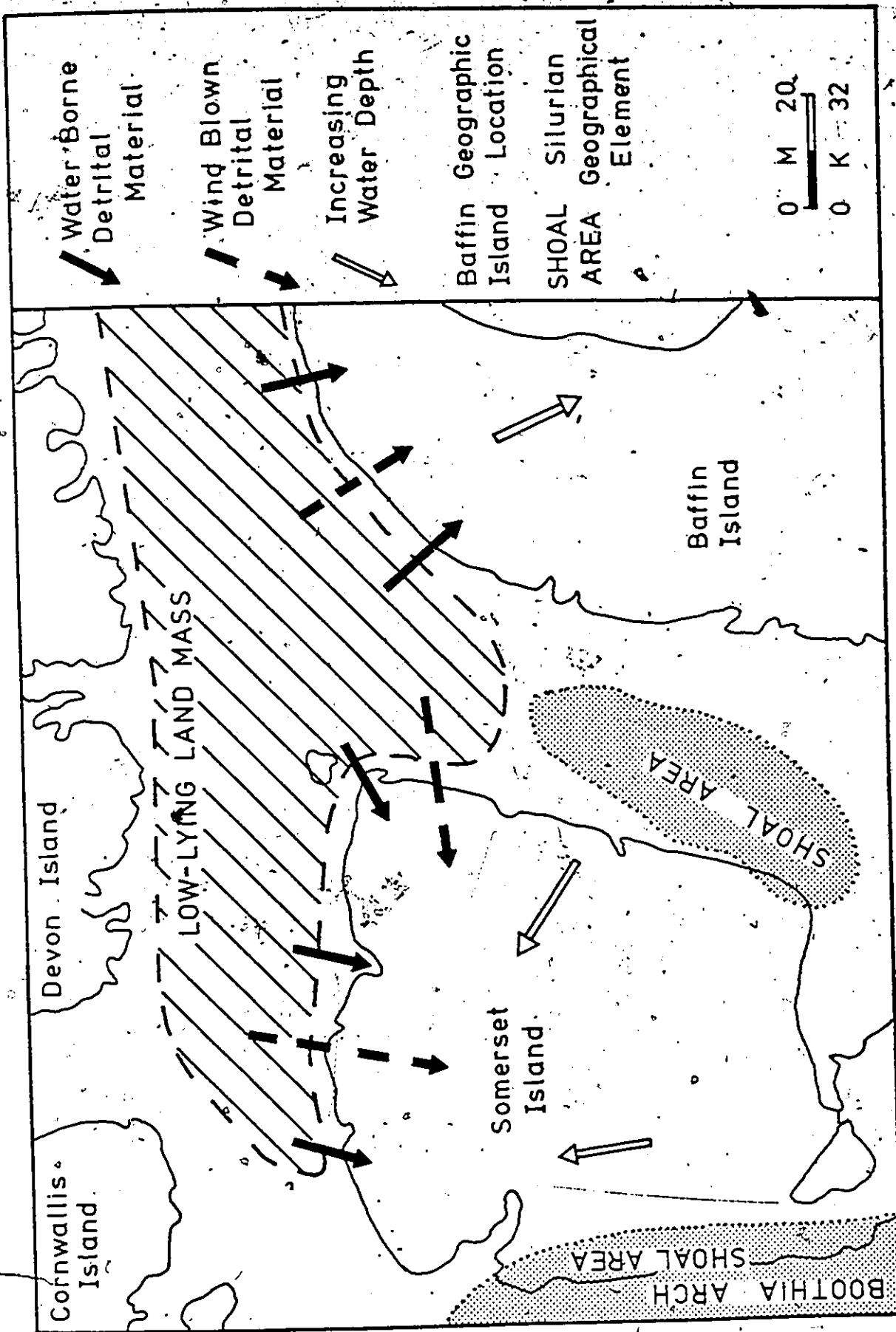
The presence of unaltered feldspar in many rocks suggests immaturity and proximity to a source area. The restricted stratigraphic occurrence of the intertidal phases in some of the sections suggests that the land mass was relatively close to the north coast of Somerset Island.

The paleogeography depicted in Text-figures 48a and 48b is based partly on the nature and distribution of this detrital material in the Read Bay Formation and presumed equivalent rocks.

The Young Bay Formation, which is 200-400 ft (about 60-120 m) thick in the vicinity of Creswell Bay, comprises a sequence of rocks which accumulated in intertidal environments. The detrital quartz in some of these rocks suggests that the Boothia Arch was the source area. The Boothia Arch was probably a low-lying land mass at this time since the detrital elements are restricted to clay- to sand-sized material. There are no conglomerates associated with the Arch as was the case when the Boothia Arch became prominent during Lower Devonian times. The Young Bay Formation occurs on western Somerset Island and eastern Prince of

Text-figure 48a

Upper Silurian paleogeography of the Somerset Island region --
regressive phase. The land mass to the north of the island would
be at its maximum elevation and the only connection with the open
sea would be to the northwest, near Pressure Point. Paleogeography
for the northwestern part of Baffin Island based on information
given in Trettin (1969).



Wales Islands between the Allen Bay and Read Bay Formations.

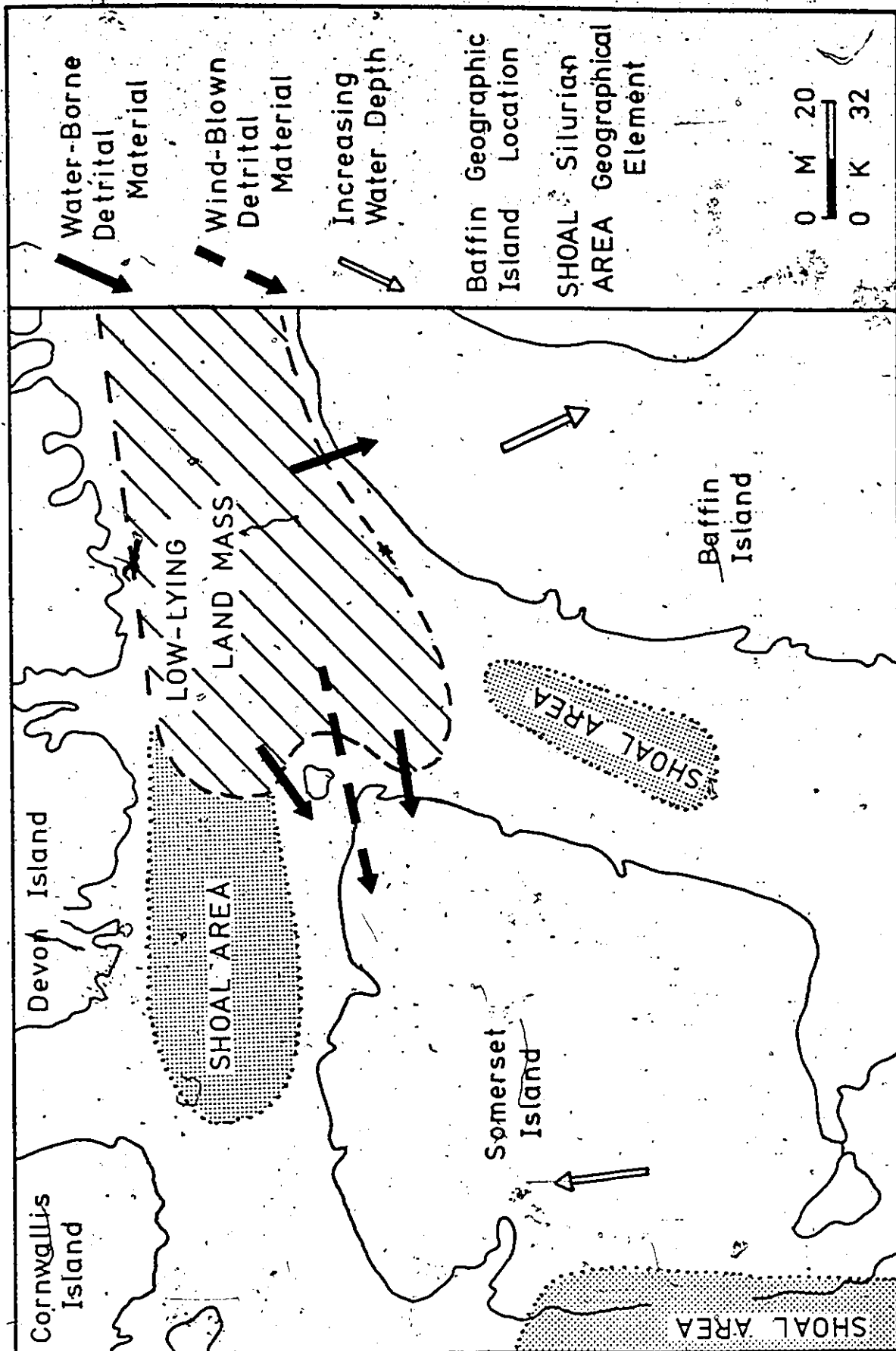
After deposition of the Young Bay sediments, the Boothia Arch possibly remained as a shoal area and could have influenced water circulation in the Jones-Lancaster Basin. There is no evidence that it supplied detrital material to the Basin during Read Bay sedimentation.

There may have been a land mass immediately north of Somerset Island while the Young Bay Formation was accumulating. There is some evidence for this in the nature of the rocks reported in the borehole southwest of Port Leopold (p. 259). The land mass was probably most persistent in the eastern part of the area since rocks of intertidal and supratidal origin are most common in the Port Leopold area. The land mass was probably low lying and is unlikely to have attained the same prominence as the Boothia Arch did during the Devonian period. The composition of the detrital material (p. 172) indicates that the land mass was a metamorphic and/or igneous terrain.

The postulated land mass north of Somerset Island (Text-fig. 48a) was probably elongated east to west in the position of the present Barrow Strait. However, it may have had an irregular coastline with southward extensions (Text-fig. 48a). One of these may explain

Text-figure 48b

Upper Silurian paleogeography of the Somerset Island region --
transgressive phase. The land mass to the north of the island
would be at its minimum elevation. Paleogeography for the
northwestern part of Baffin Island based on information given
in Trettin (1969).



the distribution of facies in the Port Leopold area, which suggests a local shoreline trending generally north-south.

The intertidal phases within the successions at Cape Admiral M'Clintock, Garnier Bay and Cunningham Inlet coincided with periods of increased influx of detrital material and probably reflect slight elevations of the land mass (Text-fig. 48a). Some of the geographically localized intertidal phases possibly were related to minor changes in the local topography of the land mass.

The upper subtidal phases of the Cape Admiral M'Clintock, Garnier Bay and Cunningham Inlet sections (Text-fig. 47) represent three different types of subtidal environment. Quiet, shallow, lagoonal conditions prevailed at Cape Admiral M'Clintock while there were deeper, more turbulent environments with bioherms in the Garnier Bay area. At Cunningham Inlet, shallow subtidal conditions prevailed. The exact relationship of these phases is difficult to determine since the geology of the intervening areas is unknown. However, one fairly simple interpretation of their paleogeographic relationship might be that depicted in Text-figure 49.

The sabkha-type sedimentary rocks on north-west Baffin Island (Trettin, 1969) probably developed in environments close to the land mass in the Barrow Strait - western Lancaster Sound area.

Text-figure 49

Depositional environments of the study area. The distribution of environments shown represents times of maximum elevation of northern land mass during the Upper Silurian. Note that all the areas studied in detail occur in different depositional environments.

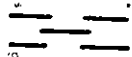
LEGEND FOR MAP

 Land areas

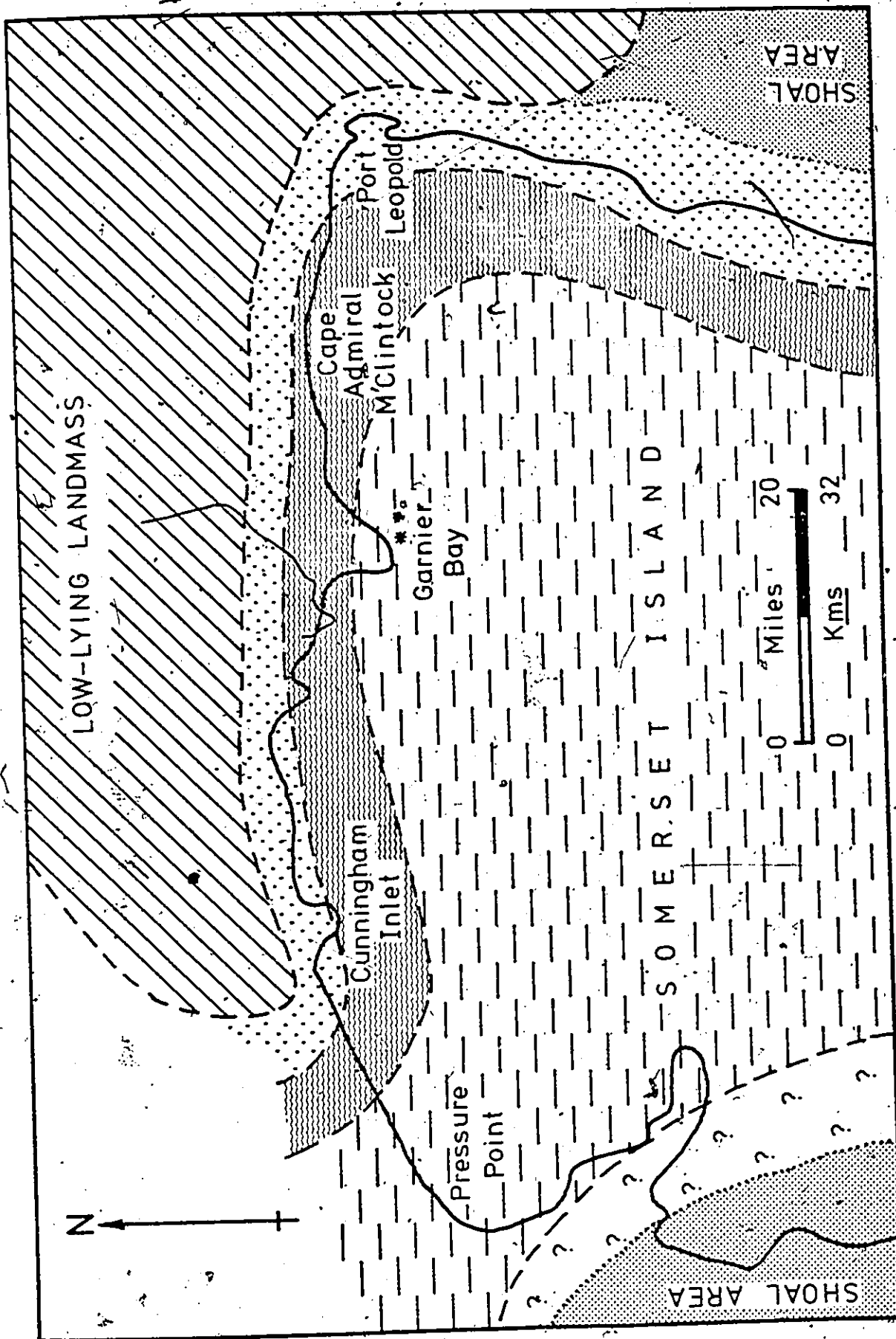
 Shoal areas

 Intertidal/Supratidal Environment

 Lagoonal Environment

 Deeper Subtidal areas

* Bioherms



The erosion surface beneath the Baillarge Formation may mark a period of instability of this land mass.

On the east coast of Somerset Island, layers of evaporites are exposed in the cliffs between Port Leopold and Elwin Bay.

(Norris, 1963, p. 137). Above the evaporite beds, which occur at the base of the cliffs, are other supratidal and intertidal rocks. Probably, they are the southerly extension of the Leopold Formation. The presence of evaporite layers suggests a shallow water area with restricted circulation. This may have been related to shoal areas (Text-fig. 48).

In Early Devonian times the Boothia Arch became active and formed a high land mass between Somerset and Prince of Wales Islands. The facies belts in the adjacent basins were orientated parallel to the Boothia Arch. Probably the lateral transition from continental facies to marine facies away from the arch on Prince of Wales Island (Miall, 1970a) was repeated on Somerset Island. The gradual emergence of the Boothia Arch at the end of Silurian times initially resulted in the transitional sequence (Lower Peel Sound Formation of Miall, 1970a) between the Read Bay and Peel Sound Formations on Somerset and Prince of Wales Islands. The easterly equivalents of the transitional sequence on Somerset Island have not been.

documented and the actual pattern of facies changes away from the Arch is not known. It is possible that the intertidal/supratidal rock units exposed in the Cunningham Inlet area (section CF) are the lateral equivalents of the transitional sequences.

The absence of Devonian strata other than the Peel Sound strata in the Cunningham Inlet graben on northern Somerset Island prevents any determination of the paleogeography of that area during lower Devonian times. It is possible that the Silurian land mass was still present.

The suggested Silurian land mass north of Somerset Island was probably fault-bounded to the north, possibly by the same east-west fault which marks the southern coast of Devon Island (Gregory et al., 1961, p. 20). The southern edge of the land mass may have also been fault-bounded in the eastern part, possibly by the fault which Bourne and Pallister (1973, p. 51) have noted along the northern coast of the Brodeur Peninsula.

The implications of such a paleogeographic scheme are far-reaching for it divides the Jones-Lancaster Basin into two distinct elements. A southern basin would have covered Somerset Island and part of Baffin Island and a northern basin would have covered Devon and southern Ellesmere Islands.

The accurate reconstruction of the Silurian paleogeography of this area requires a more detailed study of the sections on the southern coast of Devon Island, the east coast of Somerset Island and the areas between the sections described in this study.

CHAPTER 8

STATISTICAL ANALYSIS IN PALEONTOLOGY AND ITS APPLICATION TO
CERTAIN BRACHIOPODS FROM THE READ BAY FORMATIONFossil Classification

Purposes The basic aim of any classification is to provide a means of communication. By ordering particular objects into a series and labelling various stages in that series it is possible by use of only a few terms to convey to other workers which part of the series is being considered. Thus, in paleontology the Linnaean hierarchy of classification provides a method which enables one to place a fossil in a given taxon.

This method is well established and is unlikely to be altered radically within the near future. Under the Linnaean system each stage within a given series is denoted by a label. Sokal and Sneath (1963) suggested that this system of naming should be replaced by a numerical code which would represent the numerical characteristics of that fossil. However, as Jardine and Sibson (1971) have pointed out, most people can remember a latin term easier than a numerical code. Numerical coding will undoubtedly be the method used if computers are to be used in conjunction with a data retrieval system.

The success of the Linnaean method depends on the procedure

used in arriving at a given point within the Linnaean hierarchy.

As will be discussed in the following paragraphs it is these procedures which often create the difficulty and poor interpretation of that system.

Procedures Jardine and Sibson (1971) suggested that there are three possible approaches to classification and placement within the Linnaean system, each with its merits and limitations, as follows:

- (1) The conservative approach. This approach suggests that identification should follow as closely as possible the traditional classification system. Thus, a new form once identified should be placed within the framework of classification already established.

This approach relies on previously established methods of identification. However, it is rare that two workers will visualise the same fossil in the same manner. One worker may consider one attribute as being important in species identification whereas a second worker will consider it not important enough to warrant placement in a particular species.

Further, such methods often rely on study of only a few attributes whereas in reality many attributes are present.

The initial separation of groups into species is commonly

done at the 'whim' of the investigator.

Such methods and the inability of the human mind to assimilate vast amounts of data rarely allow complete and accurate assessment of ontogenetic features or features controlled by environmental factors. The ontogenetically or environmentally controlled attributes should not be used for classification unless they are first fully understood.

- (2) The cladistic approach. In this approach, classification is done as much as possible in the context of evolutionary sequences. Thus, various groups are placed in an evolutionary sequence which a particular worker may consider valid. Species names are then assigned to various stages in that sequence. The premise of such a procedure is that all the groups are related and display ancestor-descendent relationships. Commonly, no consideration is given to similarities and dissimilarities between the various groups. It is possible that vastly different species may be placed in the same group simply because a worker considers them to be related and part of the same evolutionary branch.

A similar procedure is one in which fossils are given different names because they occur in strata of different age, even though the groups may be the same. Such a procedure

is not in keeping with the original concept of Linnaean classification.

- (3) The phenetic approach. One of the basic failures of the conservative approach is that it fails to convey any idea of similarity or dissimilarity between the various identified groupings. By phenetic procedures, which treat the groupings by mathematical processes, coefficients of similarity between the various groups can be obtained.

In such a way the boundaries between the generic and specific groupings can be kept at a particular level. It need no longer be an arbitrary division based on the 'whim' of a worker..

The introduction of high speed electrical computers and the corresponding advance in statistical methods has facilitated the processing of vast amounts of quantitative data. With the use of many specimens and numerous parameters from each, the classification and understanding of fossil groupings should increase.

Choice of approach The choice of approach to classification must depend somewhat upon the classifier's concept of species. Above this rank the conservative approach is sufficiently well established to be used successfully. This is in part a consequence of the great

dissimilarities which commonly separate genera. In general as the rank of classification increases so does the degree of dissimilarity and this facilitates separation.

The assignment of specimens to a particular species poses many problems. As previously stated the presence or absence of a single attribute is often sufficient to place a specimen in one species or another. However, such a procedure excludes consideration of the total form of the specimen. Comparison of one specimen with another should be based on the consideration of all the characters.

Before proceeding further with this discussion it is necessary to consider the question of what constitutes a species, the second-to-lowest rank of the Linnaean hierarchy.

Many biologists define a species as being a population in which the individuals are capable of interbreeding. However, while this may be demonstrated with living specimens it is impossible to demonstrate an interbreeding relationship amongst fossil populations. Consequently, this approach cannot be used in paleontological studies.

Jardine and Sibson (1971) considered that species identification of modern organisms is made on the basis of the following considerations:

- (1) Dissimilarity in morphological and other attributes,

- (2) Difference in geographic and ecological range,
- (3) Cytological differences as revealed by chromosome number and degree of pairings between chromosomes at meiosis in hybrids,
- (4) Degree of infertility revealed by ease of hybridization and fertility and vigour of second generation offspring,
- (5) Serological differences,
- (6) Extent of DNA hybridization.

It is obvious that considerations 3 to 6 are inapplicable in paleontology because these attributes will not be preserved in fossil forms. Consequently, the paleontologist is left with two considerations upon which to base identifications and hence classifications.

In view of these difficulties the species as identified by the paleontologist is in reality more of a 'morphological species'. That is, all specimens assigned to one species should have the same basic form.

Thus, if the concept of species in paleontology in reality is based on morphological similarity, then one of the most accurate methods of defining a species is one which involves numerical methods. Most paleontological classification is based on morphological similarity and therefore the phenetic approach to classification is

the most logical and useful. It allows the form of the fossil to be described in numerical terms which in turn allows the worker to obtain some measure of similarity or dissimilarity between the various species being studied. Such a method also allows the identification of transitional groups between any two main groups.

However, such a method can only be applied with any degree of success when large numbers of well preserved specimens are available. Unfortunately, paleontological collections are commonly limited to a few poorly preserved fossils and in this instance the paleontologist must revert to the conservative approach.

Response of animals to environmental conditions An aspect of classification which many people overlook is the effect that environmental conditions can have on the morphology of individuals. Such an oversight can lead to many problems since it may lead to unwarranted separation into different species of morphological variants belonging to one species.

Seed (1968) showed that the environment can have a marked effect both on the size and form of the bivalve Mytilus edulis. He demonstrated convincingly that the shape of an individual shell was related to its position relative to the shoreline, and also that shells in areas away from the shoreline and hence, relatively sheltered from

tidal and current action; had a higher growth rate than shells in the near shore areas that were subjected to tidal action and high currents.

Chuang (1962) demonstrated that the size of the Recent brachiopod Lingula unguis, which lives along the Singapore coastline varies according to the amount of mud in the sediment. Shells from sediment with a high content of mud were generally smaller (both mean and maximum) than those shells from sediment with little mud.

In the Puget Sound region of Washington the brachiopod Terebratulis transversa lives in quiet to rough water habitats from mean low tide to a depth of 90 fathoms (about 115 m) (Lowenstam, 1967). Dubois (1916) showed that the shells of this species vary from 'Spirifer-like' forms in quiet water to 'round, almost smooth forms' in rough water. Lowenstam (1967) recollected this species from the same locality and showed that shells in quiet water were the largest and had the smoothest shell.

These three examples serve to illustrate that shell size and shape of brachiopods and bivalves can be affected by the environments in which they lived. Consequently, before any species assignment can be made, it is first necessary to consider how environmental conditions may have affected the shell. It is logical

that differences in the size and form of the shell caused by the environment should only be included with caution in any classification scheme. Although the effects of the environment on a shell will often be difficult to assess, an attempt should always be made to determine the possible effects.

Use of statistics

Application to the brachiopods from the Read Bay Formation. As a result of the considerations previously outlined the phenetic approach to classification was applied to some of the brachiopods from the Read Bay Formation of northern Somerset Island. The Read Bay Formation contains numerous, well-preserved brachiopods and thus, obtaining numerical data from the various assemblages was not a problem. In chapter 9 (p. 307) the brachiopod genus Atrypella is described in considerable detail using the methods which are outlined in the following paragraphs. Other brachiopods, such as Conchidium, Protathyris and Stegerhynchus were studied in a similar manner and these results will be published elsewhere. The genus Atrypella was chosen for the most detailed study because in past literature it has been extensively used as an index fossil of the Read Bay Formation. Despite this use as a index fossil few detailed studies have been made of its taxonomy and facies distribution. The

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use of statistical methods in the study of the brachiopod Atrypella provides an accurate method of separating the various species. The application of these statistical methods are described in the following sections.

Methods Before any statistical methods can be used in the phenetic approach it is first necessary to decide which parameters are to be used. With the use of a computer this number is limited only by the worker's choice and the number of possible parameters. In practise it is often better to measure as many parameters as possible for this will eventually mean that a better index of similarity will be obtained.

In the study of Atrypella eight parameters were used.

The parameters are of two types:

(1) those measured directly from the fossils (defined in Text-fig. 50),

(2) those parameters derived from the measured parameters. These parameters are defined by the following formulae:

(a) Relative Deflection of the Anterior Commissure (R.D.A.C.) = $\frac{\text{Absolute Deflection of the Anterior Commissure} \times 100}{\text{Height}}$ (A.D.A.C.)

(b) Plan Circularity Index (P.C.I.) = $\frac{\text{length} \times 100}{\text{Length} + \text{Width}}$

(c) Side Circularity Index = $\text{Height} \times 100 / \text{Length} + \text{Height}$
 (S.C.I.)

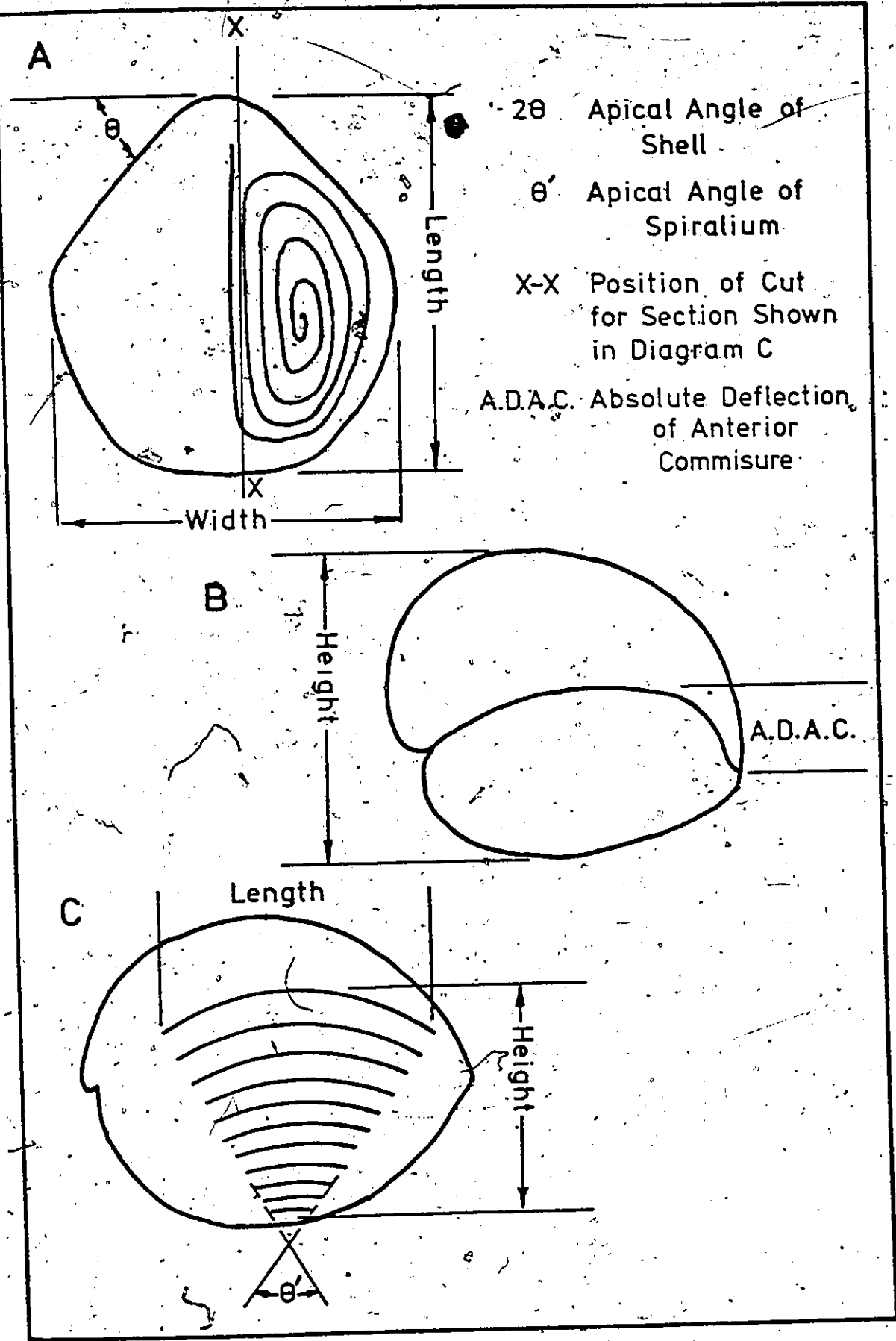
The P.C.I. and the S.C.I. are measurements of the overall shape of the shell. Such formulae have the effect of reducing the shape of the shell to a simple ellipse. In the P.C.I., length and width form the major and minor axes, respectively, of the ellipse (width is only rarely the major axis in this genus). An index of 50.00 indicates that the length and width are equal. The amount by which an index exceeds 50.00 is proportional to the amount by which length exceeds width. The S.C.I. is used in a similar manner.

