Nares Strait and the petroleum explorer

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It is important to be able to make intelligent guesses concerning the effect of lateral movement along Nares Strait on the resulting sedimentary section and the heat regime. A prognosis of the theoretical well — Lincoln No. 1 — would need to contain forecasts concerning the conditions of hydrocarbon generation in the sediments.

Case No. 1 for the postulated sedimentary section assumes 250 km of left-lateral movement along the Nares Strait lineament. Rocks are Lower Cretaceous to Pleistocene. Attendant heat is assumed to be high. Case No. 2 assumes very little movement along the lineament and, therefore, a relatively quiet tectonic history. Rocks are Cambrian to Pleistocene. Attendant heat is assumed to be average.

A simulated analysis of the geochemistry of the situation in Case No. 1 reveals that maximum expulsion of hydrocarbons occurs at 4000 metres' depth. In Case No. 2 the maximum expulsion would occur at 5000 metres. Therefore, it is tentatively concluded that Case No. 1 would provide the best conditions for hydrocarbon generation and entrapment at approximately 1000 metres shallower than Case No. 2.

Large-scale movement along the Nares Strait lineament and the attendant higher heat regime would be a beneficial circumstance for the petroleum explorer.

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It is an honour for me to be considered and requested to make a contribution to this up-to-date, thorough, and thoughtful volume. The Nares Strait lineament has attracted the attention of almost all scholars concerned with the shifting of the Earth's surface and I will not become entangled in the debate as to whether there has been substantial lateral movement along it or practically none. Rather, I will try to illustrate how a controversy such as this can make modelling for oil prospecting more hazardous than usual. There is some comfort in writing these pages which deal with possible future petroleum discoveries. It will be decades before exploration will confirm or refute my opinions.

In the mid-1960s — before the explosion of interest in sea-floor spreading — the Canadian Society of Petroleum Geologists invited Dr. Robert S. Dietz to Calgary to expand on his famous 1961 article in Nature on continental drift. He presented a thoroughly revolutionary dissertation to an audience of about 300 which was followed by a lively and controversial question period. Toward the end of the meeting the chairman asked for a show of hands to determine the number who did or did not 'believe' Dietz. About 275 hands went up to oppose him accompanied by loud cheers. The few who agreed with him raised their hands to the polite ridicule of the other scientists. Here was a case of science by vote. Since then Dietz's theory has become almost universally accepted and a vote today would certainly conclude that the majority then was wrong. I notice that a kind of running score is also being kept in this volume (Johnson & Srivastava).

A central theme in the Nares Strait symposium and one exemplified by several papers in this volume is the thesis that the tectonic evolution of Nares Strait is closely interrelated with that of Baffin Bay and Labrador Sea (Fig. 1). Hence the Nares Strait debate has very important implications for the interpretation of the history and age of the thick sedimentary sections known to occur in the offshore areas between Greenland and Canada and in the seaways around southern Nares Strait. The Strait itself is also a possible site for thick sedimentary accumulations, and it links the sedimentary basins of the Baffin Bay area to those of the Arctic Ocean. It is one such basin at the northern extremity of Nares Strait — in the Lincoln Sea — that I shall focus on in this assessment, reflecting that any forecasts on the hydrocarbon generation of the sediments in this basin also probably are valid for the basins in the southern extremity of Nares Strait in northern Baffin Bay.

Nares Strait and Lincoln Basin

The Lincoln Basin is a large volume of mainly non-magnetic rocks situated in the Lincoln Sea (Fig. 2). Some of the basin's characteristics can be deduced from the data supplied by Sobczak & Stephens (1974) and

