MOBIL

YORK HARBOUR-LARK HARBOUR-LITTLE PORT

WATER WELLS 1, 2 & 3

Final Report

Prepared By: K.W. Ullyott
D.R. Rae

Date: 97-03-26

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GENERAL

3.2 Introduction

Mobil Oil Canada Properties drilled three stratigraphic wells in the York Harbour, Lark Harbour and Little Port area approximately 30 km west of Corner Brook, Newfoundland. A map showing the location of the wells is attached. The primary purpose of the wells was to gain geological information by obtaining cutting samples of the rock structure, not to determine the presence of a hydrocarbon reservoir. The wells were drilled using a water well drilling rig owned and operated by D. A. Construction. The first well was drilled at York Harbour to a depth of 50.3 m, where drilling progress was stopped due to unstable wellbore conditions. This well has been converted into a domestic use water well. The second well was drilled in Lark Harbour to a depth of 123 m, and has been abandoned. The third and last well was drilled in Little Port to a depth of 152 m, and was also abandoned.

3.3 Map

The locations of the three stratigraphic test are shown in Figure 1.

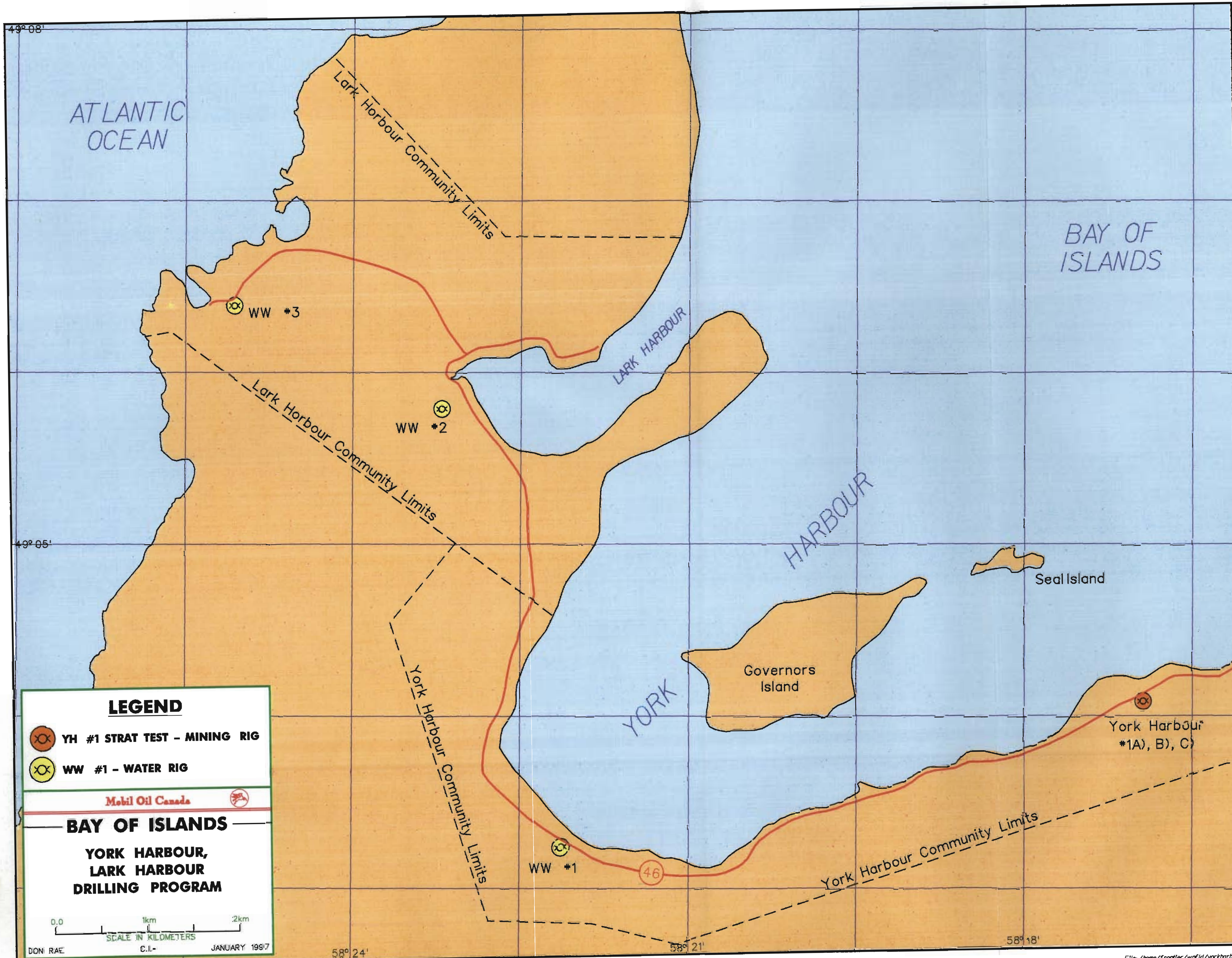
3.4 General Information

Exploration Permit: -- 96-113
Exploration License: # 96-103-02-ED

	Wellbore Coordinates	Using NAD 27	
Well Name:	WW1	WW2	WW3
General Location	York Harbour	Lark Harbour	Little Port
Northing:	5434145	5438801	5439996
Easting:	399926	398605	396468

3.5 Operations Report

The major difficulty encountered in drilling these wells was hole instability. The water well drilling unit used compressed air, with some water, as a circulating fluid. When unconsolidated formations were encountered, the wellbore walls would slough into the hole. This was particularly a problem from zones that would flow water, as the light hydrostatic pressure in the wellbore created a pressure differential from the flowing zone, and the water influx furthered the wellbore caving condition. Although the capability to drill with water had been programmed, and this rig had been selected based on this capability, when the project started it was determined that the basic equipment was present, but that several days worth of modifications and repairs would have been required to make it functional and allow drilling without air. The liquid pumping equipment on the rig had not been used for a considerable length of time, and essential parts had been disconnected and/or removed. The depth objective of 150 m was not



49° 08'
49° 05'
58° 24'
58° 21'
58° 18'
ATLANTIC OCEAN
BAY OF ISLANDS
LARK HARBOUR
YORK HARBOUR
Lark Harbour Community Limits
Lark Horbour Community Limits
York Harbour Community Limits
WW #3
WW #2
WW #1
46
Seal Island
Governors Island
York Harbour #1A), B), C)
LEGEND
YH #1 STRAT TEST - MINING RIG
WW #1 - WATER RIG
Mobil Oil Canada
BAY OF ISLANDS
YORK HARBOUR, LARK HARBOUR DRILLING PROGRAM
0.0
1km
2km
SCALE IN KILOMETERS
DON RAE
C.I.-
JANUARY 1997

FIGURE 1

achieved on the first two wells due to poor hole conditions, and it is thought that wellbore instability would have been significantly reduced if a full hydrostatic head could have been maintained while drilling.

4. Drilling Operations

Well Location	York Harbour	Lark Harbour	Little Port
4.1 G. L. Elevation:			
4.2 Total Depth:	50.3 m	123.4 m	152 m
4.3 Spud Date:	96-12-02 12:00	96-12-06 08:00	96-12-14 08:00
4.4 Drilling Completed:	96-12-9	96-12-19	97-01-05
4.5 Rig Release:	96-12-10	96-12-19	97-01-06
4.6 Well Status:	Domestic water well	Abandoned	Abandoned
4.7 Hole Sizes & Depths:	200 mm to 25.9 m 156 mm to 50.3 m	200mm to 56 m 156 mm to 123 m	200mm to 25.9m 156mm to 152m
4.8 Casing	203 mm to 25.9 m 168 mm to 28 m	168 mm to 56.4 m driven to refusal	203 mm to 25.9 m 168 mm to 36.6 m
Cementing	168 mm cemented with 0.75 m^3, 1800 kg/m^3 with 2% $CaCl_2$	168 mm cemented with 1.0 m^3, 1800 kg/m^3 w/ 2% $CaCl_2$. No returns.	168mm cemented w/ 2.5 m^3 of redi-mix grout.Casing full.
4.9 Drilling Fluid	Air and water mist	Air and water mist	Air and water mist
4.14 Abandonment/ Suspension Plugs	Wellbore filled from TD to 15 m with crushed rock for domestic water well	Emptied hole using air pumped 4 m^3 redi-mix grout from surface, hole full. Cut and capped 1 m below ground elevation.	Pumped 1.0m^3 of 1800 kg/m^3 on top of 36 m fish. Felt plug at 91.4 m. Set 2nd 1.0 m^3 plug from 88 m to 27 m. Plug was 1800 kg/m^3 cement plug with LCM. Set 3rd plug , 0.5 m^3, from 27 m to surface. All cement plugscontained 2% $CaCl_2$. Cut and capped 1 m below ground elevation.

4.10 Fluid Disposal

A closed circulating system was not used on any of the wells drilled with the water well drilling unit. Return fluid was simply fresh water with rock cuttings, and the liquid was allowed to run off. Shallow ditches were used to divert fluid to favourable locations.

4.11 Fishing Operations

An attempt to obtain a short core at TD was made on the Little Port well, using a Bowen junk basket equipped with a core catcher. The drillstring became stuck in the hole and could not be pulled. The fish that was left in the hole consisted of the junk basket, bit sub and six joints of drillpipe, which are each 6.1 m in length for a total of 38 m.

4.12 Formation Flow Tests

none conducted

4.13 Well Kicks

No kicks occurred, and there was no indication of gas influx from the formations.

5. GEOLOGY

5.1 Drill Cuttings

Three wells were attempted: WW1; WW2 and WW3 as per figure 1. The first well, WW1, was drilled to a total depth of 150 feet (45.7 m.), where excessive caving of sand precluded reaching bedrock. Consequently chip samples were not recovered for WW1.

In most cases samples for WW2 (Lark Harbour) and WW3 (Little Port) were taken approximately every 10 feet (3.048meters). The rig used 30-foot drill rods - three samples were taken per rod or every 10 feet.

5.2 Cores

Core was not recovered from any of the water wells.

5.3 Lithology

Lithological descriptions for each of the wells are provided in Appendix I.The data is summarized pictorially in Figures 3, 4 and 5.

Details of shows as determined by: 1) staining, 2) cut in tetrachloroethylene or 3) fluorescence are provided with the lithological descriptions. Zones of better fluorescence, cut and stain are also summarized as appropriate in Figures 3, 4 and 5.

5.4 Stratigraphic Column

Omnichron and Asssociates report that the WW2 well encountered mid to late Cambrian and Tremadoc - aged shales and that the amorphous organic matter was similar to the Green Point source rock. This would imply a Cook's Brook to Upper Irishtown lithology.

WW3 is reported to have encountered Early Cambrian (not earliest Cambrian) -aged shales. Omnichron reports that the non-diagnostic assemblage suggests a top Forteau Formation to March Point equivalent age. This would imply a mid to Upper Irishtown lithology.

The structural/stratigraphic position of these formations are given in the stratigraphic column in Figure .

5.5 Biostratigraphic Data

Biostratigraphic studies by Omnichron Associates of St. John's, as mentioned above, indicate an Early Cambrian to Tremadoc age for the samples recovered from WW2 and WW3 - ie. Irishtown to Cook's Brook.

Locations of the biostratigraphic samples and a summary of their findings are shown pictorially for WW2 and WW3 in Figures 4 and 5, respectively. A copy of Omnichron's report is presented in Appendix II.

6. OTHER

6.1 Core Photos

none

6.5 Core Analysis

none

6.6 Fluid Analysis Reports

See following section (6.7).

6.7 Oil, Gas and Water Analysis Reports

Water was recovered from WW1 and WW3 and sent to Chemex Labs in Calgary for analysis. The results appear in Appendix III.

WW1 had been allowed time to clean up before sampling and the water is of good quality. WW3 encountered salt water. We drilled a second well solely for the purposes of encountering water for the land owner. This second well was drilled to 175' depth several feet from the original WW3 location. A sample of water from this well was taken very shortly after reaching TD (175') and is not of good quality. Another sample will be taken once the well has been allowed to flow to clean up.

6.8 Geochemical Report

Geochemical studies of selected intervals in WW2 and WW3 were undertaken by Mobil's Dallas Lab. The anlyses include: TOC, Hydrogen Index and T_{max} These data are presented in appendix IV and summarized in Figures 4 and 5. Maturation studies were also undertaken by Omnichron and are included in their report in Appendix II and summarized in Figures 4 and 5.

6.9 Biostratigraphy Report

Chip samples from selected intervals in WW2 and WW3 were submitted to Omnichron Associates for age and maturity determinations. Results are summarized in section 4.5 above and in Appendix II and Figures 4 and 5.

6.10 Petrological Report

none

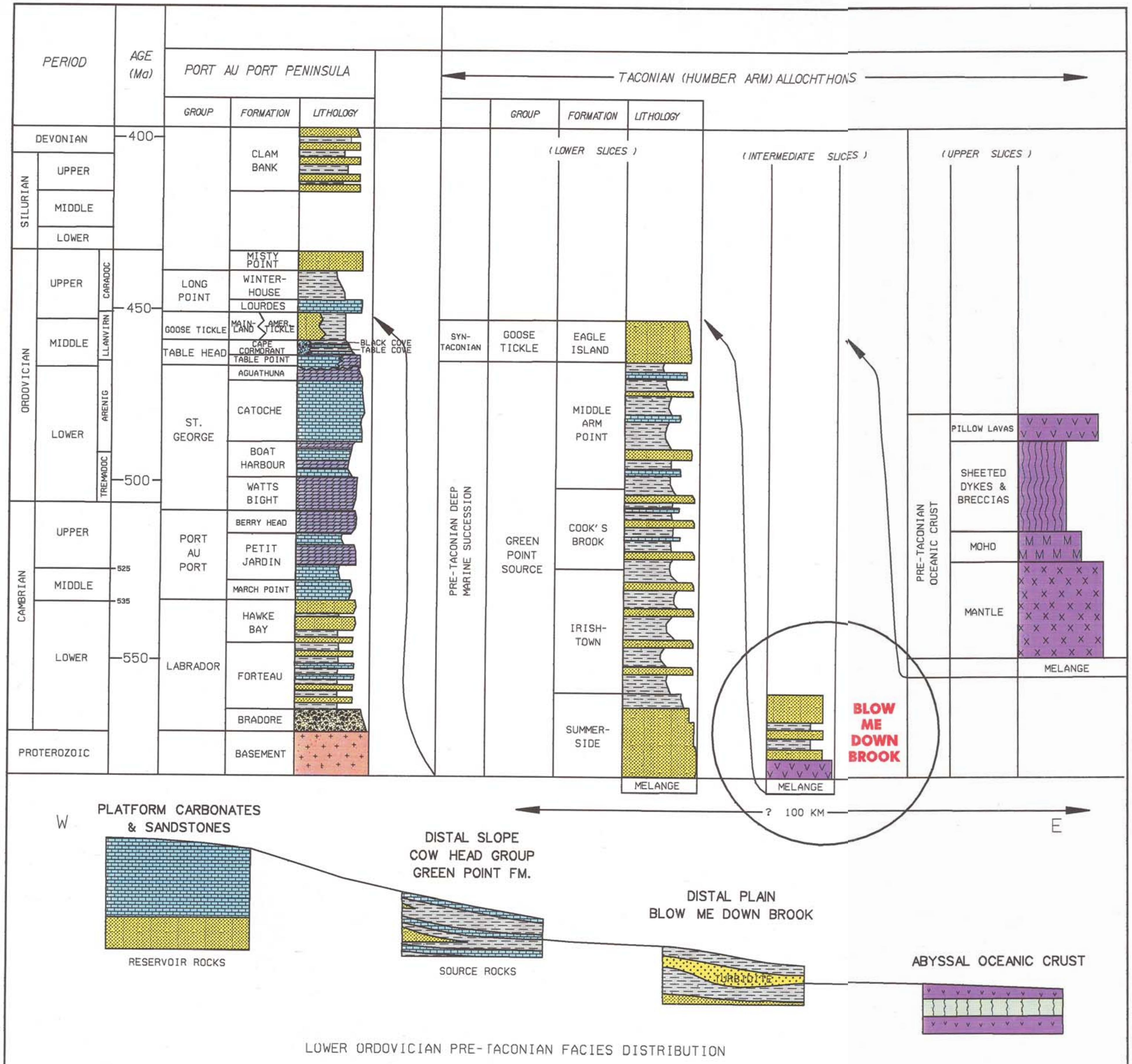
6.11 Palynological Report

See section 6.9

6.12 Paleontological Report

See section 6.9

WEST NEWFOUNDLAND STRATIGRAPHIC COLUMN



(Modified from Fowler, Knight et al, 1995)

FILE NAME: /HOME/FRONTIER/WNFLD/STRAT3CHART.DGN

FIGURE 3

Appendix I

Lithological Descriptions

MOBIL OIL CANADA PROPERTIES

Well Name: WATER WELL - WW1
Spud: Dec. 2, 1996 **Completed:** Dec. 10, 1996
GPS Coordinates: 399926 ; 5434145 (NAD 27)
Logged By: No Bedrock Samples Recovered

Depth Interval	Sample Description
8" CASING	• to 70' (21.34m.) depth
6" CASING	• to 92' (28.04m.) depth • sand/gravel/mud to T.D. (150' (45.72m.) • drilled ahead to 150' (45.72m.) - hole washing out excessively; had to abandon • no bedrock encountered

COMPLETED AS A WATER WELL FOR
MR. HAROLD LEE

MOBIL OIL CANADA PROPERTIES

Well Name: WATER WELL - WW2
Spud: Dec. 5, 1996 **Completed:** Dec. 19, 1996
GPS Coordinates: 398605 ; 5438801. (NAD 27)
Logged By: D. Rae

Depth Interval	Sample Description
190' (57.91m)- 200' (60.96m)	• 60% pale green slightly micaceous soft **shale** • 35% waxy brown to chocolate brown **shale** (grades to black in places) • 2-3% fine grain greyish **sandstone** no visible porosity, moderately hard (indurated) - slightly calcareous • 2% calcite/quartz fluorescent veining generally in chocolate brown **shale** trace oil stain colour; most appear to be calcite (vigorous fizz) • CUT- slow lazy cut on a few chips
200' (60.96m)- 210' (64.0m)	• As 190'-200' • trace bitumen coating few quartz crystals - very lazy cut? • fluorescence ~2% calcite (vigorous fizz)
210' (64.0m)- 220' (67.06m)	• 70% pale grn **shale** slightly micaceous locally pyritic (few % pyrite) ; trace fine grain siltstone • 30% choc brown to black **shale** - pale brown in places, soft waxy with minor Py; 2% fluorescent calcite; 1 grain calcite showed a definite slow streaming cut
220' (67.06m)- 230' (70.10m)	• As 210'-220' • few calcite grains with pale brown stain and slow lazy cut • 1-2% fluorescent calcite
230' (70.10m)- 240' (73.15m)	• As 210'-220' • ~2% fluorescent calcite; definite oil **stain** on several grains; few showed a slow, bright yellowish white blooming cut in tetrachloroethylene

- 40-50% light to dark grey **shale**, often with black speckles, or interlaminated - occasional piece plastic
- 1-2% calcite - ≤1% rusty grains - calcite?
- ≤1% dull yellow fluorescence CUT - fast stream

300' (91.44m)- 310' (94.49m)	• 95-95% dk gry to black **shale**, 10-20% laminated - 1-2% py • 2-5% light grey **shale** with black laminations • 1-3% blue-grey-green-black speckles & laminations • ≤1% pyrite rare pieces of plastic • ≤1% dull yellow fluorescence - CUT - moderately heavy stream
310' (94.49m)- 320' (97.54m)	• 90-95% dark grey to black **shale** - friable? - mildly calcareous • laminated fine grain pyrite in black **shale** - 2-4% • 2-5% light grey **shale**, often with black shale laminations or coatings • 1-3% greenish **shale**, with black speckles • <<1% dull yellow fluorescence - No Cut • <1% calcite
320' (97.54m)- 330' (100.58m)	• 80-90% medium to dark grey **shale**, interlaminated, mottled & slightly friable, and mixed with lighter grey - 1-2% pyrite cubes • 10-20% light grey to greenish grey, with black laminations & veins (≤1mm thick) • ≤1% calcite, often rusty • <<1% dull yellow fluorescence - CUT - slow, light, stream
330' (100.58m)- 340' (103.63m)	• 85-95% medium to dark grey **shale**, with thin laminations or fragments of green - dark grey **shale** often finely laminated, ≤1% pyrite • 5-15% light grey to greenish grey **shale** with wisps or laminations of dark grey **shale** • ≤1% calcite • <1% pale yellow fluorescence CUT - slow to moderate light stream
340' (103.63m)- 350' (106.68m)	• 60-70% dark grey to black **shale**, laminated to massive, the latter may contain fragments of green **shale** - disseminated pyrite 1-2%

- 30-40% light grey **shale** - flat, well cleaned chips, often laminated
- 1-3% small green chips ≤1% calcite, some shale chips slightly calcareous
- less than 5% of chips >1cm, usually black chips
- trace Fluorescence, dull yellow, no cut

350' (106.68m)- 360' (109.73m)

- 50-60% dark grey to black **shale**, more massive, less laminated
- 35-45% light to medium grey **shale;** flat chips, some laminated
- 3-5% greenish grey **shale** with black coating, veins? often brecciated textures
- 1-2% disseminated pyrite, ≤1% calcite, some grey chips mildly calcite
- trace Florescence

360' (109.73m)- 370' (112.78m)

- as above - ≤5% of chips ≤1cm in size
- ≤1% chips have Fluorescence, mostly pale yellow, some white - CUT - slow, lazy, very light stream

370' (112.78m)- 380' (115.82m)

- 5-10% of chips ≥1 cm
- 40-50% dark grey to black **shale**, some silty chips, massive to irregular textured, with green fragments of shale, black 'veins'
- 45-55% medium grey & greenish grey, - over half are flat-sided chips, planar laminated, black 'veins' (lines)
- 3-5% green chips, half of which have black lines/veins, and a brecciated/broken 'look'
- ≤1% calcite ≤1% pyrite
- ≤1% chips show Fluorescence - No Cut

380' (115.82m)- 390' (118.87m)

- 30-40% dark grey **shale**, as above
- 40-50% medium to greenish grey **shale**, with silty laminations occasionally
- planar laminated to massive, black coatings and 'veins'
- 10-20% blue-grey-green **shale;** approximately 50% have shiny black veins - sometimes broken/brecciated texture
- ≤1% calcite, ≤1% pyrite, trace shredded plastic
- ≤1% fluorescence, dull yellow, some white, NO CUT

MOBIL OIL CANADA PROPERTIES

Well Name: WATER WELL - WW3
Spud: Dec. 13, 1996 **Completed:** Jan. 4, 1997
GPS Coordinates: 396468 ; 5439996 (NAD 27)
Logged By: D. Rae & Jamie Meyer

Depth Interval	Sample Description
85' (25,91m)- 95' (28.96M)	• FIRST SAMPLE OF BEDROCK • 99% grey to dark grey **shale**, soft, micaceous • occasional to rare slickensided surfaces, slightly silty, noncalcareous; trace fine grain pyrite • no fluorescence, no cut; ≤1% quartz • very fine grained (<1mm) black specks • carbonaceous (graphite?) material within the shale; faintly bedded with micaceous sheen [While drilling a black scumy substance floated on surface of the return water - very greasy feel (no cut, no fluorescence) (i.e. likely graphite liberated by drilling)]
95' (28.96m)- 105' (32.0m)	• As 85'-95' - same scumy return carbonaceous material 4-5% of rock
105' (32,0m)- 115' (35.05m)	• 5% grey graphitic **shale** as 85'-95' - local slickensides; 4-5% graphite? in grey shale • 95% brick red to dark reddish brown **shale**, very micaceous (sericitic); firm to hard • slightly silty; slippery surface on micaceous sheen; faintly bedded; • December 16, 1996 - Cementing in diverter system.