The well-preserved specimens in assemblage W1 were suitable for obtaining measurements of the spiralia. Each specimen was cut vertically along a plane slightly to one side of the median plane (Text-fig. 50a) to obtain the maximum dimensions of the spiralia. Each specimen was photographed and accurate measurements of the parameters defined in Text-figure 50c were made from prints enlarged 5 times.

Each assemblage of shells consisted of the entire number of complete specimens collected at a particular locality and most assemblages contained more than 60 specimens. Sample size is important for it can have a radical effect on the subsequent analysis. Too small a sample will increase the possibility of error

Text-figure 50

Definition of parameters used to describe Atrypella. A - dorsal view,
B - side view, C - longitudinal section showing spirulum parameters.



especially in the calculation of the range (maximum - minimum) of values and the mean value. Too great a sample can mean that many of the measurements are merely being repeated. This is especially true where all the measurements fall into a restricted size range.

It was found for this study that a sample size of 60 to 100 specimens was the most satisfactory.

Once the initial data were assembled, the following statistical measures were determined (formulae given in Appendix 1) for each parameter:

(1) Maximum value	(5) Variance
(2) Minimum value	(6) Standard deviation
(3) Range	(7) Coefficient of variation
(4) Mean value	(8) Standard error of the mean

For the whole body of data the following statistical measures were calculated:

- (9) Correlation coefficient between every pair of parameters
- (10) Significance of the correlation coefficients
- (11) Gradient of the reduced major axis for all graphs where the correlation coefficients between any two variables was significantly different from zero.
- (12) Constant of the reduced major axis
- (13) Standard error of slope of the reduced major axis

(14) Absolute dispersion of points around the reduced major axis

(15) Relative dispersion of points around the reduced major axis

These parameters, which are sufficient to describe the statistical characteristics of any data, were calculated using the computer program 'Basic Statistics' written by the author.

The advantages of replacing the scatter of points on a two-dimensional graph by a reduced major axis are manifold. The fact

that a single population can be represented by a single straight line facilitates visual comparison of one population and another.

Such a method also allows statistical comparison of two reduced major axes according to the procedure outlined by Imbrie (1956),

Miller and Kahn (1962) and Kermack and Haldane (1950). This

comparison is done in two ways, as follows:

(1) comparison of the gradients of the axes

(2) comparison of the positions of the reduced major axes on the graph. This is normally only done if there is no significant difference between the gradients of the axes.

In both cases the formulae used for comparison give a Z value which can then be compared with the Z value for the 0.05 level of significance to decide whether the axes under consideration are the same or different. Such a procedure is set up under the

Null Hypothesis that the axes are the same. These comparisons of the reduced major axes by means of the calculation of the Z values are done using the computer program 'Axis Comparison' which was written by the author.

One of the goals of the phenetic approach to classification is to derive some measure of similarity or dissimilarity between various groups of fossils. One method of calculating an index of similarity is really an extension of the Pythagorean theorem. Harbaugh and Merriam (1968, p. 163) provide a good account of the theory behind this method and the reader is referred to this work for details (see also Appendix 1 for the formulae for obtaining the coefficient of similarity).

One of the concepts involved with the calculation of the similarity index is that of N-dimensional space in which each axis is of unit length. Before calculating the similarity index it is first necessary to normalize the data. An easy method of doing this and at the same time obtain maximum usage of the unit length scale is to set the maximum of a given variable at 1.0 and the minimum at 0.0 (see Appendix 1 for formulae).

A set of 10 groups will have a matrix with 100 values giving the similarity indices between every possible pair of groups.

However, since a matrix of this type is a mirror image about one diagonal only 45 indices are required. Even with this reduction, the number of indices involved is large and it is thus difficult to detect any pattern that may be present in the matrix.

Any existing pattern within a similarity matrix can be revealed by cluster analysis. This results in a two- or three-dimensional dendrogram which clearly shows the relationship between the various groups (Parks, 1966; Sokal, 1966). For the formulae used in these calculations the reader is referred to Appendix 1. The calculation of the similarity indices and the subsequent cluster analysis was done by the computer program 'Cluster Analysis' which was written by the author.

A dendrogram enables the worker to see which groups are most similar and which are most dissimilar. The nature of the groupings will also suggest how the groups should be split into species. Alternatively, phenon lines can be drawn at different similarity levels which automatically divide the groups into species (Sokal, 1966; Jardine and Sibson, 1971).

Application and interpretations

In some instances the Atrypella assemblages from a given locality consisted of several species. Thus, before consideration could be given to the individual species it was necessary to divide

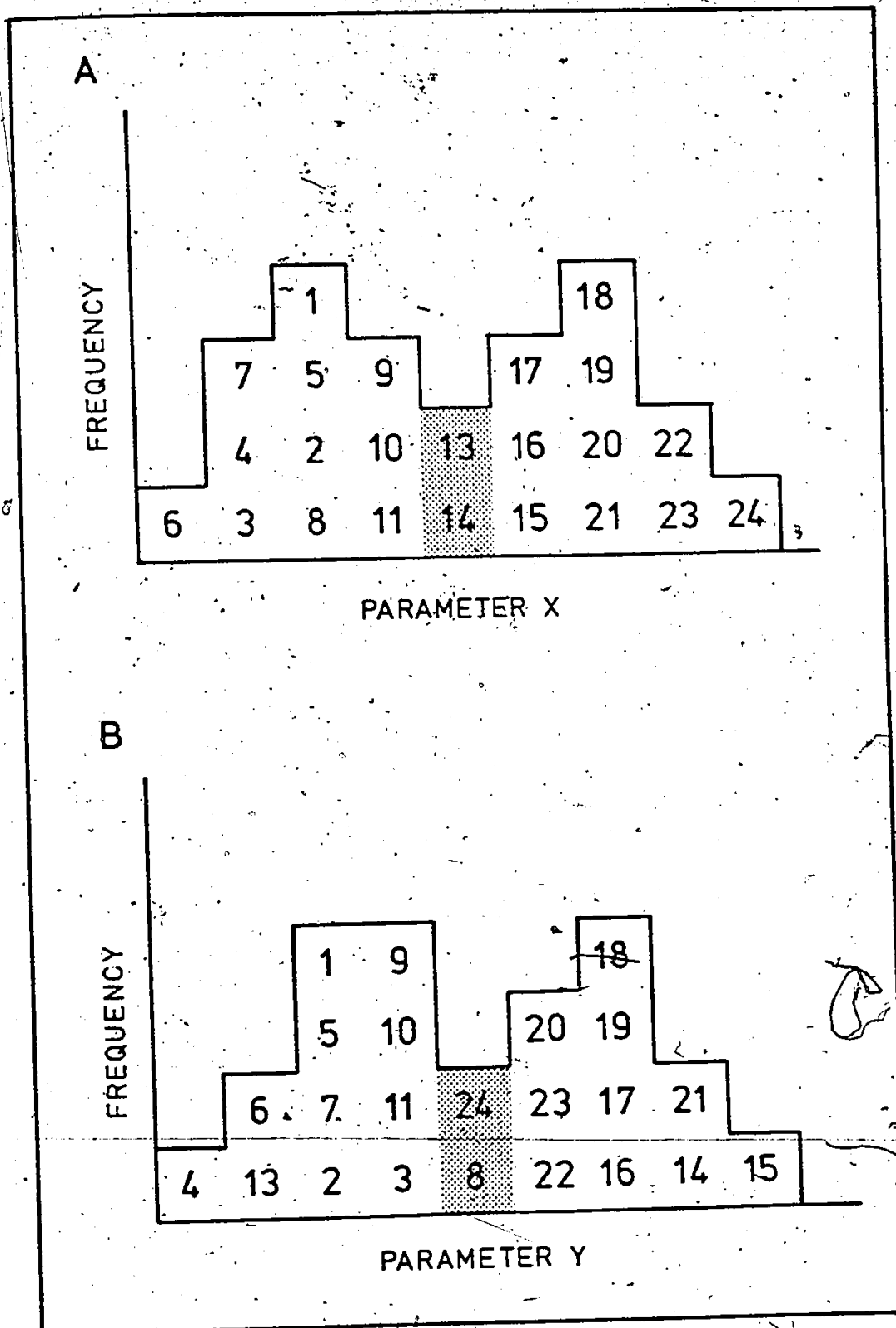
the assemblages into tentative species groupings. This separation was achieved as described in the following paragraphs.

The parameters of each fossil were used to construct frequency histograms. The presence of two species normally results in a bimodal histogram of the form shown in Text-figure 51. In the example used to demonstrate this technique it is obvious that the specimens numbered 1-11 are different from those numbered 15-24. However, the problematical specimens 13 and 14 and possibly 11 and 15 all lie in the overlap zone (shaded area on Text-fig. 51a) and it is not clear to which group they belong. In order to determine this, it is necessary to consider histograms of different parameters. In most cases where this was done the specimens that previously fell in the overlap zone were found to plot clearly in one group or another (Text-fig. 51b). Consequently, they could tentatively be assigned to one group or the other. Consideration of other histograms served to confirm the assignment of a particular specimen to one group or the other. The size of the overlap zone is in itself a measure of the similarity between the two groups.

At this stage in the procedure it is often useful to inspect the specimens 'by eye' to see if the groups indicated by the histograms are realistic. However, attributes are measured, they cannot fully depict the form of the shell and it is useful to revert

Text-figure 51

Separation of species using histograms. Numbers of individual specimens are added to frequency histogram as shown in figures A and B. Central column (containing specimens 13 and 14 in A) is combination of tails of both curves: thus it is uncertain to which modal group the specimens belong. Consequently, a second frequency histogram is constructed (figure B). Note that specimens 13 and 14 which previously placed in the area of uncertainty now plot into one modal group or the other thereby suggesting affinity to that group. See Text for further explanation.



to a qualitative judgement for confirmation of the results obtained by numerical methods.

An alternative method is to calculate the similarity index between the various specimens and then perform a cluster analysis on the resultant matrix. This would undoubtedly provide an accurate method of species separation. However, a sample of 110 specimens would involve the computation of 220 matrices, each one being 110 by 110. Such a procedure is too laborious to be done by hand. Time prevented the author from applying this method in this study but there is little doubt that it would be successful if applied.

Once the species groupings were obtained, the parameters previously outlined were calculated.

The correlation coefficient matrix for each assemblage is extremely useful as it can provide an easy method of separating the parameters affected only by inheritance from those affected both by inheritance and by ontogeny. It is quite evident that in fossil and recent brachiopods and bivalves the length of the shell increases with age. Therefore, any parameter that shows a significant correlation with length is also ontogenetically variable.

The relationship of the other parameters to length can be in one of three forms as follows:

- (1) A perfectly linear relationship
- (2) A logarithmic relationship
- (3) No relationship

In all instances in the study of Atrypa, the relationship, if present, was linear, as shown by graphical plots of each parameter with length (graphs were plotted by the computer program 'Plot' which was written by the author).

A correlation coefficient is judged significant if it differs significantly from zero. If the correlation with length is significant then that parameter is one which varies with ontogeny whereas a non-significant correlation with length indicates that the parameter did not vary with ontogeny. If the correlation coefficient is significantly different from zero then the spread of points is represented by a reduced major axis.

The magnitude of a particular parameter may be dependent on the environmental conditions in which the animal lived (p. 238). This can affect the magnitude of parameters which vary with ontogeny and those which do not. To evaluate the effect of environment on a particular species it is necessary to compare assemblages from different environments.

This comparison can be carried out in a number of ways.

The mean value of each parameter can be compared in one of several ways. If only two samples are involved, then the Student's 't' test can be employed to test the two means under the Null Hypothesis that the mean values of both were obtained from the same population. This value is then tested against a value of 't' for a given level of significance, to determine whether the Null Hypothesis can be accepted or not. However, this procedure is invalid (Sokal, 1966) since the two assemblages are from different populations. A second disadvantage of this method is that it considers only the mean value and the standard deviation of the distributions. No account is taken of the possible error that may surround the single mean value.

If more than two samples are being considered, then, rather than use the Student's 't' test, an analysis of variance can be made. This simultaneously considers all the mean values and yields one value upon which to judge the Null Hypothesis that the mean values are all the same. The disadvantage of this method is that the analysis leads to a positive or negative answer only. That is, the only conclusions that can be made are that the means are the same or that the means are different. If the means are different, no idea is given of how many are the same or by how much the means differ. To evaluate these differences further tests would be necessary.

A much easier method of comparison is afforded by the use of Dice-Diagrams (named after Dice and Leraas, 1936 - cited in Sokal, 1966). The construction of a Dice-Diagram is shown in Text-figure 52a. The mean is shown, but greater emphasis is placed on the 95% confidence limits of the mean (approximately equal to 2 standard errors of the mean on either side of the mean). Comparison of the means should make use of the 95% confidence limits (Sokal, 1966). By using these confidence limits for comparison some account is taken of the errors involved in obtaining the mean value.

Dice-Diagrams can readily be compared visually. If the 95% limits of the mean values on two diagrams overlap then the two means are considered the same (Text-fig. 52b). Conversely if no overlap occurs then the mean values are considered significantly different (Text-fig. 52c). An additional advantage of Dice-Diagrams is that in a simple manner they depict the distribution of measurements for a given parameter.

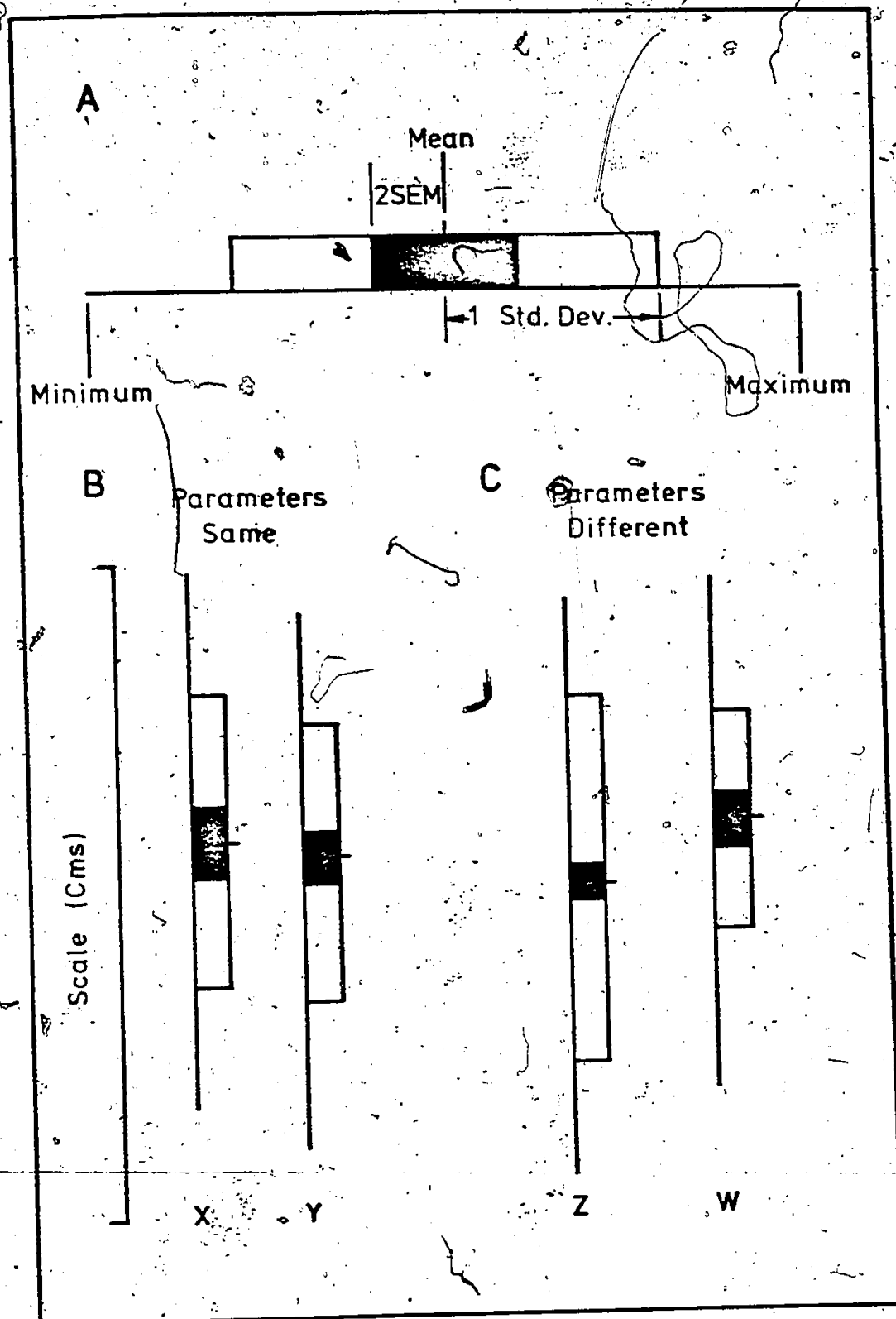
Once these comparisons have been made, the parameters that vary with ontogeny and those which do not can be further classified. Among the ontogenetically constant parameters, one that is solely genetically variable and can be used for species identification, should be unaffected by environment. Conversely, if the magnitude of that parameter, while remaining constant

Text-figure 52

A - Construction of Dice-Diagram. SEM = Standard error of the mean
Std. Dev. = Standard deviation.

B - Comparison of two parameters, X and Y, whose means are not
significantly different. Note that central shaded zones overlap.

C - Comparison of two parameters, Z and W, whose means are significantly
different. Note that central shaded zones do not overlap.



within one assemblage, varies with environmental conditions, it can no longer be considered an ideal species character. Thus, two classes of parameters can be identified, namely:

- (1) A genetically variable character which shows no ontogenetic or environmental variation.
- (2) A genetically variable character which shows environmental but not ontogenetic variation.

Comparison of the ontogenetically variable characters is more difficult because account must first be taken of the ages of the specimens. For example, it is useless to compare the lengths of two specimens if one is older than the other. To remove the ontogenetic factor from consideration, it is necessary to reduce the parameters to a relative scale. This can be done simply by plotting one of the variables against another on a two-dimensional graph. From this graph the growth rate of two assemblages can be compared. If it can be determined that the growth rates are different, then it is valid to compare the Dice-Diagrams of the parameters which vary with ontogeny. However, if the growth rates are the same or very similar, any differences in size between the two assemblages merely show that one group is older than the other.

Such comparisons of the growth rates are easily achieved by the use of the reduced major axis and its associated statistical

tests. Using this method two additional types of parameters can be distinguished, namely:

- (3) A genetically variable character which shows ontogenetic but not environmental variation.
- (4) A genetically variable character which shows both ontogenetic and environmental variation.

The classification of the parameters according to the scheme outlined above is very important because variation caused by ontogenetic and environmental factors is not used in distinguishing species unless the full range of variance is first known.

Sources of error

The possible sources of error in the phenetic methods are manifold. However, many of these can be removed or minimized by careful collecting and measurement. These possible errors and a discussion of how to minimize them are presented below:

- (1) Biased collecting may result in one portion of a population being overrepresented. It is well known that collectors tend to collect large specimens rather than small ones which are more difficult to find. A particular effort was made to collect all sizes of shells in the hope that this bias could be avoided.

(2) Errors may be introduced by the measuring instrument. These errors will be a function of the quality of the measuring instrument. However, in most circumstances these errors are so small that they can be ignored.

(3) Operator's error is probably one of the most important sources of error. The operator may overestimate or underestimate the reading of the measurement from the instrument. Errors of this type can only be minimized if the operator takes the utmost care during measurement.

Whatever the procedure and however much care is taken, there will always be some error. The degree of error is probably of the order of 5-10% although it can never fully be evaluated.

CHAPTER 9

THE BRACHIOPOD GENUS ATRYPELLAIntroduction

The Read Bay Formation of the Arctic islands is distinctive for its extremely rich fauna of brachiopods, corals, stromatoporoids and other invertebrates. Amongst the brachiopods, the genus Atrypella is the most common. Indeed, many workers consider that Atrypella is a diagnostic fossil of the Read Bay Formation. However, despite the apparent importance of Atrypella, few studies have been made of its taxonomy, facies distribution or stratigraphic distribution. The abundance and ease of collection of Atrypella in some of the strata on northern Somerset Island made a detailed study of the genus feasible.

There are numerous problems associated with the genus. Perhaps the most critical is the question of whether the genera Lissatrypa and Atrypella are distinct. The problem began when Høltedahl (1914) based identification of certain brachiopods on some unpublished work of W. H. Twenhöfel. Ultimately, Twenhöfel (1914) also published his work but despite efforts by Kirk and Amsden (1952) the problem of who published first has not been resolved. This is a critical question, for the date of publication of these

papers would determine the type species of the genus. The most logical solution, as suggested by Kirk and Amsden (1952), is to accept Twenhofel's species as the type species of Lissatrypa. With

the establishment of the genus Atrypella by Kozlowski (1929), the question of the correct generic assignment of Holtedahl's specimens arose. The status of Atrypella has been the subject of some controversy in the literature, especially between North American and Soviet authors. The majority of Soviet workers (for example, Khodalevich, 1939; Nikiforova, 1939; Nikiforova and Andreeva, 1961) considered Atrypella a synonym or subgenus of Lissatrypa. Thus, one of the basic problems examined in this chapter is the validity of the genera Lissatrypa and Atrypella.

The criteria for the recognition of species of Atrypella have previously been qualitative with great emphasis placed on shell size (small versus large), shell convexity (less convex versus more convex), the development of the sulcus (well developed versus poorly developed) and the nature of the internal structures. In all of the past studies (e.g. Holtedahl, 1914; Kirk and Amsden, 1952; Johnson and Reso, 1964) no consideration was given to the possibility that the size and form of the shell might have changed with ontogeny or environmental conditions. Thus, before any consideration

can be given to defining the species within the genus it is desirable to consider possible growth patterns and environmental controls.

Since Høltedahl (1914) placed the species phoca in the genus Lissatrypa, many authors have indirectly suggested that it belongs instead to Atrypella Kozłowski. Despite the fact that Fortier et al. (1963, p. 134 and p. 138) and Thorsteinsson (1958, p. 74) listed the species as Atrypella phoca it was not until 1970 that Nikiforova formally reassigned the species to the genus Atrypella. Thorsteinsson (1958, p. 74) stated, "In 1952, Kirk and Amsden transferred Lyssatrypa phoca and Lyssatrypa scheii to the genus Atrypella". However, Kirk and Amsden (1952) only placed Lissatrypa scheii as a synonym of Atrypella scheii (Høltedahl)? None of the previous descriptions of the species have included considerations of its ontogenetic and environmental variability. Consequently, the species is redescribed below to include the variance attributable to ontogeny and environmental factors.

Prior to this study, Atrypella shrocki Cooper (1942) was referred to only briefly in faunal lists by McMillan (in Fortier et al., 1963). This species is present in the Read Bay Formation but is not as common as A. foxi n. sp. or A. phoca (Salter).

A. shrocki is redescribed below, based on specimens from Somerset

Island.

Thirteen assemblages of Atrypella from Somerset Island were subjected to detailed statistical analysis. Their geographic and stratigraphic locations and sample sizes are given in Table 13. For the sake of brevity in the following discussion, the assemblages are referred to by the code numbers given in column 1 of Table 13.

Comparison of each species with others and with other species described in the literature has been combined in a later section of the chapter, rather than immediately following the systematic description of each species.

Systematic Descriptions

Suborder ATRYPOIDEA

Superfamily ATRYPACEA Gill, 1871

Family ATRYPIDAE Gill, 1871

Subfamily SEPTATRYPINAE Kozlowski, 1929

Genus ATRYPELLA Kozlowski, 1929

Generic diagnosis (based on this study and past literature)

Biconvex shell becoming dorsibiconvex with maturity; convexity reflects genetic, ontogenetic and environmental influences; shells normally smooth but some display growth lines; pedicle umbo strongly incurved; no foramen visible except in some small forms; anterior commissure

Table 13

Stratigraphic and geographic location of Atrypella assemblages used in the statistical analysis of the genus.

Abbreviations as follows: R.A.L. = Rubbly argillaceous limestone; M.L. = Micritic limestone; A.L. = Argillaceous limestone and M.D.L. = Mottled dolomite-limestone.

(**) height above base of Read Bay Formation

(***) height below base of Peel Sound Formation.

Assemblage Code	Geographic Location			Stratigraphic Location			Lithology	Sample Size
	Locality	Lat.	Long.	Unit Number	Level in section (above base)	Height above sea level		
<u>Species</u>								
GD2 (<u>shrocki</u>)	Garnier Bay	73° 56'	92° 10'	2	3 m	175-200 m	R.A.D.	89
M104 (<u>shrocki</u>)	Cape Admiral M'Clintock	74° 01'	91° 12'	104	71 m	110-115 m	R.A.L.	53
F16 (<u>shrocki</u>)	N. of Creswell Bay	73°	93° 45'	16	28** m	---	A.L.	46
GC2 (<u>phoca</u>)	Garnier Bay	73° 56'	92° 12'	2	Isolated exposure	5 m	A.L.	81
T31 (<u>phoca</u>)	Cunningham Inlet	74° 07'	94° 07'		Scree		A.L.	110
C (<u>phoca</u>)	Cunningham Inlet	74° 07'	94° 10'		Isolated exposure		A.L.	138
W1 (<u>phoca</u>)	Pressure Point	73° 52'	95° 12'		Isolated exposure		A.L.	46
GC5 (<u>fox1</u>)	Garnier Bay	73° 56'	92° 13'		Isolated exposure		A.L.	74
X14 (<u>fox1</u>)	Pressure Point	73° 53'	95° 12'	14	53 m	300 m	M.D.L.	62
Y18 (<u>fox1</u>)	Pressure Point	73° 53'	95° 11'	18	52 m	400-425 m	M.D.L.	70
B33 (<u>fox1</u>)	Pressure Point	73° 45'	95° 11'	33	165*** m	---	M.L.	93
M113 (<u>fox1</u>)	Cape Admiral M'Clintock	74° 01'	91° 11'	113	71 m	110-115 m	A.L.	63
F16 (<u>fox1</u>)	N. of Creswell Bay	73°	93° 45'	16	28*** m	---	A.L.	44

strongly deflected, especially in larger more mature specimens;
 fold and sulcus shallow; short hinge line; outer hinge plates parallel
 or subparallel to commissural plane; crural bases at inner edges
 of outer hinge plates increase in diameter anteriorly before
 diverging from outer hinge plates to join primary lamellae; jugum
 well developed.

Distinguished from Atrypa by absence of costae and from
Lissatrypa by absence of pedicle collar, inner hinge plates, crural
 fibres and external fibres on the shell (although this difference may
 be a function of preservation).

Atrypella foxi n. sp.

Plate 27, Figures 1-8

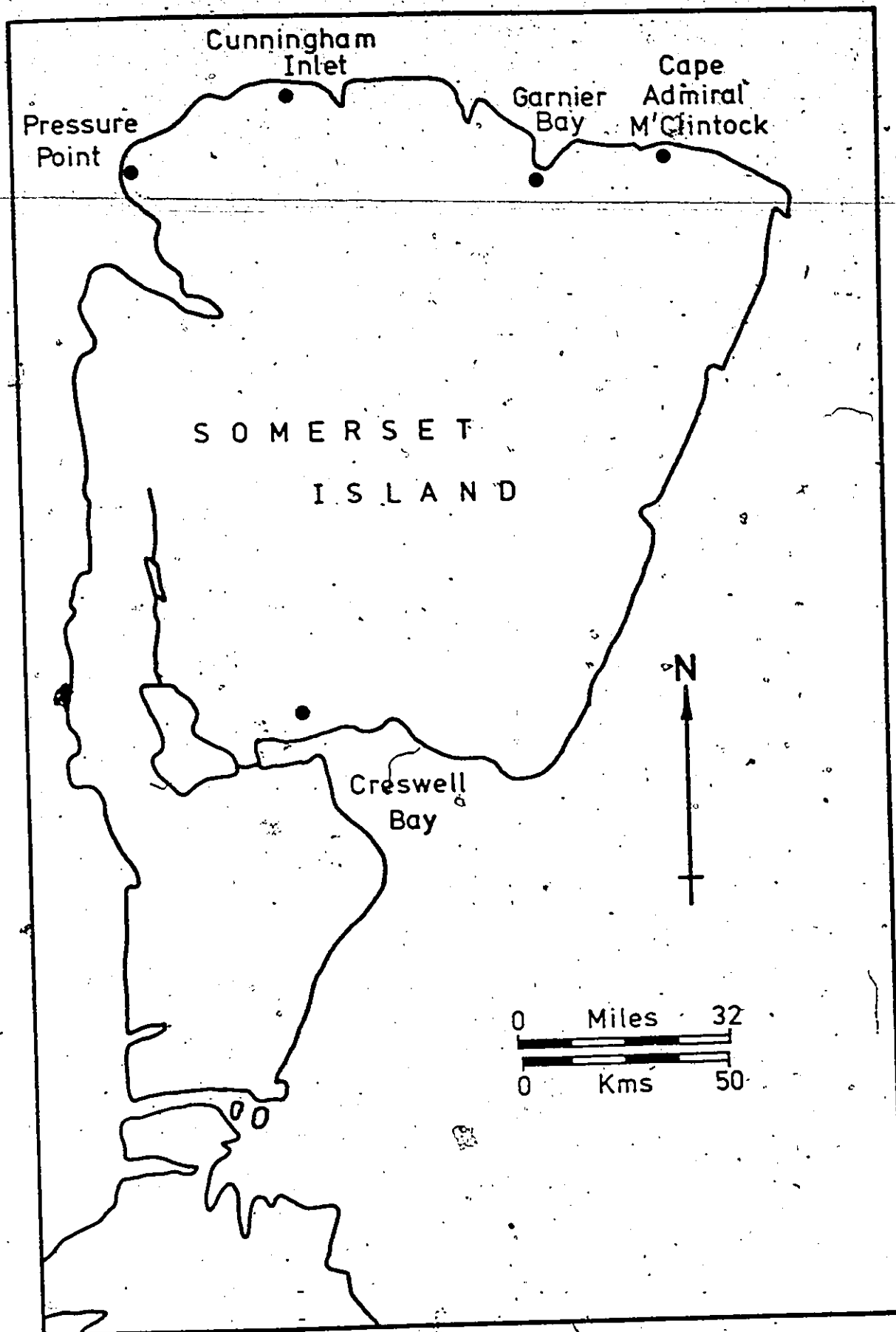
v. 1952 Atrypella scheeli (Holtedahl)? Kirk and Amsden, 1952

Derivation of name This new species of Atrypella is named after
 H.M.S. Fox in which F. Dr. M'Clintock visited Somerset Island in
 1858-1859.

