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OIL SHALES OF THE BIG MARSH AND PICTOU AREAS, NOVA SCOTIA

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ABSTRACT

Two hundred fourty-three samples, obtained from 5 coreholes of the Big Marsh (Antigonish) oil shales (Tournaisian age) and from 6 coreholes and two surface exposures of the Pictou Group (Westphalian B-C) near Stellarton, were analyzed for total organic carbon (TOC) and subjected to Rock-Eval pyrolysis.

The Big Marsh oil shales double in depositional thickness from north to south from 67 to 125m over the 12.5km distance of their exposure. A commensurate southerly decrease of hydrocarbon potential from 24.56 kg/t at the north to 12.73 kg/t at the south directly reflects diminishing yields per 1% TOC from 4.47 to 2.58 kg/t rather than decreasing TOC content. The kerogen content is an admixture of Types I and III: the variation in yield potential reflects varying distribution of Type I and III kerogens, although a southerly increase in thermal maturation may also be significant. These beds are of immature to low thermal maturity. Because of the low hydrocarbon recoveries, the economic potential of the Big Marsh oil shales is limited.

Oil shales, torbanite and stellarite are described from the Pictou area. The oil shales and torbanites are geochemically identical. Both yield near 3.5 kg/t 1% TOC, but a TOC range from 7% in the oil shales to greater than 20% in the torbanites increases yield potential significantly; however, thickness of 1m or less and limited areal distribution offset the higher yield potential of the torbanites. The oil shales and torbanites are an apparent admixture of kerogen Types III and I, with Type III possibly predominating. The Type III kerogen is possibly in the low thermal maturity range: the Type I may be immature.

Stellarite is a distinct Type I kerogen deposit, mostly a Botryococcus type algal debris, found associated with coal (Type III) in the Oil-Coal Seam. TOC ranges 7 to 25% in the stellarite, which is thermally immature, and yields approximately 7 kg/t/1% TOC. A low yield ratio of less than 2 kg/t is offset by high TOC (in part over 50%) to produce significant oil yields from the coal bed. Oil yields exceeding 60 kg/t may be expected from the average 3.0 to 3.5m of the Oil-Coal Seam, which is the most economically potential unit of the area.

INTRODUCTION

Nova Scotia has two oil shale-bearing areas of significant interest, at Big Marsh near Antigonish, and at Stellarton in the Pictou Coalfield (Fig. 1). These occurrences, both in Carboniferous strata, were first described by How (1868) and have since remained of interest because: 1) the oil shales of the Big Marsh area are stratigraphically equivalent to the Albert Formation oil shales in the Moncton sub-basin, New Brunswick, and also to those of the Pumpherston area, Scotland, which were mined economically for many years; and

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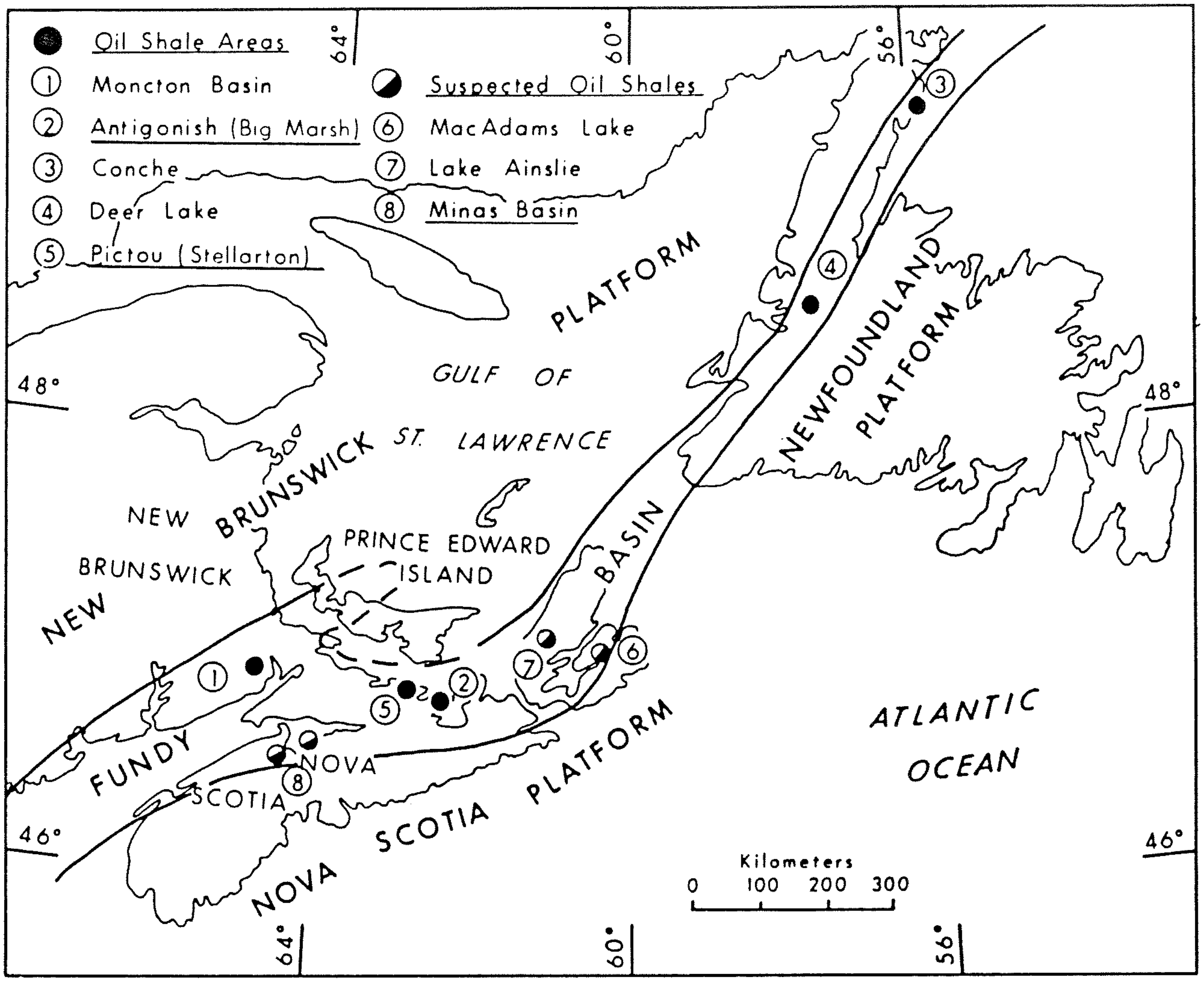


Fig. 1: Known and suspected oil shale areas, Maritime Provinces (after Macauley, 1981)

2) those at Stellarton occur within the Pictou Group which contains several mineable coal seams. Stellarite, or "stellar coal," as described by How (1868) from the Pictou Coalfield, was so named because "stars of fire" dropped from it when a flame was applied and removed. The stellarite occurs in conjunction with coal and bituminous shale and is the informally defined "oil-coal" seam of present terminology: the terms "stellar seam" and "asphalt seam" had earlier been applied to this unit (Flynn, 1926), which is assessed in considerable geochemical detail within this report.

Big Marsh (Antigonish)

As the initial phase of an oil shale evaluation project, Mazerolle and MacGillivary (1974a, 1974b) produced excellent surface maps of oil shale distribution in the Big Marsh (Antigonish) area: these are unpublished, but are available at the Nova Scotia Department of Mines and Energy, Halifax. Based on the surface geology, the Province selected nine corehole locations.

The subsequent cores were retorted at the Technical University of Nova Scotia (at that time the Nova Scotia Technical College) with equipment and conditions comparable to those of Fischer Assay analyses (Potter, 1975). These unpublished results are also available at the Nova Scotia Department of Mines and Energy. Five of the coreholes of that program were sampled for this study.

Stellarton (Pictou)

Coal beds of the Pictou Coalfield have always been, and still are, a major component of Nova Scotia energy resources. Over fifty coreholes have been completed in this area by the Nova Scotia Department of Mines and Energy to evaluate coal reserves. Several of these penetrate oil shale zones within the gross coal-bearing section. For this study, six of the cored locations of this area were sampled as were "torbanite" beds from nearby surface exposures.

Procedure

This investigation is concerned primarily with the organic geochemistry of the oil shales as a basis for future economic evaluation of the deposits. The conclusions are determined by, and interpreted from, the results of analyses for total organic carbon and Rock-Eval pyrolyses. A total of 243 samples were analyzed.

To assist further the geological interpretations of the deposits, mineral content was determined by X-ray diffraction: although this technique does not provide absolute percentage values, the relative content and distributional change of the mineral assemblage are generally apparent.

Although both oil shale-bearing intervals are of Carboniferous age, they are stratigraphically much removed (Fig. 2). Beds at Big Marsh are of probable Mississippian Tournaisian age (Benson, 1974, Bohner and Giles, 1982), whereas those at Stellarton are Pennsylvanian Westphalian B-C (Hacquebard and Donaldson, 1969). Each area will be treated as an independent section in this report.

Acknowledgements

Funding for this project was supplied by the Department of Energy, Mines and Resources, Canada, through the Institute of Sedimentary and Petroleum Geology, Calgary, Alberta.

All analyses were carried out at the Institute of Sedimentary and Petroleum Geology under the direction of Dr. L.R. Snowdon. M. Ferguson, R. Fanjoy and J. Wong provided the technical assistance.

The cores were sampled at the offices of the Nova Scotia Department of Mines and Energy, Stellarton, Nova Scotia, and at a departmental core

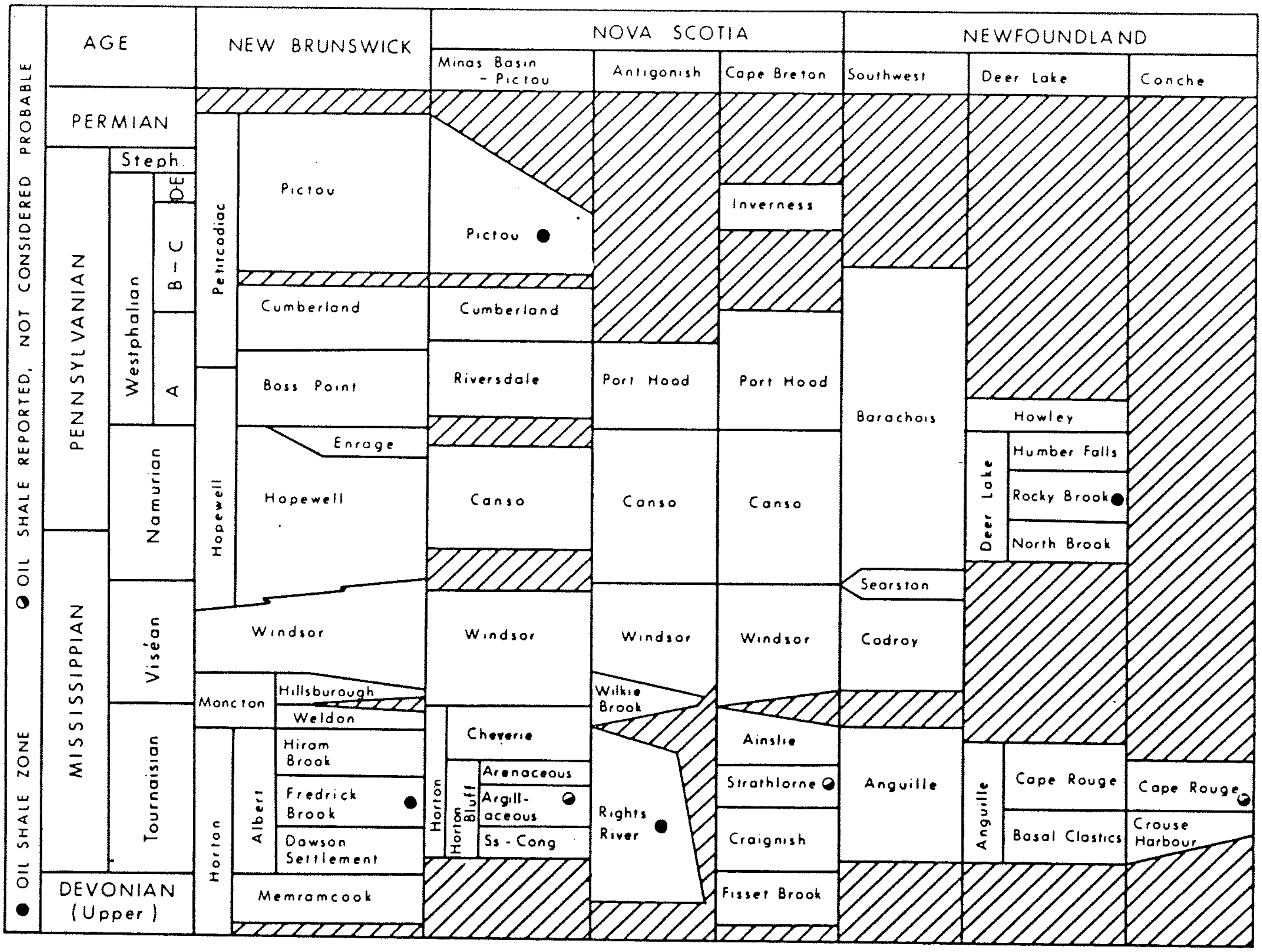


Fig. 2: Carboniferous correlations, Maritime Provinces (modified after Macauley, 1981)

storage facility at Debert, Nova Scotia. The writers are most appreciative of the co-operation and assistance of Kevin Gillis, of the Stellarton office geological staff, in sampling of the cores and of the Shaw Pit surface area as well as in provision of geological maps, stratigraphic detail of the Pictou area, and generalized lithologic logs of the coreholes.

Many of the samples are being scrutinized by Dr. W. Kalkreuth at the Institute of Sedimentary and Petroleum Geology using fluorescence and reflected light microscopy to determine maturation and composition of the organic material.

Some of the interpretations of the organic geochemistry, as noted in the text, are partially based on his investigations of the organic petrology.

L.R. Snowdon and K. Gillis read the manuscript and contributed significantly through their comments.

BIG MARSH (ANTIGONISH) AREA

Big Marsh is located approximately 3 km east of Highway 245, and 11 km north of Antigonish (Fig. 3). The surface distribution of the oil shales has been mapped by Mazerolle and MacGillivary (1974a, 1974b): this study deals with samples from coreholes at two outcrop occurrences, in the vicinity of

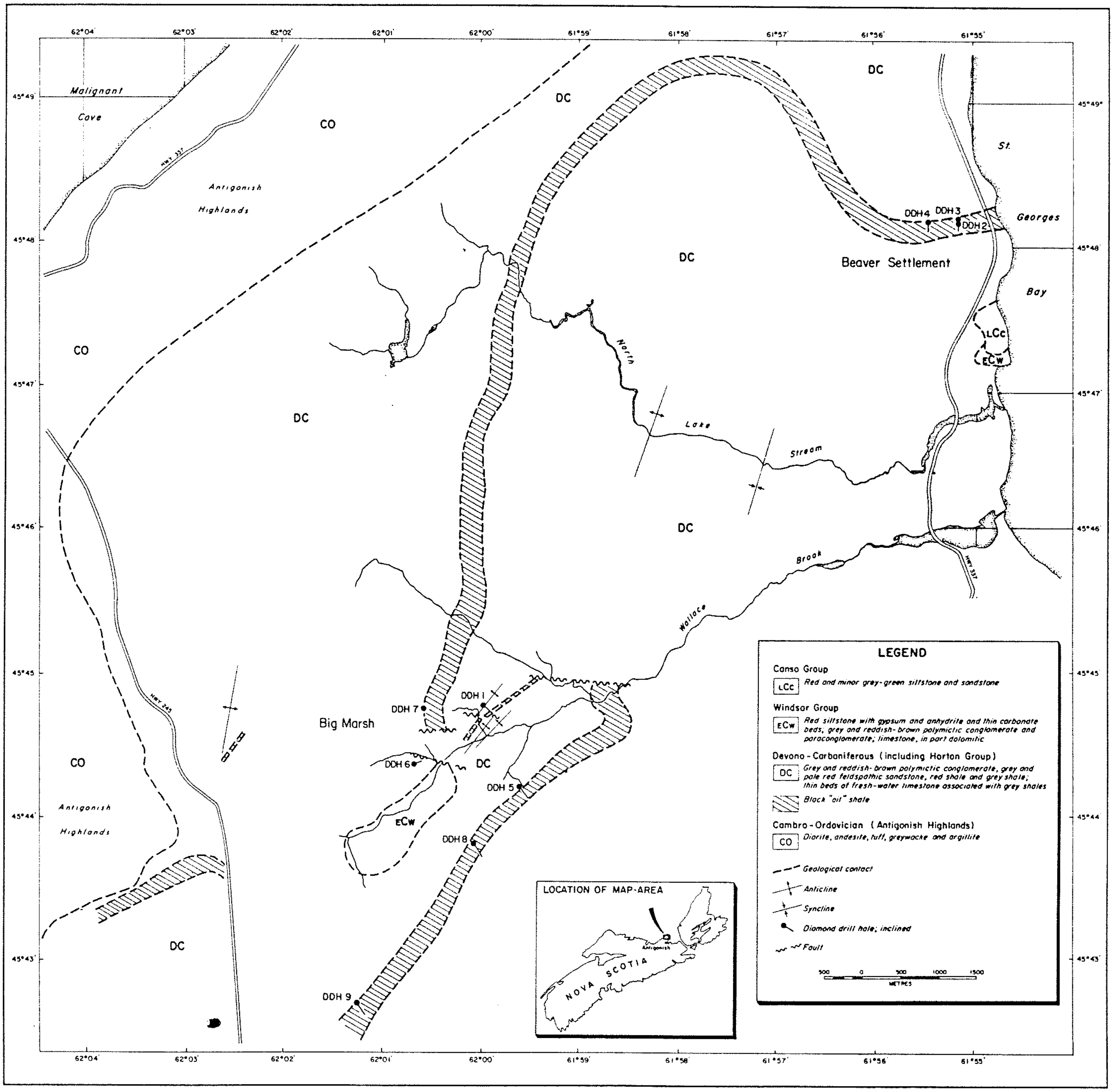


Fig. 3: Surface distribution of oil shale beds, Big Marsh (Antigonish) area (after Mazerolle and MacGillivary, 1974a) showing corehole locations

Big Marsh and at Beaver Settlement (Fig. 3).

Three holes were cored at Beaver Settlement. Together, holes 2 and 3 represent a composite of the total oil shale section: because hole #4 represents the entire section, and is located only 440 m easterly of the other locations, Big Marsh #4 was sampled to represent this area.

Near Big Marsh itself, holes 1 and 6 failed to penetrate any oil shale beds. Big Marsh coreholes 5, 8 and 9, located along a projected outcrop trend, all penetrated complete oil shale sections. Big Marsh #5 was sampled in considerable detail at continuous 5 foot (1.51 m) intervals. Because #8 and #9 are only 940 m and 3200 m respectively south of #5, samples were taken over 5 foot (1.51 m) intervals spaced every 20 feet (6.06 m). Samples were selected on a footage basis as the cores were cut and are now boxed and labelled under the English system. This will facilitate comparisons to these sample zones if required in any future investigations.

The above sampled coreholes were all directionally drilled to intercept the beds horizontally and thus define depositional thickness; however, corehole #7 encountered extreme structural irregularity, as did the #6 hole through a coarser clastics sequence. These two holes appear to cut parallel to, and/or within, a fault plane. Because of the structural contortions, only 3 spot samples were selected from the Big Marsh #7 corehole.

STRATIGRAPHY

The Big Marsh map area (Fig. 3) is underlain predominantly by undifferentiated Devono-Carboniferous sediments (Keppie, 1979: Boehner and Giles, 1982), consisting of grey and reddish-brown polymictic conglomerate, grey and red feldspathic sandstone, red and grey shale, and including thin fresh water limestone and black oil shales generally referred to as bituminous beds or shales.

Benson (1974) included the undivided Devono-Carboniferous rocks of Boehner and Giles (1982) in the Rights River Formation (Fig. 2) which, based on megafauna and florule identification, was assigned a late Devonian to early Carboniferous (Tournaisian) age, coinciding to that assigned the oil shale-bearing Albert Formation of southeastern New Brunswick (Macauley and Ball, 1982). A spore locality, sampled by Boehner and Giles, and mapped by Mazerolle and MacGillivary (1974a) as lying stratigraphically above the oil shales, has been tentatively placed by Boehner and Giles in the Wilkie Brook Formation, a succession of late Tournaisian conglomerates, sandstones, shales and limestones lying with angular unconformity on Devonian clastic sediments. This establishes a pre-late Tournaisian age for the oil shales within the underlying Rights River Formation.

