MOBIL YORK HARBOUR No. 1
Core Well

Final Well Report

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2.2 Introduction

Mobil Oil Canada Properties drilled a 299.3 m TVD well in the York Harbour area approximately 30 km west of Corner Brook, Newfoundland. A map showing the location of the well is attached. The primary purpose of the well was to gain geological information by continuous coring of the rock stratigraphy, not to determine the presence of a hydrocarbon reservoir. The well was drilled using a Longyear 34 drilling unit owned and operated by East Coast Drilling Company. Approximately 295 m of core from the Blow Me Down Brook formation was recovered over the interval. The well has been abandoned.

2.3 Map

The location of the York Harbour 1 well is shown in Figure 1.

2.4 General Information

Well Name --	Mobil York Harbour No. 1	
Exploration Permit --	96-113 (parcel 19)	
Drilling Program Approval	# 96-103-01	
Authority to Drill a Well	# 96-103-01-01	
Wellbore Coordinates	Northing:	5435750
	Easting:	406350
	Nad: 27	

2.5 Difficulties and Delays

While drilling the well the pipe became stuck in the hole twice. The first instance occurred while drilling with an NQ bit at 2.4 m below HW casing that had been turned into the ground approximately 1.5 m. Cause of the stuck drillstring was likely an unstable HW casing seat. An NQ bit and reaming shell were left in the hole. The rig was skidded back a short distance and the well was restarted.

The second case of stuck pipe occurred while drilling NQ hole at 28 m. While coring, with full circulation, the drill string became stuck. The inner barrel was recovered, but the drill string could not be recovered, even after drilling a short distance through the NQ core head. The rig was again skidded a very short distance and a new hole drilled.

Other difficulties encountered during the drilling operation was intermittent lost circulation while drilling the surface hole, and lost circulation during cementing of the NW surface casing, requiring it to be recemented.

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3. Drilling Operations

3.1 Elevation

(approximates) GL - 40 m, Rig floor - 42 m

3.2 Total Depth

299.3 m

3.3 Spud Date

96-12-06 12:00

3.4 Drilling Completed

97-01-03 17:00

3.5 Rig Release

97-01-05 08:00

3.6 Well Status

Abandoned

3.7 Hole Sizes

HQ - 98.4 mm to 92.5 m
NQ - 73 mm to 299.3 m

3.8 Bit Records

NA

3.9 Casing and Cementing Record

HW casing was rotated into the ground to a depth of approximately 3 m.

NW casing was set at 92.5 m. One cubic meter of 1800 kg/m^3 Portland cement slurry with 2% $CaCl_2$ was pumped with circulation to surface. It was displaced with 0.3 m^3 of water and the casing closed in at surface to prevent U-tubing. Returns were lost during displacement. The well was shut in for 6 hours for the cement to set, but the casing was not supported and circulation was obtained up the casing annulus. A second cement job was performed using 1m^3 of 1800 kg/m^3 Portland cement slurry with 2% $CaCl_2$ containing celloflake.

Returns were obtained for 60% of the cement job. The cement was displaced with 0.2 m^3 of water, with slight returns and pump pressure increased. Pressure was maintained while waiting on cement to set. On drillout the cement was tagged at 43 m inside the casing.

3.11 Drilling Fluid

Fresh water was used for drilling the surface hole. Fresh water with slight additions of flocculating polymer were used for clear floc water drilling in the main hole. Small sweeps of Matex polymer were also used on a random basis to ensure effective hole cleaning was occurring. A shallow surface pit measuring approximately 3 X 5 X 1 m deep was constructed for the purpose of setting the mud tanks at a lower elevation. However, the pit filled with water due to active shallow surface water and was therefore not used for any purpose, other than a water source for initially filling the drilling fluid tanks with water. The two drilling fluid tanks were set on the ground and their volume was approximately 15 cubic meters each. Each tank had two compartments Drilling fluid was circulated using these tanks throughout the well. The pit was not used for drilling.

3.12 Fluid Disposal

No fluid was disposed of downhole. Clear fluid and tank bottom sludge was hauled to municipal land fill in Corner Brook by vaccum truck. Disposal was approved by landfill operator and Gov't Services and Land Dept. Samples were taken and have been analyzed, and a copy of the analysis is included in Appendix III, titled Water Return Tank.

3.13 Fishing Operations

See section 2.5

3.14 Well Kicks

No kicks or formation inflow occurred.

3.15 Formation Leak-Off Tests

No leak-off tests were conducted.

3.16 Time Distribution

see next page following section 3.18

3.17 Directional Surveys

No directional surveys were conducted.

3.18 Abandonment Plugs

The well was abandoned with two cement plugs. The first cement plug was set from TD of 299.3 m to 150 m with 0.56 m3 of Portland cement slurry weighing 1800 kg/m^3. The second plug was set from 140 m to surface, again using 0.56 m3 of Portland cement slurry weighing 1800 kg/m^3. The cement used in both plugs used 2% $CaCl_2$. The casing was cut approximately 1 m below ground elevation and a cap welded on to the casing.

The wellsite, which is located in an abandoned quarry pit, was restored to near original conditions.

