Misc Reports

GEOLOGY - HUDSON BAY LOWLANDS

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Petroleum potential bright for Canada's Hudson Bay basin

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CANADA'S Hudson Bay region is estimated to have a potential of 9 billion bbl of oil and 55 trillion cu ft of gas.

While logistically difficult, exploration of the area has proceeded satisfactorily. Stratigraphy, structure, and other criteria are encouraging. The natural market for production lies south in the Great Lakes empire.

The setting. The Hudson Bay basin is a major subarctic sedimentary province of Canada.

Hudson Bay itself covers about ¼ million sq miles. The basin occupies about 300,000 sq miles, Fig. 1. The basin is separated on the north from Foxe basin by the Bell Arch which is part of a great arcuate positive feature extending from the Boothia Peninsula to Ungava Bay. As this arch crosses the north-south downwarp, it breaks up into a basin and range province with the upthrown blocks tilted southward. Some of the faults have throws of 5,000 to 10,000 ft. The Evans Strait subbasin belongs in this structural province.

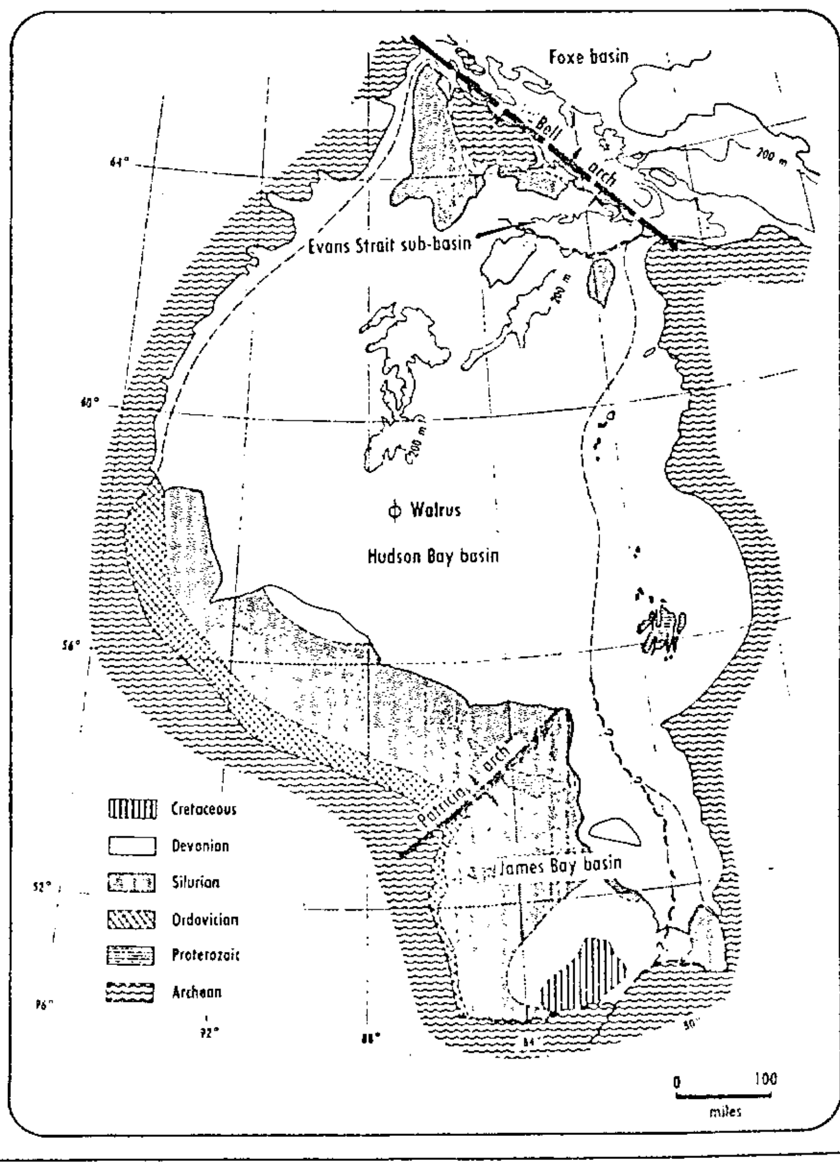
Hudson Bay basin is separated from James Bay basin by the broad Patricia arch which swings northeastward narrowing and plunging northward under the bay waters. Paleozoics in James Bay basin are about 4,000 ft thick. In the Evans Strait area they are estimated at more than 5,000 ft. The maximum onshore thickness along the Hudson Bay Coastal lowlands is about 4,000 ft, but on the basis of all available data, the Phanerozoic section in the center of the basin approaches 10,000 ft.

The section. The sedimentary section in the region is mostly Paleozoic, made up of Ordovician, Silurian, and Devonian sediments, all deposited in shallow, warm, and at times restricted seas, Fig. 2.

Reefal complexes with shaly or

Fig. 1

The Hudson Bay region



This is a condensed version of a paper presented at the Second Arctic Symposium in San Francisco, 1971.

evaporitic cap rocks are known in each of these three systems. Outcrops are rare, limited to the southwest flank and to the Northern Islands.

The 30,000-ft-thick (up to) Proterozoic sequence on the east side of the bay is important because it may have been the source of clean clastic material for the eastern part of the Hudson Bay basin during the Paleozoic.

There may have been continuous sedimentation from Proterozoic into Cambrian in the eastern part of the basin. There is, however, probably a major unconformity between the Cambrian and Ordovician. The Ordovician has porous biostromes alternating with evaporites in the southern part. The same section in the north has porous limestone and dolomite reefs, locally bituminous. In outcrop, these reefs are up to 50 ft high and ¾ mile long. In the off-reef facies, rich bituminous shales alternate with bituminous bioclastic carbonates.

The Silurian also represents a sedimentary cycle. It dominates the surface exposures around the bay and is transgressive on the Ordovician and locally on the Precambrian. The lower part of the Silurian is a massive carbonate. This massive carbonate contains occasional porous stromatoporoidal layers and is the platform for the very important Attawapiskat Reefs of Niagaran age. These reefs have porosity up to 30% and known thickness of 172 ft, at least as thick as all other Silurian reefs on the continent. The reef-off-reef distribution is the setting for a wide variety of possible traps.

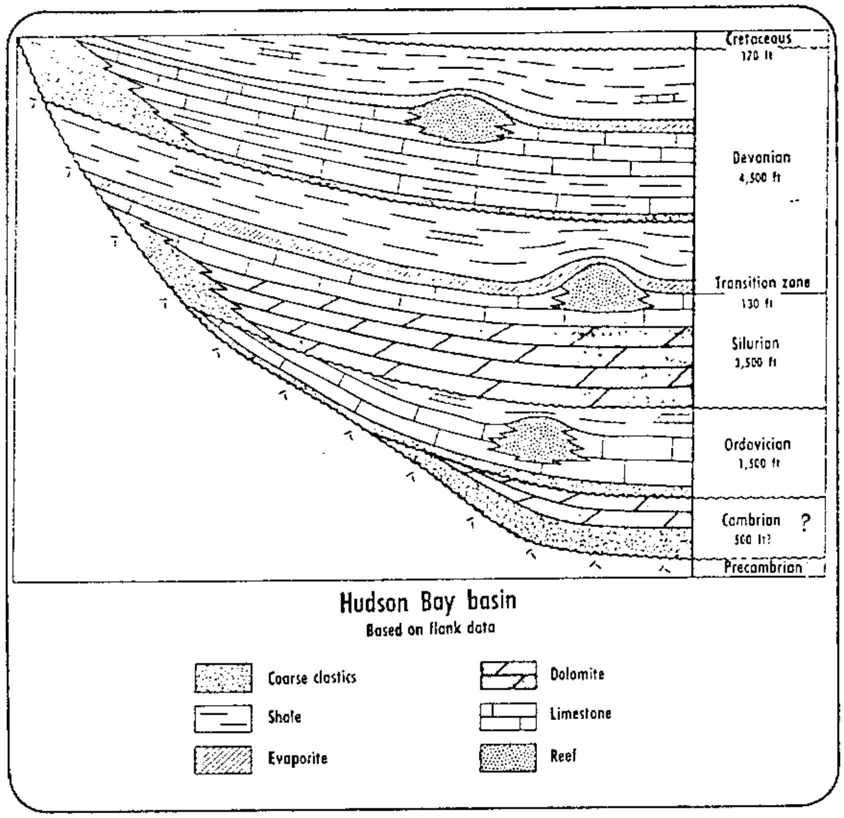
A Silurian-Devonian transition zone consists of compact primary dolomite and evaporite. Together with the overlying succession, it forms an excellent cap to the Niagaran reefs. There is possibly a major unconformity at the top of the transition zone.

Devonian strata occupy the center of the basin, up to 4,500 ft thick. They represent a third cycle, and perhaps several more cycles in the deeper part of the basin. Above the complicated reef, off-reef, and clastic assemblage of Devonian reservoir rocks lies a shale and evaporitic sequence which forms yet another cap rock. The Devonian reservoirs are main objectives.

For petroleum exploration, the basin resolves itself into several recognizable "plays."

Fig. 2

Sedimentary section



• The southwest lowland play. This is mostly aimed at Niagaran reefs. A group of ten companies, led by Aquitaine and Sogepet, has been working this play on the onshore and nearshore areas.

• Offshore area. This play has been led by a five-company group headed by Aquitaine and Atlantic Richfield. The targets include a series of reefs and clastic reservoirs in favorable structures. The Walrus well was drilled on a feature more than 40 miles long and 15 miles wide with closure at midsection in the order of 1,000 ft.

• Eastern side of bay. The play here is predicated on the possibility of a sharp structural termination to the basin perhaps by a major fault. This part of the basin may contain large clastic wedges.

• The basin and range. This province in the northern Island area is characterized by large normal faults. Abnormally thick reef development and the occurrence of repeated clastic wedges are probable. The association of rich bituminous shales adds to the favor of this area.

The two major seismic programs by the Aquitaine-ARCO group in 1968 and 1970 each shot 3,000 miles of refraction.

This is a wild place to drill. The Walrus well was drilled 150 miles offshore in 550 ft of water. Waves up to 30 ft high and 75-knot winds were recorded. Hole was suspended at near 3,900 ft, about halfway to its goal. Ice conditions are the main factor. In late winter it is 6 ft thick, but disappears completely in summer. There is no moving pack as in the Beaufort Sea and shipping may move to Churchill through Hudson Strait from July to Oct. 15.

The reserves. The Canadian Petroleum Association calculates 3 billion bbl and 17 trillion cu ft of gas for the James Bay-Hudson Bay region. The author has recalculated the reserves for Hudson Bay, taking into account, the lithology, the probable thickness of section, and the favorable structural conditions. A primary factor of 40,000 bbl/cu mile is used. A conservative estimate for the basin and Evans Strait is at least 8 billion bbl of oil and 50 trillion cu ft of gas. James Bay could have 1 billion bbl of oil and 5 trillion cu ft of gas.

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MARINE PENNSYLVANIAN ROCKS IN HUDSON BAY

B. A. TILLEMENT[1], G. PENIGUEL[2], J. P. GUILLEMIN[1]

ABSTRACT

The Narwhal O-58 well drilled in eastern Hudson Bay in 1974 revealed for the first time the existence of Pennsylvanian rocks on the Hudson Platform. The section consists of approximately 550 ft (170 m) of siltstone and shaly-silty sandstone, locally dolomitic, salt and some gypsum. The datation is based upon a spore and saccate pollen assemblage of 25 species characteristic of the Pennsylvanian Westphalian stage. A marine, nearshore, hot and humid environment of deposition is suggested by lithological and floral data, at least for the basal portion of the section.

SOMMAIRE

Le puits de Narwhal O-58 foré dans l'Est de la Baie d'Hudson en 1974 a révélé pour la première fois l'existence de dépôts Pennsylvaniens sur la plate-forme hudsonnienne. La coupe approximativement épaisse de 550 pieds (170 m), consiste en silts et grès argileux silteux, localement dolomitique et en sel. Du gypse en quantité mineure est également présent. La datation est basée sur un cortège de spores et de pollens comprenant 25 espèces. Ce cortège est caractéristique de l'étage Westphalien. Au moins pour la partie basale de la coupe, la flore et la lithologie suggèrent un milieu de dépôt marin à proximité d'une côte chaude et humide.

INTRODUCTION

The Hudson Bay Basin belongs to the Hudson Platform (Fig. 1), a large, slightly depressed, cratonic region extending from the eastern Arctic Islands in the north to the Great Lakes in the south. The various basins within this platform are, successively, from north to south:

Foxe Basin

Hudson Strait - Ungava Bay Basin

Hudson Bay Basin

James Bay or Moose River Basin

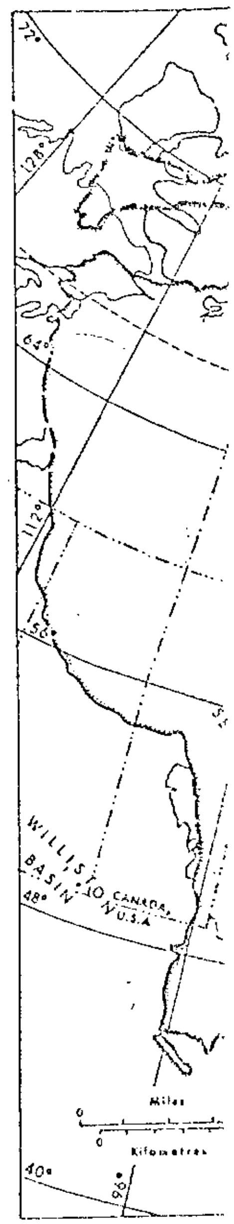
The largest of these basins is the Hudson Bay Basin with a surface area of approximately 300,000 sq mi (480,000 sq km). The total sedimentary section in the Hudson Bay Basin probably does not exceed 7,500 ft (2290 m), with this maximum thickness perhaps being reached in the

[1]Aquitaine Company of Canada Ltd., Calgary, Alberta.

[2]Société Nationale des Pétroles d'Aquitaine, Pau, France.

The authors wish to thank Aquitaine Company of Canada Ltd., Atlantic Richfield Canada Ltd., Elf Exploration and Production Canada Ltd., Petrofina Canada Ltd., Shell Canada Ltd. and Sogepet Ltd. for permission to publish the information contained in this paper.

The assistance of W. W. Taylor, Special Project Co-ordinator, Aquitaine Company of Canada Ltd., in critically reading the manuscript is gratefully acknowledged.



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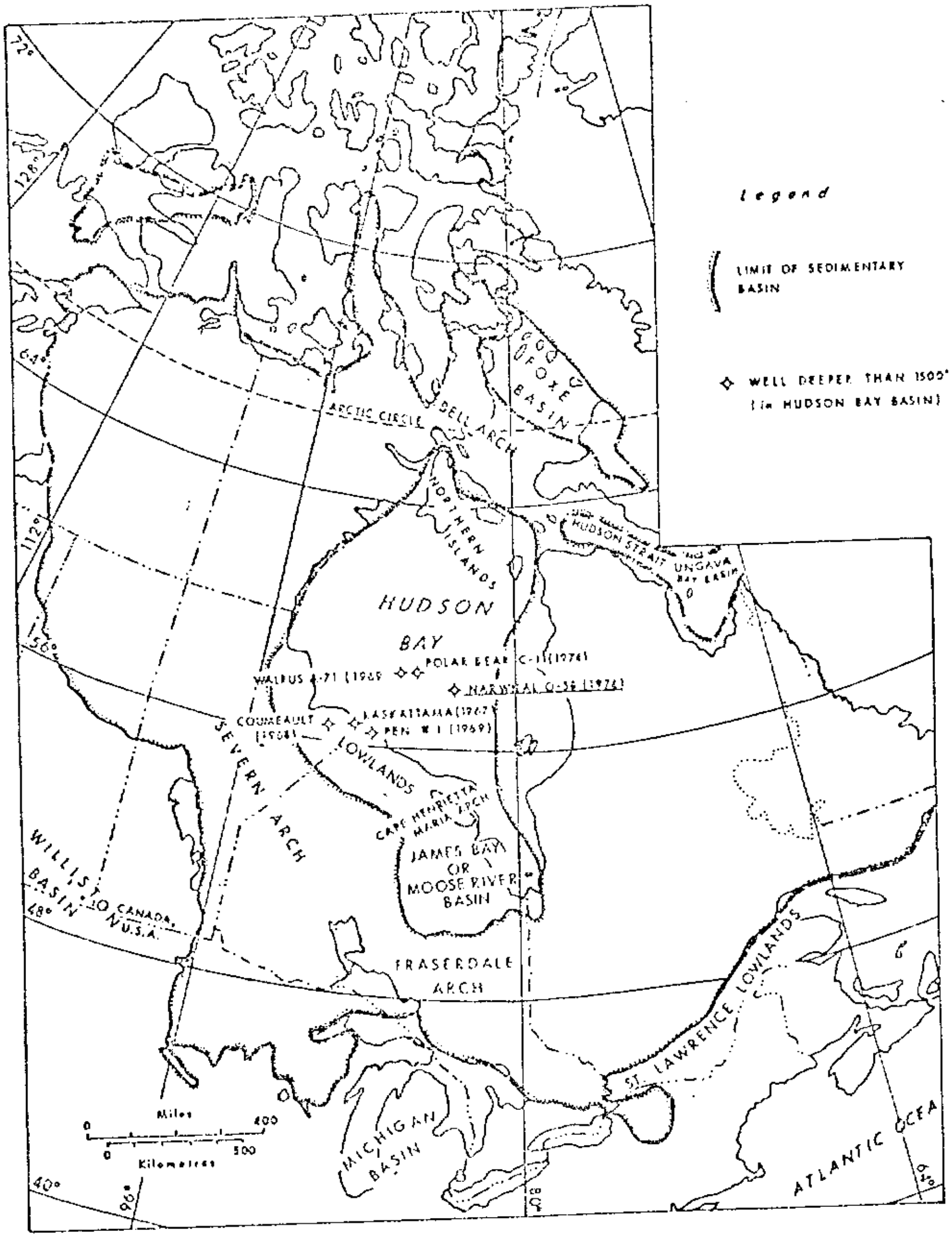

Fig. 1. Hudson Platform — location map.

middle of the Bay, as suggested by the interpretation of magnetic and seismic data.