The Rights River clastics sequence unconformably overlies older Cambro-Ordovician rocks of the Antigonish Highlands which define the western and northwestern margins of the study area (Fig. 3). At Big Marsh, an outlier of Windsor Group (Viséan age) evaporites and clastics conformably overlies the Wilkie Brook Formation: a similar sequence is present on the St. George's Bay coast, near Lakevale, in the vicinity of the Beaver Settlement oil shale exposures. The youngest known sediments of the area, an outlier of Canso Group clastics (Boehner and Giles, 1982), of Namurian age, also occurs near Lakevale.

Virtually the entire Carboniferous stratigraphic sequence of Nova Scotia and New Brunswick was established by W.A. Bell (1924, 1927, 1929, 1940, 1960): much of his nomenclature is still in use today. Along the south side of the Minas Basin (Fig. 1), the Horton Group (Bell, 1929) is subdivided into a lower Horton Bluff Formation of grey colored clastics overlain by the Cheverie Formation, an upper greenish to reddish clastics interval, which is in turn overlain by carbonate of the Windsor Group (Fig. 2). Varma (1969), from miospore correlations, equates the Cheverie to the Hiram Brook Member of the Albert Formation in New Brunswick with basal Windsor beds of the Minas Basin area stratigraphically equivalent to Moncton red beds of the Moncton sub-basin (Kelley, 1967). Black shales of the upper Horton Bluff Formation, containing paleoniscid fish scales, were readily correlated to the Albert oil shales. Potter (1974) reported the Big Marsh oil shales to occur about 454 m (1500 ft) below the Windsor-Horton contact. On the basis of their stratigraphic position, and the lithologic similarity of the zones, the Big Marsh oil shales are almost certainly the equivalents of the Minas Basin Horton Bluffs black shales and the oil shales of the New Brunswick Albert Formation Frederick Brook Member (Fig. 2).

Benson (1974) noted that much of the undifferentiated Devono-Carboniferous beds of the Big Marsh area comprised red sharpstone conglomerates, the Rights River Formation (Murray, 1960), and that the red-grey division of the Horton Group in the Minas Basin was not appropriate at Big Marsh. In this area, Rights River beds in part are directly overlain, without intervening Wilkie Brook Formation, by Windsor carbonates. Benson did not discuss the oil shale beds, nor are they indicated on the recent map by Boehner and Giles (1982).

On comparing the maps and comments of Murray (1960), Benson (1974), and Beohner and Giles (1982), the Big Marsh oil shales occur as a grey stratigraphic sub-unit within a coarse red bed sequence. Macauley and Ball (1982), from their core studies and following on the facies concepts of McLeod and Ruitenberg (1978), and McLeod (1980), found the Albert Formation oil shales to be contained above and below, as well as in part laterally, by coarse grained red and grey conglomeratic facies. Similar facies relationships are illustrated on the correlation chart for the Big Marsh area section. Benson's possible unconformity at the base of the Windsor may well represent a local unconformity similar, and possibly even time equivalent, to the local areas of unconformity between the Hillsborough and Weldon Formations of the Moncton Group in New Brunswick.

DISTRIBUTION AND THICKNESS

Mazerolle and MacGillivary (1974a) utilized the presence of oil shale float, in addition to actual outcroppings, in their criteria for approximating the limits of the oil shale sequence. This was necessitated by relatively few outcrop exposures, particularly in the more northerly part of the map area. On the basis of outcrop and float, they outlined the surface distribution as shown herein (Fig. 3). From observations relating float to underlying bedrock in preparing a New Brunswick oil shale report (Macauley and Ball, 1982) and from personal confirmation of some of the Mazerolle and MacGillivary data, the writers here conclude that the 1974 Mazerolle - MacGillivary maps present an excellent, distinctly probable interpretation of oil shale distribution in the Big Marsh area.

Keppie (1979) edited a regional small scale map of the Province of Nova Scotia, in which the oil shale beds are undifferentiated within undivided Devono-Carboniferous section. On a more detailed larger scale map (1:50,000), Boehner and Giles (1982) map the youngest Carboniferous beds at Big Marsh within a local synclinal structure independent of the Lakevale area and without indication of the structural complexities of the oil shale zone as mapped by Mazerolle and MacGillivary, which are reproduced herein. Corehole BM #1 appears to be mis-located on the Boehner and Giles map.

Faulting complicates the structural pattern at Big Marsh where corehole #7 is interpreted to drill down a possible fault zone and repetition is suspected at corehole #6 where sheared and brecciated intervals within a sandstone-siltstone sequence may represent penetration of fault zones.

The Big Marsh oil shale beds thicken southward from 67.1 m (220 ft) at the northermost #4 location to 102.1 m (335 ft) at #5, 115.8 m (380 ft) at #8, and to 125.0 m (410 ft.) at the southermost #9 corehole. The thickness essentially doubles over a distance of 12.5 km (7.75 mi). At these 4 locations, the inclined coreholes all penetrate normal to the bedding: only minor deviations occur, and true depositional thicknesses are represented. Minor slickenslided zones appear to represent slippage along bedding planes and are not considered to represent any structural thicknening of the beds by faulting.

Bedding characteristics are fairly uniform across all cores. There are no indications that the thicker beds are slump deposits or were deposited at any greater a rate of subsidence than were the thinner areas. A thickening by facies change with the overlying and underlying silstone-sandstone-conglomerate beds is considered the most probable cause of this significant thickness variation.

LITHOLOGY

Early descriptions of the Big Marsh oil beds (How, 1868: Fletcher, 1892) described black bituminous shales with some being a curly cannel type. From examination of the cores, and of surface exposures (especially along Black Shale Brook; Mazerolle and MacGillivary, 1974b), these shales are black, but do not exhibit banding or obvious lamination although variable poor to good fissility does exist. The organic content is defined by a distinctive brownish colored streak, although the beds do not normally ignite or smoke strongly in a flame. No appreciable carbonate content can be discerned by routine examination procedures.

These beds contrast strongly to well laminated, in part varved dolomitic, calcareous, brown oil shales of the New Brunswick Albert Formation.

Fish and plant remains are reportedly common but were noted to be a minor component of the sampled cores. Fish remains are rare in contrast to the Albert shales but plant remains are more common, varying from microscopic carbonaceous debris to macro plant imprints, often pyritized.

The oil shale beds grade upwards and downwards to non-organic grey to greenish and reddish shale and siltstone, sandstone and fine conglomerate. A thin coal bed and an impermeable poorly porous oil stained sandstone are included in underlying strata. The upper and lower limits of the oil shale beds are both transitional and conformable.

MINERALOGY

Because of the macroscopically apparent uniform lithology, only one-third of the Big Marsh samples were analyzed by X-ray diffraction. If significant variations had been noted, further analyses were to be done; however, the uniformity of mineral content was such that further investigations were not considered necessary. Results of the XRD analyses are contained in Appendix A.

Semi-quantitative results of the whole rock were obtained from the diffraction peak heights which may vary with degrees of crystallinity, crystal size, and with any amorphous material present. These data represent relative approximate concentrations and are not absolute values.

Only a limited mineral assemblage is present. Quartz comprises approximately one half of the rock and is almost equalled by the clay minerals, equally represented by kaolinite/chlorite, expandable/mixed layer clays, and illite. Of these, the kaolinite/chlorite is slightly more abundant than the others: kaolinite is interpreted to be much more prevalent than chlorite. Feldspar can be a significant component of shale but is here only a minor constituent, less than 5% average, commonly occurring as albite. Minor pyrite is ubiquitous.

Carbonates were not noted during sampling. The XRD results indicate the average calcite content to be less than 3%, dolomite to be essentially absent, but that siderite is present in most of the samples in significant amounts, averaging over 5% at coreholes #8 and #9. Siderite is not evident from tests in cold or hot HCl acid. A second iron-bearing carbonate, ankerite ($CaCO_3(MgFeMn)CO_3$), is sporadically recorded in minor amounts.

ORGANIC GEOCHEMISTRY

R.W. Ells (1909) listed 7 analyses of the Big Marsh oil shale, ranging from 4.0 to 23.0 Imp. gallons/ton and averaging 8.8 Imp. gallons/ton (44.1 litres/tonne). With a shale oil specific gravity range of 0.890 to 0.917 (average 0.903), this equates to an average 39.68 kg/tonne in the reporting system of the Rock-Eval analysis. Ammonium sulphate content ranged 8.7 to

38.0 lbs/ton, averaging 24.0 lbs/ton (12.0 kg/tonne). A few further analyses by R.W. Ells (1910) and S.C. Ells (1923) did not significantly expand knowledge of this zone. Since that time, the Nova Scotia Department of Mines and Energy surface mapping in 1974 and corehole program in 1975 have been the only source of further data for geochemical evaluation. This study concentrates on the corehole sections. Table I summarizes the pertinent analytical results of the total organic carbon (TOC) and Rock-Eval analyses as well as the Fischer type assay data prepared at the Technical University of Nova Scotia (TUNS).

Total Organic Carbon (TOC)

The averaged total organic carbon content does not vary significantly over most of the area (Table I), but values at #7 and #9 coreholes are about 25% less than at the other locations. No distributional pattern is evident for total organic carbon variations although a southward decrease may possibly be inferred.

How (1868), quoting Campbell (reference not given), says of the Big Marsh oil shales: "The bituminous beds appear to be divided into two groups, the lower of which appears to be about 70 or 80 feet in thickness, 20 feet of which may be regarded as good oil shale including 5 feet of curly cannel rich in oil. The upper band cannot be much short of 150 feet in vertical thickness of strata containing a large percentage of oil." No such division is evident by standard core examination: however, the upper 20 to 30% of the cored sections appear to contain less carbon than the underlying beds (Figs. 4a - d) although the relative thicknesses of the upper and lower units do not coincide with those of How.

Thermal Maturation

Tmax, a prime indicator of thermal maturation, is uniformly average at 442-445°C except at corehole #9 (Table I) where a slightly lower average value may reflect either limitations of instrument capabilities in selection of the S_2 peak where recoveries are low, or differing kerogen type. Within the normally accepted oil window range 435-465°C, these values should indicate a low thermal maturity index. A shift in the Tmax curves (Figs. 4a - c) can be visually correlated to the general increase of organic carbon content.

PI, production index, is the ratio of free hydrocarbons to total hydrocarbon recovered on pyrolysis. Here the values are minimal, 0.13 as a maximum average, and denote immaturity of sediments in contrast to low maturity by Tmax values. These values do increase slightly southward but do not represent a significant change of maturation level.

HOLE #	THICKNESS		ISPG (Rock-Eval)									(TUNS (Fischer)		
			TOC Avge %	Tmax Avge °C	HI Avge mgHC/gC	YIELD Avge 1%TOC	PI Avge	PETROLEUM POTENTIAL kg/t		ANALYSES Total of			RECOVERY kg/t	
	m	ft						Max	Avge	ISPG	TUNS		Max	Avge
2	61+	200+									39		35.49	14.70
3	67.1	220	5.50	443	410	4.47	0.02	66.17	24.56	44	43		39.77	17.31
4	102.1	335	5.26	445	382	4.08	0.02	52.84	21.47	67	67		32.78	15.96
7	42+	132+	4.06	443	134	1.43	0.08	7.45	5.81	3	28		1.85	0.18
8	115.8	380	5.62	442	321	3.38	0.03	42.14	18.97	22	78		18.12	7.26
9	125.0	400	4.03	437	227	2.58	0.13	20.34	12.73	23	83		6.72	3.45

Table I: Comparative averaged analytical data for 6 coreholes penetrating the Big Marsh oil shale beds.

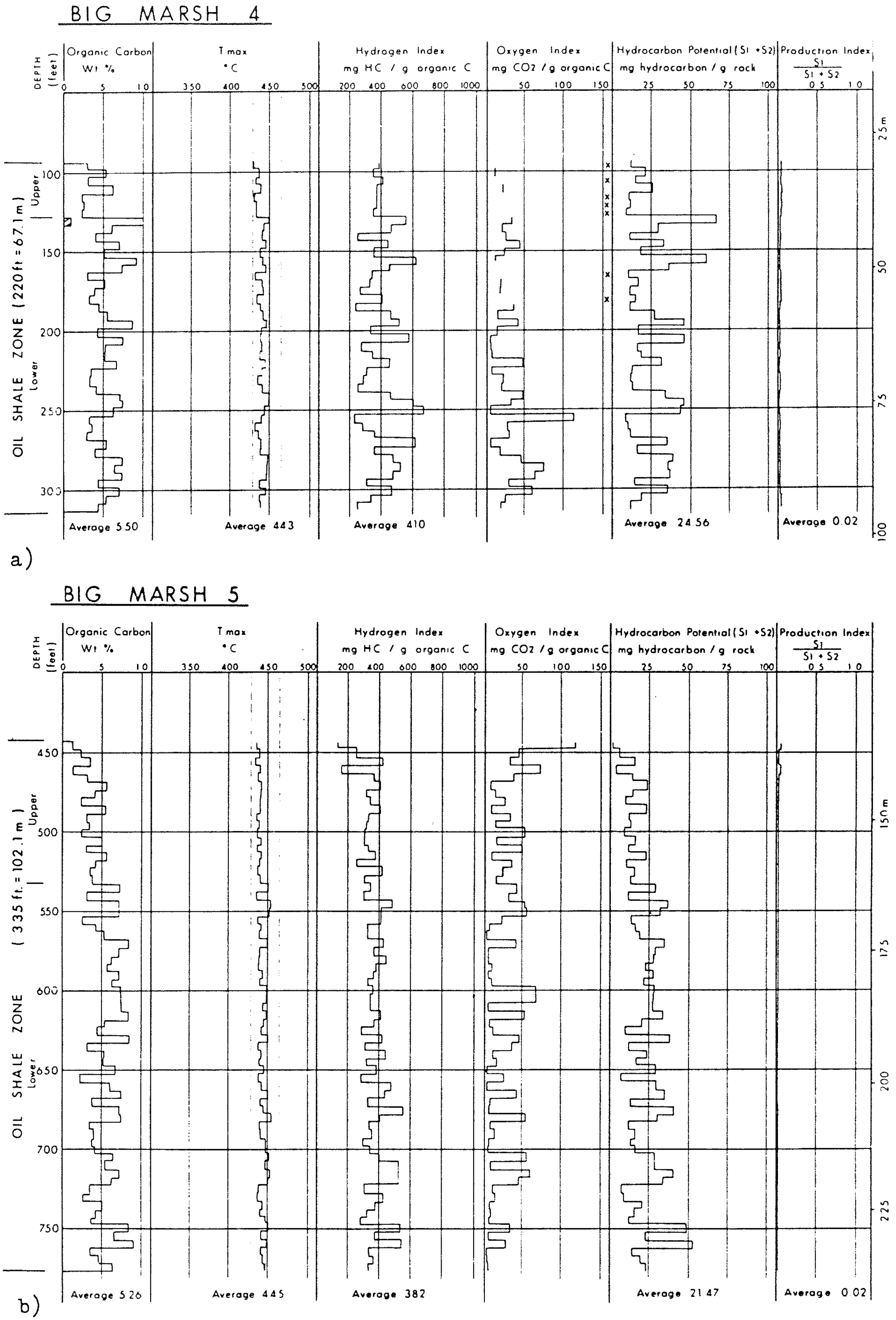
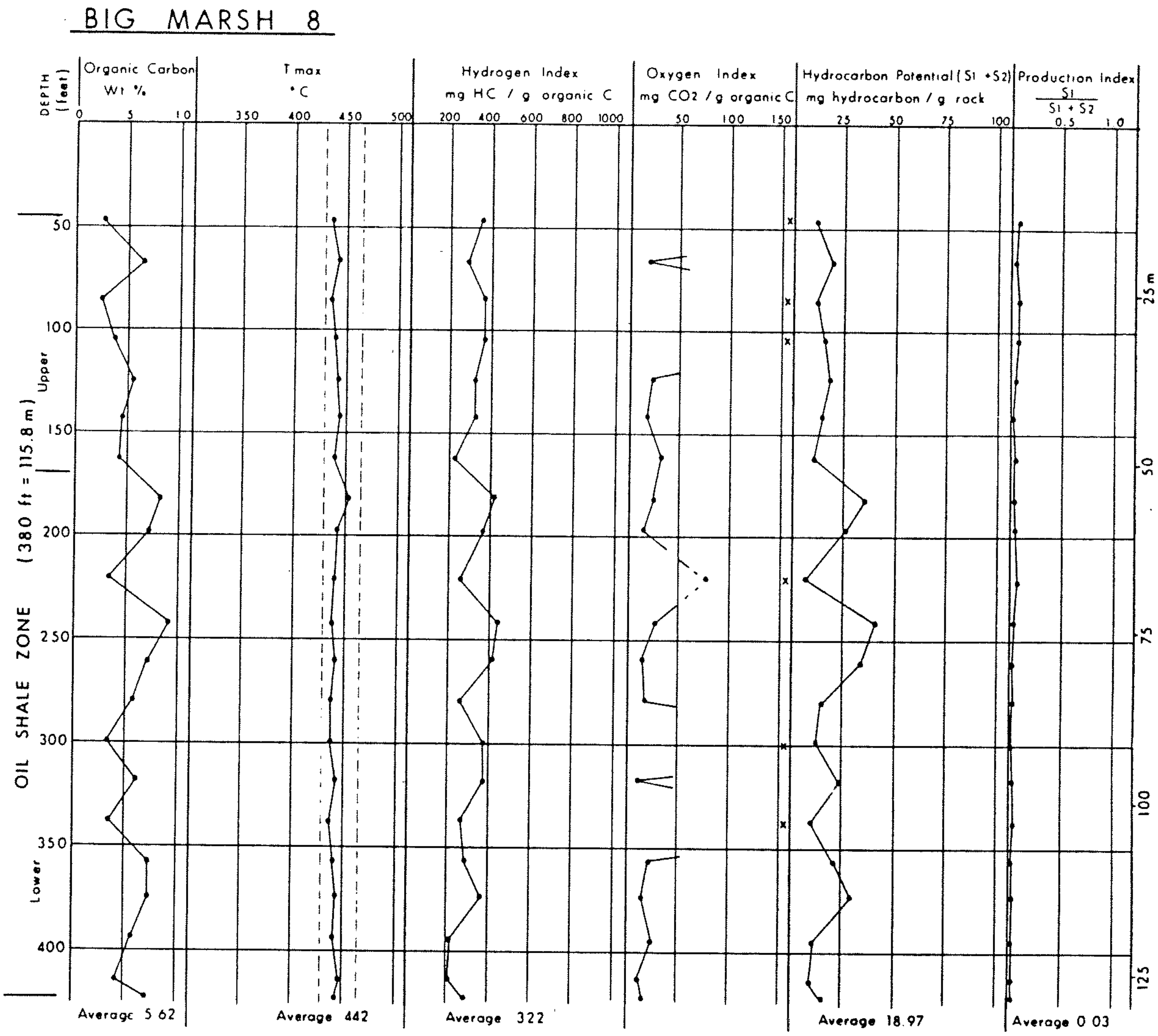


Fig. 4: Graphical plots of TOC and Rock-Evak data, Big Marsh area coreholes; a) Big Marsh #4, b) Big Marsh #5



Values plotted at depths centered in five foot (1.52m) sampled intervals

Fig. 4c; Graphical plot of TOC and Rock-Eval data, Big Marsh area corehole #8

At corehole #9, the lowest recorded average Tmax, 437°C coincides with the highest average PI value, 0.13 (Table I), which is an unexpected relationship. The Tmax value is probably anomalous, possibly a bitumen effect (Durand, 1983).

Experience with the Rock-Eval technique now indicates that different kerogen types pyrolyze within different parts of the general oil window range (Durand, 1983). These maturity data may indicate an admixture of kerogen types.

