THERMAL MATURITY AND SOURCE-ROCK POTENTIAL OF THE SEDIMENTARY SUCCESSION FROM THE *DRAKE* FIELD, SVERDRUP BASIN, ARCTIC CANADA

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The thermal maturity and source-rock potential of the sedimentary succession in the Drake *field, Melville Island, Arctic Canada, have been studied using reflected-light microscopy and* Rock-Eval *pyrolysis. The Mesozoic sediments are immature to mature (% Ro = 0.35-0.80). Vitrinite reflectance in Cretaceous sediments ranges from 0.35 to 0.56%; in Jurassic sediments, it ranges from 0.40 to 0.66%, and in Triassic sediments, from 0.50 to 0.80%. The Triassic Schei Point Group shales and siltstones contain organic matter of marine origin, whereas the predominantly plant-derived organic matter present in the Jameson Bay, Ringnes and Deer Bay Formations has higher TOC. Among the Schei Point Group sediments, the Eden Bay Member of the Hoyle Bay Formation has high TOC content (approx. 5.0%) and high HI values (in excess of 600 mg HC/g Corg). It is followed by the Cape Richards Member and the Cape Caledonia Member of the Murray Harbour Formation (approx. 5.0% TOC).*

Regional variations in the level of thermal maturity of Mesozoic sediments in the Sverdrup Basin are mainly a function of burial depth. Thermal subsidence, uplift, erosion and heat associated with periods of diapiric and igneous intrusions may have been responsible for the thermal maturity pattern in the Drake *field. The Jurassic Jameson Bay, Ringnes and Deer Bay Formations are immature to marginally mature, and have limited oil-generation potential due to their high terrestrial input. The organic matter is these formations has good gas potential.*

INTRODUCTION

The Sverdrup Basin, Arctic Canada (Fig. 1), is a pericratonic basin superimposed on deformed PreCambrian to Devonian rocks of the Franklinian Mobile, and is considered as an episutural basin having persistent eastern and western margins. The basin was probably generated by episodic, incipient rifting (Balkwill and Fox, 1982) and, as a result, contains Late Palaeozoic and Mesozoic basalt flows and gabbroic intrusions. In Melville Island, in excess of 5,000 m of Upper Palaeozoic and Mesozoic shales, siltstones and sandstones are present (Balkwill and Fox, 1982). The basin is about 1,220 km long by 400 km wide (Goodarzi *et al.*, 1989). For a more detailed description of the Mesozoic stratigraphy of Melville Island (Fig. 3), the reader is referred to Embry (1983; 1984 a,b,c).

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A number of oil- and gasfields are present in the Sverdrup Basin, containing approximately 85 MM* cu. m of oil and 370 B* cu. m of dry gas (Procter *et al.*, 1984; Goodarzi *et al.*, 1989). These fields are situated near Melville Island (the *Hecla* and *Drake* fields) (Fig. 2), or Lougheed Island to the NE (e.g. the *Whitefish, Cisco, Skate* fields). Although reconnaissance geochemical work in the Canadian Arctic Islands began prior to 1970, the source-rock potential of specific stratigraphic units within the Mesozoic succession of the Sverdrup Basin became the focus of research during the mid-1970's. The work of Baker *et al.*, (1975), Henao-Londono (1977) and Powell (1978) points to the presence of potential source rocks in the Triassic Schei Point Group, which is interpreted to be responsible for the generation of gas found in the *Hecla* and *Drake* fields. More recently, Goodarzi *et al.*, (1989), using organic petrological and organic geochemical techniques (biomarkers), concluded that the Eden Bay Member of the Hoyle Bay Formation (Upper Triassic) was one of the main source rocks in the southern margin of the Sverdrup Basin.

The hydrocarbon-generating potential and thermal maturity of the *Hecla* field, offshore Melville Island, has been discussed in detail by Gentzis and Goodarzi (1991), as has the potential of the Lougheed Island hydrocarbon fields (Goodarzi *et al.*, 1992). Therefore, the present study is concerned with the regional thermal maturity and source-rock potential of the *Drake* field only, and its purpose is threefold:

(1) to study the maturity and source-rock potential of the successions in the *Drake* field, Melville Island, and produce maturation profiles for selected drillholes;
(2) to produce maps showing contours of thermal maturation levels in the study area;
and (3) to determine zones of oil and gas generation and/or destruction.

EXPERIMENTAL PROCEDURE

Sample collection and preparation

A total of approximately 200 core and cuttings samples taken from Palaeozoic and Mesozoic sediments in ten drillholes from the *Drake* field and in four others drilled nearby were collected at the core depository of the Institute of Sedimentary and Petroleum Geology in Calgary, Alberta. Samples were collected from lithologic intervals in the Mesozoic known to be rich in organic matter (shales), as well as from siltstones and sandstones. The vertical sampling interval in the organic-poor successions was kept at a maximum of 50 m, but in organic-rich successions (source rocks) a much smaller sampling interval (10 m) was employed. This was done because of the thin nature of the source rocks, and the possibility that potential source rocks could have been missed if the sampling interval was more than 10 m. Cutting samples were also collected from other lithologies (carbonates) from the Upper Palaeozoic of the *Drake* field. The procedure followed in preparing the samples for microscopic examination is similar to that used in coal petrology (Mackowsky, 1982).

Selected samples from the *Drake* field were also analyzed using a *Rock-Eval*/TOC pyrolysis apparatus (Espitalié *et al.*, 1979) in order to estimate the level of thermal maturity and to characterize the organic matter type. Aliquots of 10 to 50 mg of powdered sample were analyzed, and the results are recorded in Table 1 (p. 53).

Equipment used

Reflectance analysis of the dispersed organic matter present in whole-rock drill cuttings and conventional cores was carried out using a reflected-light *Zeiss MPM II* microscope equipped both with white (halogen 12V, 100W) and fluorescent (HBO, 100) light sources. The microscope was attached to a *Zonax* microcomputer and *Epson* printer. An ultra-high pressure mercury lamp for 450-490 mm excitation, a dichroic mirror at 510 mm and a 520 barrier filter were used for qualitative observation of the organic matter.

* *MM: million (10^6); B: billion (10^9).*

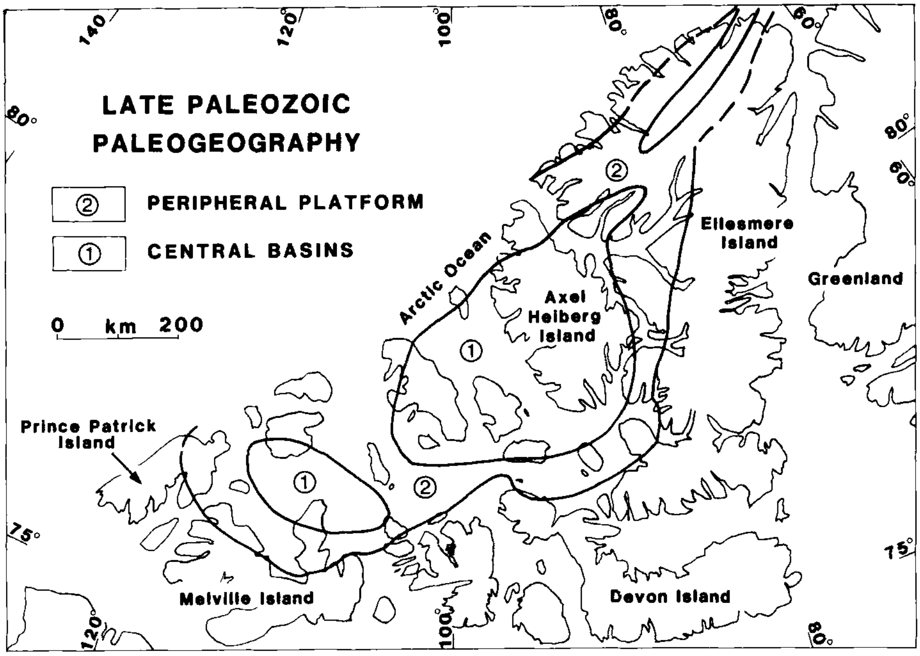


Fig. 1. Outline of the Sverdrup Basin, Arctic Canada (modified after Beauchamp *et al.*, 1987).

