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THERMAL MATURITY OF CARBONIFEROUS AND PERMIAN ROCKS OF THE SVERDRUP BASIN, CANADIAN ARCTIC ARCHIPELAGO

J. Utting, F. Goodarzi,
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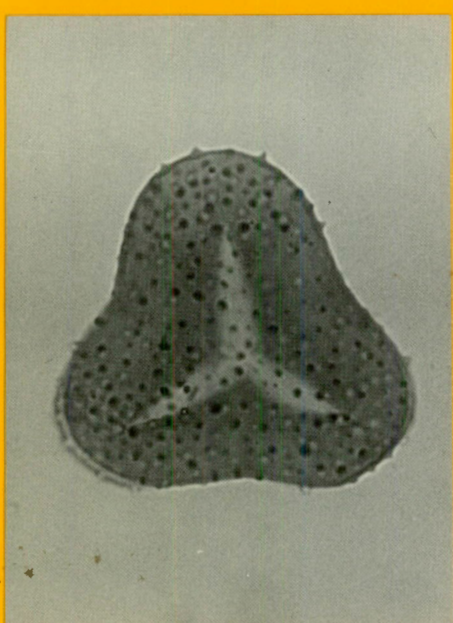

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Cover

Left: Trilete spore *Lophotriletes* sp.; magnification x1,250. Sabine Bay Formation, Tingmisut Lake, Melville Island. GSC locality C-126261. Thermal Alteration Index 2-.

Centre: Vitrinite, fusinite, and semifusinite in reflected white light; magnification x600. Emma Fiord Formation, Grinnell Peninsula, Devon Island. Vitrinite is grey globular material at top, semifusinite is pale grey elongate material at top, fusinite is white elongate material at bottom. % Vitrinite reflectance (R_{oil}): 0.4.

Right: Pectiniform conodont *Streptognathodus* sp.; magnification x100. Canyon Fiord Formation, Ibbett Bay, Melville Island. GSC locality C-134118. Conodont Colour Alteration Index 1.0.

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THERMAL MATURITY OF CARBONIFEROUS AND PERMIAN ROCKS OF THE SVERDRUP BASIN, CANADIAN ARCTIC ARCHIPELAGO

Abstract

The thermal maturity of outcrop and subsurface core samples from Carboniferous and Permian rocks of Sverdrup Basin was assessed by using the Thermal Alteration Index (pollen and spore colour), the conodont Colour Alteration Index, and reflectance of vitrinite and bitumen. These data indicate significant thermal maturity trends within the basin, which have considerable relevance to the hydrocarbon potential.

The lowest levels of thermal maturity fall within the oil generation zone, and occur in strata that form a relatively narrow (50 to 100 km wide) belt along the southern to southeastern outcrop margin of the basin. The thermal maturity increases toward the centre of the basin, and is very high in much of the northeastern area. These general trends are believed to be partly the result of variations in the thickness of the Mesozoic and Tertiary sediments that covered the upper Paleozoic strata, and partly due to the high heat flow during the Mesozoic, related to the numerous igneous intrusions present in many parts of the basin. Thermal maturity anomalies occur within a few metres of these intrusions.

Résumé

La maturité thermique de roches d'âge carbonifère et permien du bassin de Sverdrup a été évaluée en déterminant certaines caractéristiques d'échantillons prélevés sur des affleurements et sous la surface, à savoir l'indice d'altération thermique (couleur du pollen et des spores), l'indice d'altération de la couleur des Conodontes et la réflectance de la vitrinite et du bitume. Les données révèlent des tendances significatives dans la maturité thermique au sein du bassin, tendances qui sont étroitement liées au potentiel en hydrocarbures de cette région.

Les plus faibles valeurs de maturité thermique appartiennent à la zone où le pétrole se forme; on a relevé ces valeurs dans des strates formant une ceinture relativement étroite (entre 50 et 100 km de largeur) qui longe au sud et au sud-est la limite d'affleurement du bassin. La maturité thermique augmente vers le centre du bassin et les valeurs sont très élevées dans une bonne partie du secteur nord-est. On croit que cette tendance générale est le résultat, d'une part, de variations dans l'épaisseur des sédiments mésozoïques et tertiaires qui recouvraient les strates du Paléozoïque supérieur et, d'autre part, d'échanges thermiques considérables au cours du Mésozoïque, lesquels étaient liés aux nombreuses intrusions ignées que l'on retrouve à bon nombre d'endroits dans le bassin. Des anomalies dans la maturité thermique se produisent à quelques mètres de ces intrusions.

INTRODUCTION

In this study the thermal maturity of Carboniferous and Permian rocks of Sverdrup Basin was assessed, based on the following criteria: colouration of pollen and spores, colouration of conodonts, and vitrinite or bitumen reflectance measurements, although it was not possible to apply all of these criteria to every sample. Correlation of the various indices was achieved by comparing samples for which at least two of the techniques were used (Table 1). Five hundred and fifty outcrop and subsurface core samples were studied from 109 localities, and the results plotted on the accompanying thermal maturity maps (Figs. 2-4).

The Thermal Alteration Index (TAI) was assessed from the colour of pollen and/or spores in the unoxidized organic residue of a standard palynological preparation; that is, after hydrochloric and hydrofluoric acid treatment, and subsequent neutralization and heavy liquid treatment (Barss and Williams, 1973). Various workers have noted the effect of heat on spores, and the results of various experimental techniques have been summarized by Staplin (1969). Spores become darker as they are heated and this characteristic is the basis for the various thermal maturity scales that have been proposed by different authors. The scale used here (Tables 1, 2) was modified from that of Correia (1969) and Hunt (1979), and is similar to that used by Utting (1987) for a thermal alteration study of the Viséan of Atlantic Canada. Five divisions are used in this scale: 1 for yellow spores, 2 orange, 3 brown, 4 black, and 5 metallic black and brittle. The various intermediate stages are designated by + and - signs; for example, 2+ for dark orange to light brown. An attempt has to be made, when assessing the TAI, to use single-walled spores with approximately 1 micron exine thicknesses, such as certain lycopod spores (e.g., *Punctatisporites*, *Calamospora*, and *Leiotriletes*). When possible, disaccate and monosaccate pollen grains should be avoided because they are structurally more complex, and the combination of sacs and central body produces a range of thickness and, therefore, colours on a single grain; the lightest may differ from the darkest parts by up to one unit on the TAI scale. In some poorly fossiliferous samples, where no trilete spores were present, disaccate pollen were used; the colour was assessed on the saccus rather than the corpus (which in the case of ribbed or taeniate grains, varies significantly in thickness). This assessment of colour is subjective, but the problem was partially alleviated by using standard microscope light settings and magnifications, and by having all determinations made by the same worker (J.U.), with frequent reference to a set of standard slides.

Determination of the conodont Colour Alteration Index (CAI) followed the techniques and colour scale outlined by Epstein et al. (1977) and updated by Rejebian et al. (1987). The scale has eight divisions, and is based on the progressive

TABLE 1

Comparison of Thermal Alteration and conodont Colour Alteration indices, and equivalent vitrinite reflectance values related to the zones of petroleum generation and destruction (based on amorphous organic matter). Data shown in columns 1, 2 and 3 are based largely on average results obtained from the Sverdrup Basin study. (Column 4 is modified from Dow, 1977.)

Thermal Alteration Index	Conodont Colour Alteration Index	Vitrinite Reflectance	Zones of Petroleum Generation and Destruction (Amorphous organic matter)
1			
	1		
1 +			
		0.3	
		0.4	
2 -			
		0.5	-------- Oil "Birth" Line --------
2			
		0.6	
	1.5		
2 +		0.9	Peak oil generation
		1.0	Peak wet gas generation
3 -	2.0	1.20	Peak dry gas generation
	2.5	1.35	-------- Oil "Death" Line --------
3	3.0		
	3.5	1.5	
3 +			
	4.0		
4 -	4.5	2.0	--------- Wet gas floor ---------
		2.2	
4			
		3.0	----- Dry gas preservation limit -----
		3.5	
	5		
5			
	6	4.0	
		5.0	

TABLE 2

Criteria used to assess the Thermal Alteration Index

Colour of spores and pollen in transmitted light	Thermal Alteration Index
Transparent to pale yellow	1
Yellow	1+
Yellow to light orange	2-
Medium orange	2
Dark orange to light brown	2+
Medium brown	3-
Dark brown	3
Thinner parts of exine dark brown, thicker parts brownish black	3+
Thinner parts of exine brownish black, thicker parts black	4-
Dull black, haptotypic mark barely visible	4
Vitreous black, fossils brittle, often fractured, species rarely identifiable (haptotypic mark may be visible in reflected light)	5

TABLE 3

Criteria used to assess the conodont Colour Alteration Index. Temperature values from Harris (1979) and Harris and Rejebian (1986) were obtained by heating conodonts under laboratory conditions.