Kerogen Type

Type III humic kerogen is known from the recognition of carbonaceous debris and plantremains during core sampling. Other components are best

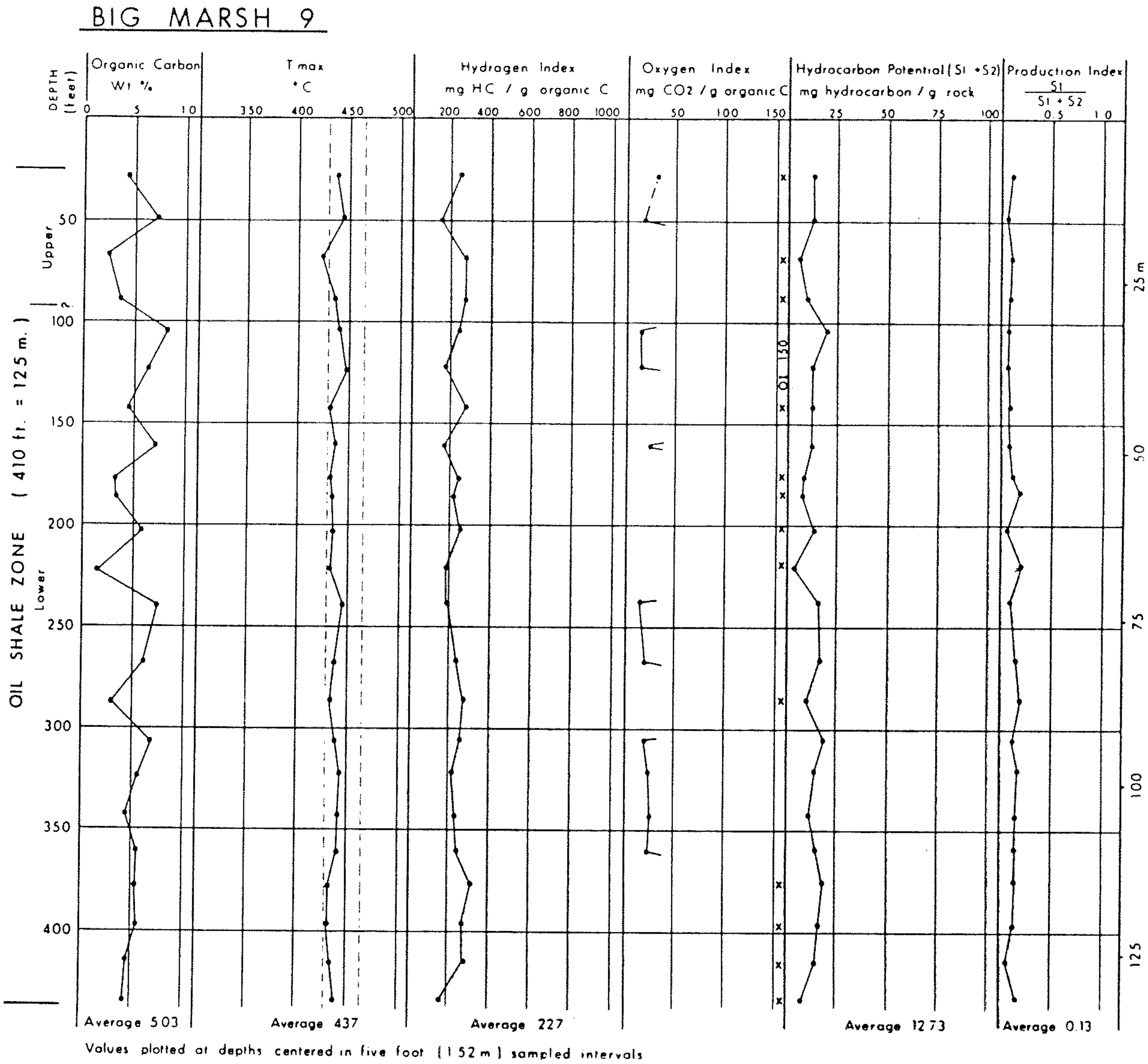


Fig. 4d: Graphical plot of TOC and Rock-Eval data, Big Marsh area corehole #9

recognized by the plot of hydrogen and oxygen indices on a modified vanKrevelen type diagram (Figs. 5a - d). Oxygen determination is the least precise measurement of the Rock-Eval analyzer and numerous abnormally high oxygen indices (greater than 150) have been recorded (See appendix B for specific values). The hydrogen index values are more significant.

Type I algal kerogen is recognized, particularly at corehole #4 (Fig. 5a). Most of the low oxygen values, paralleling the Type I curve, probably represent Type I kerogen (Figs. 4a, 4b). Low thermal maturation is implied by the dominance of hydrogen indices in the range 300 to 700 mgHC/g organic carbon. At all four coreholes many of the plotted points can be inferred to by Type II kerogen, but an admixture of Type I continental lacustrine

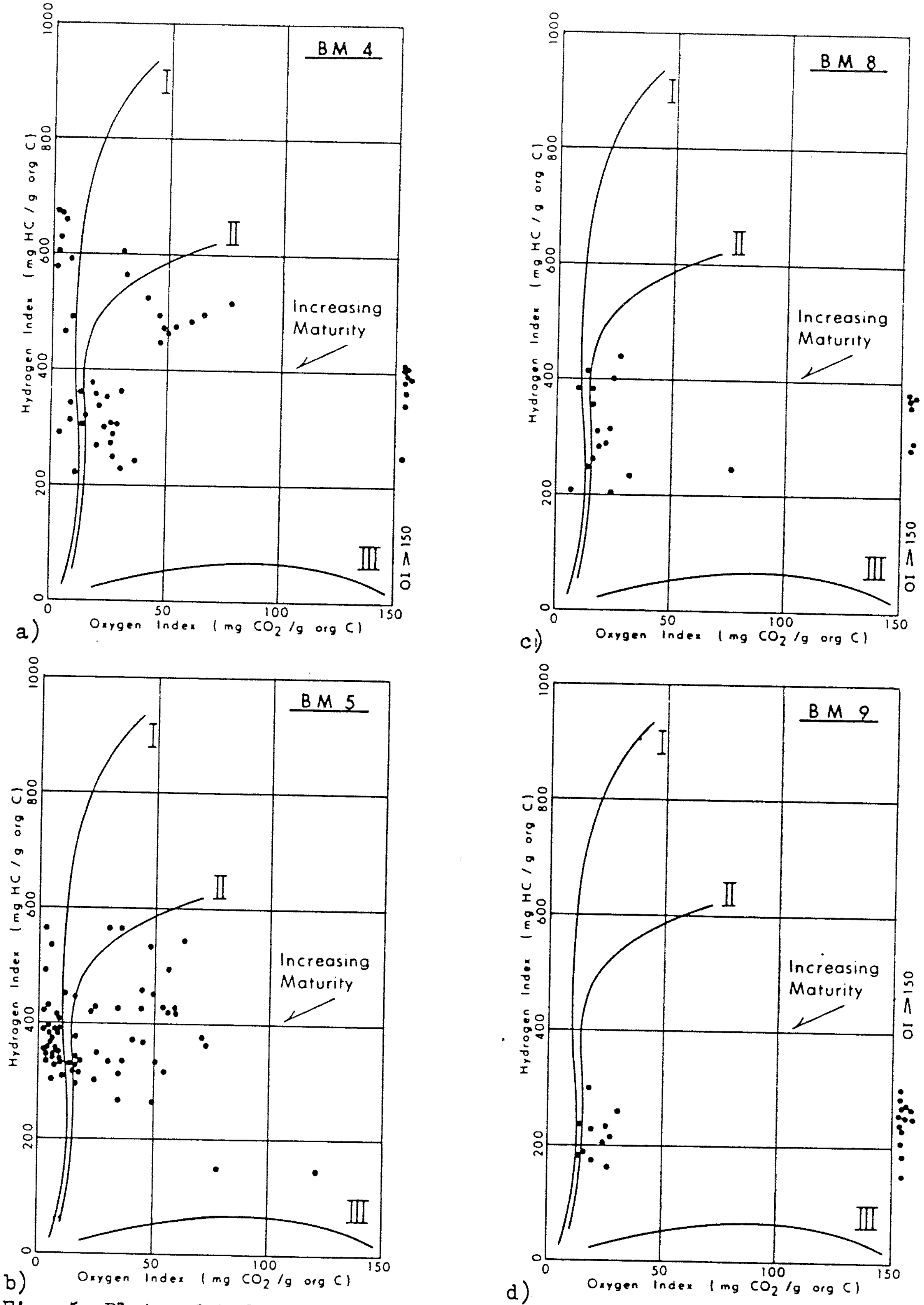


Fig. 5: Plots of hydrogen vs oxygen indices, Big Marsh area coreholes; a) Big Marsh #4, b) Big Marsh #5, c) Big Marsh #8, d) Big Marsh #9

and Type II marine is unlikely. Many of the points probably represent admixtures of partially matured Type I and Type III kerogens.

The hydrogen indices increase noticeably where both TOC and Tmax increase from the upper to the lower section (Figs. 4a, 4b). This change may relate to dominant Type III humus in the upper section with an increasing content of Type I algal sapropel in the lower interval. The upper-lower subdivision is not so readily obvious at coreholes 8 and 9 (Figs. 4c, 4d), as hydrogen indices are generally lower throughout (Table 1); this may reflect less Type I content and/or increasing maturation.

Petroleum (Hydrocarbon) Potential

Petroleum potential, the sum of recoverable free hydrocarbon (S_1) and pyrolyzable kerogen and bitumen (S_2), is a guide to anticipated recoveries from retoring processes. In general, Rock-Eval results fairly closely agree with Fischer assay data (Macauley and Ball, 1982, p.52).

Recovery data from Rock-Eval pyrolysis are recorded in milligrams hydrocarbon per gram of rock: these data are generally reported herein as kilograms hydrocarbon per tonne of rock. These ratios are numerically identical and they are directly inter-changeable.

Hydrocarbon yields at Big Marsh decrease from north to south from a best average of 24.56 kg/t (6.54 US g/t) at the north (BM #4) to 12.73 kg/t (3.39 US g/t) at the south (BM #9) (Table I). This decrease is directly reflected by diminishing yields per 1% TOC (Figs. 6a - d), which decrease southward over the range 4.47 to 2.58 kg/t/1% TOC (Table I).

The maximum recorded yield is 66.17 kg/t (17.6 US g/t): the best average, 24.56 kg/t (6.54 U.S. g/t) is considerably below the present generally accepted minimum 10 U.S. g/t for economic consideration. Although the lower 2/3 to 3/4 of the oil shale section does appear to provide better recoveries (Figs. 4a, 4b), there is no selective high yield interval within the total zone. This was expected from the apparent uniformity of the zone on visual inspection of the cores.

Rock-Eval pyrolysis yields are somewhat higher than those obtained by the TUNS Fischer type assays: the correlation of the two techniques is approximate but is certainly not direct in this area.

ECONOMIC POTENTIAL

There is little potential for commerical development of the Big Marsh

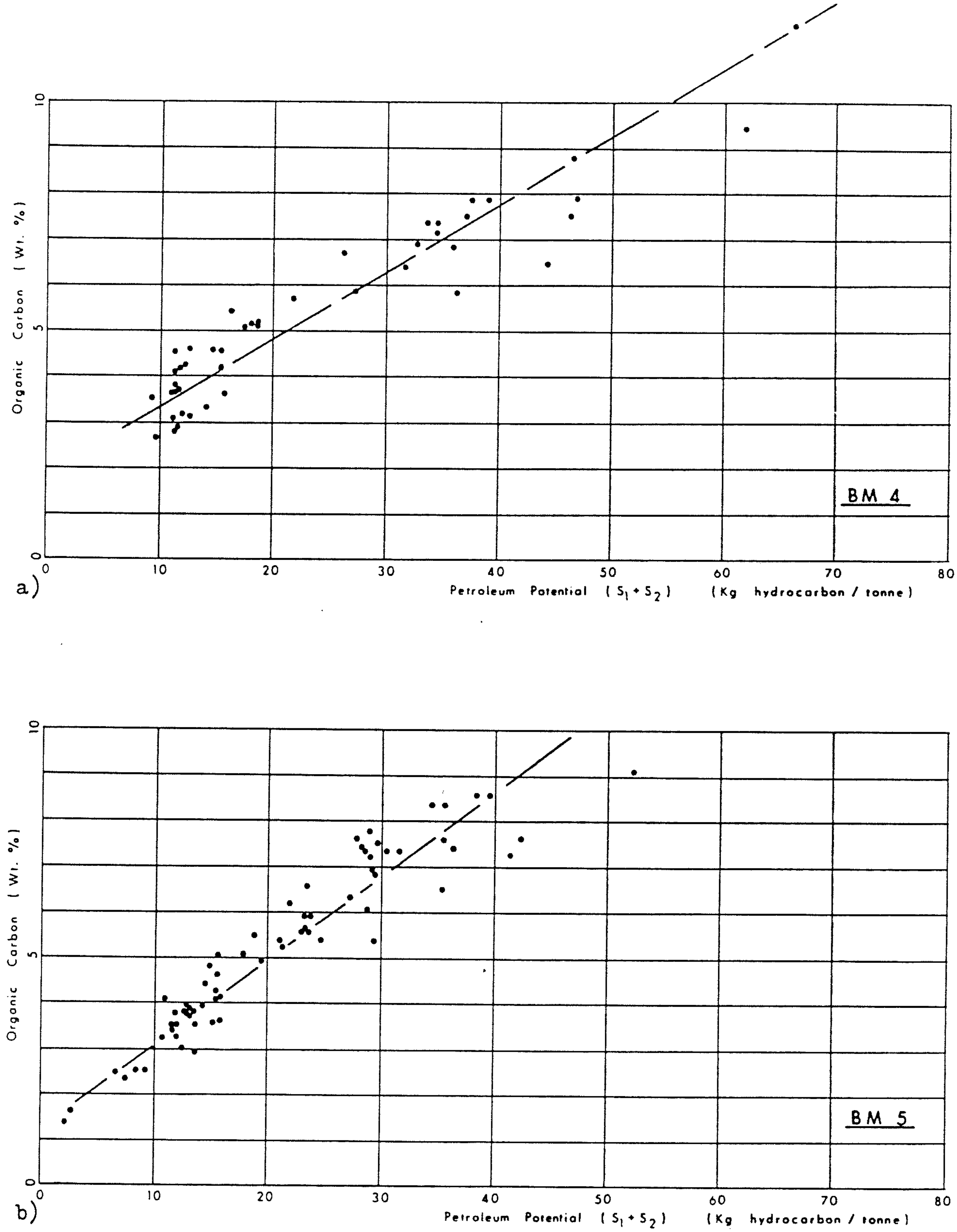


Fig. 6: Comparisons of petroleum potential (yield) to total organic carbon content, Big Marsh area coreholes; a) Big Marsh #4, b) Big Marsh #5

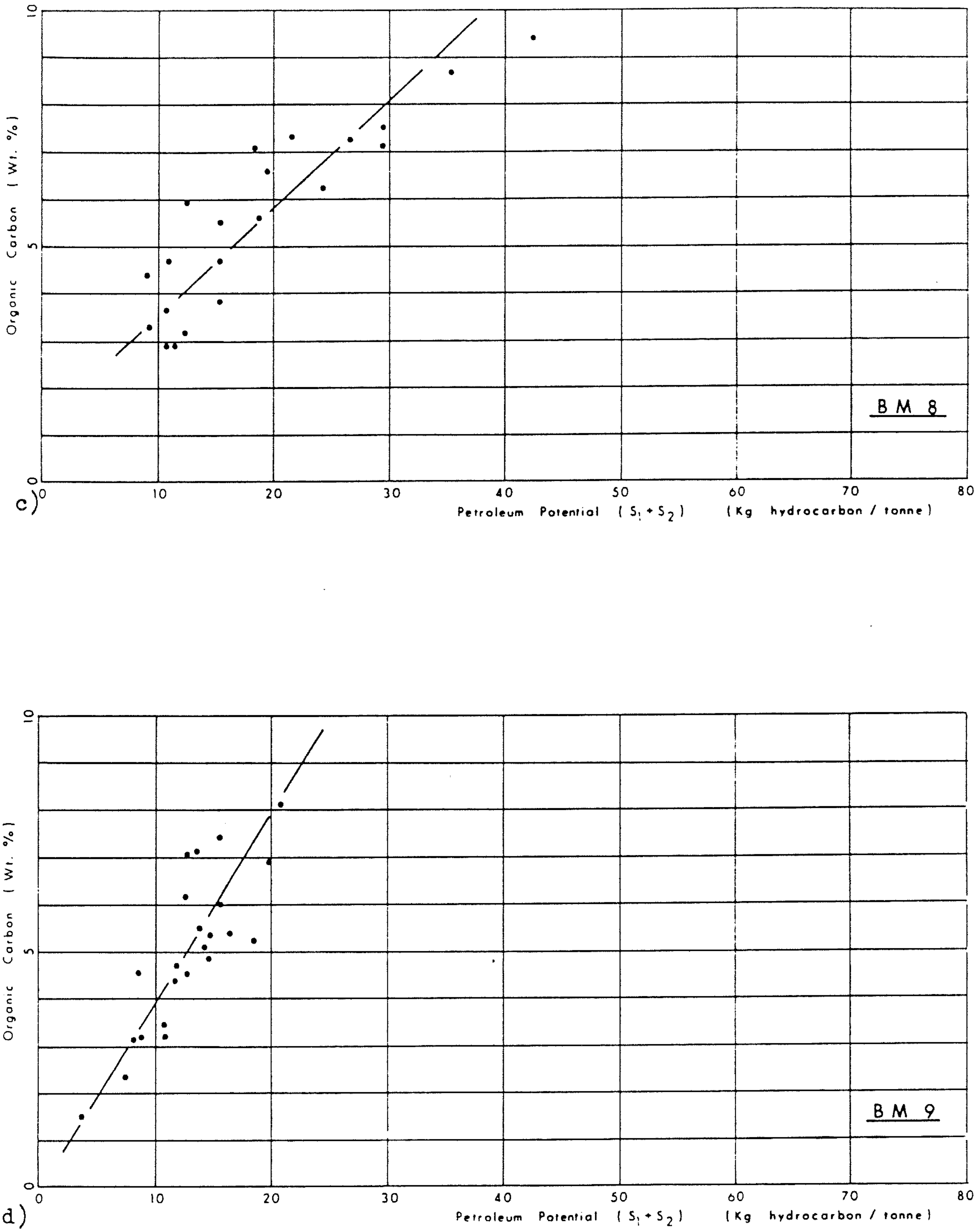


Fig. 6: Comparisons of petroleum potential (yield) to total organic carbon content, Big Marsh area coreholes; c) Big Marsh #8, d) Big Marsh #9

oil shales under present economic conditions and known mining-retorting procedures. The even distribution of the kerogen throughout the unit, without thinner zones of high yields, is discouraging.

Several factors relating to economic evaluation can be summarized. The petroleum (hydrocarbon) potential relates directly to the hydrogen index, to the yield per 1% TOC and almost directly to the TOC content (Fig. 7), and is inversely proportional to the gross thickness of the oil shale beds.

Tmax indicates low thermal maturity across the Big Marsh area, although this is not reflected by light hydrocarbon content. Variations in hydrogen indices and recoveries per 1% TOC reflect changes in the content of Type I versus Type III kerogen more than indicating varying thermal maturation. The southerly decrease of hydrocarbon (petroleum) potential thus reflects changing kerogen type and, to some degree, lessening kerogen content, and possibly a minor increase in maturation.

ORIGIN

The Rights River Formation is interpreted by Benson (1974) as an alluvial fan deposited in a relatively restricted valley. Sources in the Antigonish Highlands at the west were postulated from the assemblage of clast compositions which comprise the formation. The contrast in grain size of the Big Marsh oil shales to the bulk of the sediments which make up the Rights River Formation, and the presence of organic matter in the former, indicate relative quiescent deposition in a reducing environment. Given the stratigraphic proximity of the oil shale beds to the top of the coarse grained Rights River Formation, and the probable unconformable relationship between the Rights River and the overlying coarse grained Wilkie Brook Formation, the Big Marsh beds must mark a period of local low energy sedimentation.

The nature of the depositional environment of these oil shales has not been discussed in the existing literature. Our understanding comes from this study and from comparison with the more completely studied Albert Mines deposit in New Brunswick (Macauley and Ball, 1982).

At both Big Marsh and Albert Mines, coarse grained conglomeratic beds, deposited as alluvial fans derived from adjacent Highlands, are lateral equivalents of the oil shale strata (Fig. 8). The oil shales were deposited in local restricted lacustrine environments, contained in isolation within a regionally broader area of alluvial fan deposition.