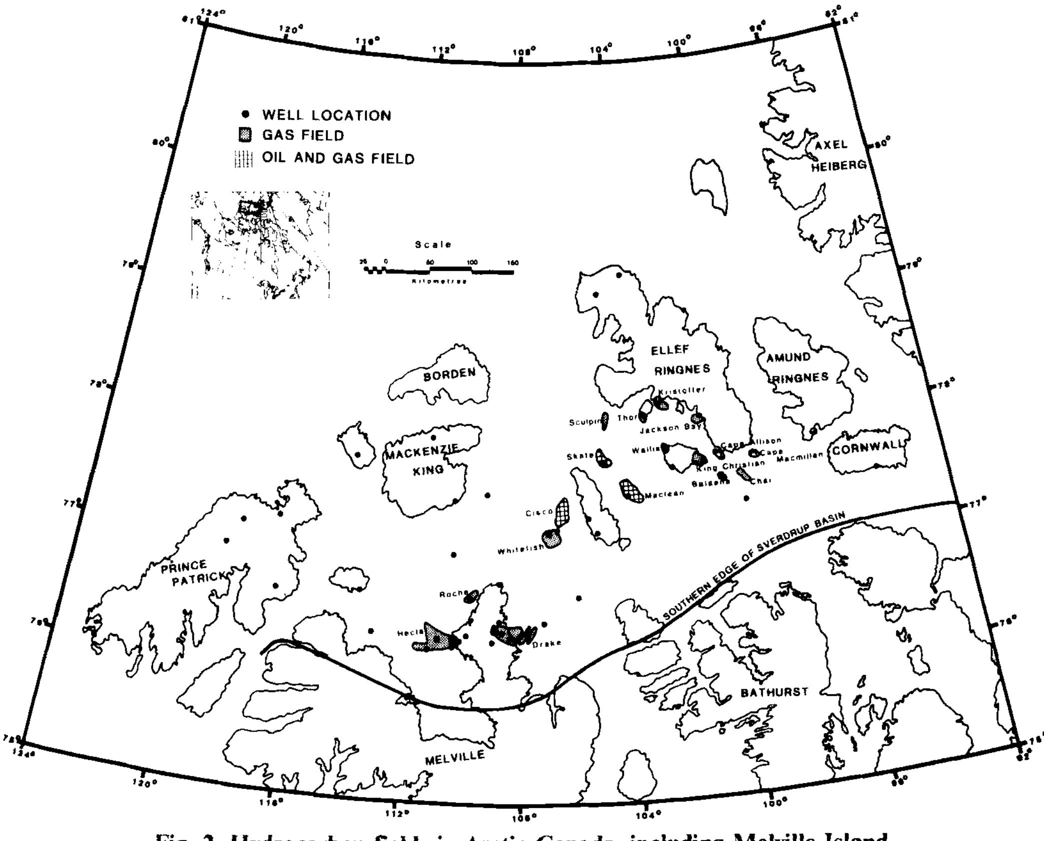


Fig. 2. Hydrocarbon fields in Arctic Canada, including Melville Island.

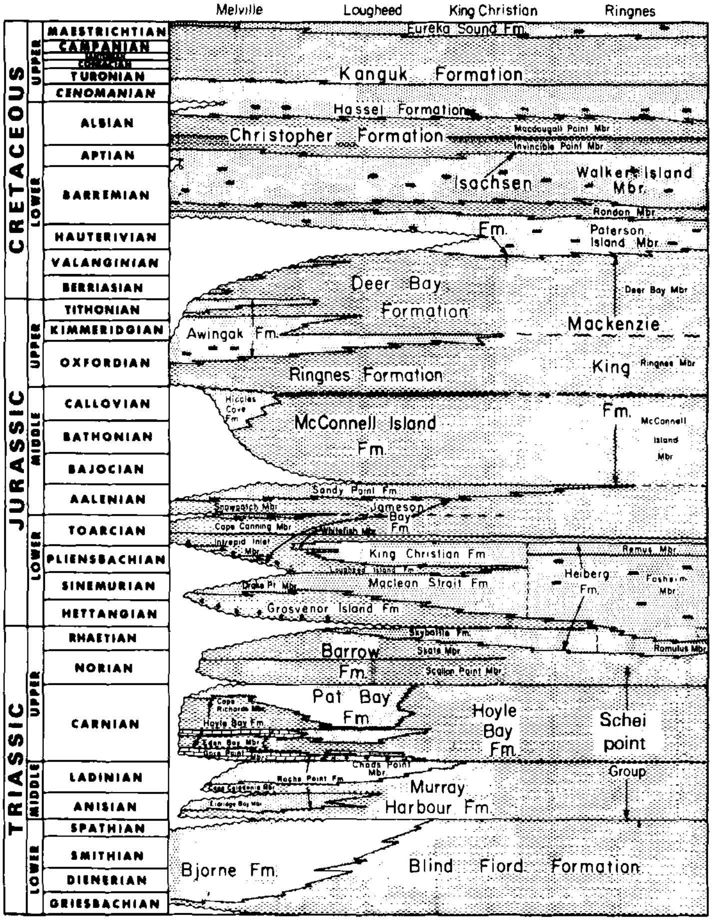


Fig. 3. Mesozoic stratigraphy of the Sverdrup Basin (modified after Embry, 1984 a,b).

RESULTS AND DISCUSSION

The source-rock potential and thermal maturity of sediments from the *Drake* field will be discussed in the following order:

(1) Organic petrology and thermal maturity of *Panarctic Drake Point D-68, Drake F-16* and *Drake P-40* — the above drillholes were selected for the following reasons: (a) *Drake Point D-68* is the deepest drilled in the field and shows the effect of igneous intrusions on reflectance; (b) due to similarities in the vitrinite reflectance *versus* depth profiles of the remaining drillholes, only two were selected, one offshore *(Drake P-40)* and one on land (*Drake F-16)*.
(2) Source-rock potential of all *Drake* field drillholes based on *Rock-Eval* and petrological data; and
(3) Regional thermal maturity of the *Drake* field in the form of structural and *iso*reflectance contour maps, accompanied by geothermal, maturation gradients and cross-sections.

The *Drake* field

The *Drake* field (Fig. 2) is located between Long. 107° to 109° and Lat. 76° to 76° 30'. Ten drillholes were drilled in or adjacent to this field, and four more were drilled in the

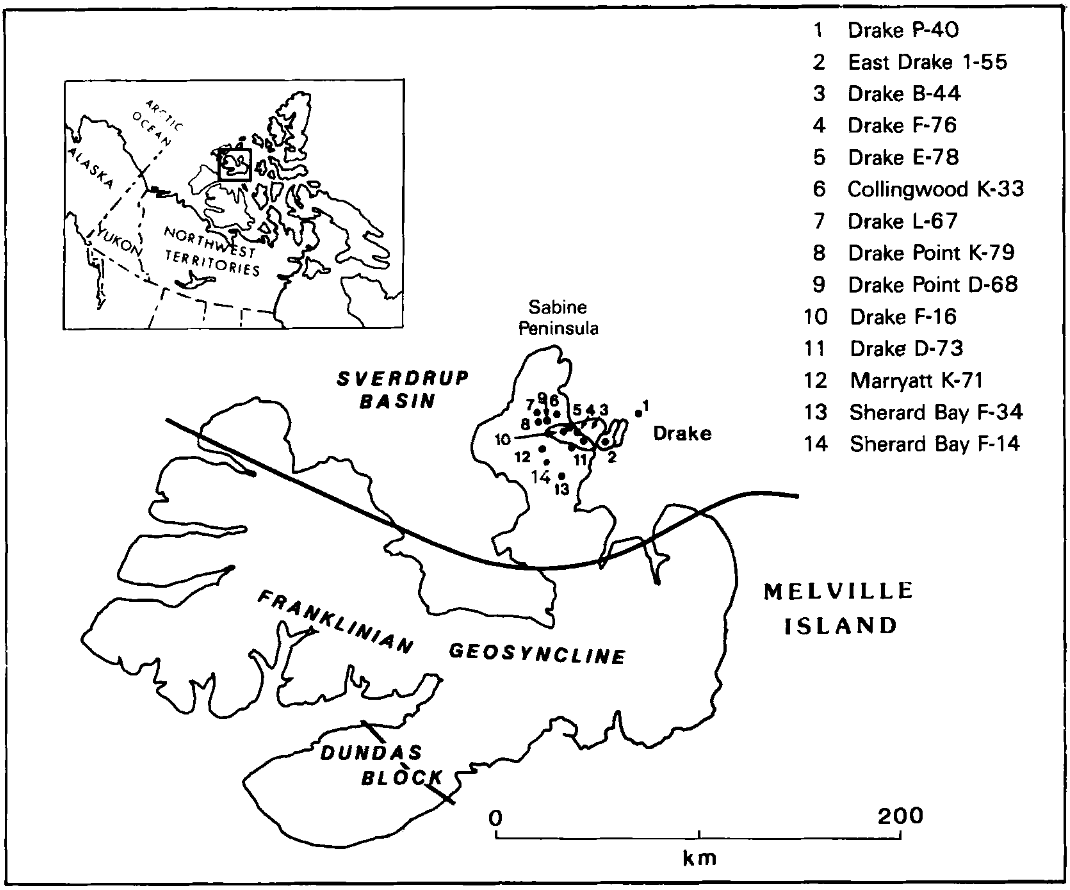


Fig. 4. *Drake* **field and vicinity, showing drillhole locations.**

general vicinity (numbered 1 to 14 in Fig. 4). Two drillholes, namely *Drake P-40* and *East Drake I-55* are situated offshore and to the east of Sabine Peninsula. The reflectance *versus* depth profile of all *Drake* field and nearby drillholes is shown in Figs. 5 to 11. Most of the drillholes are relatively shallow, penetrating the Middle to Upper Triassic Schei Point Group. The total depth ranges between 1,200 m in *Drake F-76* (Fig. 8) and 5,400 m in *Drake Point D-68* (Fig. 5), which penetrates into the Permian Hare Fiord Formation.

Thermal maturity

The maturity of the Triassic Schei Point Group ranges between 0.55 and 0.80 % Ro, indicating that the formations fall in the marginally-mature to mature stage of hydrocarbon generation. The onset of maturity (0.5% Ro) is reached at depths as shallow as 800 m in drillhole *Drake Point D-68* (Fig. 5), or as deep as 2,000 m in drillhole *Drake L-67* (Fig. 9). The lower boundary of the "oil window" (Ro approx. 1.3%) is reached at 4,300 m in *Drake Point D-68* (Fig. 5). The depth-limits of the hydrocarbon generation zone appear to vary regionally, and are a function of the amount of burial and uplift, at least in the non-intrusive areas of Melville Island. Where there are intrusives, as in the vicinity of *Drake Point D-68*, the heat generated has resulted in localized, steep maturity gradients relative to the country rock (Fig. 5).

The Schei Point Group sediments are characterized by the presence of marine organic matter. They are marginally-mature in the south part of Sabine Peninsula, but they become progressively more mature towards the centre of the Sverdrup Basin. As a result, they are overmature in the northern part of the Sabine Peninsula (Gentzis, 1991).