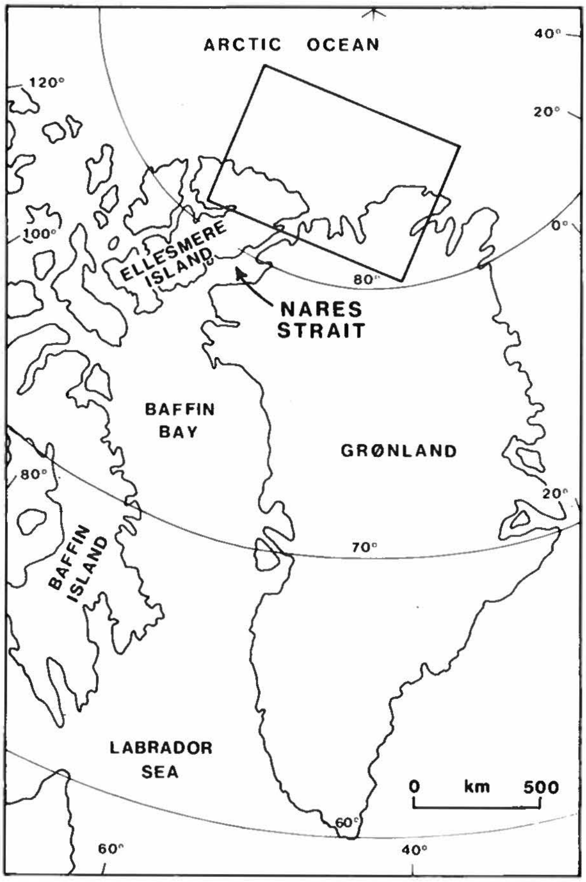


Fig. 1. Index map of the Nares Strait – Labrador Sea region; the frame indicates the area shown in Fig. 2.

Kovacs (this volume). It is an attractive basin for petroleum accumulation because of its great areal extent and depth. It is unattractive for exploration drilling with present technology because of the permanent shifting ice cover. Magnetometer and gravity surveys in the basin combined with field mapping on Ellesmere Island and Greenland allow projections and extrapolations to be made on the nature of the sediments in the basin. These projections and extrapolations are affected profoundly by the choice made in the amount of left-lateral displacement along the Nares Strait lineament. If there was practically no movement (0–25 km) the Lincoln Basin may have been a fairly quiet shelf tectonically and underlain by a stratigraphic section representing all parts of Phanerozoic time. If there has been 250 km of strike-slip movement since Campanian time the shelf may be underlain by mostly Cretaceous and Cenozoic clastics, resting on a basement of Palaeozoics injected by Mesozoic and possibly Cenozoic intrusives. Accordingly a different palaeoheat regime for each of the two possibilities needs to be envisaged when considering the petroleum potential.

To clarify and summarise some aspects of the problems in deciding how attractive the Lincoln Basin is for the occurrence, migration, and entrapment of petroleum a site for the theoretical Lincoln No. 1 well has been selected. This location appears to be on an arch; however, it could just as likely be on a horst within the basin. Case No. 1 (Fig. 3) portrays the situation where a Cretaceous–Cenozoic section rests on Palaeozoic and older continental crust which has been thinned by attenuation during large movement along Nares Strait. Case No. 2 (Fig. 4) portrays the situation that may exist if there were little or no displacement. In this case a Cenozoic–Mesozoic column may rest on a thick nonmagnetic Palaeozoic section that in turn rests on magnetic 'granitic' crust. The continental crust in this case has its original thickness and there has been very little disruption or attenuation in the area caused by substantial movement along Nares Strait.

