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**UNEDITED REPORT:
EXAMINATION OF UPPER CRETACEOUS OIL SHALES
ALONG THE MANITOBA ESCARPMENT:
AN ASSESSMENT OF REGIONAL VARIATION IN
MINERALOGY, ORGANIC RICHNESS AND ORGANIC TYPE**

Project 820037

L.J. Kovac

Geological Survey of Canada (Calgary)
3303 - 33 Street N.W.
Calgary, Alberta T2L 2A7

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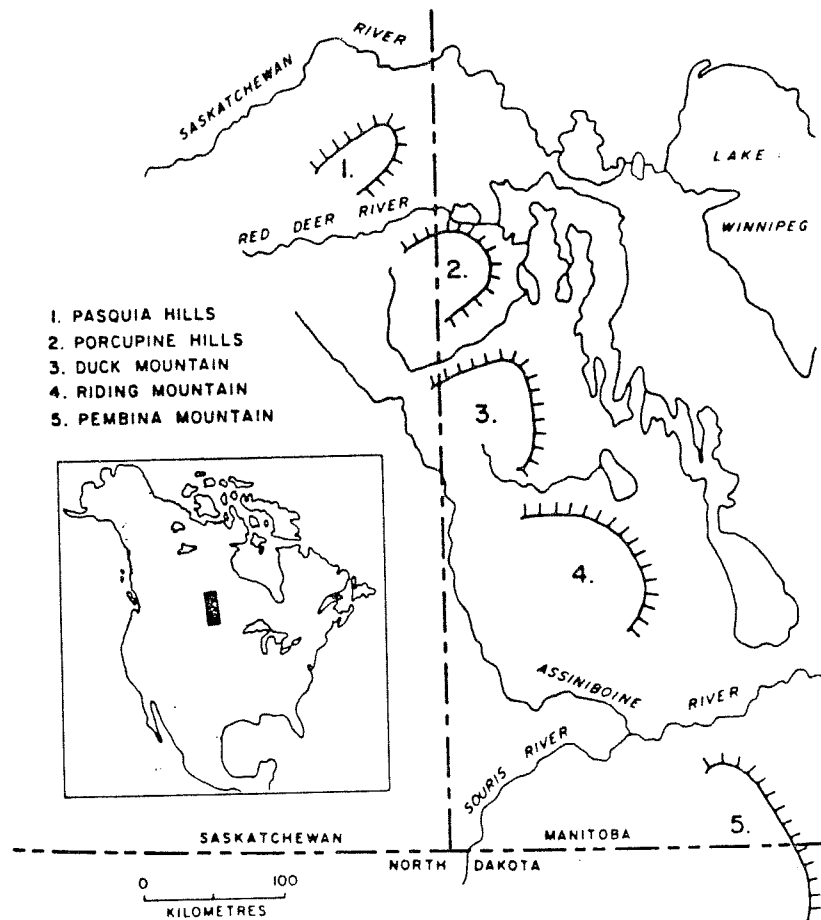
Introduction and Brief History

The existence of oil shales within Upper Cretaceous aged sediments along the Manitoba escarpment, has been known for some time. Early work recording this occurrence includes reports by Tyrell (1892), McInnes (1913), Clapp (1915), and Ells (1923).

During the mid 1960's several oil companies conducted exploration to assess the economic potential of the oil shales through drill core and outcrop sampling. The most encouraging results came from a series of forty holes drilled by the Sun Oil Company in the Pasquia Hills region of Saskatchewan (see Figure 1). Estimations of economic yields from the company's Fischer Assay results have been made by various authors (Beck, 1974; Macauley, 1981).

Land leased by the Aquitaine Oil Company was restricted to central portions of the escarpment south of Riding Mountain National Park. Their work included surface sampling and examination of mineralogy by thin section analysis. Drilling was not carried out in this area.

In the southern region of the escarpment, near Pembina Mountain, the Atlantic-Refining Company drilled three holes projected to intersect the two known oil shale zones. Unfortunately underestimation of the overburden thickness re-



adapted from McNeil and Caldwell (1981)

Figure 1: Location Map

sulted in only one of the zones being intersected within the allotted drill depth. Analyses included Fischer Assay results which were generally poor and work was discontinued.

In general, while higher Fischer Assay yields were encountered in the Pasquia Hills area, even the best results were not comparable to those of the Eocene Green River oil shales which were currently being developed in Colorado, Utah and Wyoming at that time. Except for the three cores drilled by the Atlantic-Refining Company all other cores have been lost or destroyed.

More recently, because of the attractive features of vast areal extent and great thickness, the potential of these organic-rich shales are being reassessed on a more systematic basis. The only economic estimate by Beck (1974), involved an area on the north flank of the Pasquia Hills. A recent report by Macauley (1981), modifies this estimate to 1.25 billion barrels and also offers an overview of the geology and previous work done on the oil shales. Detailed aspects of the sedimentology, mineralogy, as well as organic richness, type and maturity are currently being assessed from the existing drill core in southern Manitoba (Kovac, MSc. thesis in preparation).

Study Objectives

A long term objective for this program will be a detailed assessment of the richer zones of oil shale found within the Upper Cretaceous shales of Manitoba and Saskatchewan. This will involve a study of the sedimentology, mineralogy, organic richness and type and presented as a depositional model which will explain the conditions under which such an oil shale formed. Specific objectives of this study are to:

- 1) Obtain a representative suite of oil shale samples from outcrops along the escarpment in Manitoba and Saskatchewan.
- 2) Assess the regional variability of the organic type and organic richness from the samples collected.
- 3) Examine the regional variation of the mineralogy from the samples collected.
- 4) Investigate various types of drilling methods which could be used to obtain non-weathered samples.
- 5) Determine if weathering affects the total organic carbon and pyrolytic yield of the samples.

General Geology and Stratigraphy

The Manitoba Escarpment is comprised of an outcrop belt which trends northwest to southeast in a series of five well-defined geographic areas (Figure 1). Cretaceous rocks existing as outcrop and subcrop along the escarpment repre-

sents the eastern erosional boundary of the Western Interior Basin of North America (Figure 2). These sediments were deposited in a shallow epeiric sea as part of two major sedimentary phases known as the Greenhorn and Niobrara cycles (Kauffman, 1969; Hancock and Kauffman, 1979). Upper Cretaceous sediments which formed the oil shales have been recognized as being comprised primarily of fine-grained carbonate material made up of calcareous microfossils and deposited as a distinct facies on the eastern platform of the epeiric seaway (Rice and Shurr, 1983).

Reports from numerous authors, presenting the stratigraphy of the area, have shown a wide variation in the nomenclature used for the Upper Cretaceous (Kirk, 1930; Wickenden, 1945; Hutt, 1963; Macauley, 1981; McNeil and Caldwell 1981). Most recently, McNeil and Caldwell (1981), have examined in greatest detail the stratigraphy based on a comprehensive biostratigraphic examination of foraminifera in the Upper Cretaceous units. They present convincing evidence for revising the existing terminology. Major changes made to the stratigraphic nomenclature include: a) substituting the name Pierre Shale for the Riding Mountain and Pembina Formations, b) substituting the name Niobrara Formation in place of the Boyne formation, c) raising the Morden shale from a member to formational status (see Table 1).