The maturity and type of organic matter in the sedimentary succession for a specific unit, for example the Schei Point Group, is very similar for all drillholes in the *Drake* field. Therefore, only a few selected drillholes are discussed in detail.

Panarctic Drake D-68

This is the deepest drillhole in Melville Island, and has a total depth of approximately 5,384 m (Fig. 5). Formations range in age from Pennsylvanian to Lower Cretaceous, covering a wide range of lithologies. The Jurassic-Cretaceous interval is dominated by shales, siltstones and minor limestones, whereas the thick Triassic Bjorne Formation is composed of sandstones having a good porosity. Siltstones and shales with minor limestones and sandstones make up the Permo-Pennsylvanian part of the succession, with the exception of two intervals at 4,675 m and 4,810 m. This is a contact-metamorphic zone influenced by the intrusion of granodiorite sills (Balkwill and Haimila, 1978).

The phytoclast content in *Drake Point D-68* consists of higher plant remains (coal) in the Jurassic Awingak and Cretaceous Isachsen Formations. Most of the Triassic interval is relatively barren of organic matter due to its arenaceous nature. The Schei Point Group is often rich in marine algae, i.e. dinoflagellates and *Tasmanites* in *Drake Point D-68* and other drillholes such as *Drake F-16* and *Drake B-44.*

The maturation pattern (Fig. 5) is relatively clear to a depth of about 1,200 m, with an increase in reflectance from 0.42% to 0.53% indicating that the sediments at the base of the Jurassic are marginally mature. The Schei Point sediments contain mainly marine organic matter (Type I kerogen), and are in the early-mature stage of hydrocarbon generation (% Ro approx. 0.70). An intense "background" orange to light-brown fluorescence is observed in numerous Schei Point samples. Teichmuller and Ottenjann (1977), Creaney (1980), and Goodarzi *et al.*, (1987) describe a similar matrix effect from the *Posidonia* shale of West Germany, the Upper Cretaceous Boundary Creek Formation in the Beaufort-Mackenzie Basin, and the Carboniferous Grinnel Peninsula, Emma Fiord oil shales in Arctic Canada, and attribute it to adsorption of lipoid substances by vitrinite fragments.

Following a 1,000-m thick organic-barren interval, the Lower Triassic Blind Fiord in *Drake Point D-68* contains moderate amounts of vitrinite. This vitrinite has a Ro random of 0.8%, indicating that the section is in the mature zone of oil generation. The reflectance trend is not affected by the presence of three minor unconformities (Fig. 5).

Panarctic Drake F-16 and Panarctic Drake P-40

The first drillhole is approximately 1,500-m deep, and the formations penetrated range in age from Middle Triassic (Eldridge Bay) to Lower Cretaceous (Christopher). Vitrinite reflectance is well-represented in all formations, with the exception of the lower part of the Eldridge Bay Member (Fig. 6). Reflectance near the top is approximately 0.40%, whereas reflectance of hydrogen-rich organic matter in the Eden Bay and Cape Caledonia Members is most probably suppressed by almost 0.05%. Measured values are in the 0.52 to 0.55% range, and the extrapolated reflectance trend indicates that the reflectance level near 1,400 m should have been at least 0.6% (Fig. 6).

The second drillhole is an offshore one; the top formation is the Isachsen, and the deepest penetrated is the Eldridge Bay (Fig. 7). The drillhole is relatively shallow, and vitrinite reflectance ranges from approximately 0.4% just below the water/Isachsen contact, to 0.60% in the Middle Triassic formations (Fig. 7). The reflectance trend is relatively smooth with a continuous increase with depth. Vitrinite reflectance is well represented in all formations except the Eldridge Bay, a situation similar to that in *Drake F-16.*

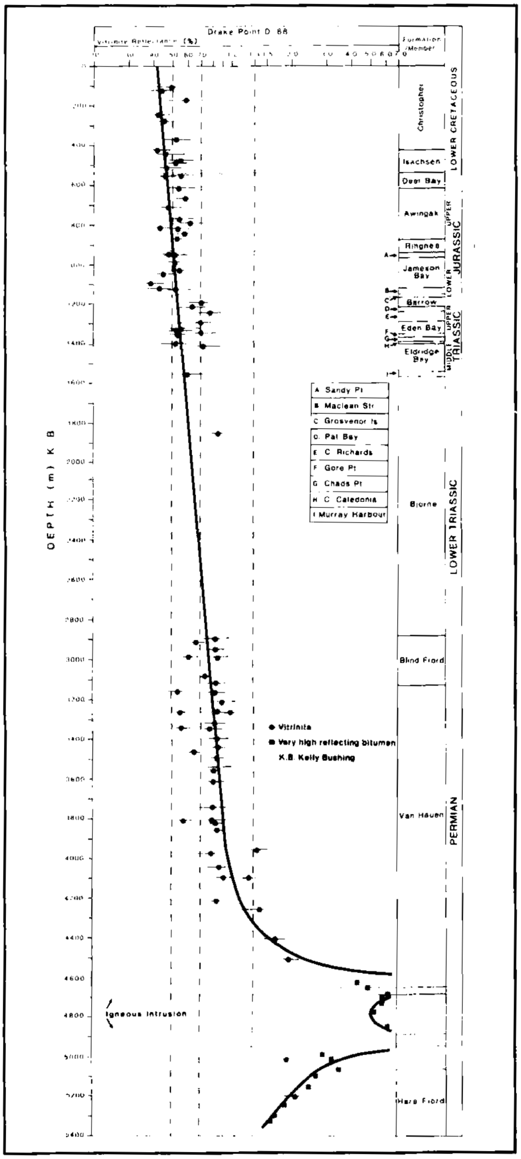


Fig. 5. Reflectance *versus* **depth profile,** *Panarctic Drake D-68.*

Optical changes in response to rapid heating

The maturity of organic matter in drillhole *Drake Point D-68* at depths of 4,650 — 4,700 m and 4,890 — 4,960 m is much higher compared to the maturity in the country rocks, due to a granodiorite intrusion (Fig. 5). Reflectance of the organic matter increases rapidly below a depth of 4,300 m, and reaches a level of >6.0% Ro max. near the contact with the sill. Near the bottom of the drillhole, at 5,400 m, reflectance follows the extrapolated trend established above 4,300 m. The sills are up to 70-m thick, but the thermal aureole caused by the igneous intrusion is three to four times the diameter of the sill. Raymond and Murchison (1989), describing the effect of igneous intrusions on organic matter in Scotland, concluded that the lithology of the host rock, the temperature of the magma, the level of maturity prior to sill emplacement, the volume of pore water in the sediments, and the thermal conductivity of the sediments are important factors which influence the

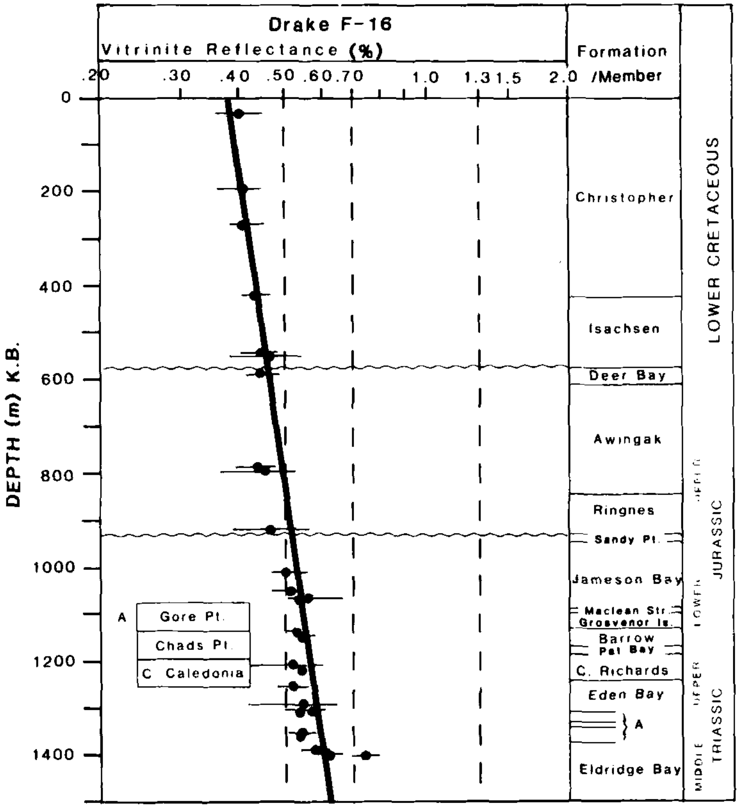


Fig. 6. Reflectance *versus* depth profile, *Panarctic Drake F-16*.

effects of intrusion on organic matter. In addition, Khavari-Khorasani *et al.*, (1990) suggested that the permeability and porosity of the intruded sediments and the overburden pressure are also significant factors influencing the pattern of reflectance increase approaching the igneous body.

In drillhole *Drake Point D-68*, the strata intruded are the Permian shales of the Van Hauen Formation, and the age of the intrusions was estimated to be approximately 130 MM yrs using K/Ar isotopic data (Balkwill and Haimila, 1978). The substantial time interval between the deposition of the sediments and the intrusion of the sill, possibly as long as 150 MM yrs, was sufficient for water expulsion and lithification of the Van Hauen shales to take place. As a result, heat loss due to water vaporization was minimal, because the shales were very well lithified and contained no pore water. During the time interval between the deposition of the shales and the intrusion, the regional geothermal gradient most probably raised the thermal maturity of the organic matter to such a level (>1.0% Ro) that it formed a granular anisotropy ("mosaic") during the intrusions. The result was the development of a very thick thermal aureole both above and below the sills; Raymond and Murchison (1988) and Synman and Barclay (1989) suggested a similar explanation for their observations in County Durham, UK, and Colorado, USA, respectively.