Occurrence Specimens of Atrypella foxi occur at Cape Admiral M'Clintock
 (assemblage M113), Carnier Bay (assemblage GC5), Pressure Point.
 (assemblages X14, Y18 and B33) and Creswell Bay (assemblage F16)
 (Text-fig. 53 and Table 13).

Text-figure 53

Collecting sites for Atrypella assemblages



Horizon and age All the assemblages were obtained from strata of the Read Bay Formation. Assemblages Y18, X14 and B33 are from the upper part of the formation. Assemblage Y18 occurs 19 m (62.3 ft) below the base of the Peel Sound Formation (Text-fig. 7, p. 9 and Text-fig. 36, p. 126) and assemblage X14 is 97 m (318 ft) below assemblage Y18 (Text-fig. 7, p. 9 and Text-fig. 35, p. 125). Assemblage B33, from a gorge 8 kms (5 miles) to the south of the gorge containing assemblages X14 and Y18, occurs 165 m (540 ft) below the base of the Peel Sound Formation. On the basis of conodonts, S. R. Williams (1973, pers. comm.) placed the base of the Peel Sound Formation at this locality in the upper Pridolian. Consequently, assemblages Y18, X14 and B33 are probably of middle to upper Pridolian age. The lack of good stratigraphic controls for assemblages M113 (Text-fig. 4, p. 6 and Text-fig. 26, p. 98), F16 and GC5 (Text-fig. 5, p. 7) prevents accurate dating of the strata from which they were collected. They may be of upper Ludlovian or Pridolian age.

Type material and repository A holotype and 19 paratypes have been designated to illustrate the substantial morphological variation shown by the species. The type specimens are held in the repository of the Geological Survey of Canada. The holotype bears G.S.C. type number 34624, and the paratypes, numbers 34625 to 34643.

Diagnosis Atrypella having the following characteristics:

- (1) A Plan Circularity Index which varies from 48 to 59 (extreme forms) and averages between 52 and 53.
- (2) A Side Circularity Index which varies from 29 to 50 and averages between 37 and 38.
- (3) An apical angle which varies from 35° to 76° and averages between 47° and 60° (environmentally controlled).

External morphology Members of this species typically have a smooth biconvex shell although a few display faint growth lines. The umbo is strongly incurved, especially in the larger, more mature specimens.

The correlation table for assemblage M113 (Table 17) shows that the width, height, A.D.A.C. and R.D.A.C. all have a significant positive correlation with length and consequently are ontogenetically variable. The S.C.I. has a good correlation with height and must also vary with ontogeny. Conversely, the apical angle and the P.C.I. have low correlation coefficients with the ontogenetically variable parameters and do not vary significantly with ontogeny.

The correlation tables for the other assemblages (Tables 14 to 19) show a similar basic pattern to that outlined for assemblage M113, with certain exceptions. These exceptions, when they occur, are generally between the apical angle or the P.C.I. and the other parameters. However, the fact that they are exceptions to the general

	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length	1.00	0.93	0.75	-0.31	0.77	0.52	0.52	0.25
Width		1.00	0.70	-0.35	0.67	0.42	0.17	0.24
Height			1.00	-0.14	0.67	0.26	0.40	0.82
Apical Angle				1.00	-0.13	-0.11	0.02	0.09
A.D.A.C.					1.00	0.87	0.51	0.33
R.D.A.C.						1.00	0.44	-0.04
P.C.I.							1.00	0.13
S.C.I.								1.00

Table 14.- Correlation table for the Atrypella foxi assemblage (X14) from

Pressure Point. Based on 68 specimens.

	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length	1.00	0.93	0.92	-0.40	0.82	0.57	0.49	0.59
Width		1.00	0.84	-0.48	0.67	0.41	0.09	0.54
Height			1.00	-0.33	0.84	0.53	0.43	0.85
Apical Angle				1.00	-0.30	-0.18	0.12	-0.16
A.D.A.C.					1.00	0.88	0.56	0.66
R.D.A.C.						1.00	0.53	0.40
P.C.I.							1.00	0.34
S.C.I.								1.00

Table 15.- Correlation table for the Atrypella foxi assemblage (Y18) from

Pressure Point. Based on 70 specimens.

	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length	1.00	0.97	0.95	-0.29	0.73	0.47	0.06	0.41
Width		1.00	0.92	-0.39	0.67	0.42	-0.17	0.39
Height			1.00	-0.21	0.76	0.46	0.07	0.67
Apical Angle				1.00	-0.03	0.05	0.42	0.07
A.D.A.C.					1.00	0.90	0.17	0.48
R.D.A.C.						1.00	0.16	0.24
P.C.I.							1.00	0.02
S.C.I.								1.00

Table 16.- Correlation table for the Atrypella foxi assemblage (B33) from

Pressure Point. Based on 93 specimens.

	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length	1.00	0.77	0.90	-0.37	0.69	0.48	0.15	0.38
Width		1.00	0.75	-0.43	0.67	0.49	-0.26	0.40
Height			1.00	-0.37	0.74	0.48	-0.03	0.69
Apical Angle				1.00	-0.26	-0.15	0.32	-0.26
A.D.A.C.					1.00	0.92	0.07	0.48
R.D.A.C.						1.00	0.11	0.28
P.C.I.							1.00	-0.26
S.C.I.								1.00

Table 17.- Correlation table for the Atrypella foxi assemblage (M113) from

Cape Admiral M'Clintock. Based on 61 specimens.

	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length	1.00	0.95	0.92	-0.48	0.68	0.49	0.13	0.43
Width		1.00	0.91	-0.47	0.66	0.48	-0.19	0.49
Height			1.00	-0.42	0.80	0.61	0.01	0.74
Apical Angle				1.00	-0.33	-0.26	0.27	-0.12
A.D.A.C.					1.00	0.94	0.05	0.69
R.D.A.C.						1.00	0.04	0.59
P.C.I.							1.00	0.19
S.C.I.								1.00

Table 18.- Correlation table for the Atrypella foxi assemblage (GC5) from

Gardner Bay. Based on 74 specimens.

	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length	1.00	0.96	0.94	-0.28	0.71	0.45	0.09	0.41
Width		1.00	0.91	-0.40	0.65	0.40	-0.15	0.39
Height			1.00	-0.19	0.75	0.45	0.09	0.68
Apical Angle				1.00	-0.01	0.06	0.42	0.07
A.D.A.C.					1.00	0.91	0.20	0.48
R.D.A.C.						1.00	0.15	0.24
P.C.I.							1.00	0.03
S.C.I.								1.00

Table 19.- Correlation table for the Atrypella foxi assemblage (Fig) from

the locality north of Creswell Bay. Based on 44 specimens.

Graph Parameters		M113 compared to											
		F16		GC5		B33		Y18		X14			
		N.V.	C.	N.V.	C.	N.V.	C.	N.V.	C.	N.V.	C.		
Length / Width	Z1	0.41	Same	0.86	Same	1.51	Same	1.83	Same	2.67	DIFF.		
	Z2	0.86	Same	3.48	DIFF.	0.25	Same	0.31	Same				
Length / Height	Z1	2.77	DIFF.	2.50	DIFF.	0.51	Same	1.19	Same	0.39	Same		
	Z2					3.65	DIFF.	4.70	DIFF.	3.79	DIFF.		
Width / Height	Z1	1.80	Same	1.32	Same	0.87	Same	0.60	Same	1.78	Same		
	Z2	1.14	Same	4.64	DIFF.	2.61	DIFF.	3.44	DIFF.	3.48	DIFF.		
Height / A.D.A.C.	Z1	1.22	Same	1.81	Same	3.85	DIFF.	2.59	DIFF.	3.80	DIFF.		
	Z2	1.12	Same	0.68	Same								
Height / R.D.A.C.	Z1	0.83	Same	1.10	Same	4.24	DIFF.	4.82	DIFF.	5.06	DIFF.		
	Z2	14.23	DIFF.	2.72	DIFF.								
Height / S.C.I.	Z1	0.37	Same	1.02	Same	0.05	Same	1.27	Same	0.26	Same		
	Z2	4.96	DIFF.	1.75	Same	7.58	DIFF.	9.64	DIFF.	9.86	DIFF.		

Table 20: Comparison of reduced major axes of assemblages M113, F16, GC5, B33, Y18 and X14 of Atrypella foxi. Significant value of Z is 1.96. If Z1 is above 1.96, Z2 value is not calculated. (N.V. = Numerical value, C. = Conclusion, DIFF. = Different).

Graph Parameters		F16 compared to										GC5 compared to	
		GC5		B33		Y18		X14		B33			
		N.V.	C.	N.V.	C.	N.V.	C.	N.V.	C.	N.V.	C.		
Length / Width	Z1	0.69	Same	1.59	Same	2.06	DIFF.	3.54	DIFF.	0.97	Same		
	Z2	5.19	DIFF.	0.28	Same					1.12	Same		
Length / Height	Z1	0.25	Same	2.59	DIFF.	1.64	Same	2.14	DIFF.	2.24	DIFF.		
	Z2	6.30	DIFF.			5.27	DIFF.						
Width / Height	Z1	0.71	Same	2.90	DIFF.	3.45	DIFF.	3.67	DIFF.	2.43	DIFF.		
	Z2	6.34	DIFF.										
Height / A.D.A.C.	Z1	0.45	Same	2.34	DIFF.	1.18	Same	0.63	Same	1.99	DIFF.		
	Z2	1.95	Same			1.26	Same	0.60	Same				
Height / R.D.A.C.	Z1	0.24	Same	3.20	DIFF.	3.94	DIFF.	4.32	DIFF.	3.00	DIFF.		
	Z2	12.28	DIFF.										
Height / S.C.I.	Z1	1.34	Same	0.48	Same	0.78	Same	0.68	Same	1.10	Same		
	Z2	7.55	DIFF.	10.53	DIFF.	11.90	DIFF.	12.13	DIFF.	7.32	DIFF.		

Table 20 (contd): Comparison of reduced major axes of assemblages F16, GC5, B33, Y18 and M13

and X14 of Atrypella foxi. Significant value of Z is 1.96. If Z1 is above 1.96,

Z2 value is not calculated. Abbreviations as on previous table.

Graph Parameters	GC5 compared to						B33 compared to			Y18 compared to		
	Y18			X14			Y18			X14		
	N.V.	C.	N.V.	C.	N.V.	C.	N.V.	C.	N.V.	C.	N.V.	C.
Length / Width	Z1	1.46	Same		2.87	DIFF.	0.49	Same	1.62	Same	1.02	Same
	Z2	0.63	Same				0.27	Same	0.46	Same	3.68	DIFF.
Length / Height	Z1	1.36	Same		1.90	Same	0.77	Same	0.06	Same	0.71	Same
	Z2	4.22	DIFF.		3.53	DIFF.	3.81	DIFF.	2.58	DIFF.	3.21	DIFF.
Width / Height	Z1	2.09	DIFF.		3.22	DIFF.	0.26	Same	1.02	Same	1.24	Same
	Z2						2.56	DIFF.	1.95	Same	2.94	DIFF.
Height / A.D.A.C.	Z1	0.77	Same		2.24	DIFF.	1.21	Same	0.54	Same	1.58	Same
	Z2	0.26	Same				4.61	DIFF.	6.50	DIFF.	3.76	DIFF.
Height / R.D.A.C.	Z1	3.77	DIFF.		4.17	DIFF.	1.09	Same	1.80	Same	0.76	Same
	Z2						42.16	DIFF.	32.98	DIFF.	22.58	DIFF.
Height / S.G.I.	Z1	2.35	DIFF.		0.88	Same	1.62	Same	0.26	Same	1.84	Same
	Z2				9.62	DIFF.	6.91	DIFF.	6.50	DIFF.	1.78	Same

Table 20 (contd.): Comparison of reduced major axes of assemblages F16, GC5, B33, Y18, M113

and X14 of Atrypella foxi. Significant value of Z is 1.96. If Z1 is above 1.96,

Z2 value is not calculated. Abbreviations as on previous table.

patterns suggests that they may be due to chance.

Comparison of the magnitude of the apical angle of the various assemblages (Text-fig. 55b) shows that, while the apical angle is the same in assemblages M113, F16 and GC5, it differs considerably from assemblages Y18, X14 and B33. As assemblages M113, F16 and GC5 came from argillaceous limestone while assemblages X14, Y18 and B33 came from micritic limestone, the apical angle appears to vary with the rock type in which the fossils were found. The P.C.I. (Text-fig. 56a) is the same for all assemblages, despite the fact that the length (Text-fig. 54a) and the width (Text-fig. 54b) vary from one assemblage to another. Thus, this parameter is genetically variable but unaffected by ontogeny or the environmental conditions in which the animals lived.

There are distinct differences between the various assemblages in the ontogenetically variable parameters (Text-figs. 54, ~~55~~ and 56). However, these differences in absolute size may simply be due to one assemblage having generally more mature specimens than another. The growth rates of the various assemblages have been compared by means of bivariate graphs (see Table 20 for full list of graphs compared) and the results are summarized in Table 20.

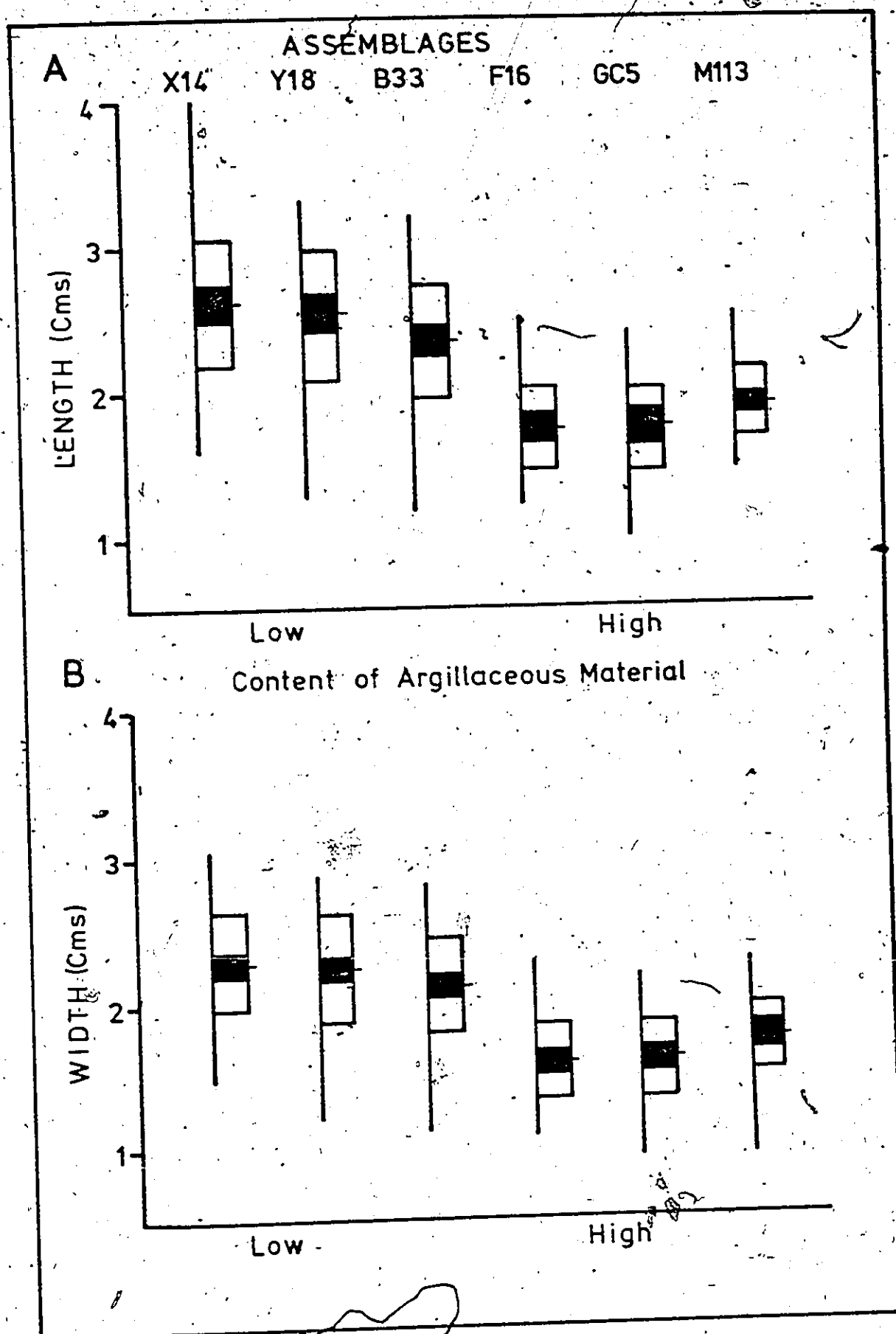
These tables demonstrate that certain aspects of the overall growth pattern may be the same but no two assemblages are identical in

Text-figure 54

Relationship between the length (A) and width (B) of Atrypella foxi and the amount of argillaceous material in the rock. There is a progressive change in the argillaceous content of the rocks from high (approximately 40%) to low (less than 10%).

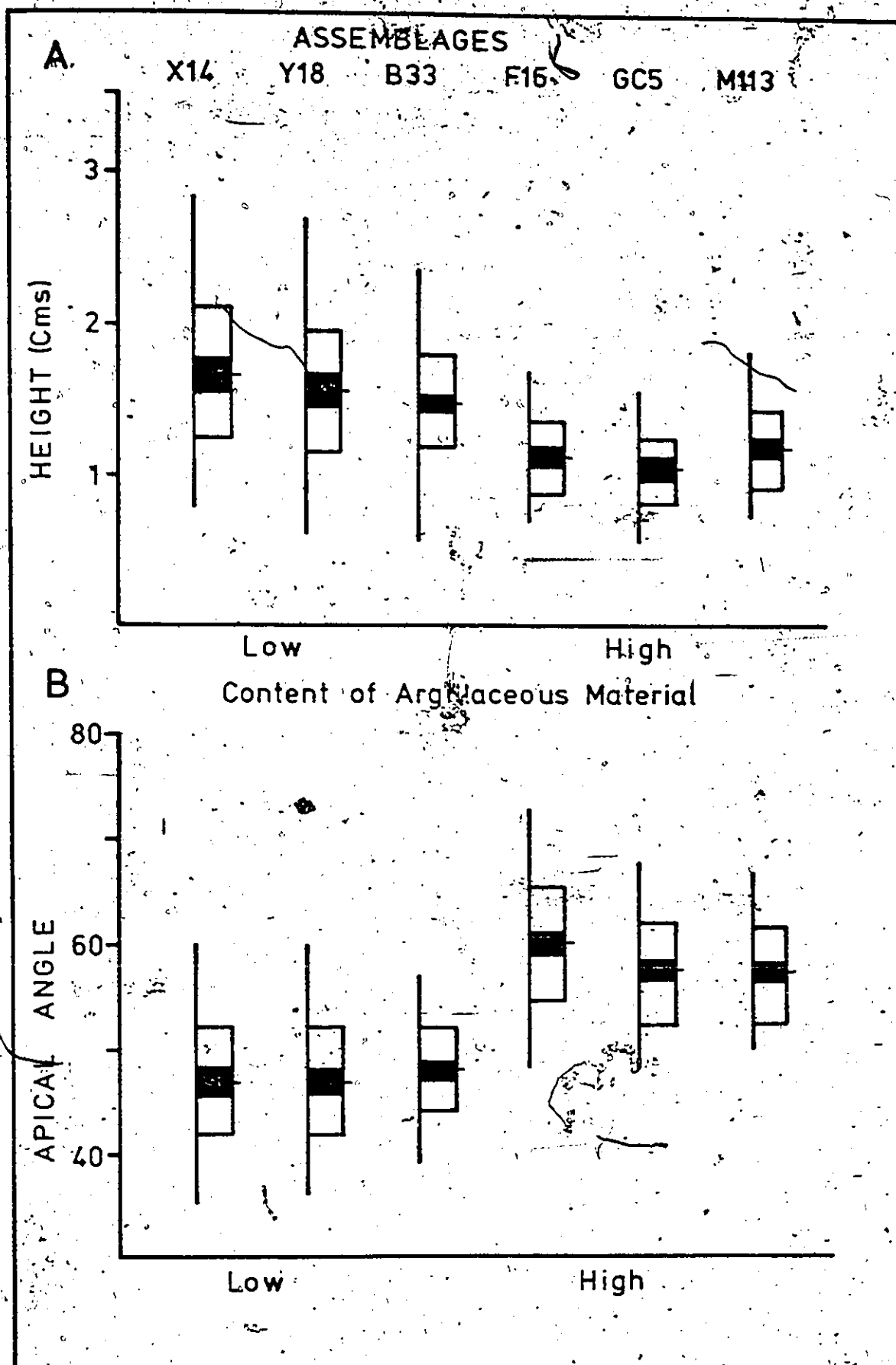
Text-figure 54

Relationship between the length (A) and width (B) of Atrypella foxi and the amount of argillaceous material in the rock. There is a progressive change in the argillaceous content of the rocks from high (approximately 40%) to low (less than 10%).



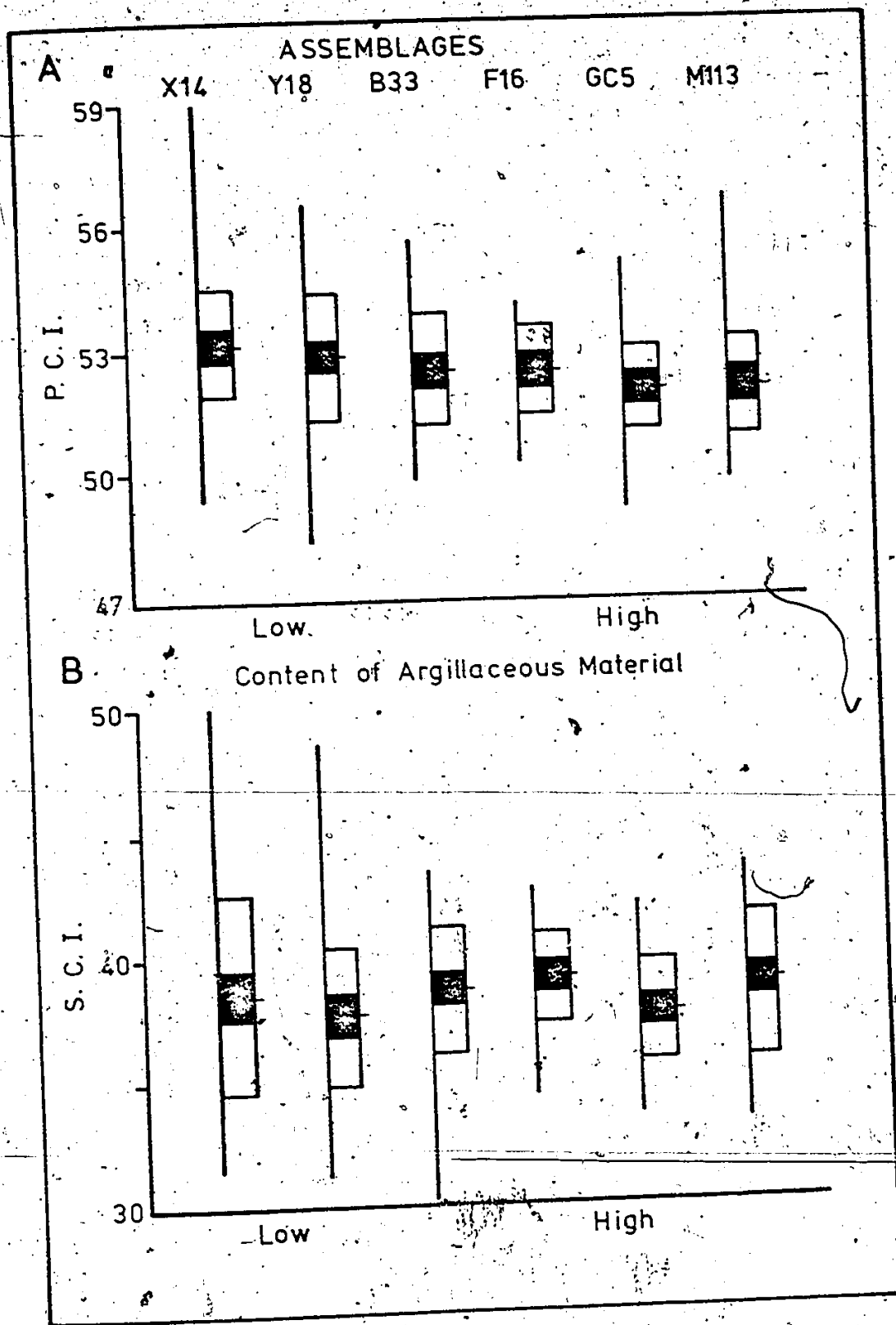
Text-figure 55

Relationship between the height (A) and apical angle (B) of Atrypella
foxi and the amount of argillaceous material in the rock. There is
progressive change in the argillaceous content of the rocks from high
(approximately 40%) to low (less than 10%).



Text-figure 56

Relationship between the Plan Circularity Index (A) and Side Circularity Index (B) of Atrypella foxi and the amount of argillaceous material in the rock. There is a progressive change in the argillaceous content of the rocks from high (approximately 40%) to low (less than 10%).



overall growth pattern. The greatest difference in growth patterns is between assemblages M113, F16 and GC5 and assemblages X14, Y18 and B33. In general, the latter groups have a higher 'initial growth factor' (Imbrie, 1956) than the other three assemblages.

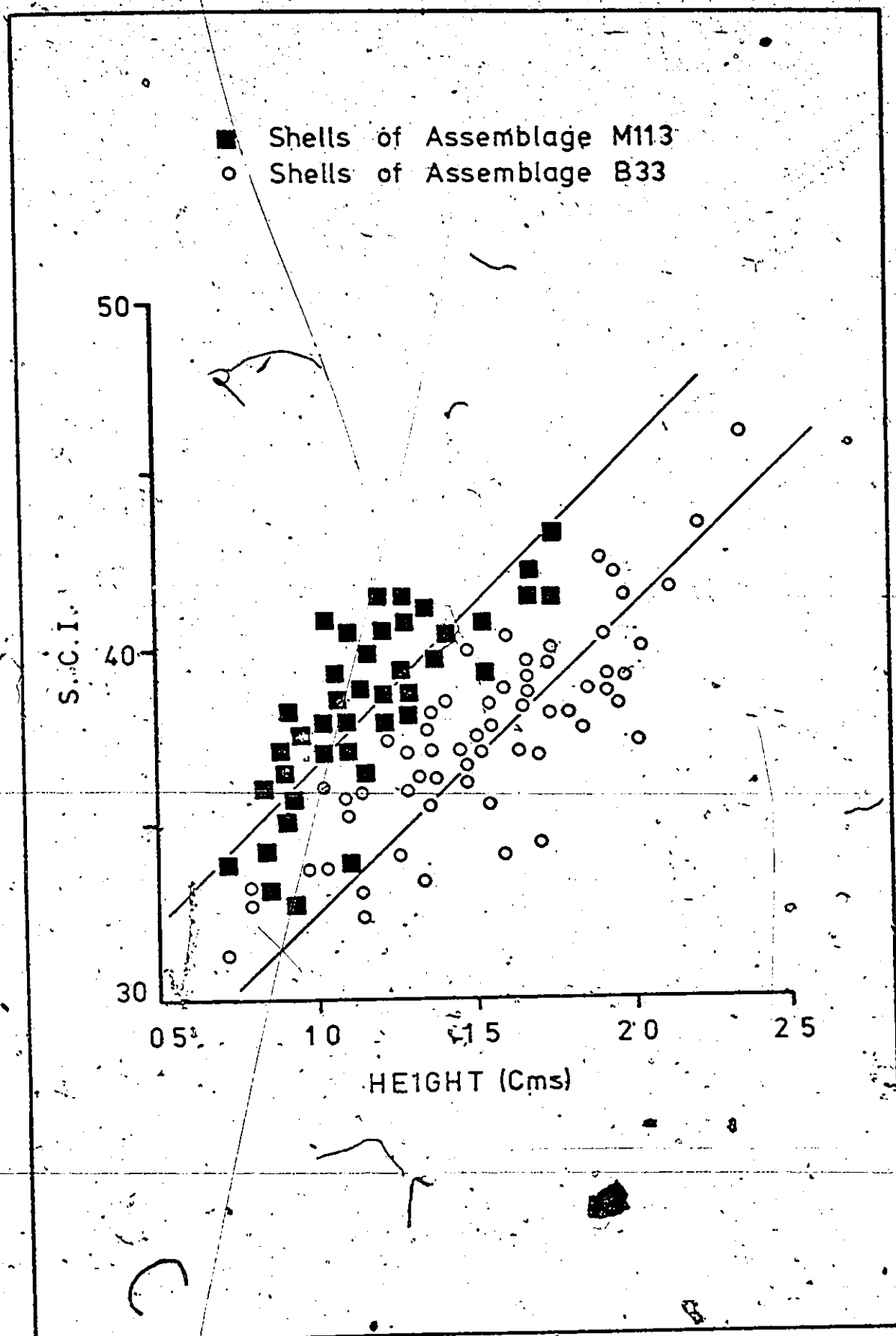
Additional differences between the assemblages are reflected by individual parameters. The Dice-Diagrams for length, width and height (Text-figs. 54a, b and 55a respectively) demonstrate that the shells in assemblages X14, Y18 and B33 are generally larger than those in assemblages M113, F16 and GC5. The S.C.I. shows little difference from one assemblage to another. As the S.C.I. is known to increase with ontogeny the shells from assemblages Y18, X14 and B33 would be expected to have a higher S.C.I. than those from the other assemblages (since these shells are generally smaller). The fact that the S.C.I. is the same for all the assemblages shows that the shells from assemblages M113, F16 and GC5 are more convex than the others. In a plot of height versus S.C.I., the graphical distribution of the specimens of assemblages M113 and X14 further demonstrates the differences in the convexity of the shells (Text-fig. 57).