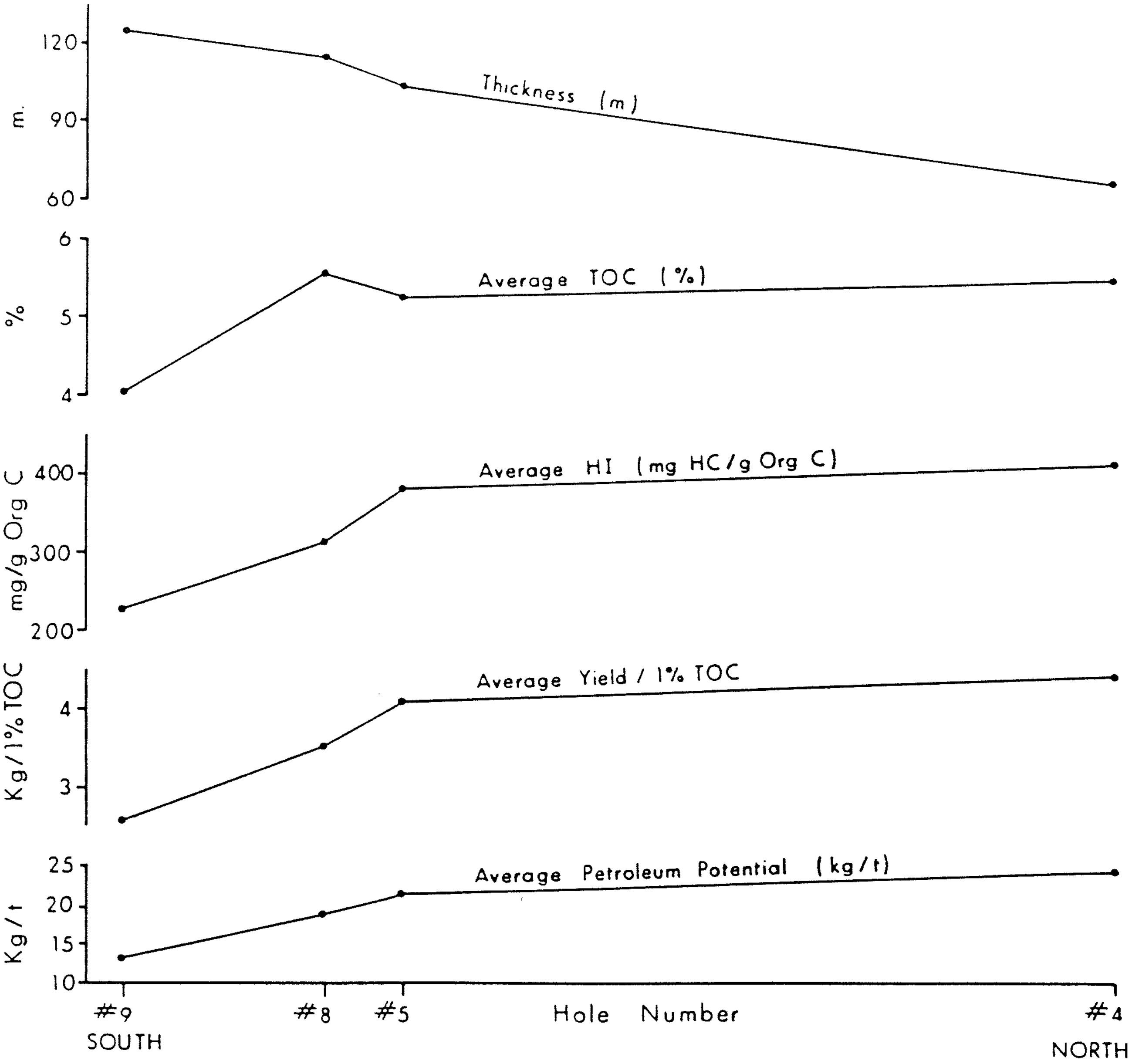


Fig. 7: Comparisons of pertinent oil shale data, Big Marsh area

Big Marsh oil shales vary from those at Albert Mines as there was no humic contribution to the Albert Mines shale but rather a much greater concentration of algal debris. The greater algal concentration at Albert Mines caused precipitation of carbonate; this did not occur at Big Marsh, possibly because of less restricted water circulation in the latter area.

These interpretations indicate that the area of individual oil shale deposits will not likely be geographically large; however, numerous local deposits are possible with considerable variation in both kerogen quantity and average type (ratio of Type I - Type III) from deposit to deposit.

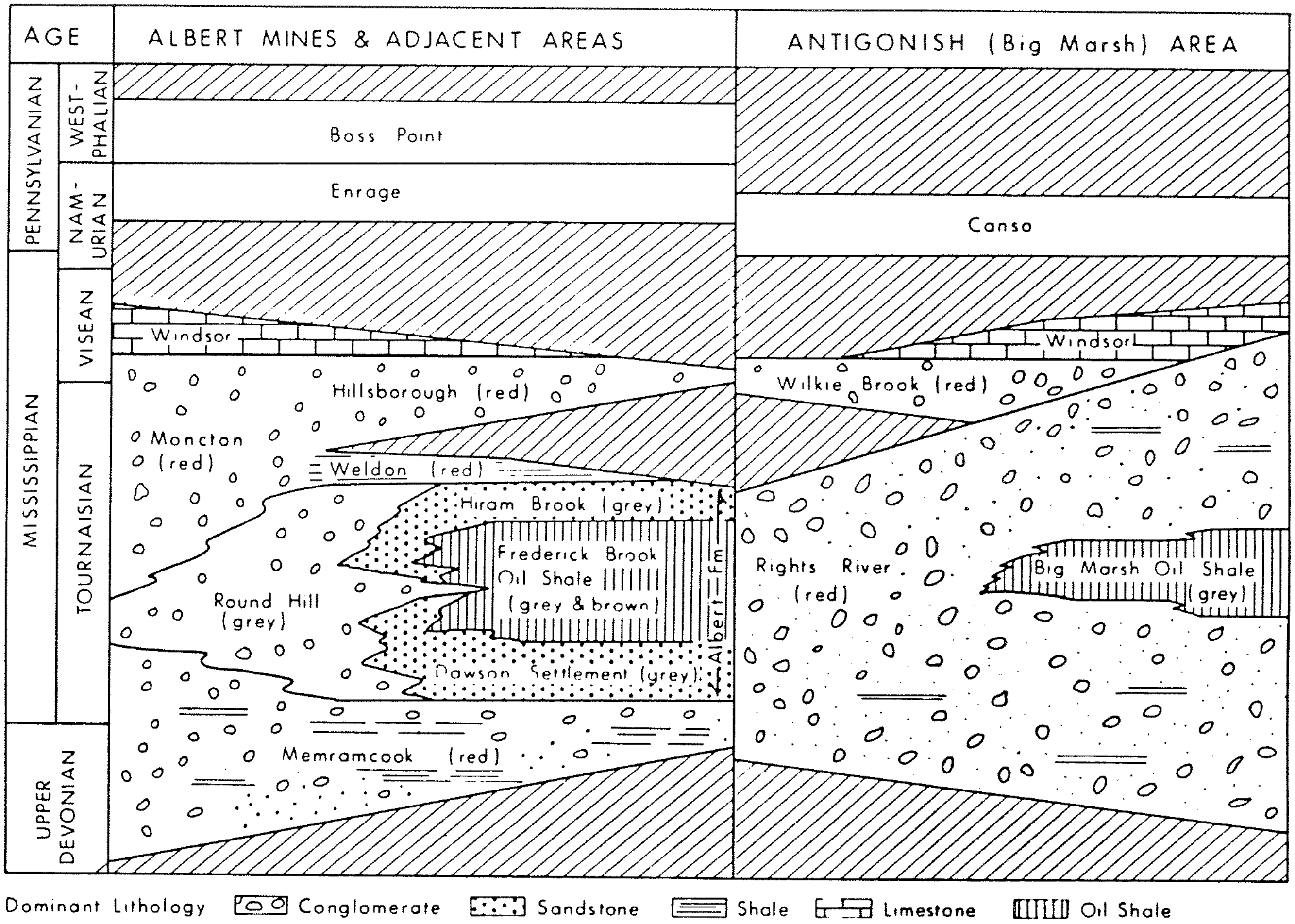


Fig. 8: Facies comparisons of Albert Mines (New Brunswick) and Big Marsh oil shale deposits

HORTON BLUFFS AREA

Black shales at Horton Bluffs, on the south side of the Minas Basin (Fig. 1), were described in early publications as possible oil shales, but R.W. Ells (1910), after detailed surface studies, concluded that most were carbonaceous, containing woody and coaly material, rather than sapropelic kerogen which could yield oil on pyrolysis. The area was first mapped and defined stratigraphically by Bell (1929, 1960) in 1913-14, and more recently by Ferguson (1983).

Bell (1929) divided the Horton Group in the area into the lower Horton Bluff and upper Cheverie Formations. The Horton Bluff Formation was further divided into an upper arenaceous member, a middle argillaceous member with black-grey shale and basal grey quartzitic sandstone sub-units, and a basal feldspathic conglomerate - sandstone member.

The obvious similarity of the three unit Horton Bluff Formation and the Albert Formation of New Brunswick has already been discussed. The presence of stratigraphically equivalent oil shales in New Brunswick and at

Big Marsh, Nova Scotia, necessitates some examination of the black shales in the Horton Bluffs middle argillaceous member. To this end, the section of black shale at Horton Bluff, on the west bank of the Avon River between Avonport Station and the northern end of Blue Beach, was traversed and five samples selected to provide comparative geochemistry to the other defined oil shales.

TOC and Rock-Eval determinations (Appendix B) indicate very low organic carbon content (less than 0.50%), almost no hydrocarbon recovery (all less than 0.50 kg/t), low hydrogen indices, and erratic Tmax values. Three Tmax values are in excess of 480°C. Although the hydrocarbon yields are sufficiently low that none of the Tmax values may be truly significant, the little kerogen present may be considered to be thermally overmature: the nature of the kerogen is indeterminate from these data.

STELLARTON (PICTOU) AREA

The Pictou coalfield (Fig. 9) is located in northeastern mainland Nova Scotia in the vicinity of the towns of New Glasgow and Stellarton. The coalfield occupies a fault bounded graben structure running approximately 17.7 kilometres on an east-west axis and 4.8 kilometres on a north-south axis. The clastic rocks in the coalfield consist of non-marine red and grey sandstones, siltstone and minor conglomerates of the Pennsylvanian Pictou Group. Megaflora and spore florule assign late Westphalian B and Westphalian C ages to the field (Hacquebard and Donaldson, 1969).

The graben is in fault contact with older Pennsylvanian sedimentary rocks (Cumberland and Canso Groups) along the northern and western boundaries. Upper Mississippian Windsor Group red sediments, limestone and gypsum bound the graben at the north and south; the latter fault contact also partially offsets Cambro-Ordovician rocks.

Surface beds are successively younger across the graben from west to east: a total thickness in excess of 2700 m is present in the coal-bearing sequence, containing as many as 45 coal seams which range from less than 0.3 m to greater than 13 m in thickness. The coal production has originated from 3 local districts, the western Westville, the central Albion and the eastern Thorburn, which lend their names to the three coal-bearing members of the Pictou Group and represent an upward succession in the stratigraphic column (Fig. 10).

A number of open anticlines and synclines having undulating axes which

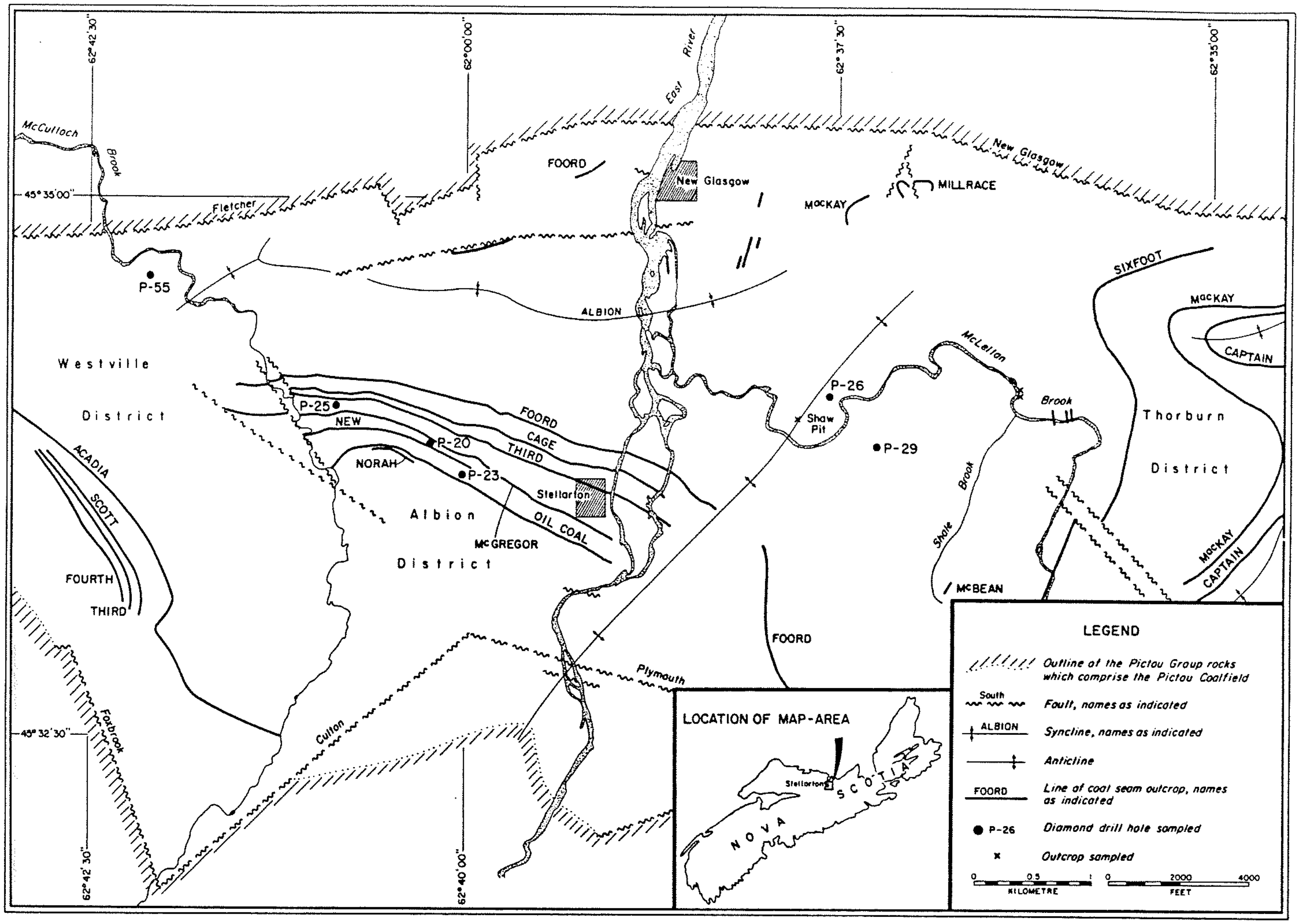


Fig. 9: Surface distribution of coal seams in the Pictou Coalfield (after Bell, 1940) with pertinent corehole and surface outcrop locations

trend northeasterly to easterly across the graben and are cut by several major and numerous minor faults.

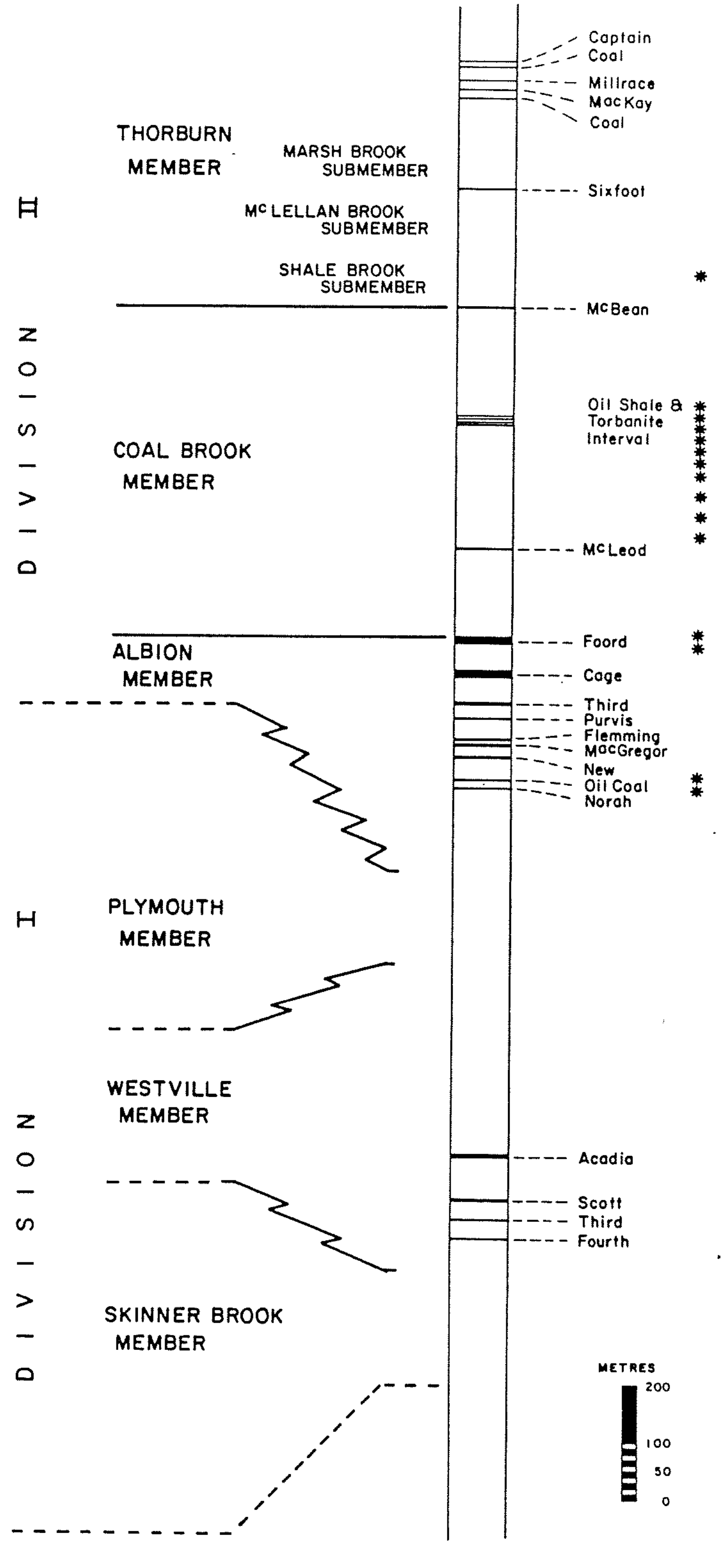
STRATIGRAPHY

Bell (1940) divided the Pictou Group sediments of the coalfield into two Divisions (I and II), each with 3 members (Fig. 10). The lower Division I consists of lower and upper red bed members (Skinner Brook and Plymouth) separated by a grey, coal-bearing member (Westville). The upper Division II consists of lower and upper grey, coal-bearing members (Albion and Thorburn) with an intermediate dark grey, coal and oil-shale bearing member (Coal Brook). Sub-members of the uppermost Thorburn Member also contain oil shale beds.

Differentiation of Division I members is based on colour, red versus grey: these contacts are diachronous. Within division II, the Foord and

McBean seams are required: where these seams are not developed, the divisions become lenticular and interfingering.

Oil shales are found associated with all three members of Division II. The Albion Member contains the Oil-Coal Seam, sampled during this study via diamond drill holes P-20, P-23, P-25 and P-55, (Fig. 9). The Coal Brook Member is composed of two facies, one consisting exclusively of dark grey argillaceous shales and the other of alternating sandstones and dark grey shales to predominantly sandstones and conglomerates. The former includes an interval of oil shales and torbanites exposed and sampled in the Shaw Pit and penetrated by diamond drill holes P-26 and P-29. Diamond drill hole P-26, in close proximity (0.25km north-east) to the Shaw Pit, intersected the entire thickness of the Coal Brook member from the oil shale interval to the Foord seam. Diamond drill hole P-29, 0.75 km east-southeast of the Shaw Pit, on the eastern limb of an anticline which includes the Pit on or near to its crest, was collared higher in the section and penetrates an additional thin section of Coal Brook sediments younger than those encountered at P-26. Oil shale and torbanite beds equivalent to those exposed in the Shaw Pit were not lithologically discernible in the



*Oil Shale and/or Torbanite sampled

Fig. 10: Stratigraphic column, Pictou Coalfield (Nova Scotia Department of Natural Resources)

cores of holes P-26 or P-29.

The lowermost Shale Brook submember of the Thorburn was sampled at exposures on McLellan Brook downstream from the mouth of Shale Brook. The stratigraphic position of the sampled outcrops was deduced from Bell's inferred position of the McBean seam, which is exposed slightly downstream from the mouth of Shale Brook on McLellan Brook in the vicinity of, but just down section from, the sampled oil shale outcrops (Fig. 9).

LITHOLOGY

Liquid hydrocarbons are recoverable from oil shale, torbanite and stellarite beds and also from coal beds with related coaly shales and black shales. The stellarite and coal associated recoveries are all from the Oil-Coal Seam.

The oil shale beds are black, massive to poorly laminated, sub-fissile and are differentiated from similar non-organic black shales by a brown versus grey streak. Sampled intervals at coreholes P-26 and P-29, within the Coal Brook Member, were selected on the basis of lithologic logs supplied by K. Gillis, Nova Scotia Department of Mines and Energy, who used the streak color to define the oil shale beds. The sub-fissility does create a horizontal semi-cleavage on breaking the core.

Torbanites are lithologically similar to the oil shales, but are much more massive, show little lamination or fissility, and break with a conchoidal fracture.

Beds of the Oil-Coal Seam are distinctive as dark grey inorganic shale grades downward to black shale, black coaly shale, then coal sharply overlying laminated black oil shale which grades downward to contorted slickensided oil shale, grading to black contorted friable organic shale. Medium grey inorganic shale underlies the kerogen-bearing interval. The oil shale (stellarite) is black with a distinctive brown streak: the coal and coaly zones are black with a grey streak, and the presence of brittle humic kerogen also readily defines the coaly intervals. The total unit averages about 3 m (10 ft) at all 4 core locations (P-20, P-23, P-25 and P-55) of this study. Relative to the other oil shales of the area and the torbanites, the stellarite is distinctively laminated, contorts and can be ignited.