3.16 Time Distribution

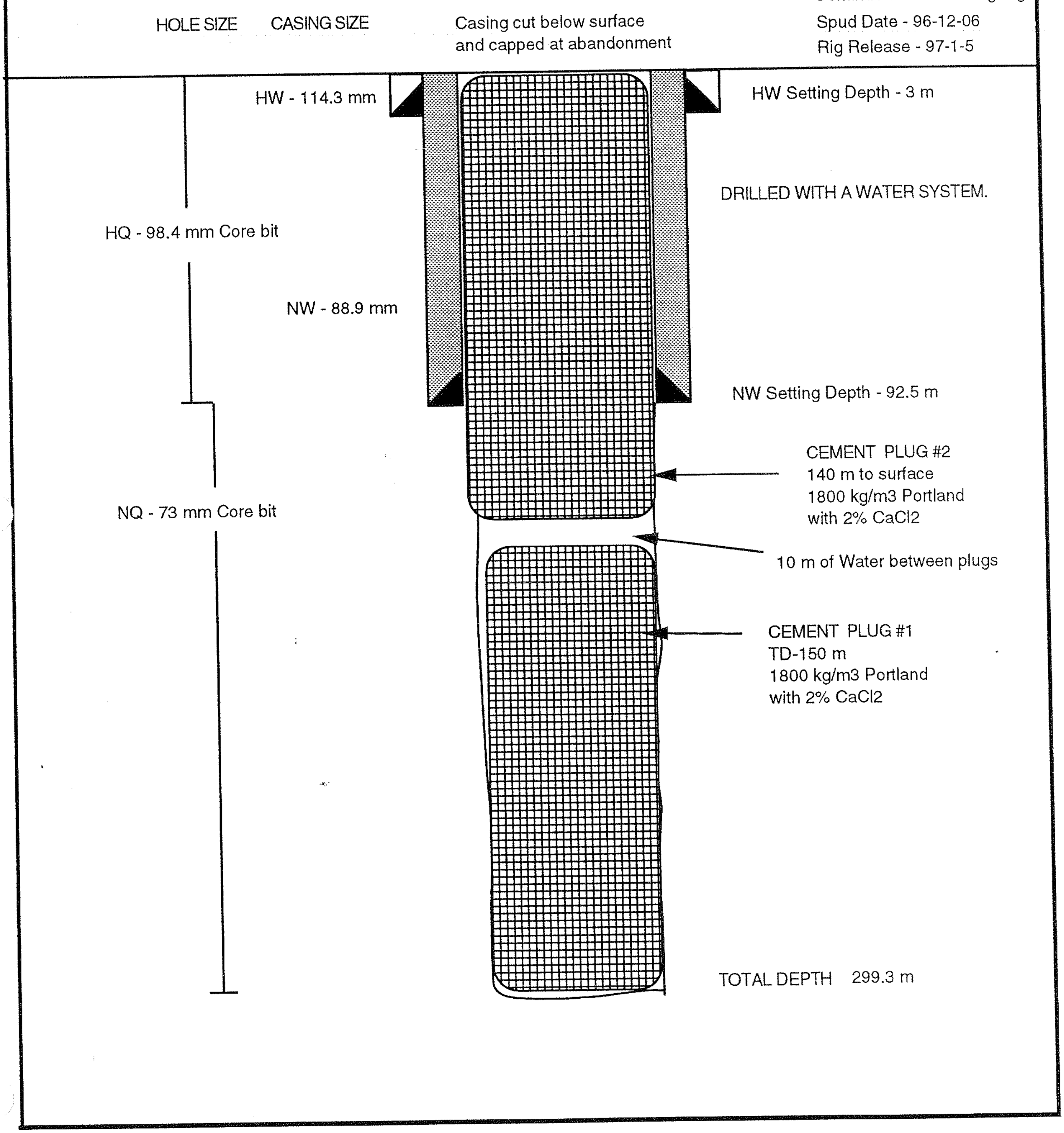
Dec. 6, 96	Spudded well and stuck pipe
Dec. 7, 96	Skidded rig and restarted
Dec. 8, 96	Cored to 28 m and stuck pipe.Fished for pipe without success.Skidded rig.
Dec. 9, 96	Restarted well and drilled to 14.5 m.
Dec. 10, 96	Cored to 47.5 m
Dec. 11, 96	Cored to 77.7 m
Dec. 12, 96	Cored to 88.1 m
Dec. 13, 96	Cored to 92.7 m. Ran NW casing to 92.5 m and cemented.
Dec. 14, 96	Repeated cement job. WOC and nipple up BOP equipment.
Dec. 15, 96	Nipple up BOP equipment. Tagged cement at 37 m, and started drilling solid cement at 42.7 m.
Dec. 16, 96	Drilled cement to 86.8 m, Pressure tested casing and BOP to 3900 kPa and drilled ahead to 109.7 m with NQ core bit.
Dec. 17, 96	Cored to 139 m
Dec. 18, 96	Cored to 171.9 m
Dec. 19, 96	Cored to 197.9 m
Dec. 20, 96	Cored to 210.5 m. Shut down due to weather, high winds.
Dec. 21, 96	Tripped for bit. Cored ahead to 217 m.
Dec. 23, 96	Cored to 244 m. Shut down rig at 14:00 hrs for X-mas break.
Dec. 27, 96	Rig equipment failure.
Dec. 28, 96	Repaired rig. Cored to 247 m.
Dec. 29, 96	Cored to 263.5 m.
Dec. 30, 96	Cored to 269.5 m. Shut down rig at 17:00 hrs for weather.
Dec. 31, 96	Shut down rig for weather, very cold, freezing problems.
Jan. 1, 96	Shut down rig for weather, very cold, freezing problems.
Jan. 2, 96	Shut down rig for weather, very cold, freezing problems. Started up at 15:30 and cored to 290 m.
Jan. 3, 96	Cored to 299.3 m and tripped to run in hole open ended for abandonment.
Jan. 4, 96	Set two cement plugs to abandon the wellbore.
Jan. 5, 96	Rig released at 08:00.

3.19 Well Schematic

see following page

WELLBORE SCHEMATIC
Mobil York Harbour #1

Rig - East Coast Drilling,
Continuous Core Mining Rig
Spud Date - 96-12-06
Rig Release - 97-1-5



4. GEOLOGY

4.1 Drill Cuttings

Only continuous cores were recovered.

4.2 Cores

Continuous core was recovered using a modified Longyear 34 mining rig. Three shallow wells were drilled within approximately one meter of each other. The first well (York Harbour 1(A)) burnt out a casing shoe at 2.82 m. depth. The rig was skidded 0.3 m. to a new location where a second hole, York Harbour 1B), was spud. At 30.18 m depth the second well jammed off and because circulation could not be re-established, a third well, York Harbour 1C, was initiated approximately 0.2 m. from the second well and drilled to 299.3m. Only this third core was subjected to tests. A summary of the lithology and tests undertaken on this core is summarized in log form in Figure 2 in the back pocket of this report.

The cores from the three wells York Harbour 1A), 1B and 1C, at the time of writing , are being stored in Petrel Robertson's storage facility at 2801-18th Street in Calgary. They shall be forwarded to a storage facility in Newfoundland yet to be designated by the Department of Mines and Energy.

4.3 Lithology

Lithological descriptions for each of the cores are provided in Appendix I. The data for the York Harbour 1C) well is summarized pictorially in Figure 2. 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 and stain are also summarized in Figure 2.

4.4 Stratigraphic Column

The only stratigraphic unit penetrated was the Blow me Down Brook Formation. The structural/stratigraphic position of this formation is given in the stratigraphic column in Figure 3.

Louise Quinn of Brandon University examined the core and petrographically studied surface and core samples to determine the formation name. Thin section sample points are summarized in Figure 2 as is the lithology. Copies of Louise Quinn's reports (3) are presented as Appendix II.

4.5 Biostratigraphic Data

Biostratigraphic studies by Omnichron Associates of St. John's confirm an Early Cambrian age , likely Forteau equivalent. Locations of the biostratigraphic samples are summarized in Figure 2 and copies of the report is presented in Appendix III.

5. Well Evaluation

5.1 Downhole Logs

Downhole logs were not run.