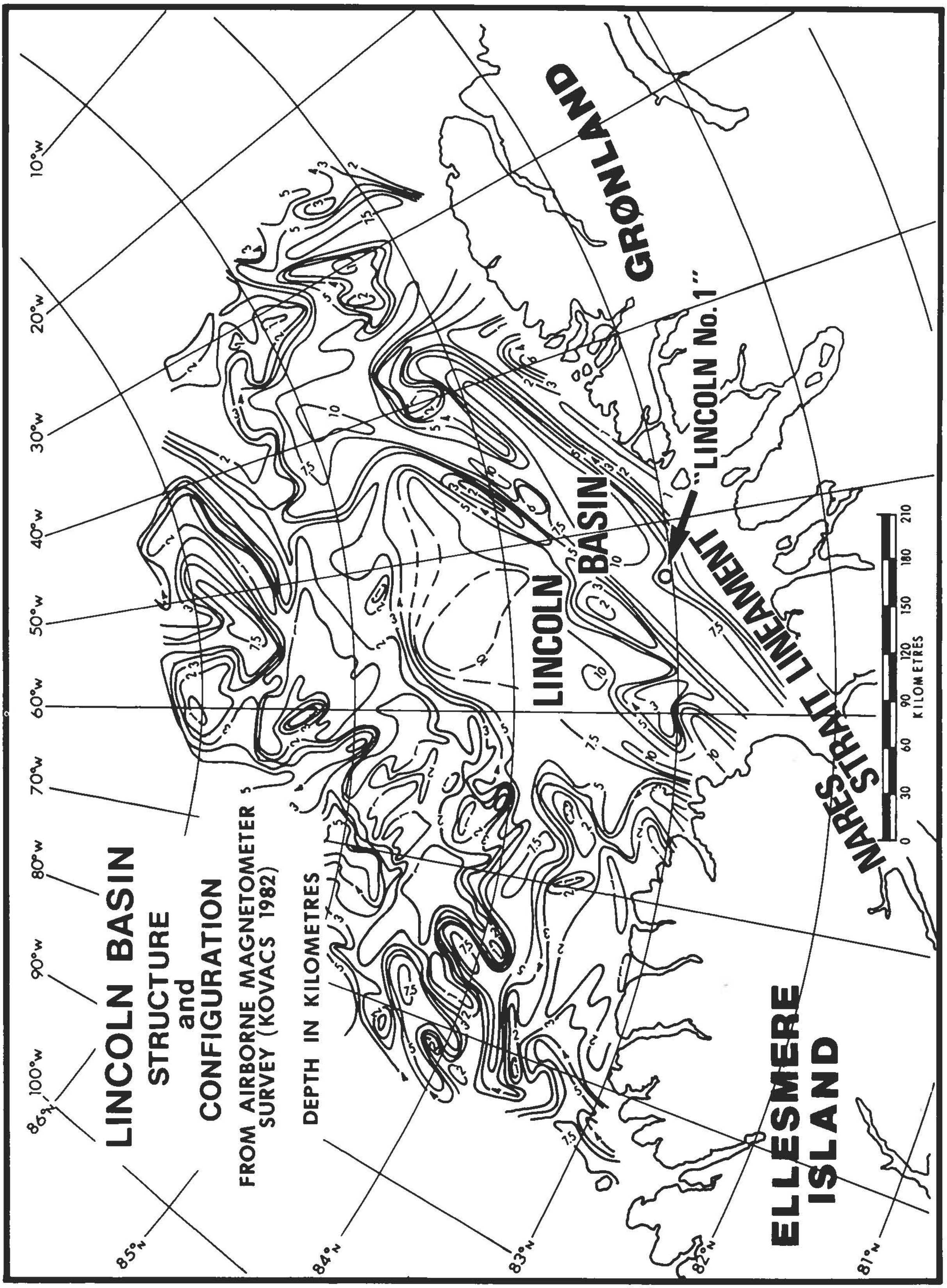
Case No. 1

The overview of the theoretical section of Fig. 3 assumes that great displacement occurred along Nares Strait accompanied by attenuation. It embraces many of the concepts, but not necessarily the timing, offered by Kovacs (this volume). A deep Cretaceous graben-like basin formed between Greenland and Ellesmere Island in a wide Nares Strait. The graben and the sediments partly filling it were moved northeastward until the end of Eocene time. Some basic volcanic rocks would be incorporated in the mainly sand-shale sequence. The continental crust may have been thinned and in places may be practically absent with oceanic crustal materials in its place as judged from the high gravity anomalies (Sobczak & Stephens 1974). Such a situation would be accompanied by high heat flow ranging between 1.60 and 1.80 units (1 unit = $1 \mu cal/cm^2$ per sec.) until at least the end of the Paleocene after which it diminished to 1.40 units by the end of the Eocene. The present-day thermal gradient is estimated to be 30°C/km. The sea-bottom temperatures used on Fig. 3 are meant to conform with the approximations of palaeoclimate given by Clark (1981).

Case No. 2

The hypothetical overview portrayed on Fig. 4 is adopted to contrast with Case No. 1. The assumption is that the continental crust is thick and has not been thinned tectonically by left-lateral movement along Nares Strait. Further, the Lincoln No. 1 site is north of the main Palaeozoic folding as known on northern Green-

Fig. 2. Structure and configuration of the Lincoln Basin based on the aeromagnetic data reported on in this volume by Kovacs.