Before 1974, the rocks in these areas were described as being exclusively of Ordovician to Devonian age and as consisting primarily of carbonate deposits.

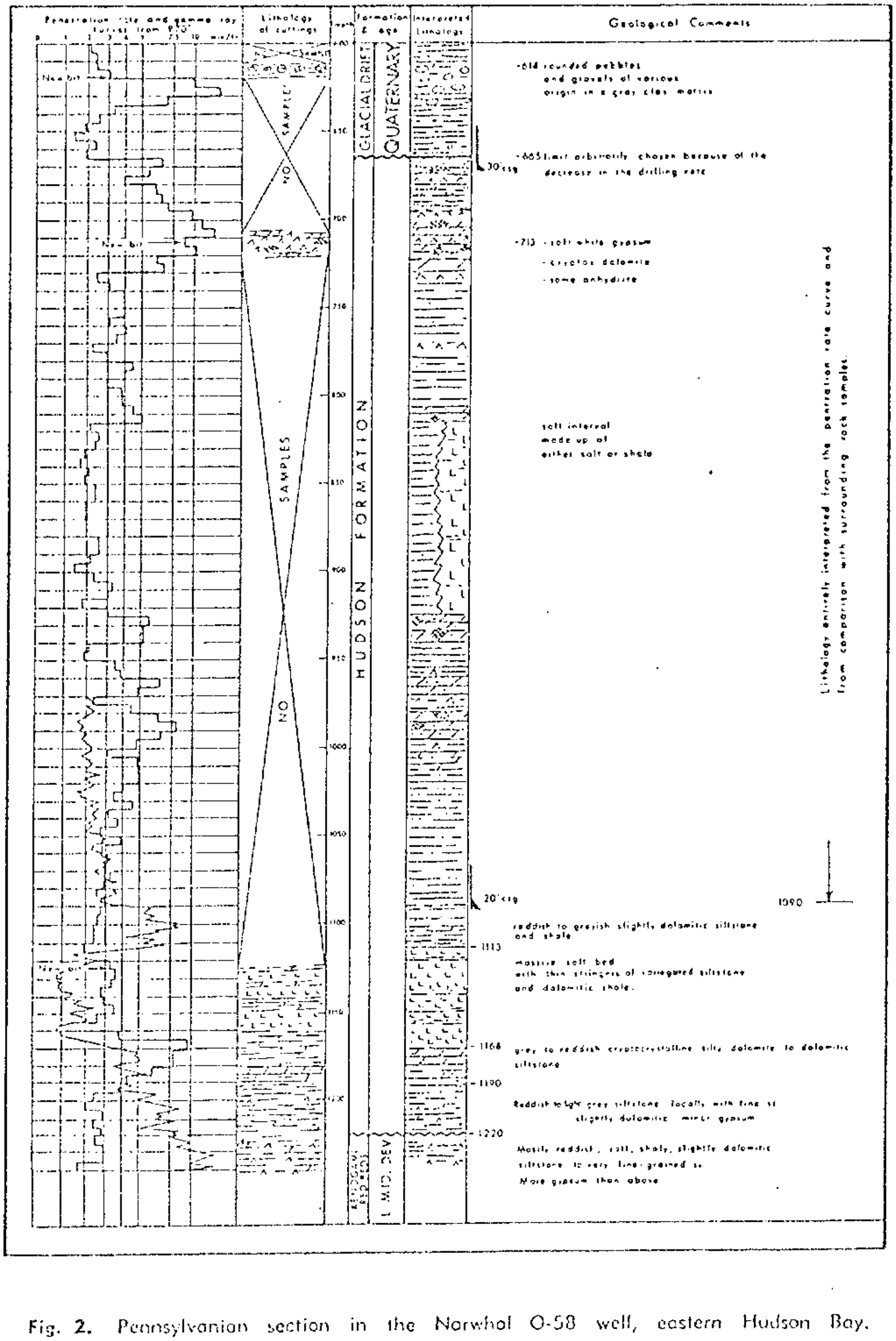

Fig. 2. Pennsylvanian section in the Narwhal O-58 well, eastern Hudson Bay.

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1168-1220'	(356-372 m)	R st
1220'	(372 m)	K

Geological information in the Hudson Bay Basin is particularly scarce, limited to isolated outcrops along rivers in the southwestern lowlands and on the northern islands (Southampton, Mansel and Coats). Subsurface information is also dramatically poor, since only four wells deeper than 1,500 ft (460 m) had been drilled in this immense area previous to 1974. Furthermore, only one offshore test, Walrus A-71 (1969), had been drilled in the greater portion of the Basin which underlies the waters of Hudson Bay, and even then it was terminated at 3926 ft (1197 m) without reaching basement, because of weather conditions.

In the summer of 1974, Aquitaine Company of Canada Ltd., acting as operator for a group of companies that included Atlantic Richfield Canada Ltd., Elf Exploration and Production Canada Ltd., Petrofina Canada Ltd., Shell Canada Ltd. and Sogepet Ltd., drilled two offshore tests to basement, Polar Bear C-11 and Narwhal O-58. The latter test has provided significant geological information concerning the eastern part of the basin which is entirely covered by the waters of Hudson Bay, revealing, for the first time, the presence of Pennsylvanian rocks in the Hudson Bay Basin.

Narwhal O-58 was located at 58°07'56" latitude and 84°08'17" longitude and bottomed at 4341 ft (1324 m) in Precambrian granite. The sea floor was at 580 ft (177 m) below KB, and all depths given in this paper are with reference to the Kelly Bushing.

Description of the Pennsylvanian Section

The Pennsylvanian Section at Narwhal (Fig. 2)

Unfortunately, as shown in Figure 2, no samples were obtained from a large part of the section assigned to the Pennsylvanian and informally referred to as the Hudson Formation. This lack is due to the fact that until the 20" casing was set, the upper part of the hole was drilled with sea water, which did not permit the return of any drill cuttings to the surface.

The lithological description for that part of the section for which there are no samples is based on the interpretation of the gamma-ray curve, the drilling-rate curve and the isolated recovery of some samples from the drilling bit at the well site by one of the authors.

The lithological reconstruction of the Pennsylvanian (Westphalian), Hudson Formation is as follows:

580- 665' (177-203 m)	Glacial drift.
665- 730' (203-223 m)	Interval of fairly hard rocks comprising cryptocrystalline dolomite, anhydrite, and some gypsum.
730-1090' (223-333 m)	Entirely unknown portion of the section, with essentially soft rocks. A salt or shale interval could be assumed from 815' to 925' (253 to 287 m).
1090-1113' (333-340 m)	Reddish to greyish, slightly dolomitic siltstone and shale intercalated with very fine sandstone.
1113-1168' (340-356 m)	Massive salt with thin stringers of variegated siltstone and dolomitic shale.
1168-1220' (356-372 m)	Reddish to grey, slightly dolomitic siltstone to fine sandstone.
1220' (372 m)	Kenogami red beds (Lower Middle Devonian).

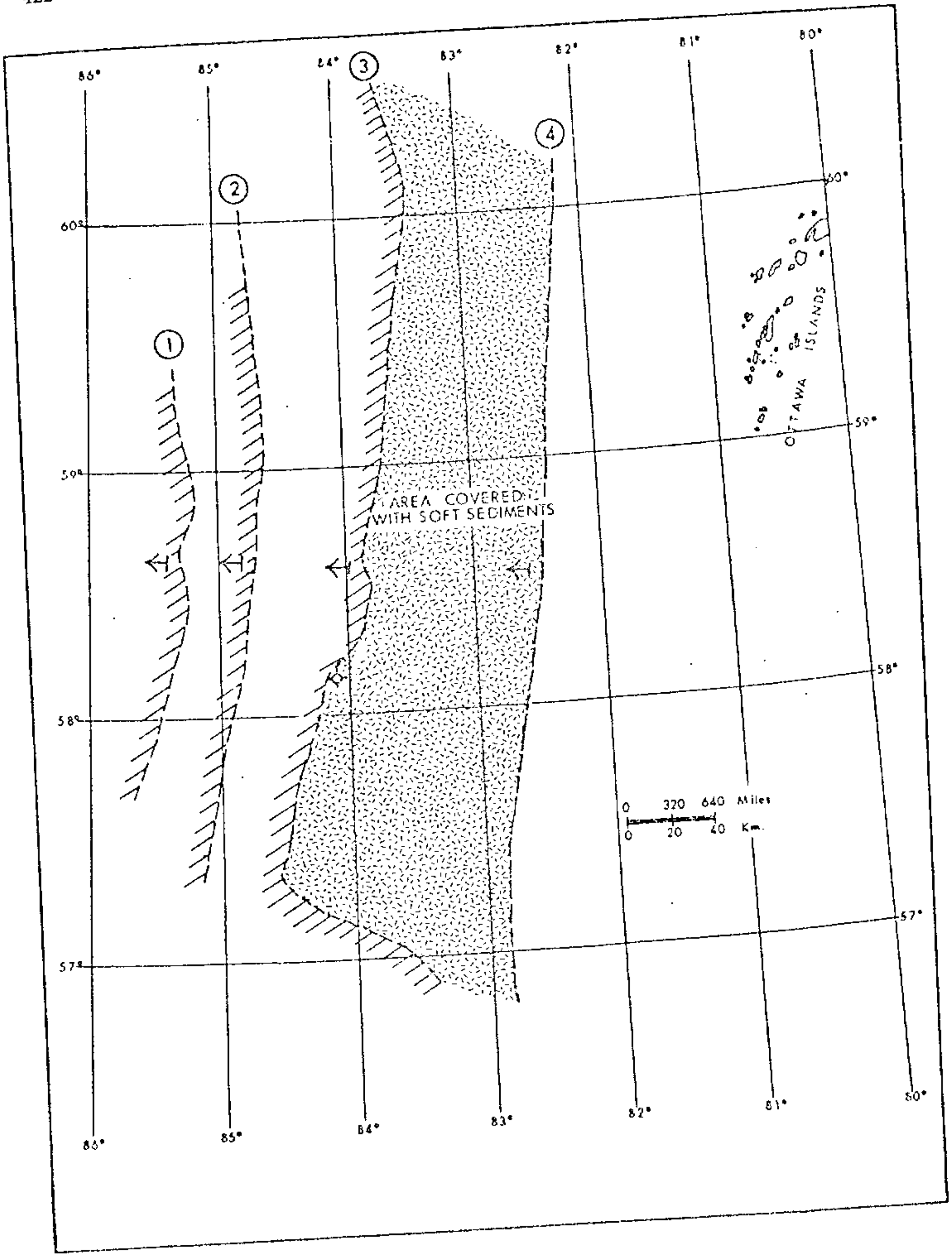

Fig. 3. Possible distribution of Pennsylvanian rocks as suggested by seismic data. ✧ = Narwhal 0-58.

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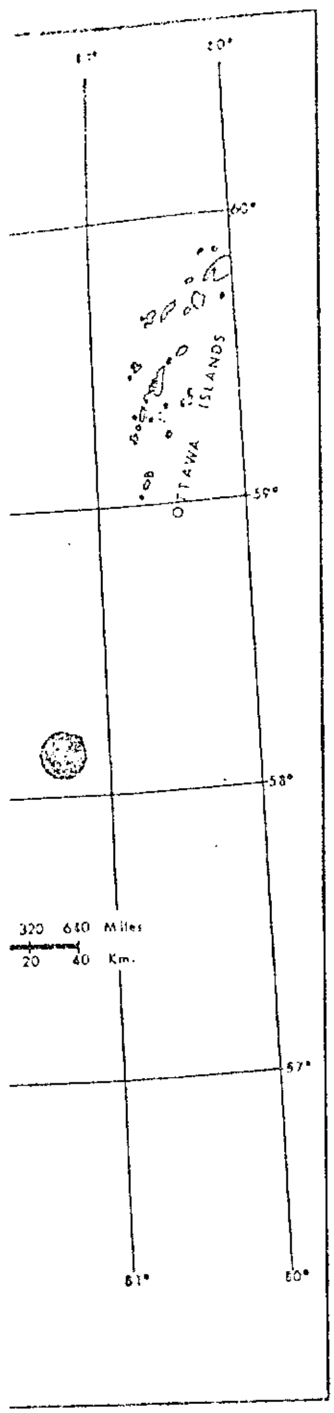

gested by seismic data.

Thickness and Distribution as Suggested by Seismic Data (Fig. 3)

Seismic velocity measurement obtained in the Narwhal well indicates a 10,500'/sec (3203 m/sec) interval velocity for the Pennsylvanian section. The underlying Kenogami red-beds section of Lower Middle Devonian age yields a slightly higher velocity: approximately 12,000'/sec (3660 m/sec).

A detailed survey of the area surrounding the Narwhal well was carried out by seismic refraction in 1971 and by seismic reflection in 1974. The results of both surveys do not provide a direct evaluation of the Pennsylvanian section. The lack of sufficient velocity contrast, as measured in the well, prevents a precise seismic distinction between the Pennsylvanian soft rocks and the underlying Devonian Kenogami red beds. Therefore, the indicated geographical distribution of Pennsylvanian rocks represents the extent of lower-velocity soft rocks within an environment of high-velocity Devonian and Silurian carbonates outcropping respectively to the west and to the east. West of the Narwhal well, the seismic refraction and the topography of the sea bottom yield good indications of the eastward extension of three major Upper Middle Devonian high-velocity (15,000'/sec, 4575 m/sec) hard-rock layers believed to overlie the Kenogami red beds.

The first layer (1) outcrops 45 mi (72 km) west of the well to form the mid-Bay shoal.

The second layer (2) emerges less spectacularly but unmistakably 25 mi (40 km) west of the well.

Unlike layers (1) and (2), which have been tested in the centre of the Bay as being high-velocity carbonates, the third high-velocity layer (3), indicated by the refraction and spreading eastward toward the well, was not controlled by drilling. The sea-bottom topography does not exhibit any anomaly corresponding to an outcrop, while layer (3) becomes very shallow and ceases to be recorded following a NNE-SSW trend which goes through the well location.

In the immediate vicinity of the above-mentioned NNE-SSW trend, a significantly lower 11,000'/sec (3355 m/sec) velocity refractor takes over as shallow event close to the sea bottom. It probably represents the top of a soft-rock layer. Its seismic velocity is comparable to that of the Pennsylvanian section measured in the well.

Consequently, the spreading of a low-velocity refractor may be correlated with the presence of a combination of Pennsylvanian and Devonian Kenogami red-beds soft rocks. An eastern limit of occurrence can be tentatively traced 75 mi (120 km) southeast of the Narwhal well where the Silurian high-velocity carbonates refractor (4) underlying the Kenogami shales is present at sea bottom. The lack of adequate seismic control in the area prevents an accurate delineation of the eastern limit (Fig. 4).

A 1,000 ft (305 m) thickness of Pennsylvanian section must be considered the maximum. It corresponds to the greatest thickness of soft material, including Quaternary, overlying the Silurian carbonates within the seismically controlled area of outcropping soft sediments.

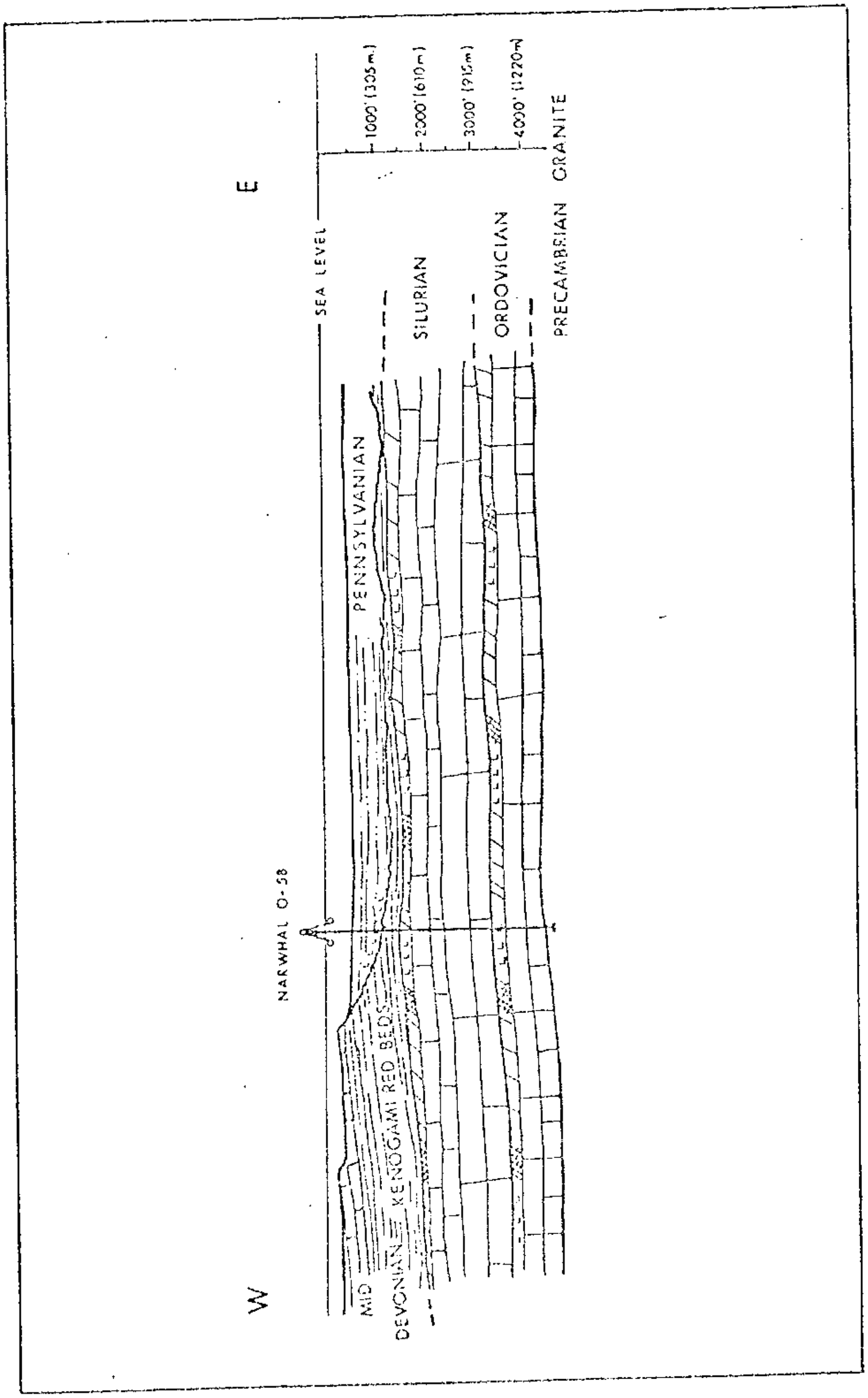

Fig. 4. Interpretive geological cross section in the Narwhal area (eastern Hudson Bay).