LOGGED BY: Jamie Meyer

Depth Interval	Sample Description
115' (35.05m)- 125' (38.10m)	• as above, reddish brown **shale**, 2-4% chips ≥1cm • trace calcite

125' (38.10m)- 135' (41.15m)	• sample appears to be 100% reddish brown **shale**, but reddish brown water 'masks' fragments - cleaned samples reveal 10-30%? greyish red brown chips; mica (±quartz?) cleavage surfaces dominate - "hard" chips, not silty • chips much smaller 2mm - 5mm, <3% ≥1cm • trace calcite - no fluorescence
135' (41.15m) 145' (44.20m)	• very "dirty" sample, chips are mixed with a light grey clay, and everything is coated with reddish brown "dirty" water - tried resieving • approximately 60% reddish brown chips, some of these are greyish and mica-rich; very little shaley cleavage in any fragments, they are mostly subrounded - slightly silty • approximately 40% grey-blue green, subrounded chips, a hard micaceous look - small percentage with black "fragments/flakes" • trace quartz and calcite No Fluorescence
145' (44.20m)- 155' (47.24m)	• exactly as above, in both samples, only ~5% ≥1cm
155' (47.24m)- 165' (50.29m)	• 80% blue-grey-green **shale** - 20% of chips >1cm • no shaley cleavage, black fragments/flakes/laminations in 50% of chips • sparkly appearance, often interlaminated with greyish red • ~15% reddish grey, 10% >1cm, sparkly appearance • ~5% reddish brown chips; more shaley cleavage • ~1-2% quartz No Fluorescence
165' (50.29m)- 175' (53.34m)	• 50% blue-grey green, 5-10% >1cm, ~25% with black fragments, both 1-2mm size, and 0.1mm speckle - poor shaley cleavage • ~25% reddish grey chips - 5-10% >1cm - sparkly look, recrystallized mica (sericite), quartz, chlorite? (soft) - non shaley cleavage • ~ 25% reddish brown, slightly shaley, mica flakes visible on fresh break (random orientation) • ≤1% quartz, trace red feldspar, No Fluorescence
185' (56.39m)- 195' (59.44m)	• ~85% red brown **shale**, 10-15% of chips ≤1cm, micaceous partings, but not many flat chips (shaley cleavage)

	• ~10% blue-grey green - black 'fragments', graptolitic forms and very fine black speckle • ~5% reddish grey with fine grain black speckle and shiney cleavage faces; ≤1% quartz; No Fluorescence
195' (59.44m)- 205' (62.48m)	• ~60% grey green **shale** - very fine grain black fleck, 5-10% with black fragments or discontinuous laminations - slightly shaley cleavage - few purple mottles/bands • ~40% reddish brown **shale** - sparkly appearance, slightly shaley cleavage • ~15-20% chips > 1cm, mostly green • ~trace red feldspar - trace calcite << 1% quartz • no fluorescence
205' (62.48m)- 215' (65.53m)	• ~95% red brown **shale** - 5-10% >1cm - sparkles on broken surfaces, poor shaley cleavage • ~5% blue-grey-green-black fragments, discontinuous irregular laminations, 1-2% quartz, trace rusty fragments, trace calcite/dolomite (mildly calcareous)
215' (65.53m)- 225' (68.58m)	• ~85% red brown **shale**, 5% >1cm, poor shaley cleavage, sericitic sheen, grey green mottling occasionally • ~15% grey-green **shale** - approx half of chips have a black 'speckle', few have black fragments? and/or discontinuous laminations • 1-2% quartz (white, translucent, yellow) • No Fluorescence
225' (68.58m)- 235' (71.63m)	• ~97% reddish brown **shale**, 1-3% of chips ≥1cm sericitic sheen on broken surfaces, poor shaley cleavage • ~3% greyish green **shale** • 1-2% calcite (veins) trace quartz vein material, rounded? • No Fluorescence
235' (71.63m)- 245' (74.68m)	• reddish brown **shale**, as above; 5-10% chips ≥1cm • trace green interlaminations, no visible calcite/quartz • No Fluorescence
245' (74.68m)- 255' (77.24m)	• reddish brown **shale** as above • calcite veins ≤1% No Fluorescence

255' (77.24m)- 265' (80.77m)	• reddish brown **shale** with 1-3% greenish interlaminations • otherwise as above - No Fluorescence
265' (80.77m)- 275' (83.82m)	• reddish brown **shale** with 1-2% greenish interlaminations • a 1cm chip of brownish white mudstone/siltstone with black fragments (<.1mm) and rounded quartz grains (fine grain) • otherwise as above - No Fluorescence
275' (83.82m)- 285' (86.87m)	• reddish brown **shale**, with 1-3% of chips ≥1cm • poor shaley cleavage; silvery grey "sheen" on 10% of chips surfaces; otherwise irregular break and sparkly appearance (due to sericite) • ~1% calcite veins - No Fluorescence
285' (86.87m)- 295' (89.92m)	• >95% reddish brown **shale**, as above <5% blue-grey green and black/green chips - the latter has disseminated pyrite & may be very black 'coating'? on green chips • ≤1% calcite veins • trace white fluorescence, & dull yellow, CUT - slow tiny stream
295' (89.92m)- 305' (92.96m)	• ~95% reddish brown **shale** as above • ~5% light greenish grey and dark grey **shale**, the latter is often laminated, black lamination, very thin & discontinuous • no fluorescence
305' (92.96m)- 315' (96.01m)	• >95% reddish brown **shale** as above • <5% light greenish grey, few black laminations • trace pyrite - trace white Fluorescence, no cut
315' (96.01m)- 325' (99.06m)	• >97% reddish brown **shale** as before • <3% light greenish grey **shale** • 1-3% of chips ≥1cm - no fluorescence
325' (99.06m)- 335' (102.11m)	• reddish brown **shale** with 1-2% green grey interlaminations/"mottles" • broken surfaces are mostly irregular with a "micaceous" sparkle • 5-10% of surfaces smooth, curvi-planar, silver red-grey sheen • poor shaley cleavage - trace calcite veining • No Fluorescence 1-3% of chips ≥1cm

335' (102.11m)- 345' (105.16m)
- as above reddish brown **shale**

345' (105.16m)- 355' (108.20m)
- reddish brown **shale** as above - 2-4% greenish grey interlaminates and light grey chips - few very thin green black irregular veins (<0.5m thick) - trace calcareous chips
- No Fluorescence

355' (108.20m)- 365' (111.25m)
- reddish brown **shale** as above - 2-4% greenish grey interlaminated beds with trace pyrite cubes -similar very thin green black irregular veins, in red **shale** - no fluorescence

(355' - 395')
NOTE: Next 4 samples were collected using plastic motor oil container - potential for slight contamination??

365' (111.25m)- 375' (114.30m)
- reddish brown **shale** as above - 1-2% greenish grey interlaminates, no pyrite visible - non-calcareous - no Fluorescence
- ~5% of chips ≥1cm

375' (114.30m)- 385' (117.35m)
- reddish brown **shale** as above - 3-5% greenish grey interlaminates, up to 5mm and with smaller black laminations/coatings
- 1-2% calcite
- No Fluorescence

385' (117.35m)- 395' (120.40m)
- reddish brown **shale** with 1-3% green to grey interlaminates, chips and mottles - micaceous sparkle in red shale, poor shaley cleavage, 1-2% calcite veins
- No Fluorescence

395' (120.40m)- 405' (123.44m)
- reddish brown **shale** as above; 2-5% greenish grey chips as above - No Fluorescence

405' (123.44m)- 415' (126.49m)
- reddish brown **shale** as above; trace quartz, 1-3% greenish grey chips - No Fluorescence

415' (126.49m)- 425' (129.54m)	• reddish brown **shale** as above, No Fluorescence
425' (129.54m)- 435' (132.59m)	• reddish brown **shale** as above; 2-4% greenish grey interlaminated **shale** chips; trace of calcite neining in green chips; calcite associated Fluorescence, dull yellow; CUT is thick, fast heavy stream (possible contamination from plastic oil container)
435' (132.59m)- 445' (135.64m)	• reddish brown **shale** as above; several black/green veinlets when broken open show sheared surfaces with pyritic shean Fluorescence in trace amounts associated with calcite
445' (135.64m)- 455' (138.68m)	• reddish brown **shale** as above; 1-3% green to grey chips probably as thin interlaminated beds; several gry fragments with thin black veinlets; No Fluorescence
455' (138.68m)- 465' (141.73m)	• reddish brown **shale** with 1-2% green to grey laminated chips; micaceous sparkle with silver grey sheen in red shale trace quartz veinlet material, No Fluorescence
465' (141.73m)- 475' (144.78m)	• reddish brown **shale** as above; No Fluorescence
475' (144.78m)- 490' (149.35m)	• reddish brown **shale** as above; No Fluorescence
490' (149.35m)-	• **END OF HOLE**

Appendix II

Biostratigraphy

AGE AND THERMAL MATURITY OF SHALLOW BOREHOLE SAMPLES FROM THE YORK HARBOUR AREA OF WESTERN NEWFOUNDLAND

A REPORT TO MOBIL OIL CANADA PROPERTIES

by Omnichron Associates
Elliott T. Burden and S. Henry Williams

March 1997

REGISTERED PROFESSIONAL GEOSCIENTIST
DR. S. HENRY WILLIAMS
SIGNATURE
11 March 97
DATE
PROVINCE OF NEWFOUNDLAND

CONTENTS

EXECUTIVE SUMMARY

Shallow boreholes from the York Harbour area of western Newfoundland were sampled for acritarchs and other organic matter to assess the age and thermal maturation properties of strata lying immediately below the Bay of Islands ophiolite complex.

Many samples are highly degraded and blackened with few if any palynomorphs recovered. Other samples contain relatively abundant and diagnostic assemblages showing Early Cambrian ages for boreholes WW3 and York Harbour 1C, and Mid to Late Cambrian and Tremadoc? ages for borehole WW2. The younger strata sampled from borehole WW2 are apparently rich in organic matter, and thermal maturation values lie within the oil window. Older strata from WW3 and York Harbour 1C contain less organic debris and lie at the bottom of the oil window.

Using Long Point M-16 as a model for burial from thrusting and therein stacking allochthonous structural slices, the thermal properties of the shallow boreholes at York Harbour correspond with depths of more than 5,000', but probably less than 8,000' (1,500 - 2,450m) in the M-16 well. Given the variety of maturation models presented for the M-16 well, there may still be significant thicknesses of potentially productive source rock lying below the ophiolite in this area. In addition, if the allochthon beneath the ophiolite is thin and in a complexly faulted structural relationship with the autochthon, prospective traps may be present.

BOREHOLE ANALYSES

Samples collected from boreholes spudded in strata lying immediately beneath the Bay of Islands ophiolite complex at York Harbour provide some of the first stratigraphic and paleontologic evidence for age and thermal properties of the allochthon in this area. Previous workers have relied on the infrequent occurrence of macrofossils in Cambrian strata or conodonts and graptolites in rocks of Ordovician age. Acritarchs, when relatively abundant and well preserved, provide substantial evidence for local and regional biostratigraphic correlation. This may be used to reconstruct the Laurentian shelf and slope, or in determining possible source rocks and thermal maturation histories.

In total, 20 samples were examined from three shallow boreholes from the York Harbour region. Two assemblages of fossils are present in these boreholes. They are identified from species composition and compared with previously reported outcrop material. In addition, these assemblages have distinctive fluorescence properties, implying subtly different thermal histories.

Borehole WW2 contains relatively rich fossil assemblages, numbering as many as 71,538 grains/g, and suggestive of source rock material nearby. Species are not particularly diverse, but they do contain large leiofusid acritarchs (including a lunate form cf. *Lunulidinium* sp.), a variety of acanthomorphs (eg. *Baltisphaeridium* sp.), and algal clusters and filaments (Plate 1). Fossil assemblages apparently share some taxa with sample M-102 from nearby outcrop. Age (not particularly diagnostic from this assemblage) is suggested to lie within the mid and late Cambrian or possibly Tremadoc; correlation is with the top of the Labrador Group and the Port au Port Group.

Thermal maturation properties for WW2 are surprisingly low, given the proximity of the ophiolite complex. Statistically, all of the samples fluoresce dull brown in colour; some fossils still show amber fluorescence (Plate 2). In addition to fluorescence, the Acritarch Alteration Index varies from 2.3 - amber to 2.6 - red. These values indicate that these rocks still lie within the oil window. For comparative purposes, the AAI for WW2 corresponds with AAI values found at 5,000' - 6,000' (1,500m - 1,800m) in the Long Point M-16 well. Given that the thermal history for that well is regionally representative of the allochthon, the base of the oil window at York Harbour might yet lie several thousand feet (perhaps a 1000m or more) beneath the ophiolite. Depending on the thickness of the allochthon in this region, some interesting prospects for light oil and gas might still be available.

Boreholes WW3 and York Harbour 1C contain similar assemblages of fossils. Species include *Acrum* sp., *Comasphaeridium* sp., *Fimbriaglomerella* sp., *Micrhystridium* sp., *Retisphaeridium* sp., and *Skiagia* sp. (Plates 3 and 4). This species assemblage occurs in Early and early Middle Cambrian strata including the upper Forteau Formation and the March Point Formation.

The Acritarch Alteration Index for these rocks is no lower than 2.8 - brown and there is little or no fluorescence. For the M-16 well, this corresponds with the interval from at least 6,000' to perhaps as much as 8,000' (1,800m - 2,450m). These maturation values are approximately the same as those seen for correlative Forteau and March Point strata on the Port au Port Peninsula, near Kippens, and on the Northern Peninsula at sample site M-168. For petroleum prospectivity, these samples are labelled "Mature borderline overmature" and "Overmature". Given the variety of thermal maturation history models presented for the M-16 well, the boreholes WW3 and York Harbour 1C are considered to lie at or near the base of the oil window.

The coincidence of widely spaced Lower Cambrian strata containing the same thermal signature is, in my opinion an important observation which might have significance for understanding the timing for assembly of the allochthon and for the prospectivity of the entire region.

PLATE 1

Slide reference corresponds with borehole, depth, and preparation number. Grid co-ordinates taken on a Zeiss Photomicroscope III.

All figures x 1250 unless otherwise indicated.

1. *Baltisphaeridium* sp. A. WW-2; 190-250m; 1/2; 13.8, 106.9.
2. *Baltisphaeridium* sp. B. WW-2; 190-250m; 1/2; 15.0, 95.8.
3. *Baltisphaeridium* cerinum WW-2; 190-250m; 1/2; 16.0, 99.5.
4. *Lophosphaeridium* sp. (verrucate) WW-2; 190-250m; 1/2; 19.0, 92.3.
5. *Leiofusa* sp. WW-2; 190-250m; 1/2; 16.0, 89.2, x300.
6. cf. *Lunulidinium*? sp. WW-2; 190-250m; 1/2; 18.0, 101.3; x300.
7. *Leiosphaerida* sp. (large folded variety) WW-2; 340-350m; 1/2; 10.0, 91.2.
8. Spherical fecal pellet WW-2; 190-250m; 1/2; 14.0, 108.6; x300.
9. Elongate fecal pellet WW-2; 190-250m; 1/2; 14.8, 98.0.
10. Ellipsoidal fecal pellet WW-2; 190-250m; 1/2; 15.0, 93.5.

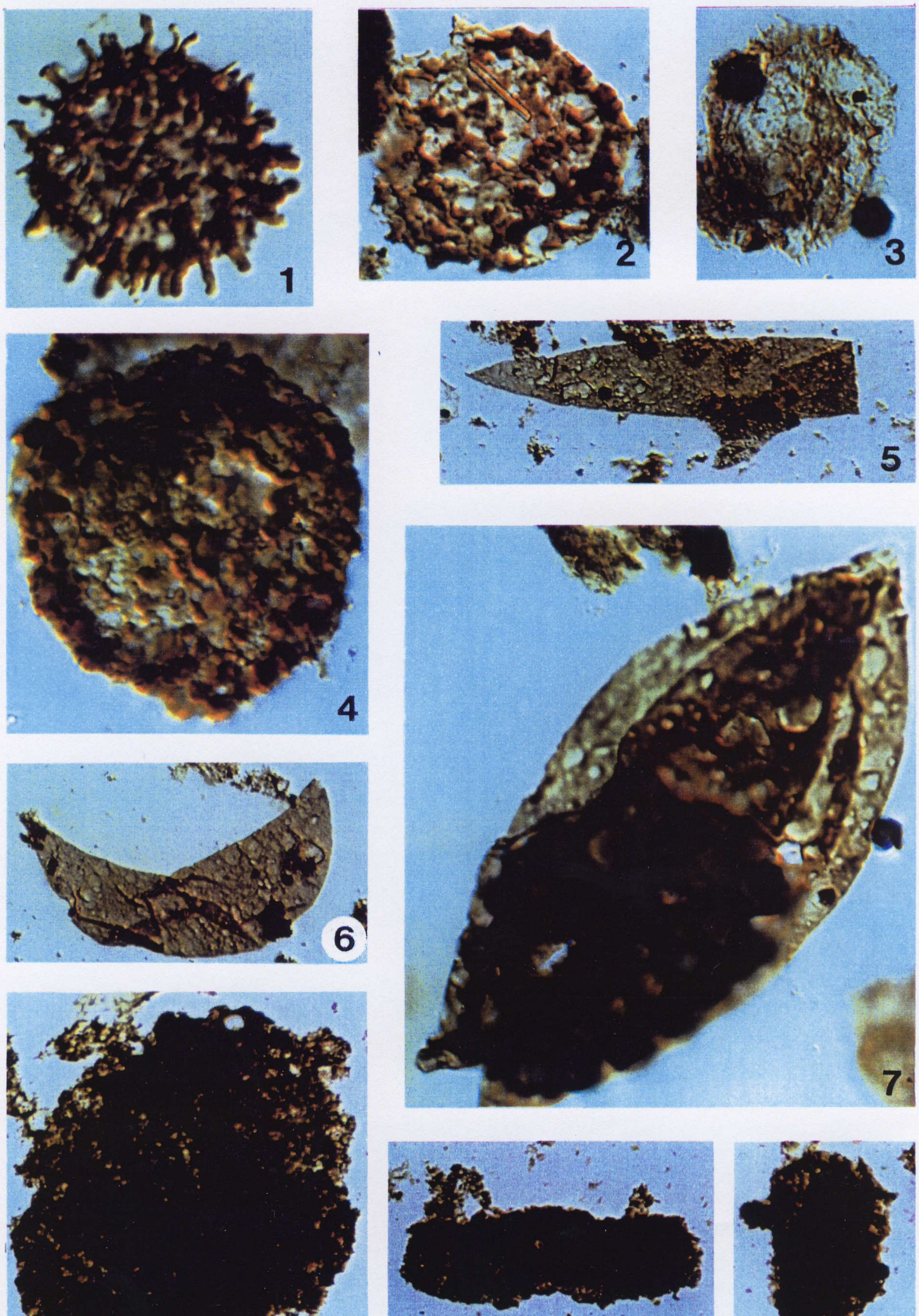

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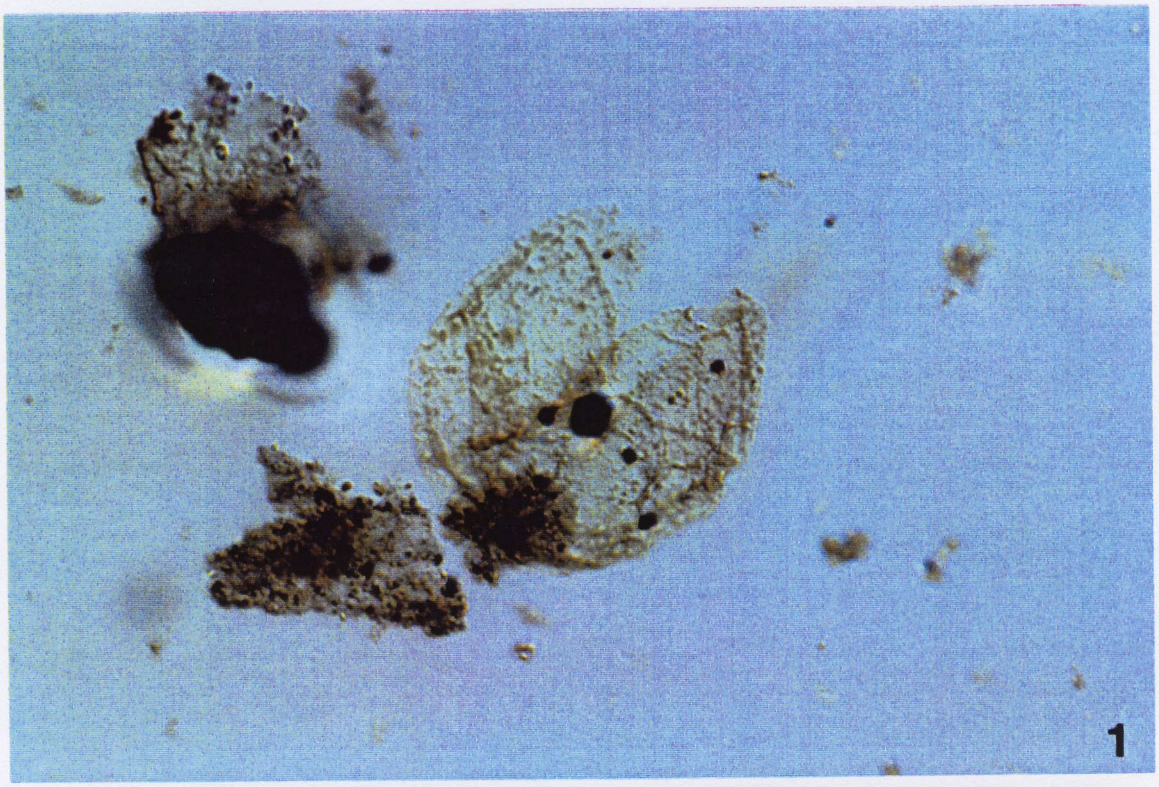
PLATE 2

Slide reference corresponds with borehole, depth, and preparation number. Grid co-ordinates taken on a Zeiss Photomicroscope III.

All figures x 1250 unless otherwise indicated.

1. *Lophosphaeridium* sp. (granular) WW-2; 190-250m; 10.0, 81.5 (Interference Contrast)

2. *Lophosphaeridium* sp. (granular) WW-2; 190-250m; 10.0, 81.5 (Amber Fluorescence).