LINCOLN BASIN
STRUCTURE
and
CONFIGURATION
FROM AIRBORNE MAGNETOMETER
SURVEY (KOVACS 1982)
DEPTH IN KILOMETRES
GRØNLAND
LINCOLN BASIN
"LINCOLN No. 1"
NARES STRAIT LINEAMENT
ELLESMERE ISLAND
0 30 60 90 120 150 180 210
KILOMETRES
10°W
20°W
30°W
40°W
50°W
60°W
70°W
80°W
90°W
100°W
86°N
85°N
84°N
83°N
82°N
81°N

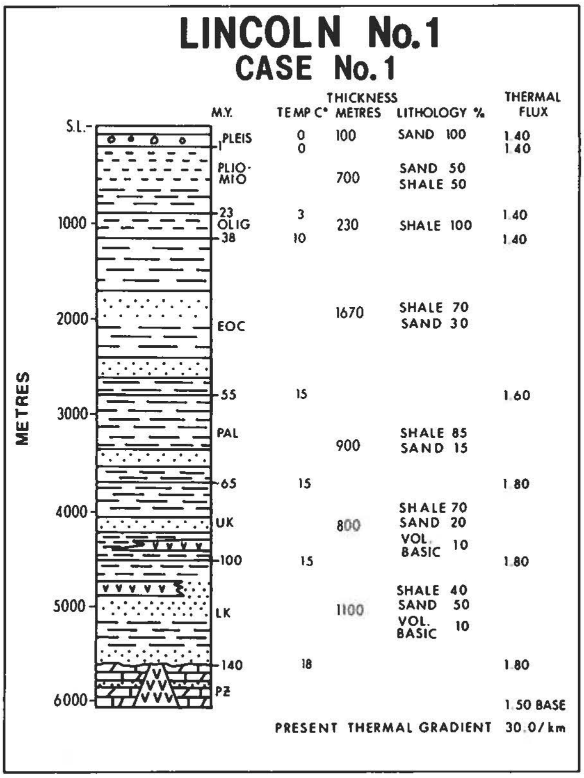


Fig. 3. Postulated sedimentary section, composition, thickness, temperature of the sediments at the time of sedimentation and the thermal flux in µcal/cm ^{2}/sec. The assumption made is that Lower Cretaceous rocks were deposited in a graben in thinned continental crust during large-scale movement along the Nares Strait lineament.

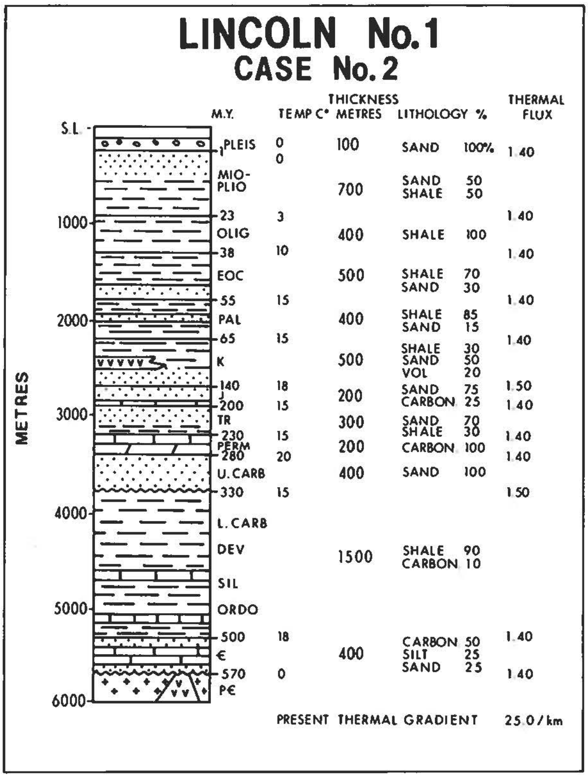


Fig. 4. Postulated sedimentary section, composition, thickness, temperature of the sediments at the time of sedimentation and the thermal flux in µcal/cm ^{2}/sec. The assumption made is that except for a brief erosional interval in the Carboniferous, sedimentation was fairly continuous. The continental crust was thick and there was very little disruption because of little or no movement along the Nares Strait lineament.