Colour of conodonts in reflected light	Colour Alteration Index	Temperature (Celsius)
Pale yellow	1.0	<50 - 80
Very pale brown	1.5	50 - 90
Brown to dark brown	2.0	60 - 140
Dark brown to greyish brown	2.5	
Very dark greyish brown	3.0	110 - 200
Very dark greyish brown to very dark brown	3.5	
Very dark brown	4.0	190 - 300
Very dark brown to black	4.5	
Black	5.0	300 - 480
Grey	6.0	360 - 550
White	7.0	490 - 720
Colourless, translucent	8.0	>600

and irreversible change of colour that conodonts demonstrate (Tables 1, 3), as the result of progressive alteration, by heating, of trace amounts of organic matter within the conodont elements (Harris, 1979; Harris and Rejebian, 1986). Temperature and time both have an important influence on CAI, for example a CAI of 3 can be obtained in 14 hours at 500°C, but at 110°C, 500 million years are required (Epstein et al., 1977).

The CAI scale, and its correlation with temperature changes and certain other alteration indices, were discussed by Nowlan and Barnes (1987). These workers correlated some of the indices of organic metamorphism, including the conodont Colour Alteration Index, the Acritarch Alteration Index, the Translucency Index (of AMOCO) and vitrinite reflectance. Goodarzi and Higgins (1987) compared CAI and vitrinite reflectance; this aspect is discussed in more detail later in the section on interpretations and conclusions. Epstein et al. (1977), Harris (1979), and Harris and Rejebian (1986) carried out a number of experiments to correlate the CAI with temperature and their conclusions are summarized in Table 3, Column 3.

Nowlan and Barnes (1987) also pointed out pitfalls in determining the CAI, and suggested that the index should be assessed from the parts of elements with the lightest colour, and one should avoid those elements that are extremely compressed or thin walled. In our study, however, we (B.J.D. and C.M.H.) took the average CAI values for representative specimens, by comparing them with standard slides provided by Harris, taking care to compare specimens of similar size and thickness.

The assessment of the thermal maturity of a sediment using the reflectance of vitrinite (Kerogen Type III, Brooks et al., 1988) is a well established technique (Hunt, 1979; Brooks et al., 1988; Tissot and Welte, 1984; Teichmüller, 1982; Murchison et al., 1985). A number of studies on the maturity of Mesozoic and Paleozoic sediments in the Arctic Archipelago have been carried out (Barker et al., 1975; Schreiber, 1975; Henao-Londoño, 1977; Fisher et al., 1980; Bustin, 1986; Brooks et al., in press; Goodarzi et al., 1987a; Goodarzi and Gentzis, in press).

Snowdon and Roy (1975) stated that the mature zone in Sverdrup Basin is mostly restricted to the Mesozoic strata, and that the optimum conditions for accumulation and preservation of hydrocarbons occur where matured sediments are associated with Tertiary structures. Powell (1978) recognized four organic maturation zones (immature, marginally mature, mature, overmature) in the Paleozoic and Mesozoic sediments of Sverdrup Basin. The marginally mature zone occurs at a burial depth of <1500 m and the mature zone at 3000 m, the boundary between the mature and overmature sediments lies between 4300 and 4600 m.

Many samples from the study area, especially those from carbonate rocks, did not contain vitrinite, but did contain bitumen fragments. Reflectance of the latter was determined, and the thermal maturity of sediment assessed, by converting bitumen reflectance values to vitrinite reflectance equivalents (Jacob, 1985; Bertrand and Heroux, 1987; Goodarzi and Macqueen, in press). Jacob (1985) established that the reflectance of bitumen is lower than that of vitrinite between 0.5 to 1.2% Ro for equivalent temperatures and times of maturation. At higher ranks (i.e., Ro > 1.2%) the reflectance of bitumen is higher than vitrinite. Reflectance of bitumen can be converted to that of vitrinite using Jacob's Formula (Jacob, 1985): $R_V = 0.618 R_B + 0.40$ (where R_V is vitrinite reflectance and R_B is bitumen reflectance). As with conodonts, time and temperature play important roles. Bostick (1973) pointed out that vitrinite buried for millions of years at temperatures of 100 to 200°C had become anthracitic. The same rank was achieved in pyrolysis experiments at temperatures of 400 to 500°C in only one hour (Goodarzi and Murchison, 1972). When the temperature to which the rocks are subjected increases only slightly, the duration of heating becomes increasingly important (Goodarzi and Murchison, 1977).

SUMMARY OF CARBONIFEROUS AND PERMIAN STRATIGRAPHY OF SVERDRUP BASIN

In the Canadian Arctic Islands, two main centres of deposition existed throughout the Phanerozoic: the Franklinian geosyncline, and the successor Sverdrup Basin (Fig. 1). The final uplift of the Franklinian geosyncline took place during the Ellesmerian Orogeny (Late Devonian and Early Carboniferous), at which time thermal uplift occurred and the rocks were intruded, deformed and metamorphosed. Rifting during the Early Carboniferous led to the development of the Sverdrup Basin, in which some 12 km of Carboniferous (Viséan) to Tertiary strata were deposited including clastic, carbonate, evaporitic and volcanic rocks (Thorsteinsson, 1974). The basin suffered two main phases of deformation: the Melvillian Disturbance, during the Early Permian (Late Artinskian) (Beauchamp, et al., 1989); and the Eurekan Orogeny, between the Late Cretaceous and middle Tertiary. The basin, which is approximately 1300 km long and 400 km wide, is now a structural synclinorium.

The first sediments deposited on the eroded surface of the Franklinian geosyncline – either prior to, or contemporaneous with, the major tectonic events that created the Sverdrup rift basin – were nonmarine, black, carbonaceous shale, coal, siltstone and marlstone, with interbedded sandstone conglomerate and oolitic algal limestone of the Emma Fiord Formation (Davies and Nassichuk, 1988; Utting et al., in press). At some localities, such as Grinnell Peninsula on Devon Island, oil shales occur within the Emma Fiord Formation (Goodarzi et al., 1987b). Palynological data suggest that these beds are of Viséan V3 age (Utting et al., 1987, in press). Rifting of the basin in the early Late Carboniferous led to the deposition of various syntectonic sediments consisting predominantly of red quartzose sandstone and conglomerate. With further enlargement of the basin (Thorsteinsson, 1974; Balkwill, 1978) a major marine transgression occurred, which led to the deposition of siltstone, shale, dolomite and limestone (Borup Fiord Formation and basal Canyon Fiord Formation). Sedimentation took place on a shallow water platform surrounding one or several deeper water basinal areas (Nassichuk and Davies, 1980; Beauchamp et al., 1987). Marked facies changes occur across the depositional axis of the basin and the formation names reflect these changes (Fig. 1). Coarse clastic rocks occur near the depositional edge (part of the Canyon Fiord Formation, and the Sabine Bay, Assistance, and Trold Fiord formations); shallow water carbonates and evaporites on the peripheral platform [part of the Canyon Fiord Formation, and the Nansen, Belcher Channel, "unnamed" (Nassichuk and Wilde, 1977), and Degerböls formations]; and deeper water shales, cherts, argillaceous limestones and evaporites in the central areas (Hare Fiord and van Hauen formations). The paleogeography of the facies belts varied considerably through time.

The carbonate belt that circles the basin is dominated by limestone of the Nansen Formation, but locally includes sandstones. In addition, lower Upper Carboniferous basalt flows (Audhild volcanics) occur on the northern rim, and were associated with the initial basin subsidence. Also in the Late Carboniferous, in the axial part of the basin, evaporites, comprising gypsum and anhydrite, were deposited (Otto Fiord Formation). This formation was probably the product of submarine precipitation at various depths (Nassichuk and Davies, 1980), whereas the overlying shales of the Hare Fiord Formation were deposited by turbidity flows in relatively deep water marine troughs. The deeper water black shale, chert and argillaceous limestone of the Hare Fiord and van Hauen formations were deposited under poorly oxygenated, probably anoxic conditions (Beauchamp et al., 1987). This is confirmed by the severe corrosion of pollen and spore exines resulting from the growth of pyrite crystals.