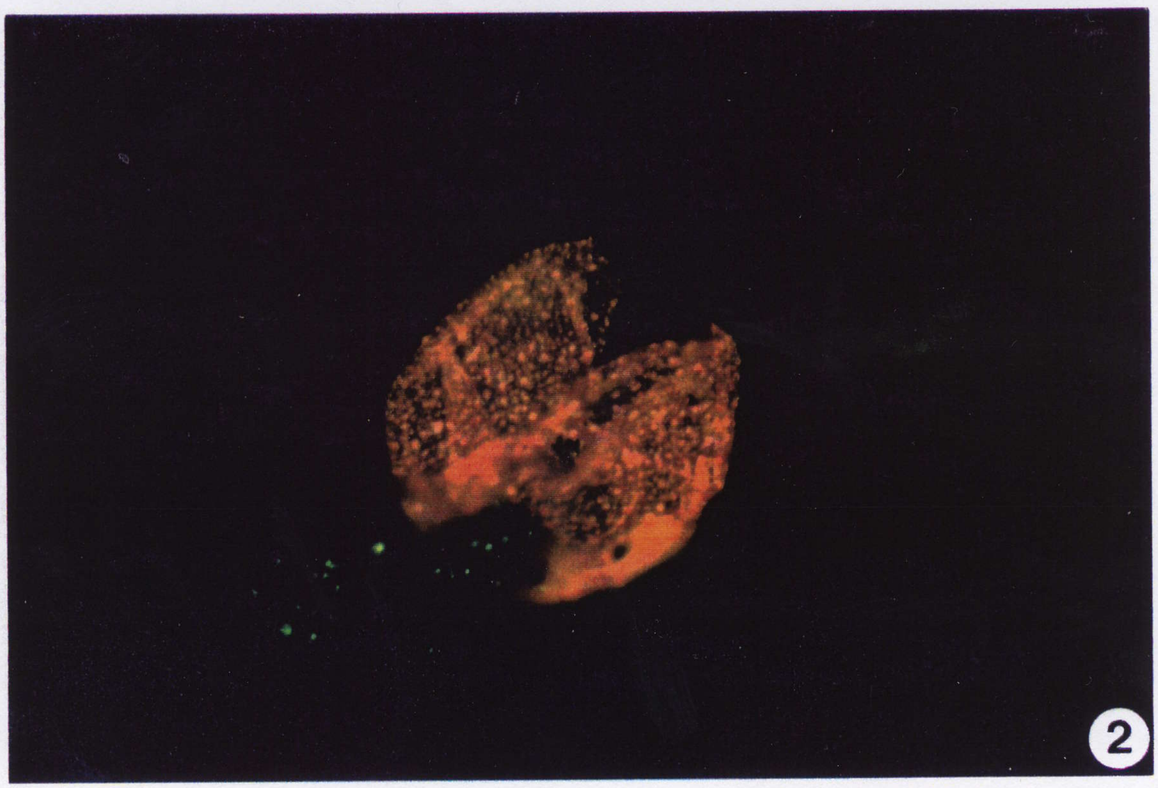


PLATE 3

Slide reference corresponds with borehole, depth, and preparation number. Grid co-ordinates taken on a Zeiss Photomicroscope III.

All figures x 1250 unless otherwise indicated.

1. *Skiagia ornata* 96-SH-3; 268.7-268.9m; 7.2, 108.4.

2. *Skiagia ciliosa* 96-SH-3; 268.7-268.9m; 9.1, 78.4.

3. *Baltisphaeridium cerinum* 96-SH-2; 264.1-264.2m; 7.0, 86.4.

4. *Micrhystridium ordensis* 96-SH-3; 268.7-268.9m; 16.0, 99.1; x1,900.

5. *Estiastra minima* 96-SH-3; 268.7-268.9m; 14.0, 108.8.

6. *Comasphaeridium* sp. of M-193a 96-SH-3; 268.7-268.9m; 16.1, 82.9.

7. cf. *Leiosphaeridium* sp. B of M-100 96-SH-3; 268.7-268.9m; 18.0, 84.5.

8. very large *Leiosphaeridium* sp. (granular) 96-SH-2; 264.1-264.2m; 13.5, 100.3.

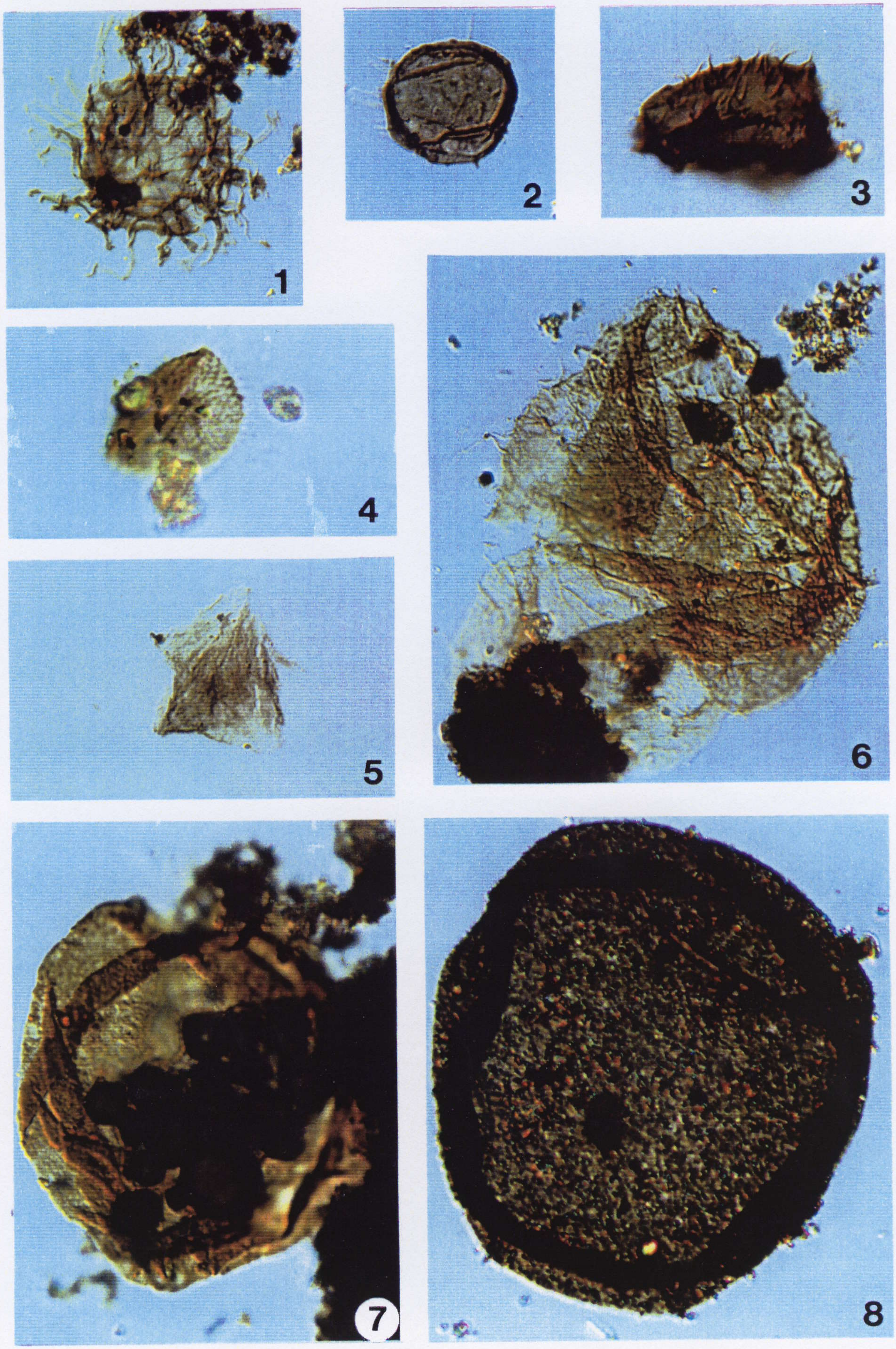

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PLATE 4

Slide reference corresponds with borehole, depth, and preparation number. Grid co-ordinates taken on a Zeiss Photomicroscope III.

All figures x 1250 unless otherwise indicated.

1. *Retisphaeridium dichamerum* WW-3; 85-95m; 7.0, 108.3.

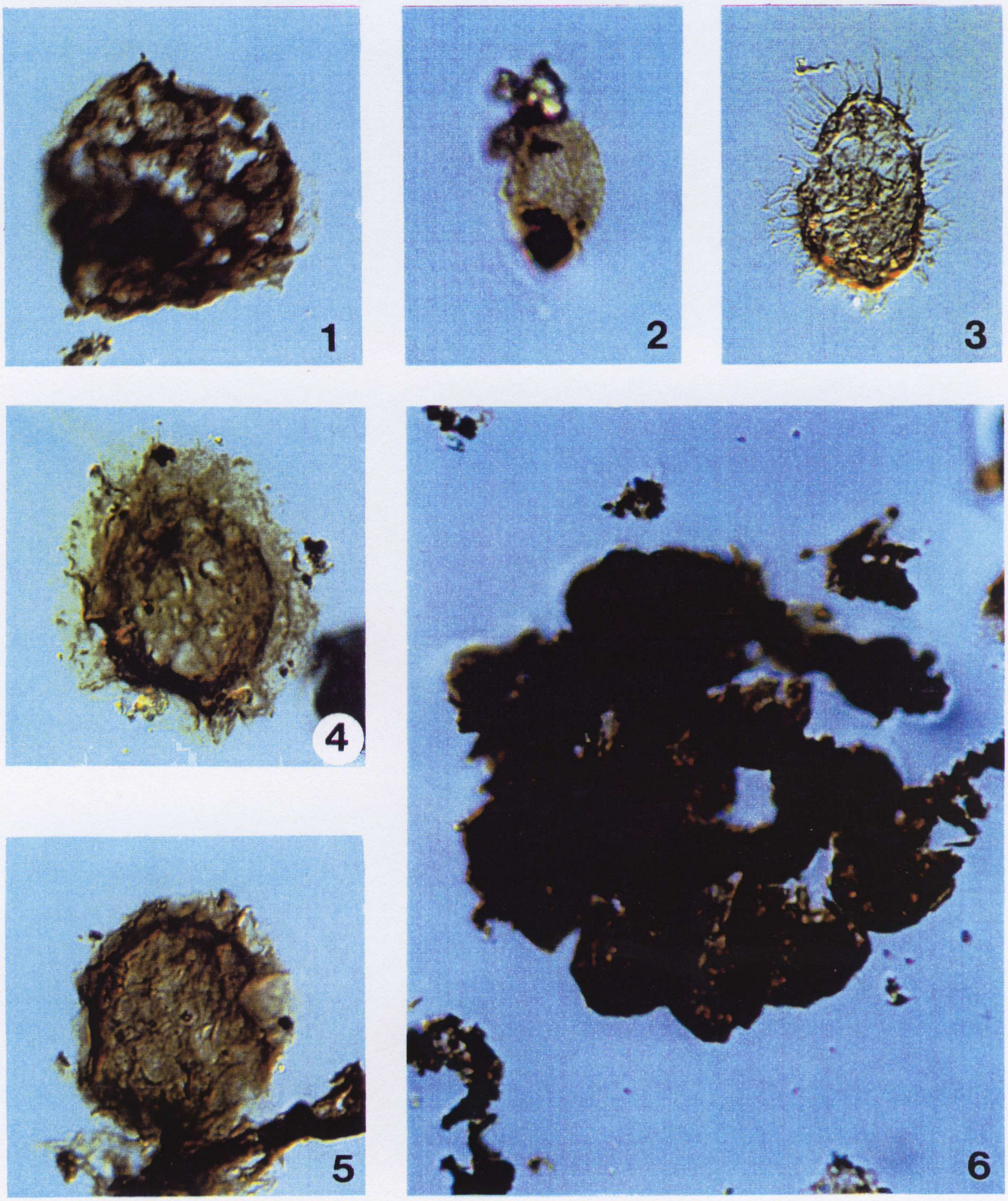
2. *Micrhystridium minutum* WW-3; 85-95m; 5.0, 83.3; x1,900.

3. *Comasphaeridium strigosum* WW-3; 85-95m; 5.3, 73.7.

4. *Fimbriaglomerella membranacea* WW-3; 85-95m; 18.1, 107.0.

5. *Fimbriaglomerella minuta* WW-3; 85-95m; 7.0, 93.3.

6. Circular cluster of reticulate sphaeromorphs, WW-3; 95-105m; 11.7, 92.3; x750.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SAMPLE ANALYSES

BOREHOLE WW2

WW2-190-250

Material: Abundant amorphous masses; black and dark brown carbonized shards; abundant pyrite; rare bitumen.

Identifiable taxa:
small ($16\mu m$) sphaeromorphs
medium ($32\mu m$) sphaeromorphs
large ($48\mu m$) sphaeromorphs
Baltisphaeridium sp. A
Baltisphaeridium sp. B
Baltisphaeridium cerinum
Lophosphaeridium sp. (granulate)
Lophosphaeridium sp. (verrucate)
Leiofusa. sp. B of sample M102 (large $> 120\mu m$)
cf. *Lunulidinium*? sp. of sample M102 (small $\sim 200\mu m$)
Micrhystridium ordensis
algal clusters
algal filaments

Chronostratigraphy: Mid? to Late? Cambrian and Tremadoc?

Concentration: 6,121 grains/g

TAI: 2.6 on amorphous material which is weakly fluorescent as dull brown; 3.0 on fecal pellets; 2.6(0.2) on acritarchs; 3.0(0.2) - dull brown fluorescence is dominant.

Maturity: Mature

Notes: Amorphous matter is reminiscent of some of the Green Point source rocks. All of the organics are very corroded; fossil concentrations are probably significantly underestimated. See sample M102 for a possible comparison.

WW2-290-300

Material: Abundant amorphous masses; black and dark brown carbonized shards; abundant pyrite; rare bitumen.

Identifiable taxa:
small ($16\mu m$) sphaeromorphs
medium ($32\mu m$) sphaeromorphs
large ($48\mu m$) sphaeromorphs

	Leiofusa. sp. B of sample M102 (large > 120μm)
	cf. *Lunulidinium*? sp. of sample M102 (small ~ 200μm)
Chronostratigraphy:	Mid? to Late? Cambrian and Tremadoc?
Concentration:	15,897 grains/g
TAI:	2.7 on amorphous material which is weakly fluorescent as dull brown; 3.0 on fecal pellets; 2.3(0.3) on acritarchs; 3.0(0.2) - dull brown fluorescence is dominant.
Maturity:	Mature
Notes:	Amorphous matter is reminiscent of some of the Green Point source rocks. All of the organics are very corroded and bleached; fossil concentrations may be underestimated. See sample M102 for a possible comparison.

WW2-340-350

Material:	Abundant amorphous masses; black and dark brown carbonized shards; abundant pyrite.
Identifiable taxa:	small (16μm) sphaeromorphs medium (32μm) sphaeromorphs large (48μm) sphaeromorphs very large (100μm) sphaeromorphs algal cluster
Chronostratigraphy:	Cambrian?
Concentration:	71,538 grains/g
TAI:	2.8 on amorphous material which is weakly fluorescent as dull brown; 2.6(0.2) on acritarchs; 3.0(0.1) - dull brown fluorescence is dominant.
Maturity:	Mature
Notes:	Amorphous matter is reminiscent of some of the Green Point source rocks. All of the organics are very corroded and bleached; fossil concentrations may be underestimated. See sample M102 for a possible comparison.

BOREHOLE WW3

WW3-85-95

Material:	Abundant amorphous masses; black and dark brown carbonized shards; abundant pyrite; rare bitumen.

Identifiable taxa: small (16μm) sphaeromorphs
medium (32μm) sphaeromorphs
large (48μm) sphaeromorphs
Acrum sp.
Archaeodiscina? sp.
Baltisphaeridium sp.
Comasphaeridium strigosum
Dictyotidium sp.
Fimbriaglomerella minuta
Fimbriaglomerella membranacea
Lophosphaeridium sp. (16μm - granulate)
Lophosphaeridium sp. (32μm - verrucate)
Micrhystridium minutum
Micrhystridium ordensis
Retisphaeridium dichamerum
algal filaments

Chronostratigraphy: Early? Cambrian (not earliest Cambrian)

Concentration: 9,983 grains/g

TAI: 3.2 on amorphous material ; 2.8(0.3) on acritarchs; 3.1(0.1) - dull brown fluorescence is dominant

Maturity: Mature borderline overmature

Notes: This non-diagnostic fossil assemblage is suggestive of species complexes from the top of the Forteau Formation.

WW3-95-105

Material: Abundant amorphous granules and bleached tissue-like masses; black and dark brown carbonized shards; abundant pyrite; rare bitumen.

Identifiable taxa: small (16μm) sphaeromorphs
medium (32μm) sphaeromorphs
Acrum? sp.
Micrhystridium sp.
algal clusters (reticulate)

Chronostratigraphy: Early? Cambrian (not earliest Cambrian)

Concentration: 17,215 grains/g

TAI: 3.6 on amorphous material ; 3.4(0.3) on acritarchs; 4.0 - black, and non -fluorescent
Maturity: Overmature
Notes: This non-diagnostic fossil assemblage has fossil abundances which suggest organic rich strata. Some of the clusters are suggestive of March Point fossils.

WW3-105-115

Material: Abundant carbonized shards.
Identifiable taxa: barren
Chronostratigraphy:
Concentration: 0 grains/g
TAI:
Maturity: Overmature
Notes: It is unclear whether the absence of fossils is a function of hydrodynamics during deposition, late stage diagenetic oxidation, or thermal overcooking.

WW3-115-125

Material: Abundant amorphous granules and abundant carbonized shards.
Identifiable taxa: barren
Chronostratigraphy:
Concentration: 0 grains/g
TAI: 3.6 on amorphous material
Maturity: Overmature
Notes: It is unclear whether the absence of fossils is a function of hydrodynamics during deposition, late stage diagenetic oxidation, or thermal overcooking.

WW3-165-175

Material: Abundant amorphous granules; black carbonized shards.
Identifiable taxa: small (16μm) sphaeromorphs
medium (32μm) sphaeromorphs
large (48μm) sphaeromorphs

	Acrum sp.
	Archaeodiscina? sp.
	Fimbriaglomerella minuta
	Lophosphaeridium sp. (granulate)
	Retisphaeridium sp.
	algal filaments
Chronostratigraphy:	Early? Cambrian (not earliest Cambrian)
Concentration:	2,000 grains/g
TAI:	3.6 on amorphous material ; 3.1(0.2) on acritarchs; 4.0 - black, and non-fluorescent.
Maturity:	Overmature
Notes:	This non-diagnostic fossil assemblage is suggestive of species complexes from the top of the Forteau Formation.

WW3-215-225

Material:	Abundant carbonized shards.
Identifiable taxa:	barren
Chronostratigraphy:	
Concentration:	0 grains/g
TAI:	
Maturity:	Overmature
Notes:	It is unclear whether the absence of fossils is a function of hydrodynamics during deposition, late stage diagenetic oxidation, or thermal overcooking.

WW3-265-275

Material:	Abundant carbonized shards.
Identifiable taxa:	barren
Chronostratigraphy:	
Concentration:	0 grains/g
TAI:	
Maturity:	Overmature
Notes:	It is unclear whether the absence of fossils is a function of hydrodynamics during deposition, late stage diagenetic oxidation, or thermal overcooking..

WW3-315-325

Material: Abundant carbonized shards.
Identifiable taxa: barren
Chronostratigraphy:
Concentration: 0 grains/g
TAI:
Maturity: Overmature
Notes: It is unclear whether the absence of fossils is a function of hydrodynamics during deposition, late stage diagenetic oxidation, or thermal overcooking.

WW3-365-375

Material: Abundant carbonized shards.
Identifiable taxa: barren
Chronostratigraphy:
Concentration: 0 grains/g
TAI:
Maturity: Overmature
Notes: It is unclear whether the absence of fossils is a function of hydrodynamics during deposition, late stage diagenetic oxidation, or thermal overcooking.

WW3-415-425

Material: Abundant carbonized shards.
Identifiable taxa: barren
Chronostratigraphy:
Concentration: 0 grains/g
TAI:
Maturity: Overmature
Notes: It is unclear whether the absence of fossils is a function of hydrodynamics during deposition, late stage diagenetic oxidation, or thermal overcooking.

WW3-475-490

Material: Abundant carbonized shards.

Identifiable taxa:	barren
Chronostratigraphy:	
Concentration:	0 grains/g
TAI:	
Maturity:	Overmature
Notes:	It is unclear whether the absence of fossils is a function of hydrodynamics during deposition, late stage diagenetic oxidation, or thermal overcooking.

BOREHOLE YORK HARBOUR 1C

YH#1C 27 m

Material:	Abundant carbonized shards.
Identifiable taxa:	barren
Chronostratigraphy:	
Concentration:	0 grains/g
TAI:	
Maturity:	Overmature
Notes:	It is unclear whether the absence of fossils is a function of hydrodynamics during deposition, late stage diagenetic oxidation, or thermal overcooking.

96 SH-1 258.1-258.4

Material:	Abundant amorphous granules; black and dark brown carbonized shards; abundant pyrite.
Identifiable taxa:	small (16μm) sphaeromorphs
	medium (32μm) sphaeromorphs
	large (48μm) sphaeromorphs
	Comasphaeridium strigosum
	Fimbriaglomerella minuta
	Granomarginata prima
	Lophosphaeridium sp. (granulate)
	Micrhystridium coniferum
	Micrhystridium ordensis
	Skiagia ciliosia
	algal clusters

	algal filaments
Chronostratigraphy:	Early? Cambrian (not earliest Cambrian)
Concentration:	5,595 grains/g
TAI:	3.6 on amorphous material ; 2.8(0.2) on acritarchs; 3.2 - infrequent dull brown fluorescencing fossils
Maturity:	Mature borderline overmature
Notes:	This non-diagnostic fossil assemblage is suggestive of species from the Forteau Formation.

96 SH-2 264.1-264.2

Material:	Abundant black carbonized shards.
Identifiable taxa:	small (16μm) sphaeromorphs medium (32μm) sphaeromorphs large (48μm) sphaeromorphs very large (>100μm) sphaeromorphs (granular) *Baltisphaeridium cerinum* *Comasphaeridium velvitum* *Fimbriaglomerella minuta*
Chronostratigraphy:	Early? Cambrian
Concentration:	250 grains/g
TAI:	3.1(0.3) on acritarchs; 4.0 - black, and non-fluorescencing fossils
Maturity:	Overmature
Notes:	

96 SH-3 268.7-268

Material:	Abundant amorphous granules; black carbonized shards.
Identifiable taxa:	small (16μm) sphaeromorphs medium (32μm) sphaeromorphs large (48μm) sphaeromorphs *Aliumella baltica* *Baltisphaeridium cerinum* *Comasphaeridium* sp. of M-193 *Comasphaeridium velvitum* *Estiastra? minima*

	Fimbriaglomerella minuta
	Granomarginata prima
	cf. *Leiosphaeridium* sp. B of M-100 (large and granulate)
	Micrhystridium minutum
	Skiagia ciliosia
	Skiagia ornata
	algal filaments
Chronostratigraphy:	Early? Cambrian (not earliest Cambrian)
Concentration:	5,356 grains/g
TAI:	3.3 on amorphous material ; 2.8(0.2) on acritarchs; 3.2 - infrequent dull brown fluorescencing fossils
Maturity:	Mature borderline overmature
Notes:	This diagnostic fossil assemblage is suggestive of species from the Forteau Formation.