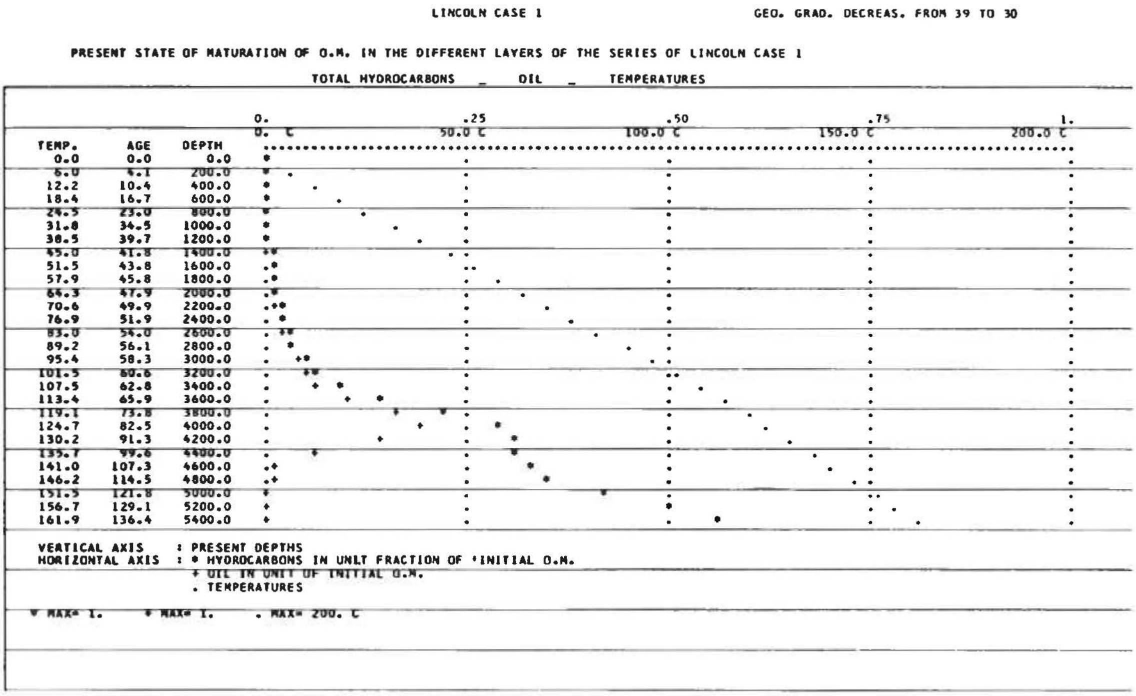
land. The Lincoln Basin is a downwarp on the craton which preserved most of the sediments deposited since the Precambrian. One unconformity of short duration (5 m.y.) is recorded in the Carboniferous. Volcanics may be preserved in the Cretaceous sediments. The source of the high gravity anomalies mapped by Sobczak & Stephens (1974) is unknown. No substantial movement is considered to have taken place along Nares Strait. Such a situation perhaps was accompanied by average heat flow (1.40 units) for most of Phanerozoic time. Exceptions may be during part of the Carboniferous and possibly in the early Mesozoic when there were tectonic readjustments or regional reheating. The present-day thermal gradient for Case No. 2 is estimated to be 25°C/km. As with Case No. 1 the sea-bottom temperatures chosen are meant to describe the palaeoclimate described by Clark (1981). The lithology of the Palaeozoic column is considered to be similar to that recorded by Dawes & Peel (1981) and summarised by Churkin & Trexler (1981: fig. 3, column 33).

Diagenetic evolution of the organic matter in the postulated sedimentary sections

The procedure in this hypothetical situation in an attempt to evaluate the ability of the sediments to yield hydrocarbons is one devised by du Rouchet (1980). The method is found to be useful in Canada as well as elsewhere. It can be applied in well-established petroleum producing areas as well as frontier areas.