When considering the fact these formations are stratigraphically equivalent to those in the northern U.S. and were de-

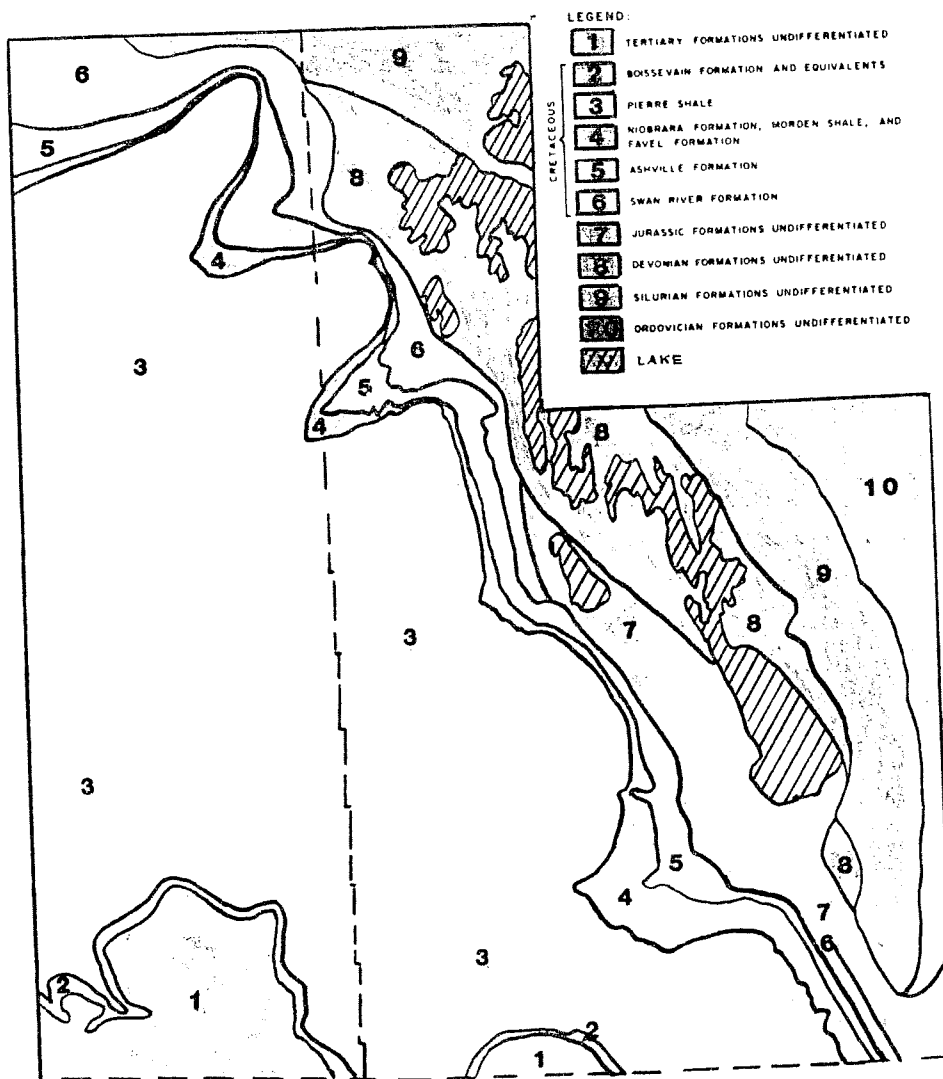


Figure 2. Geology of the Oil Shale Study Area.

CRETACEOUS NOMENCLATURE AND STRATIGRAPHIC CORRELATION CHART

CRETACEOUS NOMENCLATURE AND STRATIGRAPHIC CORRELATION CHART

ERA	PERIOD	EPOCH	SOUTHEAST SASKATCHEWAN R. B. HUTT (1963)	NORTH DAKOTA R. B. HUTT (1963) MODIFIED AFTER GILL AND COBBAN (1961)	MANITOBA* (M. R. D. USAGE)		MANITOBA (MCNEIL AND CALDWELL, 1981)	STAGES	
MESOZOIC	CRETACEOUS	UPPER CRETACEOUS	RAVENSCRAIG	FORT UNION	TURTLE MOUNTAIN	PEACE GARDEN	TURTLE MOUNTAIN		
			FRENCHMAN	HELL CREEK	BOISSEVAIN		BOISSEVAIN	MAESTRICHTIAN	
			WHITEMUD	COLGATE MEMBER FOX HILLS			UNWAHED		
			EASTEND						
			BEARPAW						

From Bannatyne and Watson (1982)

posited under the same facies conditions that existed along the eastern platform system, such recommendations are logical to accept.

The sedimentary rock that forms the oil shale deposits includes an upper calcareous zone known as the Niobrara Formation and a lower calcareous zone, the Favel Formation. To the west, in Saskatchewan and Alberta, these are known by the informal names of the first and second white specks respectively. In Manitoba an intervening non-calcareous shale known as the Morden Shale exists between these two formations.

The thickness of these formations vary considerably from the southeast to northwest along the escarpment (Table 2). In general, information from drill core and electric logs indicates that all three formations thin towards the northwest (McNeil and Caldwell, 1981).

TABLE 2
Regional Variation in Formation Thicknesses

<u>Formation</u>	<u>Thickness (in metres)</u>		
	Southeast	Central	Northwest
Niobrara	73	30	16
Morden	55	15	4
Favel	46	34	11

These thickness changes are likely due to subtle unconformities present in the sequence which resulted from uplift and erosion or a period of non-deposition (Macauley, 1981). The Morden Shale thins westward to an area where only one white speckled shale is recognized (Park, 1965).

Lithology

A concise lithological description for the pertinent formations involved with this study are presented in Table 3.

TABLE 3

Lithology of the Niobrara, Morden and Favel Formations

Formation	Member	Bed
Niobrara	Chalky Member: Buff coloured chalky shale to marlstone. Upper portion comprised of thin olive to black calcareous to non-calcareous interbeds and minor bentonite.	
	Calcareous Shale: Olive to black coloured shale with abundant calcareous white specks comprised of coccolithic debris. Rare ammonite shell. Common Inoceramus debris.	
Morden Shale	Uniform black non-calcareous shale with rare thin bentonite beds and occasional ovoid concretions plus thin lenses of fine quartzose silt.	
Favel	Assiniboine Member: olive to black coloured chalk speckled shale. Thin interbeds of bentonite and calcarenite	Marco Calcarenite Upper 2 metres. Yellow-brown prismatic calcite derived from Inoceramus. Common fish fragments.
	Keld Member: Olive to black coloured chalk speckled shale. Numerous thin bentonite seams.	Laurier Limestone: Upper 5 metres. Argillaceous limestone in beds 5'-1' thick.

Sampling Methods

Using the reports of Wickenden (1945), McNeil and Caldwell (1981) as well as Manitoba government open-file reports, a series of outcrops extending along the length of the escarpment were visited and sampled during the summer of 1983. Outcrops were chosen on the basis of access and the fact they represented exposures of either one or both of the oil shale formations. In total fifteen outcrops throughout the five geographic areas were selected. In situations where well exposed outcrop was encountered more than one sample was collected. As a result, a total of thirty-seven samples each weighing approximately one kilogram were obtained. The formation and a brief description for each sample was noted. The location of the outcrops and the number of samples taken at each are shown in Figure 3. A summary of the hand sample descriptions and their precise locations can be found in Appendix A.