5.2 Other Logs

Logs falling in the "other" category such as dipmeter, mud logs etc. were not run.

5.3 Synthetic Seismograms

not run

5.4 Vertical Seismic Profiles

not run

5.5 Velocity Surveys

not run

5.6 Formation Stimu;lation

not undertaken

5.7 Formation Flow Tests

not undertaken

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6. OTHER

6.1 Mud Loggers Report

none

6.2 Directional & Deviation Survey Report(s)

none

6.3 Final Legal Survey Plan

Coordinates (NAD 27) measured using a Trimble Scout GPS unit: 406350; 5435750

6.4 Core Photos

The core was logged in the field and then shipped to Calgary for normal and fluorescent light photography as well as other tests described above. Copies of plain light and fluorescent light photos are provided in a separate volumn as Appendix IV.

* CAUTION* Petrel Robertson had to transfer the core from the original wood core boxes to "standard-sized" trays in order to accomodate their photographing equipment. After photgraphing the core was then transferred back to the original wood core boxes. The exercise of transferring the core back and forth has in some cases caused the 1) log descriptions 2) the photgraphs and 3) the final placement of the core to differ by 1-2 meters in depth. Future attempts to reconcile the depths as seen in the photographs with its present placement in the core boxes or with the original log descriptions should bear in mind the potential for a 1-2 meter shift.

6.5 Core Analysis

The interval cored contained minimal intergranular porosity. The oil shows were associated with fractures and vugular cavities within the fracture lining cements. Six zones were selected over the core length to get a feel for the importance of this type of porosity system. The values ranged from 1.6 to 3.9% porosity and 0.04 to 0.32 md K_{max} (permeability). The sample points for the core plugs are summarized in Figure 2. The raw data in paper and digital form is presented as Appendix V.

6.6 Fluid Analysis Reports

See following section (6.7).

6.7 Oil, Gas and Water Analysis Reports

At their lab in Calgary Petrel Robertson attempted to recover fluids from 5 separate intervals as summarized in Figure 1. Two of these recovered minimal oil and water; the remaining three recoverd only water. In all cases the samples were contaminated with tolulene by the apparatus used to extract the fluid.

Three of the samples were sent for analysis to Mobil's lab in Dallas. The results of this study are presented as Appendix VI.

Petrel Robertson also determined an API gravity for the oil using refractometry at two points along the core length ... 25.6m. - 35 deg API; 198.25m. - 26 deg API. Sample points are shown in Figure 2 and the data is incorporated into Petrel Robertson's Core Analysis Data report in Appendix V.

6.8 Geochemical Report

As mentioned above in section (6.7) oil analyses (Petrel) and a geochemical study (Mobil) were performed on the extracted fluids. These data are presented in appendices V and VI. Maturation studies were undertaken by Omnichron and are included in their report in Appendix III.

6.9 Biostratigraphy Report

Surface samples and core samples were submitted to Omnichron Associates for age and maturity determinations. The E. Cambrian age (Forteau equivalent) established by this study is in agreement with Louise Quinn's stratigraphic determination as Blow Me Down Brook formation.

The sample points are indicated in Figure 2. As mentioned in section 4.5 Omnichron's report appears as Appendix III.

6.10 Petrological Report

Louise Quinn of Brandon University examined two surface samples and 7 subsurface core samples petrographically for lithology, textural, cementing and timing relationships. Sample points are shown in Figure 2 and the data is presented as three separate reports in Appendix II.

6.11 Palynological Report

See section 6.9

6.12 Paleontological Report

See section 6.9

Appendix I

Lithological Descriptions

MOBIL OIL CANADA PROPERTIES

Well Name: YORK HARBOUR 1(A)
Spud: Dec. 6, 1996 **Completed:** Dec. 6, 1996
GPS Coordinates: 406350 ; 5435750 (NAD 27)
Logged By: D. Rae

Depth Interval	Sample Description
0-2.82m (9.25')-	• medium-coarse grain, **arkosic sandstone** with local patches of conglomerate; poorly sorted; subangular to subrounded • dark grey to grey colour, clay and mica in matrix; minor calcareous cement • no porosity (very well cemented with finer grained silt) clay and minerals altering to clay; traces of distinctive jasperoid mineral and K-spar (altered volcanics?); approximately 1% shale rip up clasts; trace pyrite; bedding indiscernable • 1% dolomite patches and hairline to 3mm veinlets (generally steeply dipping but highly irregular) • No shows; no fluorescence
2.82m (9.25')-	• Burned out casing shoe. **Skid 0.3m to new location: YORK HARBOUR 1B.**

MOBIL OIL CANADA PROPERTIES

Well Name: YORK HARBOUR 1(B)
Spud: Dec. 7, 1996 **Completed:** Dec. 8, 1996
GPS Coordinates: 406350 ; 5435750 (NAD 27)
Logged By: D. Rae

Depth Interval	Sample Description
2.82m (9.25')- 30.18m (99.0')	• Lost hole at 30.18m (27.36m Core): • Recovery 98-100%
2.82m. (9.25') 23.60m. (77.43')	• coarse grain **sandstone** to fine grain conglomerate; dark grey to grey; poorly bedded; subangular to subrounded grains; rare lithic fragments appear to be fine grain acid intrusive- odd pebble to 8mm size; no visible porosity within sandstone; matrix is silt, clay; finer sand • dolomite - fluorescence and oil cut common in pale pink-white dolomite (quartz) filled fractures; oil stain rarely noted (i.e. very light oil) but streaming cut (fast to moderate) noted when placed in tetrachloroethylene. Following are zones of veinlets or single hairline veinlets where fluorescence was noted: 5.96m; 6.66m; 7.46-7.58m (streaming cut) 8.04m; 8.85m; 14.56m; 14.76m (fast cut) 16.72m; 16.95m; 17.10-17.25m (approx 10 veinlets) 18.25m; 18.95m; 20.72m (streaming cut) 20.95-21.06m; 12.20-21.30m; 21.66-21.80m; 21.98-22.06m; 22.16m; 22.35m
23.60m (77.43')- 26.0m (85.30')	• dark grey to black **shale**; sharp upper contact dips at 75° lower contact is gradational (increasing to silt size) • **shale** shows local slickensides and is polished by movement; micaceous no veinlets; no shows; no fluorescence contact dips at 75°; lower contact is gradational (increasing to silt size)
26.0m (85.30')- 29.96m (98.29')	• medium grain **arkosic conglomerate** at base; crude fining upward sequence; no distinguishable bedding; poorly sorted; subangular to subrounded; grey to dark grey locally pebbly shale in patches

- fluorescence common in fractures lined with pink **dolomite** (± quartz) not all veins have associated fluorescence. Fluorescence noted at: 26.92m; 27.04m; 27.24m; 27.64m (fast cut); 27.75;-27.87m; 27.99m; 28.05m; 28.62m; 28.68m; 28.84-28.94m; 29.12m; 29.26m; 29.35m (fast streaming cut) 29.60m (20° dip-some darker oil with fluorescence fast streaming cut)
- Most fractures are >60° dip but some can be highly irregular (anastomosing)
- Fluorescence associated with micro porosity and vugs in dolomitic veinlets.