The method employs a computer programme based on simulations of the depositional history, geothermal history, and the kinetic behaviour of the organic matter decompositions contained in the sediments. The method helps to define the times at which oil and gas were formed throughout the history of any particular basin and it describes the present situation. The reader is referred to du Rouchet's (1980) description for details.

In these specific cases it has been assumed that the



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LINCOLN CASE 1                                   GEO. GRAD. DECREAS. FROM 39 TO 30

PRESENT STATE OF MATURATION OF O.M. IN THE DIFFERENT LAYERS OF THE SERIES OF LINCOLN CASE 1
                          TOTAL HYDROCARBONS _ OIL _ TEMPERATURES

                                  0.          .25          .50          .75          1.
                                  0. C        50.0 C       100.0 C      150.0 C      200.0 C
 TEMP.      AGE      DEPTH
   0.0      0.0        0.0
   6.0      4.1      200.0
  12.2     10.4      400.0
  18.4     16.7      600.0
  24.5     23.0      800.0
  31.8     34.5     1000.0
  38.5     39.7     1200.0
  45.0     41.8     1400.0
  51.5     43.8     1600.0
  57.9     45.8     1800.0
  64.3     47.9     2000.0
  70.6     49.9     2200.0
  76.9     51.9     2400.0
  83.0     54.0     2600.0
  89.2     56.1     2800.0
  95.4     58.3     3000.0
 101.5     60.6     3200.0
 107.5     62.8     3400.0
 113.4     65.9     3600.0
 119.1     73.8     3800.0
 124.7     82.5     4000.0
 130.2     91.3     4200.0
 135.7     99.6     4400.0
 141.0    107.3     4600.0
 146.2    114.5     4800.0
 151.5    121.8     5000.0
 156.7    129.1     5200.0
 161.9    136.4     5400.0

 VERTICAL AXIS     : PRESENT DEPTHS
 HORIZONTAL AXIS   : * HYDROCARBONS IN UNLT FRACTION OF 'INITIAL O.M.
                     + OIL IN UNIT OF INITIAL O.M.
                     . TEMPERATURES

 * MAX= 1.      + MAX= 1.      . MAX= 200. C
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Fig. 5. Present state of maturation of Type II organic matter contained in rocks of Fig. 3. Estimates of amounts of oil and total hydrocarbons plotted and related to present depth, age and temperature.

organic matter is Type II, i.e. a mixture of terrigenous and algal-marine derived organic matter. This assumption seems compatible with the fact that from the Cambrian to the Present Type II organic matter is the most widely known oil source-rock in the geological series all over the world.

Present state for Case No. 1

The present state of the organic matter is recorded on Fig. 5 which is a reproduction of part of the computer print-out. This print-out supposes the presence of one per cent of Type II organic matter in each level of the series. It records oil and gas production from this organic matter for each burial depth. The present temperature and age of deposition are also given (refer also to Fig. 3).

Both oil and gas are being released now from sediments of the Paleocene at the 3000 metre level at 95°C with an amount of organic matter being converted to hydrocarbon of approximately 5 per cent. Maximum formation of oil is at the 4000 metre level at 125°C (in the Upper Cretaceous) where the total amount of the organic matter being converted approaches 30 per cent (2/3 of that amount being oil (20 per cent)). At 150°C (5000 metres) gas is being produced both directly from decomposition of organic matter and from cracking of oil — almost 40 per cent of the organic matter being converted.