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Paleontology

Description of the Palynological Assemblage

Four samples were prepared for palynological examination from the intervals 1,130-1,160 ft (345-354 m), 1,135-1,160 ft (346-354 m) (two), 1,160-1,220 ft (354-372 m) respectively. The classic chemical maceration routine was followed on these argilocalcareous sediments: hydrochloric acid (cold), hydrofluoric, hydrochloric acid (hot). The weight of rock for each sample varied from 25 to 40 g, but the organic residue obtained was always quite small (only enough to mount a slide for each sample) except for the samples from the interval 1,135-1,160 ft (346-354 m) which was very fossiliferous. Only scarce specimens were obtained from the other intervals; nevertheless, they were sufficient to identify these intervals as being Carboniferous (possibly Westphalian).

The palynological association recognized here is composed only of spores and saccate pollens, with a relatively high frequency in the sample mentioned above. The state of preservation of this organic material is on the whole not very good, as evidenced by the photographs (*see* Pl. 1), and the fact that species identification of specimens is not always possible. The 25 main types of microorganisms identified are described and illustrated in the appendix. Several species that are related to assemblages of the same age have been omitted from the descriptions as their precise identification is less reliable.

The classification adopted is "grosso-modo" that proposed by A. H. V. Smith and M. A. Butterworth (1967). There are 18 genera and 25 species present, none of which are new. All specimens extracted from the samples can be compared closely with published illustrations, particularly from North America.

The assemblage consists of:
Leiotriletes sphaerotriangulus, *Leiotriletes adnatus*, *Punctatisporites staplini*, *Granulatisporites piroformis*, *Verrucosisporites morulatus*, *Lophotriletes microsaetosus*, *Anapiculatisporites spinosus*, *Raistrickia rubida*, *Convolutispora* sp., *Camptotriletes* sp., *Triquitrites bransonii*, *Tripartites incisotrilobus*, *Reticulatisporites mediareticulatus*, *Reticulatisporites polygonalis*, *Densosporites granulosus*, *Densosporites intermedius*, *Lycospora brevijuga*, *Lycospora* cf. *pseudoannulata*, *Cirratriradites annulatus*, *Endosporites* cf. *micromanifestus*, *Endosporites ornatus*, *Vestispora cancellata*, *Florinites antiquus*, *Florinites* cf. *diversiformis*, *Florinites* sp.

Relation to Other Assemblages in North America and Europe

Table I provides a rapid comparison of the following items:

The list of species recognized in the association observed.

The countries where these species have been described or illustrated.

The corresponding stratigraphic ranges.

Not surprisingly, the Narwhal assemblage has a close affinity with those found in Nova Scotia (Canada). The comparison of the palynological association discovered in Narwhal O-58 with those illustrated by M. S. Barss (1967) for the Carboniferous and Permian of Canada is

Fig. 4. Interpretive geological cross section in the Narwhal area (eastern Hudson Bay).

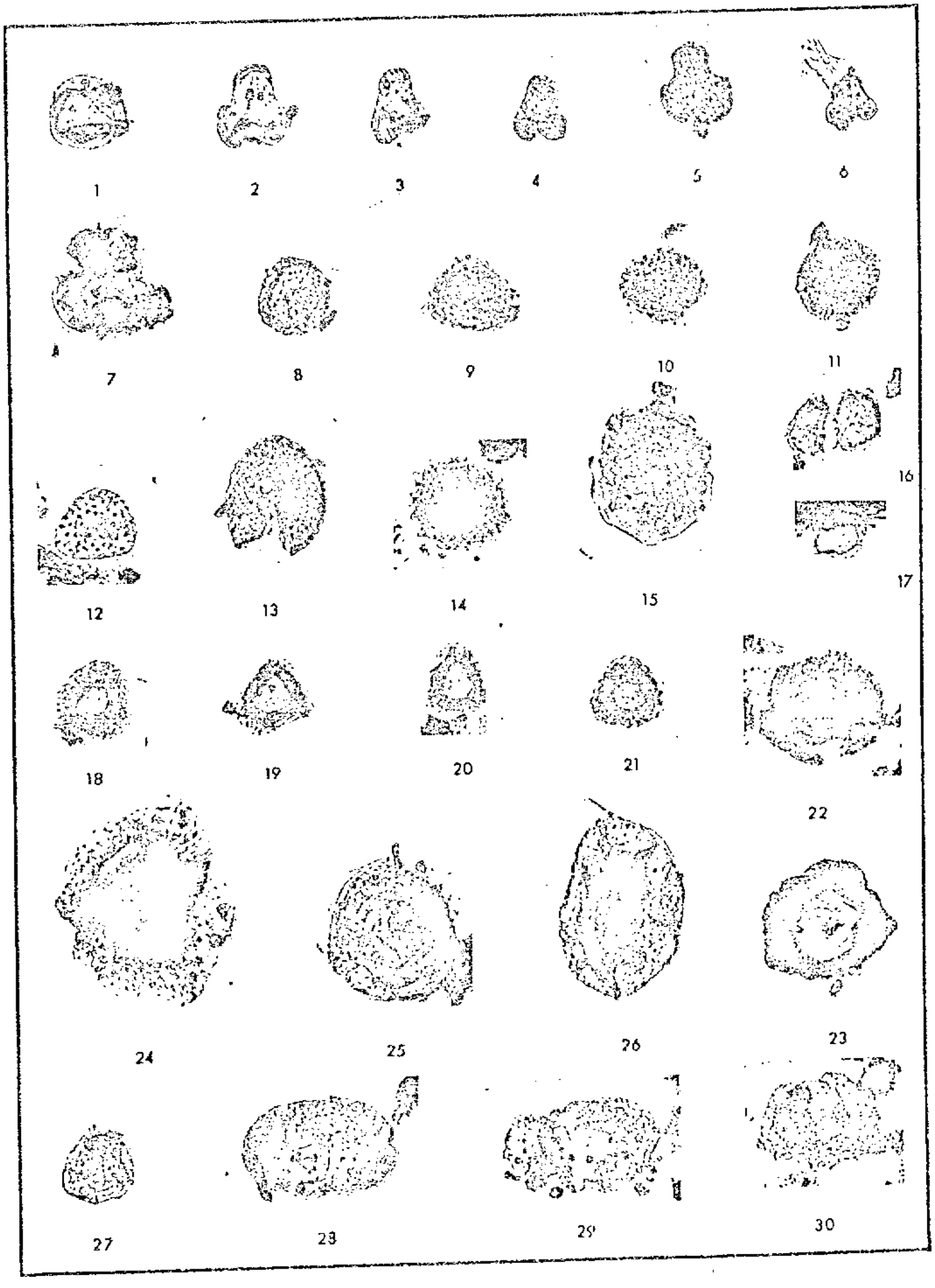

PLATE I

Fig. 1. Leiotriletes sp
Fig. 2. Leiotriletes a
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Fig. 12. Anapiculatis
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Fig. 14. Raistrickia
Fig. 15. Camptotrile
Fig. 16. Lycospora b
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Fig. 23. Reticulatisp
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Fig. 25. Vestispora
Fig. 26. Endosporites
Fig. 27. Endosporites
Fig. 28. Florinites a
Fig. 29. Florinites c
Fig. 30. Florinites sp

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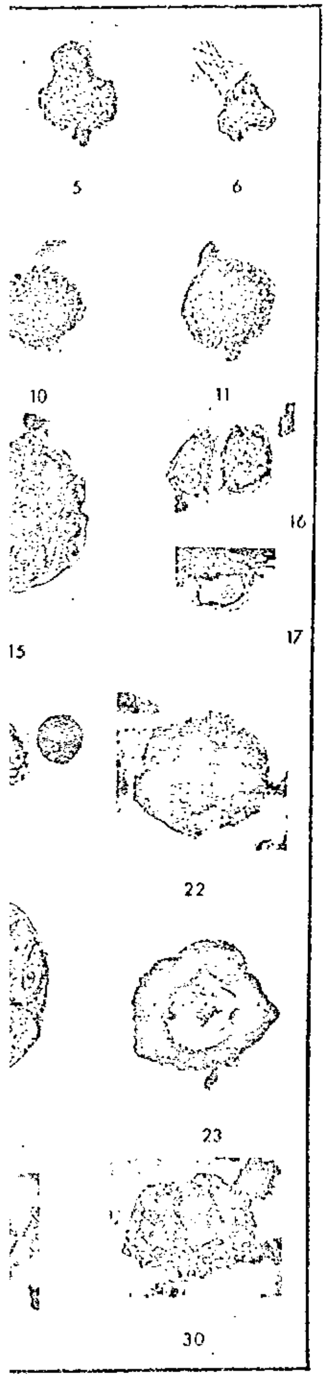

PLATE 1

(Magnification about 310x)

Fig. 1. *Leiotriletes sphaerotriangulus* (Loose) Potonié and Kremp, 1955.
Fig. 2. *Leiotriletes adnatus* (Kosanke) Potonié and Kremp, 1955.
Figs. 3, 4. *Granulatisporites piroformis* Loose, 1934.
Fig. 6. *Triquitrites bransonii* Wilson and Hoffmeister, 1956.
Fig. 5. *Lophotriletes microsaetosus* (Loose) Potonié and Kremp, 1955.
Fig. 7. *Tripartites incisotrilobus* var. *incisotrilobus* Butterworth and Williams, 1958.
Fig. 8. *Punctatisporites staplini* Peppers, 1964.
Figs. 9, 10, 11. *Verrucosisporites morulatus* (Knox) Potonié and Kremp, 1954.
Fig. 12. *Anapiculatisporites spinosus* (Kosanke) Potonié and Kremp, 1955.
Fig. 13. *Convolutispora* sp.
Fig. 14. *Raistrickia rubida* Kosanke, 1950.
Fig. 15. *Camptotriletes* sp.
Fig. 16. *Lycospora brevijuga* Kosanke, 1950.
Fig. 17. *Lycospora* cf. *pseudoannulata* Kosanke, 1950.
Fig. 18. *Densosporites intermedius* Butterworth and Williams, 1958.
Figs. 19, 20, 21. *Densosporites granulosus* Kosanke, 1950.
Fig. 22. *Reticulatisporites mediareticulatus* (Ibrahim) Potonié and Kremp, 1955.
Fig. 23. *Reticulatisporites polygonalis* (Ibrahim) Loose, 1934.
Fig. 24. *Cirratriradites annulatus* Kosanke and Brokaw, 1950.
Fig. 25. *Vestispora cancellata* (Dybova and Jachowicz) Wilson and Venkatachala, 1963b.
Fig. 26. *Endosporites ornatus* Wilson and Coe, 1940.
Fig. 27. *Endosporites* cf. *micromanifestus* Hacquebard, 1957.
Fig. 28. *Florinites antiquus* Schopf, Wilson and Bentall, 1944.
Fig. 29. *Florinites* cf. *diversiformis* Kosanke, 1950.
Fig. 30. *Florinites* sp.

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extremely strong and reliable, particularly for the Westphalian B-C. Indeed, certain species are identified by the author as Westphalian B, others in the Westphalian C, and others at the limit Westphalian B/C. Thus, there is little doubt that the Narwhal assemblage can be attributed to Westphalian B-C. A more precise age designation is not possible.

The Narwhal assemblage also has affinity with sections from Illinois, Oklahoma and Iowa in the United States, to which all references have ascribed Pennsylvanian age.

Two geographical regions in Europe, cited by several references, must be mentioned: Scotland and the Ruhr. In the latter region, the stratigraphic attribution of similar species is Westphalian B, which is consistent with the age assignment made above. In Scotland these species are generally observed stratigraphically lower: Lower Carboniferous, including Namurian. Only a few of these species are in this category; this may result from either a stratigraphic range greater than originally given,

Spores species recognized	Affinities countries	Stratigraphic ranges
Leiotriletes sphaerotriangulus	Germany: Ruhr Canada: Nova Scotia	Middle Westphalian B Westphalian B
Leiotriletes adnatus	Canada: Nova Scotia	Westphalian B-C
Punctatisporites staplini	USA: Illinois Canada: Nova Scotia	Pennsylvanian Westphalian C
Granulatisporites piroformis	Germany: Ruhr Canada: Nova Scotia	Middle Westphalian B Westphalian B-C
Verrucosisporites morulatus	Great Britain:Scotland	Lower Carboniferous
Lophotriletes microsaetosus	Germany: Ruhr Canada: Nova Scotia	Middle Westphalian B Westphalian B-C
Anapiculatisporites spinosus	USA: Illinois Canada: Nova Scotia	Pennsylvanian Westphalian B-C
Raistrickia rubida	USA: Illinois Canada: Nova Scotia	Pennsylvanian Westphalian C
Convolutispora sp.	Canada: Nova Scotia	Westphalian B
Camptotriletes sp.	Canada: Nova Scotia	Westphalian C
Triquitrites bransonii	USA: Oklahoma Canada: Nova Scotia	Pennsylvanian Westphalian C
Triquitrites incisotrilobus	Great Britain:Scotland	Lower Carboniferous
Reticulatisporites mediareticulatus	Germany: Ruhr Canada: Nova Scotia	Upper Westphalian B Westphalian B-C
Reticulatisporites polygonalis	Canada: Nova Scotia	Westphalian B-C
Densosporites granulosus	USA: Illinois	Pennsylvanian
Densosporites intermedius	Great Britain:Scotland Canada: Nova Scotia	Namurian Westphalian A
Lycospora brevijuga	USA: Illinois Canada: Nova Scotia	Pennsylvanian Westphalian B-C
Lycospora cf. pseudoannulata	USA: Illinois Canada: Nova Scotia	Pennsylvanian Westphalian B-C
Cirratriradites annulatus	USA: Illinois Canada: Nova Scotia	Pennsylvanian Westphalian D
Endosporites cf. micromanifestus	Canada: Nova Scotia	Namurian A
Endosporites ornatus	USA: Iowa Canada: Nova Scotia	Pennsylvanian Westphalian B-C
Vestispora cancellata	Poland: Silesy Canada: Nova Scotia	Westphalian B Westphalian B-C
Florinites antiquus	USA: Illinois Canada: Nova Scotia	Pennsylvanian Westphalian B-C
Florinites cf. diversiformis	USA: Illinois Canada: Nova Scotia	Pennsylvanian Westphalian A

Table 1. Relationship of Norwhal assemblage to other assemblages in North America and Europe.

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material in Westphalia

In summary, all esta
assemblage observed a
this section. Moreover

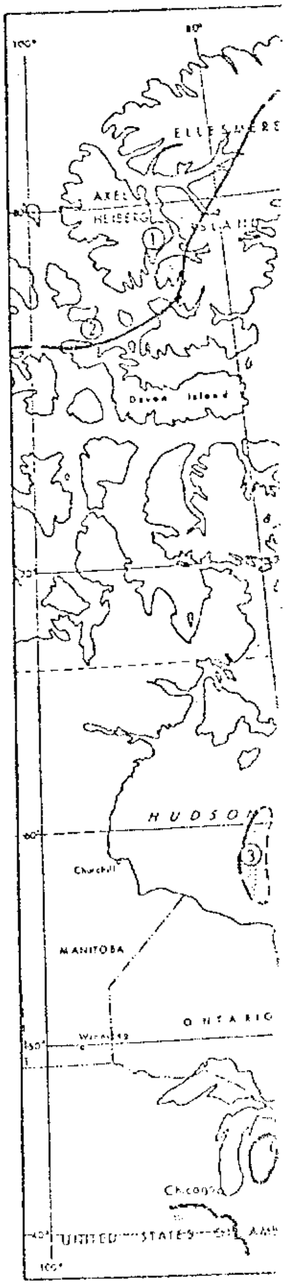

Fig. 5.

Stratigraphic ranges
Middle Westphalian B Westphalian B
Westphalian B-C
Pennsylvanian Westphalian C
Middle Westphalian B Westphalian B-C
Lower Carboniferous
Middle Westphalian B Westphalian B-C
Pennsylvanian Westphalian B-C
Pennsylvanian Westphalian C
Westphalian B
Westphalian C
Pennsylvanian Westphalian C
Lower Carboniferous
Upper Westphalian B Westphalian B-C
W[illegible]alian B-C
Pennsylvanian
Namurian Westphalian A
Pennsylvanian Westphalian B-C
Pennsylvanian Westphalian B-C
Pennsylvanian Westphalian D
Namurian A
Pennsylvanian Westphalian B-C
Westphalian B Westphalian B-C
Pennsylvanian Westphalian B-C
Pennsylvanian Westphalian A

mblages in North America

or, more probably, the occurrence of reworked lower Carboniferous material in Westphalian sediments.