The Melvillian Disturbance (Late Artinskian) resulted in local folding and a regional angular unconformity, especially along the southern margin of the basin. Eruptions of basaltic and andesitic lavas, the Esayoo volcanics, occurred on the western flank of the Tanquary High of northern Ellesmere, during an Artinskian regression (K.G. Osadetz, pers. comm., 1986) and were probably coeval with the Melvillian Disturbance. After the Sakmarian-Artinskian the sediments became silica dominated due to the abundance of silica secreting sponges. Chert is especially common in parts of the van Hauen Formation.

The uppermost Permian (Capitanian to Changhsingian) is absent from the marginal basin facies, and the contact between the Permian and the overlying Triassic rocks is a disconformity; but, in the deeper part of the basin, the contact between the black shales of the van Hauen Formation and the greenish grey shales of the Blind Fiord Formation (Griesbachian) is apparently conformable, although no paleontological evidence of rocks of latest Permian age has yet been found.

INTERPRETATION OF THERMAL MATURITY DATA, AND CONCLUSIONS

The greatest number of sample localities are in areas where the upper Paleozoic is well exposed, and/or where core samples are abundant due to exploration activity. One such area is northern Melville Island. Data from some other localities are sparse to absent.

The thermal maturity values shown on Figures 2 to 4, and Appendices 1 to 3, indicate the thermal maturity or range of thermal maturity found at a single locality. The formation from which the sample was obtained is shown as an abbreviation (see map legends). Also given, where applicable, is the depth from which the sample was collected. At some borehole localities, where several thousand metres of subsurface section are involved, the range in thermal maturity may be extensive, especially where igneous intrusions occur. For example, in the Panarctic et al. Marryatt K-71 well (C-97716) on Sabine Peninsula, Melville Island, the TAI is 2 at 3318 m in the Upper Permian, 4- at 4315 m near an igneous sill, and 3- to 3 at 5451 m in the uppermost Carboniferous to Lower Permian.

There are a few minor discrepancies in the values obtained from the three thermal maturity indicators. This is not surprising in view of the subjective nature of the techniques using spore and conodont colouration, and the fact that it is not always possible to obtain all three of the TAI, CAI and vitrinite reflectance values from a single lithology or sample. At a number of localities, especially in the northeast part of the study area, the strata sampled are close to igneous intrusions, the metamorphic effects of which may vary from one rock type to another. Difficulty may occur when differentiating TAI 4 from 5, and correlating the upper part of the TAI scale accurately with equivalent levels on the CAI scale and with the vitrinite reflectance values. Spores become dull black at a TAI value of 4, and beyond that point there are subtle changes in the quality of preservation; for

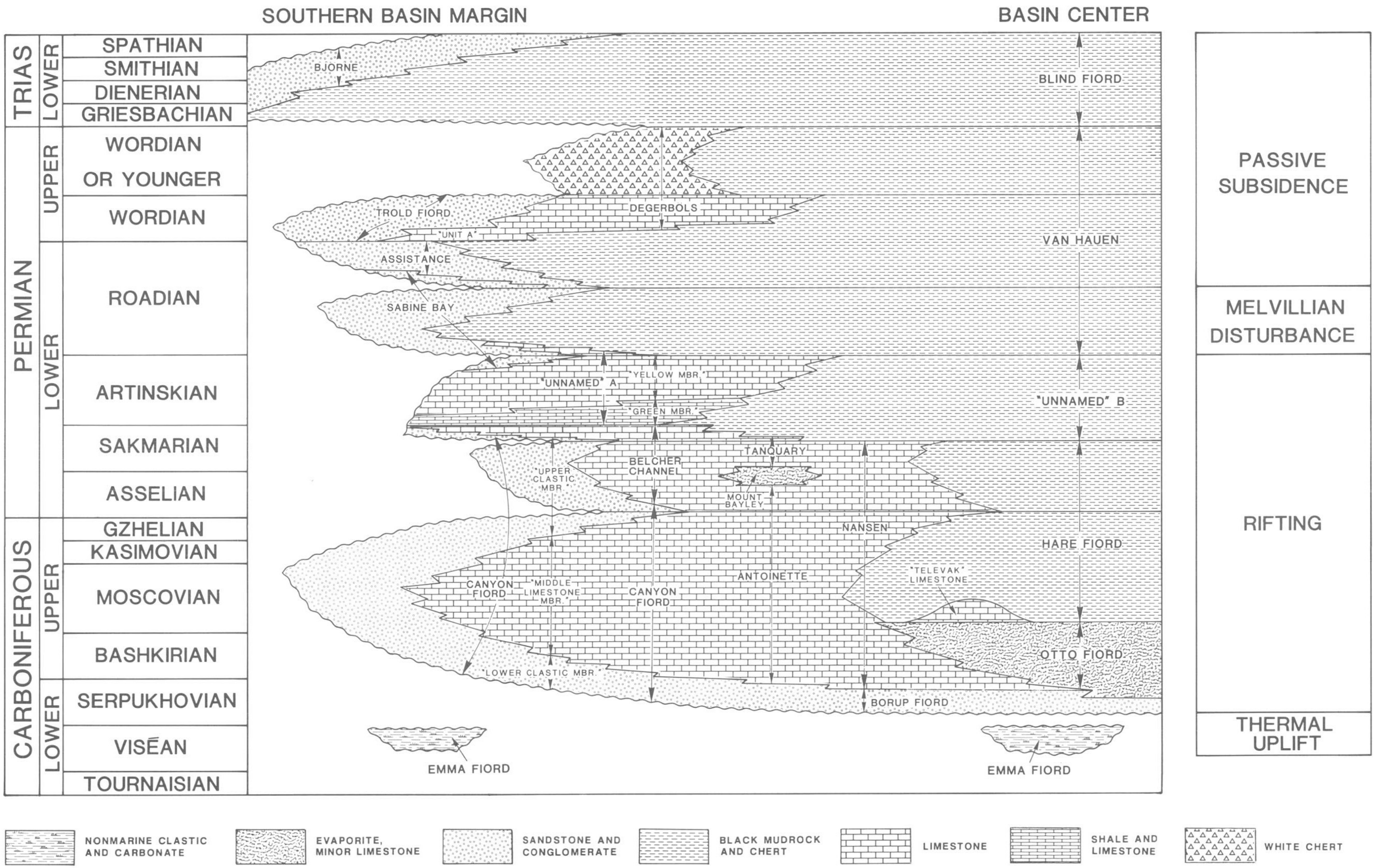


Figure 1. *Upper Paleozoic depositional sequences and formations of Sverdrup Basin along a cross-section from northwestern Axel Heiberg Island to southwestern Ellesmere Island. (Modified from Beauchamp et al., 1989.)*

example, spores become brittle and may have cracks and fissures in the exine. Also, the colour changes to vitreous black, and thin exinal fragments may have a greyish tinge. Caution should be exercised in comparing the CAI values from different lithologies, as these values tend to be higher in shales and lower in carbonates, by as much as 0.5 CAI units at the same locality. This complication can be avoided by using only data from carbonate rocks; a practice that was followed here for most samples. In conodonts from dolomites, element surfaces may be altered, pitted and etched; such surfaces do not reflect light the same as the non-etched surfaces. Colour determinations on conodonts with altered surfaces are less reliable than those made on uncorroded surfaces.

One advantage of thermal maturity assessments based on spores, bitumen, and vitrinite is that such measurements can be obtained across marine and nonmarine facies boundaries, whereas assessments based on conodonts are restricted to marine strata. The CAI and vitrinite reflectance scales have the advantage that they can be applied to more thermally altered material than the TAI, but the CAI scale has poor resolution in its lower part (Table 1). The use of spores and conodonts in determining thermal maturity has certain advantages. For example, not only is the age of in situ fossils determined, but also the age of any reworked material. The latter often can be of significance in determining the thermal alteration history of an area and the provenance of the sediments.

In this paper, thermal maturity maps for the Early Carboniferous, Late Carboniferous and Permian time intervals are presented. In a few instances, it is not certain from the biostratigraphic data so far available whether samples from the upper part of the Canyon Fiord Formation are of late Late Carboniferous or early Early Permian age. For the present, these samples have been plotted on both Figure 3 and Figure 4. There are as yet insufficient data to produce maps for shorter time intervals, although this will be possible as further biostratigraphic work is completed. When the results of such work are available, it may well become apparent that the position of the oil window boundary shown on Figure 4 for the Permian did not remain constant, but changed with time. It is not practical to compile a map for each formation because of the complex lateral facies changes and hence formational name changes. The problems are further exacerbated by the restricted age range of some formations and the wide age range of others. For example, the Assistance Formation is of Roadian age in the platform area, whereas in the basinal facies the Hare Fiord and van Hauen formations extend throughout the Upper Carboniferous to the lower part of the Upper Permian.