Text-figure 58 shows the ventral views of several shells from two rock types (see also Pl. 27, figs. 1a-8a). The shells in

Text-figure 57

Height versus Side Circularity Index in Atrypella foxi from assemblage

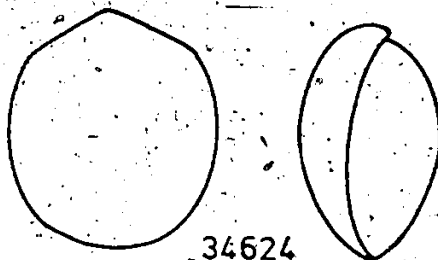
M113 and B33.



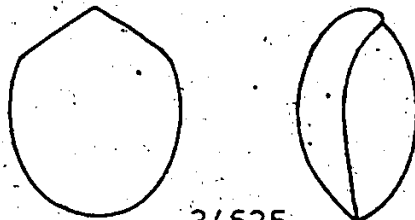
Text-figure 58

Comparison of the ventral and side views of Atrypella foxi from assemblages X14 and B33 (from micritic limestone) and assemblages M113 and F16 (from argillaceous limestone). The sequences show ontogenetic stages in each assemblage. All drawings are $X1\frac{1}{2}$ and originally traced from outline photographs of the specimens.

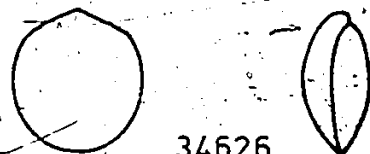
Numbers 34624 to 34635 refer to their G.S.C. type numbers.

X14

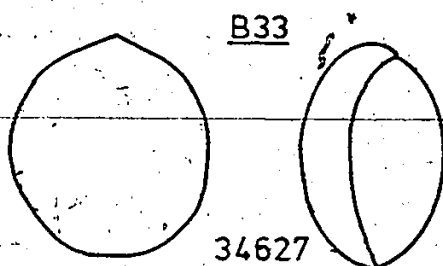
34624



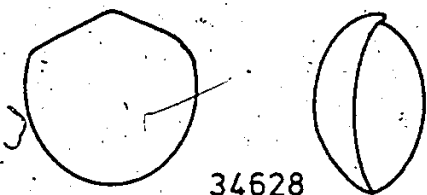
34625



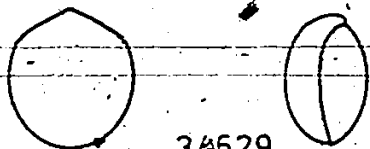
34626



34627



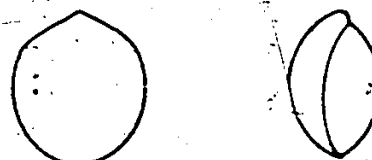
34628



34629

M113

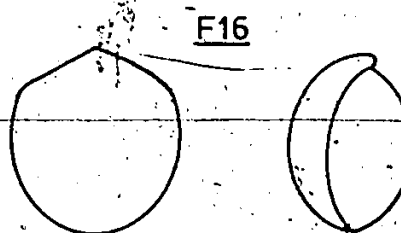
34630



34631



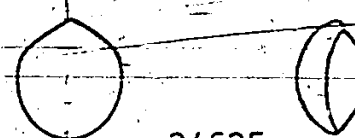
34632



34633



34634



34635

B33F16

each assemblage have been placed in order according to their length. While all the shells have approximately the same outline in ventral view, their convexity is clearly different (see also Pl. 27, figs. 1b-8b). The shells from assemblages Y18, X14 and B33 are less convex than the others.

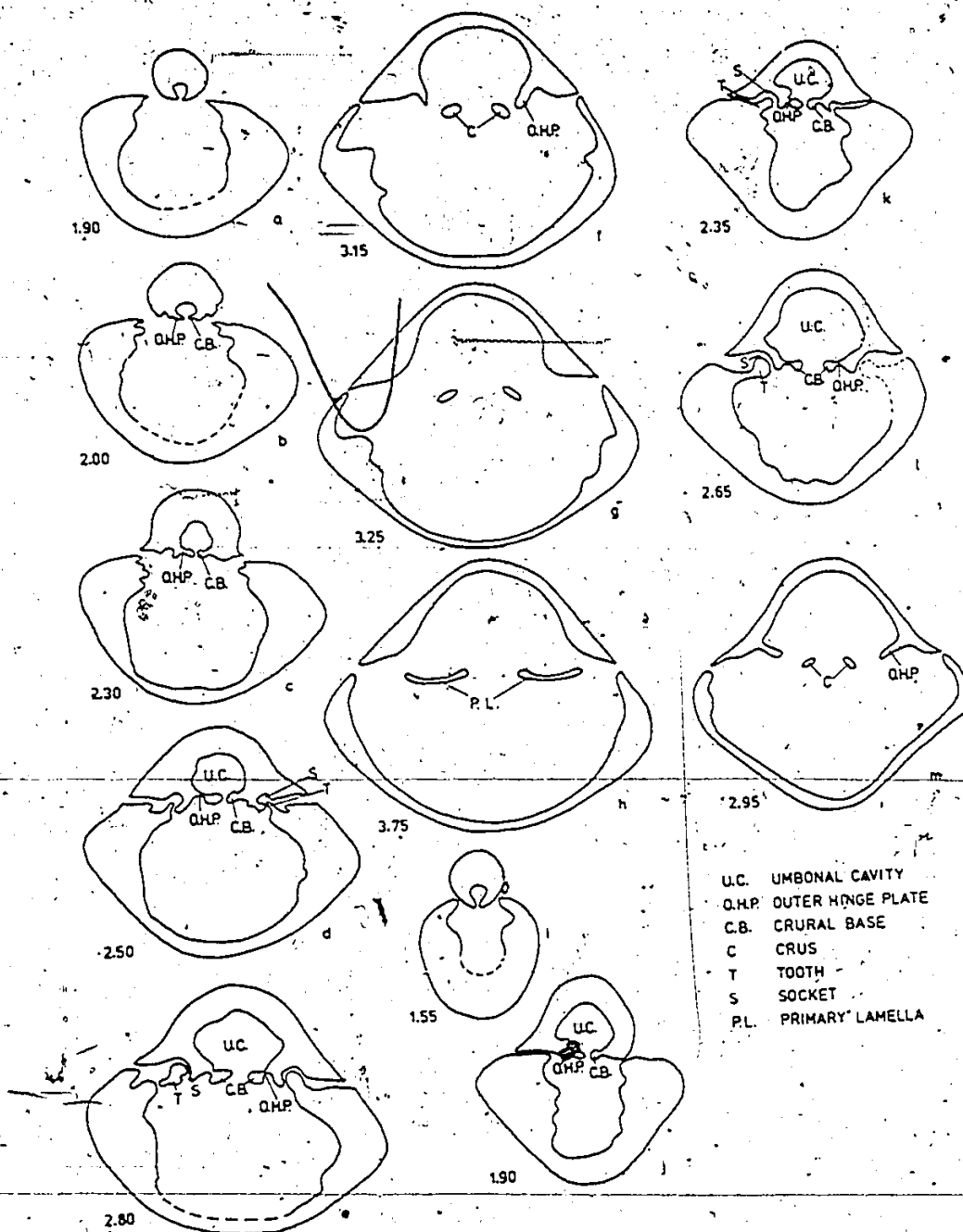
Internal morphology The form of the internal structures is relatively constant in the 12 specimens which were serially sectioned (Text-fig. 59). The outer hinge plates are parallel or subparallel to the hinge line (Pl. 28, fig. 2 and Text-fig. 59). The crural bases (Pl. 28, fig. 2 and Text-fig. 59) occur at the inner extremities of the outer hinge plates. Each crural base increases slightly in diameter anteriorly before it diverges from the outer hinge plate and rises to join the primary lamella of the spiralium. The teeth and sockets are well developed (Pl. 28, fig. 1 and Text-fig. 59). The jugum is illustrated in Plate 28, figure 3.

The spiralia are dorso-medially directed and are 'D'-shaped in horizontal profile (Pl. 28, fig. 6) and cone-shaped in vertical profile (Pl. 28, fig. 7). The apex of each spiralium is orientated towards the median plane (Pl. 28, fig. 5).

The number of volutions in each spiralium varies from 7 to 13. This is similar to Atrypella phoca (Salter) which has 6

Text-figure 59

Serial sections of Atrypella foxi. Figures a-h are from a specimen in assemblage B33 from micritic limestone. Figures i-m are from a specimen in assemblage M113 from argillaceous limestone. Distances are from the posterior end of the shell (in mm).



1 CM
 SCALE

Plate 27

Atrypella foxi n.sp.

Figs. 1a-8a, Ventral views of Atrypella foxi. Figs. 1b-8b, Side views of A. foxi. Figs. 1c-8c, Anterior views of A. foxi.

Figs. 1a, 1b and 1c are views of holotype specimen, G.S.C. number 34636. Figs. 2-8 are views of paratype specimens, G.S.C. numbers 34637-34643, inclusively. Specimens from following assemblages:

Figs. 1 and 2: X14; Fig. 3: Y18; Fig. 4: M113; Figs. 5 and 6: GC5;

Figs. 7 and 8: F16. All specimens natural size.

PLATE 27

1a



2a



3a



4a



1b



2b



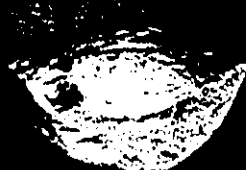
3b



4b



5a



2c



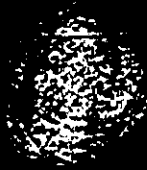
3c



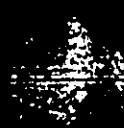
4c



5b



6a



5c



7a



5d



6b



7b



8a



Plate 28

Atrypella foxi n.sp.

Internal structures of Atrypella foxi. All measurements are from the posterior tip of the umbo. The code numbers refer to the assemblage from which the shell came. Fig. 1 - Tooth (T) and Socket (S), 2.65 mm, M113. Fig. 2 - Outer Hinge Plate (O.H.P.), Crural bases (C.B.) and umbonal cavity (U.C.), 2.35 mm, M113. Fig. 3 - Jugum (J), 12.65 mm, X14. Fig. 4 - Primary Lamella (P.L.), 9.75 mm, X14. Fig. 5 - Transverse section of shell showing conical shape of spiralia. Note apices directed towards median plane. Fig. 6 - Horizontal profile of spiralia showing 'D' shape with greatest dimension in direction of length of shell. Fig. 7 - Longitudinal section through shell showing vertical profile of spiralia. Specimens 5, 6 and 7 from assemblage M113.

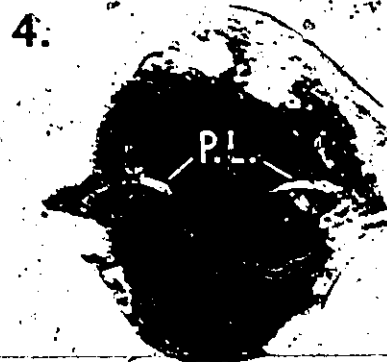
PLATE 28



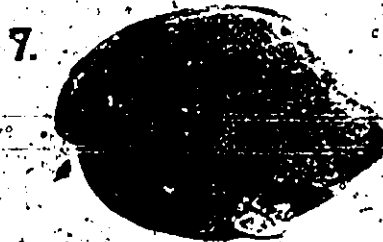
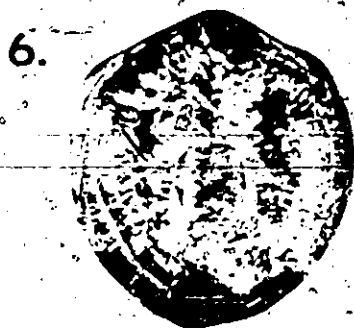
1mm



1mm



0.5 cm



to 13 volutions in each spirallium. As these assemblages constitute the type material only a few specimens were sectioned, to avoid extensive damage. Therefore, statistically significant data on the spiralia were not obtained.

Atrypella phoca (Salter)

Plate 29, figures 1-8

- 1852 Rhynchonella phoca Salter, p. 226, figs. 1-3
- 1857 Atrypa phoca (Salter) Haughton, p. 140, Pl. 5, figs. 3, 4 and 7.
- 1878 Atrypa phoca (Salter) Etheridge, p. CCXXVI, figs. 1-3.
- 1914 Lissatrypa phoca (Salter) Holstedahl, Pl. VII, fig. 13.
- 1914 Lissatrypa scheii Holstedahl, Pl. VII, figs. 9-12.
- 1924 Lissatrypa phoca (Salter) Holstedahl, p. 128.
- 1924 Lissatrypa scheii Holstedahl, p. 129, fig. 16, nos. 1-2.
- 1970 Atrypella phoca (Salter) Nikiforova, p. 111-115.
- 1970 Atrypella phoca forma typica Nikiforova, Pl. VI, figs. 8-10,
Diagram 6.
- 1970 Atrypella phoca forma media Nikiforova, Pl. II, figs. 21-26,
Pl. III, figs. 4-8, Diagram 7.
- 1970 Atrypella phoca forma longa Nikiforova, Pl. III, figs. 10-17,
Pl. IV, fig. 2, Diagram 8.

1970 Atrypella phoca forma paracamelina Nikiforova, Pl. V, figs. 11-13.

1970 Atrypella phoca forma subscheii Nikiforova, Pl. III, figs. 1-3.

1970 Atrypella scheii forma typica Nikiforova, Pl. IV, figs. 3-7.

1970 Atrypella scheii forma fossula Nikiforova, Pl. III, figs. 11-13.

1970 Atrypella scheii forma gibbera Nikiforova, Pl. III, fig. 9,

Pl. IV, fig. 12, Diagram 10.

1970 Atrypella scheii (Holtedahl) Nikiforova, p. 116-118.

Occurrence Specimens of Atrypella phoca occur at Pressure Point (assemblage W1), near Cunningham Inlet (assemblages T31 and C) and at Garnier Bay (assemblage GC2) (Text-fig. 53 and Table 13).

Horizon and age All the assemblages were obtained from strata of the Read Bay Formation. Assemblage W1 occurred 110 m (approx. 360 ft) below the base of the Peel Sound Formation (Text-fig. 7, p. 9).

S. R. Williams, on the basis of conodonts in the Pressure Point section, has placed the boundary between the Read Bay and Peel Sound Formations in the uppermost Pridolian (1973, pers. comm.). Therefore, assemblage W1 is probably of middle or upper Pridolian age. Assemblages T31 and C are of uncertain age owing to the lack of good stratigraphic controls. Assemblage C is situated about 4 m below a unit containing a coral fauna of Pridolian aspect (locality F on Text-fig. 6, p. 8 - fauna similar to that depicted in Text-fig. 32, p. 117). Thus,

assemblage C may be of middle or upper Pridolian age. Specimens in assemblage T31 were collected in the scree but their distribution strongly suggests that they came from a block in the breccia associated with fault B-B (Text-fig. 6, p. 8). Specimens were also found in the fault block. Assemblage GC2 may be of Upper Ludlowian or Pridolian age.

Plesiotypes and repository A series of 20 plesiotypes were chosen to represent the intraspecific variability observed in the species. These plesiotypes are held in the repository of the Geological Survey of Canada and bear G.S.C. type numbers 35193 to 35212.

Diagnosis Atrypella having the following characteristics:

- (1) A P.C.I. which varies from 48 to 57 (extreme forms) and averages between 51 and 52.
- (2) A S.C.I. which varies from 35 to 57 and averages between 43 and 45.
- (3) An apical angle which varies from 44° to 86° and averages between 60° and 70° .

External morphology Members of the species have a biconvex shell which is smooth in young specimens but commonly displays prominent growth lines in larger, more mature specimens (Pl. 29).

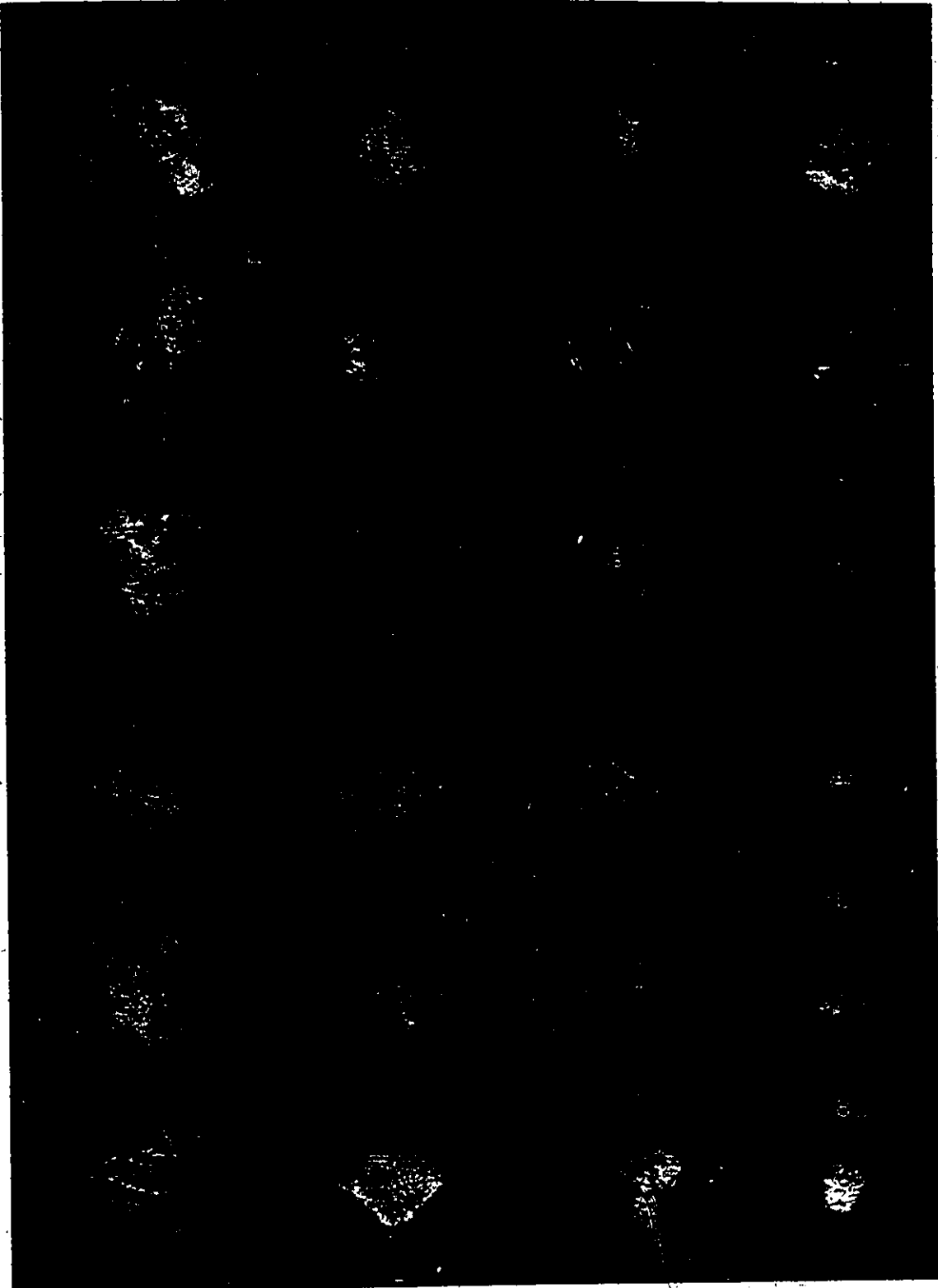
The correlation table for assemblage T31 (Table 21)

Plate 29

Atrypella phoca (Salter)

Figs. 1a-8a, Ventral views of Atrypella phoca. Figs. 1b-8b, Side views of Atrypella phoca. Figs. 1c-8c, Anterior views of Atrypella phoca. All specimens are plesiotypes of the species and bear Geological Survey of Canada type numbers 35193 to 35204. Specimens are from the following assemblages: T31 (35193-5); C (35196-8); W1 (35199-201); GC2 (35202-4). All specimens natural size.

PLATE 29



	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length	1.00	0.93	0.92	-0.02	0.83	0.63	0.17	0.46
Width		1.00	0.91	-0.19	0.80	0.59	-0.19	0.54
Height			1.00	-0.01	0.86	0.65	0.03	0.76
Apical Angle				1.00	-0.03	0.02	0.46	0.07
A.D.A.C.					1.00	0.93	0.11	0.61
R.D.A.C.						1.00	0.14	0.51
P.C.I.							1.00	-0.21
S.C.I.								1.00

Table 21.-- Correlation table for the Atrypella phoca assemblage (T31) from Cunningham Inlet. Based on 110 specimens.

Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length	1.00	0.93	-0.16	0.77	0.61	0.20	0.24
Width	1.00	0.89	-0.34	0.68	0.51	-0.20	0.35
Height	1.00	1.00	-0.18	0.75	0.56	0.07	0.59
Apical Angle			1.00	-0.19	-0.12	0.43	-0.12
A.D.A.C.				1.00	0.95	0.22	0.26
R.D.A.C.					1.00	0.28	0.15
P.C.I.						1.00	-0.27
S.C.I.							1.00

Table 22.- Correlation table for the Atrypella phoca assemblage (C) from

Cunningham Inlet. Based on 138 specimens.

	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.G.I.A	S.C.I.
Length	1.00	0.87	0.92	0.04	0.71	0.56	0.11	0.40
Width		1.00	0.88	-0.24	0.59	0.43	-0.40	0.53
Height			1.00	-0.05	0.71	0.54	-0.06	0.73
Apical Angle				1.00	-0.17	-0.17	0.56	-0.17
A.D.A.C.					1.00	0.97	0.12	0.42
R.D.A.C.						1.00	0.16	0.29
P.G.I.							1.00	-0.32
S.C.I.								1.00

Table 23.- Correlation table for the Atrypella phoca assemblage (W1) from.

Pressure Point. Based on 46 specimens.

343.

	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length	1.00	0.95	0.91	-0.28	0.75	0.68	0.14	0.51
Width		1.00	0.91	-0.38	0.78	0.72	-0.18	0.57
Height			1.00	-0.19	0.86	0.78	0.00	0.80
Apical Angle				1.00	-0.26	-0.28	-0.30	-0.03
A.D.A.C.					1.00	0.97	-0.10	0.70
R.D.A.C.						1.00	-0.11	0.66
P.C.I.							1.00	-0.22
S.C.I.								1.00

Table 24.- Correlation table for the Atrypella phoca assemblage (GC2) from

Garnier Bay. Based on 81 specimens.

Graph Parameters	T31 compared to						C compared to			W1 compared to		
	C			W1			GC2			W1		
	N.V.	C.	N.V.	C.	N.V.	C.	N.V.	C.	N.V.	N.V.	C.	C.
Length / Z1	0.22	Same	2.08	DIFF.	0.58	Same	1.17	Same	0.93	Same	0.62	Same
Width Z2	1.30	DIFF.			1.98	DIFF.	5.54	DIFF.	4.25	DIFF.	2.85	DIFF.
Length / Z1	3.82	DIFF.	0.09	Same	0.65	Same	2.63	DIFF.	3.92	DIFF.	0.61	Same
Height Z2			2.63	DIFF.	3.27	DIFF.					0.63	Same
Width / Z1	3.11	DIFF.	1.09	Same	0.15	Same	1.05	Same	2.94	DIFF.	1.14	Same
Height Z2			1.88	Same	1.78	Same	4.44	Same			1.33	Same
Height / Z1	1.00	Same	0.61	Same	0.78	Same	0.06	Same	1.66	Same	1.11	Same
A.D.A.C. Z2	2.02	DIFF.	1.73	Same	0.12	Same	6.91	DIFF.	0.96	Same	7.37	DIFF.
Height / Z1	3.30	DIFF.	2.60	DIFF.	3.32	DIFF.	0.22	Same	0.70	Same	0.01	Same
R.D.A.C. Z2							32.26	DIFF.	3.46	DIFF.		
Height / Z1	1.75	Same	0.68	Same	4.18	DIFF.	0.70	Same	2.39	DIFF.	2.73	DIFF.
S.C.I. Z2	3.72	DIFF.	6.28	DIFF.			3.82	DIFF.				

Table 25: Comparison of reduced major axes of assemblages T31, W1, C and GC2 of Atrypella

phoca. Significant value of Z is 1.96. If Z1 is above 1.96, Z2 value is not

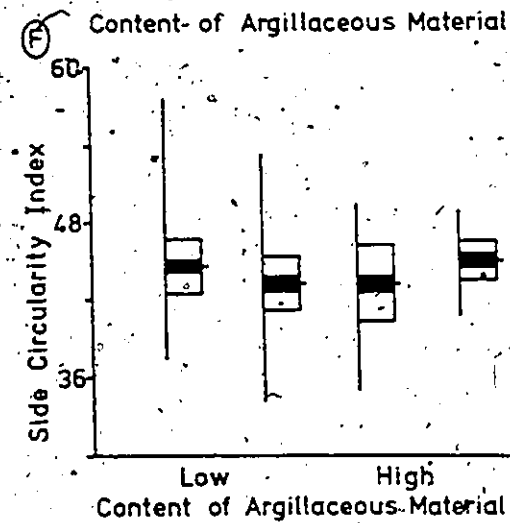
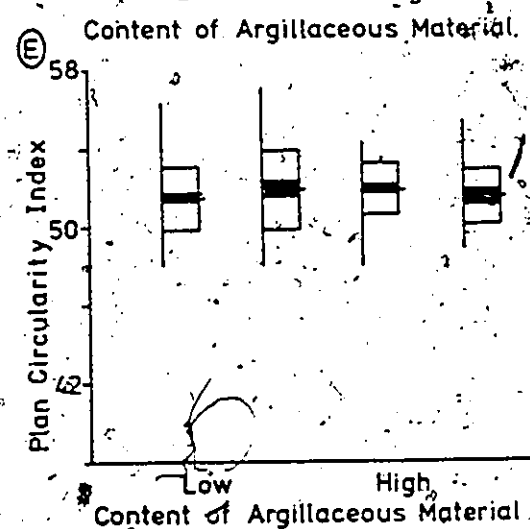
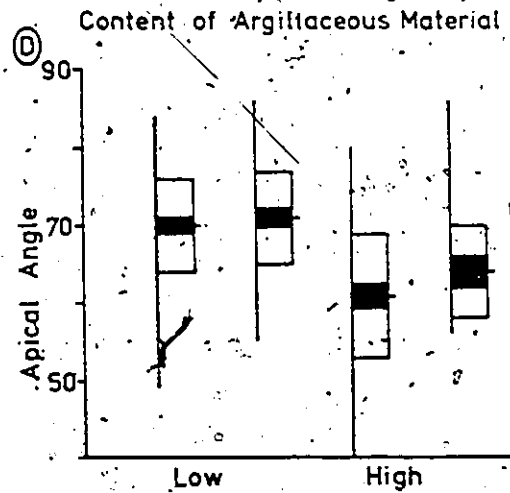
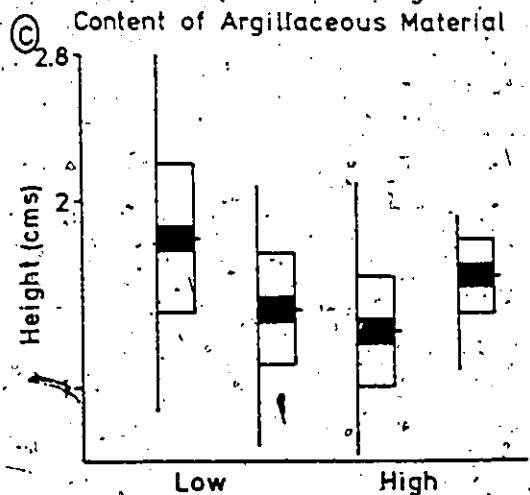
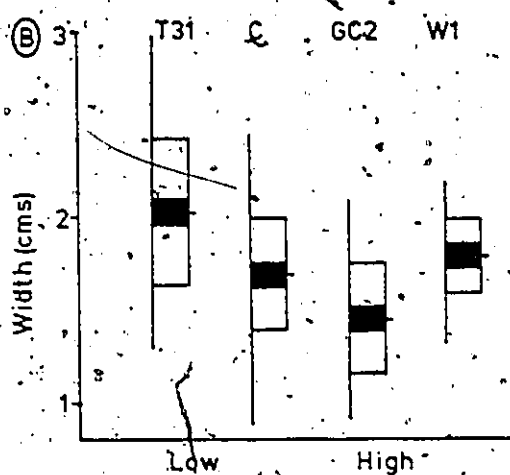
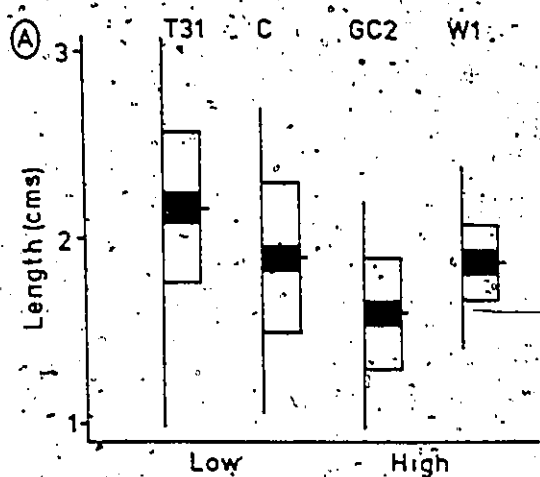
calculated. (N.V.= Numerical Value, C= Conclusion, DIFF.= Different).

demonstrates that the width, height, R.D.A.C. and A.D.A.C. have a high positive correlation with the length and consequently vary with ontogeny. The S.C.I. has a high positive correlation with height and is also ontogenetically variable. Conversely, the apical angle and the P.C.I. have a low correlation with the ontogenetically variable parameters and therefore did not change during ontogeny. The correlation tables derived for the other assemblages (Tables 22 to 24) display a similar basic pattern and substantiate these conclusions.

The ontogenetically variable parameters, length, width, height, and S.C.I. (Text-figs. 60a, 60b, 60c, 60f respectively), differ in the various assemblages. These size differences may simply be due to one assemblage containing more mature specimens than the other. Statistical comparison of the reduced major axes for various bivariate graphs (see column 1 of Table 25 for full listing of graphs compared) shows that while assemblages T31, C, W1 and GC2 have some similarities they all differ in overall growth characteristics. Assemblage T31 has a higher mean length and width than assemblage C (Text-figs. 60a and 60b). Statistical comparison of the reduced major axes for the length/width graphs demonstrates that this aspect of growth was the same for assemblages T31 and C

Text-figure 60.