At selected locations weathered and non-weathered samples were taken from the same stratigraphic levels to examine the possible effect weathering may have on the total organic carbon and the pyrolytic yield. Non-weathered samples were obtained by trenching at least one metre into fresh outcrop.

In the Pembina Mountain area two methods of drilling were investigated with the hope of obtaining non-weathered sam-

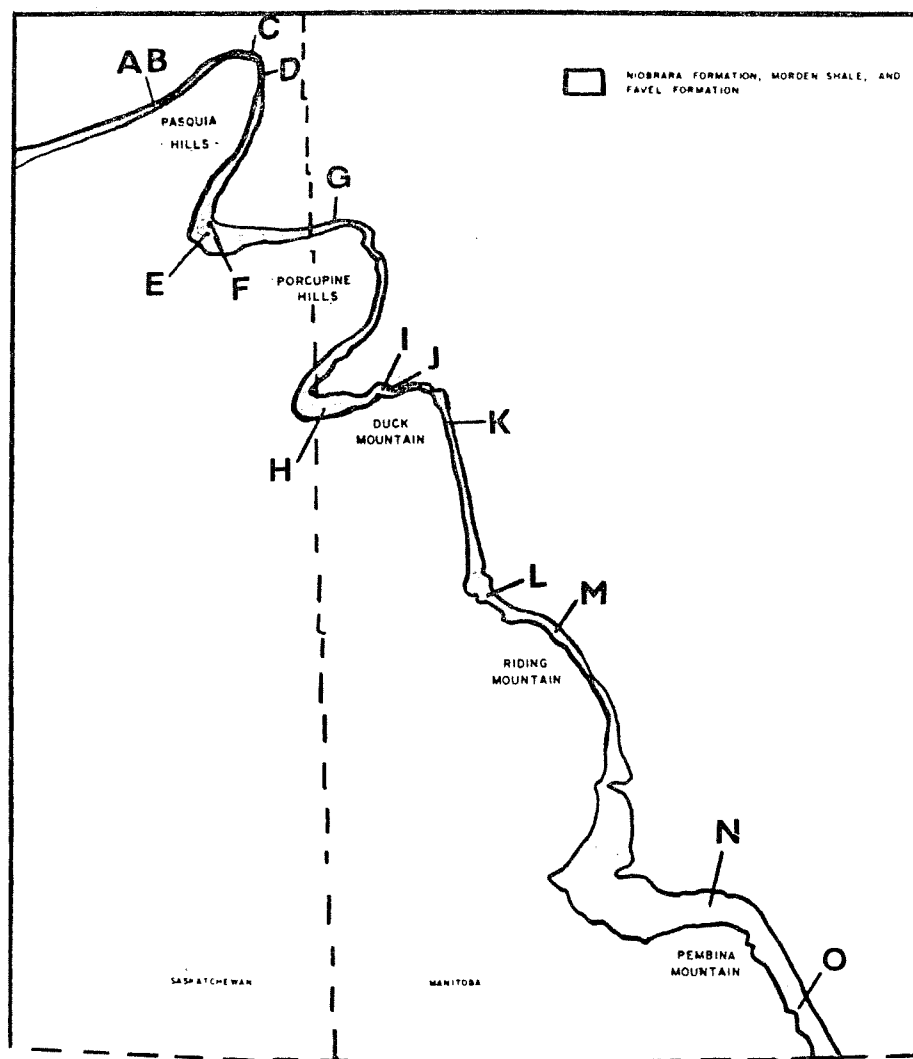


Figure 3. Outcrop and Sample Locations along the Manitoba Escarpment.

<u>Outcrop</u>	<u>Legend</u>	<u>Sample Nos.</u>
A. Man River		1-3
B. Man River		4-8
C. Mountain Creek		9-10
D. Waskwei River		11-12
E. Etomami River		13-14
F. Red Deer River		15
G. Little Woody River		16-18
H. Swan River		19-21
I. West Favel River		22-26
J. East Favel River		27
K. Sclater River		28-29
L. Wilson River		30-31
M. Ochre River		32-34
N. Assiniboine River		35
O. Deadhorse Creek		36-37

ples from greater depths. This involved testing with an Atlas-Copco overburden drill and a small two horsepower portable diamond drill.

The complete suite of samples were crushed to a clay size fraction using a swing mill and sent to the Institute of Sedimentary and Petroleum Geology in Calgary for analysis. This included semi-quantitative mineralogy, estimation of total organic carbon (TOC), and Rock-Eval pyrolysis.

Results and Discussion

Complete results of analyses for the thirty-seven samples collected are given in Appendix B and C. In order to present the regional variations in organic content and organic type the various parameters have been organized into samples representing each of the five geographic areas.

A. Organic Richness and Yield

Organic richness and yield are evaluated by total organic carbon and Rock-Eval pyrolysis (S1+S2 in kg of hydrocarbon per tonne of rock). The results on a regional basis are shown in Table 4.

These results indicate there is a general decrease in organic richness and yield along the escarpment from the northwest to the southeast. Fischer Assay results from

TABLE 4
Regional Variation in Organic Richness and Yield

for the Upper Cretaceous Oil Shales.

<u>Area</u>	<u>No. of Samples</u>	<u>Total Organic Carbon</u> (%)			<u>Rock-Eval</u> (S1+S2 kg/tonn)		
		Ave.	Min.	Max.	Ave.	Min.	Ma
Pasquia Hills	15	7.61	3.78	11.24	34.76	12.22	48
Porcupine Hills	3	7.19	7.03	7.93	35.18	34.39	38
Duck Mtn.	11	6.81	1.39	8.59	30.93	1.96	42
Riding Mtn.	5	5.92	5.85	6.45	30.23	24.10	36
Pembina Mtn.	3	5.18	4.03	6.06	16.65	12.44	20

drill core by the Sun Oil Company (1965) indicated a similar trend in yield for the area they leased.

An initial interpretation of this information may be that sediments towards the northwest were deposited under conditions having greater organic input or anoxic environment or a combination of both.

B. Weathered Versus Non-weathered Samples.

In most cases non-weathered samples were obtained by trenching past the obvious weathered zone. Due to the nature of the outcrop in some cases, only weathered samples were collected because it was impossible to trench past the weathered zone. In four locations both weathered and non-weathered samples were collected from the same stratigraphic

horizon. Results of this suite of samples are summarized in Table 5.

TABLE 5
Total Organic Carbon and Pyrolytic Yield

Comparative Results for Weathered Versus Non-weathered Samples.

<u>Location</u>	<u>Sample No.</u>	<u>Status</u>	<u>TOC</u> (%)	<u>S1+S2</u> (kg/tonne)
Etomami River	13	weathered	7.76	42.76
"	14	non-weathered	6.97	36.53
W. Favel River	22	weathered	6.58	31.14
"	23	non-weathered	8.13	40.78
Ochre River	33	weathered	6.45	32.07
"	32	Non-weathered	5.43	32.09
Deadhorse Creek	35	weathered	5.17	11.98
"	36	non-weathered	4.30	12.44

The results from the four sets of samples indicate that weathering has no appreciable effect on the amount of total organic carbon (TOC) or pyrolytic yield detected. Likewise, a recent study by Cassa (1983), tested the effects of weathering on source rocks to a depth of 15 to 21 metres (50 to 70 feet) for these same parameters. The results indicate no systematic change to the amount of total organic matter or extractable organic matter with greater depth.