96 SH-4 277.0-277.5

Material:	Abundant black carbonized shards.
Identifiable taxa:	small (16μm) sphaeromorphs
	medium (32μm) sphaeromorphs
	large (48μm) sphaeromorphs
	very large (>100μm) sphaeromorphs
	Fimbriaglomerella minuta
	Leiovalia sp.
	Micrhystridium minutum
	Micrhystridium ordensis
Chronostratigraphy:	Early? Cambrian (not earliest Cambrian)
Concentration:	666 grains/g
TAI:	3.2(0.6) on acritarchs; 4.0 - black, and non-fluorescencing
Maturity:	Overmature
Notes:	

APPENDIX 1

PALEONTOLOGICAL METHODS FOR DETERMINING THERMAL MATURATION OF PALEOZOIC STRATA IN WESTERN NEWFOUNDLAND

In order to determine source rock potential in terms of thermal maturity for strata in western Newfoundland, a number of maturity parameters have been used during this and previous studies, including thermal alteration index of spores and other organic material (TAI), thermal alteration index of acritarchs (AAI), fluorescence of organic fossils and other material, random graptolite reflectance (GR_{orand}), vitrinite reflectance (VR_{orand}) and conodont alteration index (CAI). This summary is from a manuscript currently in preparation by us, based partly on earlier work for Mobil carried out during 1991-1992.

SPORE VS. ACRITARCH ALTERATION INDICES

Because vascular land plants did not appear until the Silurian, it is generally assumed that any organic material in pre-Silurian rocks was marine in origin. Vitrinite in the strict sense did not exist, nor did other phytoclasts (trachids, cuticle and cortex) or amber. Palynomorphs were predominantly acritarchs; rare trilete spores and tetrads in Ordovician strata were probably derived from advanced algal precursors of land plants. Most palynomorph-based thermal maturation studies of Paleozoic strata employ spores, and a relative scale based on colour alteration is now well established. As the present work was restricted largely to pre-Silurian strata, spores could not be utilized, and acritarchs were employed using similar techniques. Several workers have commented to us that changes in acritarch colour, although similar to those exhibited by spores, occurred at different paleotemperatures and thermal maturation studies should not, therefore, consider measurements obtained from the two groups to be equivalent. Although A. Achab and coworkers originally proposed a distinct Acritarch Alteration Index, they have since treated spore and acritarch measurements as essentially synonymous (A. Achab, personal communication, 1996). F. Goodarzi (personal communication, 1996), however, believes that the changes within the two groups are distinct, owing to differences in their organic structure, and advocates the use of two separate schemes.

Within spores, there is considerable variation in colour change dependent on their size and the thickness of organic wall; our study suggests that such variation also occurs within acritarchs of different taxa. Notwithstanding these observations, we believe that acritarchs do indeed require a higher temperature than spores before exhibiting a change from essentially colourless to yellow then brown. This is based on the fact that a number of thermal maturation samples from unequivocally oil-rich source rocks of the Cow Head Group suggest that the rocks are apparently immature if acritarch colours are taken as strict equivalents of spore TAI values. We therefore employ Acritarch Alteration Indices (AAI's) for the present study. By comparison with fluorescence observations and changes in conodonts and graptolites (Figure 1), acritarch alteration colours appear to be almost unchanged until the upper part of the oil window is reached, then to change very rapidly during the middle part of the oil window and become essentially equivalent to spore colours before the bottom of the oil window is reached. Thus, a spore-based TAI of 3.0 and brown fluorescence, which is commonly considered to mark the lowermost limit of oil production, is apparently equivalent to an AAI of 3.0.

ACRITARCH ALTERATION INDEX (AAI) METHODOLOGY

Thermal alteration index (TAI and AAI) and fluorescence studies of palynomorphs require a palynomorph preparation technique which reduces or eliminate acids which may damage the fossil walls. For this study, crushed and weighed samples, spiked with a known number of *Lycopodium* spores useful for determining fossil concentrations, were dissolved in HCl and HF acids. After washing to remove acid, slides were made of the unsieved residues. Later, after sieving with a 10 μm screen, additional slides were prepared for sieved and unoxidized organics. Slides were scanned and fossils identified and counted in alternating fluorescence and transmitted light to obtain an indication of the palynomorph species and abundances, TAI, and fluorescence properties. Fossil assemblages were identified and concentrations calculated as an indication for source rock potential and colors matched with a color chart of TAI's which were then calibrated with true vitrinite R_o from other published (Raynaud and Robert, 1976; Staplin, 1977; Waples, 1982; Pearson, 1984) and unpublished studies (Burden and Hyde, unpublished report on western Newfoundland).

VITRINITE (R_o) AND GRAPTOLITE (R_{ograp}) REFLECTANCE

Determining the maturity of Lower Paleozoic sediments, in general, is extremely difficult because of the absence of vitrinite in the pre-Devonian rocks. The use of other maturity measures (bitumen reflectance, fluorescence of algae, etc.) provides the most suitable proxy data to define exact maturity of those rocks (Mukhopadhyay, 1992, 1994, and references therein). Land plants first evolved during the Lower or Middle Silurian, but did not become abundant until the Devonian Period. Vitrinite (telo- or gelocollinite) in the strict sense does not, therefore exist in sediments deposited before that time. Graptolite workers have, however, realized for some time that the fossilized skeletal remains of these hemichordates differ in appearance between those preserved in relatively undeformed strata and those which have been subjected to low grade regional metamorphism. Nonmetamorphosed graptolites are black with a lustrous sheen (Williams and Stevens, 1988). In contrast, those occurring in black shales of zeolite or prehnite-pumpellyite facies have a graphitic or metallic lustre (Williams, 1991). This change has been investgated quantitatively and results published by a number of authors (e.g., Bertrand and Héroux, 1987; Bertrand 1991, 1993; Goodarzi and Norford, 1985; Hoffknecht, 1991; Wang et al., 1993; Gentzis et al., 1996).

In a previous study for Mobil, we employed techniques which were more in keeping with general practice in vitrinite analyses. Here, fragments of rock chosen for analysis of graptolite reflectance are not oriented parallel to bedding (cf. Goodarzi and Norford, 1985; Wang et al., 1993; Gentzis et al., 1996). Instead, the rocks were crushed to -20 mesh size and unoriented strew mounts were impregnated in a cold-set epoxy resin and polished according to the standard procedure followed for vitrinite reflectance (ASTM, 1991; Stach et al., 1992; Mukhopadhyay, 1992). These data proved useful, but we consider AAI and TAI measurements to be more precise in and around the oil window, and thus have not attempted to employ graptolite reflectance during the present study.

CONODONT COLOR ALTERATION INDEX (CAI)

Since the study by Epstein et al. (1977), the change in conodont color (CAI) from transluscent or clear to amber, brown, black and finally white has been used widely in determining the maximum temperatures experienced by Paleozoic sediments. Recently, an alternative to the essentially qualitative method of determing conodont colour was described by Deaton et al. (1996). Whether this will prove to be a more precise and reliable way of determing thermal maturity using conodonts remains to be seen.

Local studies of CAI in western Newfoundland were first developed in a preliminary report by Stouge (1986). A comprehensive summary of CAI's throughout eastern Canada and their application in determining thermal histories of Lower Paleozoic strata was made by Nowlan and Barnes (1987). They recorded a clear increase in CAI from 1 in the southwest on the Port au Port Peninsula to 5 or more on the northwestern tip of the Northern Peninsula. It was acknowledged that much of this would have been due to increased structural burial and tectonic activity, but these authors also considered it to be related in part to the passing of the area over a hotspot during the Mesozoic.

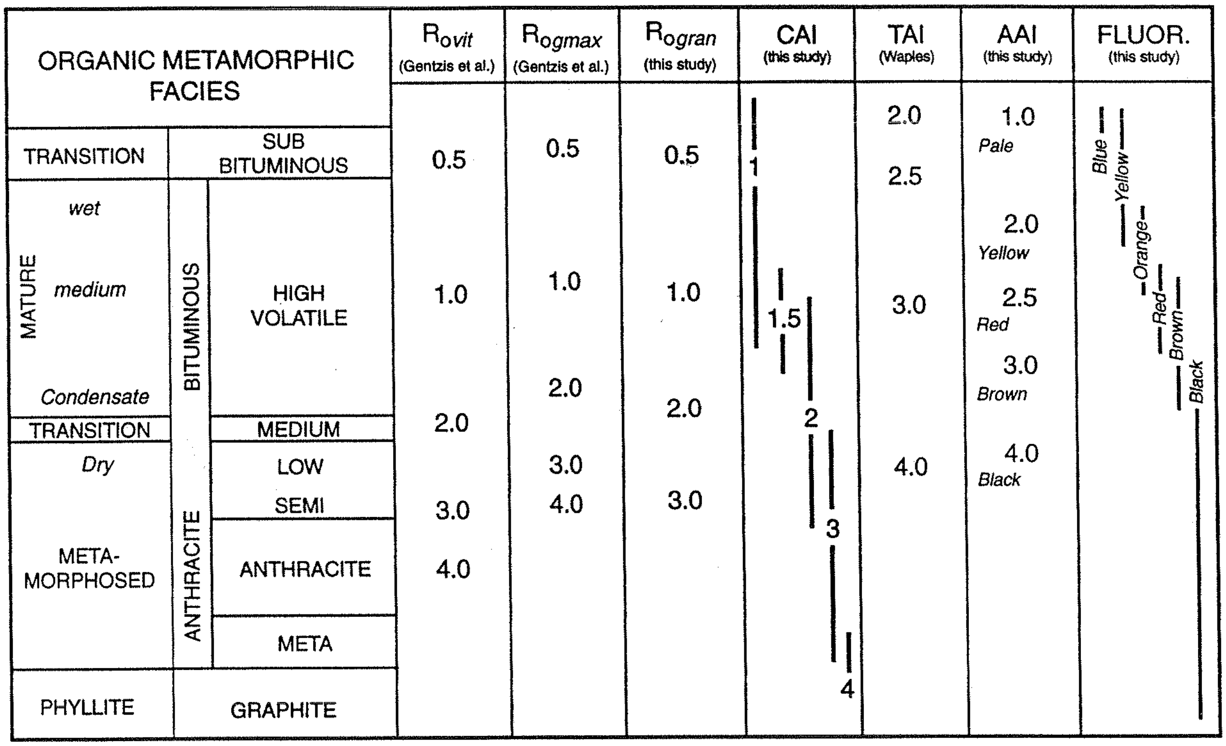

Figure 1. Correlation of thermal maturity indices discussed in text.

CORRELATION OF THERMAL MATURATION INDICES

Attempts have been made previously at calibrating graptolite reflectance (GR_o) against conodont alteration indices (CAI), true vitrinite (VR_o), scolecodont and chitinozoan "R_o's", and absolute maximum temperatures to which the rocks have been subjected (e.g., Bertrand and Héroux, 1987; Bertrand, 1991, 1993; Goodarzi and Norford, 1985; Wang et al., 1993; Gentzis et al., 1996). Goodarzi and Norford (1985), Goodarzi et al. (1988), Hoffknecht (1991), Wang et al. (1993), suggest that true vitrinite VR_o values are significantly lower than graptolite reflectance values. Goodarzi and Norford (1985) indicate that a VR_o of 2.5% corresponds to the semi-anthracite stage and a temperature higher than 130°C; however, for maximum graptolite GR_{omax}, a value of 2.5% represents a rather lower temperature of about 100°C. Hoffknecht (1991) and Wang et al. (1993) suggest a relationship between maximum graptolite GR_{omax} and vitrinite VR_o which increases with the level of thermal maturation. Thus, for a vitrinite R_o of 1.0, the maximum graptolite GR_{omax} is about 2.5; however, if vitrinite VR_o is 3.5, the maximum graptolite GR_{omax} is nearly 10.0. Goodarzi et al. (1988) and Gentzis et al. (1996) noted a similar trend in measurements of maximum graptolite GR_{omax} and conodont CAI in rocks which were thermally altered to levels well above the oil window (CAI 3+). Taken together, these studies show graptolites to be sensitive thermal maturation indicators that respond more rapidly than true vitrinite and conodonts to changes in the temperature of low grade metamorphic strata.

The random graptolite reflectance GR_{orand} employed by us previously and AAI data span the other end of the spectrum, that is in thermally immature strata and strata in the oil window (Figure 1). Correlated plots of GR_{orand} with AAI indicate that changes in GR_{orand} are subtle in strata below and within the oil window, suggesting that at this level graptolites are less reliable than acritarch AAI measurements, but are marginally better than conodonts in recording general maturation trends. Thus, for strata in western Newfoundland acritarchs and graptolites provide the most sensitive maturation indicators for burial history, with the acritarchs accurately delineating shallow burial and low burial temperatures and graptolites showing deeper burial and higher, low grade metamorphic temperatures. The conodont alteration index (CAI) shows little change above and within the oil window and is thus not sufficiently sensitive for determing hydrocarbon source rock maturity in this interval. CAI measurements are, however, of value in evaluating thermal maturity in rocks below the oil window, where the AAI ceases to be of use.

APPENDIX 2

STRATIGRAPHICALLY USEFUL FOSSILS IN WESTERN NEWFOUNDLAND

We have found that a combination of conodonts, acritarchs, chitinozoa and graptolites is most useful for biostratigraphic and thermal maturation studies of Early Paleozoic strata, with spores becoming more important in sediments of Middle and Late Paleozoic age. For outcrop studies, macrofossils such as trilobites and brachiopods could also be used at some levels; these do not, however, have any use in determining thermal maturity levels. Here we summarise the approaches we use for identifying the major lithostratigraphic units which occur in western Newfoundland in both authochthonous and allochthonous strata.

CAMBRIAN AUTOCHTHONOUS ROCKS

Labrador Group

The Bradore and locally underlying earliest Cambrian and latest Precambrian units are generally non-fossiliferous due to their lithologies and environments of formation. The Forteau Formation (Figure 2), however, yields a rich acritarch microflora and abundant specimens of the trilobite *Olenellus* (Williams et al., 1996). The acritarchs permit excellent fine-scale correlation for this part of the Early Cambrian and allow determination of thermal maturity. *Olenellus* is commonly small, and cephalons are occasionally identifiable even in cutting-size fragments due to the unique form of their facial sutures. The Hawke Bay yields occasional acritarchs but these are often of limited biostratigraphic use; most of the unit, which is composed largely of quartz sandstone, is unfossiliferous.

Port au Port Group

The earliest formations of this predominantly carbonate unit yield few acritarchs, which are apparently of little biostratigraphic use and generally oxidized, making thermal maturation determinations unreliable. One exception to this is the March Point Formation which appears to yield biostratigraphically diagnostic assemblages. Conodonts first appear in the youngest intervals of the Berry Head Formation; these are generally uncommon within this Late Cambrian formation, but when found permit precise biostratigraphic determination and limited evaluation of thermal maturation. For the present, the Port au Port Group is one of the most difficult units to subdivide using microfossil evidence. Trilobites are generally considered the most biostratigraphically

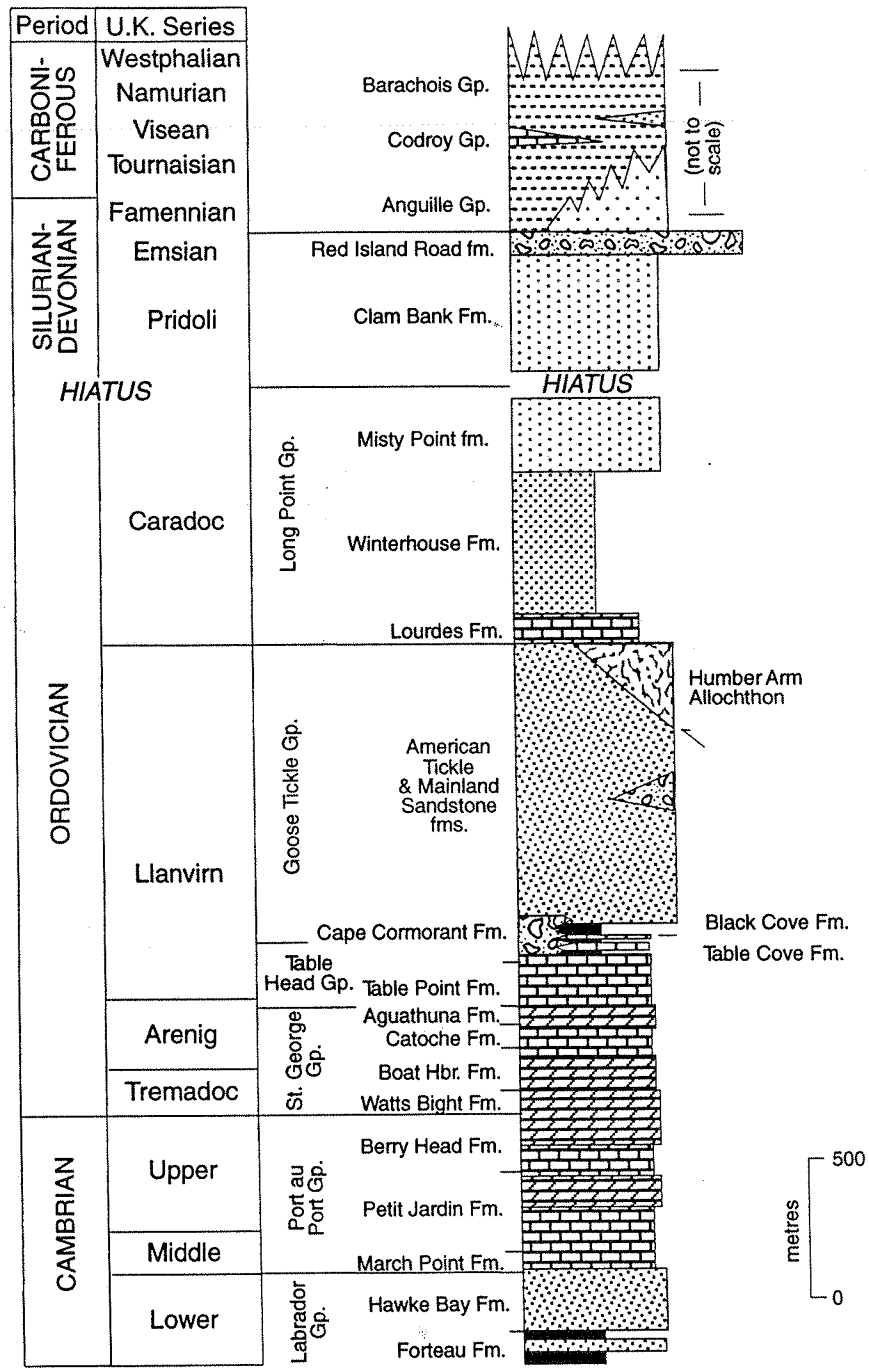

Figure 2. Paleozoic stratigraphy of autochthonous strata in western Newfoundland

useful fossils within this interval (Westrop, 1992).

EARLY-MIDDLE ORDOVICIAN AUTOCHTHONOUS ROCKS

St. George Group

Conodonts are locally abundant with a well-known biostratigraphy throughout these Early Ordovician carbonates; reference to previously published studies (Stait, 1988; Stait and Barnes, 1991; Ji and Barnes, 1994) permits precise zonal recognition and evaluation of thermal maturation (Nowlan and Barnes, 1987). Acritarchs are occasionally found but, like those in the Port au Port Group, are commonly oxidized and generally of uncertain biostratigraphic potential. Chitinozoa first appear in early Arenig strata where they provide complimentary data for conodonts. Rare graptolites have been recovered from the Catoche and Aguathuna formations which permit correlation between trilobite, conodont and graptolite zonation at these levels (Fortey, 1979; Williams et al, 1987).

Table Head Group

Conodonts are abundant throughout most of this limestone-dominated group, permitting fine-scale biostratigraphic resolution (Stouge, 1984). Acritarchs, chitinozoa and graptolites are also common in the Table Cove Formation, the youngest division of the group. Acritarchs allow reliable determination of thermal maturation, while both the graptolites and chitinozoa permit high resolution biostratigraphy (Morris and Kay, 1966; Finney and Skevington, 1979; Mitchell and Maletz, 1994; Taylor, 1997). Exposures of this interval are characterised by a rich shelly macrofauna, especially trilobites (Whittington, 1963, 1965; Whittington and Kindle, 1963) and brachiopods (Ross and James, 1987), but these are generally not preserved in subsurface cuttings or cores.

Goose Tickle Group

This clastic unit yields locally abundant graptolites, chitinozoa and acritarchs. Although the unit includes several lithological subdivisions (Quinn, 1992, 1996), these are presently indistinguishable biostratigraphically; the group as a whole appears to have been deposited within a relatively short period of time in the middle Llanvirn. The lowest division of this group, namely the Black Cove Formation and the underlying Table Cove Formation of the Table Head Group appear to be laterally equivalent to the Cape Cormorant Formation (Stenzel et al., 1990), a unit dominated by carbonate debris flows, shales and sandstone. All three formations yield a similar graptolite fauna (Taylor, 1997). Limestone conglomerates elsewhere in the Goose Tickle Group are assigned to the Daniel's Harbour Member (Stenzel et al., 1990) and yield graptolites preserved in three dimensions (Whittington and Rickards, 1969).

MIDDLE CAMBRIAN TO MIDDLE ORDOVICIAN ALLOCHTHONOUS ROCKS

These units are mostly downslope, deep marine strata deposited to the south of the Laurentian paleocontinent. The western Newfoundland allochthons have been divided into a number of groups, all of which are contained within the Humber Arm Supergroup (James and Stevens, 1986; H. Williams, 1995). Paleontologically, the carbonate and overlying siliciclastic sediments yield rich macro- and microfossil assemblages which have been documented particularly well in the Cow Head Group (Fåhraeus and Nowlan, 1978; Fortey et al., 1982; James and Stevens, 1986; Johnston, 1987; Pohler et al., 1987; Barnes, 1988; Stouge and Bagnoli, 1988; Williams and Stevens, 1988, 1991; Ludvigsen et al., 1989) and partially equivalent Curling Group (Erdtmann and Botsford, 1987; Botsford, 1988; Roy, 1989; Roy and Fåhraeus, 1989). The former group is present in and around Gros Morne National Park on the Northern Peninsula, while the Curling Group is restricted in outcrop to the Bay of Islands (Figure 3). Outside of these particular regions we consider it possible to refer to these strata only as Humber Arm Supergroup, as data from Long Point M16 revealed a sequence dissimilar to both groups as defined. Middle Cambrian strata yield a low diversity acritarch microflora, with no conodonts or graptolites. Later Cambrian and Ordovician carbonates, however, yield abundant deep water conodont assemblages (Fåhraeus and Nowlan, 1978; Johnston, 1987; Pohler et al., 1987; Barnes, 1988; Stouge and Bagnoli, 1988) which provide excellent biostratigraphic resolution and a measure of thermal maturity. Black and dark brown shales and limestones yield rich graptolite faunas in Ordovician rocks (Fortey et al., 1982; Williams and Stevens, 1988, 1991), permitting the most precise biostratigraphical zonation in the region (resolution of ca. 2 My). Large sphaeromorph acritarchs and chitinozoa are also abundant in this interval, providing additional biostratigraphic information and precise thermal maturation indices (Williams et al., 1996). Scolecodonts (polychaete worm jaws) are abundant but at present are of limited biostratigraphic use. All these fossil groups have been recovered and used successfully in subsurface drilling studies.