In summary, all established relationships concerning the palynological assemblage observed at Narwhal indicate a "Westphalian B-C" age for this section. Moreover, the predominance of the genera *Densoporites,*

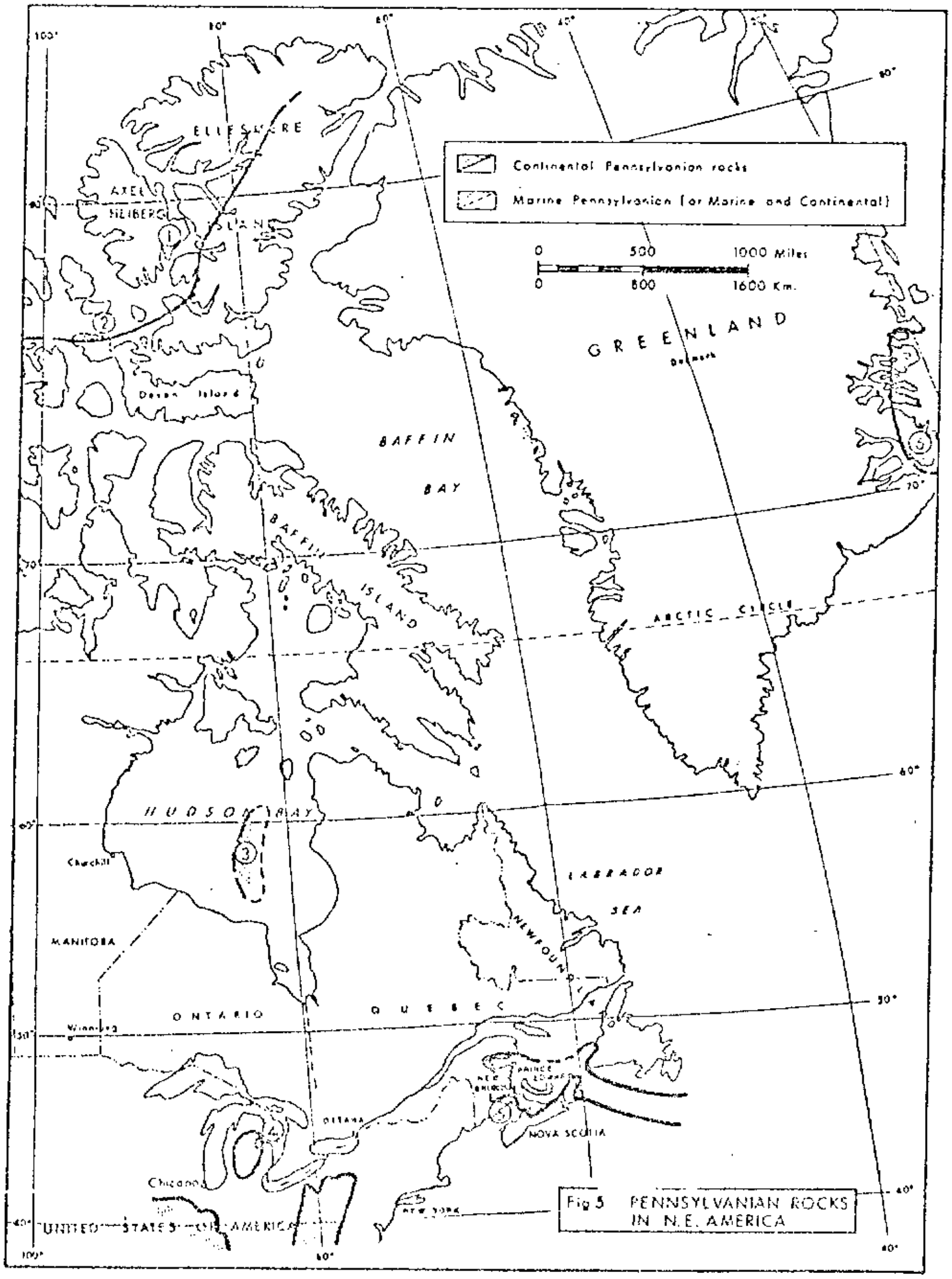

Fig. 5. Pennsylvanian rocks in northeastern America.

Reticulatisporites, *Florinites* and sometimes *Lycospora* is a well-known world-wide palynological phenomenon in this stage.

PALEOGEOGRAPHY

Proposed Paleogeographic Model of the Hudson Platform and Adjacent Areas (Figs. 5, 6)

The nearest known Pennsylvanian rocks to the section at Narwhal are in the centre of the Michigan Basin, 940 mi (1504 km) to the south. They have been divided into the Upper Pennsylvanian Woodville Formation with primarily a continental facies, consisting of sandstone, siltstone, sandy shale and coal, and the underlying marine Saginaw Formation, consisting of shale and limestone. The Saginaw Formation is assigned a Lower Pennsylvanian age by its marine fauna.

To the southeast, Pennsylvanian rocks, deposited entirely in a continental environment, occur in the Gulf of St. Lawrence, in part of the Mari-

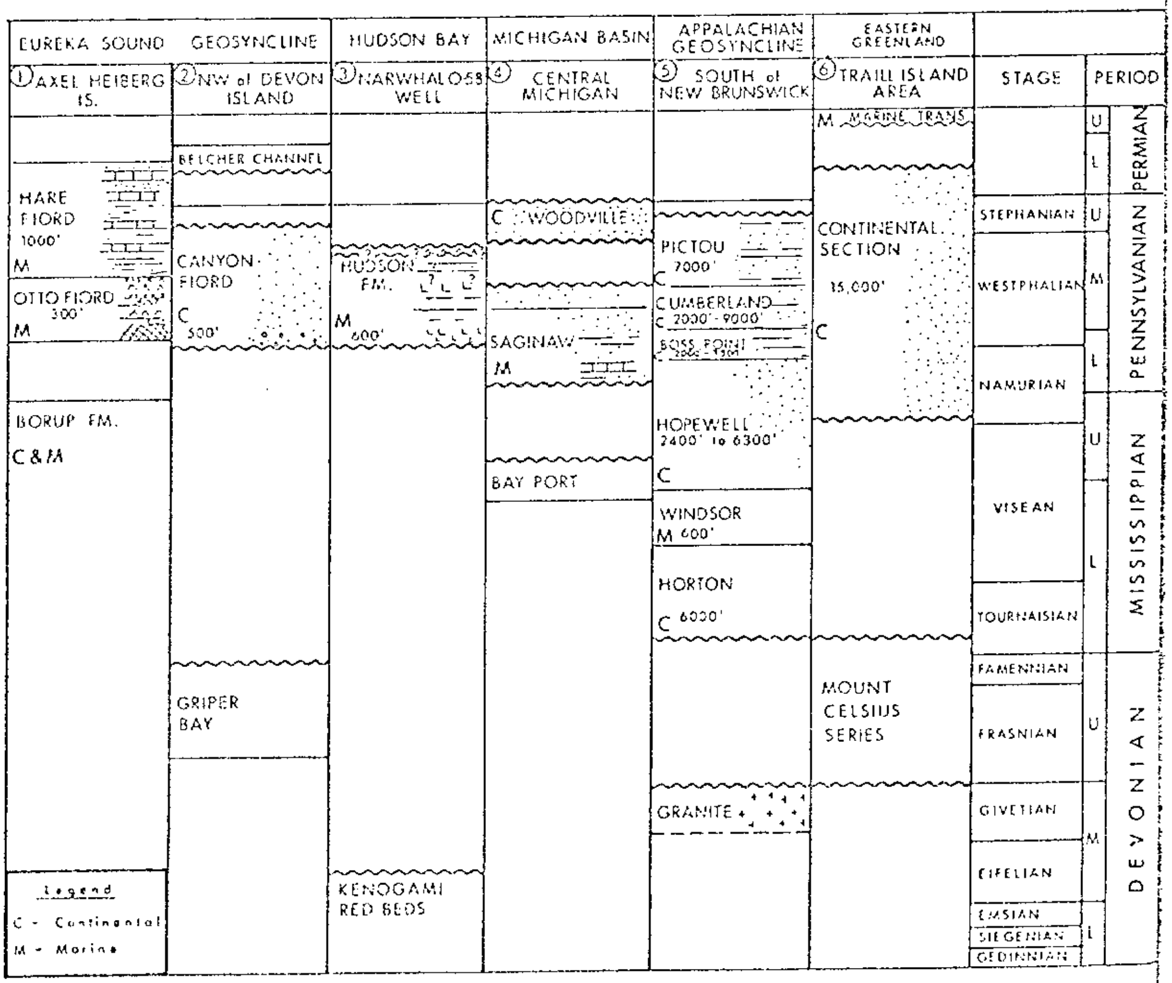

Fig. 6. Correlation chart of Pennsylvanian rocks in northeastern America.

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1975). They all con
in colour.

To the northeast,
Late Carboniferous
Greenland, a thick
continental clastic r
plants have been id

In the eastern Arc
on the eastern marg
consists of sulphates
ment (Wardlaw and
developed salt facie
with a plastic mater
passes laterally to
of the Canyon Fiord
limestone whose age

It is not easy to
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interconnected throu
to the close of the
Mississippian and E
whole landmass to t
removal of part of t

It is then possible
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Pennsylvanian trans
out by post-Devonian
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Formation, is found
basin.

Environment of De

The fact that the
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terrestrial material.
genus *Densoporites*
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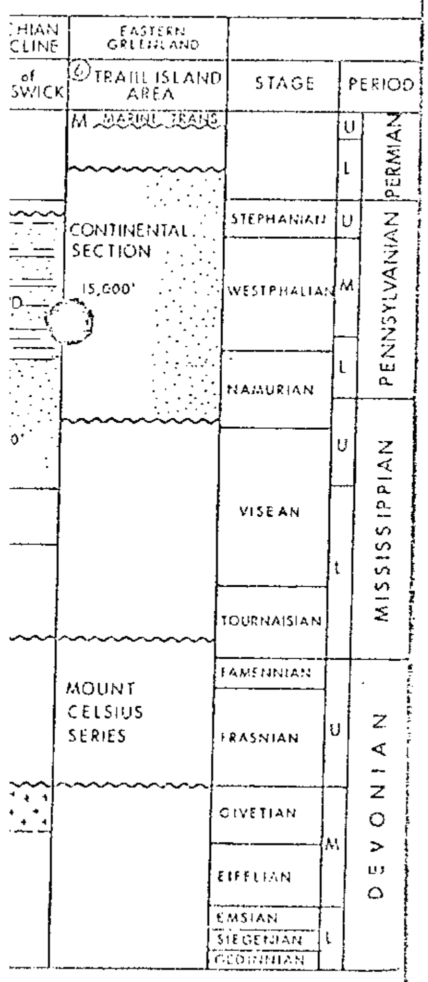
distances. However,
sociated with other
suggest that the envi
The nearby land cor
phytes) growing in
prevailing to the so
Illinois, Iowa and
distantly, in Scotlan
foundland.

:ospora is a well-known
ge.

Platform and

section at Narwhal are
.504 km) to the south.
vanian Woodville Form-
sting of sandstone, silt-
marine Saginaw Form-
Saginaw Formation is
ne fauna.

ed entirely in a contin-
nce, in part of the Mari-



ortheastern America.

times and on the Grand Banks south of Newfoundland (Howie and Barss, 1975). They all consist of siltstone, sandstone and shale, generally red in colour.

To the northeast, Davis Strait and the Labrador Sea seem devoid of Late Carboniferous deposits. However, on the northeastern shore of Greenland, a thick sequence comprising almost 15,000 ft (4,575 m) of continental clastic rocks occurs, in which Westphalian and Namurian plants have been identified.

In the eastern Arctic Islands, various Pennsylvanian rocks are exposed on the eastern margin of the Sverdrup Basin. The Otto Fiord Formation consists of sulphates and carbonates deposited in a submarine environment (Wardlaw and Christie, 1975). This formation is reported to have developed salt facies basinward, being halokinesis-prone when covered with a plastic material like shale or siltstone. The Otto Fiord Formation passes laterally to the southeast to the clastic continental sediments of the Canyon Fiord Formation, which are overlain by marine shale and limestone whose age straddles the Pennsylvanian-Permian boundary.

It is not easy to attempt any paleogeographic reconstruction with the help of only this new and limited element. However, it is generally considered that the Hudson Platform and the Michigan Basin were interconnected through the Fraserdale Arch from Emsian time onward to the close of the Devonian (Sanford and Norris, 1971). During the Mississippian and Early Pennsylvanian, the Fraserdale Arch and the whole landmass to the north were positive, with subsequent erosion and removal of part of the Devonian rocks.

It is then possible to suggest that both basins were again interconnected during the Pennsylvanian in the same manner as before, and that the Pennsylvanian transgression preferentially filled the depressions carved out by post-Devonian erosion, structural down-faulting or tectonic spreadings. Thus the Westphalian rocks occurring in eastern Hudson Bay comprise an erosional remnant, with similarity to the Michigan Basin, where the lateral equivalent of the marine Hudson Formation, the Saginaw Formation, is found as erosional remnants in the central parts of the basin.

Environment of Deposition and Climate

The fact that the palynological assemblage is composed only of spores and saccate pollens provides evidence of quite important supplies of terrestrial material. The presence of numerous specimens close to the genus *Densoporites* is considered to indicate a nearby terrestrial environment, as these heavy spores are generally transported only for short distances. However, the presence of 55 ft (17 m) of solid salt, not associated with other evaporites, and the boron content (320 ppm), strongly suggest that the environment of deposition was at least periodically marine. The nearby land consisted primarily of partially forested moors (*Lepidophytes*) growing in a hot and humid climate. The same conditions were prevailing to the south in a region corresponding now to the states of Illinois, Iowa and Oklahoma, to the east in Nova Scotia and, more distantly, in Scotland, which in its pre-drift position was closer to Newfoundland.

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Appendix

SYSTEMATIC PALEONTOLOGY

(G. Peniguel)

Anteturma SPORITES H. Potonié, 1893

Turma TRILETES
Subturma AONOTR
Infraturma LAEVIG
Genus LEIOT
Leiotriletes sph
1932: *Sporonites sp*
1934: *Laevigatispor*
Description: Smooth
to subcircular. Trilet
spore coat relatively
Locality: Narwhal
Geographic Distribu
Stratigraphic Distri
Leiotriletes
Description: Radial,
almost reach the term
Locality: Narwhal
Geographic Distrib.
Stratigraphic Distri
Genus PUNCTATIS
Pu
Description: Radial
trilete mark not alw
posed of grains, mo
regularly distributed.
Locality: Narwhal
Geographic Distrib
Stratigraphic Distri
Infraturma APICU
Subinfraturma GR
Genus GRANUL
Gr
1934: *Granulatisp*
1950: *Granulatisp*

Narwhal O-58 Well History.
's of Canada — illustrations
67-11.
'er Permian in central east
Arctic, v. 1: Univ. Toronto
small spore floras of coals
stone Group of the Lower
burgh, v. 53, pt. 2 (no. 17),
evaporites of the Carbonif-
rchipelago: Geology, May,
lichigan Basin: Am. Assoc.
he Horton Group (Missis-
no. 4, p. 301-324.
and sedimentation in the
leum Geologists, Mem. 4,
and their use in correla-
des Ruhrgebietes: Arb.
vanian cyclothems in the
n: Bull. Can. Petroleum
D. G., 1970, Geology of
eol. Rept. 1, p. 227.
s Ruhrkarbons: Palaeon-
rm: Can. Soc. Petroleum
annotated synopsis of
groups: Ill. State Geol.
he Arctic Archipelago:
rine origin in Pennsyl-
Bull. Can. Petroleum
unassigned plant micro-
lland Naturalist, v. 23,
the Crowelurg Coal:
pora Wilson and Hoff-

Turma TRILETES Reinsch emend. Dettmann, 1963

Subturma AONOTRILETES Luber emend. Dettmann, 1963

Infraturma LAEVIGATI Bennie and Kidston emend. R. Potonié, 1956

Genus LEIOTRILETES Naumova emend. R. Potonié, 1956

Leiotriletes sphaerotriangulus (Loose) Potonié and Kremp, 1955
(Plate 1, fig. 1)

1932: *Sporonites sphaerotriangulus* Loose *in* Pot., Ibr. and L., Pl. 18, fig. 45

1934: *Laevigatisporites sphaerotriangulus* Loose, p. 145

Description: Smooth to infrapunctate radial, trilete spore — outline triangular to subcircular. Trilete mark split, whoe rays reach almost to the equator — spore coat relatively thick.

Size: about 40 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: Germany, Ruhr — Canada, Nova Scotia.
Stratigraphic Distribution: Middle Westphalian B — Westphalian B.

Leiotriletes adnatus (Kosanke) Potonié and Kremp, 1955
(Plate 1, fig. 2)

Description: Radial, trilete, trilobate, smooth spore. Rays of the trilete mark almost reach the terminations of the lobes. Spore coat relatively thick.

Size: about 30-35 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: Canada, Nova Scotia.
Stratigraphic Distribution: Westphalian B-C.

Genus PUNCTATISPORITES Ibrahim emend. R. Potonié and Kremp, 1954

Punctatisporites staplini Peppers, 1964
(Plate 1, fig. 8)

Description: Radial trilete spore — outline circular to subcircular. Rays of trilete mark not always very clearly visible because of the ornamentation composed of grains, more or less regular in size (1 + o 2,5 μ of diameter), but regularly distributed. Spore coat quite thick.

Size: about 35-40 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: United States, Illinois — Canada, Nova Scotia.
Stratigraphic Distribution: Pennsylvanian — Westphalian C.

Infraturma APICULATI (Bennie and Kidston) R. Potonié, 1956

Subinfraturma GRANULATI Dybova and Jachowicz, 1957

Genus GRANULATISPORITES (Ibrahim) Potonié and Kremp, 1954

Granulatisporites piroformis Loose, 1934
(Plate 1, fig. 3, 4)

1934: *Granulatisporites piroformis* Loose, p. 147, Pl. 7, fig. 19

1950: *Granulatisporites granularis* Kosanke, p. 22, Pl. 3, fig. 2

Description: Trilobate, trilete, radial spore. Ornamentation composed of small grains more or less distributed. Spore coat thin. Tendency to thickening at the termination of each lobe. Trilete mark with narrow lips more or less visible whose rays almost reach the equator.
Size: about 28-30 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: Germany, Ruhr — Canada, Nova Scotia.
Stratigraphic Distribution: Middle Westphalian B — Westphalian B-C.