The granular anisotropy is similar to that observed in natural coke (Gentzis, 1991). The temperature of emplacement of a granodiorite sill is approximately 850°C, well above the 500°C required to produce an optical "mosaic" texture in vitrinite of caking and coking-coal rank (Goodarzi, 1984). The development of such a texture in a natural environment indicates that the vitrinitic organic matter had reached the rank level due to regional

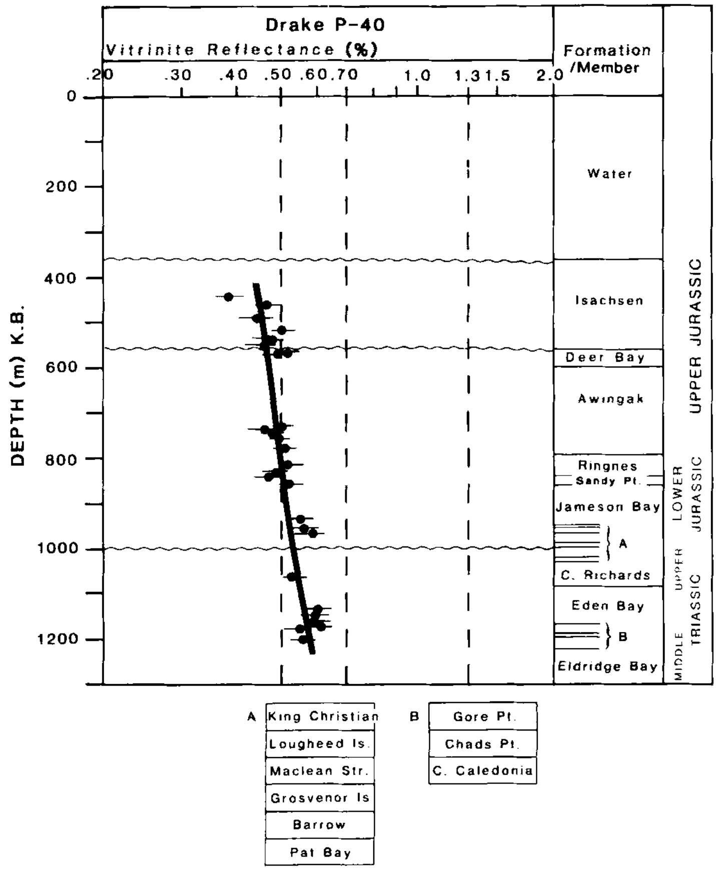


Fig. 7. Reflectance *versus* depth profile, *Panarctic Drake P-40.*

thermal maturation, at which the vitrinite's structure went through complete re-organization in response to elevated temperatures caused by the intrusions.

ROCK-EVAL PYROLYSIS

Thermal maturity

The level of thermal maturity of the highly oil-prone source rocks within the Schei Point Group is between 0.60 and 0.70% Ro, which is indicative of the early stage of hydrocarbon generation from Type II kerogen. At this level, a certain portion (possibly as much as 10%) of the thermally-labile kerogen should have been converted to hydrocarbons, a process influencing the Production Index (S1/S1+S2), provided that these values have not been affected by migrated hydrocarbons from another, deeper source.

The PI values measured range from 0.03 to 0.09%, with most values being 0.04 to 0.05% (Table 1). This in turn indicates either that the PI values are lower than expected for the indicated level of maturity, because of the early generation and expulsion of hydrocarbons from the Type II kerogen within the Schei Point source beds; or that the Schei Point Group contains mainly Type I kerogen, which has not reached the onset of the principal phase of oil generation (approx. 0.7% Ro). In reality it could be both, because certain beds within the Schei Point Group (i.e. Cape Caledonia, Cape Richards) contain an admixture of Type I/II kerogen, consisting of planktonic marine algae (*Leiosphaeridia,*

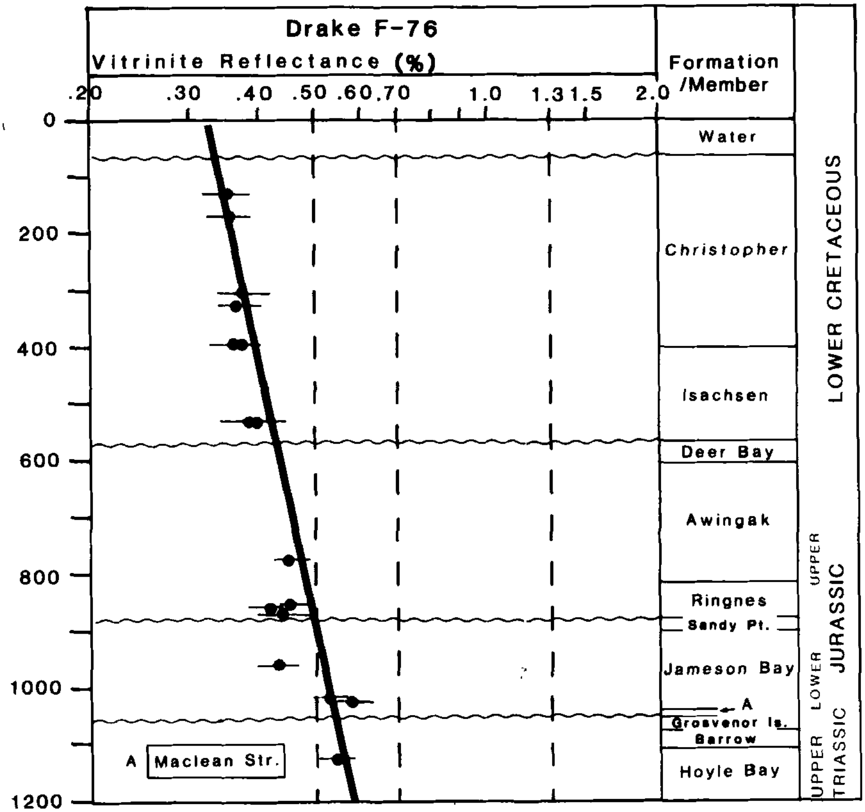


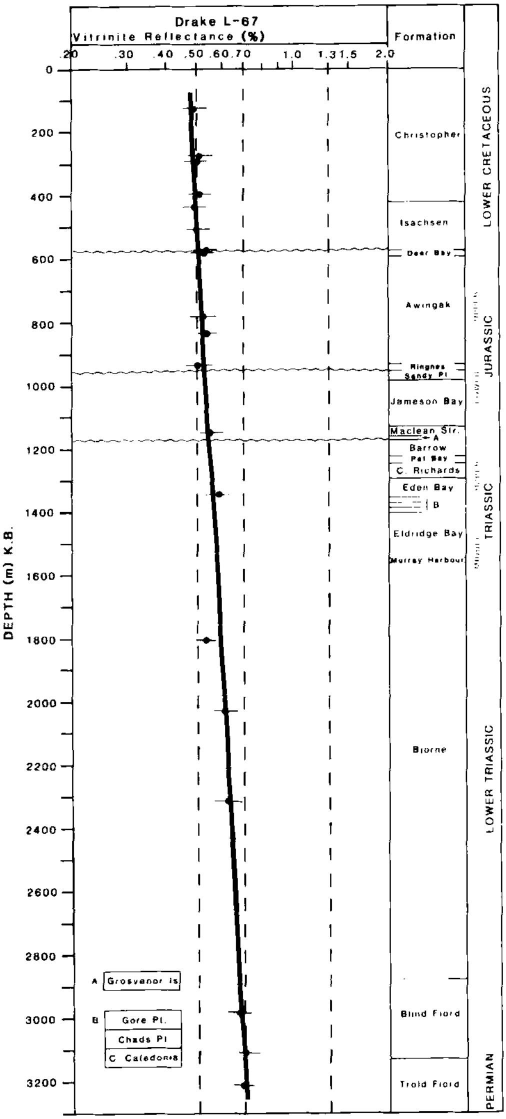
Fig. 8. Reflectance *versus* depth profile, *Panarctic Drake F-76*.

Nostocopsis, Pterosphaeridia, Tasmanites and dinoflagellate cysts) embedded in an amorphous, fluorescing matrix of bituminite, along with minor sporinite, cutinite and liptodetrinite (Gentzis, 1991). Also, the interbedded nature of the Schei Point Group sediments (shales, siltstones, sandstones and minor limestones) provide an ideal setting for secondary migration.

Source-rock potential

The good-to-excellent source-rock potential of the Schei Point Group sediments is evident from the results obtained by *Rock-Eval* pyrolysis (Figs. 12 and 13, Table 1). The area near the southern margin of the *Drake* field, in the vicinity of the Sherard Bay and Collingwood drillholes, contains organic matter with some of the highest HI values encountered anywhere in the Sverdrup Basin. Among the highest values in *Sherard Bay F-34* and *F-14* are the Cape Richards Member (474-553 mg HC/g C_{org}) and the Eden Bay Member (480-548: Table 1). The Eden Bay in *Collingwood K-33* has an HI as high as 700 mg HC/g Corg, and the Cape Caledonia Member as high as 506. In *Drake L-67*, the Eden Bay has an HI value of 650 mg HC/g C_{org} (Table 1).