Relationship between parameters of Atrypella phoca and the amount of argillaceous material in the rock. There is a progressive change in the argillaceous content of the rocks from high (approximately 40% to low (less than 10%).



(Table 25). Thus, the greater mean shell length and width is probably due to assemblage T31 having a greater mean age than assemblage C (Text-fig. 61). Despite the differing growth rates of the four assemblages some overlap is apparent in the size of the various parameters (Text-figs. 60a-60f) of the different assemblages. These similarities are probably due to differing combinations of growth rates and shell age.

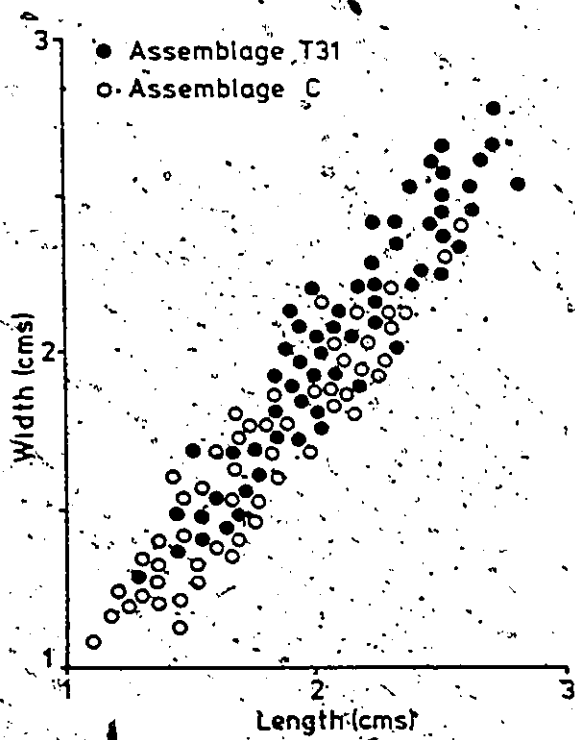
Assemblage T31 occurred in micritic limestone which contains little or no detrital material while assemblage W1 and GC2 occurred in argillaceous limestone which contains relatively large amounts of detrital material (approximately 20-45%). Assemblage C occurred in argillaceous limestone but the detrital content (5-10%) is distinctly less than that in the rocks associated with assemblages W1 and GC2.

Comparison of assemblages from different rock types (Text-figs. 60a-60f) shows that the length, width, height and apical angle are considerable larger (both mean and maximum values) in shells from micritic limestone. The fact that the P.C.I. displays no systematic variation according to the content of detrital material in the associated rock (Text-fig. 60e) is confirmed by comparison of the plan views of specimens from different assemblages (Text-fig. 62).

Text-figure 61

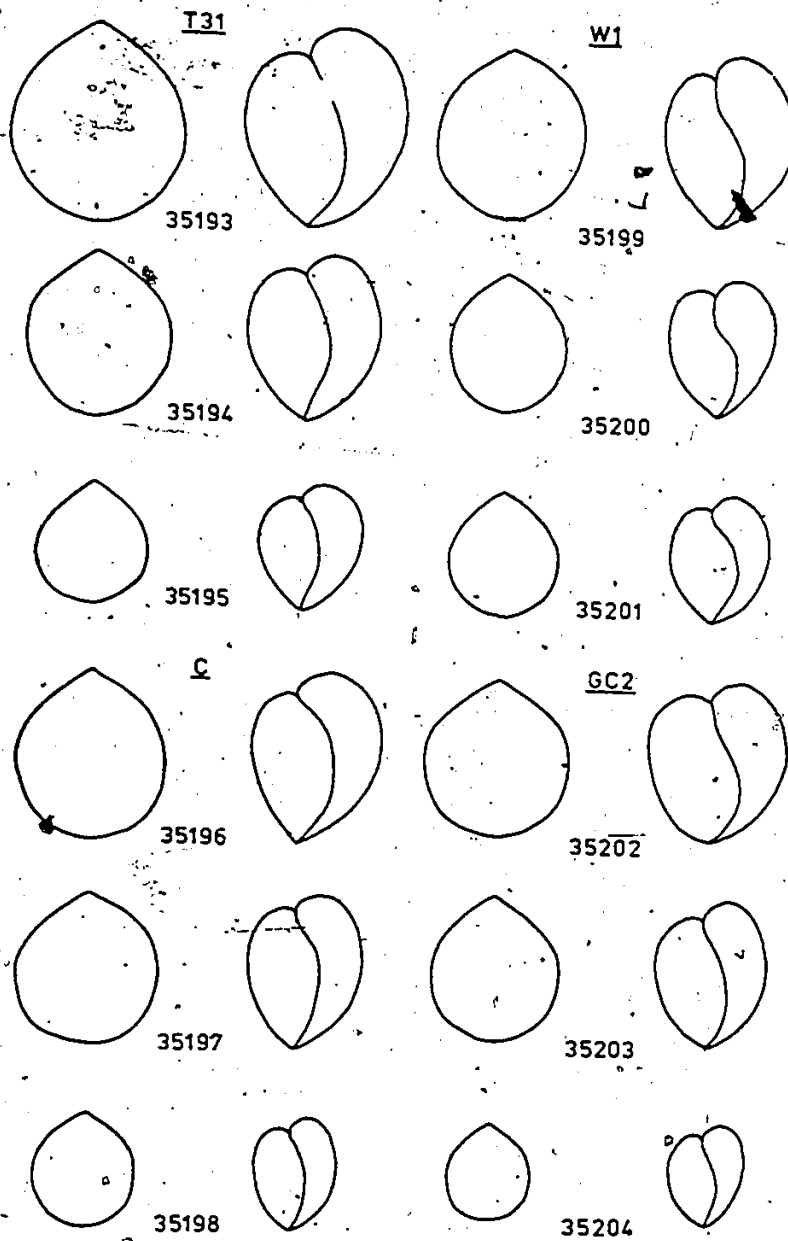
Comparison of assemblages T1 and C of Atrypella phoca in a plot
of length versus width.

348.12



Text-figure 62

Comparison of ventral and side views of Atrypella phoca from assemblages T31, W1, GC2 and C. The sequences show inferred ontogenetic stages in each assemblage. All drawings are natural size and traced from outline photographs of the specimens. Numbers 35193 to 35204 refer to their G.S.C. type numbers.



The absolute convexity of the shells, as expressed by the S.C.I., is not significantly different for the different assemblages (Text-fig. 60f). However, if the convexity is considered relative to another parameter (e.g. height) certain differences become apparent.

It is clear from Text-figures 62 and 63 that the convexity/height ratio of the shell increases as the detrital content in the associated rock increases. Thus, shells from environments which were subjected to a high influx of detrital material are smaller and more bulbous than those from environments which were subjected to low influxes of detrital material.

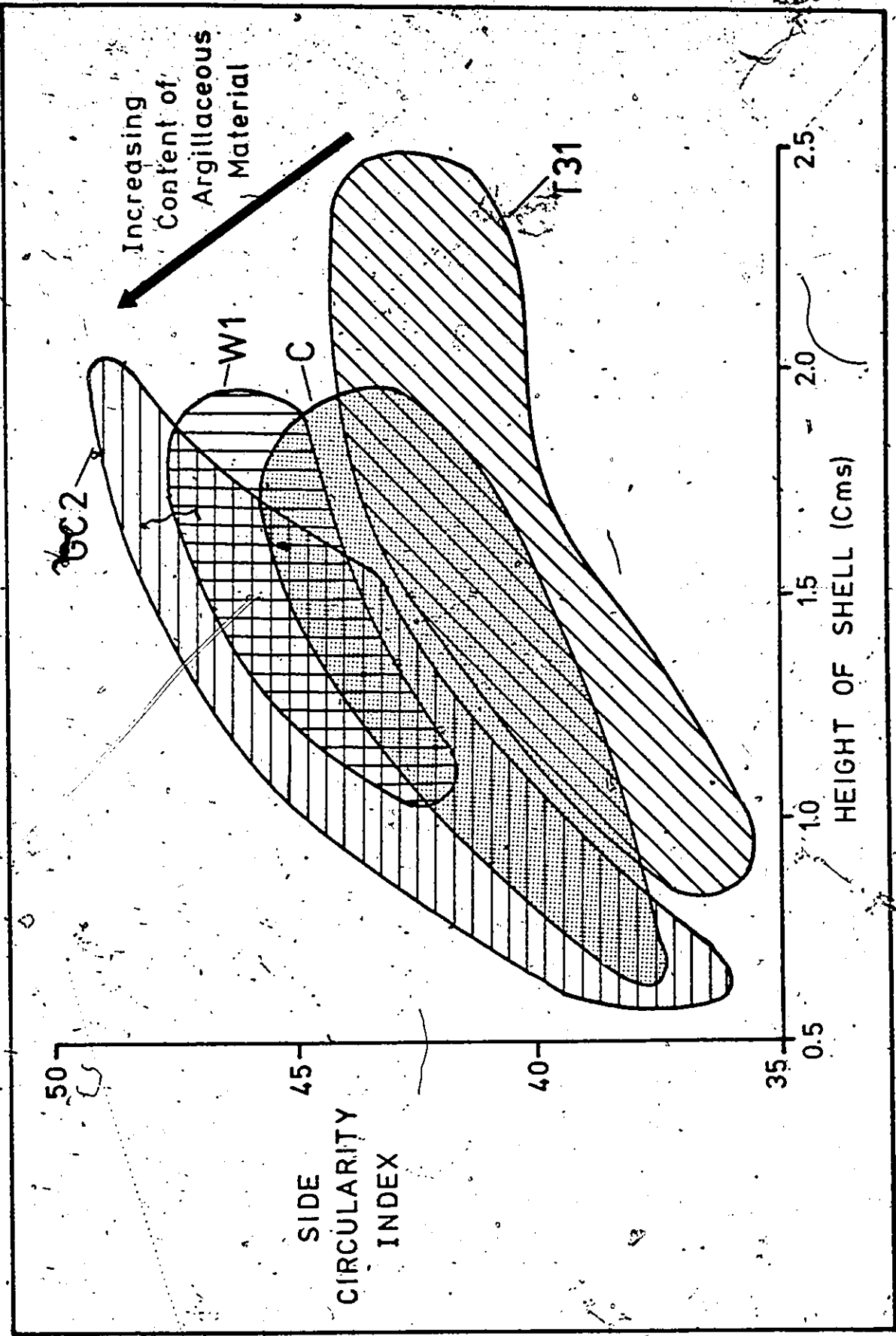
In summary, the P.C.I. remains constant regardless of ontogeny and environmental conditions while the apical angle varied according to the environmental conditions but not because of ontogeny.

The S.C.I. varied with ontogeny and environmental conditions.

Relative to the height the S.C.I. is highest for shells which come from limestone with a high content of detrital material. The remaining parameters, which vary with ontogeny and environmental conditions, are consistently smaller for specimens from limestone with a high content of detrital material.

Text-figure 63

Height versus Side Circularity. Index in Atrypella phoca from assemblages
T31, W1, GC2 and C.



Internal structures The form of the internal structures is relatively constant in the 8 specimens that were serial-sectioned. The crural bases which occur at the inner extremities of the outer hinge plates (Text-fig. 64) increase slightly in diameter anteriorly before they diverge from the outer hinge plates and rise to join the primary lamallae. The teeth and sockets are well developed (Text-fig. 64).

The spiralia are dorso-medially directed and are 'D'-shaped in horizontal profile (Pl. 30, fig. 1) and cone-shaped in vertical profile (Pl. 30, fig. 2). The apex of each spirulum is orientated towards the median plane (Pl. 30, fig. 3).

The well preserved specimens in assemblage W1 were suitable for obtaining measurements of the spiralia. A sample of 120 specimens were cut in the manner previously described (p. 291) but only 57 were preserved well enough to allow the accurate measurement of the parameters defined in Text-figure 52c (p. 292).

The correlation table (Table 26) for this assemblage demonstrates that the number of volutions in the spiralia, the apical angles of the spiralia, the length and height of the spiralia and the height/length ratio of the spiralia all changed during ontogeny. These ontogenic changes are as follows:

- (1) The number of volutions of the spiralia increased from 6 or 7

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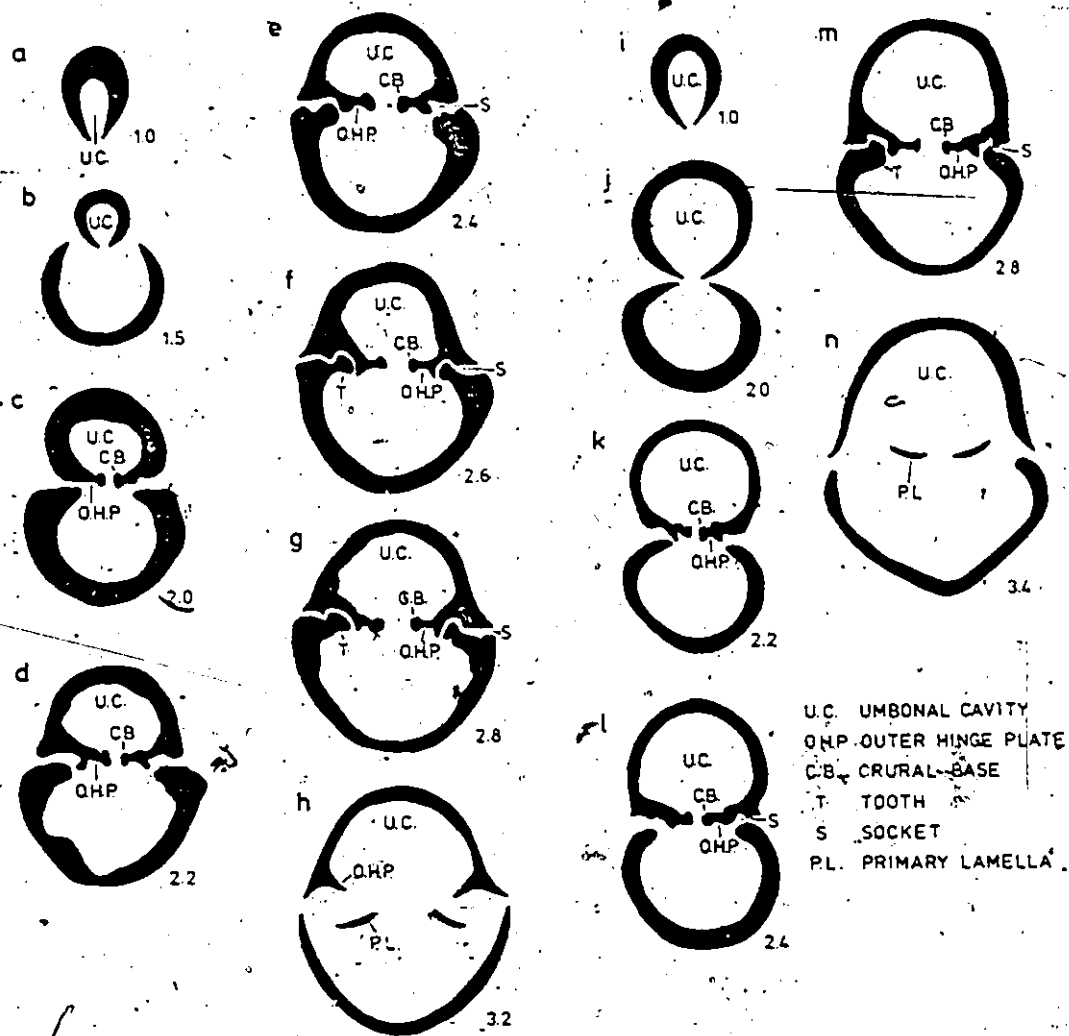
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Text-figure 64

Serial sections of Atrypella phoca. Figures a-h are from a specimen in assemblage T31 from micritic limestone. Figures i-n are from a specimen in assemblage W1 from argillaceous limestone. Distances are from posterior end of shell (in mm).



0 Cm 1

Plate 30

Spiralia of Atrypella phoca and Atrypella

shrocki

Fig. 1: Horizontal section through A. phoca showing 'D'-shaped spiralia. Fig. 2: Vertical section through A. phoca showing cone-shaped spiralia in mature specimen. Fig. 3: Transverse section through A. phoca showing cone-shaped spiralia. Note apices oriented towards median plane. Fig. 4: Vertical section through A. phoca showing cone-shaped spiralia in young specimen. Fig. 5: Horizontal section through A. shrocki showing 'D'-shaped spiralia. Fig. 6: Transverse section through A. shrocki showing cone-shaped spiralia. Fig. 7: Vertical section through A. shrocki showing cone-shaped spiralia. All specimens 2X natural size.

Specimens 1, 2, 3 and 4 from assemblage W1. Specimens 5, 6 and 7 from assemblage GD2.

PLATE 30

1.



2.



3.



4.



5.



6.



7.



SHELL PARAMETERS													SPIRALIUM PARAMETERS				
Length	Width	Height	A.A.	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.	Number Vol'ts	Apical Angle	Height	Length	H/L Ratio					
Length	1.00	0.80	0.91	-0.05	0.76	0.51	-0.01	0.50	0.74	-0.30	0.82	0.79	0.19				
Width		1.00	0.74	0.19	0.63	0.53	-0.20	0.44	0.69	-0.32	0.69	0.65	0.17				
Height			1.00	-0.04	0.80	0.62	-0.04	0.81	0.84	-0.41	0.85	0.65	0.40				
A.A.				1.00	-0.03	-0.03	-0.35	-0.04	0.15	-0.13	0.00	0.00	0.00				
A.D.A.C.					1.00	0.96	-0.06	0.61	0.69	-0.26	0.67	0.62	0.19				
R.D.A.C.						1.00	-0.10	0.46	0.54	-0.16	0.50	0.52	0.09				
P.C.I.							1.00	-0.07	-0.14	0.14	-0.06	-0.04	-0.04				
S.C.I.								1.00	0.72	-0.46	0.61	0.25	0.57				
Number Vol'ts									1.00	0.54	0.76	0.54	0.40				
Apical Angle										1.00	-0.49	-0.06	-0.59				
Height											1.00	0.69	0.53				
Length												1.00	-0.23				
H/L Ratio													1.00				

Table 26: Correlation table for the Atrypella phoca assemblage (W1) from

Pressure Point. Based on 57 specimens.

in young specimens to 13 in older more mature specimens

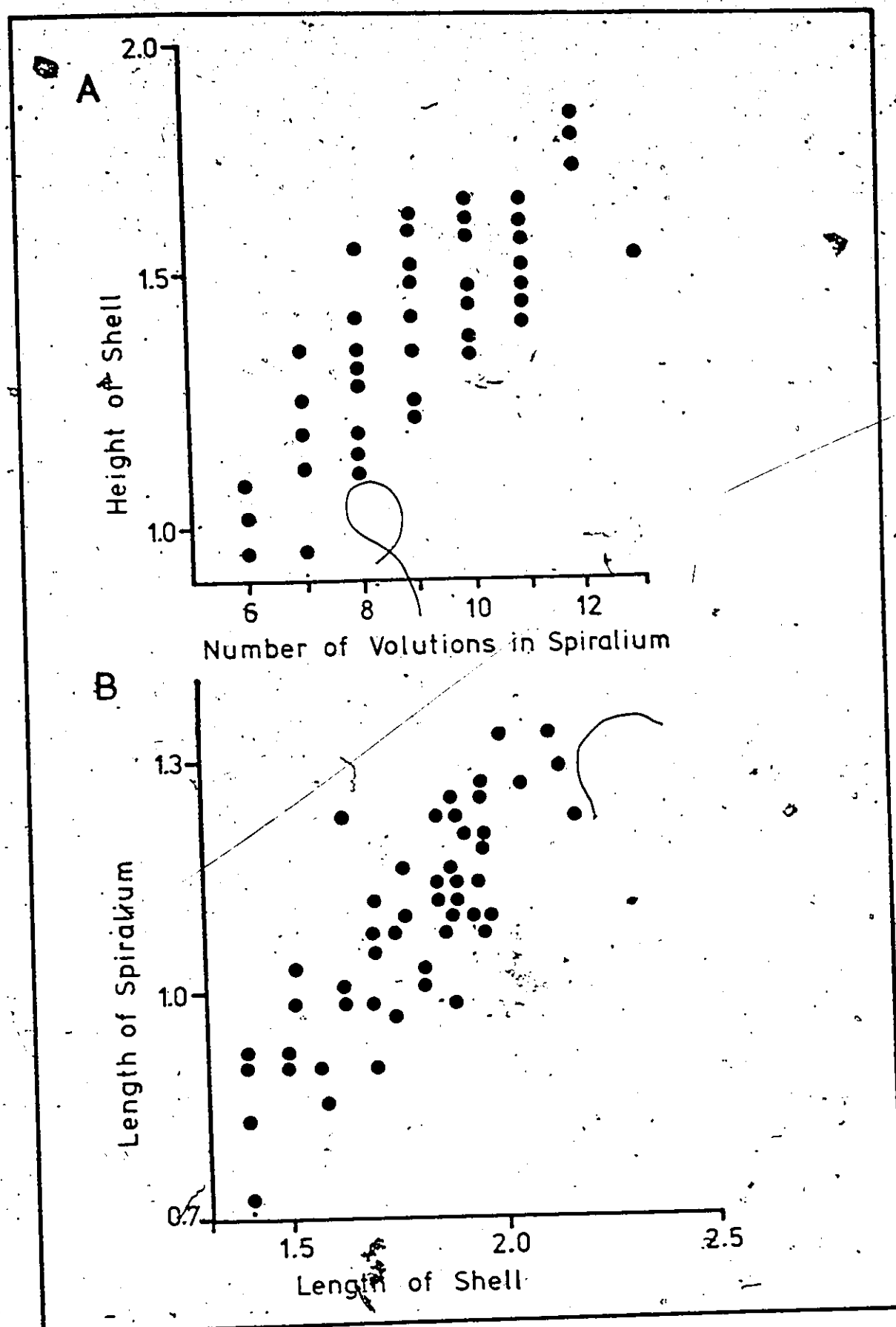
(Text-fig. 65a).

- (2) Correlation coefficients (Table 26) suggest that the apical angles of the spiralia tended to decrease with age as the the height of the shell and the number of volutions in the spiralia increased (Text-fig. 66b). However, low correlation coefficients (maximum -0.58) suggest that there is considerable departure from the ideal trend.
- (3) Both the length and height of the spiralia increased during ontogeny as shown by the high correlation coefficients between these parameters and the other ontogenetically variable parameters (e.g. length, width and height of the shell - Table 26 and Text-fig. 65a).
- (4) The height/length ratio of the spiralia tended to increase during ontogeny indicating that their height increased more rapidly than their length. However, low correlation coefficients (Table 26) suggests that there is considerable departure from the ideal trend.

The statistical results demonstrate that the size and form of the spiralia changed considerably during ontogeny. As the number of volutions increased, the volutions previously formed expanded

Text-figure 65

Relationship between spiralium dimensions and shell dimensions of Atrypella phoca. (A) Number of volutions in spiralium versus height of shell in assemblage W1. Based on 57 specimens. (B) Length of spiralium versus length of shell in assemblage W1. Based on 57 specimens. Vertical scale for A and B in cm.

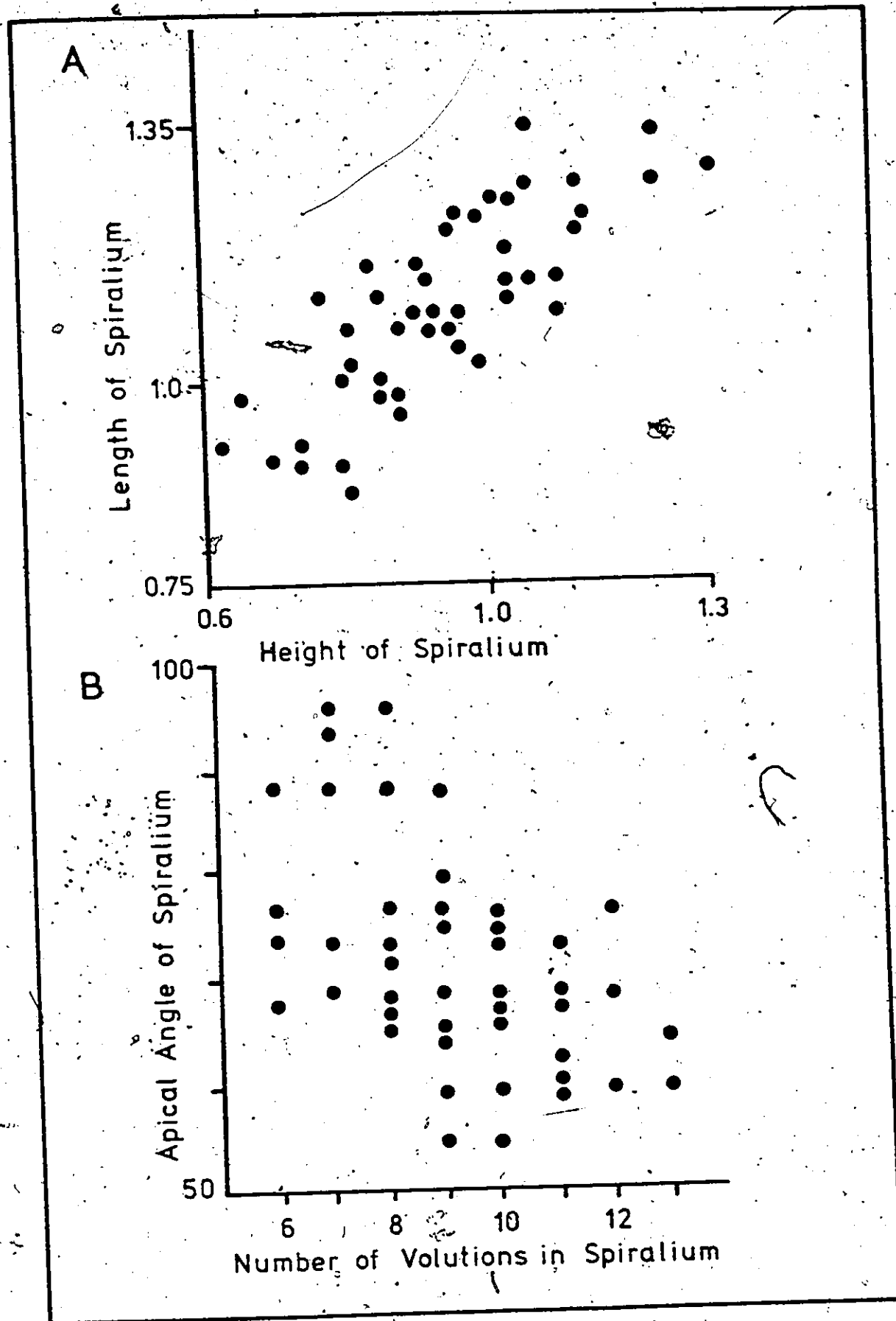


Text-figure 66

Relationship between spirulum dimensions of Atrypella phoca.

(A) Length versus height in assemblage W1. Based on 57 specimens.

(B) Number of volutions in spirulum versus apical angle of
spirulum in assemblage W1. Based on 57 specimens. Vertical scale
for A in cm.



causing an increase in the length and height of the spiralia.

As a result of this expansion the total length of the spirarium 'ribbon' increased during ontogeny. Inspection of many photographs of the spiralia suggests that the width of the spirarium 'ribbon' increased during ontogeny. In one specimen (Pl. 30, fig. 2) the spirarium 'ribbon' nearest the apex is not as wide as it is near the base of the cone. In the same specimen the vertical spacing between successive volutions also changed during ontogeny from a closer spacing near the apex to a wide spacing near the base of the cone.

In vertical profile the spirarium has been termed cone-shaped. Although this describes the form of the spirarium in general terms, many variations from the ideal cone occur. In specimens with 6 or 7 volutions the vertical profile closely approximates a cone (Pl. 30, fig. 4). However, as the animal grew, this shape gradually changed into the form shown in Plate 30, figure 2. This form is most characteristic of the larger more mature specimens.

Unfortunately, the spiralia in the shells in assemblages T31 and C are not sufficiently well preserved to be studied in a similar manner. Consequently, they could not be compared with assemblage W1 to determine the effects that environment may have had on the

form and size of the spiralia. In assemblage W1 the size and form of the spiralia have a high correlation with the size and form of the shell. Thus, since the size and form of the shells changed according to the environment in which the animal lived, then the size and form of the spiralia must also have changed accordingly.

Atrypella shrocki Cooper

Plate 31, figs. 1-6

v* 1942 Atrypella shrocki Cooper, p. 232.

v* 1964 Atrypella carinata Johnson and Reso, p. 81, Pl. 20, figs. 18-26.

Occurrence Specimens of Atrypella shrocki occur at Garnier Bay (assemblage GD2), Cape Admiral M'Clintock (assemblage M104) and Creswell Bay (assemblage F16) (Text-fig. 53 and Table 13).

Horizon and age All assemblages were obtained from strata of the Read Bay Formation. However, the absence of good stratigraphic controls prevents accurate determination of their age. All three assemblages are probably of Pridolian age, judging from their associated fauna. (Text-figs. 4 and 5).

Plesiotypes and repository A series of 10 plesiotypes was chosen to encompass the range of intraspecific variation shown by the species. These plesiotypes are held in the repository of the Geological Survey of Canada and bear G.S.C. numbers 35213 to 35222.

Diagnosis Atrypella having the following characteristics:

- (1) A P.C.I. which varies from 51 to 60 (extreme forms) and averages

between 54 and 55.

(2) A.S.C.I. which varies from 32 to 45 and averages between 39 and 42.

(3) An apical angle which varies from 45° to 84° and averages between 60° and 70° .

External morphology Members of the species typically have a smooth biconvex shell although some specimens bear faint growth lines. The pedicle umbo is strongly incurved, especially in the larger, more mature specimens. Mature shells are characterized by a strongly deflected anterior commissure (Pl. 31, figs. 4c, 5c and 6c)

The correlation table for assemblage M104 (Table 27) shows that the width, height, A.D.A.C. and R.D.A.C. have a high positive correlation with the length. The S.C.I. has a high positive correlation with height. Consequently, all these parameters must be considered ontogenetically variable. Conversely, the apical angle and the P.C.I. do not vary with ontogeny. The correlation tables derived for the other assemblages (Tables 28 and 29) display a similar basic pattern.