LATE ORDOVICIAN TO EARLY DEVONIAN SEDIMENTS

Long Point Group

The Long Point Group is exposed only along the westernmost part of the Port au Port

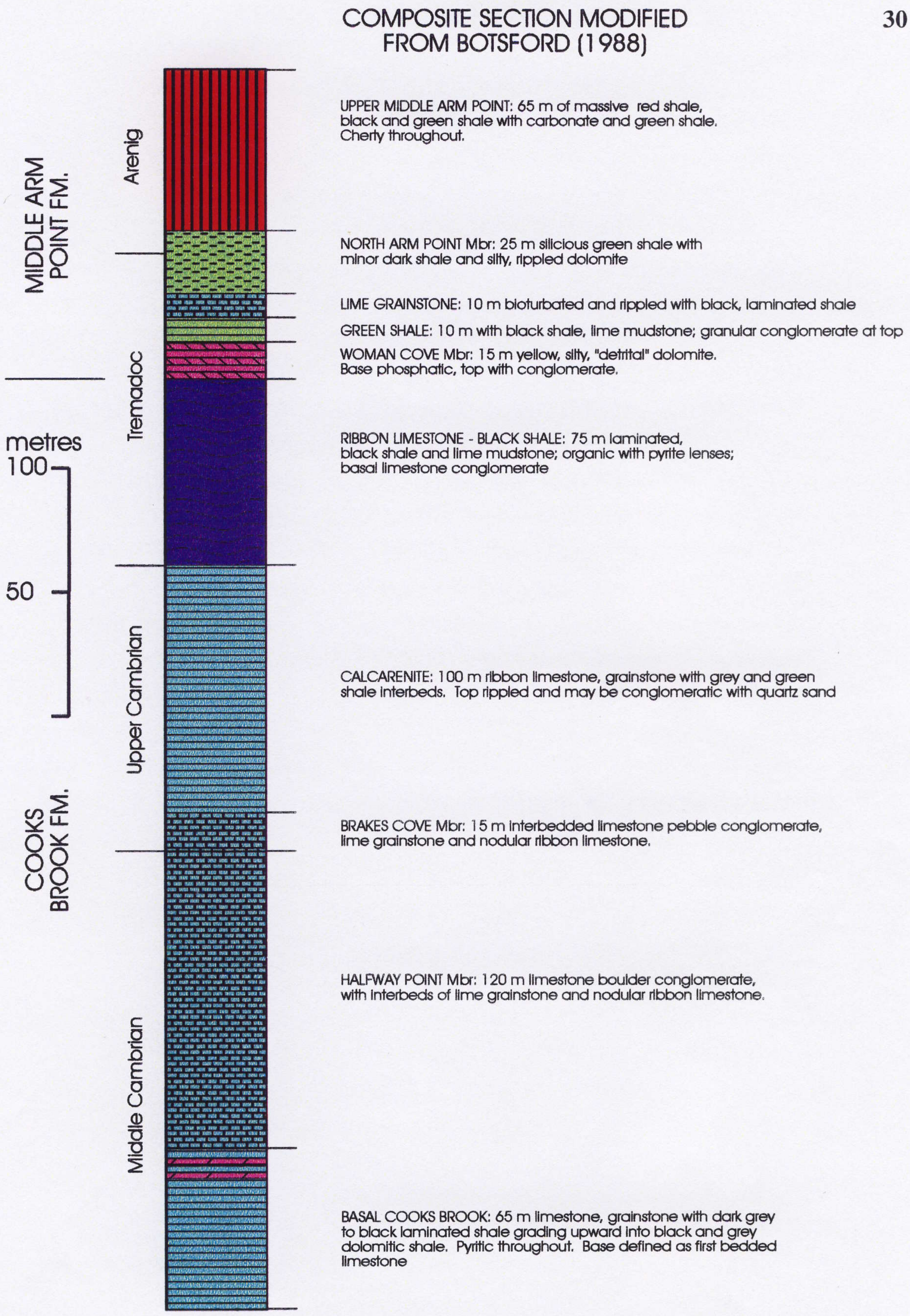

Figure 3. Composite section for allochthonous strata in the Bay of Islands region.

Peninsula. The carbonates of the Lourdes Formation yield occasional conodonts of probable early Caradoc age (Fåhraeus, 1973; Stait and Barnes, 1991); the rich macrofauna seen in outcrop (Flower, 1952; Dean, 1977; Stait, 1988; Stockmal and Waldron, 1990; Waldron and Stockmal, 1991) is unfortunately, however, not matched by the microfauna or flora. The nature of the contact between the Lourdes Formation and the underlying Goose Tickle Group on Long Point is still under debate, but appears to be a sedimentary hiatus forming the sole of a thrust (Rodgers, 1965; Stait and Barnes, 1991). The following Winterhouse Formation (now known to be the thickest sedimentary unit in western Newfoundland; Quinn et al., in prep a) yields occasional biostratigraphically diagnostic graptolites and conodonts (O'Brien, 1973; Bergström et al., 1974; Quinn et al., in prep a) and an abundant, rich acritarch microflora which permits a threefold biostratigraphic subdivision of the formation. Scolecodonts and age diagnostic chitinozoa are also common. Brachiopods are also common within the unit (Cooper, 1956). Faunal recognition and determination of thermal maturation level are therefore precise and reliable for the Winterhouse Formation both at outcrop and in the subsurface. The highest strata of the Long Point Group consist of sparsely fossiliferous red and brown sandstones; these are now referred to the Misty Point formation (Quinn et. al., in prep a). Several exposed levels yield a low diversity, marine, shelly macrofauna, while others contain acritarchs. Ages obtained from outcrop material suggest that the unit is indistinguishable in terms of age from the (laterally equivalent?) Winterhouse Formation.

Clam Bank Formation

No stratigraphic contact is exposed between the Long Point Group and the younger Clam Bank Formation which is generally considered to be of late Silurian (Pridoli) to early Devonian(?) age (O'Brien, 1973; Wright et al., 1995). It is, however, assumed that there must be a major hiatus and unconformable relationship between the two. Diagnostic conodonts and spores are present locally within the unit, but much of the formation is composed of oxidized red lithologies which are unfossiliferous (Bailey et al., in prep.).

Red Island Road formation

This newly recognized formation which is exposed only on Red Island off the west coast of the Port au Port Peninsula (Quinn et al., in prep c) is composed almost entirely of fluvial conglomerates and arkose. One narrow interval of green-grey silt and sandstone, however, contains vascular land plants and spores which indicate an early Devonian

(Emsian) age. The presence of cobbles identical to those of the Red Island conglomerates along the western shoreline of Port au Port suggests widespread submarine outcrop in the region. We believe that the Red Island Road formation probably overlies the Clam Bank Formation rather than representing a lateral equivalent because of the slightly later age.

CARBONIFEROUS (MISSISSIPPIAN & PENNSYLVANIAN) SEDIMENTS

Carboniferous sediments are found in a number of basins in western Newfoundland, including Codroy, Bay St. George and Deer Lake (Hayes and Johnson, 1938 Belt, 1968; Hyde, 1981; Knight, 1983;). A threefold lithological subdivision has been defined, comprising the Anguille, Codroy and Barachois groups. The formations of the Anguille and Barachois groups are dominated by terrestrial, siliciclastic sediments which yield abundant, age-diagnostic spore assemblages that can be used both for biostratigraphic dating and evaluation of thermal maturity (Utting, 1966, 1987; Hyde et al., 1991). In addition to these, some formations within the Codroy Group are composed of carbonates and evaporites (Dix, 1981; Dix and James, 1989; von Bitter et al., 1990, 1992) the Ship Cove and Mistaken Cove formations including a number of biostratigraphically useful conodonts (von Bitter and Plint-Geberl, 1982).

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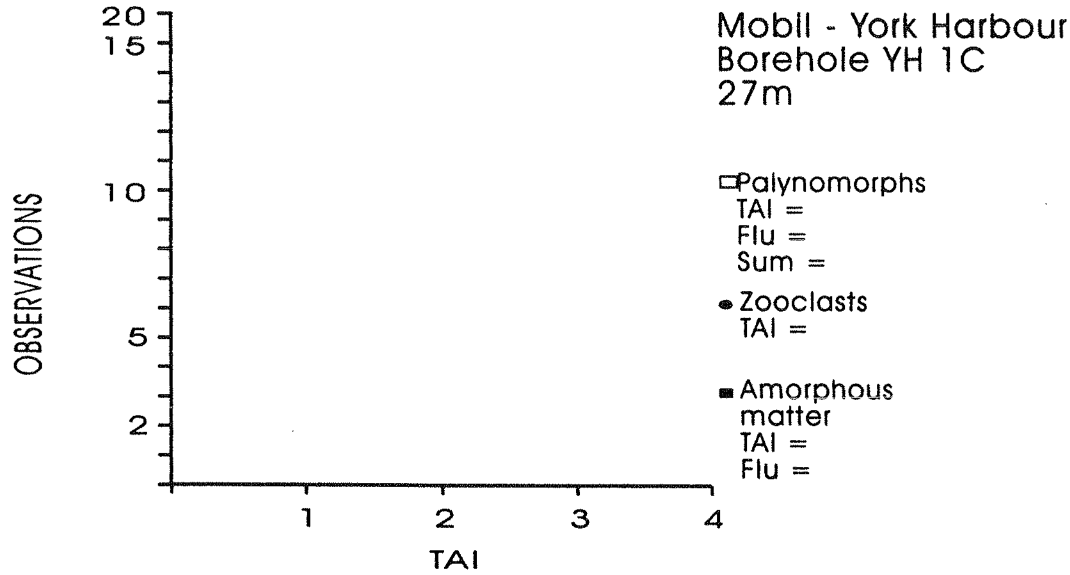
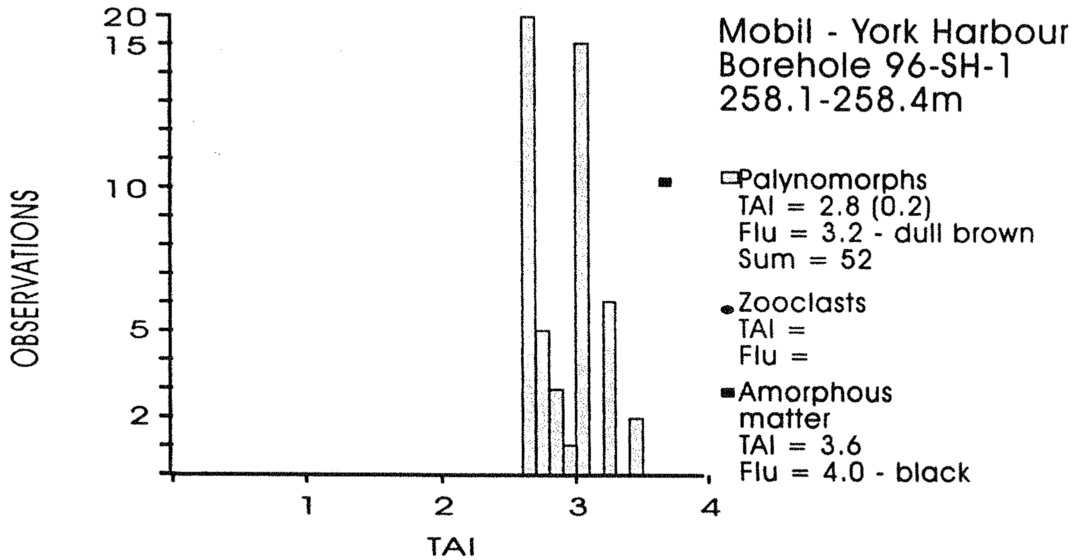
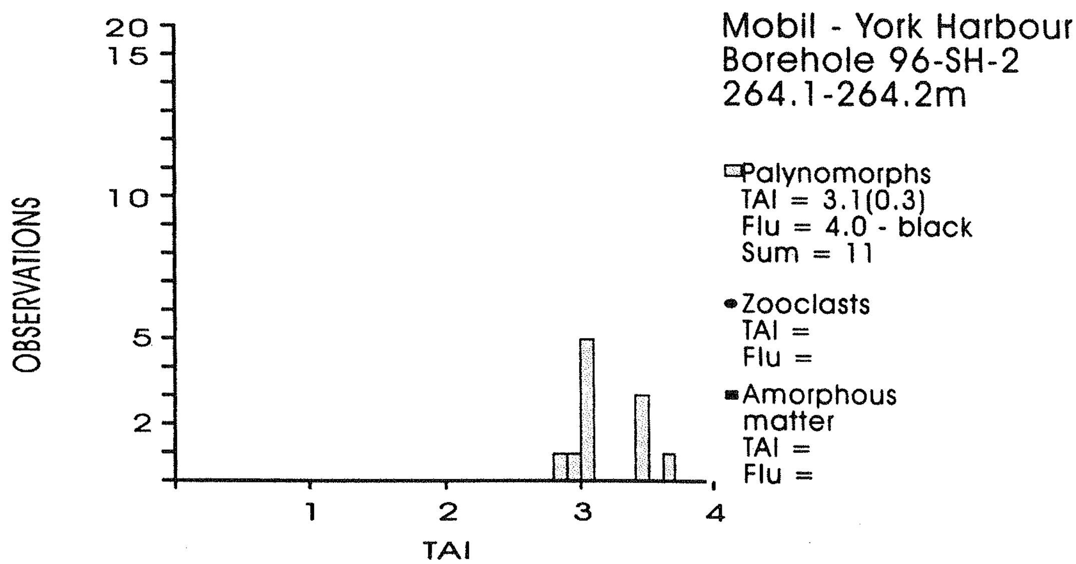


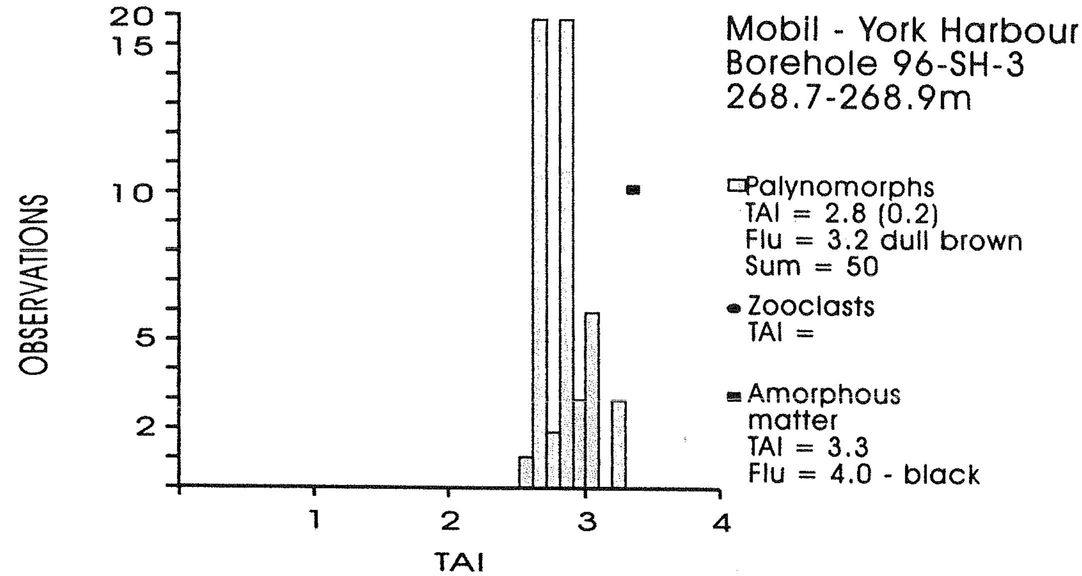
Mobil - York Harbour
Borehole YH 1C
27m
Palynomorphs
TAI =
Flu =
Sum =
Zooclasts
TAI =
Amorphous
matter
TAI =
Flu =
OBSERVATIONS
TAI

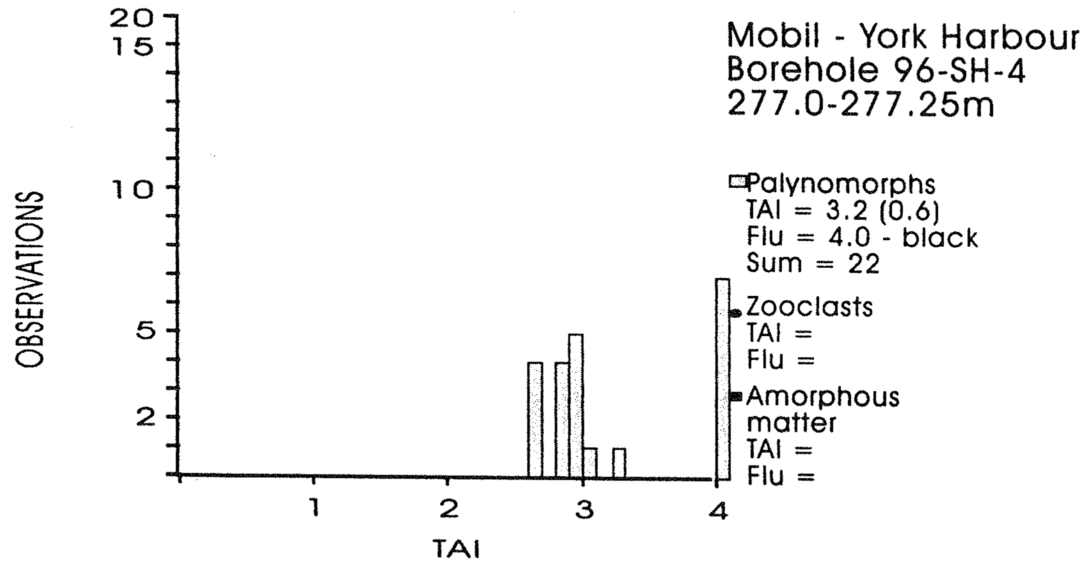


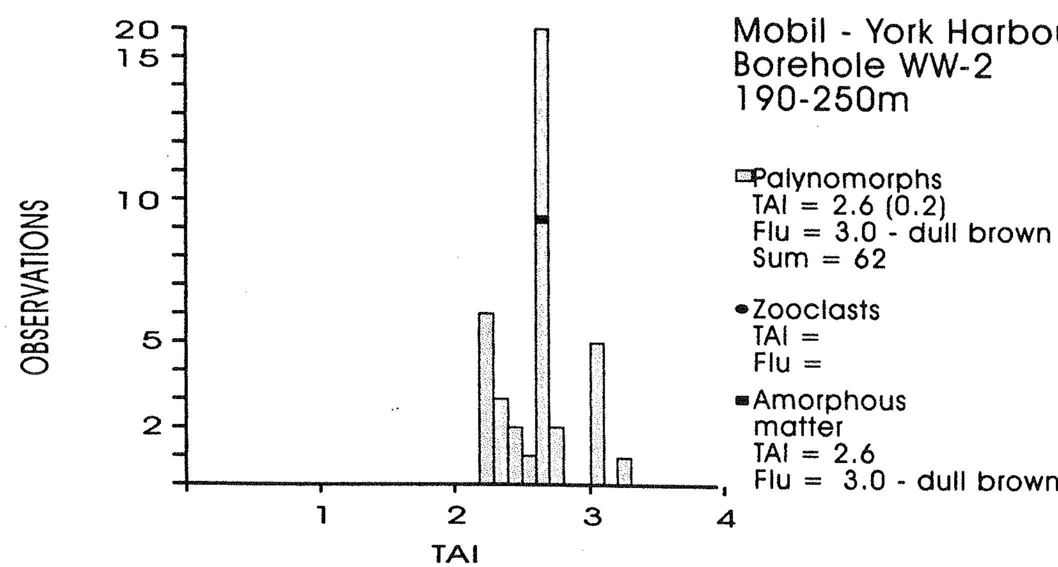
Mobil - York Harbour
Borehole 96-SH-1
258.1-258.4m
Palynomorphs
TAI = 2.8 (0.2)
Flu = 3.2 - dull brown
Sum = 52
Zooclasts
TAI =
Flu =
Amorphous
matter
TAI = 3.6
Flu = 4.0 - black
OBSERVATIONS
TAI

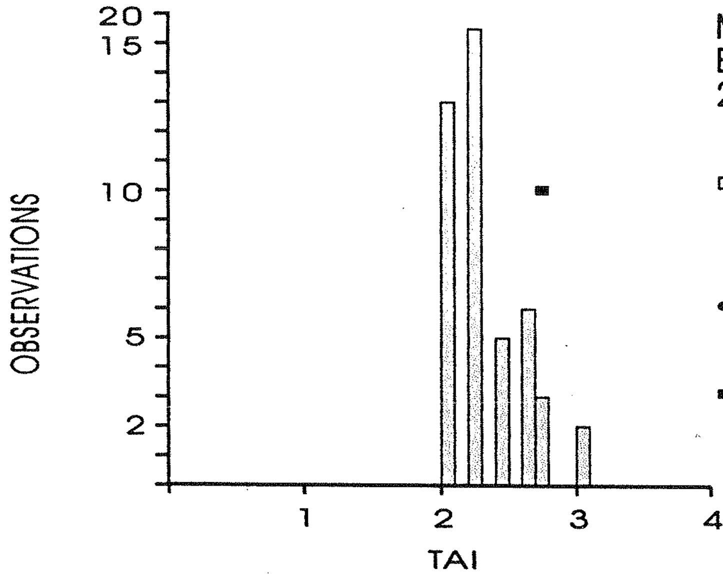


Mobil - York Harbour
Borehole 96-SH-2
264.1-264.2m
Palynomorphs
TAI = 3.1(0.3)
Flu = 4.0 - black
Sum = 11
Zooclasts
TAI =
Flu =
Amorphous
matter
TAI =
Flu =
OBSERVATIONS
TAI


Mobil - York Harbour
Borehole 96-SH-3
268.7-268.9m
Palynomorphs
TAI = 2.8 (0.2)
Flu = 3.2 dull brown
Sum = 50
Zooclasts
TAI =
Amorphous matter
TAI = 3.3
Flu = 4.0 - black
OBSERVATIONS
TAI
20
15
10
5
2
1
2
3
4


Mobil - York Harbour
Borehole 96-SH-4
277.0-277.25m
Palynomorphs
TAI = 3.2 (0.6)
Flu = 4.0 - black
Sum = 22
Zooclasts
TAI =
Flu =
Amorphous matter
TAI =
Flu =
OBSERVATIONS
TAI
20
15
10
5
2
1
2
3
4


Mobil - York Harbour
Borehole WW-2
190-250m
Palynomorphs
TAI = 2.6 (0.2)
Flu = 3.0 - dull brown
Sum = 62
Zooclasts
TAI =
Flu =
Amorphous matter
TAI = 2.6
Flu = 3.0 - dull brown
OBSERVATIONS
TAI
20
15
10
5
2
1
2
3
4