Moving towards the vicinity of *Drake Point D-68* and *K-79*, the Eden Bay still has high HI values (428-682 mg HC/g C_{org}), and a TOC of 4.2-5.7%, while T_{max} is 428-431°C and Ro is <0.7% (Table 1). The Cape Caledonia is less rich: HI is 281-559 mg HC/g C_{org}, TOC is 1.1-3.8%, T_{max} is 433-436°C. It is followed by the Cape Richards: HI = 129-508 mg HC/g C_{org}, TOC = 1.3-3.0%, T_{max} = 432-436°C, and Ro = <0.7% (Table 1). The immature Eden Bay marine shales are organic-rich throughout the *Drake* field, with an average TOC of 3.5-



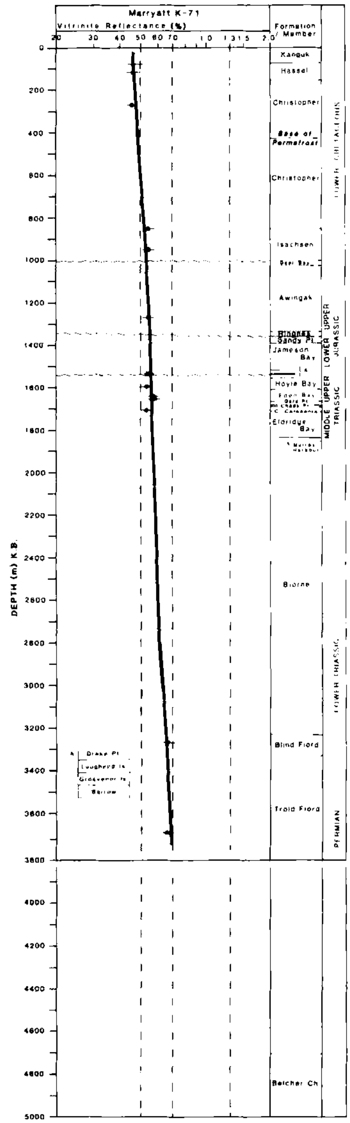
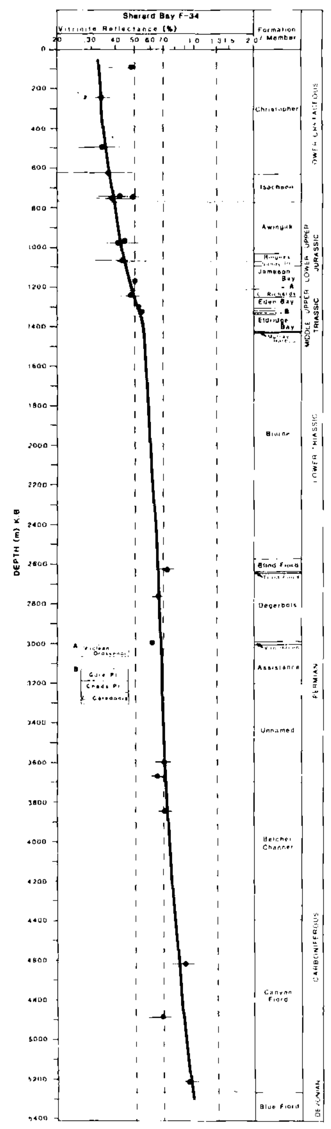


Fig. 9. *(left)* **Reflectance** *versus* **depth profile,** *Panarctic Drake L-67.*

Fig. 10. *(right)* **Reflectance** *versus* **depth profile,** *Panarctic Marryatt K-71.*

6.0% and a T_{max} of 423-432°C. The above member has an HI of 622 mg HC/g C_{org} in the *Drake F-16* drillhole, 508 in *Drake B-44*, and 623-642 in *Drake P-40* (Table 1). The Cape Richards shales have an HI value of 392 mg HC/g C_{org} in *Drake F-16*, while the Eldridge Bay has an HI of 419 in the same drillhole (Table 1). The Cape Caledonia has an HI value of 462 mg HC/g C_{org} in *Drake B-44*, and the Cape Richards a value of 433 mg HC/g C_{org} in *Drake D-73* (Table 1).

Most of the remaining Mesozoic potential source rocks, such as the Jameson Bay, Ringnes and Deer Bay, are immature to marginally-mature, and have lower HI and higher OI values (Table 1, Figs. 12 and 13). The Lower Triassic Bjorne Formation consists



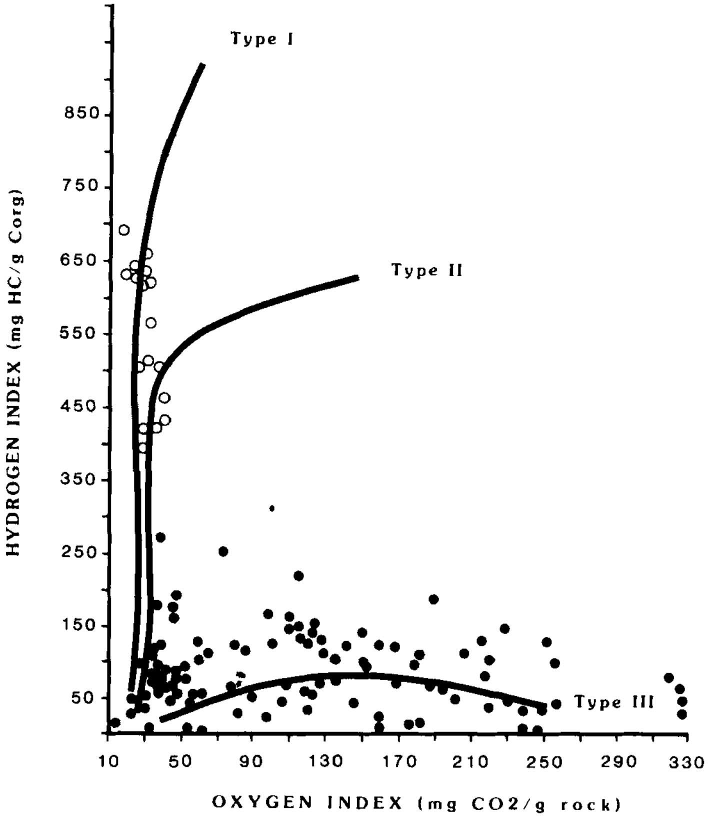


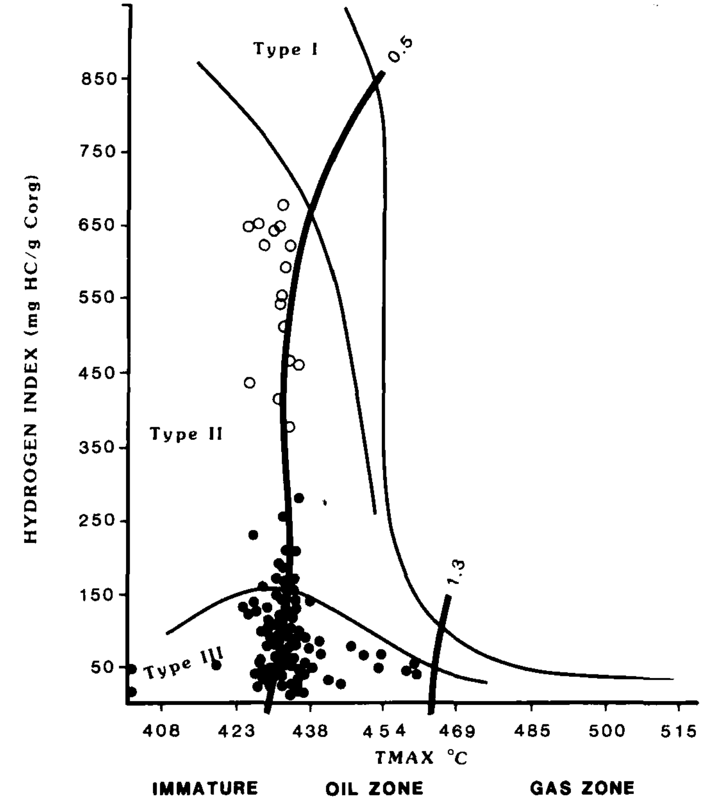
Fig. 11. *(left)* **Reflectance** *versus* **depth profile,** *Panarctic Sherard Bay F-34.*

Fig. 12. *(above)* **Plot of HI** *versus* **OI for Mesozoic samples; Schei Point (○), Jameson Bay, Ringnes, Deer Bay, and Christopher Formations (●).**

mainly of quartzose sandstones with conglomerate interbeds, whereas the Blind Fiord Formation consists of red and green silty shales (Thorsteinsson and Tozer, 1970). These formations have very little source potential as determined by organic petrology and *Rock-Eval* pyrolysis, as documented by Powell (1978).

The Permo-Pennsylvanian section is in the mature stage of hydrocarbon generation, but both *Rock-Eval* (Table 1) and petrological data indicate poor source-rock potential. The total organic carbon (TOC) values obtained from several Van Hauen Formation samples range from 0.55 to 1.23%, while the HI values are low (13-97 mg HC/g Corg), and so are the S2 values (0.10-2.89) (Table 1). Powell (1978) stated that gas yields and organic carbon values are extremely low, with the exception of drillholes in the Sabine Peninsula.

Fig. 13. Plot of HI *versus* T_{max} (°C) for Mesozoic samples; Schei Point (○), Jameson Bay, Ringes, Deer Bay, and Christopher Formations (●).



REGIONAL MAPS

A series of *iso*reflectance and structural contour maps for the most prolific source rocks in the *Drake* field has been constructed in order to evaluate the potential of sediments for hydrocarbons generation. Contour maps showing the regional variation of the hydrogen index and S2 peaks for Schei Point source rocks have been constructed, and a series of structural cross-sections showing *iso*reflectance lines superimposed on lithostratigraphic units will also be discussed.