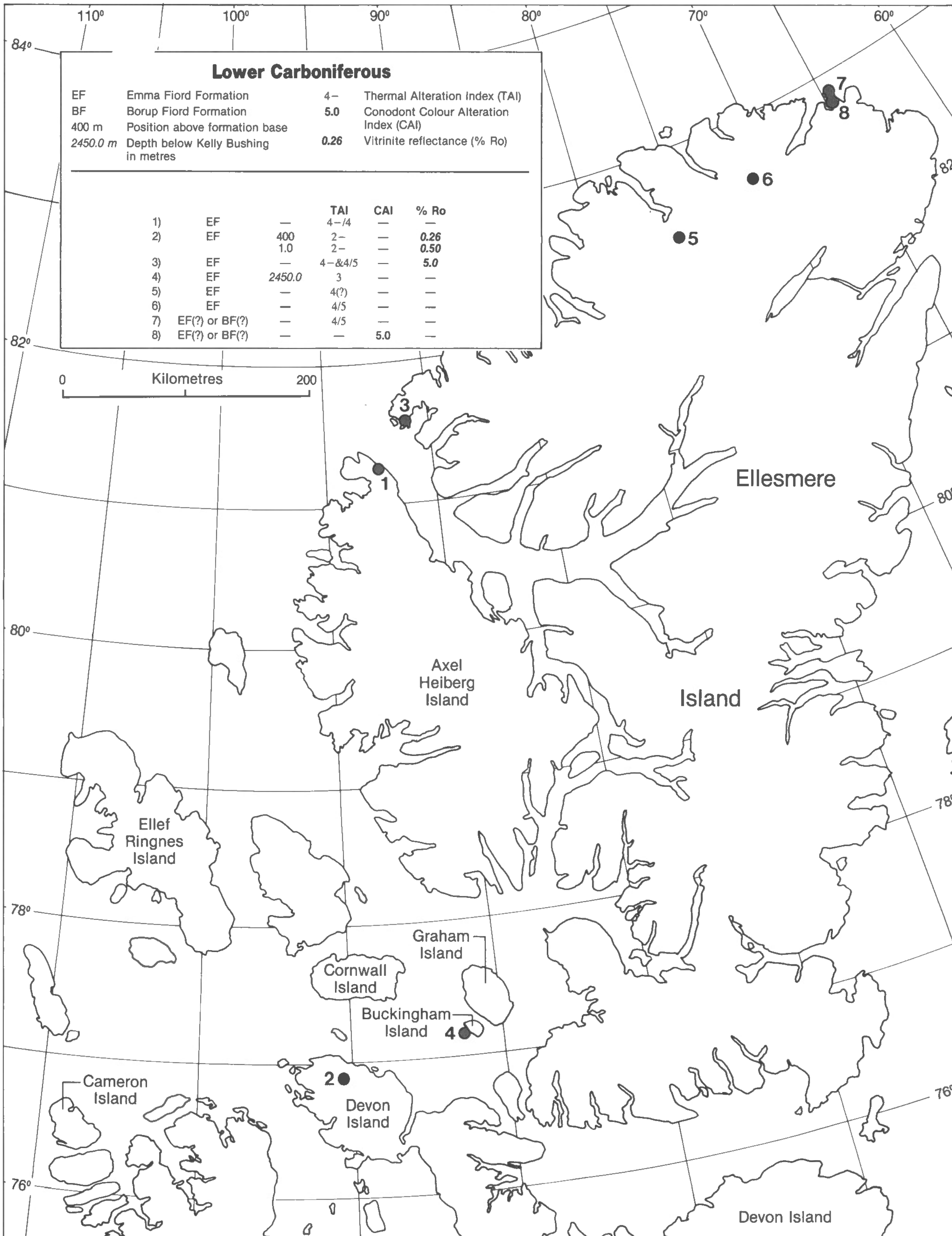
The data obtained from the Carboniferous are from a few localities only (Figs. 2, 3). Relatively few (8) Lower Carboniferous outcrop and subsurface localities are available, owing to the limited occurrence of beds of this age in the basin. They form the northeastern outcrop margin of the basin, where thermal maturity is high (TAI 4- to 5, vitrinite reflectance up to 5.0), in the Emma Fiord and Borup Fiord(?) formations on Axel Heiberg and Ellesmere islands. In view of the presence of thin coal seams in the Emma Fiord Formation, gas may well have been generated during diagenesis, in spite of the fact that some of the localities now have a thermal maturity beyond the limit for dry gas preservation. At the southern outcrop margin of the basin, the thermal maturity of the oil shales of the Emma Fiord Formation is low (TAI 2, and a vitrinite reflectance of 0.26 at the top, to 0.5 at the base of the formation) on Grinnell Peninsula, Devon Island (Fig. 2).

For the Upper Carboniferous Otto Fiord Formation, thermal maturity values are high in the northeastern part of the basin (TAI 3 to 4-, CAI 3.5 to 6, vitrinite reflectance 2.09 to 5.01), and in the Barrow Dome area of Melville Island in the southwest (TAI 4-) (Fig. 3). It is possible that the high thermal maturity in this southwestern area is partly related to the effects of salt diapirism. The Canyon Fiord Formation has a low thermal maturity (TAI 2- to 3, CAI 1.0 to 2.5) at most outcrop localities on Melville Island, although higher values occur northwards and in the subsurface; for example, in the Sherard Bay F-34 well (C-61559) on Sabine Peninsula (TAI 3- to 3, CAI 3.5; 4617 to 4621.3 m). In northern Ellesmere the maturity of the Canyon Fiord, Nansen and Hare Fiord formations is generally high (TAI 3+ to 4, CAI 2.5 to 6, vitrinite reflectance 2.09 to 5.01).

Permian strata were studied at 72 localities (Fig. 4), and the thermal maturity values were found to be generally low (TAI 2- to 3-, CAI 1 to 2) in a belt some 50 to 100 km wide along the southern and southeastern margin of the basin, but increase toward the centre and to the northeast, where, in areas such as western Ellesmere Island, they reach their maximum (TAI 3-to 4-, CAI 3.5 to 6, vitrinite reflectance 1.49 to 3.46). In northern Axel Heiberg Island, at the northern basin margin (Station 33), a low thermal maturity is indicated by conodonts (CAI 2), but higher values were obtained from spores (TAI 4). Proximity to an igneous intrusion may explain the anomalously high TAI values. An isopleth, or tentative isopleth, has been drawn at the TAI 3- to 3 boundary (equivalent to CAI 2.5), at an approximate thermal maturity level equivalent to the top of the oil window. There are, as yet, insufficient data to permit the construction of isopleths for the Lower and Upper Carboniferous, although a tentative isopleth is shown on Figure 3 for the Upper Carboniferous in the southwest part of the area; however, these units appear to follow thermal maturity trends similar to those of the Permian.