MINERALOGY

All of the samples from the cores of the Pictou coalfield were analyzed by X-ray diffraction: results are contained in Appendix A.

Although data obtained from diffraction peak heights are not absolute values, the relative concentrations of a limited mineral assemblage can be defined. Quartz comprises approximately half of the inorganic mineral component, with clay minerals representing most of the other half. Expandable and mixed layer clays, kaolinite-chlorite (dominantly kaolinite), and illite are defined clay groups which vary somewhat in their relative proportions but which do not define distinctly any specific oil shale type. The stellarite beds may contain a somewhat higher proportion of kaolin-chlorite, becoming less dominant in the oil shales, and is the least represented clay group of the torbanites. Feldspars are present in small amounts in the oil shales and torbanites (2 to 5%), but are less common (about 1%) in the stellarite. Carbonates are uncommon, especially calcite and dolomite, but siderite ($FeCO_3$) is often present in the 2 to 5% approximate range in the three oil shale types. Minor pyrite is common.

Only a few trace minerals are present: most are questionably identified. Sporadic gypsum may represent a local oxidation alteration of pyrite and siderite. One of the authors, F.D. Ball, has encountered gypsum as a surface oxidation product of coal beds in this area. Apatite, $(Ca(F,Cl)(Ca_4(PO_4)_3$ is tentatively identified in many samples: the presence of this phosphate in minor amounts is not entirely unexpected in oil shale beds.

ORGANIC GEOCHEMISTRY

Oil shales of the Pictou coalfield area are described as stellarite, torbanite and oil shale. The stellarite is readily identifiable by excellent hydrocarbon yield and by association with coal in the Oil-Coal Seam: the differentiation of torbanite from oil shale appears to be based on higher yields and a more massive bedding characteristic, along with conchoidal fracture, relative to oil shales. Attempts to evaluate torbanite beds have often resulted in recoveries much lower than anticipated from the sample appearance. Although How (1868) recognized coal-stellarite-oil shale lithologies on the basis of organic ash content, few further attempts have been made to differentiate the types and interpret their origins.

Total Organic Carbon (TOC)

TOC data are listed in Appendix B along with all other Rock-Eval results. Within the oil shales of the Coal Brook Member, sampled in coreholes P-26 and P-29 (Figs. 11a, 11b), TOC averages 6 to 7%, seldom exceeding 10%, although occasional values may reach 20%. In contrast, the torbanite beds at Shaw Pit (Fig. 11c) average almost 28% TOC, contrasted to 6.7% for the oil shale beds at that exposure. At McLellan Brook, the upper and lower samples are descriptively torbanite bracketing an oil shale bed: these are not readily definable by TOC content. At P-26 and P-29 (Figs. 11a, 11b), specific beds are correlated to the Shaw Pit torbanites in part because of higher carbon values in conjunction with stratigraphic position.

At the 4 coreholes penetrating the Oil-Coal Seam (Fig. 11d), beds are differentiated into coal, coaly shale and stellarite on the basis of lithology, by TOC content, and from Rock-Eval data. Coal beds generally exceed 50% TOC, but coaly shales and black shales, defined to be coaly, range minimal to 20% or better TOC. For the stellarite, average TOC values range from 7 to 18% across the 4 locations, and encompass a wide range of specific values from 3 to greater than 23%.

Although the oil shale beds do exhibit generally lower values, the overlap of the ranges encountered is such that TOC cannot by itself be used to differentiate oil shale, torbanite and stellarite.

Thermal Maturation

Tmax is considered to be a significant indicator of thermal organic maturation. Stellarite beds have the highest average Tmax values, about 450°C (Fig. 11d), followed by most of the oil shales, the torbanites, and the coal beds near 447°C (Figs. 11a, b, d): the youngest oil shales at McLellan Brook and above the torbanites at Shaw Pit, have Tmax averages near 440°C (Fig. 11c). From these values, all beds should be in the low to medium thermal maturity range defined by the oil generation window, 435°-465°C. Of particular note is the distinct drop in Tmax values from stellarite to coal at 3 of the 4 Oil-Coal Seam locations (Fig. 11d).

The concept of oil generation at this level of thermal maturity is not confirmed by the production indices (PI) as there is virtually no free hydrocarbon content in any of the sampled sections. PI values average near 0.10 for the oil shales, 0.07 for the torbanites, 0.07 for coal beds, and a minimum 0.02 for the stellarites. Thermally mature oil shales have PI indices

P-26

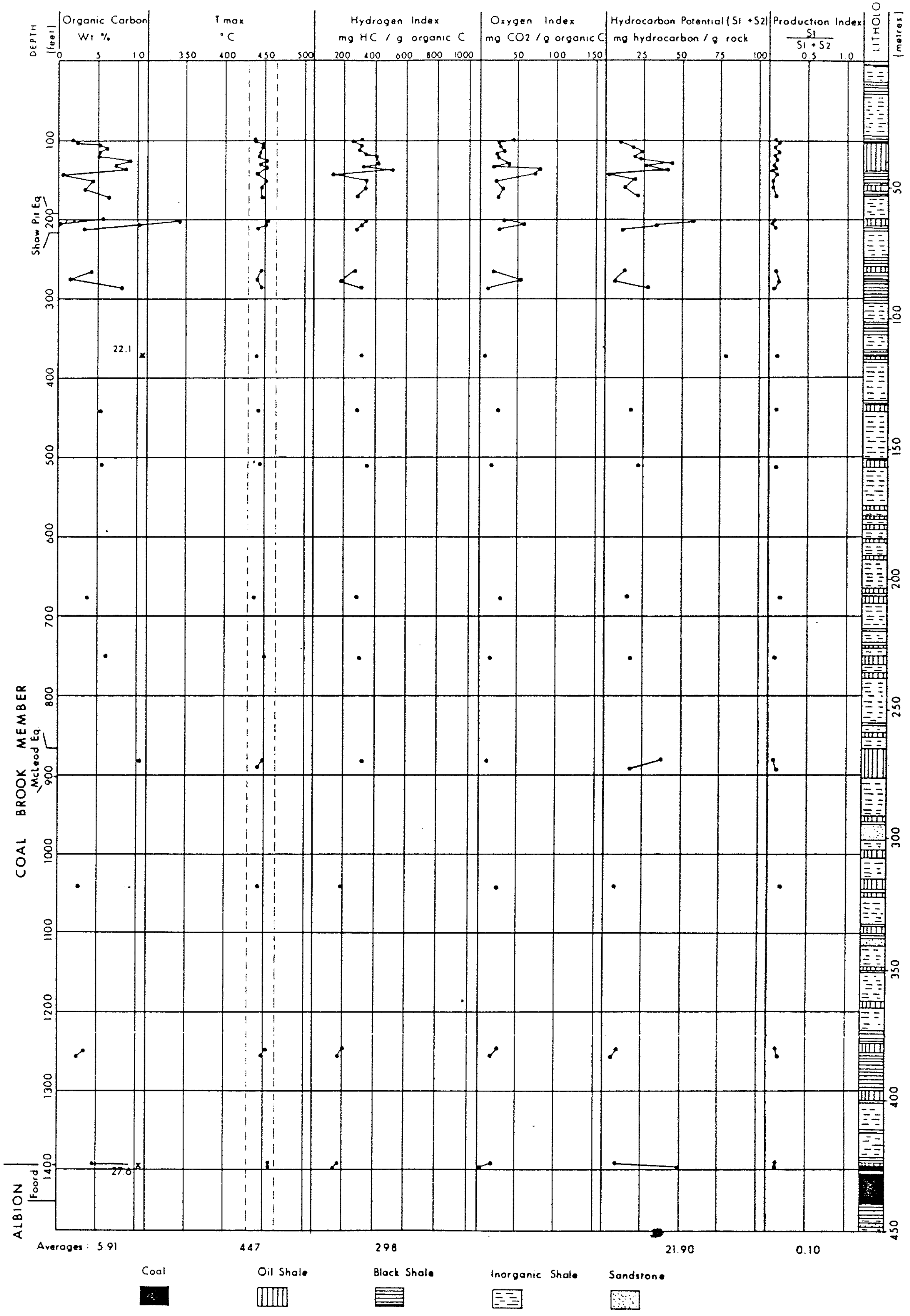


Fig. 11a: Graphical plot of TOC and Rock-Eval data, Stellarton area, Core-hole P-26

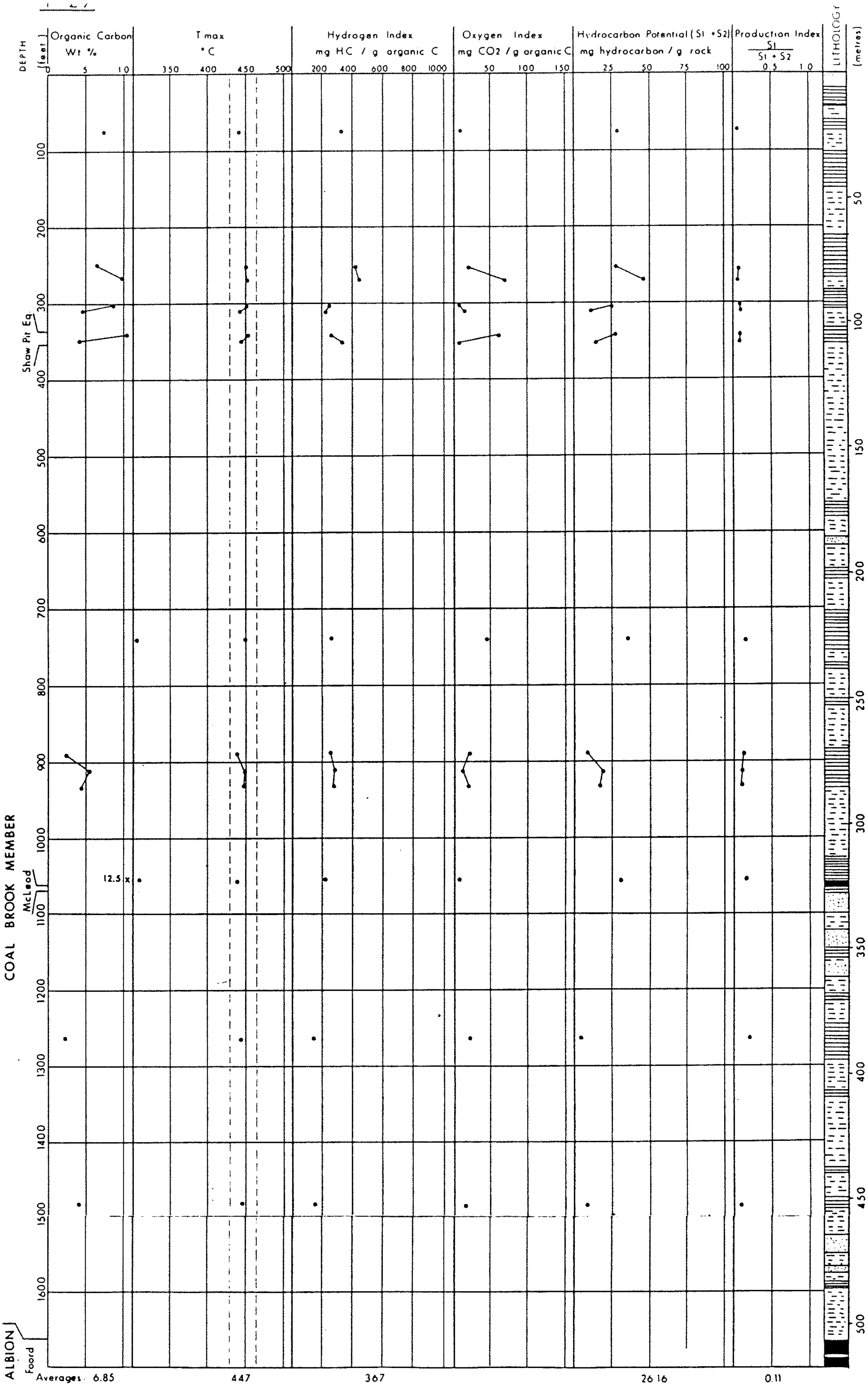


Fig. 11b: Graphical plot of TOC and Rock-Eval data, Stellarton area, Corehole P-29

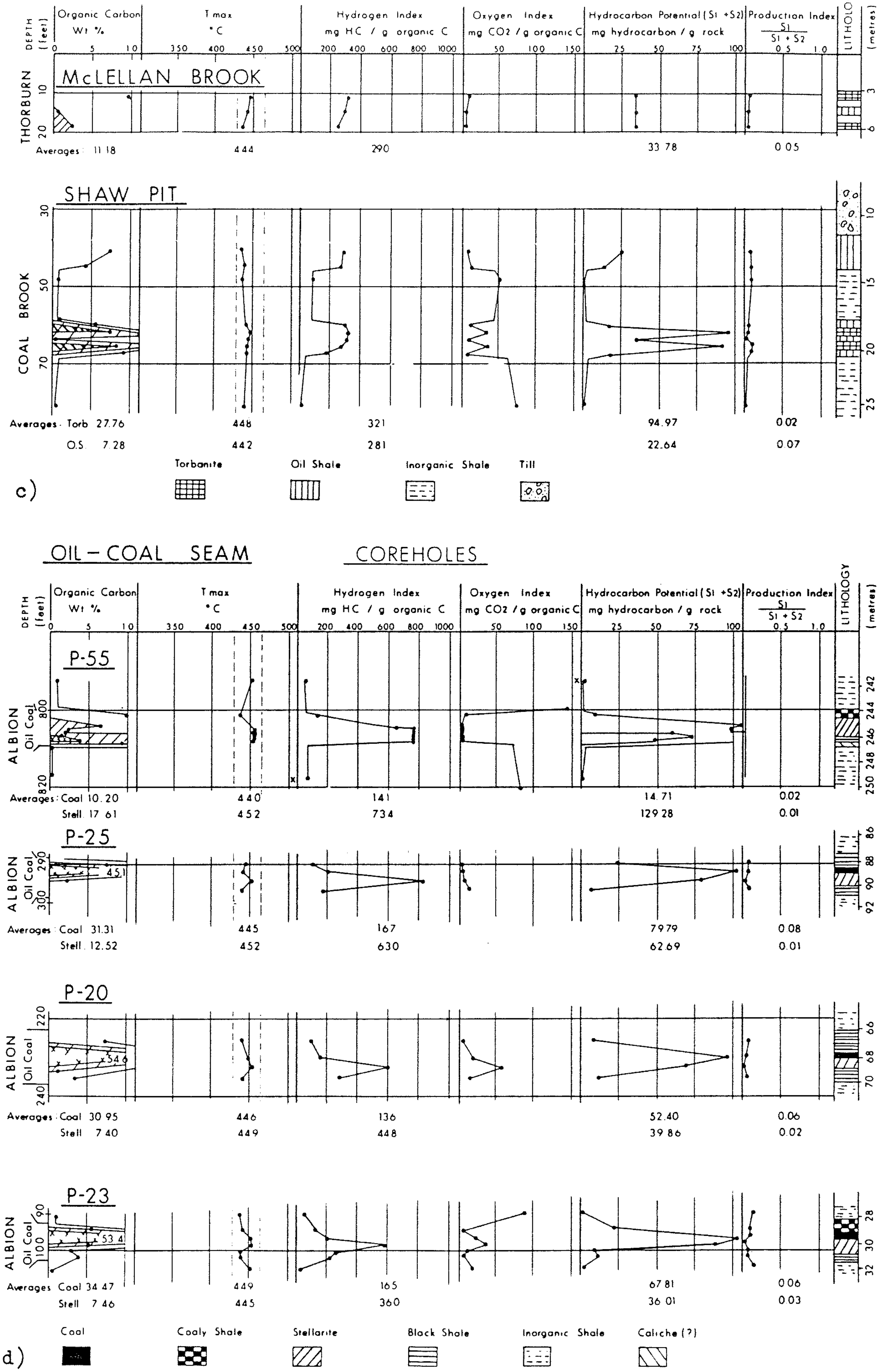


Fig. 11: Graphical plots of TOC and Rock-Eval data, Stellarton area; c) McLellan Brook and Shaw Pit surface exposures, d) Oil-Coal Seam at coreholes P-20, P-23, P-25 and P-55

up to 0.4 to 0.5, much higher than encountered in this area. By standard interpretation, these beds are of low thermal maturity at best. The PI indices for the coal are probably not significant as early maturation should produce gas which will not be recorded in the S_1 free hydrocarbon content.

Hydrogen indices (HI) can often be used to assist maturation interpretations. HI values for the oil shales and the torbanites fall in the range 260-370 (Figs. 11a-c): those of the stellarite are from 360 to 730 (Fig. 11d), whereas coal HI values range 100 to 167 mgHC/g org.C (Fig. 11d). These HI values distinctly define the stellarite, oil shale-torbanite and coal lithologies. The high stellarite values (Fig. 11d) represent low thermal maturity, less than indicated by the relatively high (450°c) Tmax average. Lower hydrogen indices for the other organic lithologies are possibly more indicative of changing type of organic content rather than increasing thermal maturation.

Vitrinite Reflectance

Coal rank data based on vitrinite reflectance measurements have been reported by Hacquebard (1978) for the Pictou coalfield. At and near surface, the rank increases from high volatile A bituminous coals in the Albion and Thorburn districts to medium volatile bituminous coals in the Westville district. Westville coals occur at depth in the Albion District where they attain a rank of low volatile bituminous below 610 m.

The coal associated with the stellarite of the Oil-Coal Seam from the four coreholes of this study in the Albion District were analyzed by Kalkreuth at ISPG: these results are presented in Table II. The reflectance date for the coal range 0.85 to 0.96% Rmax, indicating high volatile A bituminous rank at all four locations.

The reflectance values obtained from vitrinite particles within the associated stellarite are considerably lower, ranging 0.38 to 0.41% Rmax, than those of the overlying coal bed. This phenomenon is not yet fully understood, but may in part relate to a reduction of values by bitumen impregnation of the vitrinite particles.

Kerogen Type

Humic kerogen is known from the coal beds as well as by minor carbonaceous debris and occasional plant remains visible during sample examination by microscope. Type I kerogen is definitely present from the hydrogen-oxygen indices of the stellarite (Fig. 11d). Because of known presence of Type I and Type III kerogens, both continental in origin, Type II

Corehole	Depth(m)	Lithology	Tmax	Maximum Reflectance % Mean	S	N
P-20	69.72-70.08	Coal	450	0.96	0.05	50
	70.08-71.04	Stellarite	453	0.40	0.05	20
P-23	28.09-29.62	Coal	449	0.94	0.05	50
	29.62-30.56	Stellarite	445	0.41	0.11	30
P-25	88.85-89.23	Coal	445	0.92	0.06	50
	89.23-90.22	Stellarite	452	0.38	0.08	40
P-55	244.3-244.4	Coal	440	0.85	0.04	50
	245.0-246.5	Stellarite	452	0.41	0.06	30
		Coal	Average	0.92		
		Stellarite	Average	0.40		

S - standard deviation N - number of measurements

Table II: Reflectance data on the coal and stellarite beds of the Oil-Coal Seam.

marine kerogen is not anticipated.

Almost all the oil shale samples and the torbanites fall within a limited area on the HI-OI plot (Figs. 12a-c): the coal and coaly beds (Fig. 12d) plot similarly but somewhat lower on the HI axis. Kerogen of the oil shale - torbanite lithologies may be a composite of Type I - Type III kerogen: if so, the relative concentrations of kerogen types is similar for both lithologies. These could be entirely Type III deposits. There also may be some distortion of kerogen type on the HI-OI diagram because of some thermal maturation.

The hydrogen-oxygen relationship distinctly defines stellarite, coal, and oil shale - torbanite, and indicates that the oil shales and torbanites are organically identical except for the amount of kerogen present.

Flynn (1926), although including both as types of torbanite, recognized that the stellarites were composed of large yellow bodies, with outward radiating cells, in a black matrix, in contrast to orange-red particles, the remains of laminated vegetable humus, in the torbanites. According to Flynn, the stellarites can be identified by crushing a sample on a glass with a knife blade: the kerogen particles are discernible as amber colored beads having the wrinkled surface of a walnut shell. Preliminary results of flourescence microscopy by Kalkreuth at ISPG indicates that the organic material of the stellarite consists primarily of the remains of a Botryococcus-type algae.