Isoreflectance maps

*Iso*reflectance maps were constructed for the following lithostratigraphic boundaries: (1) the base of the Cretaceous Isachsen Formation (Fig. 14a); the base of the Jurassic-Cretaceous Deer Bay Formation (Fig. 14b); the base of the Jurassic Ringnes Formation (Fig. 14c); the base of the Jurassic Jameson Bay Formation (Fig. 14d); and (2) the top of the Barrow Formation (Fig. 14e).

Reflectance increases from approximately 0.4-0.5% near the Sverdrup Basin margin for all lithostratigraphic units, to approximately >0.7% in the area of *Drake Point D-68*. There is some similarity in the *iso*reflectance trends of the Mesozoic formations, particularly between the Barrow and the Jameson Bay Formations (Fig. 14e and d), as well as among the Ringnes, Deer Bay and Isachsen Formations (Fig. 14 a, b, c).

Structural contour maps

Structural contour maps were prepared for the same lithostratigraphic boundaries (Fig. 15 a-e), and were compared to the *iso*reflectance maps. The structural contour map of the top of the Barrow Formation (Fig. 15e) shows an increase of burial depth from approximately 1,000 m in *Drake P-40* to almost 1,370 m in *Drake K-79*. The base of the Jameson Bay (Fig. 15d) is encountered at approximately 850 m in *Drake P-40* and 850 m in *Drake K-79*. For the base of the Ringnes (Fig. 15c), the depths are 770 m and 1,050 m respectively; for the Deer Bay (Fig. 15b) — 540 m in *Drake D-68* and 750 in *Drake K-79*; and for the Isachsen (Fig. 15a) — 350 m in *Drake P-40* and 600 m in *Drake D-73* (Gentzis, 1991).

HI and S2 contour maps

HI values in the immature to marginally-mature source rocks of the *Drake* field range from 433 to 700 mg HC/g C_{org} (Fig. 16). This is similar to the *Hecla* field, and indicates a trend towards more anoxic conditions basinwards.

Rock-Eval pyrolysis data (Table 1) indicate good-quality potential source rocks in the Schei Point Group of the *Drake* field. S2 values for the Schei Point Group range from 10 to 37 mg HC/g rock, and are highest in the offshore drillholes (Fig. 17). This points to the occurrence of good-quality source rocks within the Murray Harbour and Hoyle Bay Formations in the *Drake* field. The S2 contour map shows a good similarity to the *iso*-HI contour map (compare Figs. 16 and 17).

Cross-sections

A series of cross-sections has been constructed through the *Drake* field, and the sediments have been divided into immature, marginally mature, mature and overmature categories.

Cross-section A-A' (Fig. 18) connects *Chads Creek B-64* in the *Hecla* field to *Drake L-67*. The strata penetrated are mainly Mesozoic, with the exception of *Chads Creek B-64, Marryatt K-71* and *Drake Point D-68*, where the oldest formations are Pennsylvanian. The 0.5% Ro *iso*reflectance line is parallel to the lithostratigraphic boundaries, whereas the 0.6% Ro line crosses the boundaries in the eastern part of the section, as well as the western part, due to the low thermal maturation gradient in *Marryatt K-71*. Cretaceous sediments are mostly immature, while Jurassic and Triassic sediments are between marginally mature and mature (% Ro >0.55).

Cross-section B-B' (Fig. 19) correlates the Sherard drillholes, which are located near the margin of the *Drake* field, to those in the *Drake* field, onshore and offshore. The strata penetrated are Mesozoic, with the exception of *Sherard F-34* which penetrates down to the Blue Fiord Formation. The structural contour lines correlate well, and the Mesozoic formations are encountered at similar depths. *Collingwood K-33* has a thicker Christopher Formation section; thus, the formation tops are slightly deeper than in the remaining drillholes. When superimposed on the structural contours, the 0.5 and 0.6% *iso*reflectance lines are sub-parallel to parallel. In fact, the 0.6% contour shows better parallelism to the structural contours than does the 0.5% *iso*reflectance line. This indicates that maturation in the *Drake* field was syndeformational with a post-deformational component, similarly to the *Hecla* field (Gentzis and Goodarzi, 1991).

Geothermal gradients

The present-day geothermal gradients in the *Drake* field are between 13 and 26°C/km, values which are at the low end of the "normal" range (Gretener, 1981). This is similar to the geothermal gradients of the *Hecla* field (13-20°C/km) (Gentzis, 1991). Similar geothermal gradients (15-34°C/km) have also been calculated for Lougheed Island, Sverdrup Basin, by Goodarzi *et al.*, (1992), Skibo *et al.*, (1990) and Jones *et al.*, (1989) (24-34°C/km). In addition, the low present-day geothermal gradient obtained for the *Drake Point D-68* drillhole (approx. 13°C/km below 1,400 m) is in agreement with previous results (Bustin, 1986).

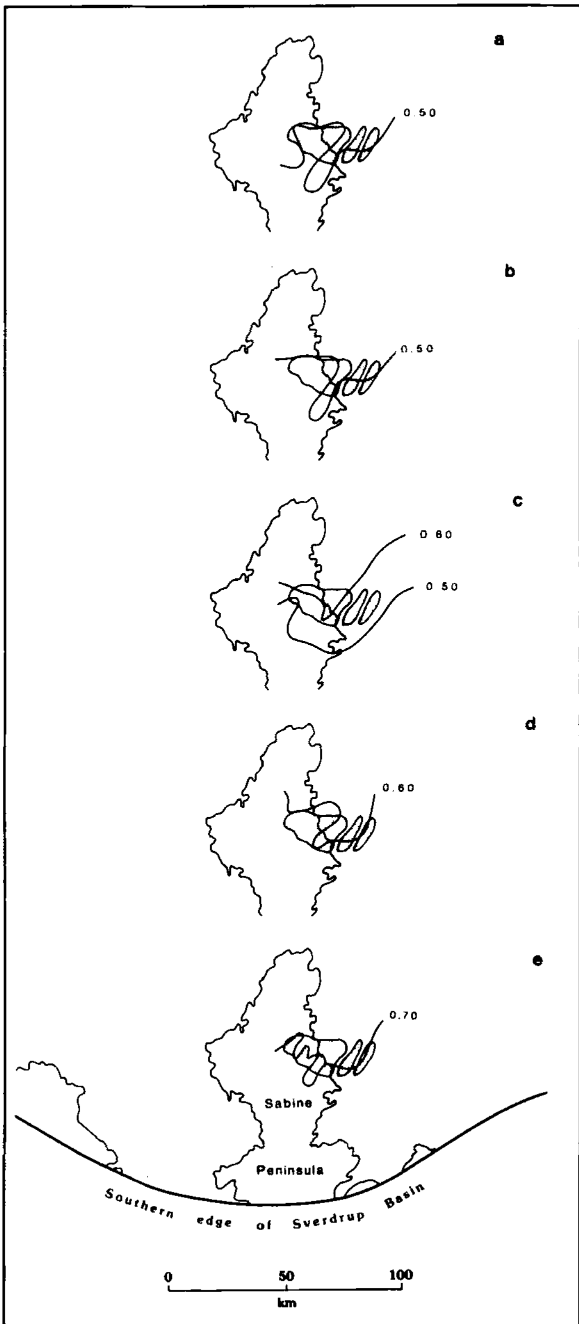


Fig. 14. ***Iso*reflectance contour maps (% Ro) for Mesozoic formations.**
Base of Isachsen Formation (a); Base of Deer Bay Formation (b); Base of Ringnes Formation (c); Base of Jameson Bay Formation (d); Top of Barrow Formation (e).

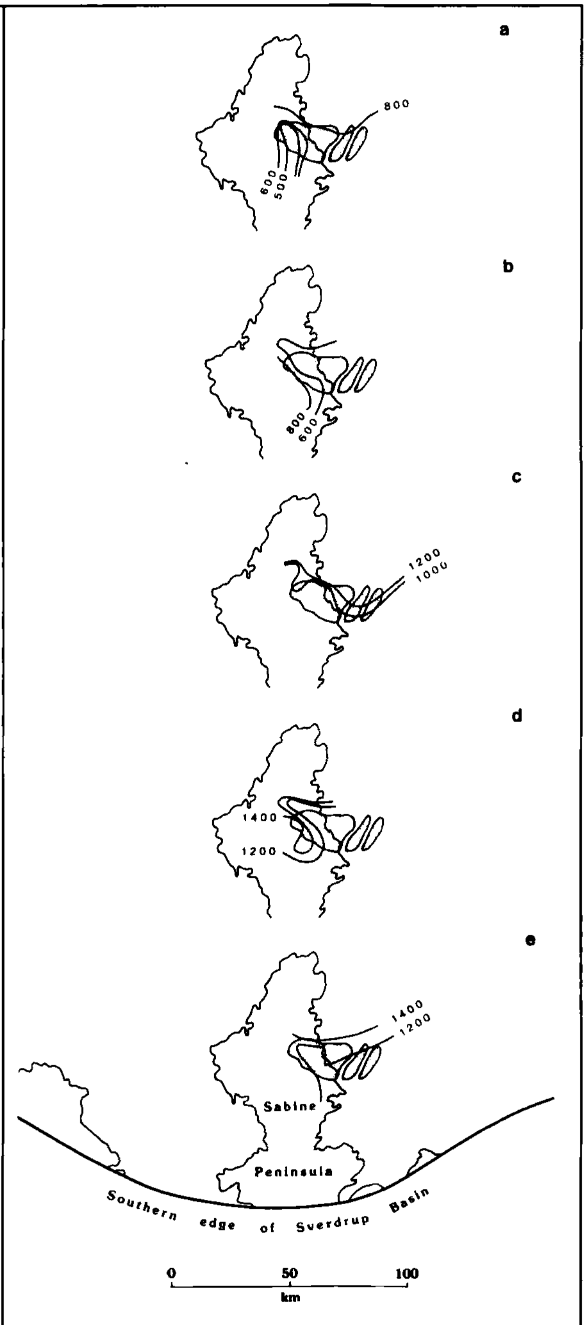


Fig. 15. Structural contour maps (m) for Mesozoic formations.
Base of Isachsen Formation (a); Base of Deer Bay Formation (b); Base of Ringnes Formation (c); Base of Jameson Bay Formation (d); Top of Barrow Formation (e).