29.96m (98.29')- 30.18m (99.02')

- Upper 15cm is grey powdery silty clay (weathered **shale**?). Benthonitic feel to clay. Last 7cm is dark grey to black shale; slickensided micaceous, soft (few quartz pebbles to 5 mm).

30.18m (99.02')

- E.OH. (JAMMED OFF-couldn't circulate). **(HAD TO START A 3RD STRAT TEST)**

Core to date shows a series of stacked, fining upward but very poorly sorted beds (likely turbidites). Age is Lower Cambrian as evidenced by samples submitted to Memorial and Brandon Universities - see separate reports

Rig was skidded .2m (NE) DDH YORK HARBOUR #1C

MOBIL OIL CANADA PROPERTIES

Well Name: YORK HARBOUR 1(C)
Spud: 96-12-09 Completed: 97-01-03
GPS Coordinates: 406350 ; 5435750 (NAD 27)
Logged By: D. Rae & Jamie Meyer
MEASURED FROM GROUND LEVEL (NO K.B.)

Depth Interval	**Sample Description**
Measured from ground level (no K.B.)	
O-1.54m (5.05')	• No recovery-in surface casing.
1.54m (5.05')- 19.4m (63.65') (HQ core size)	• coarse grain **sandstone** to fine grain conglomerate-grey to dark grey (very coarse grain at base) generally fining upward • very poorly bedded; faint bedding at 75°; subangular to subrounded grains odd pebble to 1cm size; some lithic fragments no visible porosity in sandstone; cement is finer grained sand silt clay and some kaolinitic alteration of feldspars. As in York Harbour 1(B) fluorescence and oil cut common in pale pink-white dolomite (± quartz) filled fractures. Rare oil stain noted as below. Most oil evidence is fluorescence and moderate-fast streaming yellow cut when placed in tetrachloroethylene. Below are single veinlets or zones of veinlets where fluorescence is noted. (Cut is noted where tested). Fluorescence as follows: 6.2-6.4m-heavily veined. Several specks of degraded oil noted - dissolve with streaming yellow-white cut - this zone has 15-20% pink dolomite & quartz. 6.5m-50° dip; 8.0m; 9.3m 5mm veinlet 60°; 10.8-10.9m 3 x 2mm veinlets 25°, 25° 80° dip 11.45m (fast cut-hairline fracture 30° dip) 12.0-12.1m 4 veinlets ~ 25° dip - (mod-fast streaming cut); 12.5m; 12.85-15.60m (hairline fracture 20° to subvert every few cm - i.e. 2.8m zone with too many fractures to note individually); (good cut from several pieces) 15.85m; 16.05m; 16.15m; 16.28m; 16.38m; 16.85m; 17.05m; 17.40m; 17.65m; 17.95m; 19.05m; 18.20m; 18.35m; 18.45m; 18.55m; 19.2m; 19.3m Pebble conglomerate at base.

19.4m (63.65')- 21.0m (68.90')	• Black **shale**; sharp upper contact @ 75° dip; gradational lower contact to siltstone • silty, micaceous; few % dark chlorite-like mineral
21.0m (68.90')- 26.4m (86.61')	• As above **arkosic sandstone**. Crude grading from very coarse grained sandstone at base to siltstone at top; micaceous; argillaceous matrix distinctive blue (mm size) quartz grains. • No distinct bedding; subangular to subrounded grains; no remnant porosity in **sandstone**. • Oil indications generally as fluorescence and cut where tested: 21.1-21.9m-subvertical fractures; 23.95m; 24.10m; 24.7m; 25.3-26.0m
26.4m (86.61')- 27.6m (90.55')	• **shale**, dark grey-black; increasing grain size with depth; sharp upper contact (~70° irregular dip); gradational lower contact to siltstone as 19.4-21.0m; no shows
27.6m (90.55')- 39.1m (128.28')	• medium grain **arkosic sandstone** to very coarse grain sandstone; locally pebbly **shale**; no visible bedding; no phi; as 21.0-26.4m; very coarse grain at base • Basal 10-15cm contains 3-5% rip up clasts of 1 cm x 4mm size **shale** (i.e. right way up bedding); fluorescent fractures noted as follows: 27.5-27.6m; 27.95-28.25m; 28.85-29.30m; 32.35m; 33.85-34.2m; 34.7m; 35.0m; 35.2-35.4m; 36.2-37.25m (numerous fractures local spheres of bitumen-traces of reddish greasy material in fresh break); 37.35m; 37.8-38.0m; 38.25-38.50m (darker oil at 38.4m); 38.9m
39.1m (128.28')- 39.2m (128.61')	• black micaceous **shale**; contact not measurable (broken core); as above
39.2m (128.61')- 45.6m (149.61')	• As 27.6-39.1m very coarse grain micaceous, **arkosic** poorly sorted **sandstone** - sorted crude fining upward trend; trace faint bedding 70-80° dip • Fluorescent fractures - 39.45m; 39.8-40.3m; 42.6-43.9m; 44.2-44.3m (fluorescence and black glassy) (not fluorescent bitumen - bitumen shows slow streaming cut-pale yellow); 44.6m; 44.8m; 45.1m 46.0m; 47.5m
45.6m (149.61')- 45.7m (149.93')	• **Shale** - as above dark grey green to black; micaceous; irregular contact may be a large fragment