However, in this study, it is possible that trenching to a depth of one metre may be insufficient and that all the samples collected represent the weathered zone. Until an

inexpensive method for obtaining core from outcrop such as this at greater depths is devised, this point will remain untested.

C. Organic Type

Estimation of organic type is by a plot of hydrogen index versus oxygen index parameters determined by Rock-Eval pyrolysis. Results from the thirty-seven samples representing the five geographic areas are shown in Figure 4. They indicate a wide range in values but collectively show that the oil shales are made up of a mixture of kerogen dominated by Type II and Type III. Samples from the Pembina Mountain area have consistently lower hydrogen index values and infer a relatively greater input of terrestrial organic matter.

D. Drilling

Two methods of drilling were tested with the goal of obtaining non-weathered samples from depths greater than a few metres. Unfortunately both methods proved to be unsuccessful.

The first method involved an Atlas-Copco overburden plugger commonly used to bore into a metamorphosed or igneous rock type. Samples are produced in the form of chips or rock powder thrown up by the rotary and pneumatic action of

Rock-Eval Pyrolysis

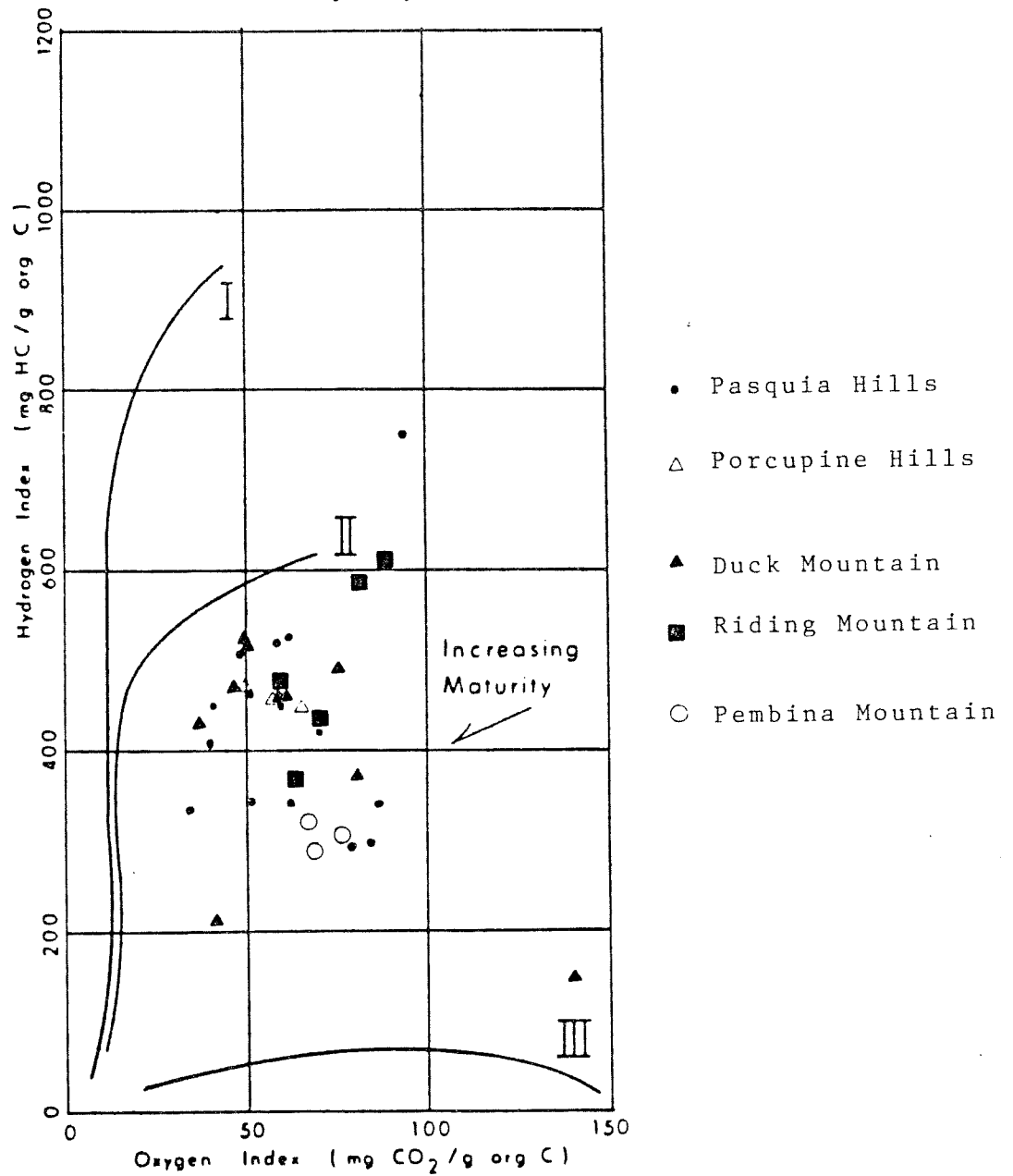


Figure 4: Organic Type

the penetrating bit. This failed to occur in the case of the oil shales due to the high moisture and clay content of the rock type.

The second method involved an attempt to core the shale with a portable diamond drill. In this test however most of the core was washed out due the weakly indurated nature of the shale and the fact water was used as a cooling medium for the diamond drill bit.

E. Mineralogy

The results of a semi-quantitative assessment of mineralogy are given in Appendix C. The percentage values were obtained from comparative diffraction peak heights and thus can be affected by factors such as degree of crystallinity, crystal size, amorphous material and organic matter present.

In general, the results indicate that carbonate material, usually in the form of calcite, make up a major portion of the shale content. This is directly related to the shales "white speckled" appearance which is comprised of chalky coccolithic and foraminiferal debris. Reports from the Sun Oil Company (1965), indicate that this fact was often used as a guide when testing the shale by Fischer Assay. It is interesting to note that a few samples collected (Nos. 2, 19, and 27) which had little or no carbonate content still

produced appreciable amounts of hydrocarbon upon pyrolysis. This suggests that the kerogen content is not directly related to the amount of carbonate material and there is a possibility of previously undetected oil shale zones within these formations of the Upper Cretaceous.

Conclusions

As a result of the analyses performed on the thirty-seven oil shale samples collected the following conclusions can be made:

1) The richness and pyrolytic yield of the oil shales increases towards the northwest in the area of Pasquia Hills as indicated by slightly higher total organic carbon (TOC) and Rock-Eval yields for this region.

2) The oil shales organic type is comprised of a mixture of Type II and Type III kerogen. The shale in the Pembina Mountain area may be dominated by a Type III (terrestrial) kerogen which would also account for the lower hydrocarbon (S2) yields.

3) No discernable difference of total organic carbon (TOC) or pyrolytic yields were detected in weathered versus non-weathered samples.

4) The mineralogy of the oil shales is dominated by carbonate material which is attributed to biogenic input in the form of foraminiferal and coccolithic debris.

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Appendix A

OUTCROP LOCATIONS AND SAMPLE DESCRIPTIONS

Outcrop A. Outcrop exposed on the south bank of the Man River in Lsd.2, Sec.5, Twp.51, Rge.5W2. Access was by travelling south on a logging road from a point where the Man River crosses Highway No. 163 for a distance of 4.7 km. then traversing due west for 100 metres. Total measured thickness - 7 metres.