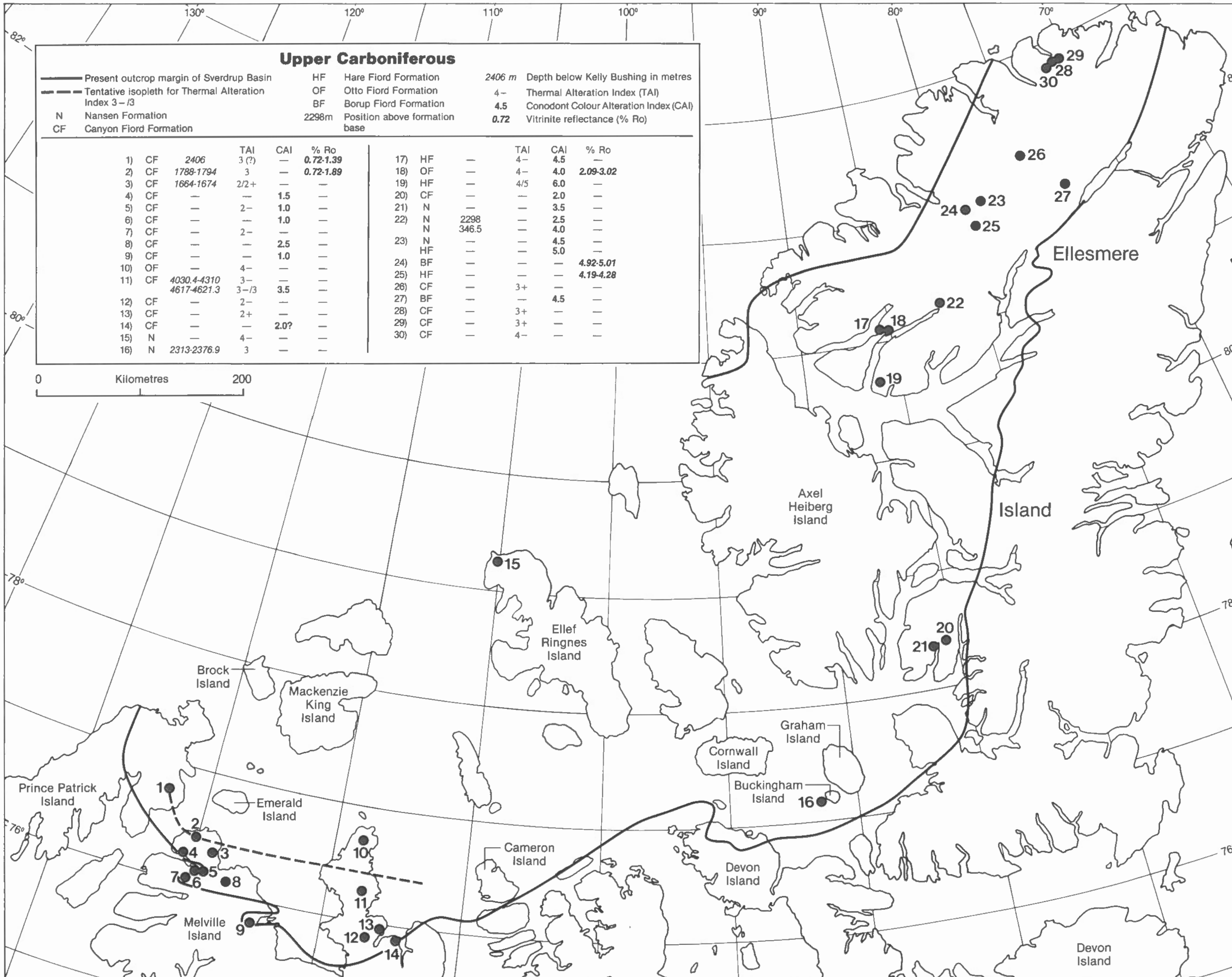
The causes of the general trends, summarized on Figures 2 to 4 and outlined above, are believed to be related to two major factors. Firstly, there are significant variations in the depth of burial of the upper Paleozoic rocks by the overlying Mesozoic and Tertiary. The southern and southwestern margins of the basin had very little Mesozoic or Tertiary cover, but the thickness of these rocks increased significantly toward the basin centres (Embry, 1982; in press). Secondly, there was increased heat flow in the northeastern part of the area in the Mesozoic and early Tertiary (Bustin, 1986), when abundant igneous intrusions were emplaced. Diapiric intrusion of salt, such as that in the Barrow Dome of Melville Island, may have been a factor locally in increasing thermal maturity.

The hydrocarbon potential of upper Paleozoic rocks of the basin is significantly influenced by the thermal maturity trends. The area in which these rocks are within the oil window (TAI 2- to 3-, CAI 1.25 to 2.5, Ro 0.5 to 1.35) is along the southern and southeastern margins of the basin (northern Melville Island; Cameron Island; Grinnell Peninsula on Devon Island; Buckingham Island; Graham Island; and near East Cape on Canyon Fiord, Ellesmere Island). The potential for wet gas and subsequently dry gas increases toward the basin centre, with some areas in the north-central part of the basin (northern Axel Heiberg Island, and northwestern Ellesmere Island) being beyond the dry gas preservation limit. Thus, for Upper Carboniferous and Permian strata, the oil window now lies mostly within the shallow water platform facies, where potential traps occur, whereas the deeper water basinal shales, which might otherwise have been potential source rocks, are now in the overmature zone. This conclusion points to the importance of understanding, and the need for research on, the migration history of any liquid hydrocarbon in the area. In order to correctly assess the source rock potential, however, further work is also necessary to determine the type and quantity of organic matter present.



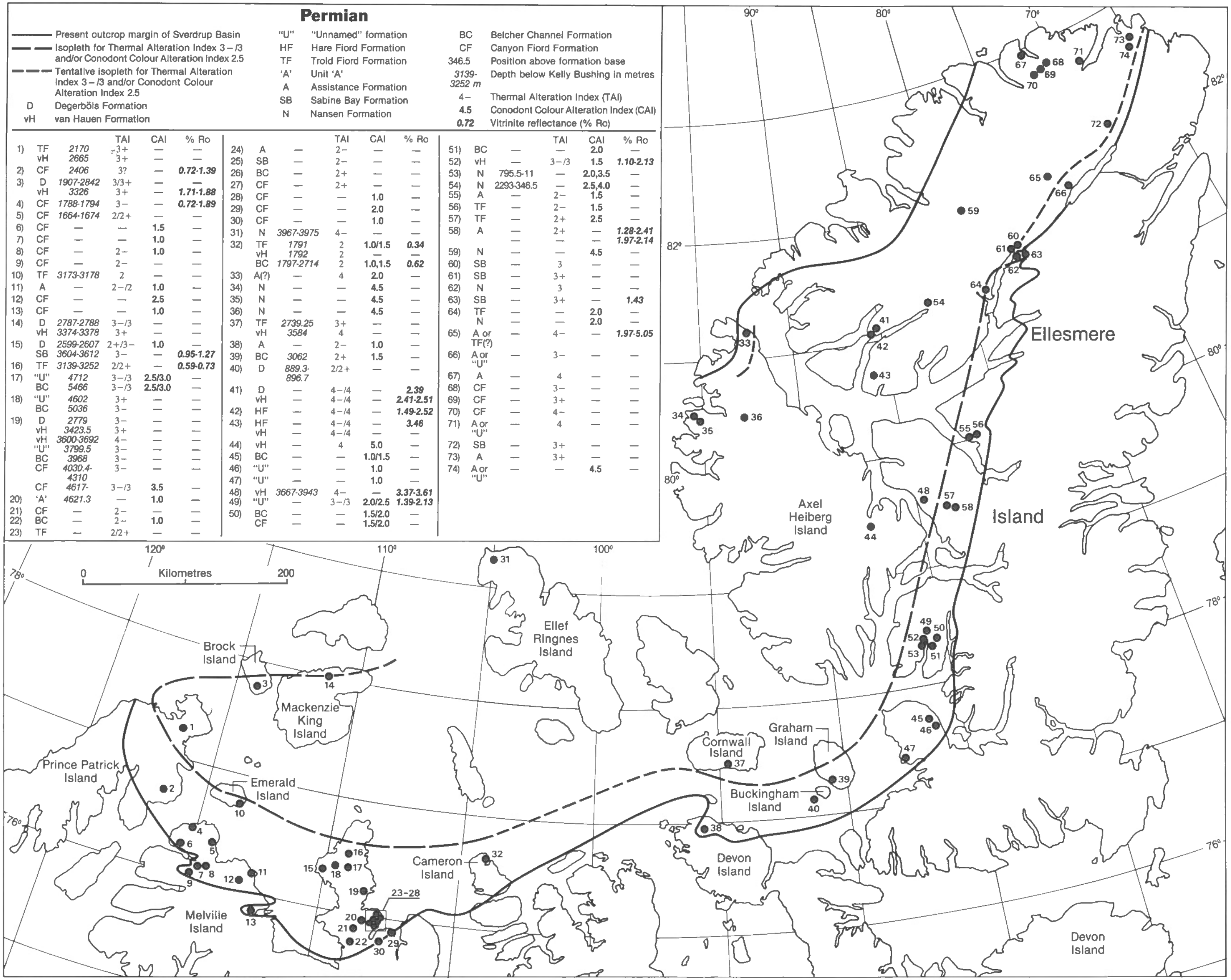
			TAI	CAI	% Ro
1)	EF	—	4–/4	—	—
2)	EF	400	2–	—	*0.26*
		1.0	2–	—	*0.50*
3)	EF	—	4–&4/5	—	*5.0*
4)	EF	*2450.0*	3	—	—
5)	EF	—	4(?)	—	—
6)	EF	—	4/5	—	—
7)	EF(?) or BF(?)	—	4/5	—	—
8)	EF(?) or BF(?)	—	—	5.0	—