Subinfraturam VERRUCATI Dybova and Jachowicz, 1957

Genus VERRUCOSISPORITES Potonié and Kremp, 1954

Verrucosisporites morulatus (Knox) Potonié and Kremp, 1954
(Plate 1, figs. 9, 10, 11)

Description: Globular spore — outline circular to subcircular. Trilete mark not clearly visible because hidden by ornamentation composed of small verrucae very well rounded and closely pressed against each other, regularly distributed.
Size: about 40 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m)
Geographic Distribution: Great Britain, Scotland.
Stratigraphic Distribution: Lower Carboniferous.

Subinfraturma NODATI Dybova and Jachowicz, 1957

Genus LOPHOTRILETES (Naum.) Potonié and Kremp, 1954

Lophotriletes microsaetosus (Loose) Potonié and Kremp, 1955
(Plate 1, fig. 5)

1932: *Sporonites microsaetosus* Loose *in* Pot., Ibr. and Loose, p. 450, Pl. 18, fig. 40

1934: *Setosisporites microsaetosus* Loose, p. 148

Description: Outline of spore clearly trilobate with terminations of lobes flattened. Ornamentation composed of short spines, broad at the base and not very sharp at the top (coni), regularly distributed on the whole spore. Trilete mark clearly visible. Rays reach almost to the equator. Spore coat thick.
Size: about 30-35 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: Germany, Ruhr — Canada, Nova Scotia.
Stratigraphic Distribution: Middle Westphalian B — Westphalian B-C.

Genus ANAPICULATISPORITES (Potonié and Kremp) Smith and Butterworth, 1967

Anapiculatisporites spinosus (Kosanke) Potonié and Kremp, 1955
(Plate 1, fig. 12)

1950: *Granulatisporites spinosus* Kosanke, p. 22, Pl. 3, fig. 7

Description: Triangular, radial, trilete spore. Rays of tetrade mark extend almost to the equator; they are narrow and without lips. Spore coat of medium thickness and characterized by an ornamentation of more or less sharp spines. Spines less numerous in the interradial areas.
Size: about 35 μ

Locality: Narwhal 1 (1130-1160 ft; 345-354 m).
Geographic Distribution: United States, Illinois — Canada, Nova Scotia.
Stratigraphic Distribution: Pennsylvanian — Westphalian B-C.

Subinfraturma BACULATI Dybova and Jachowicz, 1957

Genus RAISTRICKIA Schopf, Wilson and Bentall emend. R. Potonié and Kremp, 1957

Raistrickia rubida Kosanke, 1950
(Plate 1, fig. 14)

Description: Outline of spore triangular to circular. Spore coat thick and very ornamented by irregular and compact compressed baculae which are mainly sharp. Trilete mark not very clearly visible.

Size: about 50 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: United States, Illinois — Canada, Nova Scotia.
Stratigraphic Distribution: Pennsylvanian — Westphalian C.

Infraturma MURORNATI R. Potonié and Kremp, 1954

Genus CONVOLUTISPORA Hoffmeister, Staplin and Malloy, 1955

Convolutispora sp.
(Plate 1, fig. 13)

Description: Trilete spore with open mark. Outline subcircular. Spore coat of medium thickness ornamented with verrucae, grains and convolutae showing a tendency to make a pseudoreticule.

Size: about 60 μ

Strong similarity to the spore figured Pl. 19, fig. 25 in Barss, 1967.
Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: Canada, Nova Scotia.
Stratigraphic Distribution: Westphalian B.

Genus CAMPTOTRILETES (Naumova) Potonié and Kremp, 1954

Camptotriletes sp.
(Plate 1, fig. 15)

Description: Heavy spore outline subcircular. Very strong ornamentation of irregular tubercles more or less jointed at the bottom, not very compressed. Trilete mark not seen.

Size: about 60-65 μ

Strong similarity to Pl. 25, fig. 23 in Barss, 1967.
Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: Canada, Nova Scotia.
Stratigraphic Distribution: Westphalian C.

Genus TRIQUITRITES (Wilson and Coe) Potonié and Kremp, 1954

Triquitrites bransonii Wilson and Hoffmeister, 1956
(Plate 1, fig. 5)

Description: Trilete spore. Outline triangular to trilobate with thickening at termination of each lobe. Rays of trilete mark extend almost to the equator. Spore coat thin in the interradial areas (out of the three thickenings).

Size: about 20-22 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: United States, Oklahoma — Canada, Nova Scotia.
Stratigraphic Distribution: Pennsylvanian — Wesphalian C.

Genus TRIPARTITES (Schemel) R. Potonié and Kremp, 1954

Tripartites incisotrilobus var. *incisotrilobus* Butterworth and Williams, 1958
(Plate 1, fig. 7)

Description: Triangular to trilobate, radial trilete spore with very prominent auriculae. Central part triangular, smooth, thick with a very visible trilete mark; however without broad lips. Auriculae very broad, prominent, highly crenulate. Interradial margins short, deeply incised.

Size: about 60 μ

Locality: Narwhal 1 (1130-1160 ft; 345-354 m).
Geographic Distribution: Great Britain, Scotland.
Stratigraphic Distribution: Lower Carboniferous.

Infraturma CINGULATI (Potonié and Kremp) Neves and Playford, 1961

Genus RETICULATISPORITES (Ibrahim) Neves, 1964

Reticulatisporites mediarcticulatus (Ibrahim) Potonié and Kremp, 1955
(Plate 1, fig. 22)

Description: Trilete spore. Polygonal outline. Spore coat of medium thickness. Trilete mark partly visible. Ornamentation composed of a reticule with more or less regular lacunae. Muri narrow and sharp at the top. Polygonal disposition of lacunae and muri. Lacunae surfaces larger than muri surfaces. Equatorial cingulum quite broad.

Size: about 60 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: Germany, Ruhr — Canada, Nova Scotia.
Stratigraphic Distribution: Westphalian B-C.

Reticulatisporites polygonalis (Ibrahim) Loose, 1934
(Plate 1, fig. 23)

Description: Radial, trilete spore. Outline subcircular, irregular. Spore coat thick. Ornamentation reticulate: broad and irregular lacunae. Broad and high muri with undulated outline. Lacunae surfaces equal muri surfaces. Irregular equatorial cingulum. Trilete mark poorly visible.

Size: about 60 μ

Strong similarity to Pl. 26, figs. 12, 13 in Barss, 1967.

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: Canada, Nova Scotia.
Stratigraphic Distribution: Westphalian B-C.

Suprasubturma LAMINATITRILETES Smith and Butterworth, 1967

Infraturma CINGULICAVATI Smith and Butterworth, 1967

Genus DENSOSPORITES (Berry) Butterworth, Jansonius, Smith and Staplin, 1964

Densosporites granulosus Kosanke, 1950
(Plate 1, figs. 19, 20, 21)

Description: Radial, trilete spore. Outline subcircular to subtriangular. Opaque equatorial area broad and thick, equatorial flange very thin and narrow. Ornamentation composed of grains and spine-like projections on the whole coat; however, the density of ornamentation is higher on the equatorial thickening and flange. Trilete mark poorly visible, without lips, not prominent.

Size: about 35-40 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: United States, Illinois.
Stratigraphic Distribution: Pennsylvanian.

Densosporites intermedius Butterworth and Williams, 1958
(Plate 1, fig. 18)

Description: Radial, trilete spore. Outline subtriangular to subcircular. Very broad and thick equatorial cingulum. Ornamentation not very developed, composed of small spines. Equatorial flange very narrow. Centre of spore not or very little ornamented. Trilete mark badly visible, without lips, not prominent.
Size: about 40 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: Great Britain, Scotland — Canada, Nova Scotia.
Stratigraphic Distribution: Namurian — Westphalian A.

Genus LYCOSPORA (Schopf, Wilson and Bentall) Potonié and Kremp 1954

Lycospora brevijuga Kosanke, 1950
(Plate 1, fig. 16)

Description: Small, radial, trilete spore. Outline subtriangular to subcircular. Trilete mark clearly visible whose rays extend to the equator; lips slightly developed. Equatorial ridge narrow and small, but clearly delimited. Punctate ornamentation rather irregular (about 2 microns thick). Apical papillae present.
Size: about 30 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: United States, Illinois — Canada, Nova Scotia.
Stratigraphic Distribution: Pennsylvanian — Westphalian B-C.

Lycospora cf. *pseudoannulata* Kosanke, 1950
(Plate 1, fig. 17)

Description: Radial, trilete spore. Outline subtriangular to subcircular. Equatorial ridge and flange relatively well expanded. Rays of trilete mark poorly visible on the specimens observed. Granulose ornamentation more developed on centre of spore.
Size: about 30 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: United States, Illinois — Canada, Nova Scotia.
Stratigraphic Distribution: Pennsylvanian — Westphalian B-C.

Genus CIRRATRIRADITES Wilson and Coe, 1940

Cirratriradites annulatus Kosanke and Brokow, 1950
(Plate 1, fig. 14)

Description: Trilete, radial spore roundly triangular with a very well defined equatorial flange. Spore coat thick with an ornamentation of punctate to granulate type (variations in sizes). Flanges very clearly radially striate (with grana). Trilete mark distinct and extends to the periphery of flange. Thin, then thick zone (annulatus) at the limit between central body and flange. Similarity to Pl. 26, fig. 17 in Barss, 1967.
Size: central body about 50 μ
total spore about 90 μ

Locality: Narwhal 1 (1130-1160 ft; 345-354 m).
Geographic Distribution: United States, Illinois — Canada, Nova Scotia.
Stratigraphic Distribution: Pennsylvanian, Carbondale Group, Westphalian D.

Suprasubturma PSEUDOSACCITITRILETES Richardson, 1965

Infraturma MONOPSEUDOSACCITI Smith and Butterworth, 1967

Genus ENDOSPORITES Wilson and Coe, 1940

Endosporites cf. *micromanifestus* Hacquebard, 1957
(Plate 1, fig. 27)

Description: Zonal trilete spore. Outline subtriangular to subcircular. Central body with same shape. Bladder thin, strongly folded, finely intragranulose to almost smooth. Trilete mark clearly observed, with lips or folds, whose rays extend to or almost to the equator. Great similarity to Pl. 13, fig 28 in Barss, 1967.
Size: central body about 25 μ
total spore about 35 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: Canada, Nova Scotia.
Stratigraphic Distribution: Namurian A.

Endosporites ornatus Wilson and Coe, 1940
(Plate 1, fig. 26)

Description: Trilete, zonal spore. Globular to subglobular form. Central body more or less spherical, relatively small. Bladder thin, granulose with folds. Trilete mark very evident whose rays may extend almost to the equator.
Size: central body about 40 μ
total spore about 90 μ
Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: United States, Iowa — Canada, Nova Scotia.
Stratigraphic Distribution: Pennsylvanian, Des Moines series — Westphalian B-C.

Turma HILATES Dettmann, 1963

Suprasubturma CAVATIHILATES Smith and Butterworth, 1967

Subturma AZONOCAVATIHILATES Smith and Butterworth, 1967

Infraturma EPITYGMATI Spode

Genus VESTISPORA (Wilson and Hoffmeister) Wilson and Venkatachala, 1963

Vestispora cancellata (Dybova and Jachowicz) Wilson and Venkatachala, 1963
(Plate 1, fig. 25)

1957: *Cancellatisporites cancellatus* Dybova and Jachowicz

Description: Spore shape spherical to subspherical. Central body globular, large, not or only slightly ornamented. Bladder thin and closed with the central body. Presence of an operculum. Ornamentation of outer wall composed of pseudoreticule and folds more or less elongated, concentric folds, not numerous, not very prominent.
Size: inner body about 64 μ
total spore about 70 μ
Locality: Narwhal 1 (1135-1160 ft; 346-354 m).
Geographic Distribution: Poland, Silesia — Canada, Nova Scotia.
Stratigraphic Distribution: Westphalian B-C.

Anteturma POLLEN
Turma SACCITES
Subturma MONOSA
Infraturma ARADI
Genus FL
Florinites
Description: Monosa body thin, smooth to or less visible. Contac
Locality: Narwhal
Geographic Distrib
Stratigraphic Distri
Flor
Description: Monos outline including sacc laevigate. Bladder la
Remark: The spec Kosanke, 1950 (Pl. 1
Locality: Narwhal
Geographic Distrib
Stratigraphic Distri
Description: Monos cal outline, includin evident. Bladder inf the limit of central
Locality: Narwhal

Anteturma POLLENITES Potonié, 1931

Turma SACCITES Erdtman, 1947

Subturma MONOSACCITES (Chitaley) Potonié and Kremp, 1954

Infraturma ARADIATES Bharadwaj, 1957

Genus FLORINITES Schopf, Wilson and Bentall, 1944

Florinites antiquus Schopf, Wilson and Bentall, 1944
(Plate 1, fig. 28)

Description: Monosaccate Pollenites. Elliptical outline. Bilateral aspect. Central body thin, smooth to granulose. Bladder infrareticulate. Dehiscence mark more or less visible. Contact area between central body and bladder elliptical or oval.

Size: central body about 30 μ
total length about 70 μ
total width about 45 μ

Locality: Narwhal 1 (1135-1160 ft; 346-354 m).

Geographic Distribution: United States, Illinois — Canada, Nova Scotia.

Stratigraphic Distribution: Pennsylvanian — Westphalian B-C.

Florinites cf. *diversiformis* Kosanke, 1950
(Plate 1, fig. 29)

Description: Monosaccate Pollenites with a vestigial tetrad mark, an elliptical outline including saccus, and a bilateral aspect. Central body more or less visible, laevigate. Bladder laevigate, but internally reticulate.

Size: central body about 35 μ
total length about 75 μ
total width about 40 μ

Remark: The specimen encountered is smaller than the types figured by Kosanke, 1950 (Pl. 12, fig. 5) and Barss, 1967 (Pl. 17, fig. 7).

Locality: Narwhal 1 (1130-1160 ft; 345-354 m).

Geographic Distribution: United States, Illinois — Canada, Nova Scotia.

Stratigraphic Distribution: Pennsylvanian — Westphalian A.

Florinites sp.
(Plate 1, fig. 30)

Description: Monosaccate Pollenites with a vestigial tetrad mark, an elliptical outline, including saccus, and a bilateral aspect. Central body not clearly evident. Bladder infrareticulate and clearly bilateral with fold on each side at the limit of central body-bladder.

Size: central body about 36 μ
total length about 56 μ
total width about 40 μ

Locality: Narwhal 1 (1130-1160 ft; 345-354 m).

BEDFORD INSTITUTE OF OCEANOGRAPHY

DARTMOUTH, N.S. - CANADA

BEDROCK GEOLOGY BENEATH HUDSON BAY AS INTERPRETED FROM SUBMARINE PHYSIOGRAPHY

by

R. J. LESLIE and B. R. PELLETIER

(Geological Survey of Canada)

REPORT B.I.O. 65-12

OCTOBER 1965

CONTENTS

ILLUSTRATIONS

INTRODUCTION

During a study of Hudson Bay aboard M/V THETA in 1961 undertaken by the Marine Sciences Branch, Department of Mines and Technical Surveys, a contrast was noted in the bottom physiography of various parts of the Bay. The purpose of this report is to present a preliminary interpretation of the bedrock geology underlying Hudson Bay based on physiographic evidence.

Hudson Bay is bordered on the southwest and north by gently dipping Paleozoic sedimentary rocks, and on the east and northwest by Precambrian rocks of the Canadian Shield (Figure 1). Until recently, little had been known about the geology beneath the Bay, and it was generally thought that the Paleozoic rocks extended under the Bay as a thin blanket overlying the crystalline basement rock. Results of a sea magnetometer survey in Hudson Bay during 1961 (Hood, 1964) indicated that this previous interpretation was erroneous. Hood reported a basinal feature in central Hudson Bay containing more than 10,000 feet of sedimentary rocks, which is a much greater thickness than was formerly supposed (Figure 2). This information was of particular interest to the petroleum industry, as the presence of a sedimentary basin under the Bay increased the possibility of oil accumulations. Current economic interest in the bedrock geology of Hudson Bay is sufficient to warrant this preliminary study.

An obvious correlation exists between physiography and geology in the regions bordering Hudson Bay. The Paleozoic area to the southwest of the Bay is called the Hudson Bay Lowlands.