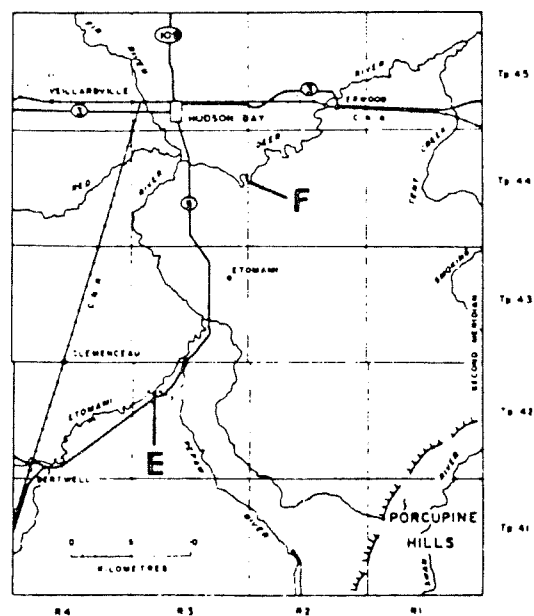
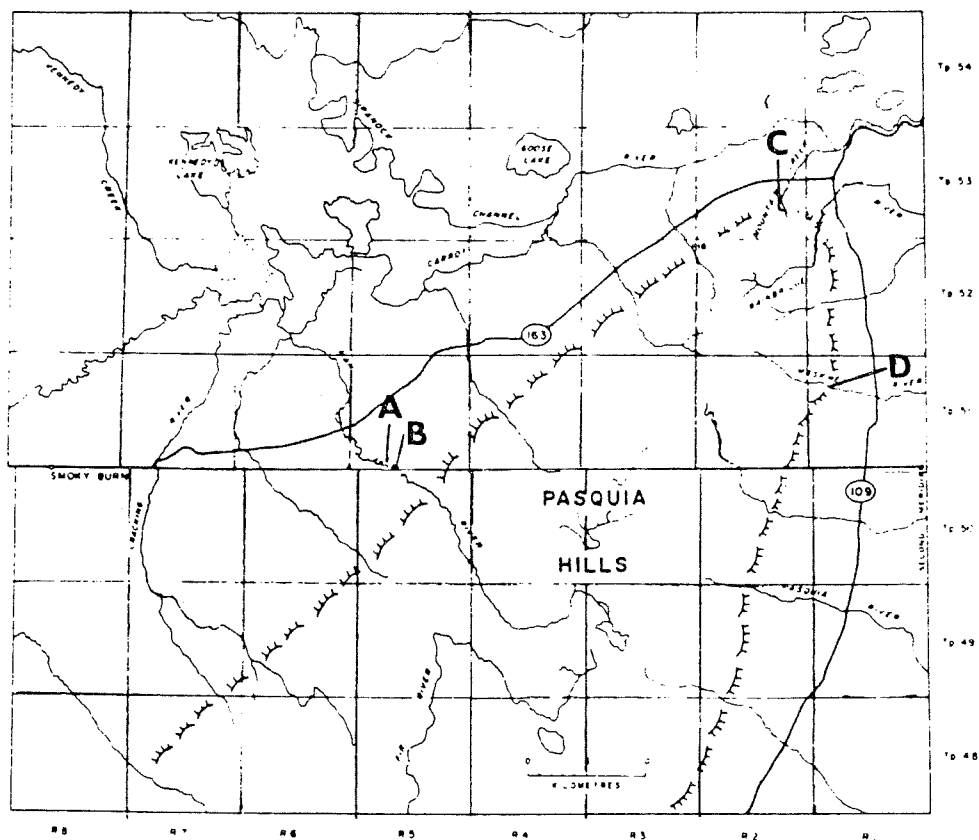
No.1 - Favel Fm. - 2 metres from surface. Extremely weathered, fissile black "paper shale". Large white specks (gypsum?) up to 1 cm in diameter.

No.2 - Favel Fm. - 4 metres from surface - Non-weathered. Black dense shale lacking any visible white specks. Strong hydrocarbon smell. Occasional Inoceramus shell fragments.

No.3 - Favel Fm. - 6 metres from surface - Non-weathered. Dark olive gray coloured shale with fine calcareous chalk specks.

No.4 - Favel Fm. - Float sample; weathered. As in No.3.

Outcrop B. Outcrop well exposed on the north bank of the Man River approximately 300 metres upstream from Outcrop A. Total measured thickness 15 metres.



OUTCROP LOCATIONS IN THE PASQUIA HILLS AREA.

No.5 - Favel Fm. - Assiniboine Member - 6 metres from surface Non-weathered. Shale, olive colour, calcareous finely chalk speckled. Lenses of argillaceous limestone with common fish fragments.

No.6 - Favel Fm. - Assiniboine Mbr. - 7 metres from surface. Non-weathered. Less resistant olive coloured shale. Lack of visible white specks.

No.7 - Favel Fm. - Keld Mbr. - 10 metres from surface. Non-weathered. Olive to gray coloured shale with abundant chalk specks and occasional fish fragment.

No.8 - Favel Fm. - Keld Mbr. - Float sample; weathered. As in No.7.

Outcrop C. A very steep, well exposed outcrop located on the west bank of Mountain Creek in Lsd.3, Sec.14, Twp.53, Rge.2W2. Total measured thickness 12.5 metres.

No.9 - Favel Fm. - Keld Mbr. - 10 metres from surface. Non-weathered. Dark gray shale, very hard, with abundant chalk specks. Common Inoceramus prisms.

No.10 - Favel Fm. - Keld Mbr. - 6 metres from surface. Non-weathered. As in No.9.

Outcrop D. Well exposed on the north bank of the Waskwei River in Lsd. 6, Sec.29, Twp.51, Rge.1W2. Access to the outcrop is by a footpath from Highway No.109 due west for a

distance of approximately 400 metres. Total measured thickness 10 metres.

No.11 - Favel Fm.? - 9 metres from surface. Weathered sample, light gray with abundant chalk specks and Inoceramus prisms.

no.12 - Favel Fm.? - Float sample - weathered. as in No.11.

Outcrop E. Outcrop exposed on the south bank of the Etomami river, approximately 7.5 km southeast of Clemenceau, Saskatchewan in Lsd.5, Sec.29, Twp.42, Rge.3W2. Total measured thickness 3.6 metres.