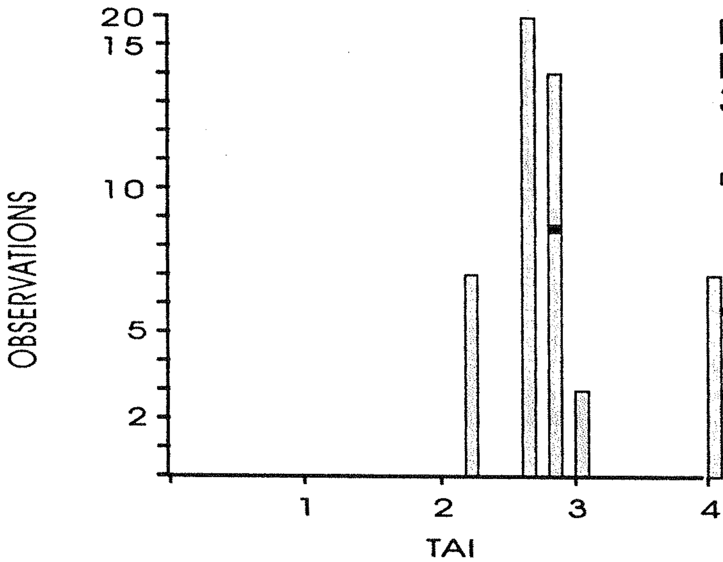


Mobil - York Harbour
Borehole WW-2
290-300m

Palynomorphs
TAI = 2.3 (0.3)
Flu = 3.0 (0.2) - dull brown
Sum = 47

Zooclasts
TAI =

Amorphous matter
TAI = 2.7
Flu = 3.1 - dull brown

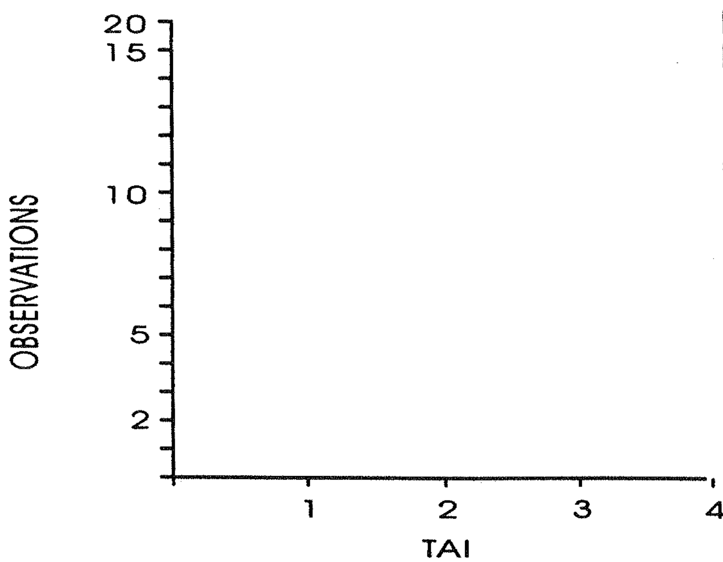


Mobil - York Harbour
Borehole WW-2
340-350m

Palynomorphs
TAI = 2.6 (0.2)
Flu = 3.0 - dull brown
Sum = 47

Zooclasts
TAI =
Flu =

Amorphous matter
TAI = 2.8
Flu = 3.1 - dull brown

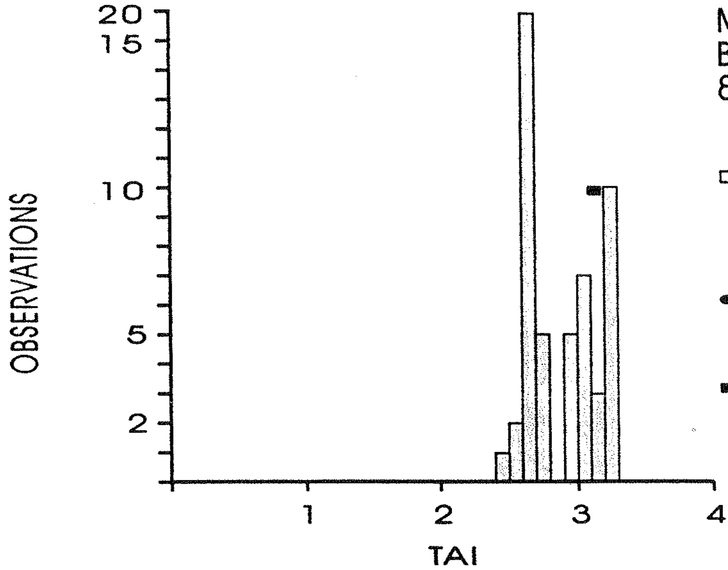


Mobil - York Harbour
Borehole WW-2

Palynomorphs
TAI =
Flu =
Sum =

Zooclasts
TAI =
Flu =

Amorphous matter
TAI =
Flu =

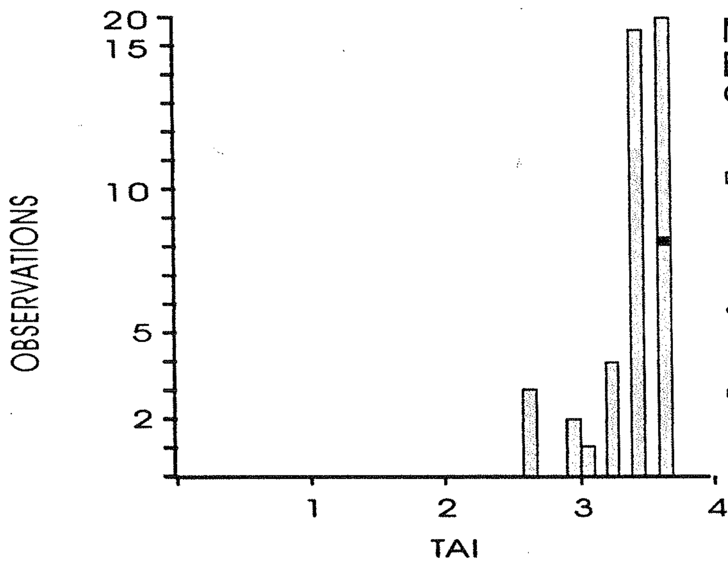


Mobil - York Harbour
Borehole WW-3
85-95m

□Palynomorphs
TAI = 2.8 (0.3)
Flu = 3.1 (0.1) - dull brown
Sum = 54

• Zooclasts
TAI =

▪ Amorphous matter
TAI = 3.2
Flu = 4.0 - black

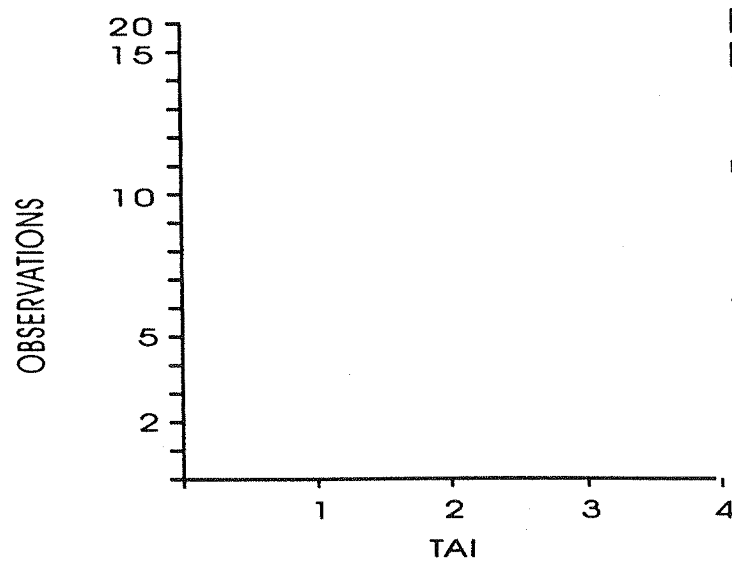


Mobil - York Harbour
Borehole WW-3
95-105m

□Palynomorphs
TAI = 3.4 (0.3)
Flu = 4.0 - black
Sum = 48

• Zooclasts
TAI =
Flu =

▪ Amorphous matter
TAI = 3.6
Flu = 4.0 - black



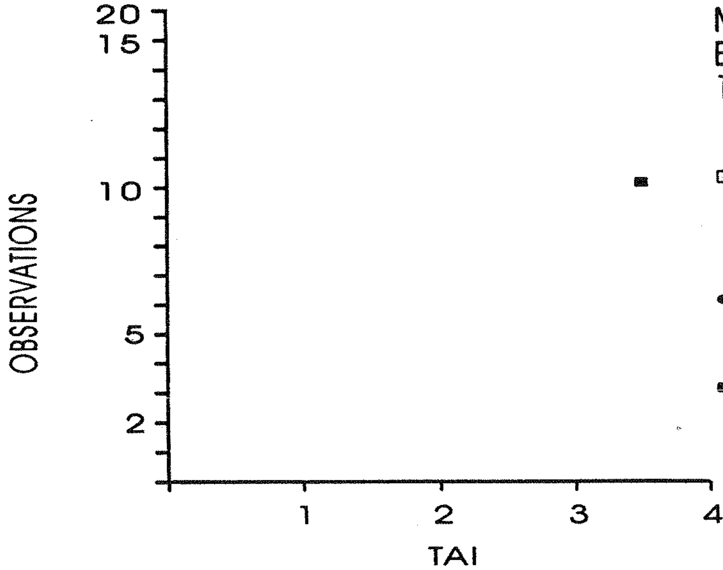
Mobil - York Harbour
Borehole WW-3
105-115m

□Palynomorphs
TAI =
Flu =
Sum =

• Zooclasts
TAI =
Flu =

▪ Amorphous matter
TAI =
Flu =

Mobil - York Harbour
Borehole WW-3
115-125m

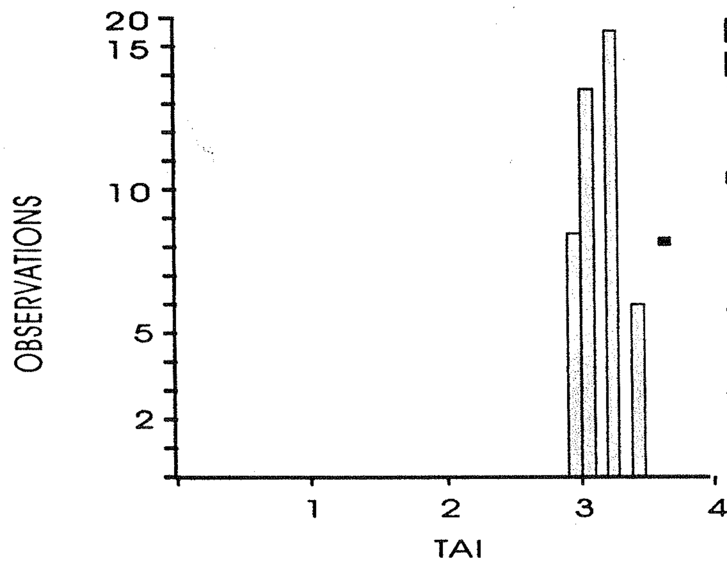


Palynomorphs
TAI =
Flu =
Sum =

Zooclasts
TAI =

Amorphous matter
TAI = 3.6
Flu = 4.0 - black

Mobil - York Harbour
Borehole WW-3
165-175m

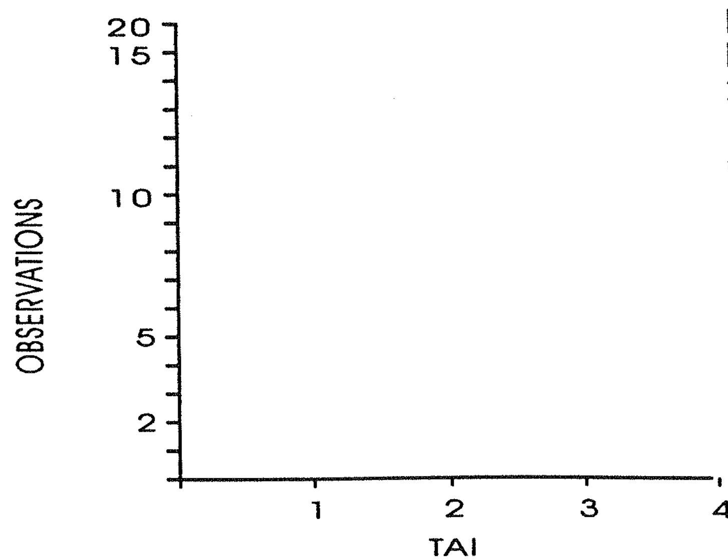


Palynomorphs
TAI = 3.1 (0.2)
Flu = 4.0 - black
Sum = 45

Zooclasts
TAI =
Flu =

Amorphous matter
TAI = 3.6
Flu = 4.0 - black

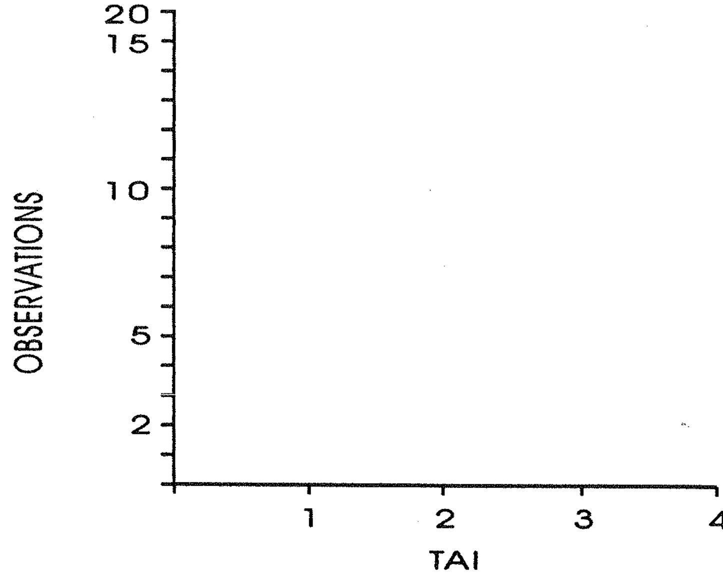
Mobil - York Harbour
Borehole WW-3
215-225m



Palynomorphs
TAI =
Flu =
Sum =

Zooclasts
TAI =
Flu =

Amorphous matter
TAI =
Flu =

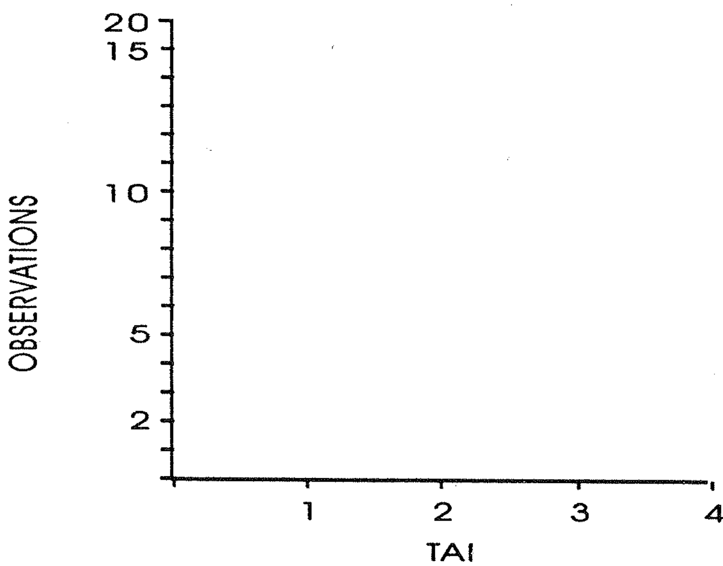


Mobil - York Harbour
Borehole WW-3
265-275m

Palynomorphs
TAI =
Flu =
Sum =

Zooclasts
TAI =

Amorphous matter
TAI =
Flu =

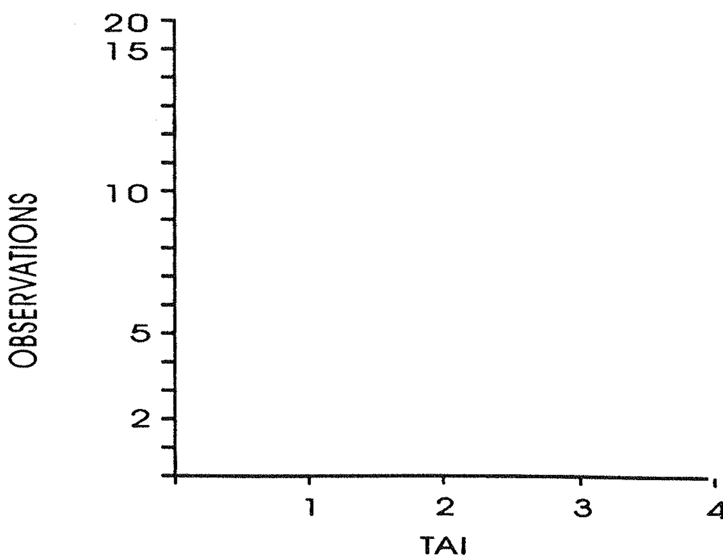


Mobil - York Harbour
Borehole WW-3
315-325m

Palynomorphs
TAI =
Flu =
Sum =

Zooclasts
TAI =
Flu =

Amorphous matter
TAI =
Flu =



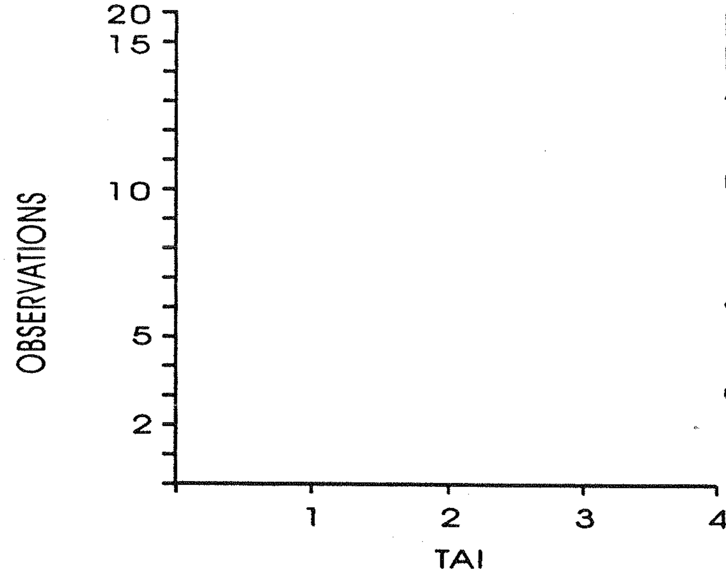
Mobil - York Harbour
Borehole WW-3
365-375m

Palynomorphs
TAI =
Flu =
Sum =

Zooclasts
TAI =
Flu =

Amorphous matter
TAI =
Flu =

Mobil - York Harbour
Borehole WW-3
415-425m

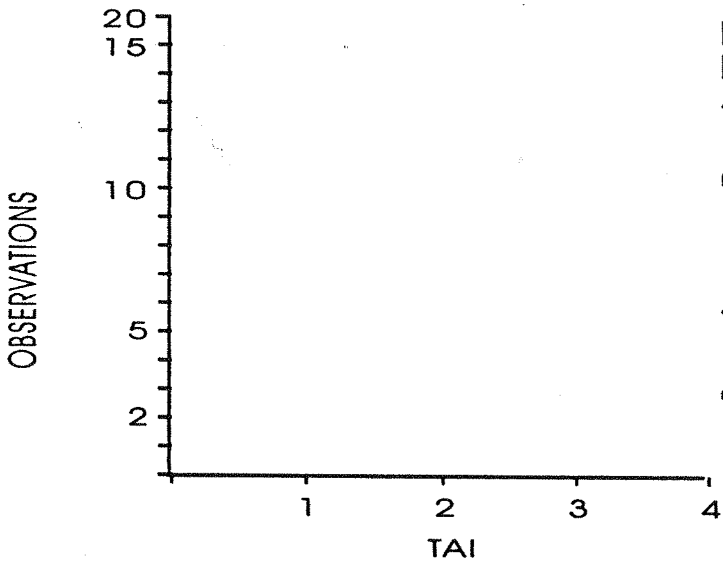


□Palynomorphs
TAI =
Flu =
Sum =

● Zooclasts
TAI =

■ Amorphous matter
TAI =
Flu =

Mobil - York Harbour
Borehole WW-3
475-490m



□Palynomorphs
TAI =
Flu =
Sum =

● Zooclasts
TAI =
Flu =

■ Amorphous matter
TAI =
Flu =

Appendix III

Water & Fluid Analysis

CHEMEX Labs Alberta Inc.

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Edmonton : 9331 - 48th Street, T6B 2R4, Telephone (403) 465-9877, FAX (403) 466-3332

MOBIL OIL CANADA
ATTENTION : KEVIN ULLYOTT

Sample Description : WW1 (B) YORK HBR N.F.
Sample Date & Time : January 23, 1997
Sampled By : KU
Sample Type : GRAB
Sample Station Code :

Chemex Worksheet Number : 97-00580-1
Chemex Project Number : MOBI345-0501
Sample Access :
Sample Matrix : WATER
Report Date : February 3, 1997

BATCH SPECIFIC QUALITY ASSURANCE REPORT

PARAMETER	DATE ANALYZED (DD-MM-YY)	QA/QC BATCH NUM ANAL	DUP Rr	MATRIX SPIKES RECOV %	MATRIX SPIKES CONTROL LIMITS LOWER	MATRIX SPIKES CONTROL LIMITS UPPER	CALIBRATION CHECK RECOV %	CALIBRATION CHECK CONTROL LIMITS LOWER	CALIBRATION CHECK CONTROL LIMITS UPPER
Calcium - (ICP) Dissolved	28-01-97	10 JCG	0.2	109.1	89.5	115.7	115.4	92.3	116.7
Magnesium - (ICP) Dissolved	28-01-97	10 JCG	0.2	101.6	95.3	107.3	100.6	96.5	109.4
Sodium - (ICP) Dissolved	28-01-97	10 JCG	0.0	105.4	92.5	109.6	105.1	93.2	111.3
Potassium -(ICP) Dissolved	28-01-97	10 JCG	0.7	103.9	88.2	112.4	102.2	90.2	112.6
Chloride - Dissolved	28-01-97	10 GK	0.8	105.5	90.8	108.8	100.0	94.3	105.6
Sulphate - (IC) Dissolved	28-01-97	1 AM	0.0	105.4	91.3	108.3	100.1	90.7	104.7
PP Alkalinity (as CaCO3)	NOT APPLICABLE								
Total Alkalinity (as CaCO3)	23-01-97	3 MC	0.7	NOT APPLICABLE			NOT APPLICABLE		
pH	23-01-97	3 MC	0.3	NOT APPLICABLE			NOT APPLICABLE		
Carbonate	NOT APPLICABLE								
Bicarbonate	NOT APPLICABLE								
Total Hardness (as CaCO3)	NOT APPLICABLE								
Hydroxide	NOT APPLICABLE								
Fluoride	31-01-97	2 MC	0.7	96.0	82.0	122.1	100.2	92.6	111.1
Specific Conductance	24-01-97	2 LG	0.0	NOT APPLICABLE			NOT APPLICABLE		
Turbidity	NOT APPLICABLE								
Total Dissolved Solids	NOT APPLICABLE								
Nitrite plus Nitrate Nitrogen as N	28-01-97	1 LZ	1.0	102.6	93.1	105.1	102.9	87.8	107.9
Iron - Dissolved (ICP-AES)	28-01-97	10 JCG	0.0	92.3	88.8	114.6	100.6	92.2	112.0
Manganese - Dissolved (ICP-AES)	28-01-97	10 JCG	0.0	99.1	87.3	112.7	102.1	89.1	107.1

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Edmonton : 9331 - 48th Street, T6B 2R4, Telephone (403) 465-9877, FAX (403) 466-3332

MOBIL OIL CANADA
ATTENTION : KEVIN ULLYOTT

NEWFOUNDLAND

Sample Description : WW3 (B) YORK HBR N.F.
Sample Date & Time : January 23, 1997
Sampled By : KU
Sample Type : GRAB
Sample Received Date: January 23, 1997
Sample Station Code :

Chemex Worksheet Number : 97-00580-2
Chemex Project Number : MOBI345-0501
Sample Access :
Sample Matrix : WATER
Report Date : February 3, 1997
Analysis Date : January 28, 1997

PARAMETER DESCRIPTION	ENVIRODAT CODE	UNITS	RESULTS	DETECTION LIMIT
Calcium - (ICP) Dissolved	020111	mg/L	4.09	0.01
Magnesium - (ICP) Dissolved	012111	mg/L	2.14	0.01
Sodium - (ICP) Dissolved	011111	mg/L	487.	0.01
Potassium -(ICP) Dissolved	019111	mg/L	2.26	0.02
Chloride - Dissolved	017206	mg/L	314.	0.5
Sulphate - (IC) Dissolved	016309	mg/L	2.7	0.1
PP Alkalinity (as CaCO3)	010151	mg/L	23.8	0.1
Total Alkalinity (as CaCO3)	010111	mg/L	660.	0.5
pH	010301	Units	8.65	0.01
Carbonate	006301	mg/L	28.5	0.5
Bicarbonate	006201	mg/L	747.	0.5
Total Hardness (as CaCO3)	010602	mg/L	19.0	0.5
Hydroxide	008501	mg/L	< 0.5	0.5
Fluoride	009105	mg/L	1.13	0.05
Specific Conductance	002041	uS/cm	2329.	0.02
Turbidity	002074	NTU	300.	0.1
Total Dissolved Solids	000201	mg/L	1214.	1.
Nitrite plus Nitrate Nitrogen as N	007110	mg/L	0.008	0.003
Iron - Dissolved (ICP-AES)	026109	mg/L	< 0.01	0.01
Manganese - Dissolved (ICP-AES)	025109	mg/L	0.030	0.001
Ion Balance		Balance	0.98	0.01

INTERPRETATION OF

POTABLE WATER ANALYSIS REPORT

The chemical characteristics of raw and treated water are significant for a number of reasons. The presence in drinking water of some chemical substances, above certain concentrations, may constitute a danger to health. Other chemicals constituents of water may interfere with water treatment processes, stain laundry and plumbing fixtures, or alter the physical characteristics of the water to the point where levels are objectionable. Absolute limits for public safety are difficult to establish since tolerance levels for certain parameters may vary from person to person.

pH: A complex situation exists between pH, carbon dioxide, hardness, alkalinity and temperature. pH levels of less than 6.5 may cause corrosion of metals in a distribution system, while levels greater than 8.5 will result in a greater probability of encrustation and scaling.