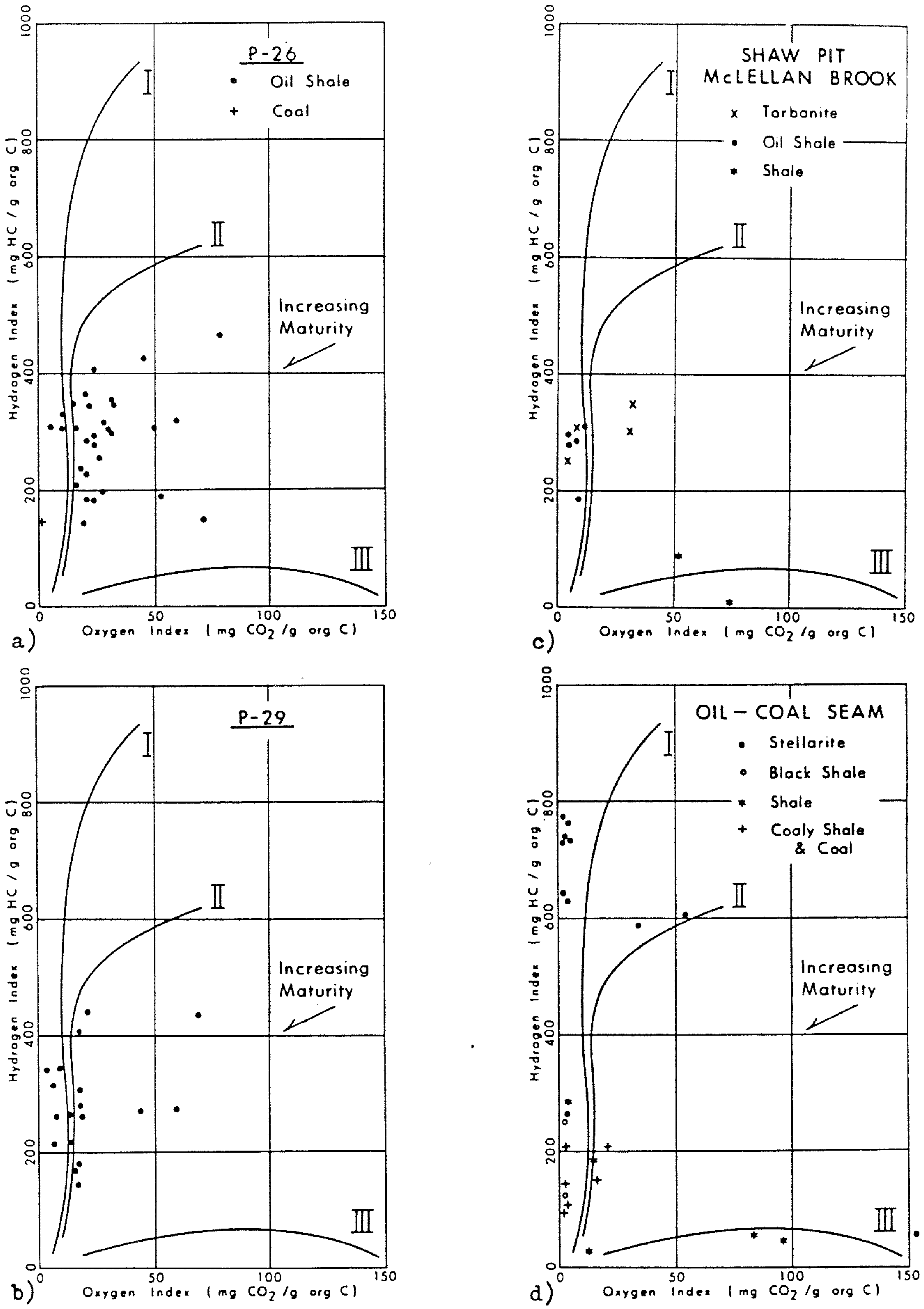


Fig. 12: Plots of hydrogen vs oxygen indices, Stellarton area; a) Corehole P-26, b) Corehole P-29, c) MeLellan Brook and Shaw Pit surface exposures, d) Oil-Coal Seam at coreholes P-20, P-23, P-25 and P-55

Petroleum (Hydrocarbon) Potential

Hydrocarbon recoveries are poor from the oil shale beds, averaging 21.90 kg/t at P-26 (Fig. 11a) and 26.16 kg/t at the P-29 corehole (Fig. 11b). Oil shales within the torbanites at Shaw Pit (Fig. 11c) are similar, although the torbanites yield considerably higher (94.97 kg/t) from much greater organic carbon content. When calculated on the basis of organic carbon content, the oil shales at P-26 (Fig. 13a), corehole P-29 (Fig. 13b) and the torbanites of the surface outcrops (Fig. 13c) are virtually identical, all yielding near 3.5 kg/t/1% TOC.

By far the greatest yields are recovered from the stellarite and the coal of the Oil-Coal Seam (Fig. 11d). At the P-55 corehole, the stellarite yielded 172.75 kg/t (45.5 US g/t) from one sample. Average yields of the stellarite decrease from a maximum 129.28 kg/t (34.1 US g/t) at the west (P-55) to only 36.01 kg/t (9.5 US g/t) at the east (P-23): however, the yield/1% TOC averages about 7.1 kg/t/1% TOC (Fig. 13d), with this average decreasing slightly easterly (7.3 to 5.4), but not sufficiently to be the major contributor to the decreasing yield.

Some of the best hydrocarbon recoveries are associated with the coal beds, with several yields in excess of 100 kg/t, although the shale oil recoveries from the coals are less than 2 kg/t/1% TOC.

Flynn (1926) noted the specific gravity of stellarite oil to be 0.91; at 0.86 that of the torbanite is slightly lighter. No specific gravity is available for the coal-derived oil. The stellarite yielded 22-26 cu ft. gas/bbl., whereas the greater humic content of the torbanite produced 56-59 cu. ft. gas/bbl. of shale oil during Flynn's investigations.

Distinct differences of organic carbon are confirmed for the coal, stellarite and oil shale-torbanite beds. Except for increased kerogen content, the torbanites are geochemically identical to the oil shale deposits.

ECONOMIC POTENTIAL

Even though oil shales (excluding torbanites) attain considerable thickness, as much as 13 m, and up to 50 m (Potter, 1975) where intervening potentially organic black shales are included, these zones are not presently of economic interest because of the limited organic carbon content (7%) coupled with the average low yield (3.5 kg/t/1% TOC). The uniformity of both kerogen content and type throughout the section is discouraging as bands of

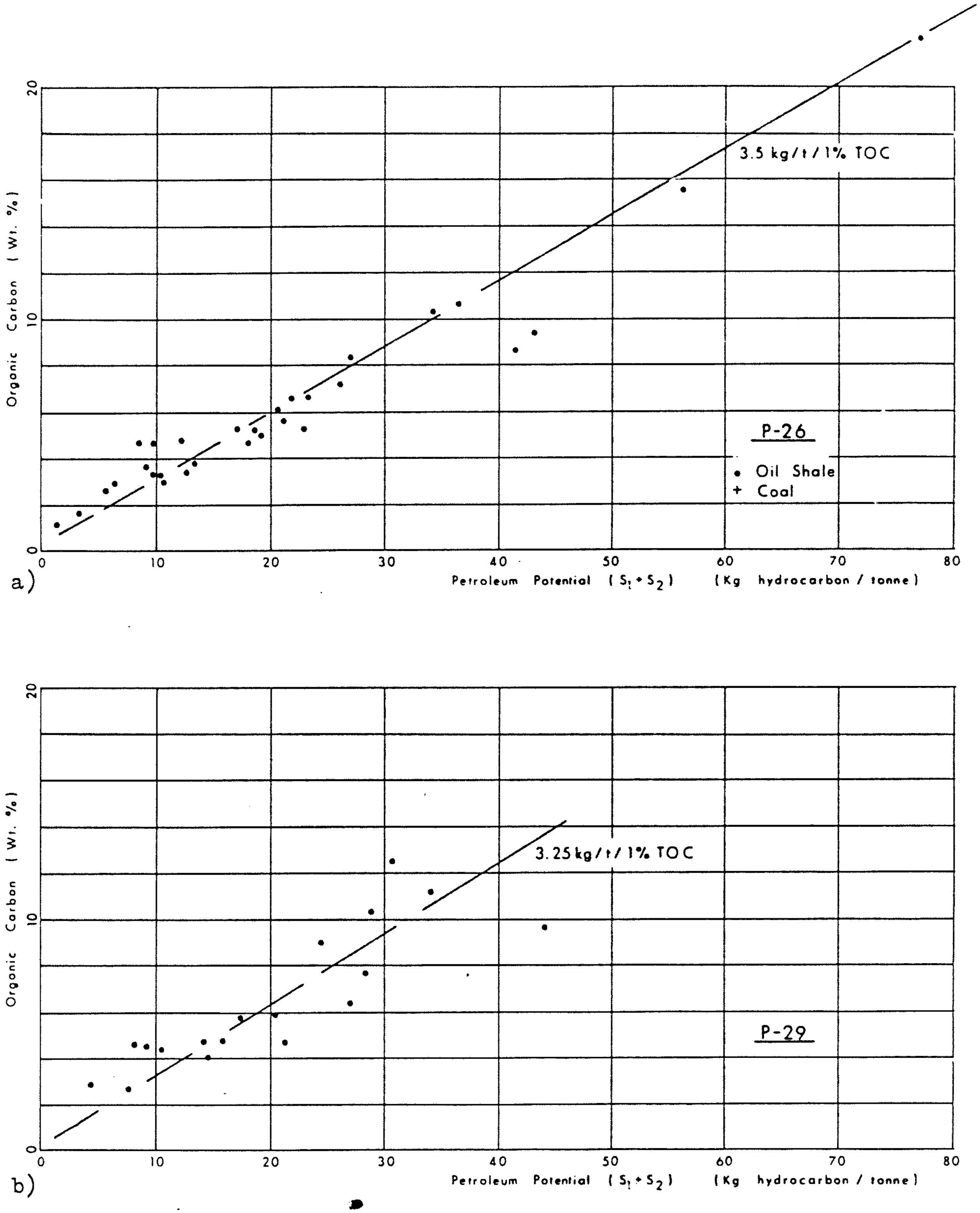
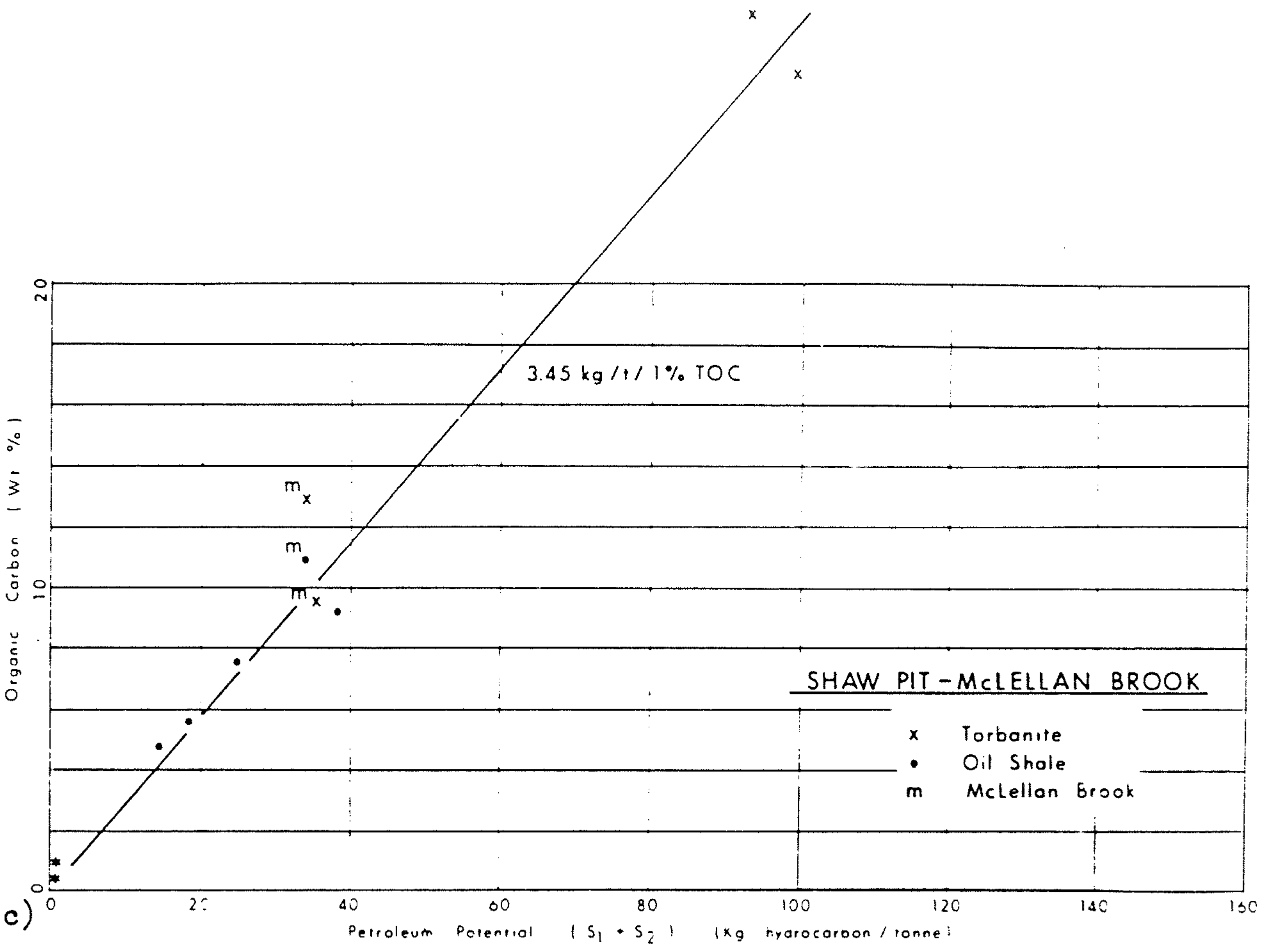


Fig. 13: Comparisons of petroleum potential (yield) to total organic carbon content, Stellarton area; a) Corehole P-26, b) Corehole P-29



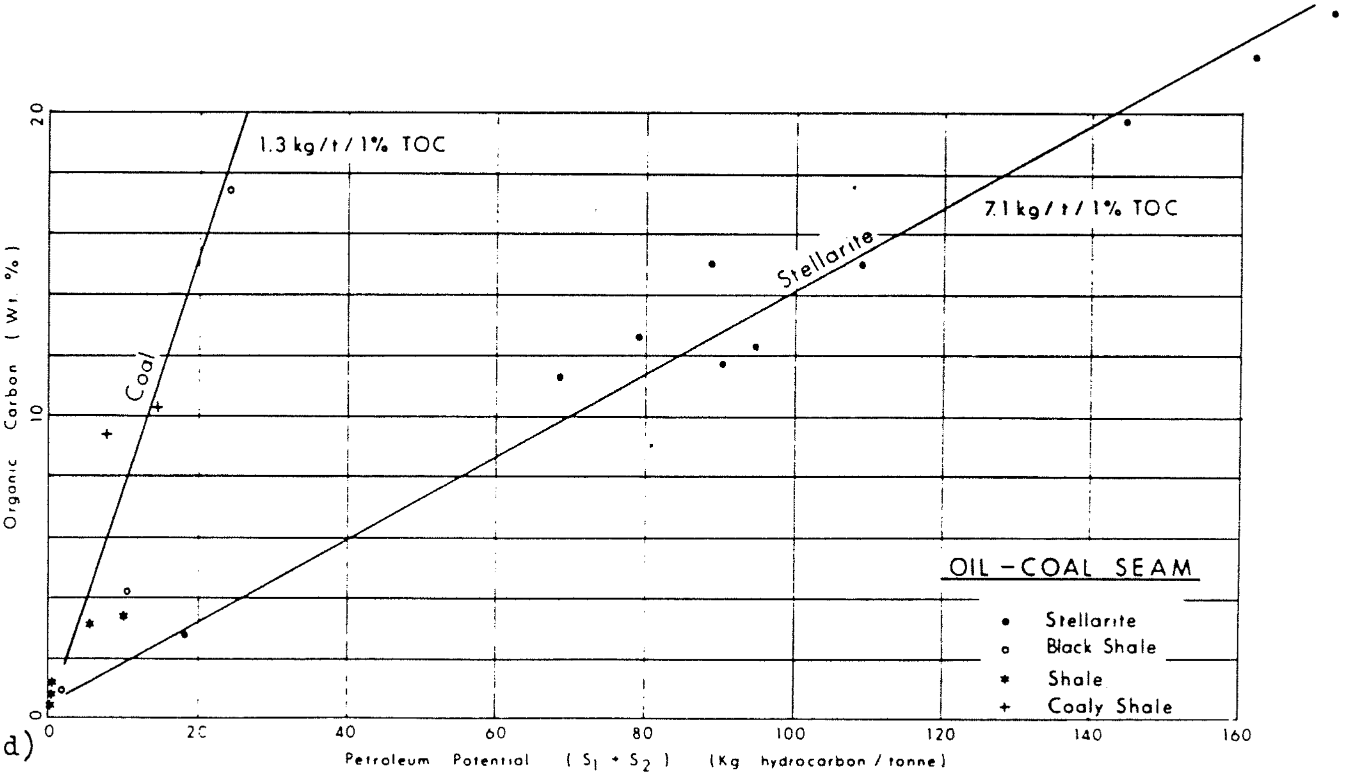


Fig. 13: Comparisons of petroleum potential (yield) to total organic carbon content; c) McLellan Brook and Shaw Pit surface exposures, d) Oil-Coal Seam at coreholes P-20, P-23, P-25 and P-55

greater kerogen variation and/or better yields must be anticipated.

Torbanites are the anticipated variations of the above oil shales, but appear to be few in number and of limited thickness. At Shaw Pit, the torbanites represent only an approximate 1.5 m out of 3 m total oil shale interval. At only 0.25 km from the Shaw Pit, the torbanite beds are barely discernible, if they really are, in the P-26 corehole. Although the organic carbon content of the torbanites is excellent (often greater than 20%), the low yield, 3.5 kg/t/1% TOC, the same as that of the oil shales, would necessitate large rock volumes to provide significant shale oil production.

Wherever coalfield exploratory and development drilling is continued, attempts should be made to search out torbanite beds, in case thicker, geographically more extensive zones are present. The massive character and conchoidal fracture may not be readily apparent in cores, but suspected torbanites may be confirmed by TOC analysis as the initial investigatory technique.

Stellarite beds vary considerably in kerogen quantity as the average carbon increases from 7.5% at the east to over 17.6% at the most westerly of the four coreholes; however, the recovery remains fairly constant near 7 kg/t/1% TOC.

Although How (1868) reported stellarite yields in the range 53 to 129 Imp. gallons/ton (approximately 230 to 730 kg/t), these high yields were not repeated in most subsequent investigations (Ells, 1909, 1910; Wright, 1922; Bell, 1924; Douglas and Campbell, 1941). Recoveries ranged 4 to 50 Imp. gallons/ton (18 to 200 kg/t). In his specific studies of the retorting properties of stellarite and torbanite, Flynn (1926) reported stellarite recoveries covering this entire yield spectrum. The variable kerogen content explains this wide range of hydrocarbon potential.

Macauley (1981, p 100) inferred that the co-presence of stellarite (torbanite) and coal could be a hindrance as the stellarite contained too much ash to be used as a coal resource. From this study, the hydrocarbon yield from the coal beds may be sufficient that the entire Oil-Coal Seam could be retorted for liquid hydrocarbons and gas, and the residue burned for generation of electrical energy. At 0.35% (Flynn, 1926), the sulfur content of the stellarite is low, and the oil quality is fair (0.91 S.G.): the equivalent characteristics of the coal need to be defined for its contribution to a retorting process.

Considerable additional drilling would also be required to define the kerogen quantity distribution of the stellarite and the coal. Coal is virtually absent at the thickest and best stellarite interval in the P-55 corehole (Fig. 13d): only thin coal laminae are there present in the mudstone overlying the stellarite.

Because coring is an expensive technique, the use of density logs in drilled holes for oil shale evaluation is now commonly attempted. Flynn (1926) noted that density/yield relationships could be established for both torbanites and stellarite, but that these relationships were not identical. This is to be expected from the different yield to TOC ratios.

Source Rock Potential

Tmax values indicate some degree of thermal maturation within the oil generation window, a concept confirmed by the coal grades and by the orange-red color of the humic component in this section. The yellow color of the stellarite algal component suggests minimal thermal alteration.

Thermal maturation has been limited to the Type III humic component of the oil shales, torbanites, and the coal and coaly beds: in this case, gas has probably been the prime generated free hydrocarbon rather than oil, which would explain the lack of S_1 component and consequent low PI ratio; however, the hydrocarbon yields on pyrolysis of the coal indicate the coal to be a potential oil source rock.

Type I kerogens require higher temperatures for thermal maturation than those of Type III. Even though Tmax approximates 450°c in the stellarite, there may not have been any significant oil generation from this unit.

ORIGIN

The coals of the Pictou Coalfield are of fairly uniform megascopic composition exhibiting marked vertical uniformity upon petrographic examination (Hacquebard and Donaldson, 1969). The vertical thicknesses of "clean" coal vary greatly over short lateral distances, terminating by lithification as opposed to splitting and digitation. Clean coal is effectively confined to the center of the depositional basin with increasing percentages of clastics towards the margins. Palynological study shows that the vertical distribution of spore florule indicates markedly little variation although, between coal seams, varying proportions of species permit seam separation and identification.