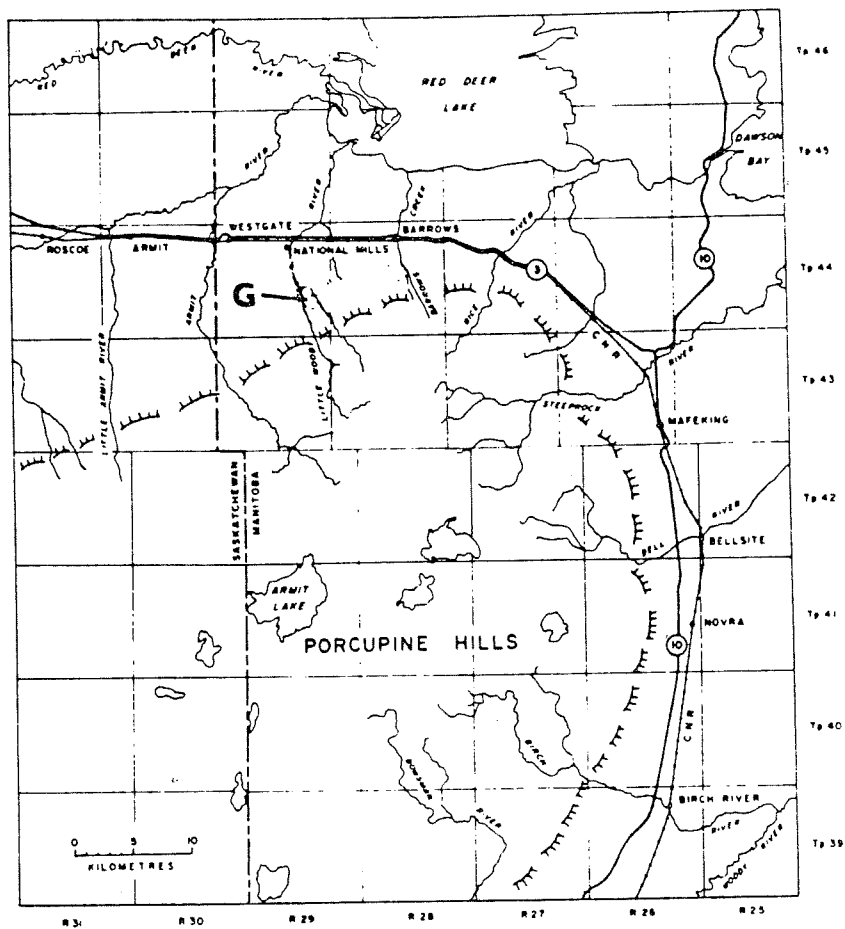
No.13 - Niobrara Fm. - 3.5 metres from surface. Weathered light gray coloured shale with abundant chalk specks. Laminated appearance. Very fissile. Inoceramus prisms common.

No.14 - Niobrara Fm. - 3.5 metres from surface. Non-weathered. As in No.13.

Outcrop F. Poorly exposed slumped outcrop located in a gully 100 metres south of the Red Deer River in Lsd.4, Sec.19, Twp.44, Rge.2W2.

No.15 - Favel Fm. - Keld Mbr. Float sample; weathered. Black shale with fine white chalk specks.

Outcrop G. Well exposed outcrops on both banks of the Little Woody River, approximately 3.2 km south of National



OUTCROP LOCATIONS IN THE PORCUPINE HILLS AREA.

Mills, Manitoba in Lsd.11, Sec.14, Twp.44, Rge.29W1. Total measured thickness 6.4 metres.

No.16 - Favel Fm. - Keld Mbr. - 2 metres from surface. Non-weathered. Dark gray shale relatively hard with abundant chalk specks.

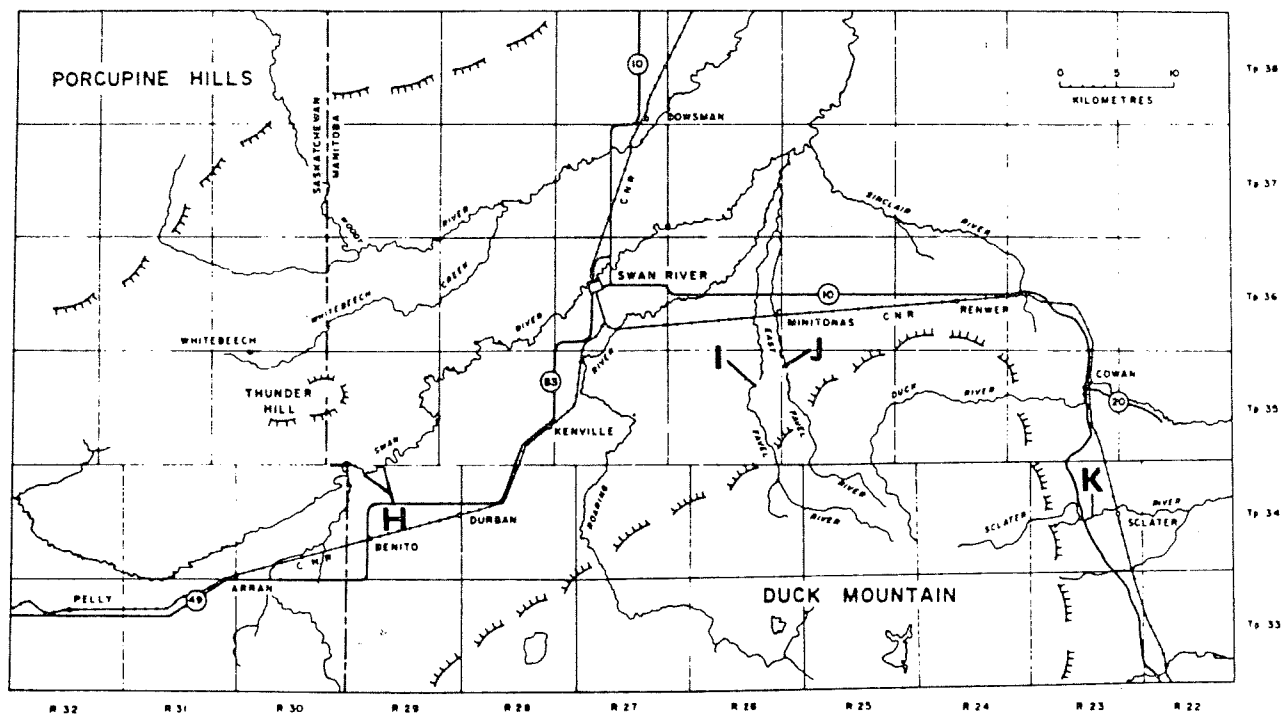
No.17 - Favel Fm. - Keld Mbr. - 4 metres from surface. Non-weathered. Lighter gray coloured shale with chalk specks and Inoceramus prisms and worm burrows(?).

No.18 - Favel Fm.(?) - 300 metres upstream Non-weathered. As in No.17.

Outcrop H. Two well exposed outcrops on the south bank of the Swan River; No.19 located in Lsd.10, Sec.31, Twp.34 Rge.29W1, and Nos. 20 and 21 in Lsd.16, Sec.32, Twp.34, Rge.29W1. Thicknesses measured were 5.5 and 1.8 metres respectively.

No.19 - Favel Fm. - Assiniboine Mbr. - 5.4 metres from surface. Non-weathered. Dense black shale lacking distinct white specks. Strong smell of hydrocarbon. Very wet leached area.

No.20 - Favel Fm. - Assiniboine Mbr. - 1.6 metres from surface. Non-weathered. Light gray coloured calcarenite with abundant fish scales.



OUTCROP LOCATIONS IN THE DUCK MOUNTAIN AREA.

No.21 - Favel Fm. - Assiniboine Mbr. - 1.0 metres from surface. Non-weathered. Olive to black coloured "paper shale". Minor amounts of white specks.

Outcrop I. Excellent outcrop well exposed on the west bank of the West Favel River in Lsd.7, Sec.26, Twp.35, Rge.26W1. Total measured thickness 16.89 metres.

No.22 - Favel Fm. - Keld Mbr. - Float sample. Weathered sample. Found at the base of a scree slope. Light gray coloured with abundant white specks. Strong hydrocarbon smell.