Figure 2. *Lower Carboniferous thermal maturity map.*



			TAI	CAI	% Ro
1)	CF	*2406*	3 (?)	—	***0.72-1.39***
2)	CF	*1788-1794*	3	—	***0.72-1.89***
3)	CF	*1664-1674*	2/2+	—	—
4)	CF	—	—	**1.5**	—
5)	CF	—	2–	**1.0**	—
6)	CF	—	—	**1.0**	—
7)	CF	—	2–	—	—
8)	CF	—	—	**2.5**	—
9)	CF	—	—	**1.0**	—
10)	OF	—	4–	—	—
11)	CF	*4030.4-4310*	3–	—	—
		4617-4621.3	3–/3	**3.5**	—
12)	CF	—	2–	—	—
13)	CF	—	2+	—	—
14)	CF	—	—	**2.0?**	—
15)	N	—	4–	—	—
16)	N	*2313-2376.9*	3	—	—
17)	HF	—	4–	**4.5**	—
18)	OF	—	4–	**4.0**	***2.09-3.02***
19)	HF	—	4/5	**6.0**	—
20)	CF	—	—	**2.0**	—
21)	N	—	—	**3.5**	—
22)	N	2298	—	**2.5**	—
	N	346.5	—	**4.0**	—
23)	N	—	—	**4.5**	—
	HF	—	—	**5.0**	—
24)	BF	—	—	—	***4.92-5.01***
25)	HF	—	—	—	***4.19-4.28***
26)	CF	—	3+	—	—
27)	BF	—	—	**4.5**	—
28)	CF	—	3+	—	—
29)	CF	—	3+	—	—
30)	CF	—	4–	—	—

Figure 3. *Upper Carboniferous thermal maturity map. Area between outcrop margin and isopleth falls within oil window.*



	Formation	Depth / position	TAI	CAI	% Ro
1)	TF	2170	3+	—	—
	vH	2665	3+	—	—
2)	CF	2406	3?	—	0.72-1.39
3)	D	1907-2842	3/3+	—	—
	vH	3326	3+	—	1.71-1.88
4)	CF	1788-1794	3–	—	0.72-1.89
5)	CF	1664-1674	2/2+	—	—
6)	CF	—	—	1.5	—
7)	CF	—	—	1.0	—
8)	CF	—	2–	1.0	—
9)	CF	—	2–	—	—
10)	TF	3173-3178	2	—	—
11)	A	—	2–/2	1.0	—
12)	CF	—	—	2.5	—
13)	CF	—	—	1.0	—
14)	D	2787-2788	3–/3	—	—
	vH	3374-3378	3+	—	—
15)	D	2599-2607	2+/3–	1.0	—
	SB	3604-3612	3–	—	0.95-1.27
16)	TF	3139-3252	2/2+	—	0.59-0.73
17)	"U"	4712	3–/3	2.5/3.0	—
	BC	5466	3–/3	2.5/3.0	—
18)	"U"	4602	3+	—	—
	BC	5036	3–	—	—
19)	D	2779	3–	—	—
	vH	3423.5	3+	—	—
	vH	3600-3692	4–	—	—
	"U"	3799.5	3–	—	—
	BC	3968	3–	—	—
	CF	4030.4-4310	3–	—	—
	CF	4617-	3–/3	3.5	—
20)	'A'	4621.3	—	1.0	—
21)	CF	—	2–	—	—
22)	BC	—	2–	1.0	—
23)	TF	—	2/2+	—	—
24)	A	—	2–	—	—
25)	SB	—	2–	—	—
26)	BC	—	2+	—	—
27)	CF	—	2+	—	—
28)	CF	—	—	1.0	—
29)	CF	—	—	2.0	—
30)	CF	—	—	1.0	—
31)	N	3967-3975	4–	—	—
32)	TF	1791	2	1.0/1.5	0.34
	vH	1792	2	—	—
	BC	1797-2714	2	1.0,1.5	0.62
33)	A(?)	—	4	2.0	—
34)	N	—	—	4.5	—
35)	N	—	—	4.5	—
36)	N	—	—	4.5	—
37)	TF	2739.25	3+	—	—
	vH	3584	4	—	—
38)	A	—	2–	1.0	—
39)	BC	3062	2+	1.5	—
40)	D	889.3-896.7	2/2+	—	—
41)	D	—	4–/4	—	2.39
	vH	—	4–/4	—	2.41-2.51
42)	HF	—	4–/4	—	1.49-2.52
43)	HF	—	4–/4	—	3.46
	vH	—	4–/4	—	—
44)	vH	—	4	5.0	—
45)	BC	—	—	1.0/1.5	—
46)	"U"	—	—	1.0	—
47)	"U"	—	—	1.0	—
48)	vH	3667-3943	4–	—	3.37-3.61
49)	"U"	—	3–/3	2.0/2.5	1.39-2.13
50)	BC	—	—	1.5/2.0	—
	CF	—	—	1.5/2.0	—
51)	BC	—	—	2.0	—
52)	vH	—	3–/3	1.5	1.10-2.13
53)	N	795.5-11	—	2.0,3.5	—
54)	N	2293-346.5	—	2.5,4.0	—
55)	A	—	2–	1.5	—
56)	TF	—	2–	1.5	—
57)	TF	—	2+	2.5	—
58)	A	—	2+	—	1.28-2.41
		—	—	—	1.97-2.14
59)	N	—	—	4.5	—
60)	SB	—	3	—	—
61)	SB	—	3+	—	—
62)	N	—	3	—	—
63)	SB	—	3+	—	1.43
64)	TF	—	—	2.0	—
	N	—	—	2.0	—
65)	A or TF(?)	—	4–	—	1.97-5.05
66)	A or "U"	—	3–	—	—
67)	A	—	4	—	—
68)	CF	—	3–	—	—
69)	CF	—	3+	—	—
70)	CF	—	4–	—	—
71)	A or "U"	—	4	—	—
72)	SB	—	3+	—	—
73)	A	—	3+	—	—
74)	A or "U"	—	—	4.5	—

Figure 4. *Permian thermal maturity map. Area between outcrop margin and isopleth falls within oil window. Some samples from the subsurface within this area may have thermal maturity values higher than oil window due to depth of burial and/or the effect of igneous intrusions.*

The thermal maturity results obtained may have significant biostratigraphic implications, especially with respect to the selection of type sections. Palynological investigations and, to a lesser extent, the study of conodonts are severely limited by high thermal alteration of the fossil material. Thus, the selection of type sections in areas of high thermal maturity should be avoided whenever possible.

As further studies are completed in the Sverdrup Basin and more localities are sampled, it will be necessary to revise the maps accompanying this paper. Eventually, thermal maturity maps for shorter time intervals will be produced, but detailed biostratigraphic work is required before this goal can be attained.

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APPENDICES 1-3

Position below K.B. is provided for all subsurface samples. Position above formation base is provided for surface samples only where there is significant variation of thermal maturity over a studied interval.

In the appendices and some figures, 4/5 denotes a range from 4 to 5; 4, 5 denotes two separate readings of 4 and 5.

APPENDIX 1

Lower Carboniferous

Station	Curation (C) No.	Locality or *Well Name*	Latitude Longitude	Formation	Position in metres above Formation Base or *below K.B.*	TAI	CAI	%Roil
1	134493	Svartevaeg Cliffs, Axel Heiberg Is.	81°17'N 92°40'W	Emma Fiord		4-/4		
2	32905, 07 10, 12, 18	Lyall River, Grinnell Pen., Devon Is.	76°53'30"N 95°15'W	Emma Fiord	400 1.0	2- 2-		0.26 0.50
3	31146, 53	Kleybolte Pen., N. Ellesmere Is.	81°34'N 91°18'W	Emma Fiord		4- 4/5 (near intrusion)		5.0
4	97749	*Buckingham O-68*, Offshore Buckingham Is.	77°08'00.190"N 91°23'55.263"W	Emma Fiord	*2450.0*	3		
5	69919, 20, 21	McClintock Glacier, N. Ellesmere Is.	82°16'N 75°35'W	Emma Fiord		4(?)		
6	83451	Clements Markham Glacier, N. Ellesmere Is.	82°28'N 70°55'W	Emma Fiord		4/5		
7	70149, 50, 66, 67, 72, 75, 77, 81	Clements Markham Inlet, N.E. Ellesmere Is.	82°53'N 64°50'W	Emma Fiord (?) or Borup Fiord (?)		4/5		
8	99616	Gable Cliff, N.E. Ellesmere Is.	82°47'N 65°17'W	Emma Fiord (?) or Borup Fiord (?)			5.0	