SODIUM: A maximum acceptable concentration for sodium in drinking water has not been established. Sodium is not considered a toxic metal, and up to 10 grams/day may be consumed by adults in good health without apparent adverse effects. Intake of sodium from water is only a small fraction of that consumed in a normal diet.

Usually <300 mg/L is considered safe on a salt restricted diet. Persons who have hypertension or congestive heart failure may be on a sodium restricted diet. If this is the case, they should consult with their physician. Excessive levels of sodium salts may cause water to effervesce when glasses are filled, stain aluminum ware, leave white deposits on glasses and utensils, and also leave a dark colored scum on cooked vegetables. Water softening using ion-exchange may add significant amounts of sodium to domestic water supplies.

POTASSIUM: Potassium is an essential nutritional element but at levels greater than 1000 mg/L it may have laxative properties.

CALCIUM: Calcium makes a contribution to hardness. Excessive calcium levels are detrimental for domestic users such as washing, bathing, and laundering because it may cause scaling of distribution systems. Recommended maximum level is 200 mg/L.

FLUORIDE: Fluoride is naturally present in most water supplies. The recommended level of fluoride in drinking water is 1.0 mg/L which is the optimum level for the control of dental caries. Fluoride at levels above 1.5 mg/L may cause fluorosis, which shows white spots on the teeth. At levels above 2.0 mg/L, mottling of the teeth may occur.

NITRATE & NITRITE: Nitrite-nitrogen and nitrate-nitrogen occur in natural and polluted waters. A temporary blood disorder, methemoglobinemia, has occurred in infants (less than 12 months of age) following ingestion of well water containing nitrates in concentrations greater than 10 mg/L as nitrogen. Nitrate and nitrite may not be removed by simple means (e.g. boiling of water).

NITRITE: The recommended limit is 1 mg/L based on the relationship between nitrite in drinking water and the incidence of infantile methemoglobinemia. (see Nitrate & Nitrite)

TOTAL DISSOLVED SOLIDS: The effects of dissolved solids in drinking water depend on the level of each parameter. Excessive hardness, taste, mineral content and corrosion are common properties of highly mineralized water. Deep wells (greater than 50 ft. deep) usually have more dissolved mineral substances than shallow wells. Over 1000 mg/L is considered high.

CONDUCTIVITY: Conductivity is a measure of the water's capacity to carry an electrical current which in turn is directly related to the concentration of ionized substances (dissolved inorganics) in the water. Over 2000 μS/cm is considered high.

HARDNESS: Public acceptability of the degree of hardness may vary considerably from one community to another. The hardness of water is the results of dissolved (polyvalent) metallic ions, principally calcium and to a lesser extent magnesium. Depending on the interaction of other factors, such as pH and alkalinity, water with a hardness above 200 mg/L may cause scale deposition in a distribution system. It may result in excessive soap consumption and subsequent "scum" formation. The recommended maximum value is 500 mg/L based on taste and household use.

MAGNESIUM: Magnesium is a constituent of hardness and relatively non-toxic to man. At high concentrations, magnesium salts may have a laxative effect, particularly upon new users, although the body can develop a tolerance over a period of time. Recommended maximum level is 125 mg/L, but if the sulfate level exceeds 250 mg/L, the recommended maximum level is 30 mg/L.

IRON: Although iron is an essential element in human nutrition, drinking water is not considered to be an important source. At levels over 0.3 mg/L, iron stains laundry and plumbing fixtures and causes an undesirable taste in beverages. The precipitation of excess iron gives an objectionable reddish-brown color to the water. Increases in the concentration of iron in water may be due to the presence of iron bacteria or change in ground water quality.

BICARBONATES: The concentration of bicarbonates in natural and polluted waters is related to other factors such as temperature, pH and concentration of other dissolved solids. Not a health hazard, however a recommended limit of 600 mg/L is occasionally used.

ALKALINITY: Alkalinity is the result of the presence of carbonates, bicarbonates and hydroxides of various minerals. It is not considered to be detrimental to health but is generally associated with high pH values, hardness and excessive dissolved solids. Levels of 500 - 1000 mg/L total alkalinity are considered high. Excessive levels of alkalinity may cause scaling in household plumbing fixtures, cooking utensils, pipes and water heaters.

SULPHATE: Although no serious health effects are associated with high sulphate levels, concentrations over 500 mg/L are considered high and in most cases unacceptable. Sulphates may impart a noticeable taste to the water. Waters high in sulphates may cause a laxative effect in occasional users, however, continuous users tend to be acclimatized.

CHLORIDE: The main consideration regarding chloride in drinking water is prevention of undesirable taste. For this reason a maximum chloride concentration of 250 mg/L is recommended. Levels in excess of this may be tolerated but will affect the taste of the water.

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MOBIL OIL CANADA
ATTENTION : KEVIN ULLYOTT

NEWFOUNDLAND

Sample Description : WATER RETURN TANK S#1.2.3.4
Sample Date & Time : January 23. 1997
Sampled By : KU
Sample Type : COMPOSITE
Sample Received Date: January 23. 1997
Sample Station Code :

Chemex Worksheet Number : 97-00580-3C
Chemex Project Number : MOBI345-0501
Sample Access :
Sample Matrix : SLUDGE
Report Date : February 3. 1997
Analysis Date : January 29. 1997

PARAMETER DESCRIPTION	ENVIRODAT CODE	UNITS		RESULTS	DETECTION LIMIT
Calcium - (ICP) Dissolved	020111	mg/L		961.	0.01
Magnesium - (ICP) Dissolved	012111	mg/L		0.14	0.01
Sodium - (ICP) Dissolved	011111	mg/L		93.0	0.01
Potassium -(ICP) Dissolved	019111	mg/L		54.0	0.02
Chloride - Dissolved	017206	mg/L		168.	0.5
Sulphate - (IC) Dissolved	016309	mg/L		0.5	0.1
PP Alkalinity (as CaCO3)	010151	mg/L		1866.	0.1
Total Alkalinity (as CaCO3)	010111	mg/L		1930.	0.5
pH	010301	Units		11.99	0.01
Carbonate	006301	mg/L		76.6	0.5
Bicarbonate	006201	mg/L	<	0.5	0.5
Total Hardness (as CaCO3)	010602	mg/L		2403.	0.5
Hydroxide	008501	mg/L		613.	0.5
Specific Conductance	002041	uS/cm		8105.	0.02
Total Dissolved Solids	000201	mg/L		1970.	1.
Nitrite plus Nitrate Nitrogen as N	007110	mg/L		0.969	0.003
Arsenic - Total (ICP-AES)		mg/L	<	0.2	0.2
Beryllium - Total (ICP-AES)	004009	mg/L		0.117	0.001
Cadmium - Total (ICP-MS)	048023	mg/L		0.0286	0.0002
Hexavalent Chromium	024101	mg/L	<	0.003	0.003
Iron - Dissolved (ICP-AES)	026109	mg/L	<	0.01	0.01
Lead - Total (ICP-MS)	082016	mg/L		2.17	0.0003
Manganese - Dissolved (ICP-AES)	025109	mg/L		0.003	0.001
Mercury - Total (CVAA)	080011	ug/L		2.50	0.05
Nickel - Total (ICP-MS)	028016	mg/L		0.966	0.0005
Selenium - Total (ICP-AES)		mg/L	<	0.04	0.04
Silver - Total (ICP-MS)	047016	mg/L		0.0062	0.0001
Thallium - Total (ICP-MS)		mg/L		0.003	0.001
Uranium - Total (ICP-MS)		mg/L		0.0414	0.0004

NOTES : Anion-cation balance is higher than our normal limits. Possibly due to the severe matrix of the sample.

CHEMEX Labs Alberta Inc.

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Edmonton : 9331 - 48th Street, T6B 2R4, Telephone (403) 465-9877, FAX (403) 466-3332

MOBIL OIL CANADA
ATTENTION : KEVIN ULLYOTT

Sample Description : WATER RETURN TANK S#1.2.3.4
Sample Date & Time : January 23. 1997
Sampled By : KU
Sample Type : COMPOSITE
Sample Station Code :

Chemex Worksheet Number : 97-00580-3C
Chemex Project Number : MOBI345-0501
Sample Access :
Sample Matrix : SLUDGE
Report Date : February 3, 1997

BATCH SPECIFIC QUALITY ASSURANCE REPORT

PARAMETER	DATE ANALYZED (DD-MM-YY)	QA/QC BATCH NUM ANAL	DUP Rr	MATRIX SPIKES RECOV %	MATRIX SPIKES CONTROL LIMITS LOWER	MATRIX SPIKES CONTROL LIMITS UPPER	CALIBRATION CHECK RECOV %	CALIBRATION CHECK CONTROL LIMITS LOWER	CALIBRATION CHECK CONTROL LIMITS UPPER
Calcium - (ICP) Dissolved	29-01-97	10 JCG	0.0	103.1	89.5	115.7	103.9	92.3	116.7
Magnesium - (ICP) Dissolved	29-01-97	10 JCG	0.0	97.8	95.3	107.3	99.5	96.5	109.4
Sodium - (ICP) Dissolved	29-01-97	10 JCG	0.0	97.7	92.5	109.6	98.8	93.2	111.3
Potassium -(ICP) Dissolved	29-01-97	10 JCG	0.0	97.9	88.2	112.4	95.7	90.2	112.6
Chloride - Dissolved	28-01-97	10 GK	0.8	105.5	90.8	108.8	100.0	94.3	105.6
Sulphate - (IC) Dissolved	30-01-97	10 AM	0.1	99.2	91.3	108.3	99.2	90.7	104.7
PP Alkalinity (as CaCO3)	NOT APPLICABLE								
Total Alkalinity (as CaCO3)	28-01-97	3 MC	1.5	NOT APPLICABLE			NOT APPLICABLE		
pH	28-01-97	3 MC	0.3	NOT APPLICABLE			NOT APPLICABLE		
Carbonate	NOT APPLICABLE								
Bicarbonate	NOT APPLICABLE								
Total Hardness (as CaCO3)	NOT APPLICABLE								
Hydroxide	NOT APPLICABLE								
Specific Conductance	28-01-97	2 LG	0.1	NOT APPLICABLE			NOT APPLICABLE		
Total Dissolved Solids	NOT APPLICABLE								
Nitrite plus Nitrate Nitrogen as N	28-01-97	1 LZ	1.0	102.6	93.1	105.1	102.9	87.8	107.9
Arsenic - Total (ICP-AES)	29-01-97	10 JCG	N.A.	95.8	72.0	130.2	93.0	81.5	112.6
Beryllium - Total (ICP-AES)	29-01-97	10 JCG	0.0	105.8	88.2	118.0	98.0	89.2	110.9
Cadmium - Total (ICP-MS)	28-01-97	20 WEM	0.0	115.5	78.1	120.3	96.6	83.4	114.8
Hexavalent Chromium	28-01-97	1 LG	0.0	100.0	83.0	110.8	100.8	86.7	110.6
Iron - Dissolved (ICP-AES)	29-01-97	10 JCG	1.0	103.7	88.8	114.6	98.0	92.2	112.0
Lead - Total (ICP-MS)	28-01-97	20 WEM	1.3	98.3	80.5	116.9	101.4	77.8	129.8
Manganese - Dissolved (ICP-AES)	29-01-97	10 JCG	0.2	103.9	87.3	112.7	98.6	89.1	107.1
Mercury - Total (CVAA)	28-01-97	2 TME	0.0	86.0	66.0	132.7	100.0	69.9	131.2
Nickel - Total (ICP-MS)	28-01-97	20 WEM	0.0	97.3	78.4	116.6	102.0	83.3	118.4
Selenium - Total (ICP-AES)	29-01-97	10 JCG	N.A.	109.9	75.6	130.4	90.8	86.0	115.0
Silver - Total (ICP-MS)	28-01-97	20 WEM	3.2	104.5	77.7	117.7	102.4	87.3	111.0
Thallium - Total (ICP-MS)	28-01-97	20 WEM	0.0	99.6	71.3	125.0	102.0	84.2	113.6
Uranium - Total (ICP-MS)	28-01-97	20 WEM	1.5	108.7	77.0	125.0	101.3	81.5	114.2

MOBIL OIL CANADA
ATTENTION : KEVIN ULLYOTT

NEWFOUNDLAND

CHEMEX Labs Alberta Inc.

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Edmonton : 9331 - 48th Street, T6B 2R4, Telephone (403) 465-9877, FAX (403) 466-3332

Sample Description : WATER RETURN TANK S#1,2,3,4
Sample Date & Time : January 23, 1997
Sampled By : KU
Sample Type : COMPOSITE
Sample Received Date: January 23, 1997
Sample Station Code :

Chemex Worksheet Number : 97-00580-3C
Chemex Project Number : MOBI345-0501
Sample Access :
Sample Matrix : SLUDGE
Report Date : February 3, 1997
Analysis Date : January 28, 1997

PARAMETER DESCRIPTION	ENVIRODAT CODE	UNITS	RESULTS	DETECTION LIMIT
Flash Point		Celcius	> 100	1.

MOBIL OIL CANADA
ATTENTION : KEVIN ULLYOTT

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Sample Description : WATER RETURN TANK S#1.2.3.4
Sample Date & Time : January 23, 1997
Sampled By : KU
Sample Type : COMPOSITE
Sample Station Code :

Chemex Worksheet Number : 97-00580-3C
Chemex Project Number : MOBI345-0501
Sample Access :
Sample Matrix : SLUDGE
Report Date : February 3, 1997

BATCH SPECIFIC QUALITY ASSURANCE REPORT

PARAMETER	DATE ANALYZED (DD-MM-YY)	QA/QC BATCH NUM ANAL	RELATIVE PERCENT DIFFERENCE	REFERENCE VALUE	REFERENCE CONTROL LIMITS LOWER	REFERENCE CONTROL LIMITS UPPER	CALIBRATION CHECK RECOV %	CALIBRATION CHECK CONTROL LIMITS LOWER	CALIBRATION CHECK CONTROL LIMITS UPPER
Flash Point	NOT APPLICABLE								

Appendix IV

Geochemistry

Mobil Technology Company

MOBIL EXPLORATION & PRODUCING TECHNICAL CENTER
P.O. BOX 819047
DALLAS, TEXAS 75381-9047

13777 MIDWAY ROAD
DALLAS, TEXAS 75244-4390

Date: March 14, 1997

To: Don Rae, Mobil Oil Canada

ORGANIC GEOCHEMISTRY OF CUTTINGS FROM SHALLOW TEST WELLS, WESTERN NEWFOUNDLAND, CANADA JOB NO. MBGJ17A

We have completed TOC and Rock-Eval analyses of the cuttings from the shallow test wells WW-2 and WW-3 drilled in Western Newfoundland. These analyses found:

1. Cuttings from 190 to 300 feet have low to negligible source potential

2. Cuttings from 300 to 400 feet have significant residual source potential. TOC values range from 0.56 to 1.49 percent and Hydrogen Indices range from 120 to 243 mg/g. Calculations of the degree of fractional conversion (f) and original TOC based on assumed original Hydrogen Indices suggest that the original source potential for the Green Point shale at this location is fair-to-good. We estimate that the shales have undergone about ~65 to 85% fractional conversion.

3. Cuttings from the WW-3 well have negligible source potential.

Please contact me (BM 381-8456) if you have any questions concerning the data or their interpretation.

Clifford C. Walters
Supervisor, Petroleum Systems

bcc: E.C. Griffiths
S.J. Moncrieff
J.W. Stinnett
M.B. Toon (Geochemistry Files)
Technical Library

CCWalters
Enclosures

Organic Geochemistry of Cuttings from the WW-2 & WW-3 Test Wells, Western Newfoundland, Canada

Clifford C. Walters

Reviewed by: J. Guthrie

Work by: R. Barrow, E.M. Flagg, C.L. Hellyer, Y. Liu, and M.B. Toon

INTRODUCTION

At the request of Don Rae, MOCAN, MEPTEC Geochemistry Labs analyzed cuttings from the WW-2 and WW-3 wells. These shallow test wells were drilled in 1996 as part of MOCAN's evaluation of Western Newfoundland.

EXPERIMENTAL & RESULTS

Total Organic Carbon & Rock-Eval

In order for a sedimentary rock to be a significant source of petroleum it must contain sufficient amounts of organic matter. Although it was once believed that 0.5 percent organic carbon was sufficient for a rock to be considered a source, an organic carbon content greater than 1.0 percent is a more realistic minimum. Various factors, however, must be considered when dealing with well cuttings. The total organic carbon (TOC) content of a source unit may have been changed by thermal events or influenced by oil-staining or recent contaminants. Source beds that are thinner than the sampling interval may have higher concentrations of organic matter than measured because of sedimentary rock dilution.

Total organic carbon measurements are merely the first step in screening potential source rocks. Samples that have high TOC may, in fact, contain mostly inert carbonaceous matter that is incapable of generating hydrocarbons. Samples with low TOC may contain oil-prone kerogen that, if present in sufficient quantities elsewhere in the basin, could be a source of petroleum.

The Rock-Eval pyrolysis technique provides an easy and rapid method for screening the source characteristics of sedimentary rocks. Free hydrocarbons that have either migrated into the sample or generated within the rock are reported by the parameter S_1. Pyrolyzate hydrocarbons, compounds generated from the kerogen by rapid, high-temperature heating, are reported by the parameter S_2. The latter measurement provides an indication of the sediment's remaining source potential. Measuring the temperature of maximum pyrolyzate yield (T_{max}) can derive a rough approximation of thermal maturity. The amount of oxygen bound in the kerogen is approximately measured by the S_3 parameter. By comparing the amount of S_2 and S_3 to the TOC, the Hydrogen (HI) and Oxygen (OI) Indices are obtained. These parameters are roughly proportional to the atomic H/C and O/C ratios and can be used to estimate kerogen type when plotted on a pseudo-Van Krevelen diagram. The Transformation Index (TR), also known as the Production Index (PI), is the ratio of $S_1/(S_1+S_2)$, the proportion of free-to-pyrolyzate hydrocarbons. PI is a measure of the amount of kerogen conversion, but can also be used as an indication of staining.

A summary of interpreting TOC and Rock-Eval threshold values is included in Appendix A.

Cuttings available for the MEPTEC study of the WW-2 well ranged from 190 feet to 400 feet, with sample spacing of 10-foot interval. Cuttings available for study of the WW-3 well ranged from 85 feet to 490 feet, with sample spacing ranging from 5 to 15 feet, but typically at a 10-foot interval. All cuttings were tested for total organic carbon (%TOC). These samples exceeding a minimum threshold of >0.12% TOC were analyzed by Rock-Eval (Tables 1-2, Figure 1).

DISCUSSION & CONCLUSIONS

WW-2 Cuttings from 190 to 300 feet have low to negligible source potential. TOC values range from only 0.19 to 0.33 percent and the Hydrogen Index range from 16 to 77 mg/g. The original source potential of this interval was not appreciably higher than the measured values.

Cuttings from 300 to 400 feet have significant residual source potential. TOC values range from 0.56 to 1.49 percent and Hydrogen Indices range from 120 to 243 mg/g. This interval is presumably Green Point Formation, the known rich source unit of petroleum in Western Newfoundland.

We can attempt to calculate the original source potential of these samples by assuming various values for the original Hydrogen Index (HI°). Table 3 shows calculations of the degree of fractional conversion (f), original TOC, expelled matter, and expulsion efficiencies. The latter two calculations are suspect as they rely on measured Production Indices, which in the case of shallow samples made have been influenced by surface processes (biodegradation, water washing, and oxidation).

Assumed Hydrogen Indices of 300, 500, and 700 mg/g were used in the calculations. 300 mg/g is the lowest reasonable value as the sample from 300-310 ft. has a measured HI of 243. We have seen examples of Green Point shale with HI exceeding 700 mg/g, but these are exceptionally rich zones and are not typical of the unit's average. 500 mg/g, the middle value in our assumptions appears to be the most likely scenario.

Averaged values for the degree of fractional conversion ranged from 0.56 to 0.90, with a value of 0.80 for HI° = 500 mg/g. A 65 to 80% degree of conservation is consistent with measured T_{max} values that average ~446° over this interval, given the Type I/II nature of the kerogen. The original TOC values for the HI° = 500 mg/g assumption range from 0.86 to 2.01 percent. Hence, the original source potential for the Green Point shale at this location is fair-to-good.

WW-3. Cuttings from the WW-3 well have negligible source potential. TOC values do not exceed 0.26 % and are typically below 0.15%. Even the richest samples failed to generate enough pyrolyzate to yield reliable Rock-Eval T_{max} values.