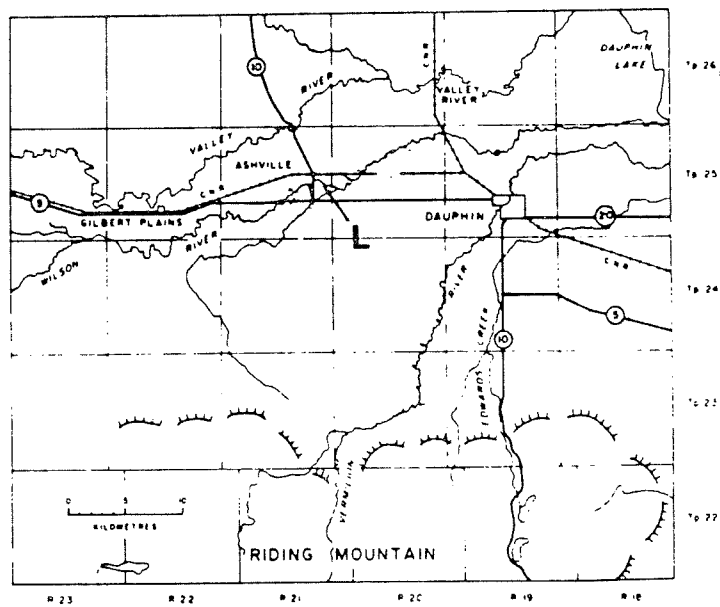
No.23 - Favel Mbr. - Keld Mbr. - 16.39 metres from surface. Non-weathered sample. Massive, resistant, olive to gray coloured shale. Absence of white specks. Fine selenite crystals.

No.24 - Favel Fm. - Keld Mbr. - 15.89 metres from surface. Non-weathered sample. Olive coloured shale with abundant white specks as fine laminae.

No.25 - Favel Fm. - Keld Mbr. - 12.89 metres from surface. Non-weathered sample. As in No.24.

No.26 - Favel Fm. - Keld Mbr. - Float sample. Weathered sample. As in No.22.

Outcrop J. Well exposed outcrop on the west bank of the East Favel River in in Lsd.3, Sec.30, Twp.35, Rge.25W1. This exposure of the Morden shale was used as a test to compare against the other formations.



OUTCROP LOCATIONS IN THE RIDING MOUNTAIN AREA.

Morden Fm.-Weathered sample. Dense black shale. Hematite and jarosite./ Outcrop K. Outcrop exposed on the north bank of the Sclater River in Lsd.14, Sec.15, Twp.34, Rge.23W1. Total measured thickness 13.48 metres.

No.28 - Favel Fm. - Keld Mbr. - 13 metres from surface. Non-weathered sample. Gray to black coloured shale with fine white specks and Inoceramus prisms.

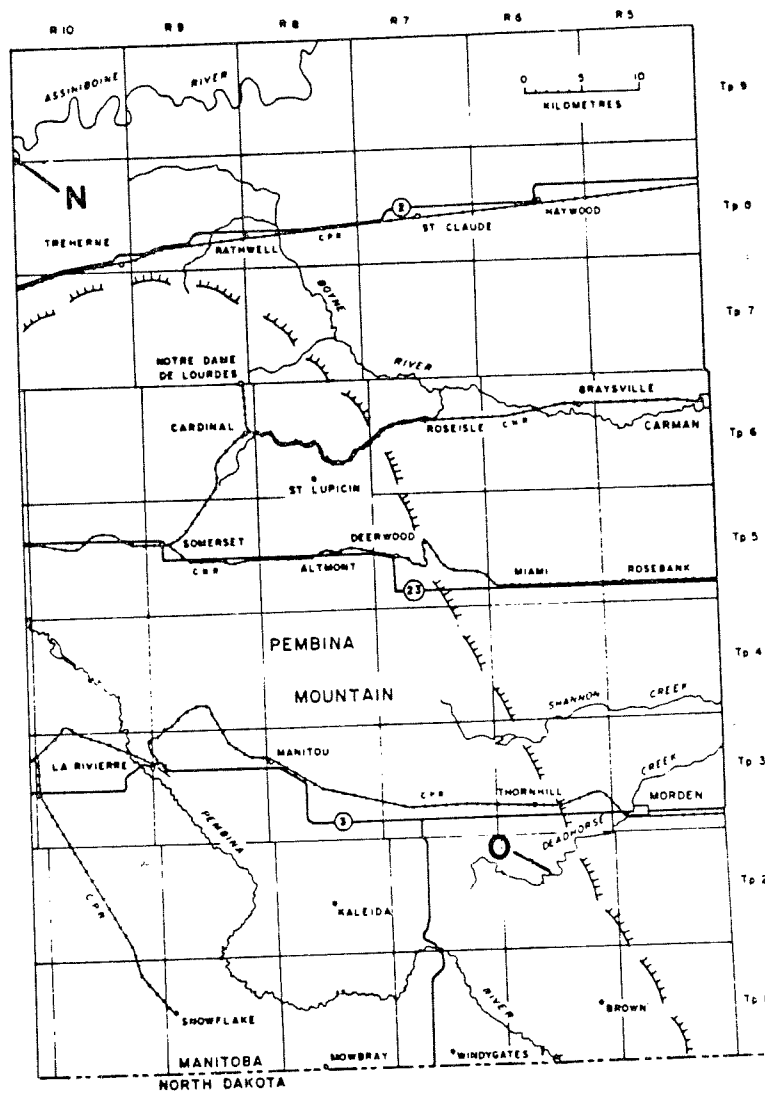
No.29 - Favel Fm. - Keld Mbr. - 6 metres from surface. Non-weathered sample. Dark black coloured "paper shale". Lack of any definite white specks.

Outcrop L. Well exposed outcrop on the north bank of the Wilson River in Lsd.9, Sec.15, Twp.25, Rge.21W1. Total measured thickness 10 metres.

No.30 - Favel Fm. - Keld Mbr.- 3 metres from surface. Non-weathered sample. Dark gray coloured shale with abundant white specks as laminae. Inoceramus prisms and fish fragments common.

No.31 - Ashville Fm.(?). Non-weathered sample. Light gray coloured shale with chalk specks.

Outcrop M. Well exposed, accessible, outcrop on both banks of the Ochre River at Skains Crossing located in Lsd.9, Sec.15, Twp.22, Rge.17W1. Total measured thickness approximately 12 metres.



OUTCROP LOCATIONS IN THE PEMBINA MOUNTAIN AREA.

No.32 - Favel Fm. - 9 metres from surface. Non-weathered sample. Olive to gray coloured resistive shale. Extremely calcareous with abundant Inoceramus prisms and some fish fragments. Slight hydrocarbon odour.

No.33 - Favel Fm. - 9 metres from surface. Weathered sample. As in No.32.

No.34 - Favel Fm. - 6 metres from surface. Black "paper shale" very fissile. Non-calcareous.

Outcrop N. Poorly exposed outcrop on the southeast bank of the Assiniboine River in Lsd.13, Sec.31, Twp.8. Rge.10W1. Most of the outcrop had slumped due to spring runoff.

No.35 - Favel Fm. Keld Mbr. Weathered sample. Olive-gray coloured shale with very fine chalk specks.