45.7m (149.93')- 53.1m (174.21')	• **Arkosic sandstone**; micaceous-coarse grain as above; crude bedding faint @ ~ 65° at 46m. Less fractured and less dolomite than beds above. Fluorescence diminishing: 46.1m; 47.5m; 49.1m; minor patchy fluorescence @ 49.15m; 49.3m; 50.0m • Crude grading from medium-coarse grain down to very coarse grain - to conglomeratic (max grain size 8mm x 5mm). Bottom 0.5m 2-3% rip-up clasts of shale. Basal contact @ 45° dip. Bedding dips 56° @ 48.8m; 36° @ 50.0m; 45° @ 53.1m
53.1m (174.21')- 54.9m (180.12')	• medium grain **arkosic** poorly sorted **sandstone** coarsening downward to very coarse grained sandstone-large conglomerate basal .3m common (2%) rip-up clasts of shale./No shows; no fluorescence abundant (2-3%) black glassy bitumen conchoidal fracture; anastomosing pattern thicker (2mm) veinlets subvertical (bitumen has slow to moderate white blooming cut)
54.9m (180.12')- 55.7m (182.74')	• Large **arkosic sandstone** at top coarsening downward to very coarse grain sandstone to conglomerate with shale rip-up clasts (sandstone composition very poorly sorted with quartz, feldspars, <1% red jasperoid mineral; blue-quartz) • Bitumen (black glassy more common in upper fine grain to medium grain portion) • Fluorescence minor hairline fractures 55.0m; 55.1m; 55.2m
55.7m (182.74')- 57.3m (187.99')	• as above fine grain to very coarse grain graded bedding; no dips; common glassy black bitumen in finer upper portion; minor patchy fluorescence @ 57.1-57.2m; hairline fracture @ 57.0m
57.3m (187.99')- 61.25m (200.95')	• As 54.9-55.7m. Lower coarse grain to fine grain contact @ 25° dip. • Basal .5mm common **shale** rip-up clasts (1mm x 4mm) Max grain size 5mm x 5mm • Very common anastomosing bitumen-filled veinlets; subvertical veins to 1mm wide with slow-moderate streaming yellow white cut patchy yellow fluorescence @ 59.3m; 59.7m • Bitumen does not fluoresce but shows good cut
61.25m (200.95')- 65.1m (213.58')	• crudely bedded; fine grain-medium grain thru very coarse grain **sandstone** (conglomerate); very abundant coarse (1-2mm) veinlets of bitumen (no fluorescence but strong

yellow-white streaming cut) ~ 2-3%; bedding chaotic ~ 45°

65.1m (213.58')- 67.1m (220.14')	• as 61.25-65.1m - no fluorescence; bitumen less common (1% or less)
67.1m (220.14')- 69.8m (229.0')	• as 61.25-65.1m - no fluorescence anastomosing fine grain bitumen less common
69.8m (229.0')- 74.5m (244.42')	• fine grain grey green **sandstone** at top chaotically grading to very coarse grain sandstone (fine grain conglomerate) at base • sharp upper & lower contacts; lower contact @ 20°; composition as above; minor black glassy bitumen with moderate-fast streaming cut; good strong bright yellow fluorescence in fractured zones 69.8-70.5m; 72.3-72.5m
74.5m (244.42')- 79.8m (261.81')	• fine grain muddy **sandstone** @ top; increasing grain size with depth; basal 1.5m is very coarse grain to conglomerate; minor fracturing & veining; hairline fluorescence @ 76.15m and 76.4m. Minor black bitumen; black glassy good cut-greasy look, basal contact with underlying fine grain sandstone is at 30° • some fluorescence is mineral fluorescence white to yellowish-white fluorescence dolomite-quartz mixture; oil fluorescence minor at 76.2m; 77.9m; 70.4m; @ 76.4m brighter fluorescence shows a very faint slow cut in tetrachloroethylene
79.8m (261.81')- 82.1m (269.36'	• as 74.5-79.8m (fine grain to coarse grain sequence) • Basal 1m is very coarse grain **sandstone** to 3% **shale** rip-up clast (2mm x 5mm) maximum quartz-plagioclase grain size is approximately 6mm x 6mm
82.1m (269.36')- 85.3m (279.86')	• fine-very coarse grain **sandstone** sequence; top portion is fine grain dirty sandstone green-greenish grey with anastomosing dark veinlets (some chlorite) thicker veinlets at 83.7m appear bituminous basal 30cm is very coarse grain as above
85.3m (279.86')- 89.7m (294.29')	• as 82.1-85.3m. Top very fine grain clay-rich **sandstone** green greenish-grey with anastomosing dark green-black veinlets • tested positive for bitumen (tetrachloroethylene) in thicker veinlet at 86.3m (dark glassy greasy looking material) shows slow yellow streaming cut; no fluorescence (mineral

or oil)

- 85.5-87.0m common (3-5%) pink dolomite patches and irregular veinlets-no fluorescence) PATCHY bright yellow fluorescence @ 88.0m; 88.2-88.4m (strong bright yellow with bitumen-lined fractures) fluorescence associated with minor pink dolomite porosity traces in fractures and fine pinhole vugs 88.6-89.5m bright (iridescent) yellow fluorescence local light brown oil stain; streaming slow-moderate fast cut in tetrachloroethylene
  oil stain mm quartz crystals @ 88.8m

89.7m (294.29')-
91.2m (299.21')

- dark brown-black soft waxy **shale** interbedded with soft pale-green slightly micaceous **shale** interbeds up to 0.1m irregular to wispy. No shows; no fluorescence

91.2m (299.21')-
92.7m (304.13')

- 70% fine grain **arkosic sandstone** as above with wispy beds and fragments of dark brown-black and pale green shales as seen above (89.7-91.2m)
- several black bituminous slickensided surfaces with pale pink dolomite no stain, no fluorescence

END OF HQ CORES

- **Running casing and preparing to nipple up BOP - a.m. December 14, 1996**

⋆The zone 82.2-92.7m is deformed. Initially the "wispy interbeds and fragments" were thought to be due to soft sediment deformation. It appears they are part of a fault zone (no lost circulation drilling - but lost cement when cementing operation began). Breccia zones 86.2-86.6m & 90.5-92.2m. Few slickensided surfaces @ 55° dip. Some pink dolomite as above and oil stain associated with the "fault zone".

Drilled out cement past previous TD @ 92.7m. Lost Core to 95.1m in placing NW SHOE. First recovery of Core (NQ) at 95.1m.

95.1m (312.0')-
103.3m (338.91')

- Similar to 92.0-92.7m (seen in last box of HQ core).
  Grey to grey green fine grain (locally medium grain) dirty **arkosic sandstone**; distinct red jasperoid mineral (<1%); quartz, plagioclase common; no visible porosity; silica & clay cements; very poor to non existent beds; faint beds @ ~45° dip;
- **shale** breaks <0.1m at 96.2m & 97.6m; heavily slickensided; dark green-black waxy slickensided shale 101.6-102.3m; contact very steep 70-80% with a definite tectonic overprint
- Fluorescence - generally bright vibrant yellow to yellowish

white - some mineral fluorescence; oil show & cut (moderate streaming) @ 99.0m; slow-medium streaming cut @ 100.4m; Fluorescent zones @:
95.5-96.8m; 97.2m; 98.7m; 99.0m; long interval 99.2-102.4m; 103-103.5m common 2-3% pink dolomite fills fractures - greasy bituminous specs & narrow veinlets, - see 100.4m - good cut; Bedding @ 99.0m ~ 45°

103.3m (338.91')-107.0m (351.05')