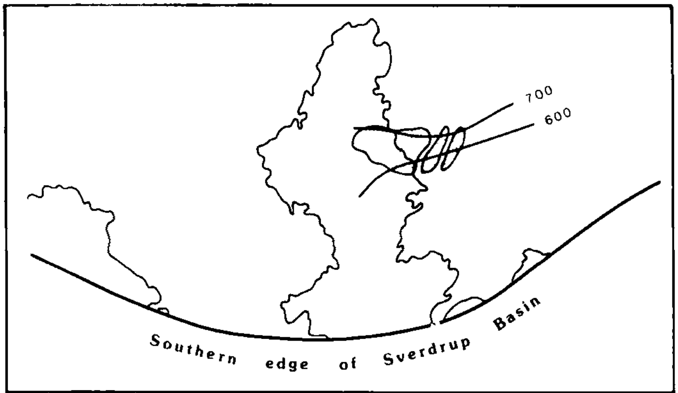


Fig. 16. HI contour map (mg HC/g Corg) of Schei Point sediments.

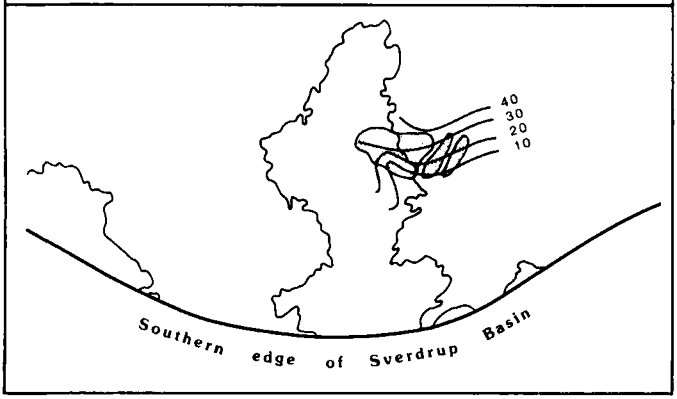


Fig. 17. S2 contour map (mg HC/g rock) of Schei Point sediments.

The above gradients were calculated from equilibrium bottom-hole temperatures (BHT) and drillstem tests. The low geothermal gradients in the Sverdrup Basin are probably caused by the thick sedimentary-rock section.

Maturation gradients

The maturation gradients range from 0.08 to 0.20 log % Ro/km, with most of the drillholes having a gradient of about 0.15 log % Ro/km (Table 2, page 54). The highest gradient is observed in drillholes *Drake B-44*, *Drake F-76* and *East Drake I-55*, and the lowest in drillhole *Drake L-67*.

The low maturation gradients observed in the *Drake* field correspond to "less-than-average" temperature gradients, and may have resulted either from the imposition of low palaeogeothermal gradients during maturation, or from rapid sedimentation and uplift in the Tertiary (Eurekan Orogeny), so that an equilibrium geothermal gradient may not have been possible. The Sverdrup Basin was initiated by episodic, incipient rifting, and received large volumes of sediment, which resulted in high sedimentation rates.

Similar observations have also been made in Lougheed Island (Goodarzi *et al.*, 1992), in the *Hecla* field (Gentzis, 1991; Gentzis and Goodarzi, 1991) and in other sedimentary basins. For example, the relatively low maturation gradient of the Gippsland Basin in Australia (0.08 to 0.15 log % Ro/km) is related to very rapid subsidence and sedimentation since Early Tertiary or Cretaceous times (Shibaoka and Bennett, 1977). Low maturation gradients have been reported by Bostick *et al.*, (1978) from the Los Angeles and Ventura Basins, where sedimentation rates have been up to 1.82 mm/yr (1.82 km/MM yrs) in the last 3 MM yrs.

The maturation gradient map (Fig. 20) shows that the gradients increase from south to north within the *Drake* field. One of the effects of a low maturation gradient is that a great

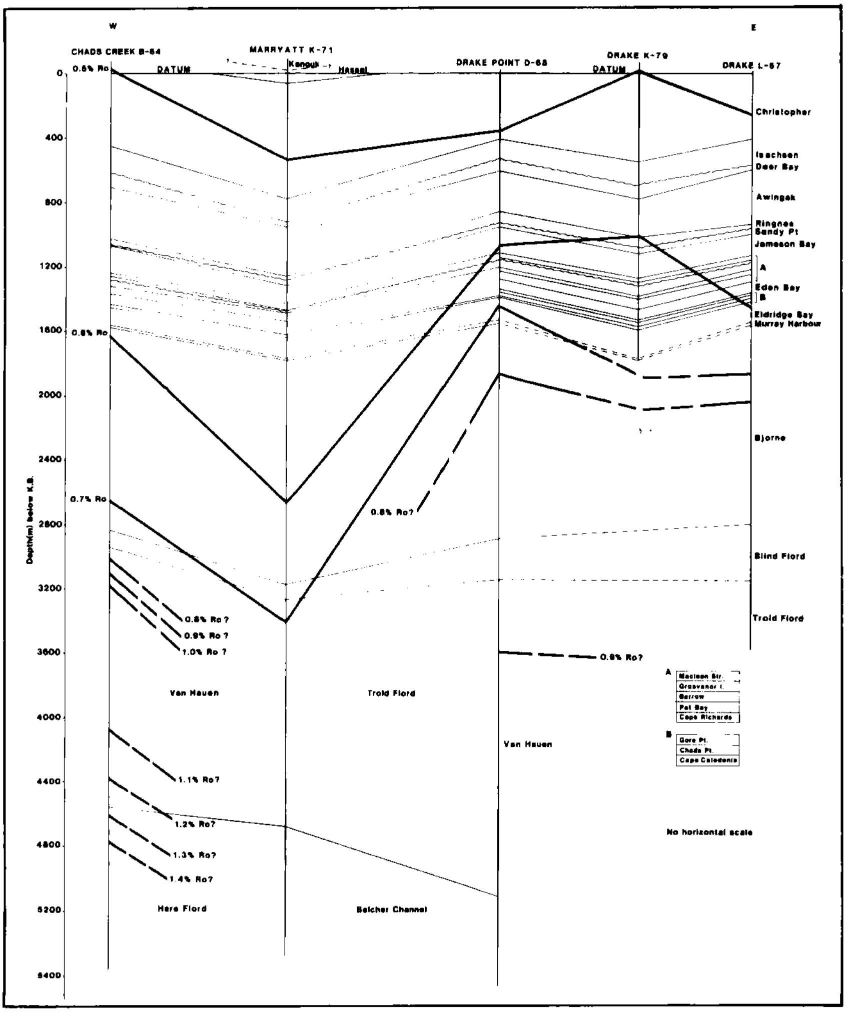


Fig. 19. Cross-section A-A', *Hecla* field to *Drake* field.

thickness of strata now lies within the hydrocarbon generation zone. The regional maturity pattern and depth to the oil-generation zone is shown in Fig. 21 (the oil generation threshold is taken to be 0.5% Ro), but it can vary between 0.5 and 0.7% Ro depending on organic-matter type.

CONCLUSIONS

The present results indicate that the *Drake* field contains organic-rich shales and siltstones in the Schei Point Group, some of which have experienced a favourable maturation history. These sediments are from the Cape Richards Member of the Hoyle Bay Formation. They contain marine organic matter, are marginally mature, and have high HI, TOC and S2 values in the subsurface. In addition, the parameters for the marginally-mature Eden Bay Member of the Hoyle Bay Formation and the Cape Caledonia Member of the Murray Harbour Formation, which contain marine organic