Outcrop O. Well exposed outcrop on the north bank of Dea-dhorse Creek, Approximately 9.0 km southwest of Morden, Manitoba in Lsd.11, Sec.21, Twp.2, Rge.6W1. Total measured thickness 7.33 metres.

No.36 - Niobrara Fm. - Chalky Mbr. - 7 metres from surface. Weathered sample. Light gray coloured shale to marlstone. Occasional fish fragments.

No.37 - Niobrara Fm. - Chalky Mbr. - 7 metres from surface. Non-weathered sample. As in No.36.

APPENDIX B. Results of Total Organic Carbon and Rock Eval Pyrolysis for the Upper Cretaceous Oil Shale Samples.

Sample No.	T.O.C.	S ₁ +S ₂	Tmax	S ₁	S ₂	S ₃	HI	OI	Outcrop Location	Formation/Member	Status*
Pasqua Hills Area											
1	7.18	25.14	432	0.71	24.43	6.37	340	88	A.Man River	Niobrara(Boyne)	W
2	8.26	29.71	408	0.65	29.06	3.05	351	36	" "	Favel	N
3	11.24	47.65	400	1.31	46.34	4.65	412	41	" "	Favel	N
4	10.14	48.12	399	1.62	46.50	4.33	458	42	" "	Favel	W
5	10.70	39.75	405	1.22	38.53	6.67	360	62	B.Man River	Favel	N
6	3.78	12.22	406	0.62	11.60	3.21	306	84	" "	Favel	N
7	4.35	13.63	407	0.36	13.27	3.47	305	79	" "	Favel	N
8	6.22	49.05	402	1.66	47.39	5.92	761	95	" "	Favel	W
9	4.58	20.18	408	0.61	19.57	3.31	421	72	C.Mountain Creek	Favel	N
10	9.34	33.81	401	0.99	32.82	4.91	351	52	" "	Favel	N
11	7.75	37.02	396	1.45	35.57	4.69	458	60	D.Waskwei River	Favel	W
12	7.86	39.29	403	1.26	38.03	4.14	483	52	" "	Favel	W
13	7.76	42.76	411	1.23	41.53	4.61	535	59	E.Etomami River	Niobrara(Boyne)	W
14	6.97	36.53	406	0.93	35.60	3.44	510	49	" "	Niobrara(Boyne)	N
15	8.06	46.50	401	1.60	44.90	4.66	557	57	F.Red Dear River	Favel/Keld	W
	7.61	34.76									
Porcupine Hills Area											
16	7.93	38.08	403	1.34	36.74	5.34	463	67	G.Little Woody R.	Favel/Keld	N
17	7.03	34.39	400	1.26	33.13	4.15	471	59	" " "	Favel/Keld	N
18	6.61	33.07	404	0.81	32.26	3.31	488	50	" " "	Favel/Keld	N
	7.19	35.18									
Duck Mountain Area											
19	7.11	32.26	410	1.05	31.21	2.61	438	36	H.Swan River	Favel/ Assiniboine	N
20	1.39	1.96	410	0.03	1.93	1.97	138	141	" "	" "	N
21	6.67	36.25	402	1.22	35.03	3.40	517	50	" "	" "	N
22	6.58	31.14	401	0.81	30.33	4.00	460	60	I.West Favel R.	Favel/Keld	W
23	8.13	40.78	408	1.11	39.67	3.73	487	45	" " "	Favel/Keld	N
24	8.21	41.48	409	1.10	40.38	6.17	491	75	" " "	Favel/Keld	N
25	6.38	32.22	405	1.02	31.20	4.81	489	75	" " "	Favel/Keld	N
26	7.61	42.08	404	1.33	40.75	3.73	535	49	" " "	Favel/Keld	W
27	8.59	19.56	405	0.92	18.64	3.79	216	44	J.East Favel R.	Morden?	
28	6.91	33.30	407	0.69	32.61	4.16	471	60	K.Sclater River	Favel/Keld	N
29	7.31	29.16	404	0.80	28.36	5.93	387	81	" "	Favel/ Assiniboine	N
	6.81	30.93									
Riding Mountain Area											
30	5.93	24.10	411	0.53	23.57	3.97	397	66	L.Wilson River	Favel/Keld	N
31	5.85	26.38	407	0.65	23.73	4.24	439	72	" "	Ashville?	N
32	6.45	32.07	405	0.73	31.34	3.99	485	61	M.Ochre River	Favel	N
33	5.43	32.09	402	0.93	31.16	4.33	573	79	" "	Favel	W
34	5.93	36.51	410	0.82	35.69	5.33	601	89	" "	Favel	N
	5.92	30.23									
Pembina Mountain Area											
35	6.06	20.52	414	0.44	20.08	4.06	331	66	N.Assiniboine R.	Favel/Keld	W
36	5.17	16.98	413	0.39	16.59	3.99	320	77	O.Dead Horse Cr.	Niobrara(Boyne)	W
37	4.30	12.44	418	0.20	12.24	2.89	284	67	" " "	Niobrara(Boyne)	N
	5.18	16.65									

*W = Weathered; N = Non-weathered.

APPENDIX C. Results of Mineralogy (semi-quantitative) for the Upper Cretaceous Oil Shale Samples.

Sample No.	Exp/ M.L.C.	Illite	Kaolinite Chlorite	Gypsum	Zeolite	Quartz	Feldspars	Calcite	Pyrite	Others
1	8	10	5	38	-	35	3	2	-	-
2	14	8	5	4	-	41	4	19	5	-
3	-	-	-	2	19	5	-	67	2	siderite diaspore
4	-	-	-	-	10	6	-	80	2	siderite
5	-	-	-	3	13	5	-	72	2	Siderite
6	-	2	2	5	-	8	2	80	1	-
7	-	-	-	3	12	4	-	80	-	-
8	-	-	-	6	18	5	-	68	2	siderite
9	-	-	-	3	8	10	-	60	1	apatite cristobalite
10	2	-	-	-	14	4	-	76	1	siderite
11	-	-	-	3	18	5	-	70	1	siderite
12	3	4	2	4	4	15	3	59	3	-
13	4	3	2	3	3	12	4	68	1	-
14	8	11	3	3	3	21	2	46	3	-
15	-	3	-	3	14	9	-	66	3	siderite
16	12	5	4	4	-	16	2	57	tr	-
17	2	2	2	2	-	8	-	84	-	-
18	6	2	-	-	16	4	-	72	-	-
19	26	10	10	2	2	39	4	-	7	-
20	7	-	-	-	5	3	-	85	-	-
21	12	7	4	4	3	19	2	43	4	dolomite
22	2	2	-	-	65	2	1	27	1	-
23	20	12	7	-	-	40	6	11	4	-
24	17	8	5	10	-	20	5	33	2	-
25	8	5	4	5	-	9	-	69	-	-
26	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	-
27	18	7	7	4	4	32	4	-	24	-
28	6	4	4	1	-	20	2	60	3	-
29	4	2	-	2	8	9	-	75	-	-
30	8	7	3	-	-	14	-	68	-	-
31	2	4	3	5	-	13	-	71	2	-
32	10	8	7	6	-	22	-	42	4	-
33	4	3	3	5	-	9	-	79	2	anhydrite
34	9	7	4	34	-	23	-	21	2	-
35	-	-	-	2	19	5	-	67	2	siderite
36	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	-
37	-	4	3	tr	-	14	-	77	2	-