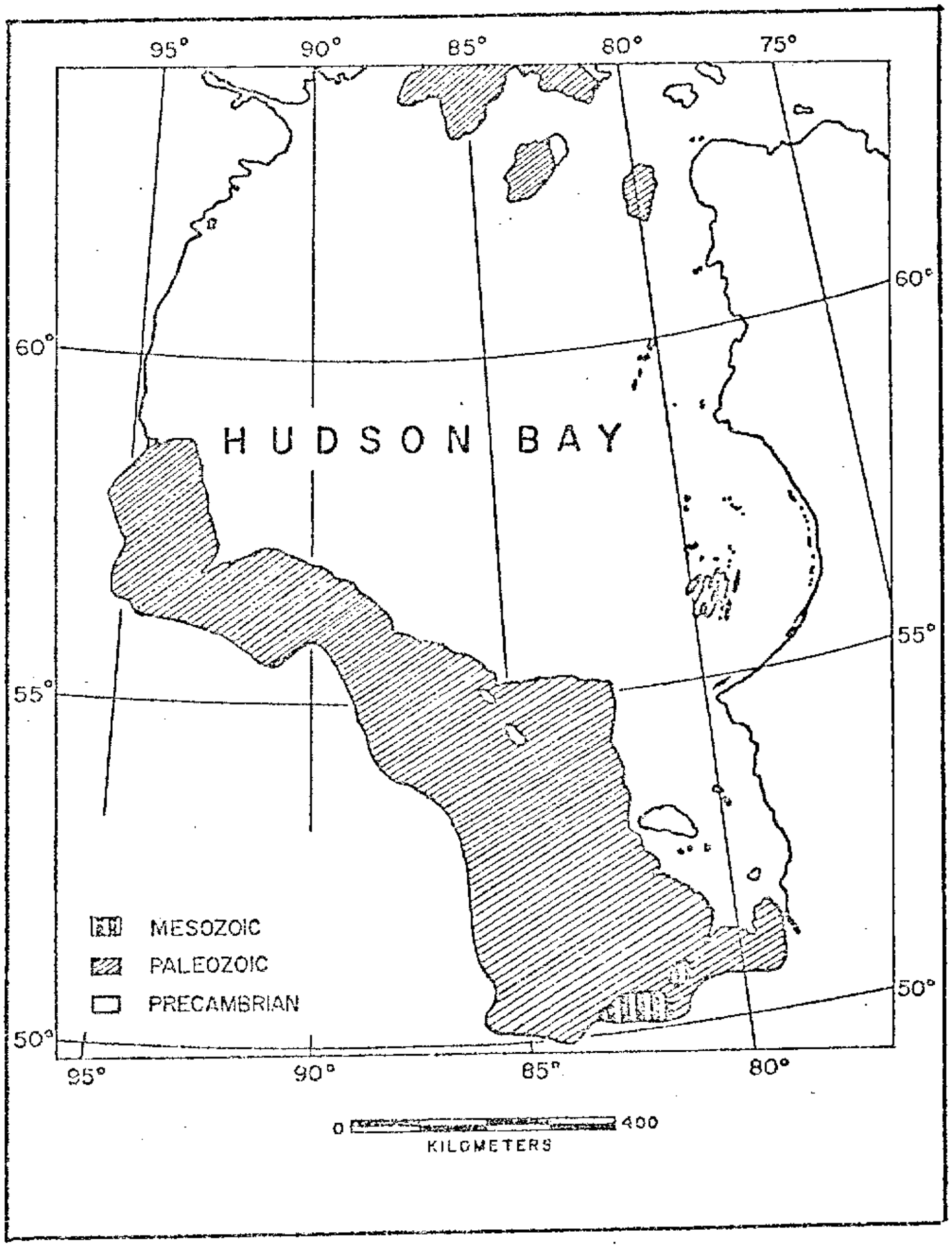

Figure 1. General geology of the Hudson Bay area. (Modified from: Anonymous, 1955)

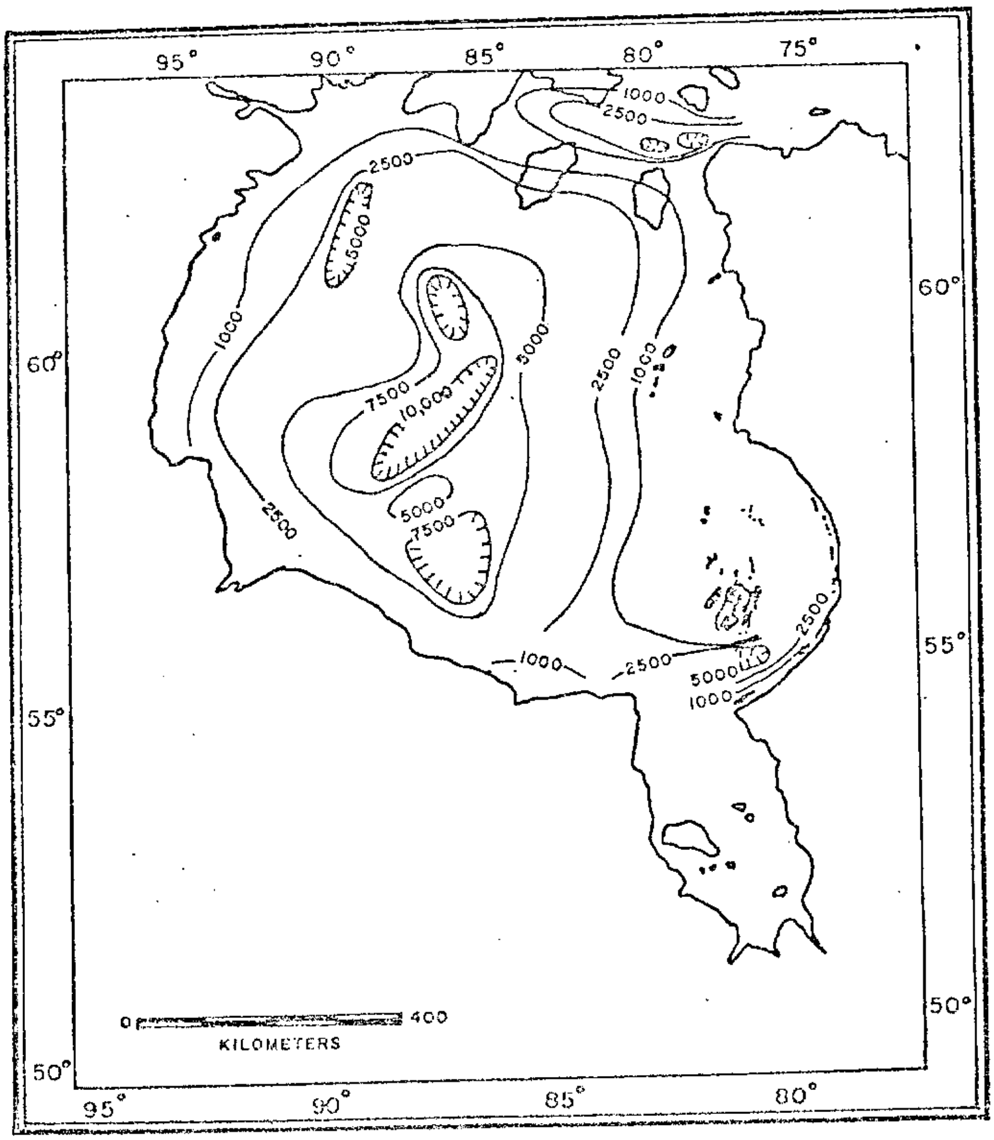

Figure 2. Interpreted basement contour map of Hudson Bay. Depths given in feet below mean sea level. (After Hood, 1964)

This is a broad plain underlain by almost flat-lying strata and bordered by a low escarpment that marks the boundary between the Paleozoic lowlands and the rolling Precambrian terrain to the south. (Caley and Liberty, 1957). On Southampton Island in northern Hudson Bay the contrast in the physiography between the eastern region of Precambrian crystalline rocks and the region to the west underlain by Paleozoic carbonates is apparent. In a detailed study of the geology and geomorphology of this island, Bird (1953) stated:

> "Since the early part of the nineteenth century when Parry entered Duke of York Bay, explorers have been impressed with the contrast on Southampton Island between the broken, often highly scenic uplands of the interior and east coast of Southampton Island, and the flat monotonous lowlands of which the remainder of the island consists. This contrast is present not only on the land but extends out from the shore onto the adjacent continental shelf, and is due essentially to the presence of two widely dissimilar rock types on which geomorphic processes, acting through geological time, have produced the different landscapes we see today."

As it is possible to delineate on the basis of physiography the regions surrounding Hudson Bay that are underlain by Paleozoic rocks, a similar delineation of these rocks in the region beneath the Bay is reasonable.

Fathograms representing approximately 6,500 nautical miles taken along the lines shown in Figure 3 were studied, and changes in regional topography were plotted. Positions of the cruise lines are based on dead reckoning which was controlled by radar fixes near shore. Information from bottom grab samples, cores, and bottom photographs was considered along with the physiographic data in the interpretation of the bedrock geology of Hudson Bay.

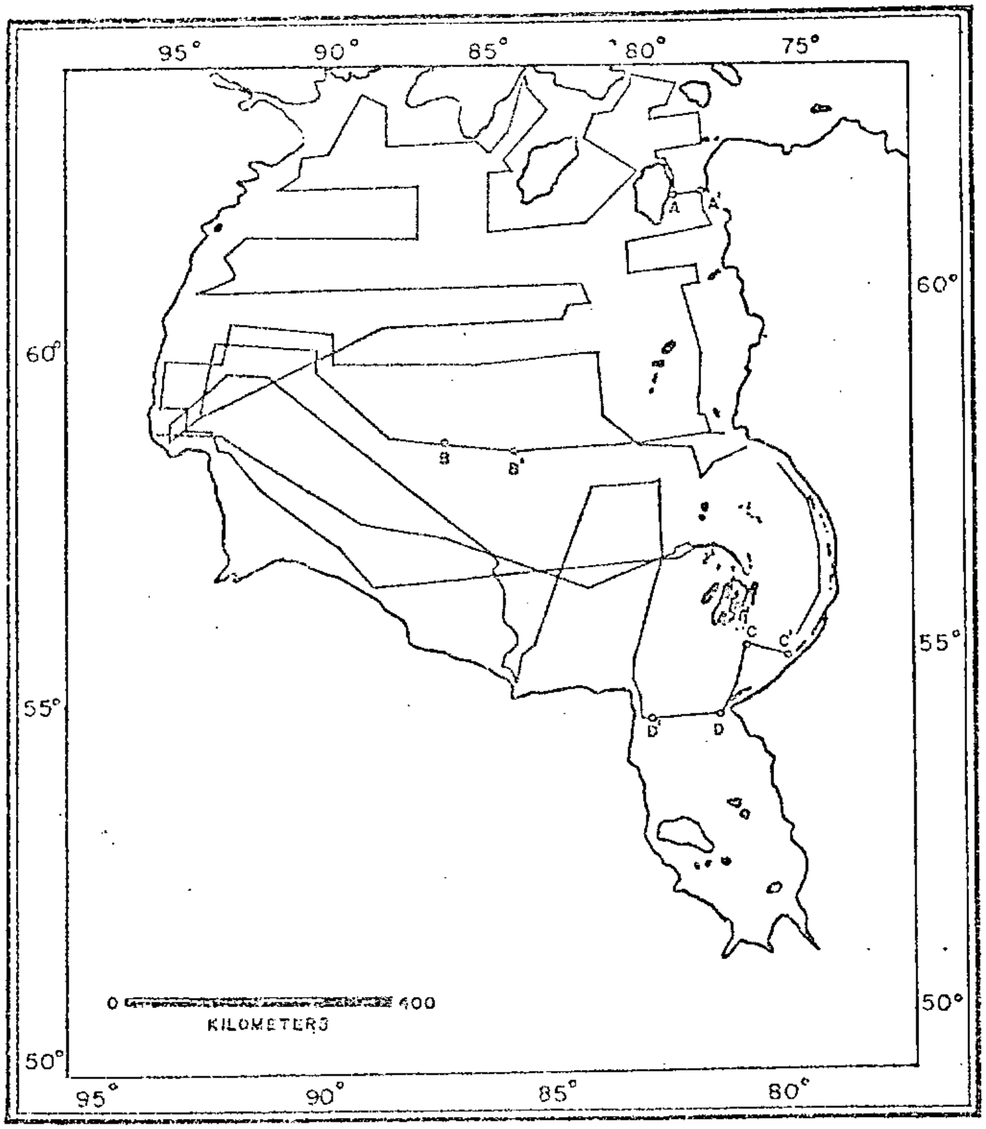

Figure 3. Track of MV THETA in Hudson Bay.

ACKNOWLEDGMENTS

The writers wish to express their gratitude to F. G. Barber, senior scientist on the Hudson Bay cruise, and to Captain C. Maro and the crew of the M/V THETA from which the fathograms were taken. The fathogram of the line extending between Mansel Island and the mainland of Quebec was supplied by our colleague, A. C. Grant, on one of his traverses aboard the launch NEEDLIK. Appreciation is extended to our colleagues L. H. King of the Bedford Institute of Oceanography, and C. V. G. Phipps of the University of Sydney, Australia, who provided many useful suggestions during conversations related to Hudson Bay.

Special thanks are reserved for our technician, T. A. Holler, who arranged and drafted all the illustrations for this report.

DISCUSSION

Section A-A′ shown in Figure 4 is a fathogram from Mansel Island to the Quebec mainland. The island is underlain by Paleozoic carbonate rocks, and the land rises from the shore in a series of broad terraces. Continuation of the terrace topography towards the east beneath the Bay is evident in the fathogram, and indicates that this part of the section is underlain by Paleozoic rocks. The Precambrian granite gneiss of the adjacent Quebec mainland is characterized by a rolling topography of hills and valleys. There is a continuation of this topography towards the west under the Bay. The arrow on section A-A′ points to an abrupt topographic change and indicates the probable contact between Paleozoic and Precambrian rocks along the section.

A fathogram across the bank in central Hudson Bay is shown in section B-B′ of Figure 4. The depth of water over the shallowest portion of this bank is less than 20 fathoms. A comparison of this fathogram with the one off Mansel Island shows that section B-B′ has a bottom profile similar to the portion of section A-A′ underlain by Paleozoic rocks. Therefore, the central shoal is a broad, east-west arch, underlain by Paleozoic rocks. The features on the flanks of the arch are probably Late Tertiary terraces cut into bedrock and thus are similar to those on Southampton Island described by Bird (1953).

There is a marked contrast between the fathograms of section C-C′ between the Belcher Islands and the mainland, and section D-D′

across the mouth of James Bay (Figure 4). Section C-C' is bounded by Precambrian rocks, and shows the rugged profile that is characteristic of Precambrian terrain. Section D-D' is from the Paleozoic lowlands on the west towards the Precambrian uplands on the east. The smooth, gently sloping bottom profile indicates an extension of Paleozoic rocks under James Bay. The probable contact between the Paleozoic and Precambrian is shown by the arrow at the point where the topography becomes irregular. It is unlikely that the contact occurs at the sharp drop present on the eastern portion of the profile, because most of the contacts on land show Precambrian rocks higher than recessive Paleozoic rocks.

Fathograms from the region near the entrance to Hudson Strait were difficult to interpret due to frequent course changes, greater depths, and the possibility of sediment accumulation. The basin between Nottingham Island and Cape Wolstenholme has a smooth, flat bottom with steep sides. The slope of the basin rising towards Mansel Island has a terraced topography typical of Paleozoic regions. The flat bottom of the basin may be the result of infilling by recent marine sediments, however, the topographic evidence supports Hood's (1964) interpretation of this region as a graben underlain by up to 2,500 feet of sedimentary rocks.

A factor to consider in the interpretation of the bathymetry of Hudson Bay is the thickness of overburden, and the extent to which it has masked the bedrock configuration. In section A-A′ between Mansel Island and mainland Quebec the contrast in the bottom configuration due to a change in bedrock is still evident although bottom samples indicate the region is covered by marine mud. Similarly, the terraces on the flanks of the central shoal, which are characteristic of Paleozoic terrain on land, have not been obliterated by the accumulation of recent marine sediments. The irregularities of section C-C′, off the Belcher Islands, are undoubtedly related to bedrock, but the question arises whether the smooth profile of section D-D′, across the mouth of James Bay, is a reflection of bedrock or has resulted from sediment accumulation. However, it is unlikely that the steep slope near the eastern end of the profile would have been preserved if sediment accumulation was excessive. Also, the bottom rises towards the west in a series of subdued terraces that are probably related to the underlying bedrock.

Evidence from bottom samples, cores, and bottom photographs was used as an aid in physiographic interpretation of the bedrock. Figure 5 shows the distribution of calcium carbonate in the bottom sediments of the bay. The high percentages in the southwest and northern portions of the bay coincide with regions that are bordered and probably underlain by Paleozoic carbonate rocks. Therefore, the high values over the central shoal provide additional evidence that it is underlain by Paleozoic carbonate rocks.

A sediment core taken at Station 84 (Figure 5) penetrated

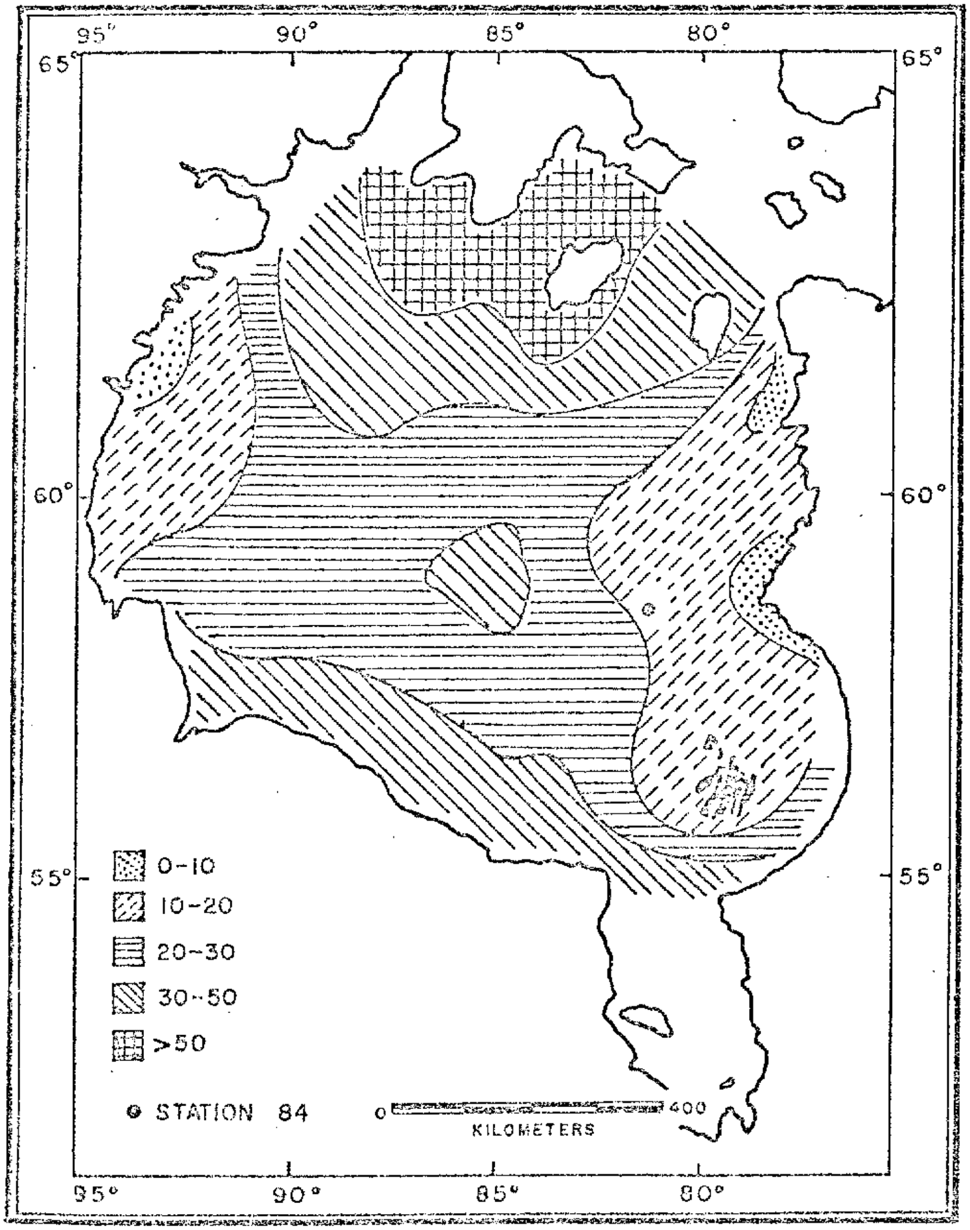

Figure 5. Calcium carbonate percentages in the bottom sediments of Hudson Bay.

probable glacial till beneath 1 metre of marine mud (Leslie, 1965). The coarse fraction of this till is composed predominantly of carbonate rock particles. As the major constituents of glacial till are usually of local origin, the preponderance of carbonate fragments in the till indicates that it overlies carbonate rocks.