APPENDIX 2

Upper Carboniferous

Station	Curation (C) No.	Locality or *Well Name*	Latitude Longitude	Formation	Position in metres above Formation Base or *below K.B.*	TAI	CAI	%Roil
1	126379	*Jameson Bay C-31,* Prince Patrick Is.	76°40'12.04"N 116°43'45.39"W	Canyon Fiord	*2406*	3(?)		0.72 to 1.39
2	30224	*Sandy Point L-46,* Melville Is.	76°25'38.40"N 115°18'14.24"W	Canyon Fiord	*1788-1794*	3		0.72 to 1.89
3	85232	*Depot Island C-44,* Melville Is.	76°23'14.47"N 114°17'44.65"W	Canyon Fiord	*1664-1674*	2/2+		
4	133805	Ibbett Bay, Melville Is.	76°29'N 115°30'W	Canyon Fiord			1.5	
5	134116, 18, 59	Ibbett Bay, Melville Is.	76°09'N 114°35'W	Canyon Fiord		2-	1.0	
6	134217, 18, 19, 23	Ibbett Bay, Melville Is.	76°08'N 114°42'W	Canyon Fiord			1.0	
7	128752	Purchase Bay, Melville Is.	76°01'N 115°00'W	Canyon Fiord		2-		
8	133800	Kitson River, Melville Is.	76°05'N 113°40'W	Canyon Fiord			2.5	
9	134149, 52	McCormick Inlet, Melville Is.	75°51'N 112°30'W	Canyon Fiord			1.0	
10	80011, 147	W. Central Barrow Dome, Melville, Is.	76°40'N 109°00'W	Otto Fiord		4-		
11	61559	*Sherard Bay F-34,* Melville Is.	76°13'21.622"N 108°43'39.423"W	Canyon Fiord	*4030.4-4310* *4617-4621.3*	3- 3-/3	 3.5	
12	128743	Weatherall Bay, Melville Is.	75°50'N 108°30'W	Canyon Fiord		2-		
13	126279, 83	Tingmisut Lake, Sabine Peninsula, Melville Is.	75°56'35"N 107°50'10"W	Canyon Fiord		2+		
14	133761	Weatherall Bay, Melville Is.	75°52'N 106°55'W	Canyon Fiord			2.0(?)	
15	67946	N.W. Ellef Ringnes Is.	79°16'39"N 105°16'35"W	Nansen		4-		
16	97749	*Buckingham O-68,* Offshore Buckingham Is.	77°08'00.190"N 91°23'55.263"W	Nansen	*2313-2376.9*	3		
17	99344, 49 99400, 20 105348, 55, 57	van Hauen Pass, Ellesmere Is.	81°05'N 85°31'W	Hare Fiord		4-	4.5	
18	99387, 8 105339-44	van Hauen Pass, Ellesmere Is.	81°04'N 85°30'W	Otto Fiord		4-	4.0	2.09 to 3.02

APPENDIX 2

Station	Curation (C) No.	Locality or *Well Name*	Latitude Longitude	Formation	Position in metres above Formation Base or *below K.B.*	TAI	CAI	%Roil
19	99187 99429, 50 99001, 114	Blue Mountains, Ellesmere Is.	80°44'N 85°50'W	Hare Fiord		4/5	6.0	
20	125296-99 125300	East side of Blind Fiord, S.W. Ellesmere Is.	78°25'N 85°31'W	Canyon Fiord			2.0	
21	125012 125191, 197 125486 125489-491	West side of Blind Fiord, S.W. Ellesmere Is.	78°22'N 85°55'W	Nansen			3.5	
22	106721, 800 107501, 46	East End of Hare Fiord, N. Ellesmere Is.	81°13'N 82°13'W	Nansen	2298 346.5		2.5 4.0	
23	45449	Yelverton Inlet, N. Ellesmere Is.	81°54'N 78°55'W	Nansen Hare Fiord			4.5 5.0	
24	45330, 31, 57	Yelverton Inlet, N. Ellesmere Is.	81°56'N 79°25'W	Borup Fiord				4.92 to 5.01
25	45361, 64	Yelverton Inlet, N. Ellesmere Is.	81°45'N 79°25'W	Hare Fiord				4.19 to 4.28
26	69949, 52, 56, 57, 59, 67	Henrietta Nesmith Glacier, N. Ellesmere Is.	82°15'N 75°30'W	Canyon Fiord		3+		
27	69854, 55	Henrietta Nesmith Glacier, N. Ellesmere Is.	81°55'08"N 73°05'W	Borup Fiord			4.5	
28	70001	Markham Fiord N. Ellesmere Is.	82°50'N 70°40'W	Canyon Fiord		3+		
29	70011	Markham Fiord, N. Ellesmere Is.	82°50'N 71°00'W	Canyon Fiord		3+		
30	70032, 37	Markham Fiord, N. Ellesmere Is.	82°49'N 71°30'W	Canyon Fiord		4–		

APPENDIX 3

Permian

Station	Curation (C) No.	Locality or *Well Name*	Latitude Longitude	Formation	Position in metres above Formation Base or *below K.B.*	TAI	CAI	%Roil
1	58206	*Satellite F-68,* Prince Patrick Is.	77°17'21"N 116°55'10"W	Trold Fiord van Hauen	*2170* *2665*	3+ 3+		
2	126379	*Jameson Bay C-31,* Prince Patrick Is.	76°40'12.04"N 116°43'45.39'W	Canyon Fiord	*2406*	3?		0.72 to 1.39
3	30542	*Brock C-50,* Brock Is.	77°49'00.12"N 114°17'24.09"W	Degerböls	*1907-2842*	3/3+		
				van Hauen	*3326*	3+		1.71 to 1.88
4	30224	*Sandy Point L-46,* Melville Is.	76°25'38.40"N 115°18'14.24"W	Canyon Fiord	*1788-1794*	3-		0.72 to 1.89
5	85232	*Depot Island C-44,* Melville Is.	76°23'14.47"N 114°17'44.65"W	Canyon Fiord	*1664-1674*	2/2+		
6	133805	Ibbett Bay, Melville Is.	76°29'N 115°30'W	Canyon Fiord			1.5	
7	134217, 18, 19, 23	Ibbett Bay, Melville Is.	76°08'N 114°42'W	Canyon Fiord			1.0	
8	134116, 18, 59	Ibbett Bay, Melville Is.	76°09'N 114°35'W	Canyon Fiord		2-	1.0	
9	128752	Ibbett Bay, Melville Is.	76°01'N 115°00'W	Canyon Fiord		2-		
10	30844	*Emerald K-33,* Emerald Is.	76°42'43"N 113°48'21"W	Trold Fiord	*3173-3178*	2		
11	134166-72 134183	Green Creek, Raglan Range, Melville Is.	76°11'N 112°35'W	Assistance		2-/2	1.0	
12	133800	Kitson River, Melville Is.	76°05'N 113°40'W	Canyon Fiord			2.5	
13	134149, 52	McCormick Inlet, Melville Is.	75°51'N 112°30'W	Canyon Fiord			1.0	
14	30221	*Wilkins E-60,* MacKenzie King Is.	77°59'19"N 111°21'45"W	Degerböls	*2787-2788*	3-/3		
				van Hauen	*3374-3378*	3+		
15	23415	*Hecla J-60* Melville Is.	76°19'37.88"N 110°19'49.07"W	Degerböls	*2599-2607*	2+/3-	1.0	
				Sabine Bay	*3604-3612*	3-		0.95 to 1.27
16	30239	*Drake Point L-67,* Melville Is.	76°27'36.85"N 108°55'23.01"W	Trold Fiord	*3139-3252*	2/2+		0.59 to 0.73