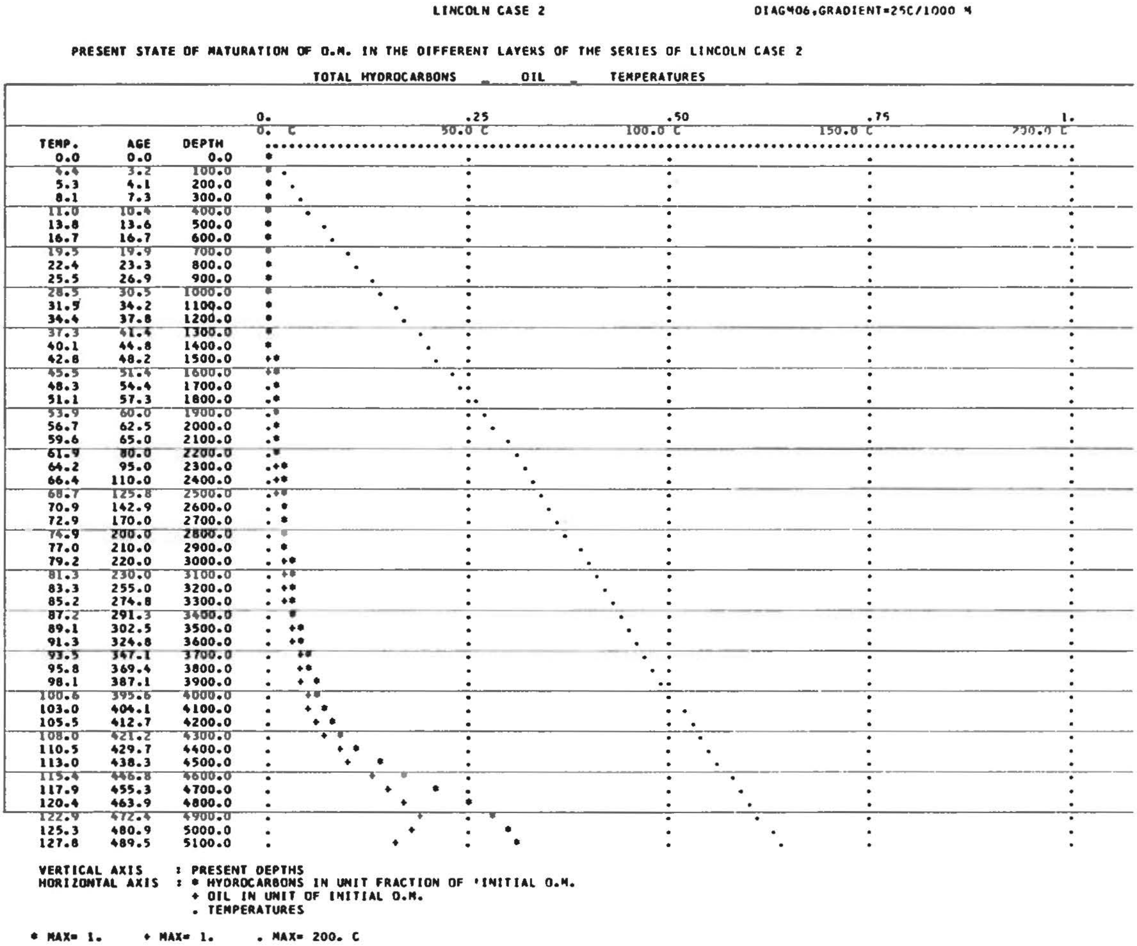
Neglecting substantial upward migration of the oil and gas through fracture systems it is reasonable to suggest that any suitable reservoirs in the Paleocene and Upper Cretaceous may contain oil or gas. The Lower Cretaceous would probably have a tendency to contain gas (refer also to Fig. 3).

Present state for Case No. 2

The present state for Case No. 2 is shown on the reproduction of part of the computer print-out contained in Fig. 6. These results should be referred to Fig. 4.

The 95°C temperature level occurs at 3800 metres in this case and the 125°C temperature level is at 5000 metres. At 5100 metres (the deepest simulated in this programme) the amount of oil being released from the organic matter begins decreasing and the amount of gas is increasing. Hydrocarbons probably are being released from all of the lower section to 5700 metres (see Fig. 4.) but the temperature at the Precambrian unconformity likely will be less than 150°C. The fractions of organic matter being converted to hydrocarbons are the same as they are in Case No. 1.

Generated hydrocarbons will be restricted to any reservoirs that are present in the Lower Palaeozoic section.