A photograph taken at Station 138 at a depth of 120 metres shows the bottom covered with angular cobbles (Figure 6). These cobbles were at first thought to represent a concentration of ice-rafted material (Leslie, 1964), however, an examination of other photographs taken at this station revealed that the coarse material is much more evenly distributed over the bottom than is usual for ice-rafted sediments. It is more probable that the bottom represents the upper surface of a glacial till which has been only partially covered by subsequent marine deposition. Most of the cobbles have the characteristic tabular shape of carbonate rock fragments, and, as the major constituents of till reflect the underlying bedrock, it is probable that the region is underlain by Paleozoic carbonate rocks.

The distribution of Paleozoic rocks beneath Hudson Bay shown in Figure 7 represents an extension of the land geology based on interpretation of the submarine physiography as previously described. The location of the boundary north of Churchill, shown by the dashed line, was difficult to establish because of many changes in the ship's course, accumulation of sediment from the Churchill River, and complicated land geology which is reflected in the abrupt change in direction of the shoreline. Difficulties

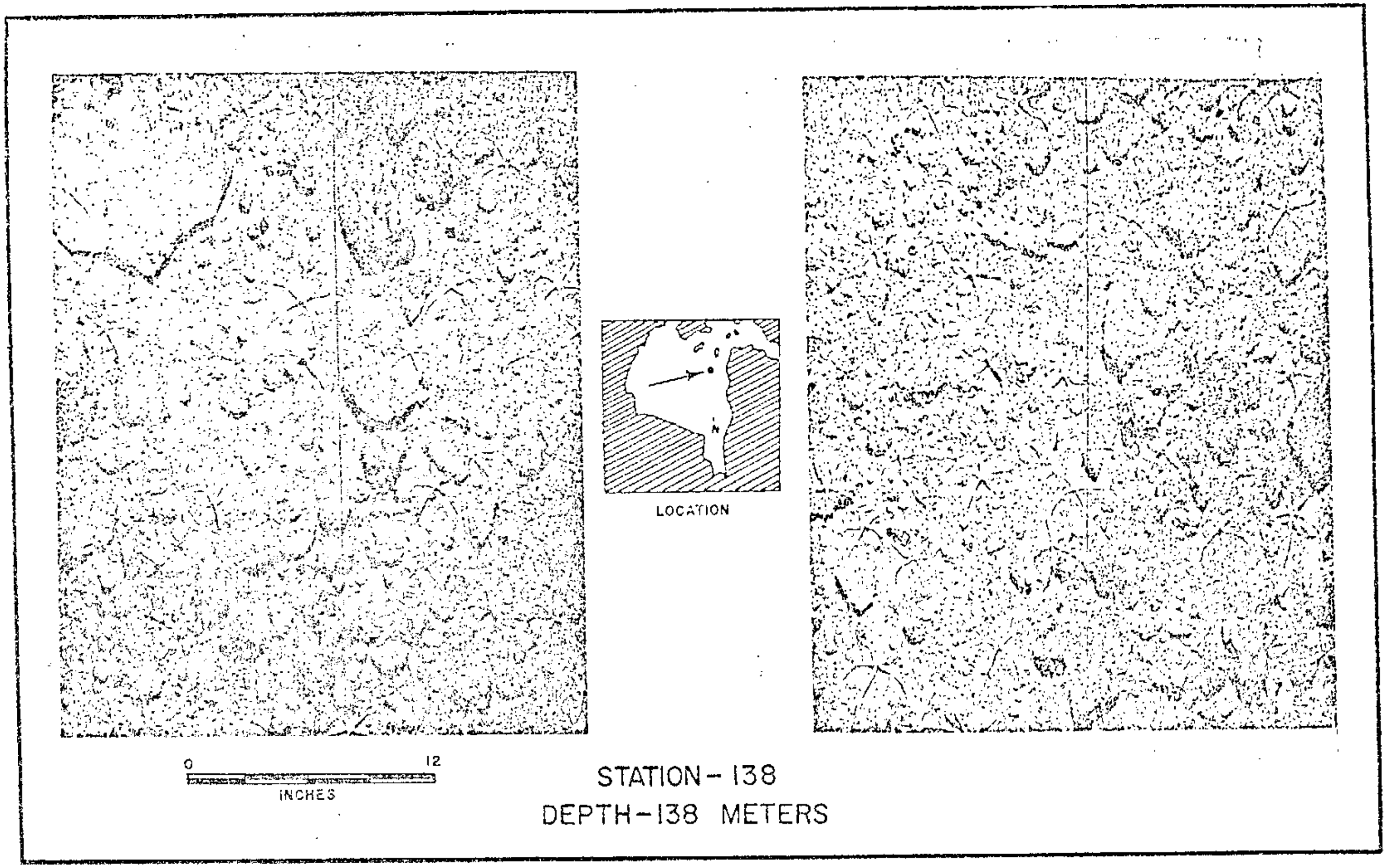

Figure 6. Underwater photographs of the floor of Hudson Bay showing the profuse distribution of blocky, carbonate fragments thought to be Paleozoic in age.

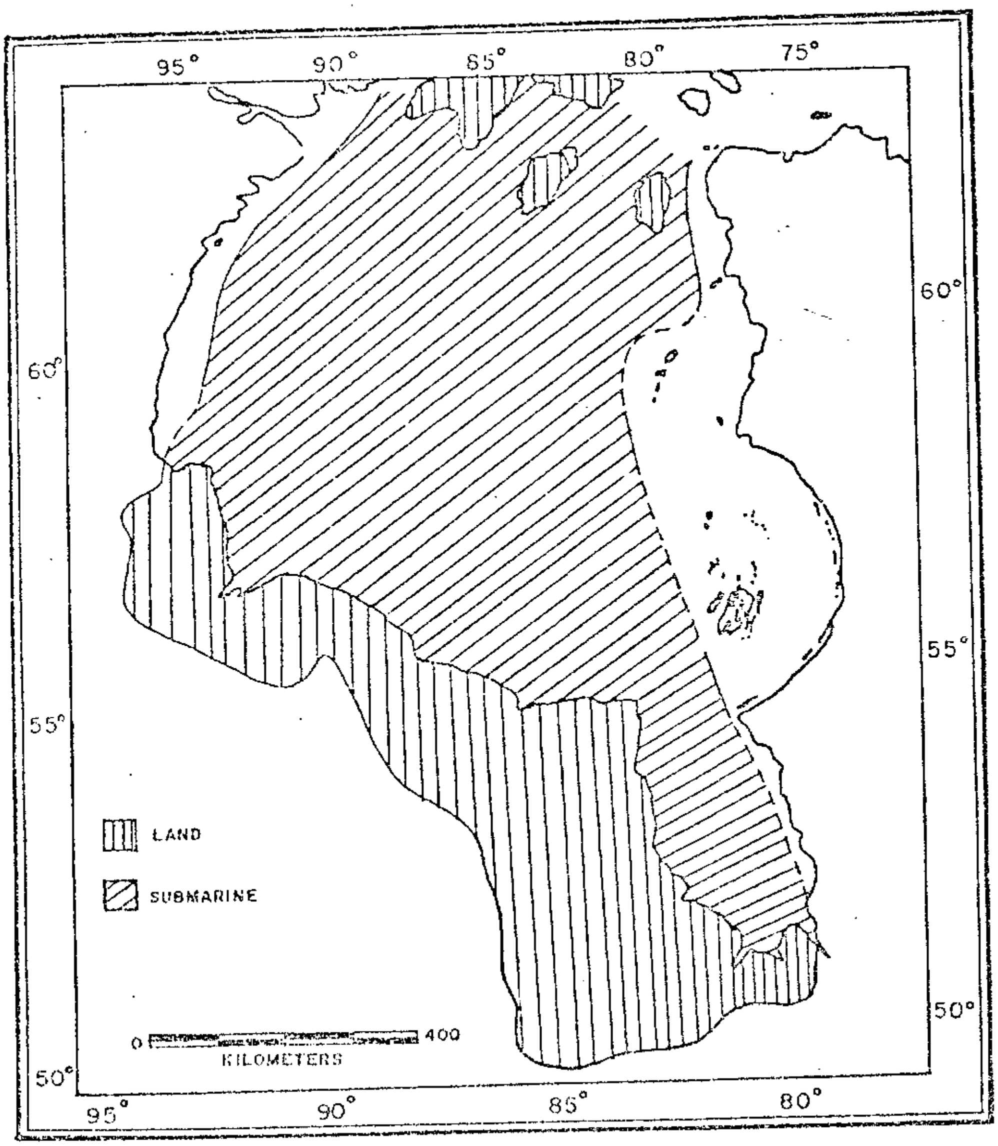

Figure 7. Distribution of Paleozoic rocks beneath Hudson Bay based on interpretation of submarine topography.

were also encountered in determining the boundary between Paleozoic and Precambrian rocks in the region west of the Ottawa Islands and south towards the Belcher Islands. Fathograms in this area show many abrupt changes from flat Paleozoic type terrain to irregular topography typical of the Precambrian. Hood (in press) tried to distinguish the contact west of the Belcher Islands from an east-west sparker record of the sub-bottom profile, but encountered similar complications which he attributed to the presence of Paleozoic outliers.

It is evident from the present study that the configuration of Hudson Bay is directly related to the aerial distribution of Paleozoic rocks. Consideration of this relationship leads to interesting speculation concerning other areas. The presence of Paleozoic rocks on the north and east coasts of Foxe Basin indicates that most of the basin is probably underlain by rocks of similar age. Ungava Bay is bordered by Precambrian rocks, but Akpatok Island in the west-central part of the bay is underlain by Paleozoic rocks. It appears probable that the location and general configuration of Ungava Bay is directly related to the aerial distribution of these younger rocks in a manner similar to that found for Hudson Bay.

CONCLUSIONS

1) Physiographic interpretations of the bedrock geology beneath Hudson Bay indicate that most of the Bay is underlain by Paleozoic rocks.

2) An east-west profile of the bank in central Hudson Bay reveals that this bank is a broad arch underlain by Paleozoic rocks.

3) A fathogram record across the mouth of James Bay indicates that the Paleozoic-Precambrian contact is near the east coast, and therefore Paleozoic rocks occur beneath most of this bay.

4) The location and general configuration of Hudson Bay is directly related to the aerial distribution of Paleozoic rocks. It is probable that rocks of this age also underlie most of Foxe Basin and Ungava Bay.

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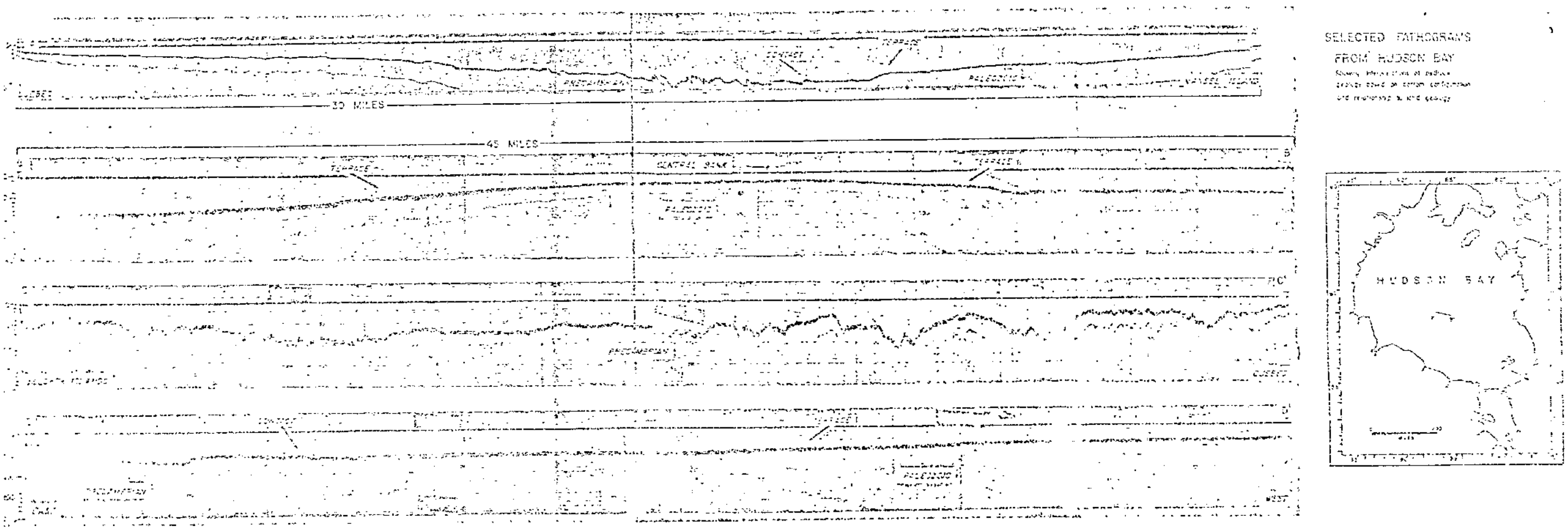
SELECTED FATHOGRAMS
FROM HUDSON BAY
30 MILES
45 MILES
CENTRAL BANK
PRECAMBRIAN
PALEOZOIC
HUDSON BAY

Figure 4.

BULLETIN OF CAN[illegible] PETROLEUM GEOLOGY
VOL. 17, NO. 4 (DE[illegible] 1969), P. 370-375

SUBSURFACE AND OUT[illegible], HUDSON BAY BASIN

RONALD D. JOHNSON[1] and SAMUEL J. NELSON[2]
Calgary, Alberta

ABSTRACT

The first petroleum stratigraphic test in the Hudson Bay Basin, Sogepet Aquitaine Kaskattama Province No. 1, was drilled in 1966 and 1967. Located in Manitoba on the southwestern coast of Hudson Bay, at latitude 57° 04′ 18.487″ and longitude 90° 10′ 29.408″, the well reached a total depth of 2941 ft after drilling 2913 ft of Phanerozoic strata and 28 ft of crystalline Precambrian. Besides Ordovician and Silurian rocks, Upper? Silurian and Devonian rocks hitherto only observed as drift and rubble in the Hudson Bay Basin, were penetrated. The most promising reservoir rock is the Middle Silurian Attawapiskat Formation an intensely reefal and porous unit 230 ft thick.

Reconnaissance surveys were made by Sogepet Limited in 1963 and 1964 of Southampton, Coats and Mansel islands in northern Hudson Bay. These surveys examined the Phanerozoic rocks and resulted in the discovery of oil shale on Southampton Island.

The Sogepet-Aquitaine Kaskattama Province No. 1 well is situated at latitude 57° 04′ 18.487″ and longitude 90° 10′ 29.408″ on the southwest shore of Hudson Bay in the central Hudson Bay Lowlands about 5 m. north of the mouth of the Kaskattama River (Fig. 1). Drilled intermittently from September 1966 to July 1967, this well penetrated 2913 ft of Phanerozoic strata and bottomed at 2941 ft in Precambrian basement. The well is important both in showing that a relatively thick Phanerozoic section occurs on the southwest flank of the Hudson Bay Basin, and in proving the presence of Devonian strata in this basin, a possibility hitherto suggested by rubble studies (Nelson and Johnson 1966). It is of economic interest in establishing the presence in subsurface of a reef reservoir and overlying cap-rock.

Until 1966 when drilling began on the Kaskattama No. 1 well, subsurface data in the Hudson Bay Basin was available from only three rather incomplete wells drilled by mining companies (Nelson and Johnson, 1966). After the well was drilled, the Geological Survey of Canada undertook a rather detailed study of the surface geology of the Hudson Bay Lowland during Operation Winisk (Sanford *et al.*, 1968). Three further stratigraphic tests have been drilled by oil companies, including the first offshore hole by Aquitaine and associated companies. Information from the latter is as yet not available. Location of the various wells is indicated on Figure 1.

---

[1]R. D. Johnson & Associates Ltd., Calgary.

Our appreciation is extended to the partners of the well: Sogepet Lim[illegible] Aquitaine Company of Canada Limited, Elf Oil Exploration and Produ[illegible] Canada Ltd., French Petroleum Company of Canada Ltd., Canadian [illegible] Limited, Sun Oil Company, Texas Gulf Sulphur Company, Bralorne Oil and [illegible] Ltd., Teck Corporation Limited and Western Decalta Petroleum Ltd. [illegible] particular thanks are expressed to Sogepet Limited for release of [illegible] material.

[2]The University of Calgary.