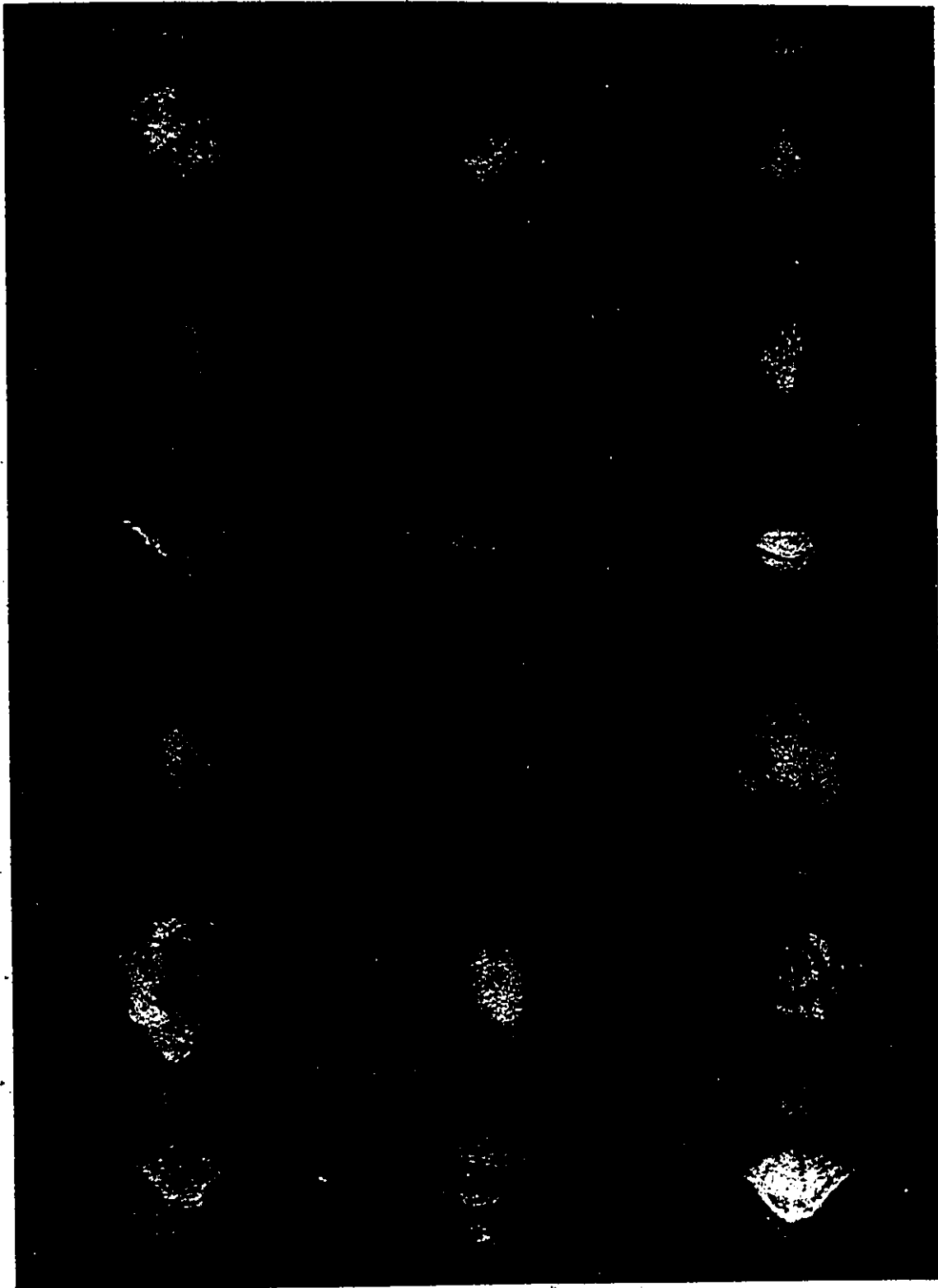
All three assemblages occurred in argillaceous limestone which prevented assessment of their variability in relation to the amount of detrital material in the enclosing rock. Consequently, only ontogenetic variation can be described with any degree of certainty.

Plate 31

Atrypella shrocki Cooper

Figs. 1a-6a, Ventral views of Atrypella shrocki. Figs. 1b-6b, Side views of Atrypella shrocki. Figs. 1c-6c, Anterior views of Atrypella shrocki. All specimens are plesiotypes of the species and bear the Geological Survey of Canada type numbers 35213 to 35218. Specimens from following assemblages: M104 (35213-4); F16 (35215-6); GD2 (35217-8). All specimens natural size.

PLATE 31



	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length	1.00	0.95	0.94	0.21	0.85	0.78	0.49	0.69
Width		1.00	0.91	0.08	0.82	0.76	0.19	0.68
Height			1.00	0.28	0.92	0.84	0.44	0.88
Apical Angle				1.00	0.21	0.11	0.42	0.28
A.D.A.C.					1.00	0.97	0.39	0.83
R.D.A.C.						1.00	0.35	0.79
P.C.I.							1.00	0.31
S.C.I.								1.00

Table 27.- Correlation table for the Atrypella shrocki assemblage (M104) from

Cape Admiral M'Clintock. Based on 53 specimens.

	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length	1.00	0.89	0.94	-0.08	0.74	0.56	0.13	0.27
Width		1.00	0.85	-0.19	0.64	0.49	-0.32	0.29
Height			1.00	0.00	0.80	0.62	0.09	0.58
Apical Angle				1.00	-0.02	-0.48	0.36	-0.01
A.D.A.C.					1.00	0.96	0.16	0.47
R.D.A.C.						1.00	0.11	0.40
P.C.I.							1.00	-0.08
S.C.I.								1.00

Table 28. Correlation table for the Atrypella shrocki assemblage (F16) from

the locality north of Creswell Bay. Based on 41 specimens.

	Length	Width	Height	Apical Angle	A.D.A.C.	R.D.A.C.	P.C.I.	S.C.I.
Length.	1.00	0.70	0.83	-0.02	0.56	0.26	0.51	0.00
Width		1.00	0.66	-0.20	0.51	0.29	-0.26	0.14
Height			1.00	-0.15	0.58	0.20	0.32	0.56
Apical Angle				1.00	-0.12	-0.07	0.21	-0.22
A.D.A.C.					1.00	0.91	0.13	0.21
R.D.A.C.						1.00	-0.02	-0.03
P.C.I.							1.00	-0.17
S.C.I.								1.00

Table 29.- Correlation table for the Atrypella shrocki assemblage (GD2) from

Carnier Bay. Based on 89 specimens.

Graph Parameters		M104 compared to				GD2 compared to	
		GD2		F16		F16	
		N.V.	C.	N.V.	C.	N.V.	C.
Length /	Z1	0.41	Same	2.48	DIFF.	1.53	Same
Width	Z2	1.80	Same			7.33	DIFF.
Length /	Z1	3.18	DIFF.	1.19	Same	1.85	Same
Height	Z2			10.33	DIFF.	28.26	DIFF.
Width /	Z1	2.78	DIFF.	2.67	DIFF.	0.06	Same
Height	Z2					31.39	DIFF.
Height /	Z1	3.63	DIFF.	7.00	DIFF.	2.70	DIFF.
A.D.A.C.	Z2						
Height /	Z1	7.77	DIFF.	3.23	DIFF.	3.77	DIFF.
R.D.A.C.	Z2						
Height /	Z1	2.61	DIFF.	1.44	Same	3.45	DIFF.
S.C.I.	Z2			16.74	DIFF.		

Table 30: Comparison of reduced major axes of assemblages

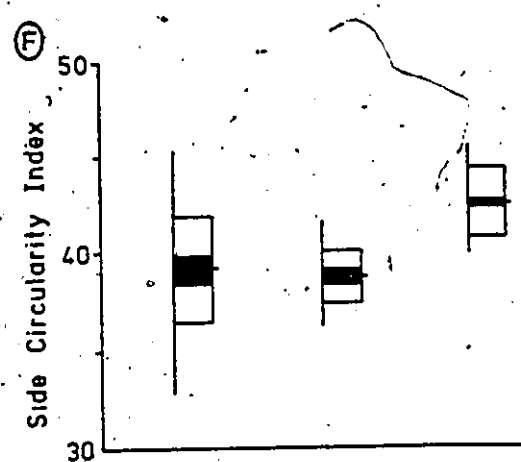
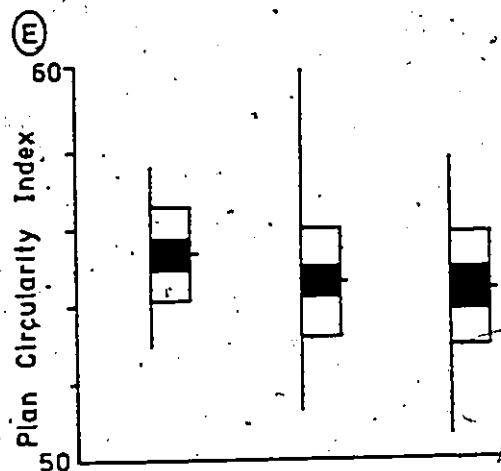
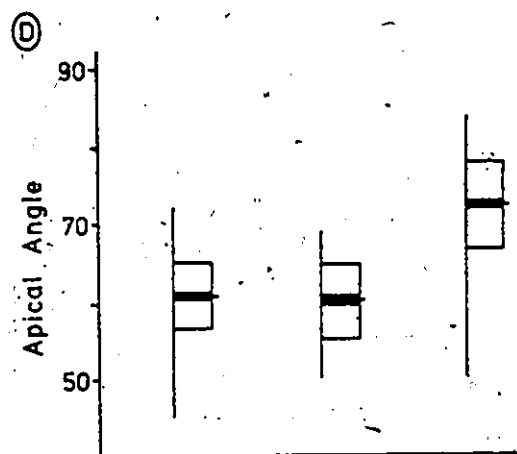
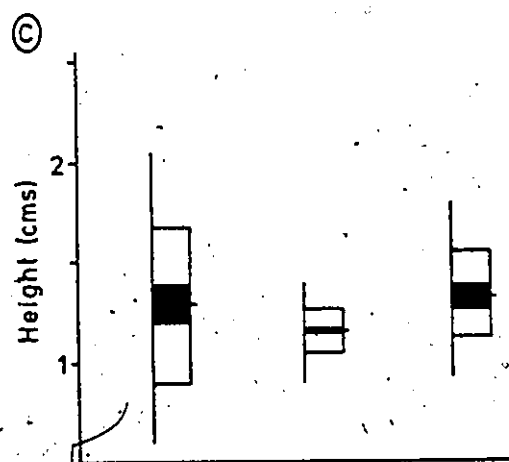
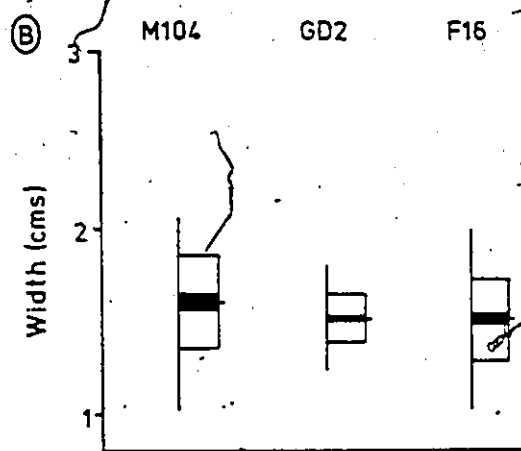
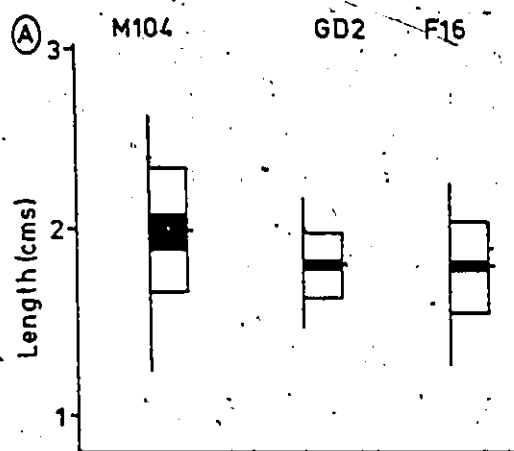
GD2, F16 and M104 of Atrypella shrocki. Significant value of Z is 1.96. If Z1 is above 1.96, Z2 value is not calculated. (N.V.= Numerical value, C.= Conclusion, DIFF.= Different).

The bivariate graphs (Table 30) demonstrate significant differences in the growth characteristics of the three assemblages. Consequently, the differences in absolute size of the various parameters (Text-fig. 67) can be attributed, at least in part, to differing growth rates. However, as these assemblages all came from argillaceous limestone, it appears that other variables besides environmental controls were responsible for the differences. Nevertheless, some of the variation may be related to slight variations in the amount of detrital material in the argillaceous limestone.

Assemblage GD2 occurred in a local 'pocket' within the unit. The attitude of the brachiopods, with their pedicle valves facing upwards, the fact that all the specimens were articulated and unabraded, and the normal distribution of each parameter plotted on a frequency histogram, all suggest that this is a life assemblage. The density of the shells within this pocket was extremely high and few specimens were found outside the pocket. In sharp contrast, the shells of assemblage M104 were spread more evenly throughout the unit suggesting that the population density was relatively low. The assemblage is characterized by all the features (except population density) listed for assemblage GD2 and thus appears to be a life

Text-figure 67

Comparison of parameters of Atrypella shrocki in assemblages F16,
GD2 and M104.



assemblage as well. As these assemblages have shells of different size and display different growth characteristics it appears that the original population density may have affected the growth patterns of the shells.

Internal morphology The internal structures of Atrypella shrocki Cooper (1942) are very similar to those of A. phoca (p. 352) and A. foxi (p. 332). The outer hinge plates (Text-fig. 68) are parallel or subparallel to the commissural plane. The crural bases are situated at the inner edges of the outer hinge plates (Text-fig. 68). Each crural base increases slightly in diameter anteriorly before it diverges from the outer hinge plate and rises to join the primary lamella. The teeth and sockets are strongly developed (Text-fig. 68).

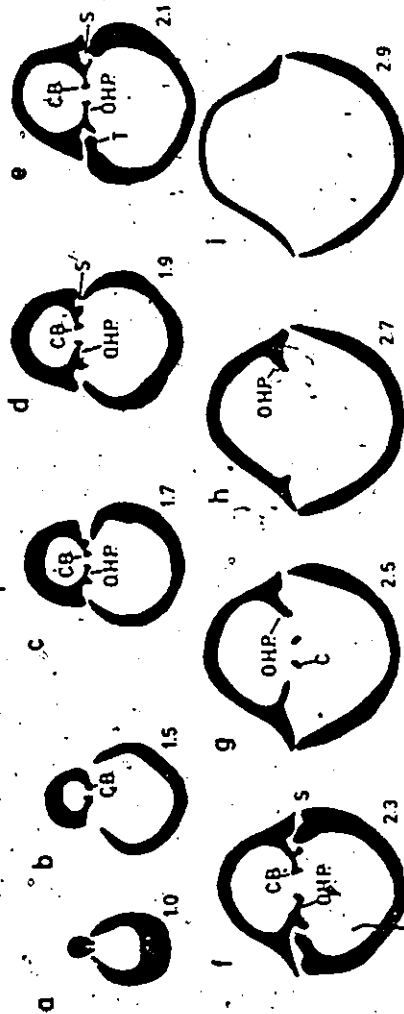
The spiralia are dorso-medially directed and are 'D'-shaped in horizontal profile (Pl. 30, fig. 5) and cone-shaped in vertical profile (Pl. 30, fig. 7). The apical portions of the spiralia converge towards the median plane (Pl. 30, fig. 6). Each spiraliun contains between 7 and 13 volutions.

Comparison of Atrypella foxi, Atrypella phoca and Atrypella shrocki

Distinguishing morphology Although the three species differ externally they have very similar internal structures. The most dependable way to distinguish species is to use parameters which do not vary

Text-figure 68

Serial sections of Atrypella shrocki from assemblage F16. Distances are from the posterior end of the shell (in mm).



0 cm



with ontogeny or environmental conditions. In Atrypella, the P.C.I. is the only parameter of this type. Although the mean value of the P.C.I. for A. phoca is slightly less than that for A. foxi (Table 31) the overlap between the two species means that it cannot be used by itself for distinguishing the two species. The P.C.I. can be used to distinguish A. shrocki from A. foxi and A. phoca because it is significantly higher for this species (Table 31).

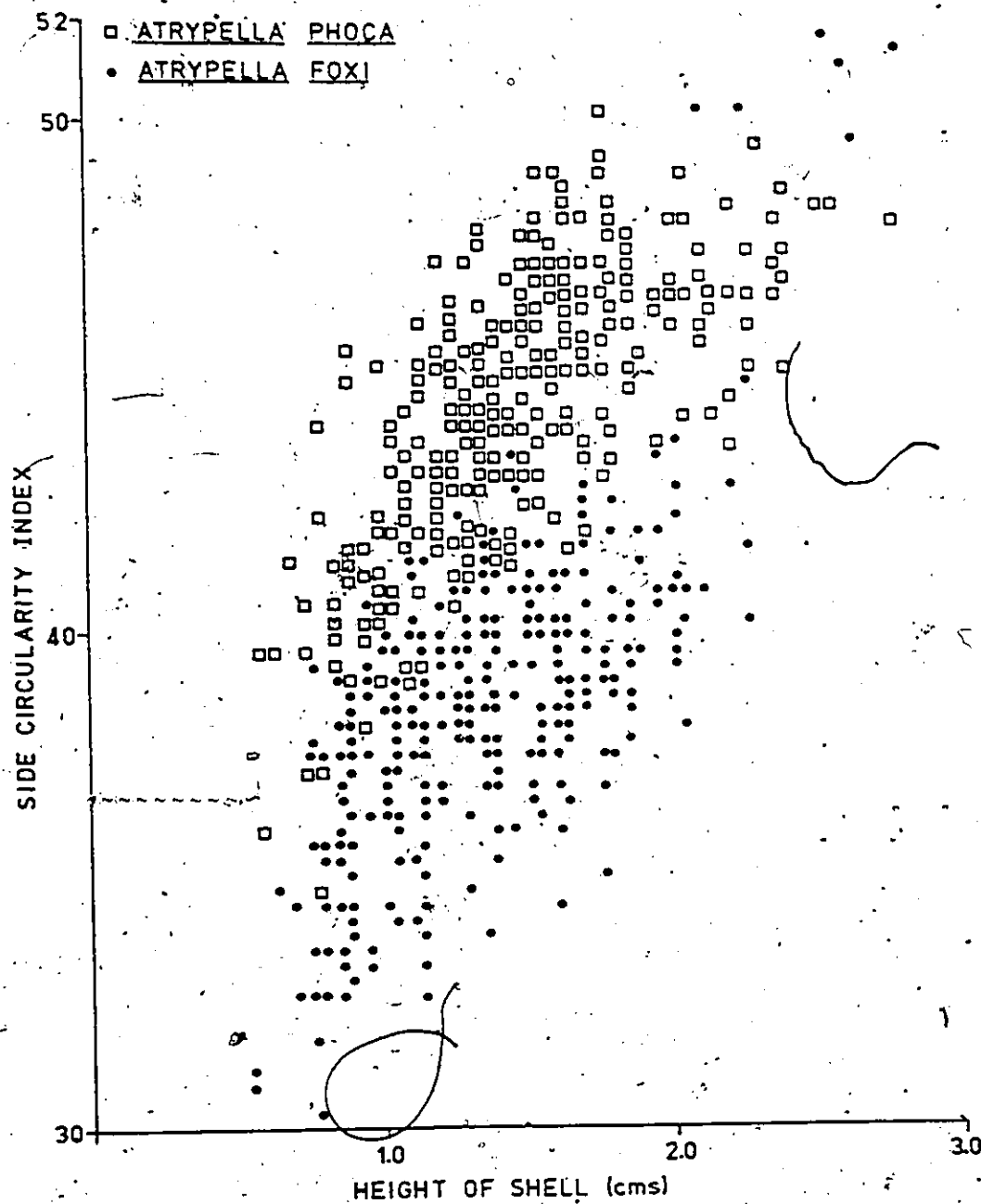
Although the S.C.I. varies with ontogeny and environment it can be used for species identification since the extent of its variation has been well documented. The environmental effects can be removed from consideration by comparing only specimens from the same rock type. The S.C.I. of assemblages of A. phoca and A. foxi from the same rock type are significantly different. Thus, specimens of A. phoca have a higher S.C.I. than specimens of A. foxi (Table 31). This difference, which can be graphically illustrated in a plot of the S.C.I. and the height of the shell (Text-fig. 69), is apparent in assemblages from micritic limestone and assemblages from argillaceous limestone. The S.C.I. suggests that A. shrocki occupies an intermediate position between A. phoca and A. foxi. However, the degree of overlap of the full range of values makes it difficult to distinguish A. shrocki from A. phoca and A. foxi, solely on the basis of S.C.I.

	<u>Atrypella foxi</u>		<u>Atrypella phoca</u>		<u>Atrypella shrocki</u>	
SIDE CIRCULARITY INDEX	M113	37.90 - 39.30	T31	44.22 - 45.30	F16	42.22 - 43.10
	B33	38.02 - 39.05	C	42.80 - 43.56	M104	38.37 - 39.85
	F16	38.41 - 39.95	W1	44.85 - 45.43	GD2	38.60 - 39.12
	Y18	37.21 - 38.49	GC2	43.11 - 44.43		
	X14	37.51 - 38.03				
	GC5	37.02 - 38.02				
PLAN CIRCULARITY INDEX	M113	52.25 - 52.59	T31	50.98 - 52.18	F16	54.21 - 54.83
	B33	52.19 - 52.71	C	51.67 - 52.35	M104	54.77 - 55.49
	F16	52.04 - 52.88	W1	51.23 - 52.07	GD2	54.21 - 54.85
	Y18	52.52 - 53.32	GC2	50.78 - 51.32		
	X14	52.83 - 53.59				
	GC5	51.55 - 52.18				
APICAL ANGLE	M113	56.62 - 59.02	T31	68.71 - 71.87	F16	59.53 - 61.53
	B33	47.51 - 49.23	C	69.85 - 71.89	M104	60.40 - 63.60
	F16	59.14 - 62.54	W1	62.19 - 62.55	GD2	71.53 - 74.13
	Y18	45.89 - 48.25	GC2	59.00 - 62.40		
	X14	46.72 - 49.20				
	GC5	56.55 - 58.72				

Table 31: Mean values of parameters of Atrypella foxi, Atrypella phoca and Atrypella shrocki used in computation of dendrograms. The mean values of the S.C.I., P.C.I. and apical angle are given at the 95% confidence limits. See table 13 for location of assemblages.

Text-figure 69

Comparison of Atrypella foxi and Atrypella phoca in a plot of height versus the Side Circularity Index. The graph is based on 375 specimens of Atrypella phoca and 414 specimens of Atrypella foxi. Specimens are from assemblages X14, Y18, B33, GC5, M113, F16 (Atrypella foxi), T31, C, W1 and GC2 (Atrypella phoca).



The apical angle varies according to environmental conditions. Consequently, comparison of this parameter amongst species must be made on specimens from the same rock type. The apical angle is useful for distinguishing A. phoca from A. foxi if the specimens are from pure limestone. In these rocks the apical angle of A. phoca is significantly higher than it is for A. foxi (mean value of 68° - 71° and 47° - 49° respectively -- see Table 31). However, the apical angles of the two species do not differ significantly in assemblages from argillaceous limestone. In these rocks the apical angle of A. foxi is only slightly smaller than that of A. phoca (56° - 59° and 59° - 62° respectively -- see Table 31). The slight difference is scarcely significant when the full range of values of both species are compared.

The apical angle of A. shrocki is so similar to those of A. phoca and A. foxi that it is of little use in distinguishing the species from the others.

The differences can be summarized as follows:

- (1) The P.C.I. of A. shrocki is higher than for A. phoca and A. foxi indicating that A. shrocki has a very elongate shell compared to the more rounded forms of the others.
- (2) The S.C.I. of A. phoca is higher than for A. foxi indicating that A. phoca is more bulbous (even with environmental and

ontogenetic variance removed from the consideration). The

S.C.I. for A. shrocki is intermediate between those of A. phoca and A. foxi.

- (3) The apical angle is useful for distinguishing A. foxi from A. phoca in micritic limestone only, where A. foxi has a lower apical angle. In all other instances the apical angles of the three species display such a high degree of overlap that they are of no use for identification.

For the greatest accuracy in identification all three parameters should be considered. The differences outlined previously serve as the main distinguishing characteristics while other differences can be used to support this distinction.

The remaining parameters (length, width, height, A.D.A.C. and R.D.A.C.) are of little use for identification because of their degree of variability in relation to ontogeny and environmental conditions.

Relationships of the species One of the basic aims of the phenetic method of classification is to provide some measure of similarity between the various species. To do this, a similarity coefficient based on the distance between groups in N-dimensional space can be used. The results of the analysis are summarized on a dendrogram (see p. 295 for full discussion).

The number of dimensions used in the N-dimensional analysis is determined by the number of parameters used to define each fossil. As 8 were used for Atrypella, (see p. 290), the similarity indices are based on 8-dimensional space. Each parameter is represented by one axis and all the axes are at right angles to each other.

If all the specimens from each assemblage are plotted in this 8-dimensional space then the plotted points form an 8-dimensional cluster. To simplify the calculations, this cluster can be represented by its central point. The centroid of each assemblage cluster will be defined by 8 co-ordinates, each being the mean value of the parameter for that co-ordinate.

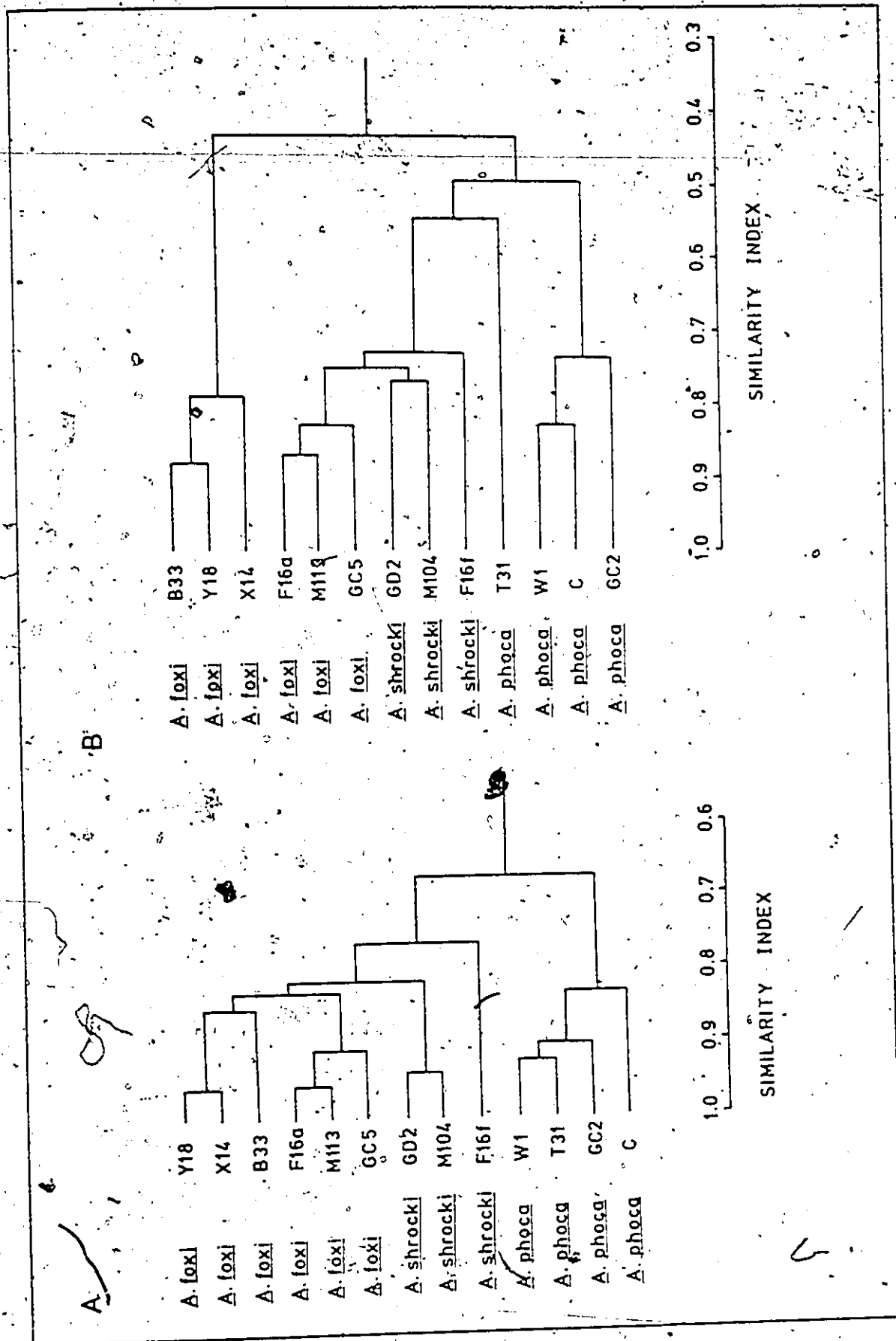
The data were analysed by the computer program 'Cluster Analysis' which was written by the author.

Initially all the assemblages of A. foxi, A. phoca and A. shrocki were analysed. It is apparent from the resulting dendrogram (Text-fig. 70b) that the various species groups tend to plot out in distinct clusters. However, it is also apparent that assemblages F16(a), M113 and GC5 (A. foxi) show a closer similarity to assemblages GD2, M104 and F16(f) (A. shrocki), and T31, C, W1 and GC2 (A. phoca) than to assemblages B33, X14 and Y18 (A. foxi). It has been noted previously that assemblages B33, X14 and Y18 are from micritic limestone and are

Text-figure 70

Dendrograms showing relationship between species of Atrypella.