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17	97716	*Marryatt K-71,* Melville Is.	76°21'37.48"N 108°58'25.90"W	"Unnamed" (Nassichuk and Wilde, 1977)	*4712*	3-/3	2.5/3.0	
				Belcher Channel	*5466*	3-/3	2.5/3.0	
18	97730	*Chads Creek B-64,* Melville Is.	76°23'08"N 109°54'21"W	"Unnamed"	*4602*	3+		
				Belcher Channel	*5036*	3-		
19	61559	*Sherard Bay F-34,* Melville Is.	76°13'21.622"N 108°43'39.423"W	Degerböls	*2779*	3-		
				van Hauen	*3423.5*	3+		
				van Hauen	*3600-3692*	4-		
				"Unnamed" (Nassichuk and Wilde, 1977)	*3799.5*	3-		
				Belcher Channel	*3968*	3-		
				Canyon Fiord	*4030.4-4310*	3-		
				Canyon Fiord	*4617-4621.3*	3-/3	3.5	
20	126001	Sabine Peninsula, Melville Is.	75°57'40"N 108°10'00"W	Unit 'A' (Nassichuk, 1965)			1.0	
21	128743	Weatherall Bay, Melville Is.	75°51'N 108°30'W	Canyon Fiord		2-		
22	133763-64	Sabine Bay, Melville Is.	75°46'N 108°33'W	Belcher Channel		2-	1.0	
23	99228-46	Tingmisut Lake, Melville Is.	75°59'20"N 107°58'50"W	Trold Fiord		2/2+		
24	126251-56	Tingmisut Lake, Melville Is.	75°58'30"N 107°59'10"W	Assistance		2-		
25	126257-78	Tingmisut Lake, Melville Is.	75°57'40"N 107°59'00"W	Sabine Bay		2-		
26	126284-94	Tingmisut Lake, Melville Is.	75°56'20"N 107°56'40"W	Belcher Channel		2+		
27	126279-83	Tingmisut Lake, Melville Is.	75°56'35"N 107°50'10"W	Canyon Fiord		2+		
28	114936-48	Tingmisut Lake, Melville Is.	75°59'59"N 107°59'10"W	Canyon Fiord			1.0	
29	133761	Weatherall Bay, Melville Is.	75°53'N 107°20'W	Canyon Fiord			2.0	
30	134001	Weatherall Bay, Melville Is.	75°48'N 107°50'W	Canyon Fiord			1.0	
31	67946	*Isachsen J-37,* Ellef Ringnes Is.	79°16'39.6"N 105°16'35.7"W	Nansen	*3967-3975*	4-		
32	59411	*Robert Harbour K-07,* Cameron Is.	76°36'32"N 104°02'14"W	Trold Fiord	*1791*	2	1.0/1.5	0.34
				van Hauen	*1792*	2		
				Belcher Channel	*1797-2714*	2	1.0, 1.5	0.62

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33	135477-80 123987	Svartevaeg Cliff, Axel Heiberg Is.	81°13'N 92°05'W	Assistance(?)		4 (near intrusion)	2.0	
34	115674-90	Arthaber Creek, Axel Heiberg Is.	80°34'N 95°35'W	Nansen			4.5	
35	115691-97	Arthaber Creek, Axel Heiberg Is.	80°33'N 95°28'W	Nansen			4.5	
36	115652-73	Griesbach Creek, Axel Heiberg Is.	80°28'N 94°28'W	Nansen			4.5	
37	61558	*Cornwall O-30,* Cornwall Is.	77°29'47"N 94°38'58"W	Trold Fiord van Hauen	*2739.25* *3584*	3+ 4		
38	148178, 83 148049, 62	Lyall River, Grinnell Pen., Devon Is.	76°57'50"N 95°20'30"W	Assistance		2-	1.0	
39	46846	*Graham C-52,* Graham Is.	77°21'14"N 90°51'25"W	Belcher Channel	*3062*	2+	1.5	
40	97749	*Buckingham O-68,* Offshore Buckingham Is.	77°08'00.190"N 91°23'55.263"W	Degerböls	*889.3-* *896.7*	2/2+		
41	99426, 27 99301 99421, 26	van Hauen Pass, Ellesmere Is.	81°04'N 86°20'W	Degerböls van Hauen		4-/4 4-/4		2.39 2.41 to 2.51
42	99394, 99 99400	van Hauen Pass, Ellesmere Is.	81°03'N 86°27'W	Hare Fiord		4-/4		1.49 2.52
43	99429, 50 99187 99115, 82	Blue Mountain, Ellesmere Is.	80°44'N 85°50'W	Hare Fiord van Hauen		4-/4 4-/4		3.46
44	125609, 11	Buchanan Lake, Axel Heiberg Is.	79°27'45°N 87°12'W	van Hauen		4	5.0	
45	148351	N.E. Bjorne Pen., S.W. Ellesmere Is.	77°36'N 86°15'W	Belcher Channel			1.0/1.5	
46	148403	N.E. Bjorne Pen., S.W. Ellesmere Is.	77°35'30"N 86°13'W	"Unnamed" (Nassichuk and Wilde, 1977)			1.0	
47	148329, 32	Great Bear Cape, S.W. Ellesmere Is.	77°22'30"N 87°45'W	"Unnamed" (Nassichuk and Wilde, 1977)			1.0	
48	51834	*Fosheim N-27,* Fosheim Pen., Ellesmere Is.	79°36'54.230"N 84°43'18.994"W	van Hauen	*3667-* *3943*	4-		3.37 to 3.61
49	125002, 03, 05, 06	West side Blind Fiord, Ellesmere Is.	78°28'N 85°42'W	"Unnamed" (Nassichuk and Wilde, 1977)		3-/3	2.0/2.5	1.39 to 2.13
50	125314, 15	East side Blind Fiord, S.W. Ellesmere Is.	78°25'N 85°31'W	Belcher Channel Canyon Fiord			1.5/2.0 1.5/2.0	

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51	125227	East side Blind Fiord, S.W. Ellesmere Is.	78°22'15"N 85°39'W	Belcher Channel			2.0	
52	125180, 87, 89	West side Blind Fiord, S.W. Ellesmere Is.	78°22'N 85°57'W	van Hauen		3-/3	1.5	1.10 to 2.13
53	125020, 23 28, 160, 164, 167, 174	West side Blind Fiord, S.W. Ellesmere Is.	78°22'N 85°55'W	Nansen	795.5-11		2.0, 3.5	
54	106721-800 107501-46	East end of Hare Fiord, N. Ellesmere Is.	81°13'N 82°13'W	Nansen	2293-346.5		2.5, 4.0	
55	82359-403 82413,	Hamilton Pen., N. Ellesmere Is.	80°03'20"N 81°44'00"W	Assistance		2-	1.5	
56	82372-81 82423-39	Hamilton Pen., N. Ellesmere Is.	80°02'35"N 81°43'45"W	Trold Fiord		2-	1.5	
57	82293 82322-342	Sawtooth Range, Fosheim Pen., N. Ellesmere Is.	79°30'10"N 83°21'30"W	Trold Fiord		2+	2.5	
58	82261, 66	Sawtooth Range, Fosheim Pen., N. Ellesmere Is.	79°29'55"N 83"19'50"W	Assistance		2+		1.28 to 2.41 1.97 to 2.14
59	45455	Yelverton Pass, N. Ellesmere Is.	81°54'N 78°55'W	Nansen			4.5	
60	82479	N. End Tanquary Fiord, N. Ellesmere Is.	81°27'05"N 76°29'10"W	Sabine Bay		3		
61	82485	N. End Tanquary Fiord, N. Ellesmere Is.	81°23'20"N 76°28'20"W	Sabine Bay		3+		
62	45449 45502	N. End Tanquary Fiord, N. Ellesmere Is.	81°24'N 76°55'W	Nansen		3		
63	45170, 72	N. End Tanquary Fiord, N. Ellesmere Is.	81°20'00"N 76°18'00"W	Sabine Bay		3+		1.43
64	82451	McKinley Bay, N. Ellesmere Is.	81°10'10"N 79°03'45"W	Trold Fiord Nansen			2.0 2.0	
65	82533, 34 38, 40, 44	Henrietta Nesmith Glacier, N. Ellesmere Is.	81°54'00"N 73°38'30"W	Assistance or Trold Fiord (?)		4-		1.97 to 5.05 (near intrusion)
66	99711	Lake Hazen, N.E. Ellesmere Is.	81°46'N 72°12'W	Assistance or "Unnamed" (Nassichuk and Wilde, 1977)		3-		

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67	99551	Markham Fiord, N. Ellesmere Is.	82°58'N 71°20'W	Assistance		4		
68	70011	Markham Fiord, N. Ellesmere Is.	82°50'N 71°00'W	Canyon Fiord		3-		
69	70001	Markham Fiord, N. Ellesmere Is.	82°50'N 71°15'W	Canyon Fiord		3+		
70	70032, 37	Markham Fiord, N. Ellesmere Is.	82°49'N 71°30'W	Canyon Fiord		4-		
71	70236	Clements Markham Inlet, N. Ellesmere Is.	82°40'N 68°35'W	Assistance or "Unnamed" (Nassichuk and Wilde, 1977)		4		
72	82503	Piper Pass, N. Ellesmere Is.	82°10'25"N 68°35'45"W	Sabine Bay		3+		
73	83469	Parker Bay, N. Ellesmere Is.	82°42'N 65°15'W	Assistance		3+		
74	83480	Parker Bay, N. Ellesmere Is.	82°39'N 65°20'W	Assistance or "Unnamed" (Nassichuk and Wilde, 1977)			4.5	