- chaotic mix of fine-medium grain **sandstone** and dark green to black **shale** (rock likely structurally altered - fault zone - rock changes every 0.1-0.2cm);
- **shale** zones clearly slickensided & fractured/ fluorescence - 103.7-104.1m; 106.0-106.4m

Logged By: Jamie Meyer

107.0m (351.05')- 116.6m (382.55')

- greenish grey **sandstone** with dolomitic veining and 4 shale bands
- **sandstone** is fine-medium grain, rare coarse grain and rounded shale clasts (~1cm)
- distinctive white, wispy patches in top metre-very irregular, 1-3cm, due to bleaching? white cement
- **sandstone** is **arkosic**, still has pink to red grains of kspar and jasper?
- no visible porosity, except for rare linear vug (weathered out vein?)
- thin (1-2mm) white dolomitic veining common, thicker (2-5mm) pink dolomite veining less common - vugs in latter type of veins
- subtle coarsening up around 115m & 116m
- 40cm green grey **shale** @ 109.5m (very broken initially);
- faint laminations, waxy slickensided fractures, but 50% quite massive
- 30cm **shale** @ 113.1m - as above ; two more shale bands of 10-15cm thick
- Fluorescence visible at 107.8m, several lines, associated with dolomite veining - no additional fluorescence when core broke open
- at 108m, **sandstone/siltstone** very broken, some missing core

116.6m (382.55')- 120.1m (394.03')

- grey to green **shale** with sandstone/siltstone bands
- **shale** is highly fractured, with a few more competent intervals
- waxy, slickensided fractures on 60%-70% of **shale**, in remainder can see colour laminations, dark grey, green grey, rare red - banding is @ 45° to 90° from hz. - in one section the shale coarsens upward through siltstone into fine grain sandstone
- cut by dolomite veining only rarely, slightly calcareous in a 5cm interval
- no fluorescence observed

120.1m (394.03')- 124.0m (406.82')

- green grey **sandstone** with several shale breaks
- **sandstone** is fine-coarse grained, very hard, very low porosity; still has pink to red grains (<1%); rare, rounded shale clast (~laminated)
- good fining up sequences over 20cm to 100cm intervals

- pink, vuggy dolomite veins (1-7mm thick) in top 15cm, rare otherwise
- 1-2mm thick, white dolomite veins in remainder, hz to vertical
- 20cm **shale** @ 121.5m, dark grey to green, finely laminated, only slight fracturing, minor slickensides (top & bottom)
- 3 other **shale** breaks <5cm
- no fluorescence observed

124.0m (406.82')- 136.6M (447.18')

- very mixed interval of **sandstone and shale** - 15% badly broken - 1 occurrence of poor fluorescence associated with dolomite vein

MORE DETAILED DESCRIPTION TO FOLLOW OF THIS INTERVAL

124.0m (406.82')- 126.0m (413.39')

- (cont'd)
- green and red to brown **shale** with lesser green grey sandstone
- very distinctive red to chocolate brown **shale** interbanded/laminated with grey green shale and thin siltstone/sandstone laminations - bedding at 65° to hz
- red colouration may be secondary diagenetic alteration
- bedding is contorted and brecciated in spots
- minor white dolomite veins in **shale**
- 25cm fine-medium grained, green grey **sandstone** - pink to red grains less common
- very thin (≤1mm) black 'seams' - very irregular
- bottom 30cm contains brecciated to contorted bedding with **sandstone** and **shale** - slickensides common - ends with broken up waxy grey shale

126.0m (413.39')- 130.0m (426.51')

- green grey **sandstone** with 2 **shale intervals** - single grey white dolomite and quartz vein with weak fluorescence @ 126.3m
- **sandstone** is fine-medium grain with occasional coarse grain; white mica visible on broken ends - pink to red, kspar & jasper? grains still present, <<1%
- 1-3mm wide dolomite veins, very irregular, often vuggy
- shiny black "veins" ≤1mm, can see shiny black bitumous material in rare thicker one; typically 70°-80° to hz
- 128.1m - coarsening up sequence - **shale** → **sandstone**
- @ 127.2m → 50cm highly fractured, waxy, charcoal grey **shale**, many slickensides
- @ 128.5m → 50cm^{+}? greenish grey to charcoal grey

- **shale** - initially massive, remainder highly fractured
- break in drilling - very broken **sandstone & shale**

**130.0m (426.51')-
134.9m (442.59')**

- green grey **sandstone** and green to grey **shale** - moderately to extremely broken - at least in part due to drilling
- initial 1m very 'mangled' - followed by 60cm wispy, laminated green & grey **shale**, bedding at times chaotic - immediately below lenses of green shale in sandstone - soft sediment deform? followed by a 10cm 'patch' of grey to white sandstone with shale fragments
- remainder consists of fine-medium grain green grey **sandstone**, 1-3mm thick dolomite veins, black 'lines' ≤1mm thick, both at high angles to hz. (60° to 80°) - typically breaking in 10cm intervals with black slickensides
- 40cm green and grey **shale** @ 134.5m - laminated but bedding contorted

**134.9m (442.59')-
141.0m (462.6')**

- grey to green grey **sandstone with 2 shale intervals**, 1 very broken interval
- **sandstone** light to dark green grey, speckled white when coarse grain but mostly fine-medium grain - ≤1cm to 3cm green shale fragments and very rare pink grains - no visible porosity, very tightly cemented (silica & clay?)
- fining up sequences over 50-100cm, with soft sediment deform at base of most sequences
- irregular white dolomite veins and vug-infilling(?)
- stylolitic-like black lines, not common (chlorite?)
- 25cm green **shale** @ 139.1m, intermixed with **sandstone** (soft-sed def)
- 50cm charcoal grey **shale** @ base, moderate to highly fractured, waxy - slickensides common
- Fluorescence @ 139.5 → 139.7m - mostly speckles, few bands of moderate to strong fluorescence - a very slight stream from cut @ 139.4m - small 2-4mm bands, only moderately bright

**141.0m (462.6')-
143.0m (469.16')**

- green grey **sandstone** with abundant black shiny veinlets (network of bitumen ± chlorite?)
- fine-medium grain **sandstone**, subtle fining up sequences - 30cm dark green grey shale @ 142.3m, fairly competent, waxy surfaces where broken - sandstone/shale contact 30° from hz
- veins and vein networks of shiny black bituminous looking material (does not smell or cut) gives brecciated

appearance to sandstone - black veins up to 4mm wide, patches up to 1cm

- small amount dolomite veining, can be seen to infill fractures already lined with black material
- Fluorescence @ 141.4m - 5mm wide dolomite vein did cut (very slow stream) - not bright @ 142.8m a 2-4mm 'spot' - not bright
- while the bituminous material did not appear to cut, after 15 minutes could see "fluorescent ring" in sample dish

143.0m (469.16')- 148.0m (485.56')

- grey green **sandstone** with **minor shale** - fining up sequences over 40-80cm; disrupted bedding in shale @ top of sequences - charcoal grey shale units range from 1-20cm, getting thicker at end of this interval; moderate to highly fractured, waxy and slickensides
- **sandstone** is fine to medium grain, no visible porosity, occasional shale fragments, often associated with disrupted bedding and patches of light grey sandstone (bleached??)