Table 1. TOC & Rock-Eval Data, Mobil Canada, WW-2, West Newfoundland, Canada

Sample ID	Sample Depth (feet)	Sample Type	TOC (wt %)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	Tmax (deg C)	Hydrogen Index	Oxygen Index	Production Index
1894-03-01	190-250	Cuttings	0.28	0.04	0.19	0.04	440	68	14	0.17
1894-03-02	250-260	Cuttings	0.19	0.01	0.03	0.04	440*	16	21	0.25
1894-03-03	260-270	Cuttings	0.20	0.02	0.07	0.04	428*	35	20	0.22
1894-03-04	270-280	Cuttings	0.28	0.04	0.16	0.04	441	57	14	0.20
1894-03-05	280-290	Cuttings	0.33	0.03	0.25	0.00	442	76	0	0.11
1894-03-06	290-300	Cuttings	0.31	0.05	0.24	0.07	442	77	23	0.17
1894-03-07	300-310	Cuttings	1.49	0.31	3.62	0.18	447	243	12	0.08
1894-03-08	310-320	Cuttings	0.91	0.14	1.12	0.13	446	123	14	0.11
1894-03-09	320-330	Cuttings	0.66	0.11	0.80	0.10	444	121	15	0.12
1894-03-10	330-340	Cuttings	0.95	0.19	1.45	0.04	446	153	4	0.12
1894-03-11	340-350	Cuttings	0.64	0.13	0.82	0.10	446	128	16	0.14
1894-03-12	350-360	Cuttings	0.63	0.15	0.86	0.10	447	137	16	0.15
1894-03-13	360-370	Cuttings	0.86	0.16	1.61	0.05	447	187	6	0.09
1894-03-14	370-380	Cuttings	0.75	0.13	1.00	0.06	445	133	8	0.12
1894-03-15	380-390	Cuttings	0.69	0.11	1.10	0.10	447	159	14	0.09
1894-03-16	390-400	Cuttings	0.56	0.10	0.67	0.05	444	120	9	0.13

TOC=Total organic carbon (wt.%)
S_2=Pyrolyzate hydrocarbons (mg/g of rock)
HI=Hydrogen Index (S_2*100/%TOC)
T_{max}=Temperature of maximum S_2 yield, °C
PI = Production Index $S_1/(S_1+S_2)$

S_1=Free hydrocarbons (mg/g of rock)
S_3=CO_2 released during pyrolysis (mg/g of rock)
OI=Oxygen Index (S_3*100/%TOC)
*Tmax values are suspect due to low S_2 yield

Table 2. TOC & Rock-Eval Data, Mobil Canada, WW-3, West Newfoundland, Canada

Sample ID	Sample Depth (feet)	Sample Type	TOC (wt %)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	Tmax (deg C)	Hydrogen Index	Oxygen Index	Trans Ratio
1894-03-17	85-95	Cuttings	0.26	0.00	0.02	0.04	439*	8	15	0.00
1894-03-18	95-105	Cuttings	0.23	0.01	0.03	0.05	389*	13	22	0.25
1894-03-19	105-115	Cuttings	0.15							
1894-03-20	115-125	Cuttings	0.10							
1894-03-21	125-135	Cuttings	0.10							
1894-03-22	135-145	Cuttings	0.13							
1894-03-23	145-155	Cuttings	0.11							
1894-03-24	155-165	Cuttings	0.19	0.02	0.03	0.21	318*	16	111	0.40
1894-03-25	165-175	Cuttings	0.23	0.01	0.01	0.11	XXX	4	48	0.50
1894-03-26	175-185	Cuttings	0.09							
1894-03-27	185-195	Cuttings	0.10							
1894-03-28	195-205	Cuttings	0.09							
1894-03-29	205-215	Cuttings	0.10							
1894-03-30	215-225	Cuttings	0.10							
1894-03-31	225-235	Cuttings	0.13	0.00	0.00	0.05	XXX	0	38	X
1894-03-32	235-245	Cuttings	0.09							
1894-03-33	245-255	Cuttings	0.10							
1894-03-34	255-265	Cuttings	0.10							
1894-03-35	265-275	Cuttings	0.12							
1894-03-36	275-285	Cuttings	0.09							
1894-03-37	285-295	Cuttings	0.09							
1894-03-38	295-305	Cuttings	0.13	0.00	0.00	0.02	XXX	0	15	X
1894-03-39	305-315	Cuttings	0.12							
1894-03-40	315-325	Cuttings	0.09							
1894-03-41	325-335	Cuttings	0.06							
1894-03-42	335-345	Cuttings	0.09							
1894-03-43	345-355	Cuttings	0.14	0.00	0.00	0.01	XXX	0	7	X

Table 2 (continued). TOC & Rock-Eval Data, Mobil Canada, WW-3, West Newfoundland, Canada

Sample ID	Sample Depth (feet)	Sample Type	TOC (wt %)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	Tmax (deg C)	Hydrogen Index	Oxygen Index	Trans Ratio
1894-03-44	355-365	Cuttings	0.10							
1894-03-45	365-375	Cuttings	0.10							
1894-03-46	375-385	Cuttings	0.10							
1894-03-47	385-395	Cuttings	0.11							
1894-03-48	395-405	Cuttings	0.13							
1894-03-49	405-415	Cuttings	0.12							
1894-03-50	415-425	Cuttings	0.09							
1894-03-51	425-435	Cuttings	0.20	0.01	0.13	0.03	455	65	15	0.07
1894-03-52	435-445	Cuttings	0.12							
1894-03-53	445-455	Cuttings	0.09							
1894-03-54	455-465	Cuttings	0.09							
1894-03-55	465-475	Cuttings	0.13	0.00	0.00	0.00	XXX	0	0	X
1894-03-56	475-490	Cuttings	0.09							

TOC=Total organic carbon (wt.%)
S_2=Pyrolyzate hydrocarbons (mg/g of rock)
HI=Hydrogen Index (S_2*100/%TOC)
T_{max}=Temperature of maximum S_2 yield, °C
S_1=Free hydrocarbons (mg/g of rock)
S_3=CO_2 released during pyrolysis (mg/g of rock)
OI=Oxygen Index (S_3*100/%TOC)
*Tmax values are suspect due to low S_2 yield
XXX = Unable to calculate Tmax value due to extremely low or non-existant S_2 yield.
X = Unable to calculate Transformation Ratio due to extremely low or non-existant S_1 and S_2 yield.

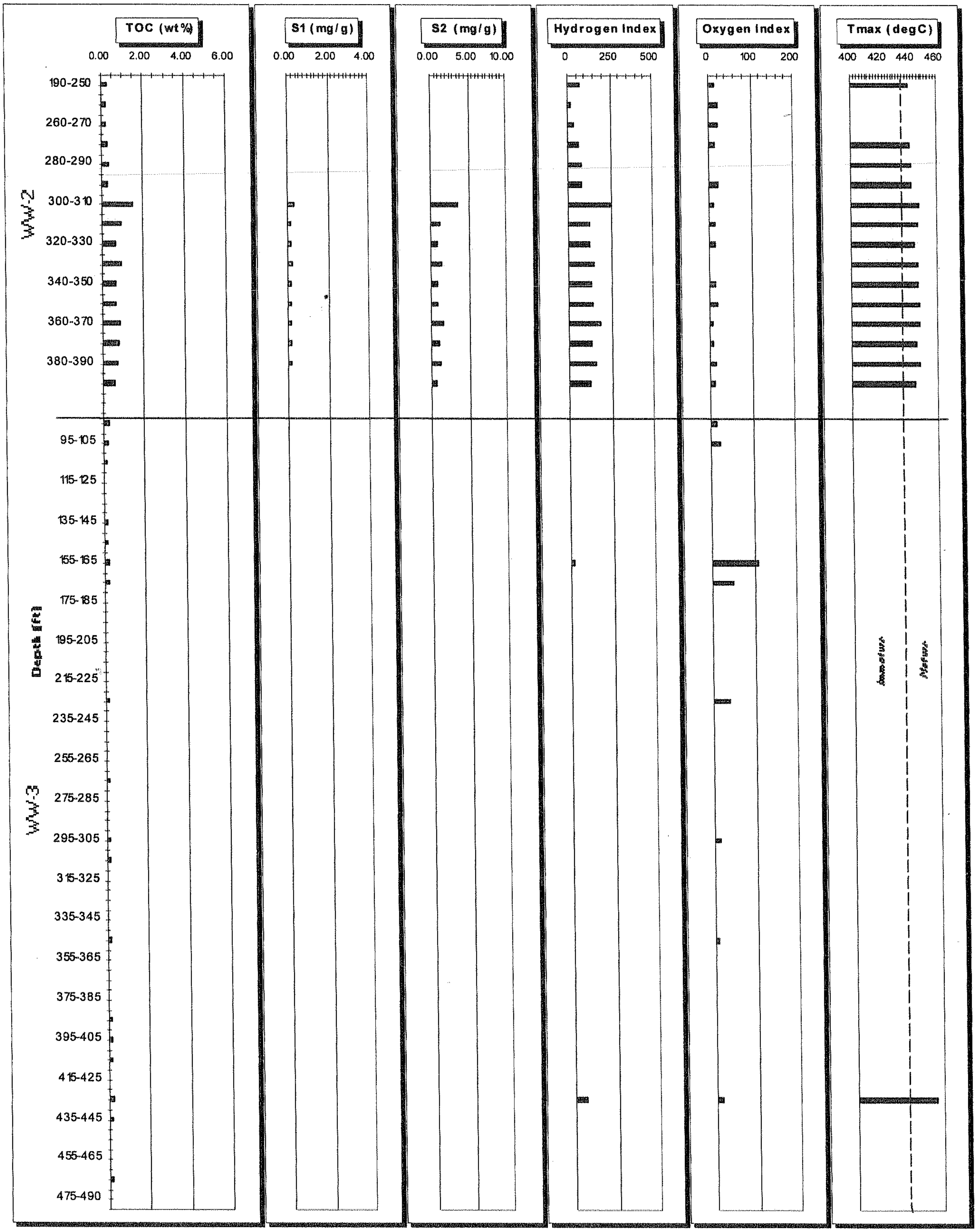


Figure 1. Geochemical log showing TOC & Rock-Eval data from the WW-2 & WW-3 wells, Western Newfoundland.

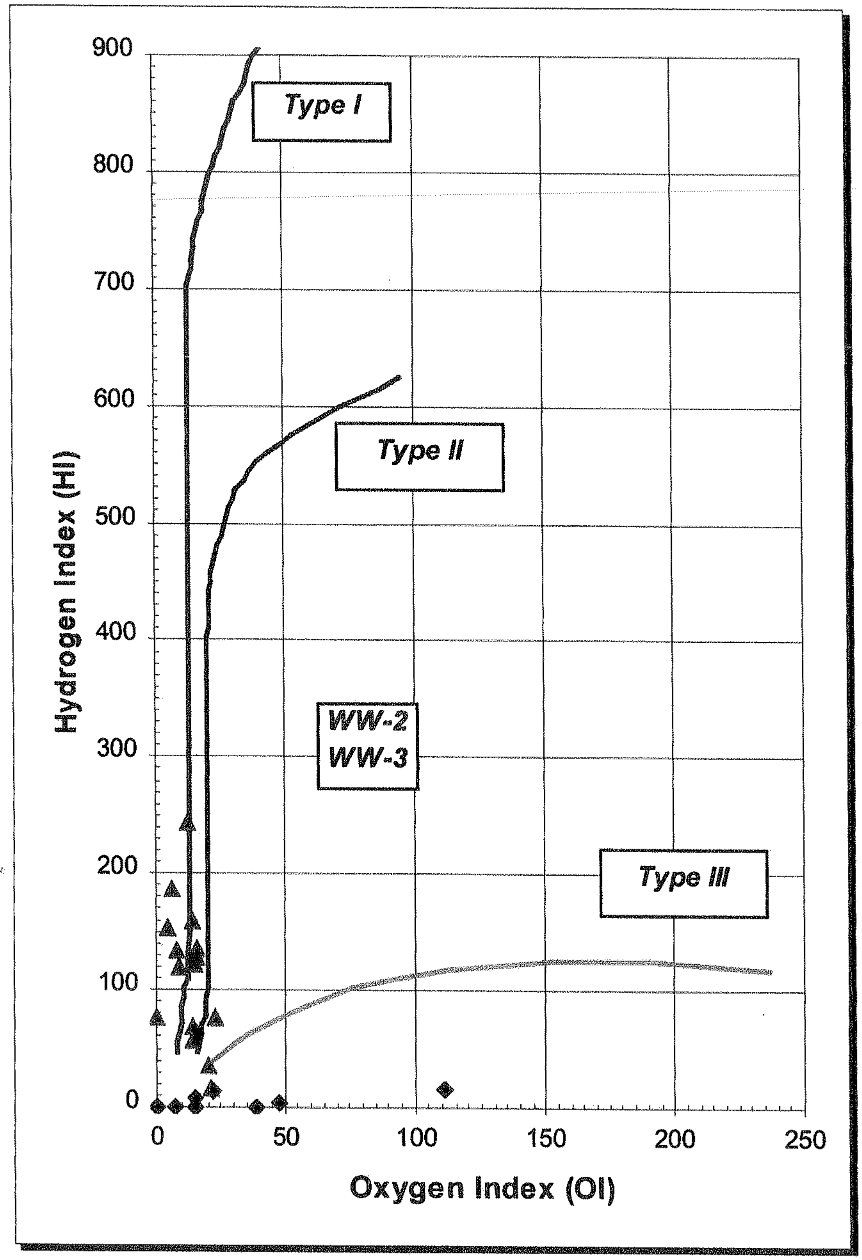


Figure 2. Modified Van Krevlen Diagram showing relatioship of Hydrogen & Oxygen Indices for cuttings from the WW-2 and WW-3 Wells.

Table 3. Calculation of fractional conversion, orginial TOC, and Expulsion Efficiency of cuttings from WW-2 based on assumed origin

Sample Depth (ft)	TOC (wt %)	Hydrogen Index	Prod. Index	Assumed PI	Assumed HI	*f*	Original TOC	S1 Expelled	Exp. Eff. %
300-310	1.49	243	0.08	0.02	300	0.23	1.56	0.85	73
	1.49	243	0.08	0.02	500	0.64	2.01	6.35	95
	1.49	243	0.08	0.02	700	0.82	2.83	16.31	98
310-320	0.91	123	0.11	0.02	300	0.65	1.08	2.04	94
	0.91	123	0.11	0.02	500	0.84	1.39	5.85	98
	0.91	123	0.11	0.02	700	0.92	1.96	12.78	99
320-330	0.66	121	0.12	0.02	300	0.66	0.78	1.49	93
	0.66	121	0.12	0.02	500	0.84	1.01	4.26	97
	0.66	121	0.12	0.02	700	0.92	1.43	9.31	99
330-340	0.95	153	0.12	0.02	300	0.56	1.09	1.70	90
	0.95	153	0.12	0.02	500	0.80	1.41	5.55	97
	0.95	153	0.12	0.02	700	0.90	1.98	12.55	99
340-350	0.64	128	0.14	0.02	300	0.64	0.75	1.35	91
	0.64	128	0.14	0.02	500	0.83	0.97	4.01	97
	0.64	128	0.14	0.02	700	0.92	1.37	8.87	99
350-360	0.63	137	0.15	0.02	300	0.61	0.73	1.23	89
	0.63	137	0.15	0.02	500	0.82	0.95	3.82	96
	0.63	137	0.15	0.02	700	0.91	1.34	8.55	98
360-370	0.86	187	0.09	0.02	300	0.44	0.96	1.16	88
	0.86	187	0.09	0.02	500	0.74	1.23	4.53	97
	0.86	187	0.09	0.02	700	0.87	1.74	10.69	99
370-380	0.75	133	0.12	0.02	300	0.62	0.88	1.56	92
	0.75	133	0.12	0.02	500	0.82	1.14	4.67	97
	0.75	133	0.12	0.02	700	0.91	1.60	10.34	99
380-390	0.69	159	0.09	0.02	300	0.54	0.79	1.21	92
	0.69	159	0.09	0.02	500	0.79	1.02	4.00	97
	0.69	159	0.09	0.02	700	0.89	1.44	9.10	99
390-400	0.56	120	0.13	0.02	300	0.66	0.66	1.27	93
	0.56	120	0.13	0.02	500	0.84	0.86	3.62	97
	0.56	120	0.13	0.02	700	0.92	1.22	7.92	99
				Average	300	0.56	0.93	1.39	89
					500	0.80	1.20	4.67	97
					700	0.90	1.69	10.64	99

TOC^x=measured total organic carbon, HI^x=measured Hydrogen Index, PI^x=measured Production Index ($S_1/(S_1+S_2)$)
PI°=Assumed initial Production Index, HI°=Assumed initial Hydrogen Index
f = fractional conversion = $1\text{-}Hi^x\{1200\text{-}[HI°/(1\text{-}TR°)]\}/HI°\{1200\text{-}[HI^x/(1\text{-}Pi^x)]\}$
Original TOC = $83.33(HI^x)(TOC^x)/[HI°(1\text{-}f)(83.33\text{-}TOC^x)+HI^x(TOC^x)]$
Petroleum (S1) Expelled = $1000[TOC°\text{-}TOC^x)/(83.33\text{-}TOC^x)$
Exp. Eff. = Expulsion Efficiency = $100 \times \{1\text{-}(1\text{-}f)*[PI^x/(1\text{-}PI^x)/[f\text{+}PI°/(1\text{-}PI°)]$

Appendix A. Guidelines for describing the quantity, quality, and thermal maturity of organic matter in source rocks (Peters and Cassa, 1994).

Table 1. Petroleum Potential (Quantity) of an Immature Source Rock

Petroleum Potential	Organic Matter: TOC (wt.%)	Rock-Eval Pyrolysis: S_1 [a]	Rock-Eval Pyrolysis: S_2 [b]	Bitumen [c] (wt. %)	Bitumen [c] (ppm)	Hydrocarbons (ppm)
Poor	<0.5	<0.5	<2.5	<0.05	<500	<300
Fair	0.5 - 1	0.5 - 1	2.5 - 5	0.05 - 0.10	500 - 1000	300 - 600
Good	1 - 2	1 - 2	5 - 10	0.10 - 0.20	1000 - 2000	600 - 1200
Very Good	2 - 4	2 - 4	10 - 20	0.20 - 0.40	2000 - 4000	1200 - 2400
Excellent	>4	>4	>20	>0.40	>4000	>2400

[a] mg HC/g dry rock distilled by pyrolysis
[b] mg HC/g dry rock cracked from kerogen by pyrolysis
[c] Evaporatio of the solvent used to extract bitumen from a source rock or oil from a reservoir rock causes loss of the volatile hydrocarbons below about n-C15. Thus, most extracts are described as "C_{15+} hydrocarbons". Lighter hydrocarbons can be at least partially retained by avoiding complete evaporation of the solvent (e.g., C_{10+})

Table 2. Kerogen Type (Quality) and Expelled Products[a]

Kerogen Type	Rock-Eval: Hydrogen Index (mg HC/g TOC)	Rock-Eval: HI/OI S_2/S_3	Atomic H/C	Main Expelled Product at Peak Maturity
I	> 600	>15	>1.5	Oil
II	300-600	10-15	1.2-1.5	Oil
II/III[b]	200-300	5-10	0.7-1.0	Mixed oil and gas
III	50-200	1-5	0.7-1.0	Gas
IV	<50	<1	<0.7	None

[a] Based on a thermally immature source rock. Ranges are appoximate
[b] Type II/III designates kerogens with compositions between Type II and III pathways that show intermediate HI.

Appendix A (continued). Guidelines for describing the quantity, quality, and thermal maturity of organic matter in source rocks (Peters and Cassa, 1994).

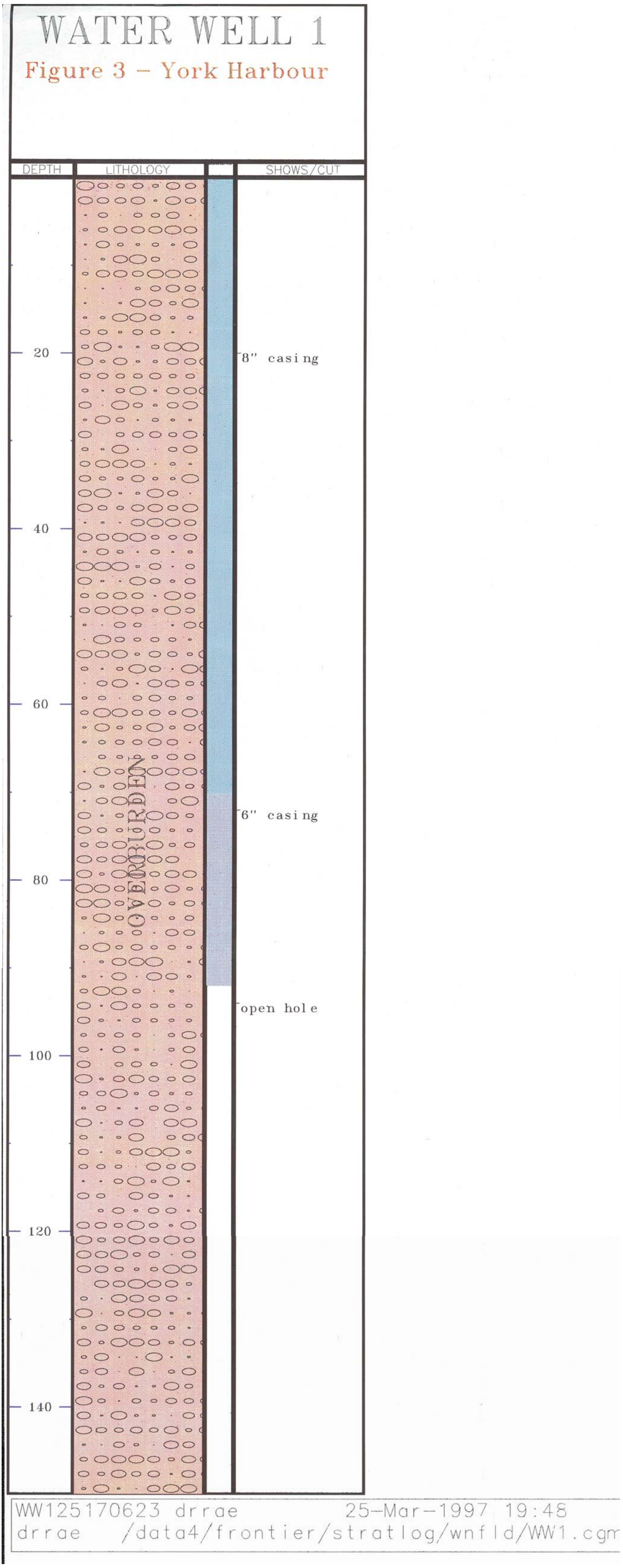
Table 3. Themal Maturation

Stage of Themal Maturity for oil	Rock-Eval Tmax (°C)	Rock-Eval PI $S_1/(S_1+S_2)$	Generation of Bitumen (mg/g rock)	Bitumen[b] / TOC	Optical Petrography Ro (%)	Optical Petrography TAI[a]
Immature	<435	<0.10	<50	<0.05	0.2 - 0.6	1.5 -2.6
Mature						
Early	435 - 445	0.10 - 0.25	50 -150	0.05 - 0.15	0.6 - 0.65	2.6 - 2.7
Peak	445 - 450	0.25 - 0.40	150 - 250	0.15 - 0.25	0.65 - 0.90	2.6 - 2.9
Late	450 - 470	> 0.40	—	—	0.90 - 1.35	2.9 - 3.3
Post Mature	>470	—	—	—	>1.35	> 3.3

[a] TAI, Thermal Alteration Index, May vary depending on calibration scale

[b] Mature oil-prone source rocks with Type I or II kerogen commonly show bitumen/TOC ratios in the range of 0.5 to 0.25. Caution should be applied when interpreting extract yields from coals. Gas-prone coals show high extract yields suggesting oil-prone character, but extract yield nomralized to TOC is low (<30mg HC/g TOC). Bitumen/TOC ratios over 0.25 can indicate contamination, oil-staining, or can be artifiacts caused by ratios of small, inaccurate numbers.

Peters, K.E., and M.R. Cassa, 1994, Applied source-rock geochemistry. In: The petroleum system--from source to trap (L.B. Magoon and W.G. Dow, eds.) American Association of Petroleum Geologists Memoir No. 60, p. 93-120.



WATER WELL 1
Figure 3 – York Harbour
DEPTH
LITHOLOGY
SHOWS/CUT
20
40
60
80
100
120
140
8" casing
6" casing
open hole
OVERBURDEN
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WATER WELL 2

Figure 4 – Lark Harbour Ballfield

WATER WELL 3

Figure 5 – Little Port

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drrae /data4/frontier/stratlog/wnfld/WW3.cgm