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                              LINCOLN CASE 2                        DIAGM06,GRADIENT=25C/1000 M

    PRESENT STATE OF MATURATION OF O.M. IN THE DIFFERENT LAYERS OF THE SERIES OF LINCOLN CASE 2
                         TOTAL HYDROCARBONS _ OIL _ TEMPERATURES

                                 0.           .25          .50          .75          1.
                                 0. C        50.0 C       100.0 C      150.0 C      200.0 C
   TEMP.     AGE     DEPTH
    0.0      0.0       0.0
    4.4      3.2     100.0
    5.3      4.1     200.0
    8.1      7.3     300.0
   11.0     10.4     400.0
   13.8     13.6     500.0
   16.7     16.7     600.0
   19.5     19.9     700.0
   22.4     23.3     800.0
   25.5     26.9     900.0
   28.5     30.5    1000.0
   31.9     34.2    1100.0
   34.4     37.8    1200.0
   37.3     41.4    1300.0
   40.1     44.8    1400.0
   42.8     48.2    1500.0
   45.5     51.4    1600.0
   48.3     54.4    1700.0
   51.1     57.3    1800.0
   53.9     60.0    1900.0
   56.7     62.5    2000.0
   59.6     65.0    2100.0
   61.9     80.0    2200.0
   64.2     95.0    2300.0
   66.4    110.0    2400.0
   68.7    125.8    2500.0
   70.9    142.9    2600.0
   72.9    170.0    2700.0
   74.9    200.0    2800.0
   77.0    210.0    2900.0
   79.2    220.0    3000.0
   81.3    230.0    3100.0
   83.3    255.0    3200.0
   85.2    274.8    3300.0
   87.2    291.3    3400.0
   89.1    302.5    3500.0
   91.3    324.8    3600.0
   93.5    347.1    3700.0
   95.8    369.4    3800.0
   98.1    387.1    3900.0
  100.6    395.6    4000.0
  103.0    404.1    4100.0
  105.5    412.7    4200.0
  108.0    421.2    4300.0
  110.5    429.7    4400.0
  113.0    438.3    4500.0
  115.4    446.8    4600.0
  117.9    455.3    4700.0
  120.4    463.9    4800.0
  122.9    472.4    4900.0
  125.3    480.9    5000.0
  127.8    489.5    5100.0

   VERTICAL AXIS    : PRESENT DEPTHS
   HORIZONTAL AXIS  : * HYDROCARBONS IN UNIT FRACTION OF 'INITIAL O.M.
                      + OIL IN UNIT OF INITIAL O.M.
                      . TEMPERATURES

 * MAX= 1.     + MAX= 1.     . MAX= 200. C
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Fig. 6. Present state of maturation of Type II organic matter contained in rocks of Fig. 4. Estimates of amounts of oil and total hydrocarbons plotted and related to present depth, age and temperature.

Summary of the present state and history

The organic matter in the entire section of Case No. 1 from approximately 3000 metres to 5700 metres has been exposed to generating conditions from the past to the present time.

In Case No. 2 favourable conditions have only barely been accomplished and presently extend from 3800 metres to 5700 metres.

Conclusions

There are great hazards in drawing even tentative conclusions about the petroleum potential of the area under the two alternative sets of circumstances suggested. One can make only a guess as to the type of organic matter. The total amount of organic matter surely would not be equal in each of the cases. Great pitfalls loom when estimates are made for the palaeotemperature of deposition of sediments. The same forebodings can be feared when the kinds of sediments that are postulated to have been deposited are chosen. The estimate of the palaeoheat regime as well as the present thermal gradient are open to debate.

Nevertheless petroleum prospectors must make these kinds of choices, and be bold about it when comparing and contrasting widely separated basins in the world. It is clear that Case No. 1 provides the best situation for the generation of hydrocarbons. Furthermore, in Case No. 1 prospecting can begin almost 1000 metres shallower than in Case No. 2.

Therefore, a tectonic regime involving a left-lateral movement of 250 km along the Nares Strait lineament as envisaged by Kovacs (this volume) will provide favourable conditions for petroleum generation in the Lincoln Basin. The explanation is that formation of grabens and thinning of the continental crust provide a higher heat regime. If there has been little or no displacement along the Nares Strait lineament, there may not have been graben formation and crustal thinning to cause the favourable heat regime for oil generation in Lincoln Basin.

The conclusion that has been made here concerning the Lincoln Basin may apply equally to the situation in the northern part of Baffin Bay.

Acknowledgements

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