Hacquebard and Donaldson deduced from their investigations that the sediments were deposited in a narrow intermontane lake basin, the center of which essentially coincides with the center of the graben, indicated by the position of the axis of the Albion Syncline. Streams descending from surrounding basin highlands, transporting detrital material onto the peatlands, deposited decreasing quantities of detritus toward the basin center. Sudden, possibly seasonal stream fluctuations, although causing increased clastic sedimentation at the basin margins and transport of fine detrital quartz into the basin center, were not long enough lasting to cause changes in the groundwater level which would have resulted in marked banding in the coal. Intermittent flooding and the resultant turbulence caused a thorough mixing and maceration of the vegetal matter with the result that the coals are classified as hypautochthonous in that they consist of plant debris which has been transported but not beyond their general area of growth. The constancy in vertical distribution of spore florule indicates insufficient ecological changes to cause any alterations in vegetation types. Vertical variations in the proportions of vegetation types through the stratigraphic column suggest complete termination and renewal of plant growth between periods of peatland development.

Deposition of the oil shales and torbanites under similar intermontane lake conditions is probable. The humic material is present in lesser amounts than for coal beds, and more algal (Type I) material was present. These deposits may represent conditions intermediate between the open water deposition of the inorganic shales and the plant overgrown conditions required for coal generation.

Deposition of the stellarite requires a somewhat unique condition whereby a lacustrine body has limited circulation to allow the concentrated algal growth and subsequent preservation, and either lacks adjacent areas of vegetation or has insufficient movement of water into the lake to contaminate the deposit with humic debris.

SUMMARY

The oil shale beds at Big Marsh double in depositional thickness from north to south along the 12.5 km distance of their exposure. Although minor faulting has occurred within the oil shales, structural thickening is not significant. Depositional thickening due to facies change with the overlying coarser grained clastics is thought to be the major cause of this variation.

Organic maturation, indicated by Tmax and the production index, appears to vary. This variation is attributed to admixture of partially mature Type I algal and Type III humic kerogens. An increase in hydrogen indices, related to an increase in TOC and Tmax, occurs between the upper and the lower section of the oil shale bed. A dominance of Type I over Type III kerogen in the lower section would explain the phenomenon. A southerly decrease in hydrocarbon potential reflects a change in kerogen type (decreasing Type I), a slight lessening of kerogen content, and possibly some increase in maturation.

The economic potential of the Big Marsh oil shales is limited. Average yields over any appreciable thickness do not approach the generally accepted minimum of 10 US g/t for economic consideration. The lack of carbonate content precludes their consideration as a sulphur capture agent for co-combustion with high sulphur coals.

The oil shales at Big Marsh, as were those at Albert Mines, were deposited in a local restricted reducing lacustrine environment laterally equivalent to coarse-grained alluvial fan deposits (Rights River Formation). In contrast to the Albert Mines oil shales, those at Big Marsh have a much reduced organic content based upon algal growth, with a corresponding reduction in carbonate content, and increased clastic content, suggesting less restricted water circulation.

In the Pictou Coalfield, liquid hydrocarbons are recoverable from oil shale, torbanite, and stellarite beds and from coal beds with associated coaly shales and black shales. The three oil shale types, oil shale, torbanite and stellarite are black, massive to poorly laminated, sub-fissle and exhibit a brown streak. Stellarite produces excellent hydrocarbon yields and is associated with coal in the Oil-Coal Seam. Torbanite produces yields intermediate to stellarite and oil shales and exhibits massive bedding and conchoidal fracture in contrast to oil shales.

The overlap in the ranges of the total organic carbon content of the three oil shale types negates the use of TOC by itself as a means of differentiating between the types. Ranges of hydrogen indices do, however, offer a means of distinguishing oil shale-torbanite, stellarite and coal; their respective ranges of 260-370, 360-730 and 100-167 mg HC/g org. C are distinct. Interpretations of Tmax, of production indices, and of hydrogen indices, do not necessarily define the degree of thermal maturation. As was noted at Big Marsh, the degree of maturation will vary with the type of organic material present.

The oil shale-torbanites apparently consist of fairly constant relative concentrations of both Type I and Type III kerogens: Type III may predominate. Stellarite is composed essentially of Type I kerogen and the coal beds of Type III kerogen. Carbonaceous plant debris (Type III) is found in at least limited amounts in the bulk of the samples selected. The hydrogen-oxygen ratios indicate that oil shale-torbanite, stellarite and coal are distinct types, and that the oil shales and torbanites are organically identical, varying only in the quantity of kerogen present.

The stellarites and coal of the Oil-Coal Seam produce the highest yields, to a maximum of 172.75 kg/t. Recoveries are fairly constant near 7 kg/t/1% TOC. The hydrocarbon yield from the coal beds may be sufficient to allow the entire Oil-Coal Seam to be retorted for liquid hydrocarbons and gas, with the residue used as a solid fuel for thermal power generation. The sulphur content of the stellarite is low and the shale oil quality is fair. Given similar characteristics for the oil derived from the coal, and suitable distribution of the kerogen quantity, the Oil-Coal Seam may offer some potential for development.

The torbanites, although limited in number and thickness, offer a high (+20%) organic carbon content, tempered however, with low yields (3.5 kg/t/1% TOC). Ongoing drilling should be monitored in order to determine whether more extensive torbanite zones exist: large volumes of material would be required to provide shale oil production.

Gas has probably been the prime free hydrocarbon generated from the thermal maturation of the Type III humic component of the oil shales, torbanites, coal and coaly beds. The Type I algal kerogen of the stellarites exhibits minimal thermal alteration: no significant oil generation has occurred.

The oil shales and torbanites contain less humic material and more algal material than the coal beds. Both oil shale types may represent similar depositional environments, with intermediate to open lacustrine and paludal conditions. The stellarites require a lacustrine environment of limited circulation but with little or no development or deposition of humic material.

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APPENDIX A

X-RAY DIFFRACTION RESULTS

One portion of powdered sample was pelletized on a cellulose substrate and x-rayed with Co$k\alpha$ radiation, iron filter, settings of 40 Kv-20 ma with chart speed at 2 cm/min., 1°/2 cm. A second analysis was made with Cu$k\alpha$ radiation, nickel filter, and the same settings and chart speed.

Semi-quantitative mineral percentage compositions of the inorganic part of the rock were obtained from diffraction peak heights which may vary with degrees of crystallinity, crystal size and with any amorphous material present. These data represent relative approximate concentrations and are not absolute values.

ABBREVIATIONS

Amph:	amphibole
Anh:	anhydrite
Ank:	ankerite
Ap:	apatite
Bar:	baryte
Cal:	calcite
Ch:	chlorite
Dol:	dolomite
F:	feldspar
Gyp:	gypsum
Hun:	huntite
Ill:	illite
Jar:	jarosite
K:	kaolinite
Mag:	maghemite
MLC:	mixed layer/ expandable clays
Qtz:	quartz
Py:	pyrite
Rho:	rhodocrosite
Sid:	siderite
Sph:	sphalerite
tr:	trace

Note: All samples from the coreholes are averaged over a stratigraphic interval for which the depth indicated on the data line is the top of the interval: unless stated otherwise for the specific location, the base is shown on the following line. At Big Marsh coreholes 7, 8 and 9, only the interval top is shown as sampling was discontinuous.

Surface samples from Horton Bluffs, Shaw Pit and McLellan Brook are all spot samples and are approximated for thickness distribution as shown on the Rock-Eval data plot figure 11c.

Depth (ft)	(m)	Ill %	MLC %	K/Ch %	Qtz %	F %	Sid %	Py %	Other %
Big Marsh #4 (5 foot intervals - base not recorded)									
93	28.3	12	8	17	52	4	5	--	Cal 2
113	34.4	11	10	19	53	3	4	--	
133	40.5	11	12	13	54	5	4	1	Ap tr
153	46.6	12	14	18	47	5	--	--	Ank 3, Cal 1
173	52.7	12	10	23	49	5	1	--	
193	58.8	11	12	14	53	6	2	tr	Anh tr, Ank tr
213	64.9	11	11	17	52	9	--	--	
233	71.0	11	9	13	58	5	4	--	
253	77.1	11	10	12	54	6	2	tr	Cal 5
273	83.2	10	15	11	55	6	3	--	Cal tr
293	89.3	13	12	14	54	5	2	--	
Big Marsh #5 (5 foot intervals - base not recorded)									
443	135.0	12	11	16	52	3	6	--	
463	141.1	13	12	15	52	3	5	--	
483	147.2	9	9	16	52	6	3	3	Cal 2
503	153.3	12	11	19	50	3	5	--	
523	159.4	11	15	21	49	--	2	--	Cal 2
543	165.5	11	16	12	46	5	2	1	Cal 5, Ank 2
563	171.6	12	18	18	47	3	2	--	
583	177.7	10	11	13	49	3	8	tr	Hun(?) 4, Ank 2
603	183.8	10	13	12	43	3	9	2	Hun(?) 6, Mag 2
623	189.9	12	15	14	51	4	4	--	
643	196.0	9	11	10	47	4	18	1	
663	202.1	10	9	13	56	3	4	--	Dol 3, Cal 2
683	208.2	11	10	10	63	2	2	--	Cal 2
703	214.3	10	13	13	53	3	4	2	Cal 2
723	220.4	11	13	11	49	3	3	1	Cal 9
743	226.5	8	11	8	69	3	1	--	
763	232.6	12	11	18	50	3	2	--	Cal 4
Big Marsh #7 (5 foot intervals - base not recorded)									
45	13.7	10	13	25	42	3	--	2	Cal 4, Jar 1
70	21.3	11	11	11	50	3	--	3	Cal 5, Ap(?) 4
145	44.2	10	10	33	38	3	--	1	Cal 3, Bar 2
Big Marsh #8 (5 foot intervals - base not recorded)									
45	13.7	12	11	14	51	3	6	--	Sph(?) 3
64	19.5	12	11	15	50	7	5	--	
83	25.3	14	11	14	54	2	5	--	
102	31.1	12	14	14	53	3	4	--	
122	37.2	7	11	9	41	3	17	2	Cal 7, Ank 3
140	42.7	12	14	12	56	4	2	--	
159	48.5	13	17	10	45	4	11	--	
178	54.3	10	13	9	53	5	8	--	Ank 2
196	59.7	11	14	12	56	4	3	--	
219	66.8	12	18	12	44	5	9	--	
239	72.8	10	22	13	43	4	tr	--	Ank 8
258	78.5	14	13	6	54	5	3	2	Cal 3
277	84.4	11	14	11	57	4	3	tr	
297	90.8	14	15	10	51	4	6	tr	

Depth		Ill	MLC	K/Ch	Qtz	F	Sid	Py	Other
(ft)	(m)	%	%	%	%	%	%	%	%
315	96.0	15	15	10	54	4	2	--	
335	102.1	12	15	11	51	4	--	1	Cal 6
353	107.6	7	11	8	52	4	9	4	Cal 5
372	113.4	12	13	10	55	7	3	tr	
391	119.2	10	9	12	52	5	8	--	Cal 4
412	125.6	11	12	14	48	4	5	1	Cal 5
420	128.0	12	14	18	47	4	1	--	Cal 4
Big Marsh #9 (5 foot sample intervals - base not recorded)									
27	8.2	13	14	16	48	6	3	--	Cal tr
102	31.1	9	13	7	44	5	15	tr	Cal 7
174	53.0	14	17	7	53	5	4	--	
237	72.2	10	12	6	58	7	5	tr	Cal 2
320	97.5	11	12	6	49	5	2	2	Cal 8
395	120.4	10	11	11	48	7	8	2	Cal 3
Horton Bluffs - Surface									
Top	Top	17	12	15	48	3	--	--	Cal 3, Dol 2
+45	+13.7	16	5	12	55	3	tr	1	Cal 6, Talc(?) 2
+25	+ 7.6	25	8	16	45	3	1	--	Cal 2
+10	+ 3.0	21	4	13	55	4	1	--	Cal 2
Base	Base	19	tr	13	57	5	2	tr	Cal 4
P-20									
224.0	68.3	17	26	20	29	3	3	--	Ap(?) 2
225.0	68.6								
228.9	69.8	7	19	19	48	--	--	3	Dol 4
229.9	70.1	5	7	30	46	1	6	--	Ap(?) 4, Dol 1
233.0	71.0	7	11	25	40	2	10	2	Ap 2
235.0	71.6								
P-23									
90.4	27.6	15	29	24	25	--	2	2	Hun(?) 3
90.5	27.6								
94.0	28.7	16	20	23	41	--	--	--	
95.0	29.0								
96.7	29.5	8	18	27	47	--	--	--	
97.7	29.8	5	7	41	39	2	1	1	Hun(?) 4
99.2	30.2	9	13	25	33	2	2	6	Cal 10
100.3	30.6	6	11	30	45	3	3	2	
103.0	31.4								
104.5	31.9	10	11	21	54	tr	4	--	
106.0	32.3								
P-25									
289.0	88.1	9	22	25	41	--	--	3	
290.0	88.4								
291.5	88.8	14	19	27	40	--	--	--	
292.7	89.2	6	14	28	43	--	9	--	
295.9	90.2	9	10	30	32	--	2	8	Cal 3, Gyp 3, Rho(?) 2
298.0	90.8								Dol 1

Depth		Ill	MLC	K/Ch	Qtz	F	Sid	Py	Other
(ft)	(m)	%	%	%	%	%	%	%	%
P-26 (5 foot samples, base not always shown, unless otherwise indicated)									
101	30.8	13	15	6	45	2	19	tr	
102	31.1								
104	31.7	14	16	6	52	3	9	tr	
105	32.0	19	15	7	52	3	--	2	
110	33.5	12	13	5	53	4	6	3	Ap(?) 4
115	35.1	14	16	6	57	4	2	1	
120	36.6	14	15	6	62	3	--	--	
125	38.1	15	17	6	54	3	3	2	
130	39.6	20	12	7	46	--	5	3	
135	41.1	21	20	7	39	--	6	2	
137	41.8								
143	43.6	20	19	9	46	tr	3	3	
144	43.9								
150	45.7	18	14	10	53	--	2	--	Rho(?) 3
160	48.8	14	13	9	57	2	5	tr	
170	51.8	15	16	5	47	3	2	2	Rho(?) 3
200	61.0	13	10	6	49	3	3	2	Amph 2, Anh 2
205	62.5	12	11	9	52	4	--	5	Cal 5
210	64.0	16	12	7	54	2	6	--	Ap(?) 3
263	80.2	14	19	8	48	3	3	1	Cal 4
275	83.8	19	13	10	45	4	9	--	
285	86.9	20	23	7	39	4	4	3	
373	113.7	12	14	12	52	3	2	5	
376	114.6								
439	133.8	15	21	11	47	3	1	2	
508	154.8	13	15	9	52	3	4	2	Ap(?) 2
676	206.0	13	19	7	46	4	6	2	Ap(?) 3
750	228.6	14	19	13	46	3	1	2	Hun(?) 2
882	268.8	7	12	14	56	2	3	tr	Cal 6
884	269.4								
840	271.3	10	19	11	41	2	15	2	
1039	316.7	11	15	13	55	2	4	tr	
1245	379.5	13	16	13	50	4	4	--	
1253	381.9	14	14	15	53	--	4	--	
1392	424.3	13	13	23	45	4	2	tr	
1397	425.8	14	22	12	48	--	2	1	
1400	426.7								
P-29 (5 foot sample intervals - base of zone not recorded)									
72	21.9	14	17	4	48	3	3	3	Cal 4, Gyp 2, Ap(?) 2
252	76.8	13	20	11	47	4	2	1	Ap(?) 2
267	81.4	16	20	5	50	3	2	3	Ap(?) 1
304	92.7	16	21	5	48	3	2	1	Ap(?) 1
309	94.2	17	16	5	42	4	3	2	
342	104.2	12	15	8	50	4	3	2	Ap(?) 3
350	106.7	23	15	9	46	3	3	1	
737	224.6	17	28	9	39	--	4	3	
887	270.4	21	30	8	33	4	4	--	
910	277.4	14	23	6	46	2	2	2	Cal 3, Ap(?) 2
931	283.8	13	21	10	45	2	5	1	Ap(?) 2, Gyp 1
1054	321.3	10	17	7	42	2	20	2	

Depth		Ill	MLC	K/Ch	Qtz	F	Sid	Py	Other
(ft)	(m)	%	%	%	%	%	%	%	%
1262	384.7	11	18	10	56	3	2	--	
1484	452.3	13	22	10	46	4	4	1	
P-55									
	242.0 242.1	11	13	19	29	--	25	--	
	244.3 244.4	16	27	24	30	--	--	3	
	245.0	4	tr	25	68	2	--	1	
	245.2	3	tr	10	83	4	--	--	
	245.4	5	tr	28	60	--	7	--	
	245.6	--		31	48	--	21	--	
	246.0	tr	--	29	52	2	11	tr	Rho(?) 6
	246.2 246.5	tr	--	30	48	--	22	--	
	249.0 249.1	7	6	19	64	3	1	--	
Shaw Pit - Surface									
#A		11	16	5	62	4	1	1	
B		16	16	6	46	2	2	2	
C		18	21	8	47	2	3	1	
1		17	27	7	46	3	--	tr	
2		6	11	6	66	3	4	1	Gyp 2, Ap 1
3		12	19	12	47	2	--	2	Gyp 3
4		7	18	6	51	3	2	3	Gyp 6, Bar 1
5		10	19	7	57	3	--	2	
6		12	11	14	62	--	1	--	
McLellan Brook - Surface									
#1		13	8	7	63	5	1	1	Gyp 2
1A		23	11	11	46	6	2	1	
2		25	7	14	47	5	2	--	

APPENDIX B

TOTAL ORGANIC CARBON AND ROCK-EVAL DATA

ABBREVIATIONS

Depth	
ft:	feet
m:	metres
TOC:	Total Organic Carbon measured by weight percent
Tmax:	Maximum temperature of pyrolysis
S_1:	Yield of free hydrocarbons, in milligrams/gram of rock
S_2:	Yield of hydrocarbons from pyrolysis of kerogen and bitumen, in milligrams/gram of rock
S_3:	CO_2 produced by pyrolysis of organic matter, in milligrams/gram of rock
HI:	Hydrogen Index, the ratio of pyrolyzed hydrocarbon recovery (S_2) to percentage organic carbon content
Pet Pot:	Petroleum Potential, total recovered hydrocarbons ($S_1 + S_2$) in milligrams/gram of rock, which is directly equatable to kilograms/tonne (kg/t)
PI:	Production Index, the ratio of free hydrocarbon to total recovered hydrocarbon $(S_1/(S_1 + S_2))$

Note: All samples from the coreholes are averaged over a stratigraphic interval for which the depth indicated on the data line is the top of the interval with the base shown on the next line. At Big Marsh coreholes 7, 8 and 9, only the top of the sampled interval is shown as sampling was not continuous.

Samples from surface exposures at Horton Bluffs, Shaw Pit and McLellan Brook, are all spot samples and are approximated for thickness relationship as shown on data plot figure 11c.