"Initial Summary" 148.0m (485.56')- 168.2m (551.84')

- massive green grey **sandstone** with **minor shale** at top - light dolomite veining, heavy in one spot
- light fluorescence in 4 spots

***DETAILED NOTES BELOW*:**

148.0m (485.56)- 150.5m (493.77')

- green grey **sandstone**, fine-medium grain, thin black veins/vein networks throughout; gives core a brecciated look
- on broken surfaces veins are dark grey black with brown streak; the shiny black material in veins does NOT fluoresce, but it does CUT (extremely slow stream)
- **sandstone** has dolomite veining, 2-7mm wide, often discontinuous, patchy to vug infilling?? - also very thin (≤1mm) white dolomite veinlets
- 2 small occurrences of calcite (0.5 x 1.0cm) or 1st?? dull white to brownish white, cut by dolomite veins

150.5m (493.77')- 153.1m (502.3')

- very broken interval of **sandstone and shale** - mostly fine, lesser medium grained green grey sandstone, many high angle contacts with shale and contains fragments of shale and fragments of black, net veined sandstone (2-5cm size)
- many black slickensided surfaces
- unusual 8-10cm wide band of **shale/siltstone**, fining up,

BUT it cuts through sandstone and truncates other veining?? @ 150.8m, possibly again at 151.6m

- bottom 60cm, core badly broken; **sandstone** with very high angle fracturing and shale ground into mud

153.1m (502.3')-155.5m (510.17')

- grey to greenish grey **sandstone**, black net veining, **minor shale**
- **sandstone** is fine-medium grain, rare coarse grain, occasional rounded shale fragments, and very, very rare pink or red grains
- black veining moderate to very heavy 'net veined' vertical to hz, but typically high angle to hz - a couple very shiny black slickensides, coaly looking
- disrupted bedding common, **shale** squeezed along high angle contacts with sandstone, often truncating black net veining?? shale rarely has black veining
- 30cm green grey **shale** @ 154.0m
- 2 intervals of 5-10cm, broken waxy, slickensided **shale**
- trace of spotty fluorescence @ 154.7m, in dolomite veining

155.5m (510.17')-162.7m (533.79')

- mixed interval of massive **sandstone**, sandstone with white patches, sandstone with black veining, and thin shale intervals
- several zones of massive **sandstone**, up to 1m, faint bedding @ 70° to hz, very rare pink & red grains, no visible veining, no visible porosity
- 50-100cm intervals of massive **sandstone** with very irregular light grey to white patches 2mm to 3cm across, rounded to angular shaped - colour due to white calcite cement (moderate fizz) - also several 1-2mm white calcite veins
- 4 zones of broken up **shale**, 2cm to 20cm, waxy green grey
- 2 intervals, 2cm to 5cm, competent grey green **shale**, overlain by coarse sandstone which is fining upward
- black net veining as before, in 2 intervals of 15cm, isolated veinlets elsewhere

  Fluorescence: @ 157.8m-two 2-3mm wide bands, moderately bright, associated with 1mm dolomite vein @ 159.8m - two 1.0cm by 0.5cm oval-shaped patches, moderate to very bright, with staining - a smaller patch, moderately bright @ 159.7m

162.7m (533.79')-164.9m (541.01')

- **sandstone** with light to heavy dolomite veining
- fine-medium grain, green grey **sandstone** with occasional

black veinlets
- dolomite veining - thin (≤1mm), white irregular and at all angles and/ - thicker zones of pink to white, <1cm-3cm
- the thicker veins are very vuggy with well formed dolomite crystals and occasional pyrite cubes
- infrequent, irregular patches of white to light grey **sandstone** ("no fizz") - two calcite veins (vug infilling?)

Fluorescence: @ 163.2m, three ovals, 0.5 by 1.5cm, in dolomite veins; moderately bright

164.9m (541.01')- 169.7m (556.76')

- grey to green grey **sandstone** with calcite veins and white patches with calcite cement; 2 shale intervals ≤2cm
- **sandstone** is medium grain, less coarse & fine, hints of fining up, rare pink and red grains
- white calcite veining, at all angles; continuous ≤1mm veins, and discontinuous 2mm to 1 cm wide veins (quick tapering of these ones at high angles)
- light grey to whitish grey patches of calcite cement, concentrated in 25cm to 50cm intervals - generally very irregular shape, but a 20cm interval with crude banding @ 60° to hz
- **sandstone** composition easier to see in white patches: 40-50% quartz, 30-40% plagioclase 1-2% pink kspar, 1-3% rock fragments and mica, ≤1% pyrite
- tightly cemented with silica

169.7m (556.76')- 176.0m (577.43')

- **sandstone** and **shale**, at times chaotic bedding, graded sequences
- 20cm of distinctive red to chocolate brown **shale** (at top) - contact with overlying sandstone shows soft sedimentary 'faulting', possibly scouring - the overlying sandstone is very arkosic, brown, grey, grades into green grey and fines upward
- 50% of this interval is **sandstone**, medium to coarse, **arkosic**, brown to green grey, 1-3% pink feldspar grains; cut by 1-3mm green chloritic? seams
- many 1cm to 10cm **shale** inclusions, extremely contorted shapes, (soft sed modif) although occasionally 1-2cm rounded inclusions
- 5% of **sandstone** has black net veining; white dolomite veining (vug infilling?) present but not common
- **shale** intervals 2cm to 30cm, often near vertical contacts with sandstone, typically slickensided
- bottom 50cm consists of interbedded **shale/siltstone/**fine grain **sandstone** - while bedding is disrupted, can still see

interlaminated grey green shale and grey siltstone & sandstone - graded beds?? on cm scale

Fluorescence: 170.2-170.4m dull yellow patches, 0.5cm to 1.5cm long - in green grey sandstone
175.3m - 3 or 4 bands, 2-4mm thick, dull white, associated with dolomite veins

176.0m (577.43')-187.0m (613.52')