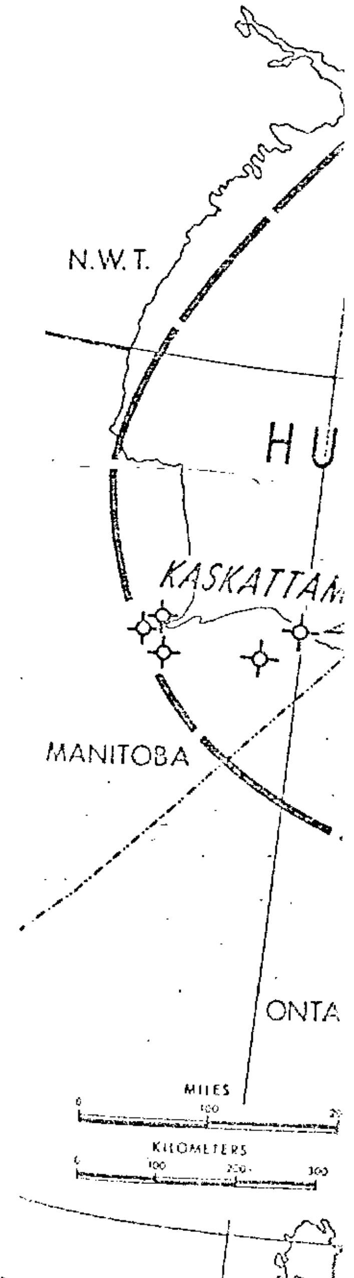

Figure 1. Location map of Soge[illegible] Bay Basin.

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ON BAY BASIN

J. NELSON[2]

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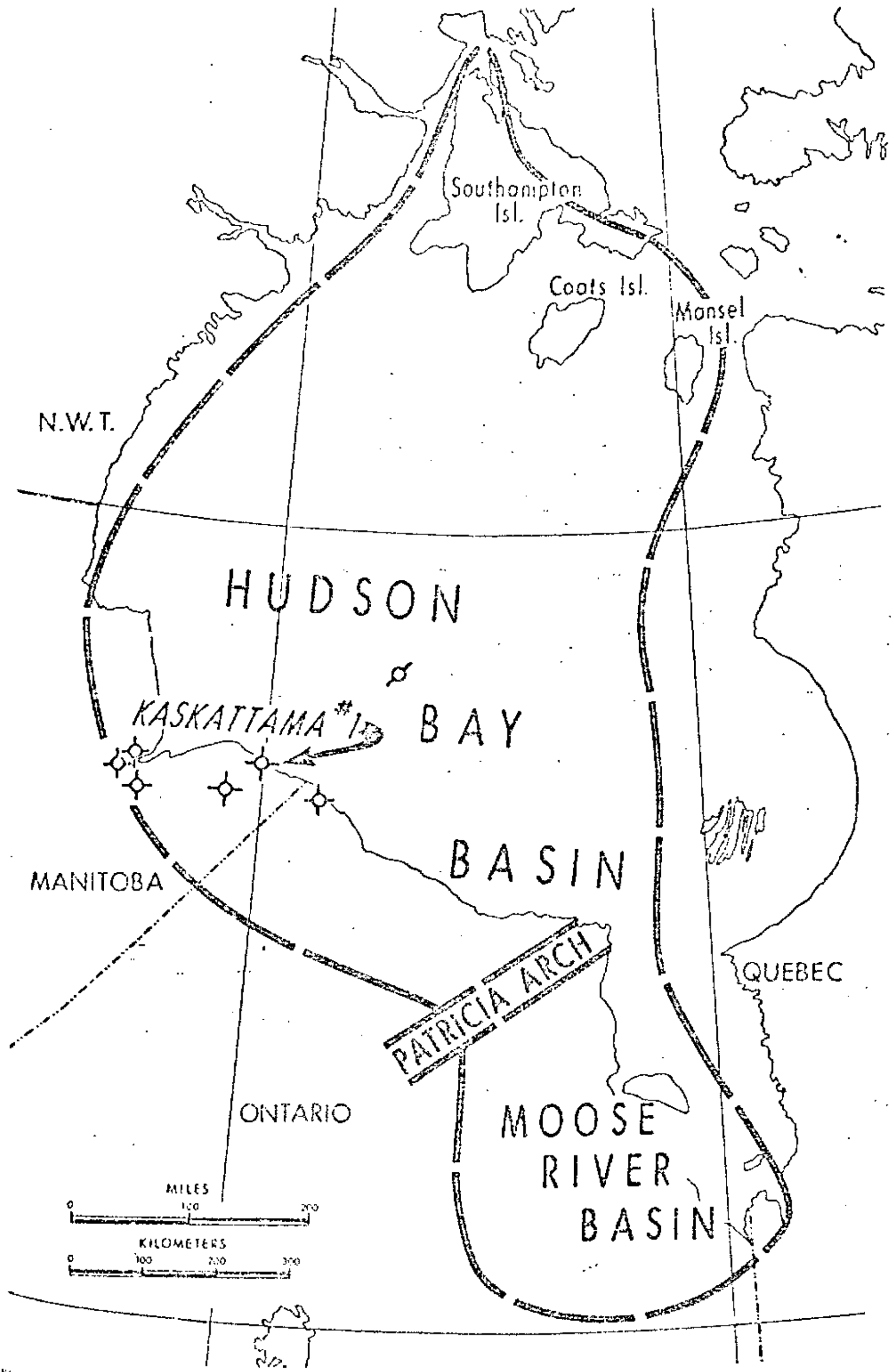

Figure 1. Location map of Sogepet-Aquitaine Kaskattama No. 1 and other wells in the Hudson Bay Basin.

The purpose of the present paper, prepared as part of the Alberta Society of Petroleum Geologists' Calgary Core Conference, 1969, is to review briefly the stratigraphy of the Sogepet-Aquitaine Kaskattama No. 1 well, earlier described by Nelson and Johnson (1968) and by Johnson and Nelson (1969). More important, this paper describes the lithology and stratigraphy of the reefal and porous Attawapiskat Formation in the well. This formation, considered one of the more promising reservoir limestones in Hudson Bay Basin was, for security reasons, only briefly referred to in previous articles by the authors.

The Kaskattama well was 2/3 cored, including portions of each stratigraphic unit penetrated. A representative 743 segments from these cores (including 75 from the Attawapiskat reef) as well as 10 outcrop samples of the Silurian of the Lowlands and of the oil shale of Southampton Island (Nelson and Johnson, 1966) were displayed at the Core Conference. The presentation was intended to provide a large number of petroleum geologists with an opportunity to examine rocks from this very large but little known Canadian sedimentary basin.

The Hudson Bay Basin (Nelson and Johnson, 1966), in which Sogepet-Aquitaine Kaskattama No. 1 was drilled, underlies much of Hudson Bay. The only outcrops occur in the southwest along the central and northern Hudson Bay Lowlands, and in the northwest on Southampton, Coats and Mansel islands. Exposed rocks are Late Ordovician and Silurian carbonates. Outcrops of Devonian strata have not been found although rubble studies (Nelson and Johnson, 1966) along the shore areas from near Fort Severn to the Hayes River and drilling at Kaskattama No. 1 establish its presence in the basin. Devonian rocks are unknown on Southampton, Coats and Mansel islands in the north. Grab samples of bottom sediments, however, suggest they may underlie a fair area of Hudson Bay (Nelson and Johnson, 1966).

The Hudson Bay Basin is separated from the smaller Moose River or James Bay Basin to the south by the Patricia Arch.[3] The northern basin is three to four times as large as the southern basin with a stratigraphic section three to four times as thick.

In the Hudson Bay Basin, formational terminology has only been applied to the outcropping rock along the flank of the basin and then just on the southwestern portion of the Hudson Bay Lowland. The Ordovician rock units have their type sections in the Hudson Bay Basin. Several of the Silurian units, however, have their type sections in the Moose River Basin and the nomenclature has been extended northward into the Hudson Bay Basin.

No Devonian formations have their type section in the Hudson Bay Basin, and their stratigraphy and extent is uncertain. Devonian is fairly extensive and well known in the Moose River Basin where type sections for rock units have been established. Some of these units have been extended by Sanford *et al.* (1968) northward into the Lowland portion of the Hudson Bay Basin. This has been done on the basis of relatively few rubble occurrences so that the extent and stratigraphic succession of these formations should be regarded as very tentative.

[3]The Patricia Arch was later renamed as the Cape Henrietta Maria Arch by Sanford *et al.* (1968) without discussion. The earlier name 'Patricia Arch,' of course, has priority and the latter term must be discarded.

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Table 1. Tentative cor... well to outcrop formations... those discussed by Nelson a...

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	OVERBURDEN-PLEIST...
DEVONIAN	EARLY MIDDLE DEVONIAN ABITIBI RIVER FORMATION
SILURIAN ?	LATE ? SILURIAN KENOGAMI RIVER FORMATION
SILURIAN	MIDDLE SILURIAN ATTAWAPISKAT, EKWAN RIVER AND SEVERN RIVER FORMATIONS
	UNASSIGNED
	EARLY ? SILURIAN
ORDOVICIAN	LATE LATE ORDOVICIAN CHURCHILL RIVER GROUP
	UNASSIGNED
	LATE MIDDLE OR EARLY LATE ORDOVICIAN BAD CACHE RAPIDS GROUP
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Table 1. Tentative correlation of strata in the Sogepet-Aquitaine Kaskattama No. 1 well to outcrop formations. Faunal Assemblages and Unassigned Intervals indicated are those discussed by Nelson and Johnson (1968) and Johnson and Nelson (1969).

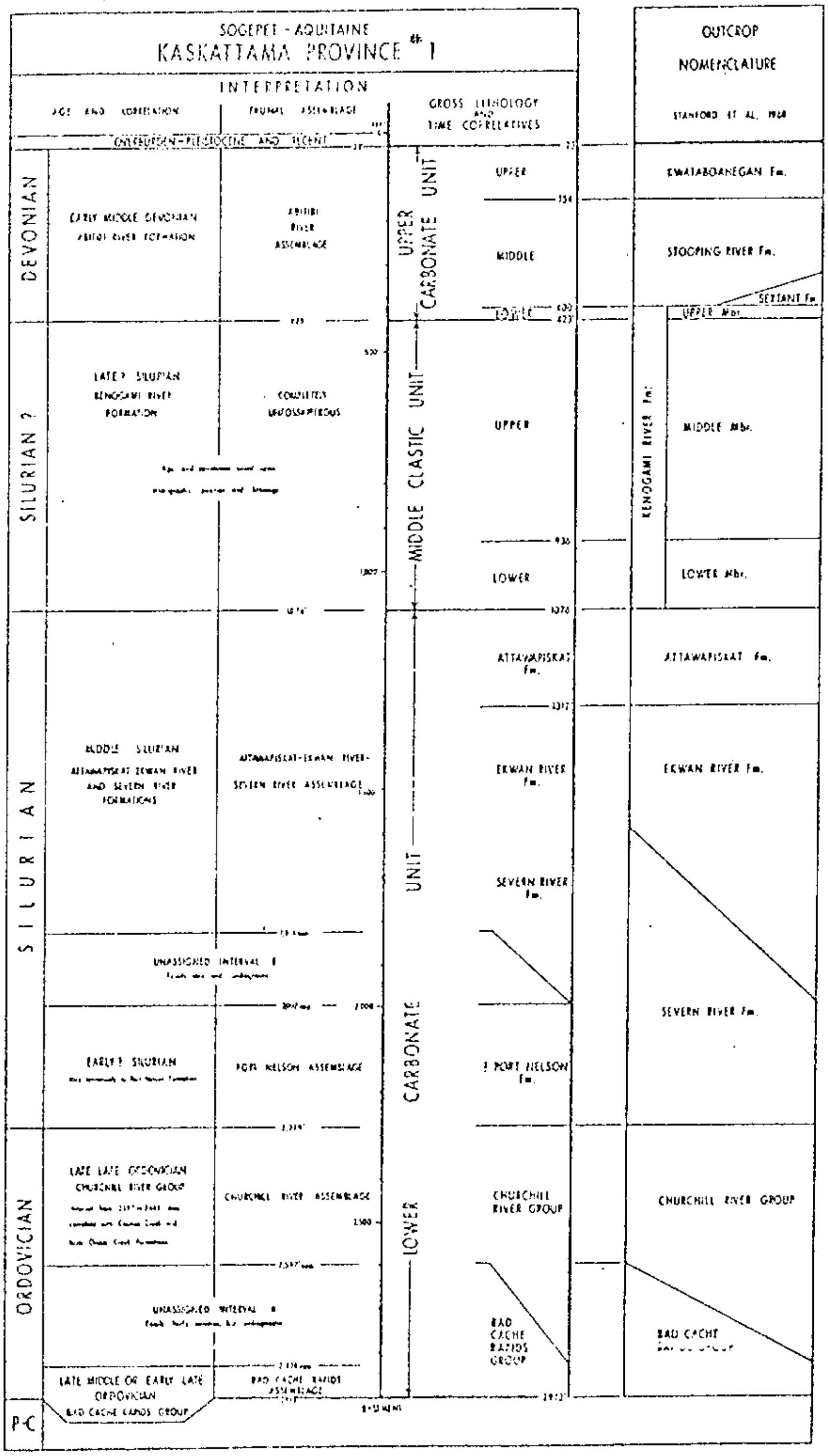

Table 1 illustrates the relationship of outcrop rock units as revised by Sanford *et al.* (1968) to the subsurface as applied in the Kaskattama well by the authors. Variations and uncertainties between the outcrop sections and the subsurface preclude the application of most formational divisions to the subsurface. Therefore, the threefold division of the subsurface (Johnson and Nelson, 1969) is still adhered to, that is:

Lower Carbonate unit, Middle Clastic unit, Upper Carbonate unit.

The Lower Carbonate unit is applied by Johnson and Nelson (1969) to the lowest 1837 ft of Phanerozoic strata in the Kaskattama No. 1 well. It extends from 2913 ft at the Precambrian contact to 1076 ft at the top of the Attawapiskat Formation.

The unit contains Late Ordovician, Early and Middle Silurian. The Ordovician portion is 634 ft thick from 2913 to 2279 ft and contains fossil representatives of the Bad Cache Rapids and the Churchill River Groups of outcrop (Table 1). The Silurian portion, 1203 ft thick, extending from 2279 to 1076 ft, contains fossil representatives of the Early Silurian Port Nelson and the Middle Silurian Severn River, Ekwan River and Attawapiskat Formations of outcrop. The Lower Carbonate unit is predominantly a cyclic sequence of limestone and dolomite with minor anhydrite. Basal beds are thin sandstone and shale. This cyclic sequence appears continuous from Ordovician through most of the Early and Middle Silurian, although minor shale partings occur near the contact.

Above 1800 ft in the Middle Silurian, organic limestones become increasingly abundant culminating in the intensely reefal Attawapiskat Formation extending from 1312 ft to 1076 ft. The Attawapiskat Formation in subsurface has not previously been described.

At the present stage of subsurface knowledge, the Attawapiskat is the only rock unit sufficiently well defined lithologically to warrant application of the outcrop name. Although the strata below the Attawapiskat Formation can be faunally related to outcrop, their cyclic similarity prevents lithologic correlation to the outcrop formations. In the well, the Attawapiskat Formation stands out by its lighter coloration and intense organic development.

The Attawapiskat reef is 236 ft thick; 177 ft were cored with 174 ft recovered. The remaining 50 ft were drilled mainly without recovery and therefore the lower 25 per cent of the formation is poorly known. Based on the recovered core material, the Attawapiskat at the Kaskattama location can be described as a limestone reef with a dolomite base. It is in part light grey, in part cream to buff to brown; cryptocrystalline to finely crystalline; in part calcarenitic with the calcarenites exhibiting tendencies towards oolitic development in interbeds. Fauna in the reef include corals, algae(?), stromatoporoids, brachiopods, gastropods, octracods and crinoids. Some eighty per cent of the cored section exhibits porosity. The porosity is mainly of the poor to good pinpoint and small vuggy type with occasional large vuggy sections. It averages less than five per cent in some sections, fifteen per cent in others and occasionally exhibits twenty per cent or better. No engineering details are offered here, but the excellent reservoir aspects of the Attawapiskat reef are obvious.

The Middle Clastic unit (Johnson and Nelson, 1969) is a striking assemblage of siltstones and minor evaporites dominated by vivid maroon colors. The unit is 653 ft thick with a basal light grey and brown evaporitic dolomite 140 ft thick. It is abruptly overlain by the main siltstone portion of the unit consisting of striking dark red, occasionally green, frequently gypsiferous siltstone 513 ft thick.

The unit is devoid of diagnostic organic material. However, Johnson and Nelson (1969) correlated it with the Kenogami River Formation of the Moose River Basin to the south on lithological similarity and stratigraphic position. The basal dolomite has been tentatively accepted as the equivalent of the lower dolomite of the Kenogami Formation in the Moose River Basin and projected northward by Sanford *et al.* (1968) into the outcrop section of Hudson Bay Basin. However, as pointed out (Johnson and Nelson, 1969), this dolomite is lithologically more closely related to the Lower Carbonate unit and may perhaps be an off-reef facies of continued Attawapiskat development.

The Upper Carbonate unit of the Kaskattama No. 1 well is the first Devonian rock found *in situ* in the Hudson Bay Basin and represents and Early (?) and Middle Devonian sequence. Of the 400 ft penetrated, only 84 ft were cored with 29 ft recovered. This limited material suggests that the Upper Carbonate unit has a threefold lithologic division: a basal 23 ft of cryptocrystalline, dolomitic, poorly fossiliferous limestone; a middle 264 ft of marly, sucrosic, unfossiliferous limestone; and an upper 131 ft of bioclastic, fossiliferous limestone.

Johnson and Nelson (1969) originally correlated the Upper Carbonate unit with the Abitibi River Formation of the Moose River Basin to the south. Recently, Sanford *et al.* (1968) separated the Abitibi River Formation into the new Stooping River, Kwataboahegan, Murray Island Formations together with the pre-existing Moose River Formation. The lower two of these formations on the strength of rubble have been projected by these authors into the Hudson Bay Basin. If the projections of outcrop from the Moose River Basin into the Hudson Bay Basin prove valid, the correlation to subsurface would appear to be upper Kenogami carbonate with the lower limestone of the Upper Carbonate unit, the Stooping River Formation with the middle limestone and the Kwataboahegan with the upper limestone of the Upper Carbonate unit.

Presentation of the data and material from the Kaskattama well is intended to serve as an introduction to the subsurface geology of the Hudson Bay Basin. As further data from drilling becomes available, the relationship between outcrop and subsurface can be formalized and economic prospects given perspective.

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