Depth		TOC	Tmax	S_1	S_2	S_3	HI	OI	Pet Pot	PI
(ft)	(m)	%	°C		mg/g				kg/t	
Big Marsh #4										
93	28.3	3.18	434	.41	12.55	14.48	394	455	12.96	.03
98	29.8	5.73	439	.44	21.42	.85	373	14	21.86	.02
103	31.4	3.32	436	.36	13.89	10.97	418	330	14.25	.03
108	32.9	6.73	442	.42	25.71	1.40	382	20	26.13	.02
113	34.4	2.81	434	.37	10.76	11.18	382	397	11.13	.03
118	36.0	2.93	436	.34	11.31	19.34	386	660	11.65	.03
123	37.5	2.65	436	.30	9.68	12.89	365	486	9.98	.03
128	39.0	11.60	451	.67	65.50	3.91	564	33	66.17	.01
133	40.5	6.31	443	.47	30.79	1.27	487	20	31.26	.02
138	42.1	4.19	442	.25	11.47	1.06	273	25	11.72	.02
143	43.6	7.31	446	.45	33.22	3.45	454	47	33.67	.01
148	45.1	5.11	439	.34	18.44	1.23	360	24	18.78	.02
153	46.6	9.46	444	.68	59.49	1.25	628	13	60.17	.01
158	48.2	7.84	447	.52	37.18	4.11	474	52	37.70	.01
163	49.7	3.13	433	.30	11.08	19.84	353	633	11.38	.03
168	51.2	5.12	444	.21	17.37	1.04	339	20	17.58	.01
173	52.7	4.10	444	.26	11.10	.80	270	19	11.36	.02
178	54.3	3.67	437	.41	14.96	11.73	407	319	15.37	.03
183	55.8	4.58	440	.26	11.17	1.69	243	36	11.43	.02
188	57.3	5.82	444	.32	27.05	.93	464	15	27.37	.01
193	58.8	8.80	448	.57	46.22	3.65	525	41	46.79	.01
198	60.4	4.60	444	.21	15.29	.73	332	15	15.50	.01
203	61.9	7.92	445	.63	46.93	.45	593	5	47.56	.01
208	63.4	5.38	443	.45	15.96	.58	296	10	16.41	.03
213	64.9	5.25	439	.39	18.37	.49	349	9	18.76	.02
218	66.4	6.90	447	.46	32.42	3.50	469	50	32.88	.01
223	68.0	3.73	445	.15	11.70	.33	313	8	11.85	.01
228	69.5	3.66	439	.41	10.99	.86	300	23	11.40	.04
233	71.0	4.30	444	.37	11.76	.83	272	19	12.08	.03
238	72.5	7.42	451	.50	34.41	3.61	463	48	34.91	.01
243	74.1	7.56	450	.73	46.14	2.45	610	38	46.87	.02
248	75.6	6.47	447	.69	43.95	.37	679	5	44.64	.02
253	77.1	3.63	445	.39	9.03	4.21	248	115	9.42	.04
258	78.6	3.81	438	.45	11.08	1.08	290	28	11.53	.04
263	80.2	3.20	440	.20	11.90	.98	371	30	12.10	.02
268	81.7	5.86	444	.53	36.19	.51	617	8	36.70	.01
273	83.2	4.18	443	.31	15.36	.87	367	20	15.67	.02
278	84.7	7.81	452	.60	38.78	3.73	496	47	39.38	.02
283	86.3	6.80	449	.51	35.67	5.25	524	77	36.18	.01
288	87.8	7.50	449	.60	36.68	4.93	489	65	37.28	.02
293	89.3	4.64	441	.25	14.50	1.34	312	28	14.75	.02
298	90.8	7.14	448	.53	34.46	4.46	482	62	34.99	.02
303	92.4	5.11	442	.40	17.85	1.33	349	26	18.25	.02
308	93.9	4.61	443	.34	12.42	1.06	269	23	12.76	.03
313	95.4									
Big Marsh #5										
443	135.0	1.35	438	.10	1.91	1.62	141	120	2.01	.05
448	136.6	2.49	441	.16	6.55	1.21	263	48	6.71	.02
453	138.1	3.61	436	.25	15.50	1.25	429	34	15.75	.02
458	139.6	1.63	443	.11	2.80	1.27	171	77	2.91	.04

Depth (ft)	Depth (m)	TOC %	Tmax °C	S_1	S_2 mg/g	S_3	HI	OI	Pet Pot kg/t	PI
463	141.1	3.52	439	.20	13.30	1.42	377	40	13.50	.01
468	142.6	5.68	442	.29	22.91	.56	403	9	23.20	.01
473	144.2	4.39	441	.15	14.32	.67	326	15	14.47	.01
478	195.7	2.59	440	.12	9.29	.69	358	26	9.41	.01
483	147.2	5.67	440	.23	23.20	.56	409	9	23.43	.01
488	198.7	3.43	438	.18	11.56	1.07	337	31	11.74	.02
493	150.3	3.86	440	.19	12.63	.52	327	13	12.82	.01
498	151.8	2.58	437	.16	8.08	1.46	313	56	8.24	.02
503	153.3	5.04	443	.27	15.18	.85	301	16	15.45	.02
508	154.8	3.45	438	.22	11.78	1.73	341	50	12.00	.02
513	156.4	5.91	444	.32	23.18	.64	392	10	23.50	.01
518	157.9	4.05	441	.16	10.79	1.45	266	35	10.95	.01
523	159.4	3.55	439	.27	15.01	.86	422	24	15.28	.02
528	160.9	3.96	443	.22	12.54	.64	316	16	12.76	.02
533	162.5	7.49	451	.30	27.81	3.44	371	45	28.11	.01
538	164.0	3.28	438	.23	10.18	1.17	310	35	10.41	.02
543	165.5	7.31	453	.31	36.17	4.04	494	55	36.48	.01
548	167.0	7.32	452	.22	30.00	4.29	409	58	30.22	.01
553	168.6	3.00	437	.25	12.52	.69	417	23	12.77	.02
558	170.1	4.69	442	.19	15.67	.35	334	7	15.86	.01
563	171.6	5.46	441	.26	18.44	.29	337	5	18.70	.01
568	173.1	8.38	450	.42	35.25	3.66	421	43	35.67	.01
573	174.7	7.38	442	.48	28.10	.51	380	6	28.58	.02
578	176.2	6.26	441	.44	26.95	.41	430	6	27.39	.02
583	177.7	5.95	439	.38	23.37	.54	392	9	23.75	.02
588	179.2	7.15	446	.38	27.42	.50	383	6	27.80	.01
593	180.7	6.19	441	.38	21.55	.58	348	9	21.93	.02
598	182.3	7.51	450	.44	29.13	5.25	387	69	29.57	.01
603	183.8	7.80	450	.37	28.21	5.56	361	71	28.58	.01
608	185.3	7.66	447	.29	27.46	.32	358	4	27.75	.01
613	186.8	8.32	450	.37	34.45	4.76	414	57	24.82	.01
618	188.4	5.33	446	.25	20.77	.45	389	8	21.02	.01
623	189.9	4.79	442	.22	14.57	.50	304	10	14.79	.01
628	191.4	8.67	452	.40	38.02	4.29	438	49	38.42	.01
633	192.9	3.42	439	.21	11.52	1.24	336	36	11.73	.02
638	194.5	5.39	443	.23	24.42	.68	453	11	24.65	.01
643	196.0	5.07	440	.18	17.13	.84	337	16	17.31	.01
648	197.5	6.95	446	.30	28.82	.30	414	4	29.12	.01
653	199.0	2.40	440	.14	7.22	.62	300	25	7.36	.02
658	200.6	6.01	443	.27	29.59	.30	492	4	29.86	.01
663	202.1	7.58	452	.28	34.84	3.29	359	43	35.12	.01
668	203.6	3.76	443	.18	12.79	.31	340	8	12.97	.01
673	205.1	7.21	447	.39	41.66	.51	577	7	42.05	.01
678	206.7	7.30	456	.38	30.99	4.16	424	56	31.37	.01
683	208.2	3.36	444	.19	11.86	.29	352	8	12.05	.02
688	209.7	4.07	445	.22	15.25	.68	374	16	15.47	.01
693	211.2	3.89	450	.25	12.72	.29	326	7	12.97	.02
698	212.8	4.18	450	.25	15.64	.22	374	5	15.89	.02
703	214.3	6.87	453	.33	28.90	4.03	420	58	29.23	.01
708	215.8	5.40	448	.39	29.31	.35	542	6	29.70	.01
713	217.3	7.65	455	.48	41.76	4.75	545	62	42.24	.01
718	218.9	6.49	452	.39	35.08	3.18	540	48	35.47	.01

Depth (ft)	Depth (m)	TOC %	Tmax °C	S_1	S_2 mg/g	S_3	HI	OI	Pet Pot kg/t	PI
723	220.4	3.77	441	.44	12.40	.51	328	13	12.84	.03
728	221.9	2.95	438	.45	13.16	.52	446	17	13.61	.03
733	223.4	5.23	446	.53	20.53	.47	392	8	21.06	.03
738	224.9	4.27	444	.35	15.20	.41	355	9	15.55	.02
743	226.5	3.74	448	.29	11.52	.26	308	6	11.81	.02
748	228.0	8.65	453	.52	48.98	3.13	566	36	49.50	.01
753	229.5	5.67	445	.40	22.61	.44	398	7	23.01	.02
758	231.0	9.13	452	.71	52.13	2.81	570	30	52.84	.01
763	232.6	3.98	445	.28	14.03	.15	352	3	14.31	.02
768	234.1	4.98	447	.40	19.24	.21	386	4	19.64	.02
773	235.6	6.55	449	.55	22.60	.39	345	5	23.15	.02
778	237.1									

Big Marsh #7 (5 foot intervals - base not recorded)

Depth (ft)	Depth (m)	TOC %	Tmax °C	S_1	S_2 mg/g	S_3	HI	OI	Pet Pot kg/t	PI
45	13.7	4.42	446	.45	7.00	.31	159	7	7.45	.06
70	21.3	2.90	435	.33	3.24	.63	111	21	3.57	.09
145	44.2	4.87	449	.53	5.87	.32	122	6	6.40	.08

Big Marsh #8 (5 foot intervals - base not recorded)

Depth (ft)	Depth (m)	TOC %	Tmax °C	S_1	S_2 mg/g	S_3	HI	OI	Pet Pot kg/t	PI
45	13.7	2.92	436	.51	10.29	11.63	352	398	10.80	.05
64	19.5	6.61	441	.60	19.10	1.32	288	19	19.70	.03
83	25.3	2.94	436	.65	10.68	11.39	363	387	11.33	.06
102	31.1	3.83	438	.99	14.30	10.87	373	283	15.29	.06
122	37.2	5.67	441	.53	18.17	1.32	320	23	18.70	.03
140	42.7	4.70	443	.34	14.73	.88	313	18	15.07	.02
159	48.5	4.69	438	.28	10.25	1.61	218	34	10.53	.03
178	54.3	8.71	447	.50	35.01	2.27	401	26	35.51	.01
196	59.7	7.29	443	.48	26.36	1.28	361	17	26.84	.02
219	66.8	3.26	438	.69	8.48	2.57	260	78	9.18	.08
239	72.8	9.42	452	.58	41.56	2.64	441	28	42.14	.01
258	78.5	7.14	445	.43	29.26	1.02	410	14	29.69	.01
277	84.4	5.55	441	.36	14.75	.99	263	17	15.11	.02
297	90.8	3.16	439	.35	11.90	7.87	376	249	12.25	.03
315	96.0	6.21	444	.44	23.74	.72	382	11	24.18	.02
335	102.1	3.63	438	.46	10.34	8.95	284	246	10.80	.04
353	107.6	7.30	442	.38	21.35	1.67	292	22	21.73	.02
372	113.4	7.52	445	.65	28.74	1.15	382	15	29.39	.02
391	119.2	5.97	444	.28	12.20	1.45	204	24	12.48	.02
412	125.6	4.35	447	.37	9.09	.49	208	11	9.46	.04
420	128.0	7.14	446	.79	17.44	1.07	244	14	18.23	.04

Big Marsh #9 (5 foot intervals - base not recorded)

Depth (ft)	Depth (m)	TOC %	Tmax °C	S_1	S_2 mg/g	S_3	HI	OI	Pet Pot kg/t	PI
27	8.2	4.37	438	1.22	10.60	1.40	243	32	11.82	.10
47	14.3	7.12	444	.93	12.35	1.42	173	19	13.28	.07
65	19.8	2.36	425	.87	6.31	9.30	267	394	7.18	.12
86	26.2	3.44	432	.96	9.21	12.23	268	355	10.20	.09
102	31.1	8.16	442	1.17	19.17	1.26	234	15	20.34	.06
121	36.9	6.18	448	.89	11.68	1.00	188	16	12.57	.07
140	42.7	4.56	431	1.03	11.83	9.74	259	213	12.86	.08
158	48.2	7.04	437	.97	11.84	1.85	168	26	12.81	.08
174	53.0	3.22	431	1.02	7.46	9.06	231	281	8.48	.12
185	56.4	3.18	436	1.39	6.41	12.99	201	408	7.80	.18

Depth (ft)	(m)	TOC %	Tmax °C	S_1	S_2 mg/g	S_3	HI	OI	Pet Pot kg/t	PI	
201	61.3	5.16	434	1.30	12.70	9.62	246	186	14.00	.09	
219	66.8	1.55	431	.69	2.84	6.56	183	423	3.53	.02	
237	72.2	7.42	447	1.38	13.69	1.18	184	15	15.70	.09	
265	80.8	6.00	436	1.69	13.74	1.14	229	19	15.43	.11	
284	86.6	3.28	433	1.86	8.40	14.27	256	435	10.26	.18	
303	92.4	6.92	439	2.33	17.33	1.31	250	18	19.66	.12	
320	97.5	5.58	444	2.47	11.38	1.32	203	23	13.85	.18	
340	103.6	4.75	443	1.94	10.00	1.37	210	28	11.94	.16	
358	109.1	5.32	440	2.01	12.67	1.40	238	26	14.68	.14	
376	114.6	5.22	432	2.32	15.83	10.30	303	197	18.15	.13	
395	120.4	5.44	432	2.17	14.32	8.07	263	148	16.49	.13	
412	125.6	4.83	435	1.11	13.12	8.82	271	182	14.28	.09	
432	131.7	4.58	437	1.11	7.01	7.49	153	163	8.12	.14	
Horton Bluffs - Surface											
Top	Top	.42	486	.01	.28	.03	66	7	.29	.03	
+45	+13.7	.46	495	.02	.38	.13	82	28	.40	.05	
+25	+ 7.6	.43	342	.01	.01	.01	2	2	.02	.50	
+10	+ 3.0	.50	361	.01	.01	.06	2	12	.02	.50	
Base	Base	.47	481	.02	.36	.23	76	48	.38	.05	
P-20											
224.0	68.3	7.30	442	.69	7.64	.26	104	3	8.33	.08	Coaly Sh
225.0	68.6										
228.9	69.8	54.60	450	4.54	91.94	10.12	168	18	96.48	.05	Coal
229.9	70.1	11.42	453	.58	68.73	6.68	601	51	69.31	.01	OS
233.0	71.0	3.38	446	.42	9.98	.38	295	11	10.40	.04	Sh
235.0	71.6										
P-23											
90.4	27.5	.94	440	.05	.47	.84	50	89	.52	.10	Sh
90.5	27.6										
94.0	28.7	15.80	444	1.64	20.29	.52	128	3	21.93	.07	Blk Sh
95.0	29.0										
96.7	29.5	53.14	453	6.11	107.58	10.84	202	20	113.69	.05	Coal
97.7	29.8	15.06	453	.44	88.83	4.98	589	33	89.27	.01	OS
99.2	30.2	3.06	440	.46	7.97	.33	260	10	8.43	.05	OS
100.3	30.6	4.27	440	.49	9.86	.33	230	7	10.35	.05	Blk Sh
103.0	31.4										
104.5	31.9	.69	451	.04	.21	.11	30	15	.25	.16	Sh
106.0	32.3										
P-25											
289.0	88.1	17.53	446	1.42	22.36	.36	127	2	24.30	.08	Blk Sh
290.0	88.4										
291.5	88.8	45.10	443	7.70	93.48	1.64	207	3	101.18	.08	Coal
292.7	89.2	12.52	452	.80	78.99	.97	630	7	79.79	.01	OS
295.9	90.2	3.12	440	.35	5.89	.42	188	13	6.24	.06	Sh
298.0	90.8										

Depth (ft)	(m)	TOC %	Tmax °C	S_1	S_2 mg/g	S_3	HI	OI	Pet Pot kg/t	PI	
P-26	(5 foot samples unless otherwise indicated)										
101	30.8	3.06	439	1.00	9.64	1.43	315	46	10.64	.09	
102	31.1										
104	31.7	3.30	437	1.18	8.60	.95	260	28	9.78	.12	
105	32.0	5.50	449	1.36	17.26	1.02	313	29	18.02	.07	
110	33.5	6.64	448	2.87	20.41	2.17	307	32	23.28	.12	
115	35.1	5.21	446	1.48	17.90	1.19	343	22	19.38	.08	
120	36.6	5.27	445	1.89	21.19	1.26	402	23	23.08	.08	
125	38.1	9.48	455	2.87	40.22	3.75	424	39	43.09	.07	
130	39.6	7.18	446	2.07	24.12	1.39	335	19	26.19	.08	
135	41.1	8.50	454	2.28	39.33	6.63	462	78	41.61	.05	
137	41.8										
143	43.6	.99	440	.16	1.45	.73	146	73	1.61	.10	
144	43.9										
150	45.7	4.61	451	1.10	17.03	.96	369	20	18.13	.06	
160	48.8	3.45	447	.81	12.08	1.10	350	31	12.89	.06	
170	51.8	6.73	449	1.87	20.06	1.73	298	25	21.93	.09	
200	61.0	15.77	454	2.48	54.19	5.50	343	34	56.67	.04	Torb
205	62.5	10.26	452	1.50	32.77	6.24	319	60	34.27	.04	Torb
210	64.0	3.38	440	1.01	9.30	.81	275	23	10.31	.10	
263	80.2	4.71	448	1.00	11.25	.87	238	18	12.25	.08	
275	83.8	1.68	442	.35	3.29	.89	195	52	3.64	.10	
285	86.9	8.21	444	1.86	25.21	.96	307	11	27.07	.07	
373	113.7	22.10	444	7.64	69.54	1.48	314	6	77.18	.10	
376	114.6										
439	133.8	5.48	444	1.29	15.98	1.16	291	21	17.27	.07	
508	154.8	5.67	445	1.25	19.93	.94	351	16	21.18	.06	
676	206.0	3.96	440	1.61	11.56	1.05	291	26	13.17	.12	
750	228.6	6.11	450	1.69	18.72	1.07	306	17	20.41	.08	
882	268.9	10.59	448	2.32	34.67	1.17	327	11	36.99	.06	
884	269.4										
890	271.3	10.79	443	1.62	16.18	1.57	152	15	17.78	.09	
1039	316.7	3.00	447	.84	5.85	.78	195	26	6.69	.13	
1245	379.5	3.78	452	1.27	7.93	.62	209	16	9.20	.14	
1253	381.9	2.51	449	.86	4.57	.58	182	23	5.43	.16	
1392	424.3	4.69	455	1.18	7.94	.94	169	20	9.12	.12	
1397	425.8	27.64	457	5.46	42.51	.74	153	2	47.97	.11	Coal
1400	426.7										
P-29											
72	21.9	7.81	443	1.43	26.90	.66	344	8	28.33	.05	
252	76.8	6.35	450	1.16	26.07	1.16	410	18	27.23	.04	
267	81.4	9.80	452	1.99	43.42	6.94	443	70	45.41	.04	
304	92.7	8.81	450	1.61	22.93	.77	263	8	24.54	.07	
309	94.2	4.47	444	.86	10.09	.60	225	13	10.95	.08	
342	104.2	10.22	452	1.83	27.18	6.20	265	60	29.01	.06	
350	106.7	4.00	443	.89	13.78	.29	344	7	14.67	.06	
737	224.6	11.28	448	3.92	30.62	4.82	271	42	34.54	.11	
887	270.4	2.75	442	.76	7.16	.53	260	19	7.92	.10	
910	277.4	5.95	449	1.60	17.47	.64	293	11	19.07	.09	
931	283.8	4.67	449	1.39	16.02	.87	342	18	17.41	.08	

Depth (ft)	(m)	TOC %	Tmax °C	S_1	S_2 mg/g	S_3	HI	OI	Pet Pot kg/t	PI	
1054	321.3	12.52	441	4.15	26.69	.92	213	7	30.84	.13	
1262	384.7	2.81	446	.97	3.94	.58	140	20	4.91	.20	
1484	452.3	4.41	448	.96	7.79	.75	176	17	8.75	.11	
P-55											
	242.0 242.1	1.06	451	.00	.62	2.59	58	244	.62	.00	Blk Sh
	244.3 244.4	10.20	440	.25	14.46	.84	141	8	14.71	.02	Coaly Sh
	245.0	16.72	452	.92	109.03	.60	652	3	109.95	.01	OS
	245.2	12.15	456	.50	94.66	.66	779	5	95.16	.01	OS
	245.4	11.81	452	.57	90.83	.83	769	7	91.40	.01	OS
	245.6	21.75	455	.79	161.09	1.62	740	7	161.88	.01	OS
	246.0	23.51	455	.97	171.78	1.39	730	5	172.75	.01	OS
	246.2 246.5	19.72	451	.94	144.25	1.13	731	5	145.19	.01	OS
	249.0 249.1	.30	523	.00	.19	.24	63	80	.19	.00	Sh
Shaw Pit - Surface											
#A		7.73	439	2.50	22.66	.58	293	7	25.16	.10	OS
B		4.71	441	1.37	13.39	.52	284	11	14.76	.09	OS
C		.91	439	.09	.83	.47	91	51	.92	.10	Sh
1		5.88	444	.75	17.74	.81	301	13	18.49	.04	OS
2		26.80	450	4.00	92.94	8.75	346	32	96.94	.04	Torb
3		10.47	444	.67	35.08	.93	335	9	35.75	.02	OS
4		28.71	446	7.96	85.03	9.77	296	34	92.99	.09	Torb
5		9.11	445	1.73	17.32	.81	190	8	19.05	.09	OS
6		.28	443	.00	.02	.21	7	75	.02	.00	Sh
McLellan Brook - Surface											
#1		9.98	448	1.71	32.31	.90	323	9	34.02	.05	Torb
1A		10.91	444	1.32	32.34	.72	296	6	33.66	.04	OS
2		12.67	439	1.67	31.99	.61	252	4	33.66	.05	Torb