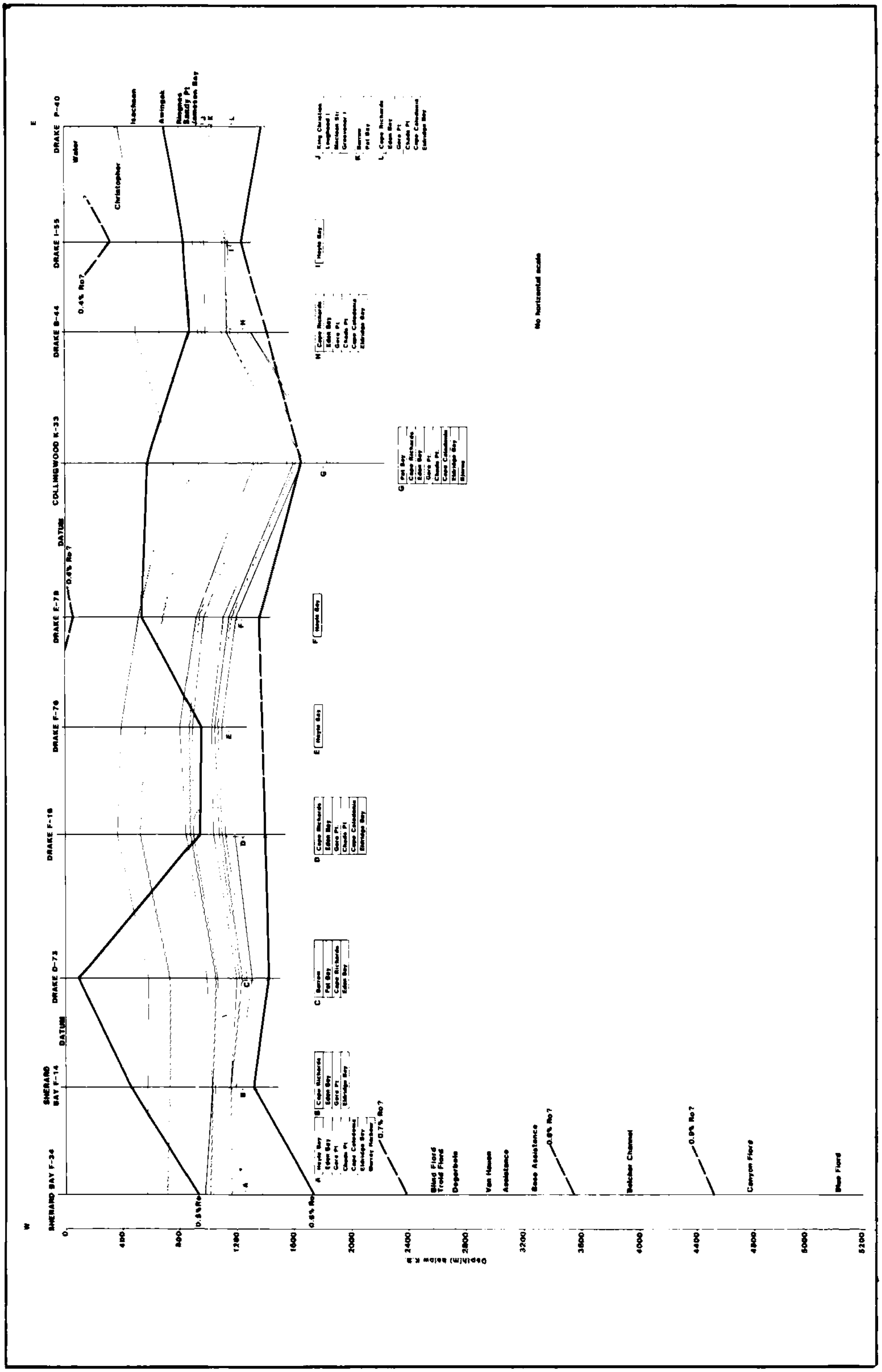


Fig. 18. Cross-section B-B', correlating *Sherard* and *Drake* drillholes.

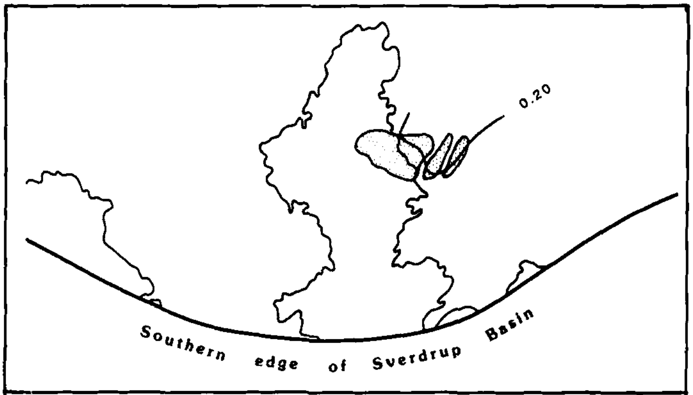


Fig. 20. Maturation gradient contour map (log % Ro/km).

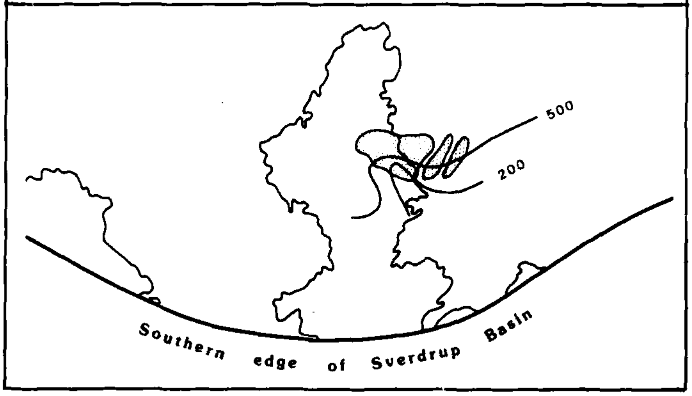


Fig. 21. Contour map (m), showing depth to the "oil window".

matter, are also high in the *Drake* field, suggesting a good source-rock potential for these formations in the area south and east of the Sabine Peninsula.

The Jameson Bay, Ringnes and Deer Bay shales, all of Jurassic age, are immature or marginally mature and have limited oil-generation potential due to a higher input of terrestrial organic matter. However, they have a good gas-generating potential at favourable maturation levels. The Upper Palaeozoic sediments, although mature, are poor source rocks with the exception of the Lower Triassic Blind Fiord and the Permian Van Hauen Formations, which have limited gas potential.

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(Continued on p. 54)

Table 1. ***Rock-Eval* pyrolysis data, *Drake* field.**

Depth (m)	*Tmax (°C)*	*S2 mg HC/g rock*	*PI S1/S1 + S2*	*TOC wt %*	*HI mg HC/g Corg*	*OI mg CO_2/g Corg*	*Formation/member*
Drake D-68							
1289	432	1.69	.04	1.31	129	32	Cape Richards
1319	433	5.35	.03	1.25	428	28	Eden Bay
1331	428	27.81	.03	4.26	652	17	Eden Bay
1346	431	30.03	.03	4.57	647	22	Eden Bay
1396	433	21.03	.04	3.76	559	34	Cape Caledonia
1547	432	.23	.04	.39	58	158	Bjorne
3269	447	.35	.40	.55	63	45	Trold Fiord
3471	451	.21	.21	.61	54	34	Van Hauen
3831	453	.56	.43	.84	66	26	Van Hauen
3973	458	.23	.36	.25	27	24	Van Hauen
4272	444	.18	.53	1.04	17	17	Van Hauen
4523	459	.33	.28	.76	43	23	Van Hauen
5034	489	.28	.34	.83	18	11	Van Hauen
Drake K-79							
1476	436	15.24	.03	3.00	508	26	Cape Richards
1545	430	36.91	.04	5.70	647	14	Eden Bay
1564	430	28.87	.04	4.23	682	15	Eden Bay
1615	433	7.41	.05	1.46	507	34	Cape Caledonia
Drake L-67							
1342	432	33.90	.07	5.38	630	17	Eden Bay
1974	400	.13	.60	.23	56	143	Blind Fiord
2947	437	.03	.75	.17	17	100	Blind Fiord
3116	443	.13	.19	.23	56	39	Blind Fiord, Core
3233	447	.53	.34	.64	82	26	Van Hauen, Core
Drake B-44							
1182	430	1.56	.08	.90	173	50	Cape Richards
1291	432	23.75	.03	4.67	508	22	Eden Bay
1333	433	.46	.04	1.83	462	31	Cape Caledonia
Drake D-73							
1312	427	9.75	.06	2.25	433	34	Hoyle Bay
Drake F-16							
1209	431	6.16	.06	1.57	392	25	Cape Richards
1303	426	30.70	.06	29.23	622	21	Eden Bay
1400	431	8.31	.04	1.98	419	28	Eldridge Bay
Drake P-40							
1148	427	33.82	.03	5.26	642	25	Eden Bay
1157	428	31.32	.03	5.03	623	29	Eden Bay
Drake I-55							
1170	434	3.26	.07	1.17	278	37	Hoyle Bay
Sherard F-34							
1248	423	21.32	.03	3.85	553	27	Cape Richards
1292	424	21.17	.04	3.86	548	24	Eden Bay
1299	423	21.49	.04	3.94	545	24	Eden Bay
1308	425	17.99	.03	3.28	548	29	Eden Bay
2630	417	.28	.50	.28	100	196	Blind Fiord
2674	426	.07	.40	.32	21	121	Trold Fiord, Core
2768	430	.07	.42	.23	30	217	Trold Fiord
2989	434	.15	.30	.55	27	176	Van Hauen
3224	435	1.26	.21	1.29	97	37	Van Hauen
3450	442	.72	.13	1.04	69	35	Van Hauen
3458	439	.60	.19	1.10	54	55	Van Hauen
3485	439	.41	.41	1.03	39	86	Van Hauen
3548	440	.10	.84	.96	13	48	Van Hauen
3599	460	.38	.42	1.11	34	90	Van Hauen
3674	444	.62	.35	1.23	50	47	Van Hauen
3845	438	.18	.31	.46	39	126	Belcher Channel
4184	445	.19	.38	.61	27	63	Canyon Fiord
4617	461	.02	.00	.41	04	17	Canyon Fiord, Core
4883	451	.17	.23	.59	28	98	Canyon Fiord
5209	454	.22	.27	1.03	21	24	Canyon Fiord, Core
Sherard F-14							
1209	428	15.32	.03	3.23	474	41	Cape Richards
1270	430	18.64	.05	3.88	480	39	Eden Bay

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Table 2. Maturation gradients (log % Ro/km), ***Drake*** **field.**

Drillhole Name	*% log Ro/km*
Drake D-68	0.11
Drake P-40	0.17
East Drake I-55	0.20
Drake B-44	0.17
Drake F-76	0.20
Drake E-78	0.13
Drake F-16	0.15
Drake D-73	0.13
Drake L-67	0.08
Drake K-79	0.14