- (A) Similarity indices based on P.C.I., S.C.I. and apical angle of all assemblages.
- (B) Similarity indices based on all measured parameters of all assemblages.



characterized by considerably larger shells than assemblages from argillaceous limestone. Since parameters such as length, width and height of the shell are being included in this analysis (see p. 350 for relationship between parameter magnitude and environment) it follows that the dendrogram must in part reflect environmental effects on the size and shape of the shell.

To determine the similarity between one species and another, parameters that are not environmentally dependent must be used. The effect of the environment can be removed in one of ~~two~~ ways:

- (1) The similarity indices can be calculated using only the parameters whose magnitude is not primarily a response to environmental conditions. Thus, the length, width and height of the shell would be excluded.
- (2) The similarity indices can be calculated using all the parameters, but only the assemblages from the same rock types are compared. Thus, all assemblages from micritic limestone would be included in one analysis while all assemblages from argillaceous limestone would be included in a separate analysis.

The length, width, height, A.D.A.C. and R.D.A.C. all vary according to environmental conditions and therefore are of minimal use for identifying the various species. The P.C.I. is genetically variable

and can thus be included in the first analysis (of both A. foxi and A. phoca). The magnitude of the apical angle was influenced by environmental conditions. However, this parameter can be useful for distinguishing one species from another; for this reason the parameter can be included in the first analysis. The S.C.I. varies according to environmental conditions and ontogeny. Despite the variance introduced by these factors, the magnitude of the parameter appears to be controlled mainly by inheritance. Thus, the S.C.I. can also be included in the first analysis.

In the calculation using only three parameters (P.C.I., S.C.I. and apical angle) the similarity indices are based on 3-dimensional space. The resultant dendrogram (Text-fig. 70a) clearly demonstrates that the three species previously identified fall into distinct groups. From the dendrogram (Text-fig. 70a) it is apparent that A. foxi is more similar to A. shrocki than to A. phoca.

In addition, similarity indices were calculated for assemblages from particular rock types. Only A. phoca and A. foxi were obtained from micritic limestone and only 5 assemblages were included.

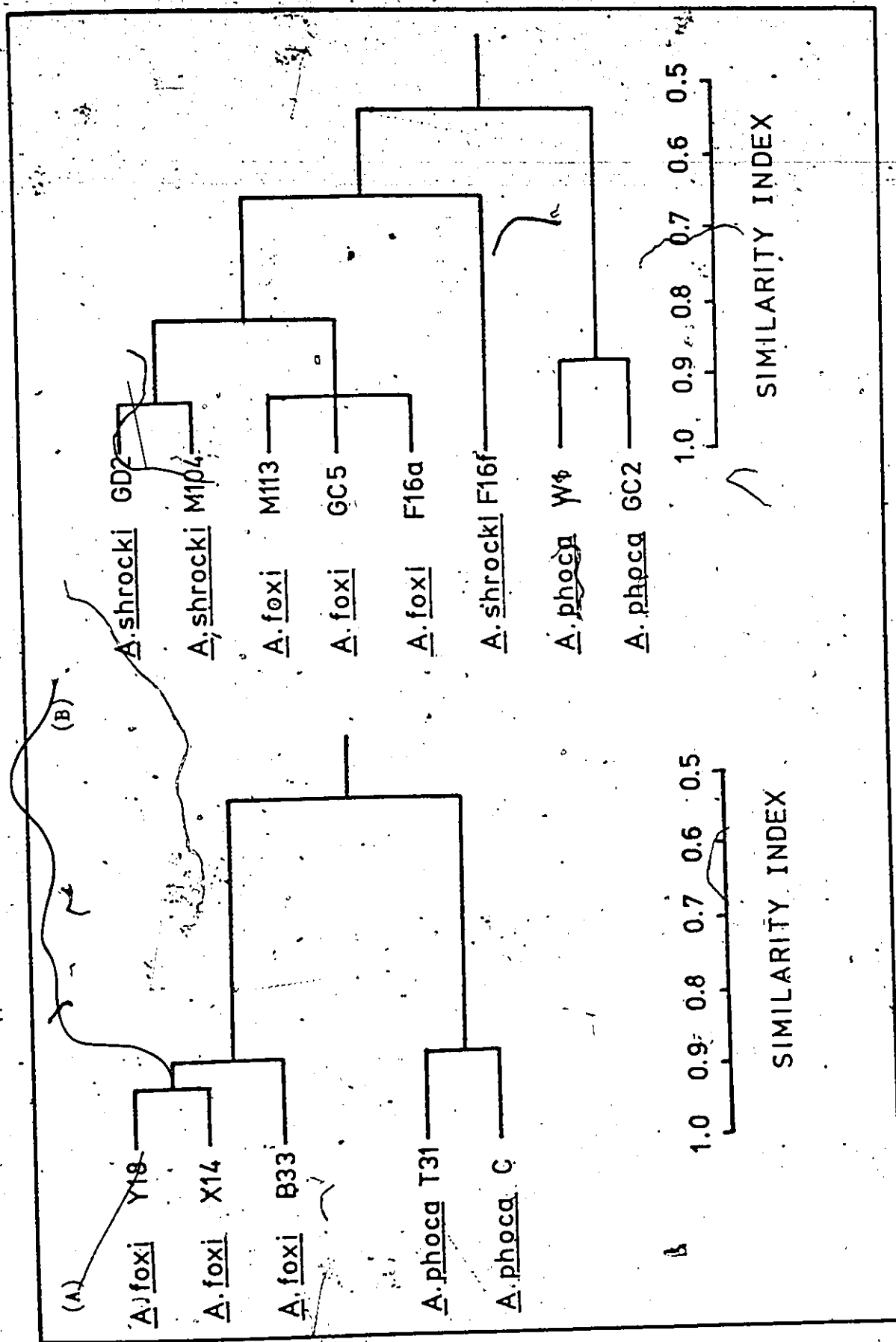
In this analysis (Y18, X14, B33, T31 and C). The resultant dendrogram clearly demonstrates that the two species are distinct (Text-fig. 71a).

Eight assemblages (GD2, M104, M113, GC5, F16a, F16f, W1 and

Text-figure 71

Dendrograms showing relationship between species of Atrypella.

- (A) Similarity indices based on all measured parameters of all assemblages of A. phoca and A. foxi from micritic limestone.
- (B) Similarity indices based on all measured parameters of all assemblages of A. foxi, A. phoca and A. shrocki from argillaceous limestone.



GC2) of A. foxi, A. phoca and A. shrocki which are from argillaceous limestone were analyzed. The dendrogram for this analysis (Text-fig. 71b) demonstrates that there are three distinct clusters, each representing one of the three species previously identified. Once again it is apparent that A. foxi is more similar to A. shrocki than it is to A. phoca.

History of the genera Atrypella and Lissatrypa

In studying the brachiopods from the Upper Silurian of Gotland, Dalman (1828) described a new species which he named Atrypa prunum (Text-fig. 72).

Salter (1852) in studying brachiopods from the Arctic Islands of Cornwallis, Leopold, Griffith's and Seal, described a new species which he named Rhynchonella phoca. Following re-examination of these specimens, Haughton (1857) removed the species phoca from Rhynchonella and placed it in the genus Atrypa since he could find "no trace of an aperture in or under the beak" (ibid., p. 240). Text-figures 72a-c are taken from Haughton's paper and show the form that he designated Atrypa phoca. Etheridge (1878) followed Haughton in designating similar specimens as Atrypa phoca.

The next reference to a brachiopod of this form is by

Text-figure 72

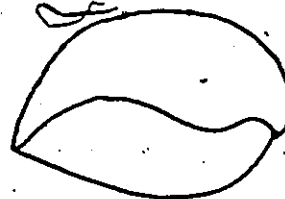
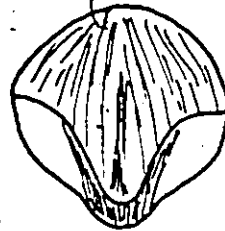
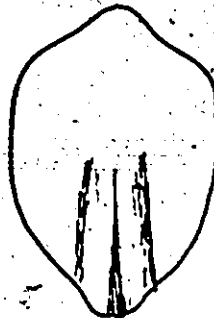
Outline drawings of (A) Atrypa phoca (Salter) (from Haughton, 1857, Pl. 5, figs. 3, 4 and 7); (B) Atrypa prunum Dalman (from Dalman, 1828, Pl. 5, fig. 2); (C) Lissatrypa scheii Holtedahl (from Holtedahl, 1914, Pl. VII, fig. 12) and (D) Lissatrypa phoca (Salter) (from Holtedahl, 1914, Pl. VII, fig. 13). All at natural size.

A



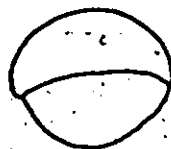
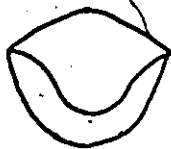
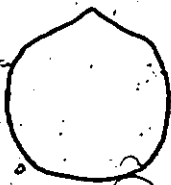
Atrypa phoca
Haughton 1857

B



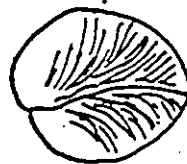
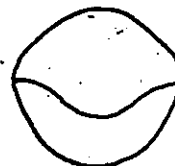
Atrypa prunum
Dalman 1828

C



Lissatrypa scheii
Holte dahl 1914

D



Lissatrypa phoca
Holte dahl 1914

Holte^Cdahl (1914) who verified that the internal structures of Atrypa phoca confirmed its inclusion in the family Atrypidae. However, he noted that Atrypa phoca lacked the prominent striations or fine plications that characterized atrypids and thus felt the need to erect a new genus to include these smooth atrypids. However, Holte^Cdahl (1914, p. 25) noted: "I myself intended to establish a new genus but learnt at an early date that Dr. W. H. Twenhofel of the University of Kansas in the manuscript of a monograph on the Ordovician and Silurian rocks and fossils of Anticosti Island, had preceded me by proposing a new generic name, Lissatrypa for the same type of shell."

Consequently, Holte^Cdahl (1914) removed the species from the genus Atrypa and placed it in the new genus Lissatrypa. However, Holte^Cdahl (1914) referred the majority of his specimens to a new species, Lissatrypa schei. The difference between the two species (Holte^Cdahl, 1914, p. 26) is mainly in the size of the shell, L. phoca being the larger. However, as demonstrated previously the size and form of the shells and their apical angle could have been affected by the environment in which they lived. The change in apical angle will alter the outline of the shell to a certain extent and may be the reason why Holte^Cdahl (1914, p. 26) noted an additional difference between L. phoca and L. schei as being: "In outline L. schei is more rectangular than the

other form, that has a rather acute triangular outline in the posterior part." Comparison of the figures in Høltedahl's paper (1914) further serves to demonstrate these similarities (Text-figs. 72a and 72c).

In 1924 Høltedahl reported on the 1921 Norwegian expedition to Novaya Zemlya. Concerning the relationship between L. phoca and L. scheii, he stated: "Having now seen a great amount of specimens of L. phoca, the likeness between the forms has become still more evident to me; in fact the most natural conclusion would probably be to regard the Ellesmereland form as a (somewhat smaller) variety of the typical L. phoca" (ibid., p. 129).

As shown previously, the size of the shell and the magnitude of the apical angle varied according to the environmental conditions. If a parameter can only be used as a criterion for identification of a species providing it does not vary according to environment, or its relationship to ontogeny and environmental controls is known, then L. phoca and L. scheii must be considered the same species. Consequently, the species name scheii is invalid and phoca, as the first-named species takes precedence.

In a study of the Silurian brachiopods of Anticosti Island, Twenhofel (1914) erected a new genus Lissatrypa with the new species Lissatrypa atheroidea the type species. Kirk and Amsden (1952) argued

the question of whether L. atheroidea or L. phoca should be the type species of the genus. The reader is referred to Kirk and Amsden's paper for a full discussion of the problem; it is sufficient to note here that Lissatrypa atheroidea is generally regarded as the type species.

Kozłowski (1929), in studying the brachiopods from the Upper Silurian of Poland, in addition to accepting the genus Lissatrypa, also erected the new genus Atrypella. Kozłowski (1929) took Atrypa prunum Dalman (1828) as the genotype. He separated this form from Atrypa because of the smooth outer surface of the shell (it differs from the 'true' atrypids that are characterized by a plicated shell) and the fact that this form has a ventral valve which had a convexity equal to or greater than the dorsal valve. In this species Kozłowski also included the species Gruenwaldtia prunum (Dalman) Wieniuków (1899) and Gruenwaldtia prunum (Dalman) Siemiradzki (1906).

Thus, both Holtehdahl (1914) and Kozłowski (1929) felt the need to remove Atrypa phoca and Atrypa prunum from the atrypid group because of the lack of plications. Kozłowski (1929) noted that Holtehdahl (1924) considered that Terebratula camelina and Atrypa prunum belonged to the genus Lissatrypa. However, Kozłowski (1929) argued that this is invalid because these species lack the concentric

ornamentation that is present on Lissatrypa and because the structure of the cardinal plates is different (the 'two apophyses' are much less massive and further apart than in Atrypella). Thus, Kozłowski (1929) considered the two genera distinct, and in addition stated: "It is doubtful that a direct generic relationship exists between the two genera."

While the value of concentric growth lines for identification may be questioned, the internal structures are more likely to be useful for identification. Consequently, Lissatrypa and Atrypella are regarded as distinct genera.

In 1939, Khodalevich reported on brachiopods from the Upper Silurian strata of the eastern slopes of the Urals. A large proportion of these specimens were placed in the genus Lissatrypa. However, the serial sections given by Khodalevich (1939, p. 50, fig. 24, p. 52, fig. 25 and p. 60, fig. 26) show structures that are characteristic of Atrypella and not Lissatrypa (inner hinge plates are missing). Where serial sections are ~~not provided~~ Khodalevich frequently stated that the "internal structures are the same as those for Lissatrypa." In other instances, the author stated that "...the internal structures are unknown" (ibid., p. 57).

Khodalevich (1939) made no reference to Kozłowski's (1929) paper and thus made no comparison of the specimens with Atrypella.

Text-figure 73

Internal structures in serial sections of (A) Atrypella prunum (Dalman) (from Kozlowski, 1929, p. 176, fig. 57); (B) Atrypella schell (Holtedahl)? (from Kirk and Amsden, 1952, p. 58, fig. 3); (C) Atrypella tenuis Kirk and Amsden (from Kirk and Amsden, 1952, p. 60, fig. 5); (D) Atrypella borealis Kirk and Amsden (from Kirk and Amsden, 1952, p. 60, fig. 6) and (E) Lissatrypa atheroidea Twenhöfel (from Kirk and Amsden, 1952, p. 59, fig. 4).

A



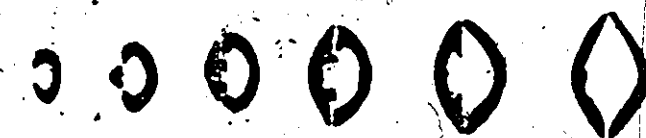
Atrypella
prunum
Kozłowski
1929
x3

B



Atrypella
scheii
(Holtedahl)?
x1.5

C



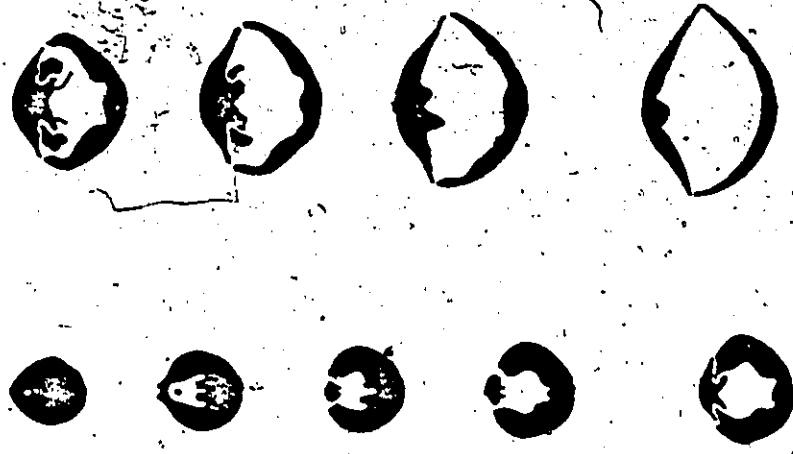
Atrypella
tenuis
Kirk and
Amsden
1952
x3

D



Atrypella
borealis
Kirk and Amsden
1952
No Scale Given

E



Lissoatrypa
atheroidea
Twenhofel, 1914
x3

On the basis of serial sections and the photographs Khodalevich provided, it would seem that most, if not all, belong to the genus Atrypella and not Lissatrypa.

Khodalevich (1939), who listed 16 species (6 new) and 2 varieties of Lissatrypa, commonly based his identifications on only one or two specimens, some of which were damaged. Consequently, no account was taken of possible environmental or ontogenetic variability. Probably the species foxi, phoca and shrocki described in this thesis encompass many of the species listed by Khodalevich (1939).

Of the forms listed by Khodalevich (1939), Atrypella foxi appears to be very similar to L. linguata Buchwald (Khodalevich, 1939, Pl. 10, figs. 6 and 7) and L. camelina Buchwald (ibid., Pl. 12, figs. 1-5). The serial sections of L. camelina (ibid., p. 50, fig. 24) are very similar to those of A. foxi. A. shrocki is very similar to Lissatrypa gigas (ibid., Pl. 21, fig. 3), and L. peritus elongata Khodalevich (ibid., Pl. 20, fig. 6).

In 1939 Nikiforova published her monograph on the brachiopods of the Cambrian and Silurian systems of the U.S.S.R. Nikiforova considered that the genus Atrypodea Mitchell and Dunn (1920) should be referred to Lissatrypa Twenhofel. Such a conclusion was based on comparison of external features and the fact that both genera have

dorso-medially directed spiralia. However, until serial sections of Atrypoidea are available, this conclusion cannot be confirmed or rejected.

Nikiforova (1939, p. 79) considered that the presence of strongly developed dental plates in Kozłowski's Lissatrypa leprosa was markedly different from Lissatrypa and the species should therefore be referred to a separate genus.

Nikiforova (1939, p. 79) also compared Atrypella prunum with Lissatrypa Twenhofel and concluded that the genus Atrypella "...should undoubtedly be referred to the genus Lissatrypa..." However, in serial sections of Lissatrypa camelina Buch. given by Nikiforova, the structures are more similar to Kozłowski's Atrypella than to Twenhofel's Lissatrypa. Consequently, it is the author's opinion that Nikiforova's Lissatrypa should be referred to the genus Atrypella Kozłowski.

Nikiforova (1939; p. 46) erected the new species L. muschketev in addition to describing L. camelina Buch., L. linguata Buch., L. linguata var. columbella Barrande and L. (?) tectiformis Tschernyschew.

Nikiforova (1939, 1954) followed Khodalevich's practise of listing many species of Lissatrypa, often on the basis of only one or two specimens. Probably many of these forms listed are equivalent to

A. foxi, A. phoca and A. shrocki.

In 1942 Cooper established the new species Atrypella shrocki on the basis of specimens from the Huntington Limestone (Sil.) of Indiana. Cooper compared this species with Atrypella phoca (Salter) from the Arctic and stated that "...they differ in having a more elongate outline, deeper sulcus, narrower and more elevated fold and less convex dorsal valve." Unfortunately, no photographs or diagrams were provided with this paper. Judging from two poor photographs of the species in Shimer and Shrock (1944, p. 319) the differentiation between the two species appears to be valid.

Atrypella shrocki strongly resembles Atrypella prunum in many respects. It has a similarly shaped shell and the sulcus has a similar form. Unfortunately, Kozlowski (1929) did not provide any illustrations of Atrypella prunum and inspection of Dalman's original diagrams of Atrypa prunum leaves some doubts concerning its similarity to Atrypella shrocki. Consequently, until the original specimens of Atrypella prunum and Atrypella shrocki can be examined, no definite conclusions can be made concerning their similarity. If they prove to be the same then Atrypella shrocki must be included as a synonym of Atrypella prunum (Dalman).

The next main contribution to the study of Atrypella was by

Kirk and Amsden (1952) on the Upper Silurian brachiopods of southeastern Alaska. Kirk and Amsden (1952, p. 58) transferred Lissatrypa scheii from the genus Lissatrypa to Atrypella, thus giving Atrypella scheii (Holstedahl)? However, this in itself is unsatisfactory on three accounts:

- (1) Holstedahl (1924, p. 129) pointed out that he considered scheii a smaller variety of phoca.
- (2) It has been demonstrated that the size of the shell and the apical angle varied according to the environment in which the animals lived. This supports Holstedahl's conclusion.
- (3) The brachiopods figured by Kirk and Amsden (1952, Pl. 7, figs. 12-22) appear to be different from those figured by Holstedahl (1914, p. VII, figs. 9-13). Those figured by Holstedahl are very bulbous forms and are apparently characterized by well-developed concentric growth lines. The specimens figured by Kirk and Amsden are more elongate, less bulbous and lack well developed growth lines. Kirk and Amsden's forms are most similar to the author's A. foxi n. sp. while Holstedahl's forms are most similar to the author's A. phoca (Salter).

For these reasons the present author considers the species scheii to be invalid and has included the species figured by Kirk and

Amsden as A. scheii as a synonym of A. foxi n. sp.

Kirk and Amsden (1952) compared their A. scheii (Holtedahl)? and A. prunum (Dalman) with Lissatrypa but considered them different genera for the following reasons:

- (1) With reference to A. scheii (Holtedahl)?, Kirk and Amsden (1952, p. 59) stated, "Specimens of Lissatrypa are much smaller and and not so strongly biconvex."
- (2) "The pedicle musculature of Atrypella, however, seems to be much less deeply impressed than that of Lissatrypa; it lacks the strongly indented diductor scars and high separating platform which characterizes Lissatrypa." (ibid., p. 59).
- (3) The brachial valve of Atrypella has a much less strongly developed medium septum and the hinge structure is not as massive.

If the size and convexity of the shells of Atrypella were affected by environmental conditions, then valid comparisons of size and convexity cannot be made except between forms from the same environment. Thus, Kirk and Amsden's (1952) recognition of differences in size and convexity cannot be used for distinguishing the genera Atrypella and Lissatrypa, and the differences between the genera must be looked for in the internal structures. However, an additional point to consider is whether the environmental conditions can also affect the size and the character of the internal structures.

Kirk and Amsden (1952) also erected two new species, Atrypella tenuis and Atrypella borealis. The serial sections for these species are shown in Text-figures 73c and 73d. Kirk and Amsden, in comparing these species, suggested that the main differences between the two are:

- (1) The shell wall of A. borealis is relatively thick for a shell of this size while that of A. tenuis is relatively thin.
- (2) A. borealis is a much smaller species than A. tenuis.
- (3) A. borealis is more convex than A. tenuis.
- (4) A. tenuis lacks the ventral sulcus which is so clearly defined on A. borealis.

Once again the relationship between the size and convexity of the shell and the environment is important, as well as the relationship of the convexity of the shell to ontogeny. Thus, it is difficult to determine whether the differences noted by Kirk and Amsden (1952) are valid species differences or merely differences effected by environment or ontogenetic changes. The increased convexity of A. borealis might also explain the relatively thick shell seen in the serial sections near the posterior end of the shell. Valid comparisons of the shell thickness can only be made if the true thickness was determined perpendicular to the shell surface. The internal structures

of the two species are similar; the only difference is that the internal structures in A. borealis tend to be more massive than those in A. tenuis.

Kirk and Amsden (1952) separated A. tenuis and A. borealis from A. scheii (Holtehdahl)? for the following reasons:

- (1) A. scheii (Holtehdahl)? is larger and more strongly biconvex than A. tenuis.
- (2) With reference to A. borealis, Kirk and Amsden (1952, p. 61) stated: "A. scheii (Holtehdahl)? is much larger and does not develop a ventral sulcus until it is about half grown."

As previously discussed both of these statements concern features which were subject to environmental and ontogenetic variation and this makes their use as species characters dubious.

Kirk and Amsden (1952, p. 60) claimed that the internal structures of A. tenuis are similar to those of A. scheii (Holtehdahl)? However, they noted that A. scheii (Holtehdahl)?, while having a spirallium and jugum similar to A. tenuis, does not have such a well developed brachial septum or pedicle platform. The attitudes of the cardinal plates and the crural plates in A. scheii (Kirk and Amsden, 1952, p. 58; reproduced in Text-fig. 73b) are similar to those in Atrypella prunum (in Kozlowski, 1929, p. 176). In both, the cardinal plates are

thin and clearly separated from the other structures. They are normally parallel or subparallel to the commissural plane. The crural bases are distinct 'globular' structures at the extreme inner ends of the outer hinge plates. No internal structure is present between the two crural bases and the brachial valve is characterized by an umbonal cavity. These internal structures differ in several important ways from those of Lissatrypa atheroidea Twenhofel (given in Kirk and Amsden, 1952, p. 58, reproduced in Text-fig. 73e). The cardinal plates are not as distinct and 'thin' as in Atrypella scheii (Holtedahl)? and A. prunum. The crural bases are not as distinct because of a medial structure, the inner hinge plates. Both of these characters serve to produce a 'heavy' hinge structure. Also, there is no umbonal cavity in the early stages of the brachial valve. The main difference between Lissatrypa and Atrypella appears to be the presence or absence of the inner hinge plates.

A comparison of A. borealis and A. tenuis with Lissatrypa and Atrypella reveals some significant differences. Both A. tenuis and A. borealis lack the distinct cardinal plates and crural plates which are so evident in A. scheii (Holtedahl)? and A. prunum. Both A. borealis and A. tenuis lack the umbonal cavity in the early stages of the development of the brachial valve, again different from A. prunum.

and A. scheff (Høltedahl)? Thus, following the suggestion of Johnson and Reso (1964, p.81), A. tenuis and A. borealis should be removed from the genus Atrypella.

Johnson and Reso (1964, p. 81) suggested that A. borealis is most closely related to the genera Lissatrypa or Glassia rather than Atrypella. Both A. tenuis and A. borealis may be based on specimens of the same species which are from slightly different environments. The internal structures are most similar to those of Lissatrypa thus suggesting that they should be included in that genus.

Nikiforova and Andreeva (1961) claimed that Kozlowski's description implied that Lissatrypa and Atrypella differ only in the scale of the hinge structure. Nikiforova and Andreeva (1961, p. 228) concluded that Atrypella should be considered a subgenus of Lissatrypa for the following reasons:

- (1) The external features of Atrypella and Lissatrypa are similar.
- (2) The muscle impressions in Lissatrypa and Atrypella show no significant difference.
- (3) While the size of the hinge plates is generally considered the diagnostic difference between Atrypella and Lissatrypa, it is also variable within the genus Atrypella. Thus, Nikiforova and Andreeva (1961) considered this criterion invalid.

Their suggestion that the size of the hinge plate is variable within the limits of the one genus, was based on consideration of the serial sections of A. tenuis Kirk and Amsden and A. borealis Kirk and Amsden and A. scheii (Holtedahl)? Kirk and Amsden. However, their assessment is based on the assumption that these three species are cogenetic. As there is considerable doubt whether A. tenuis and A. borealis should be included in the genus Atrypella, Nikiforova and Andreeva's opinion that Atrypella has variable hinge plate sizes is questionable as their initial assumption may well be wrong.

In describing Lissatrypa recta n. sp., Nikiforova and Andreeva stated: "If we regard the genera Lissatrypa and Atrypella as independent, then in this case it is difficult to decide to which genera the species described below should be related, because according to the hinge plate it is closer to Atrypella..."

The serial sections (Nikiforova and Andreeva, 1961, p. 229, figs. 31, 32 and 33) and the photographs (op. cit., Pl. XLVIII, figs. 1-11) of L. recta suggest that this species should be assigned to Atrypella and not Lissatrypa.

In 1964 Johnson and Reso designated Atrypella carinata as a new species. Internal structures were described but no serial sections were figured. The photographs of A. carinata (Johnson and Reso, 1964,

Table 32: List of occurrences of Atrypella. * Indicates forms originally identified as Lissatrypa but now assigned to Atrypella. ** Indicates a form originally identified as Atrypa but now assigned to Atrypella. *** Indicates forms identified as Atrypoides which may be synonymous with Atrypella. + Unpublished M. Sc. thesis (Oregon State University).

Locality No. on Text-figure	Location as Given by author	Stratigraphic unit	Age as given by author	Reference
74	S. W. Ellesmere land	Schei's Series B	Niagaran or Keyser	Holte Dahl (1914)
2	Various Arctic islands			
6	Hazen Trough and Southern Grant Land Mountains	Marvin Formation	Ludlovian	Trettin (1971)
	Cornwallis Island	Read Bay Formation	Lud.-Prid.	Thorsteinsson (1958)
	Stefansson Island	Read Bay Formation	U. Sil.	Thorsteinsson & Tozer (1962)
	Grinnell Peninsula, Devon Island	Douro Formation	Pridolian	R. Smith (1973) ⁺
	Somerset Island	Read Bay Formation	Pridolian	This study
	Prince of Wales Island	Read Bay Formation	U. Sil.	G.S.C. Open File 66

Table 32 (contd.)

3	3	Prongs Creek	Road River Formation	Pridolian	Lenz (1970)
4	5	Haceta & Koscuisko Islands	----	U. Sil.	Kirk & Amsden (1952)
5	2	Pahrangat Range, S.E. Nevada	Sevy Dolomite	Ludlovian	Johnson & Reso (1964)
6	1	Nr. Georgetown, Indiana	Huntington Limestone	U. Sil.	Cooper (1942)
7		Novaya Zemlya	Greben Horizon (Cherkesova, 1973)	U. Sil.	Holtedah1 (1914) Cherkesova (1973)
8		Dolgiy & Zelenets Islands	Greben Horizon	U. Sil.	Cherkesova (1973)
9		Meyero River	---	/	Nikiforova & Andreeva (1961) *
10		E. Slope of Urals	<u>Striatum & Marginalis</u> Beds	U. Sil.	Khodalevich (1939) *
11		Gotland	Hemegruppen	L. Lud.	Dalman (1828) **
12		Podolia & Moldavia	Skala Limestone	U. Sil.	cited in Khodalevich (1939)
13		Bohemia	E ₂ & E ₁ Horizon	U. Sil.	cited in Khodalevich (1939)
14		Eastern Fergana	Marginalis Beds	U. Sil.	Nikiforova (1939)
15		Malaya	----	U. Sil.	Boucot <u>et al.</u> (1966)
16		Australia	----	U. Sil.	Mitchell & Dunn (1920) (cited in Khodalevich, 1939) ***

Pl. 20, figs. 18-26; Boucot et al., 1965, p. H643, figs. 50-51 and paratypes of this species suggest that A. carinata is the same as A. shrocki Cooper (1942). While Johnson and Reso compared A. carinata with other forms from the Arctic and Russia no comparison was made with A. shrocki. Collectively this evidence suggests that A. carinata is a junior synonym of A. shrocki.

Boucot et al. (1965) followed the conclusions outlined by Boucot et al. (1964) in dividing the family Lissatrypidae Twenhofel (1914) into two subfamilies, the Lissatrypinae Twenhofel (1914) and Septatrypinae Kozlowski (1929). The difference between the two subfamilies is the presence of inner hinge plates in the Lissatrypinae and their absence in Septatrypinae. Thus, Lissatrypa belongs to the subfamily Lissatrypinae while Atrypella belongs to the subfamily Septatrypinae.

In 1970 Nikiforova reported on the Upper Silurian brachiopods from the Greben Horizon on Vaygach Island. Many of the brachiopods were assigned to the genus Atrypella under the main species of phoca and scheii. Nikiforova identified 5 varieties of phoca and 3 varieties of scheii on the basis of the shell size, convexity, ornamentation and sulcus form. According to her diagram on page 119 varieties such as A. phoca forma typica, A. phoca forma media and A. scheii forma

fossula have a distinct stratigraphic range. The problem with this type of classification system is that it places too much emphasis on the size and convexity of the shell, parameters which varied with ontogeny and environment. Thus, some of the varieties identified on this basis may in fact be the same species but at differing stages of maturity or from differing environments. Until specimens of these varieties are available for inspection no confident decision on the question of their validity can be made.

Copper (1973) re-examined the type species of Lissatrypa atheroidea Twenhofel using specimens from the Jupiter Formation of Anticosti Island (Canada). He considered the division of the smooth atrypids on the basis of the presence or absence of inner hinge plates dubious because "...inner hinge plates are not recognizable structures in any of these atrypids except as thick or thin pads flanking the socket plates" (ibid., p. 70). However, despite the problem of the validity of distinguishing genera based on the presence or absence of inner hinge plates, Copper (1973) described other features of Lissatrypa which have not been found in Atrypella. These features are: (1) a pedicle collar, (2) crural fibres and (3) small radial fibres on the external surface of the shell (although they may be missing from Atrypella because of weathering prior to preservation). In addition,

the forms described by Kirk and Amsden (1952) have calcitic material between the crural bases so that there is no umbonal cavity.

Irrespective of whether the features between the crural bases are inner hinge plates (Boucot et al., 1964) or thick calcitic tissue (Copper, 1933) they are features which have not been found in Atrypella and are therefore an additional difference between the two genera.

Geographic distribution of Atrypella

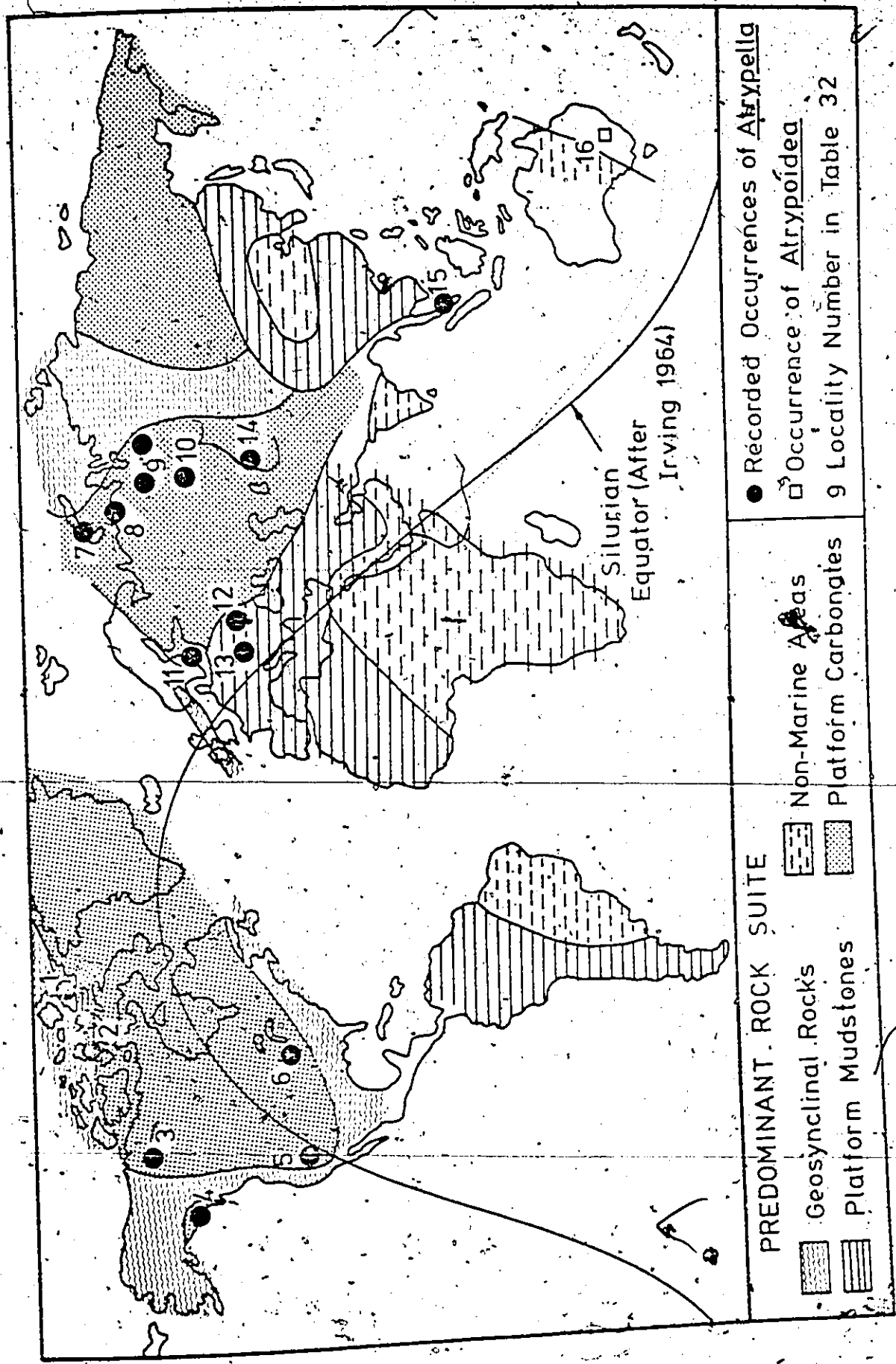
The genus Atrypella appears to have had a very limited global distribution. According to the literature Atrypella is limited almost entirely to the northern hemisphere and in particular to the Arctic regions of Canada and the U.S.S.R. (Text-fig. 74). The following factors have an important bearing on the distribution shown in Text-figure 74:

- (1) The original distribution of Atrypella
- (2) The present day occurrence of Silurian strata
- (3) The degree of study of the Silurian strata that are presently exposed
- (4) The taxonomic status of the genus Atrypella

As Holland (1971, p. 65) pointed out, the information in past literature "...comes from occurrences at present on land...". Thus, three quarters of the earth's surface, which is water-covered, is

Text-figure 74

Geographic distribution of Atrypella ---World wide.



automatically excluded from consideration. Similarly, the absence of Atrypella from some land areas could be attributed to the absence of Silurian marine strata. Even in the localities where Silurian strata are present, they are commonly poorly known because of the lack of detailed work. Thus, as Holland (1971, p. 65) noted, "...Cocks, Brunton, Rowell and Rust (1969) have only recently described the first Lower Paleozoic fauna to be found in Africa south of the Sahara." Similarly Boucot et al. (1966) have only recently described some of the Silurian fauna from Malaya.

One of the main problems in determining the distribution of Atrypella from the literature is that of determining which brachiopods are true Atrypella and which are true Lissatrypa. It is notable that, prior to Nikiforova's paper in 1970, the majority of Russian workers referred brachiopods of this type to Lissatrypa, while the majority of American workers referred the brachiopods to Atrypella.

However, as discussed previously, (p. 307) many of the forms identified as Lissatrypa should properly be assigned to Atrypella.

The problem thus becomes one of deciding which should remain in Lissatrypa. For the purpose of this study the forms noted in the previous discussion (p. 387) as being synonymous with Atrypella are treated such. The relationship of Atrypella Mitchell and Dunn.

(1920) to Atrypella is uncertain although Nikiforova (1939) considered that it was synonymous with Lissatrypa (=Atrypella). Consequently, the location of Atrypodea is included in Text-figure 74 with the reservation that it may or may not be synonymous with Atrypella.

Past literature suggests that the distribution of Atrypella closely follows the path of the Silurian equator (position after Irving, 1964). However, this pattern of distribution may merely be a reflection of the distribution of Silurian exposures at the present day, which itself tends to follow the path of the Silurian equator (Holland, 1971; p. 65).

Despite the obvious difficulties concerning the distribution of Silurian strata, the state of exploration of those strata and the taxonomic status of the genus, some patterns of distribution can be detected. For example, no specimens of Atrypella have been recorded from the Silurian strata of the British Isles or France. These strata, which in places have a rich shelly fauna, contain brachiopods which are found with, or near to Atrypella in other parts of the world, (e.g. Atrypa, Gypidula, Stegerhynchus).

Silurian strata are very widespread on the North American continent and yet the Atrypella distribution does not reflect this. Brachiopods of this type have not been recorded in beds of equivalent

465

age in southern Ontario, New York State or Michigan. These beds, however, do contain faunas similar to those associated with, or occurring near to Atrypella in other areas (e.g. Verulamius, Favosites, Atrypa, Fardenia and Stegorhynchus).

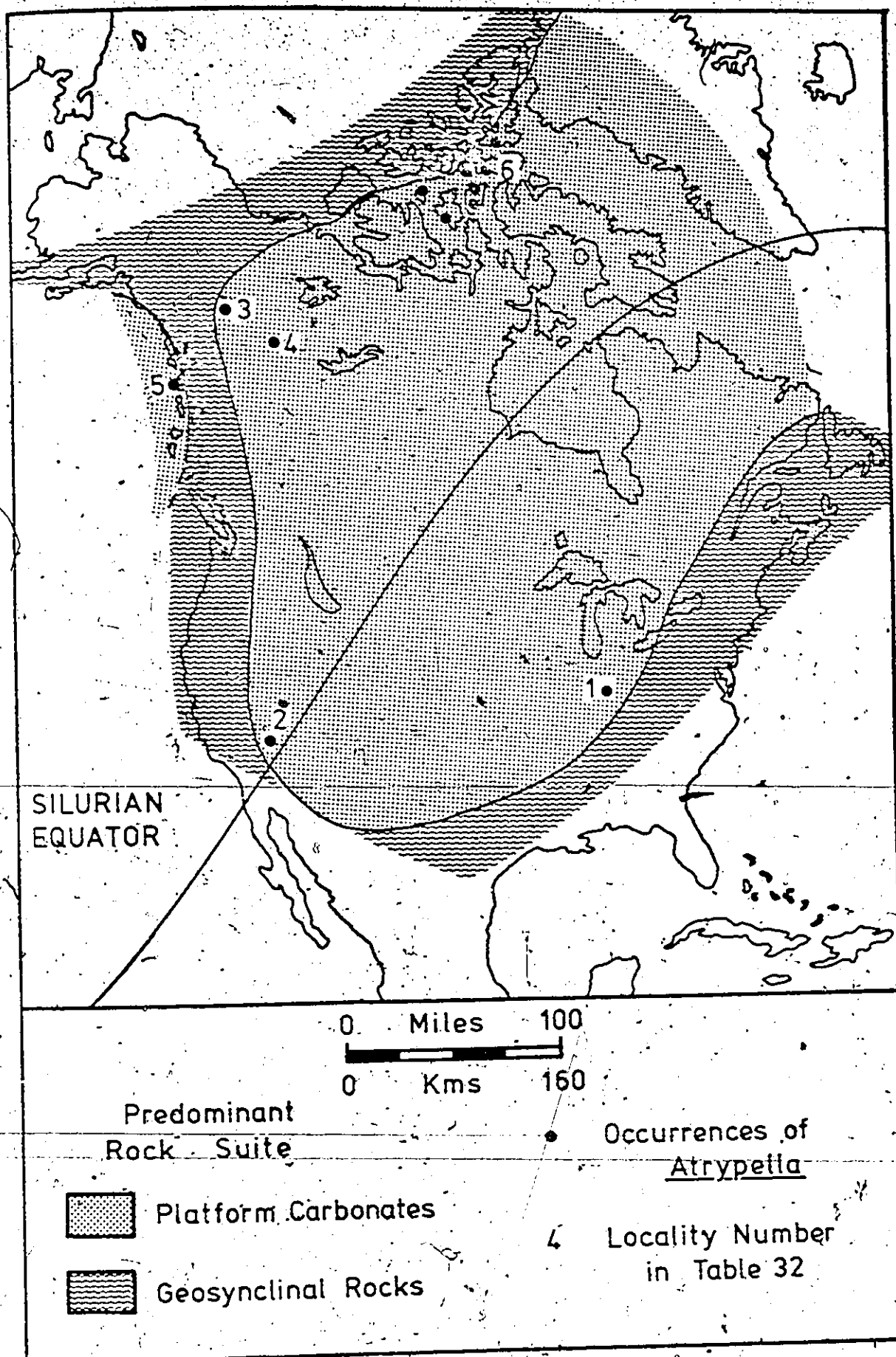
It is apparent that Atrypella had a distinct distribution during the Upper Silurian. The genus appears to be confined mainly to the Arctic Islands, northern Yukon and southeastern Alaska (Text-fig. 75). Berry and Boucot (1967) noted that one of the characteristic features of the Silurian period was the vast areal extent of platform areas compared to the limited expanse of the major geosynclines. This pattern certainly seems to have applied to the North American continent, since the geosynclines were narrow belts as shown in Text-figure 75.

The vast, shallow-water platform areas were the sites of considerable carbonate formation and provided ideal environments for shelly faunas. There must have been some barrier which restricted the migration to the more southerly portions of the North American platform. However, some connection probably did exist between the areas to allow Atrypella to become established locally, as for example A. shrocki in the Huntington Limestone of Indiana.

It is very difficult to detect the factors which controlled the distribution of Atrypella. It is locally very abundant and commonly

Text-figure 25

Geographic distribution of Atrypa in North America. For information on each occurrence see Table 32. Position of Silurian equator after Irving (1964).



occurs in beds which contain little or no other fauna. Thus, Atrypella possibly could survive in environments unsuitable for other animals.

One of the most distinctive features of the distribution of Atrypella is that it apparently inhabited areas bordering the geosynclinal zones. This is apparent both on a world-wide scale (Text-fig. 74) and on a continental scale (Text-fig. 75). The exceptions to this general pattern are the occurrences of Atrypella at localities 11, 12 and 13 on Text-figure 74. However, these localities were either in or near environments in which large quantities of argillaceous detrital sediment were being deposited. In many of the localities in the U.S.S.R. and northern Canada Atrypella occurs in rubbly argillaceous limestone or argillaceous limestone.

Consequently, it appears that Atrypella favoured environments in which fine-grained detrital material was being deposited. The exception to this is the occurrence of Atrypella in the Sevy Dolomite. The most likely explanation for the association of Atrypella with argillaceous sediment is that it was one of the few animals that could survive in such turbid environments. Its ability to survive in this type of environment and the lack of competition from other animals might explain its profusion in certain units. Atrypella occurs less commonly in micritic limestone with little or no detrital

material. There, it normally occurs with other faunas (e.g., corals and trilobites) and displays higher growth rates than the specimens from argillaceous limestone.

Stratigraphic distribution of Atrypella

Copper (1973) considered Atrypella to be Ludlovian to lower Gedinian in age, whereas Lissatrypa ranged from Ludlovian to Siegenian.

This appears to be in general agreement with the age of Atrypella recorded in the literature (Table 32). The exception to this is the

Wenlockian species Lissatrypa turjensis Khodalevich (1939, p. 69).

This species should probably be assigned to Atrypella and not Lissatrypa and if this is so, the range of Atrypella should be extended. The

majority of forms recorded by Nikiforova (1939) and Khodalevich (1939)

(Table 32- forms originally assigned to Lissatrypa but probably

synonyms of Atrypella) came from Ludlovian strata (Marginalis and

Striatus beds). Thorsteinsson (1958) considered that Atrypella was

confined to Upper Silurian strata in the Canadian Arctic.

Cherkesova (1973, p. 259) stated: "The best key marker

horizon traceable through the Arctic consists of argillaceous limestone

containing Atrypella phoca and Atrypella schell. The marker bed near

the Siluro-Devonian boundary is important because it is easily

recognizable everywhere." Thus, Cherkesova (1973) considered the genus

useful for correlation purposes and dating by virtue of its position near the Siluro-Devonian boundary.

In the western Soviet Arctic, deposits containing Atrypella phoca and Atrypella scheili were assigned to the Greben Horizon (Cherkesova, 1973). The Greben Horizon, which lies on the Khatanzeya Horizon, consists of approximately 200 metres of grey and greenish-grey nodular limestone. The age of the Greben Horizon is uncertain but it is probably of Ludlovian or Pridolian age (Cherkesova, 1973). Nikiforova (1970) considered it to be of Pridolian age. Cherkesova (1973) considered that the Khatanzeya and Greben Horizons are probably correlatable with the Read Bay Formation of the Canadian Arctic.

As it occurs in various strata in the Soviet and Canadian Arctic, Atrypella can probably be used for correlative purposes, providing the correlation is on a large scale (i.e. correlation of the Read Bay Formation with the Greben Horizon). However, because of the facies-controlled distribution of Atrypella, its absence should never be used for suggesting that the strata are not of Upper Silurian age.

The stratigraphic distribution of the various species of Atrypella is difficult to determine because of the confusion in past literature over the species framework of the genus. The problem is further accentuated by the restricted facies distribution of the

animals. Consequently, the following discussion on the stratigraphic and facies distribution of the various species of Atrypella is based on the Atrypella assemblages in the Read Bay Formation of northern Somerset Island.

It is difficult to assign an accurate age to many of the Atrypella assemblages cited in this study. However, in the sections studied no readily discernable differences in the stratigraphic distribution of A. foxi, A. phoca or A. shrocki could be detected, but a consistent distribution with respect to depositional environment was evident.

A section at Cape Admiral M'Clintock provides an excellent example of the common range of the three species of Atrypella. All the rocks that contain Atrypella at this locality are characterized by a relatively high content of detrital material. Consequently, the specimens found in the strata of this section are of the 'small' variety. In Text-figure 76, the suggested environmental conditions are based on sedimentological evidence. Despite the subjectivity of the estimates of abundance, there appears to be some correlation between the abundance of a particular species and the environmental conditions. Specimens were most abundant in subtidal environments. In rocks representing progressively shallower waters, the abundance of specimens decreased until few or no specimens were present in rocks of high intertidal or supratidal origin.

Text-figure 76

Distribution of Atrypella at Cape Admiral M'Clintock. The suggested environmental conditions are based on sedimentary evidence in the Read Bay Formation.

Abundance of Atrypella Occurrence of Atrypella Species Environmental Conditions



113

A. foxi

107

A. foxi

Subtidal

104

A. shrocki

Intertidal

66

A. phoca

Decreasing Water Depth

62

A. foxi

48

A. phoca

46

A. phoca

40

A. phoca

38

A. phoca

34

A. foxi

Subtidal

32

A. phoca

High Intertidal

30

A. foxi

22

A. foxi

10

A. phoca

Subtidal

Very Common

Common

Rare

10-Unit Number

Vertical Scale

6 metres
0

Sections at Garnier Bay confirm this basic pattern of distribution. In a stream section (section GB) at Garnier Bay, rocks that accumulated in high intertidal and supratidal conditions pass vertically into rocks of subtidal origin. Atrypella was found only in the subtidal rocks.

Both A. phoca and A. foxi occur at Pressure Point where the strata are of middle-upper Pridolian age. In this section the greater size of the shells appears to reflect the lesser amount of detrital material in the rock compared to the sections further east.

It is apparent from these sections that the distribution of A. phoca, A. foxi and A. shrocki was facies controlled and that the three species range throughout the stratigraphic interval studied.

The second conclusion agrees with Thorsteinsson (1958, p. 74) who stated: "The 'Atrypella phoca fauna' is not one of age as considered by many writers but apparently ranges from Wenlockian to upper Ludlovian and possibly even higher in its occurrence in series B of Ellesmere Island." However, the evidence presented previously contradicts Thorsteinsson's point 3 (1958, p. 74) that "The occurrence of Atrypella phoca itself is confined to Localities 3 and 39 in the lower part of member C of the Read Bay formation which very probably represent a restricted zone that is approximately middle Ludlovian in age."

At Pressure Point an assemblage of A. phoca occurs 110

below the boundary between the Read Bay and Peel Sound Formations and is thus of middle to upper Fridolian age. The discrepancy between Thorsteinsson's conclusion and the evidence presented in this chapter is probably attributable to the fact that Thorsteinsson regarded

A. phoca and A. scheii of Holtedahl (1914) as distinct species, whereas it appears now that scheii is merely a smaller variety of phoca as originally suggested by Holtedahl (1924).

CONCLUSIONS

Prior to this study the Paleozoic sedimentary basins of the southern Arctic islands were considered to be areas of carbonate sedimentation which displayed limited lateral and vertical variation. However, study of the Upper Silurian strata of northern Somerset Island clearly demonstrates that this is a greatly oversimplified view.

In the eastern part of the Jones-Lancaster Basin supratidal and intertidal rocks with sparse faunas predominate, as exemplified by the Leopold succession. In the western part of the basin subtidal and intertidal rocks constitute the Read Bay Formation. Fossil brachiopods, corals, trilobites and stromatoporoids are common in the subtidal rocks.

The dolomitic rocks of the Leopold succession are the result of early diagenetic dolomitization of micritic limestones. The localized occurrence of the dolomite suggests that dolomitization patterns in the Upper Silurian intertidal and supratidal areas were very complex; possibly related to the distribution of old channels. A high percentage of the subtidal rocks of the Read Bay Formation are rubbly limestones. Although these rocks were probably heterogeneous prior to diagenesis, compaction, recrystallization and dolomitization resulted in complex textures which prevent identification of original

sediment. The resistant lumps in the rubbly limestone may have been corals, stromatoporoids or calcareous sponges or may have been formed by bioturbation or algal action. The presence of substantial quantities of mottled dolomite and mottled limestone suggests that the Upper Silurian seawater of this area may have had an abnormal composition.

The postulated landmass to the north of Somerset Island was of critical importance since its elevation and position controlled the patterns of sedimentation in the adjacent basins. This low-lying land mass, which was probably formed of metamorphic and igneous rocks, supplied detrital quartz, plagioclase, microcline and muscovite to the adjacent basins where they accumulated along with the carbonate sediments. Of importance is the fact that this land mass effectively divided the Jones-Lancaster Basin thereby virtually isolating a shallow, possibly restricted, sea in the areas of Somerset and northwest Baffin Islands.

Dating of the measured sections is difficult because of the scarcity of diagnostic fossils. The limited faunal evidence suggests that the Leopold succession is the lateral equivalent of the Read Bay Formation. The faunas in most of the sections show more resemblance to Pridolian than to Ludlovian or Devonian faunas and therefore appear to correlate with members C and D of the type section on Cornwallis Island.

Detailed statistical analysis of Atrypella clearly

demonstrates its morphological variability during ontogeny and in relation to environment. Forms from micritic limestone with little detrital material are generally 'larger' and 'less convex' than those from argillaceous limestone. Such variations are analogous to variations in modern Lingula and Mytilus.

The Read Bay Formation on Somerset Island contains three distinct species of Atrypella, A. foxi n.sp., A. shrocki Cooper (1942) and A. phoca (Holtedahl). A. foxi includes specimens referred to A. scheii (Holtedahl)? by Kirk and Amsden (1952). A. shrocki Cooper includes A. carinata Johnson and Reso (1964) as a junior synonym. Study of the type material of A. prunum (Dalman) is required to determine whether it includes A. shrocki (and therefore A. carinata) as a junior synonym. A. phoca includes both Lissatrypa phoca Holtedahl and Lissatrypa scheii Holtedahl. Despite the wide use of the name A. scheii for specimens which generally have been regarded as an index fossil of the Read Bay Formation, it has been clearly demonstrated that A. scheii is a junior synonym of A. phoca. The form most commonly referred to A. scheii appears to be merely a morphological variant of the species A. phoca.

Atrypella is commonly used as an index fossil for Upper Silurian rocks of the Canadian Arctic and in particular for the

recognition of the Read Bay Formation. However, Atrypella should only be used as an index fossil providing consideration is given to the fact that Atrypella lived only in environments where normal marine conditions prevailed. Many Upper Silurian environments were unsuitable for Atrypella and thus many sections of this age contain no in situ Atrypella.

All three species appear to occur throughout the interval represented by the Read Bay exposures on northern Somerset Island. Indeed, the occurrence of Atrypella primarily reflects the occurrence of subtidal rocks rather than any particular stratigraphic level.

APPENDIX 1

The following formulae were used to calculate the statistical measures obtained from the computer program: 'Basic Statistics'

The following abbreviations are used in the formulae:

S_x = Standard deviation of variable x

$\bar{X}$ = Mean value of variable x

N = Sample size

R = Correlation coefficient

A_1 = Gradient of reduced major axis for sample 1

B_1 = Constant of reduced major axis for sample 1

SE_1 = Standard error of slope of reduced major axis for sample 1

X_0 = Biological significant value of x

$\bar{X}_1$ = Mean value of sample 1

Ad = Absolute dispersion of points about reduced major axis

Rd = Relative dispersion of points about reduced major axis

(1) Mean = Sum of x / N

(2) Standard deviation = $\sqrt{\sum (x - \bar{X})^2 / N - 1}$

(3) Variance = $(S_x)^2$

(4) Coefficient of variation (V) = $100(S_x) / \bar{X}$

(5) Standard error of the mean = $S_x / \sqrt{N}$

(6) Range = Maximum - Minimum

$$(7) \text{ Correlation coefficient} = (x - \bar{X})(y - \bar{Y}) / \sqrt{(x - \bar{X})^2(y - \bar{Y})^2}$$

$$(8) \text{ Significance of } R \quad t = \sqrt{R^2(N-2)/(1-R^2)}$$

$$(9) \text{ Gradient of reduced major axis} = S_y / S_x$$

$$(10) \text{ Constant of reduced major axis} = \bar{Y} - (\bar{X})(A_1)$$

$$(11) \text{ Standard error of slope of reduced major axis} = A_1 \sqrt{1 - (R)^2} / N$$

$$(12) \text{ Absolute dispersion of points around reduced major axis}$$

$$= 2\sqrt{(1-R)((S_x)^2 + (S_y)^2)}$$

$$(13) \text{ Relative dispersion of points around reduced major axis}$$

$$= 100(Ad) / \sqrt{(\bar{X})^2 + (\bar{Y})^2}$$

$$= 100 \sqrt{2(1-R)((S_x)^2 + (S_y)^2) / (\bar{X})^2 + (\bar{Y})^2}$$

For further information on the formulae above and a more detailed outline of procedures the reader is referred to the following papers:

Imbrie (1956) -- outlines procedures for reduced major axis and associated tests

Kermack and Haldane (1950) -- original paper outlining procedures for reduced major axis

For comparison of the reduced major axes as calculated by the computer program 'Comparison of reduced major axes' the following formulae were used:

$$(1) Z_1 = A_1 - A_2 / \sqrt{(SE_1)^2 + (SE_2)^2}$$

$$(2) \quad Z_2 = X_0(A_1 - A_2) + (B_1 - B_2) / \sqrt{(SE_1)^2(X_0 - X_1)^2 + (SE_2)^2(X_0 - X_2)^2}$$

if $X_0 = X_1$ then above formulae reduces to:

$$Z_2 = X_1(A_1 - A_2) + (B_1 - B_2) / \sqrt{(SE_2)^2(X_1 - X_2)^2}$$

For further information on the formulae above and a more detailed outline of procedures the reader is referred to Imbrie (1956) and Miller and Kahn (1962).

For the calculation of the Similarity Index between species groups, and subsequent Cluster analysis as done by the computer program 'Cluster Analysis', the following formulae were used:

(1) Similarity Index in Euclidean space (N-dimensional space)

$$D = \sqrt{\sum_{i=1}^n (x_{i1} - x_{i2})^2}$$

where i = Number of variables

$x_{1,1}$ = refers to first variable of group 1

$x_{2,1}$ = refers to first variable of group 2

Commonly it is more useful to express the similarity index on a scale of 0.0 to 1.0, thus the formula becomes:

$$(2) \quad d = 1 - \sqrt{\sum_{i=1}^n (x_{i1} - x_{i2})^2 / N}$$

Thus, if there are 2 samples and 3 variables:

$$d = 1 - \sqrt{((x_{1,1} - x_{1,2})^2 + (x_{2,1} - x_{2,2})^2 + (x_{3,1} - x_{3,2})^2) / N}$$

The formulae above will work only if x_1 is positive and less than 1.0

To make x_1 less than 1.0, the data must be normalized. The following formula normalizes the data and makes maximum use of the unit scale by setting the minimum value of x at 0.0 and the maximum value at 1.00.

$$\text{Normalized data} = (\text{True value} - \text{Minimum value}) / (\text{Maximum value} - \text{Minimum value})$$

Once the matrix of similarity indices is obtained, cluster analysis can be performed by the following procedures:

- (1) Matrix is searched for the highest similarity index
- (2) Data for two samples having highest similarity is combined
- (3) Combined data is averaged using a weighting factor of 1 for each sample (hence if new data comprises two samples, the weighting factor is 2)
- (4) One of the two samples involved is deleted from further consideration while the other is retained
- (5) New similarity index matrix is calculated using averaged sample obtained from consideration 3 and ignoring deleted sample
- (6) Procedure starting at stage 1 is repeated

For further information regarding the calculation of the Similarity Index and Cluster Analysis the reader is referred to the following papers:

Harbaugh and Bonham-Carter (1970) -- outline of theory regarding

N-dimensional space and formulae for obtaining index

Parks (1966) — Formulae for obtaining Similarity Index in N-dimensional space and description of method of cluster analysis.

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