- green grey **arkosic sandstone** with thin shale splits and 'modified' shale rip-up clasts
- **sandstone** is fine-coarse grained, poorly sorted, **arkosic** →'dirty'
- well cemented (silica & clay?), dominantly quartz & plagioclase, ~1% pink feldspar & jasper, 1-2% rock fragments, $1\%^{+}$? pyrite (not consistent)
- no/low porosity, slightly fractured; massive beds ($1m^{+}$ solid core)
- occasional light grey to white patches, slightly calcareous
- dolomite ± quartz veins, 1-5mm wide, low angle to hz, in spots dolomite & quartz crystals intergrown - thin ≤1mm dolomite veins every 5-15cm, typically @ 45° - a couple white calcite veins (sub-hz)
- black veinlets every 10-20cm; two intervals (15cm) net veining of black breccia-like material
- **shale** clasts 1-10cm long, usually orientated at high angle to bedding - even vertical - can see laminated zones in shale

Florescence: @ 178.8m - moderately bright white, in dolomite vein
@ 180.3m - faint dull yellow, in sandstone
@ 182.8m - moderate bright yellow, 2-4mm patches in hz calcite vein
@ 184.2m - with dolomite vein, pale yellow, CUT (small, slow stream)
@ 186.3m - 2 bands 2-4mm wide, moderate white to yellowish white, associated with dolomite vein & black net vein
@ 183.1 - black bitumen, slickensided surface CUT (slow stream)

187.0m (613.52')-189.5m (621.72')

- **conglomerate/sandstone/shale** - at times chaotic mixing; black net veining
- between overlying **sandstone** and the **conglomerate** at top of this interval, there is a broken zone, high angle contacts, couple cm of charcoal grey shale - faulted??
- 25cm **conglomerate** - white to grey quartz pebble (2-5mm)

angular to subrounded, poorly sorted, sandy matrix, grades down into coarse sandstone - looks like 70° bedding angle - cut by 1-2mm dolomite veins

- underlain by 70cm medium-coarse **sandstone** - if anything, is fining down?? abundant black lines/veins ≤1mm - on fracture very coaly looking (black streak) - pyrobitumen?
- in turn underlain by dark grey fine **sandstone** and highly fractured waxy grey shale-chaotic interbedding and high angle contacts
- above sequences repeated in full, or part - at base, vertical, laminated **shale**, cut at 70° by pink dolomite, 3-8mm wide

Fluorescence: @ 189.2m - the dolomite vein above - has bright white to pale yellow colour - CUT - light, faint stream

189.5m (621.72')-193.6m (635.17')

- **conglomerate** - white to grey quartz - 2-10mm pebbles, angular to subrounded 50-70% quartz, 20-30%? white feldspar, 5-10% black rock fragments; 1-2% pink feldspar; ≤1% jasper (altered volcanics?)
- grey to green, siliceous to chloritic veinlets very common, at any angle - a couple of waxy grey black slickensides

193.6m (635.17')-194.9m (639.44')

- green grey **sandstone** with black net veining, shale rip-ups
- fine grain with lesser medium grain - fines upward into waxy, green grey shale, slickensided/fractured/broken
- green shale rip-ups at base of sequence, in **sandstone**
- black net veining, core interval 10-15cm (possibly large clast) of medium grain **sandstone** is ~50% black veins?

Fluorescence: @ 194.0m - initially check revealed fluorescence, but no colour visible now . . .

194.9m (639.44')-199.0m (652.89')

- grey to green grey **sandstone** - medium to coarse grain, with diffuse light grey to whitish patches (1-3cm sized) with slightly calcareous cement
- **sandstone** has 1-5cm, irregular shaped grey shale rip-up clasts and occasional rounded black shale clast
- rare pink or red grains
- very white, 1-4mm wide dolomite to slightly calcareous veins at 45°, or sub-hz

Fluorescence: @ 196.7m - associated with calcite vein - bright to moderate yellow - CUT- fast, small stream
@ 196.75m - vuggy dolomite vein, brownish staining,

- excellent zone with 10 bands, 2-5mm wide, over a 10cm interval
- bright white to dull yellow - CUT - small, very slow stream
- some shining black, very very fine grain black crystal? grain? aggregates
- associated with calcite veins

@ 196.8m - a 2-4mm & 1-2mm dolomite (slight fizz) vein with bright white fluorescence and adjacent dull yellow (staining?)

199.0m (652.89')-206.9m (678.81')

- **conglomerate** & **sandstone** with fining up sequences - & reverse grading?
- 40% **conglomerate** - slightly less coarse than before, greenish tint, only 30-40% white quartz & feldspar on average, but varies
- much higher sand content 10-30% in places
- from 201.8m to 201.0m, reverse grading? **sandstone→conglomerate** then back to sandstone
- 60% of interval is **sandstone**, green grey, medium-coarse grain, occasional black slickensided surface; occasional calcite vein 1-3mm wide
- slightly friable **conglomerate** @ 205.1-205.3m, with vuggy dolomite veins up to 1cm thick - abundant patch to banded bright FLUORESCENCE - mostly bright white, but also dull yellow - CUT fast, medium to heavy stream
- one of the better zones seen - many associated bands & patches of Fluorescence, but only CUT one other place, very small slow stream

other Fluorescence:

@ 199.1m - bright white to pale white CUT - fast, moderate stream

@ 199.5m - bright white, CUT - slow thin stream

@ 202.5m - associated with calcite vein - bright white, small yellow 4mm patches

@ 204.4m - 2 yellow white, bright, subvertical bands 2-3mm wide

@ 204.5m - bright white 3mm band, small 2mm blotches, no cut

@ 204.7m - 2 bands, bright white 1-3mm wide, a 1.5cm dull yellow stain

@ 205.1-205.3m - described above

206.9m (678.81')- 211.0m (694.88')

- grey to green grey **sandstone** with thin broken shale intervals
- **sandstone** is generally medium grain with lesser fine & coarse grain - quite hard and massive ($1m^+$ runs, no break) - very very rare pink or red grains
- rare black **shale** fragments (≤1cm)
- very little dolomite veining, generally associated with black veining
- 5 zones of moderate to heavy black veining (5cm to 35cm intervals) - the black veins are ≤1mm, but in 3 intervals they are very closely spaced in 1-2cm wide bands, typically @ a high angle (to hz) and associated with shale which has been tectonically squeezed? or maybe just soft sediment deformed
- 5 intervals of broken **shale** (3-15cm wide) green & grey, waxy, black slickensides, 'squeezed'/deformed contacts

211.0m (694.88')- 216.9m (711.61')

- grey to green-grey, fine-coarse **sandstone** ± quartz granules; and thin conglomerate intervals
- hard, massive ($1m^+$ runs) **sandstone** - very 'dirty', tightly cemented, low (no?) porosity - very poorly sorted, as there are quartz (and plagioclase?) granules (2-5mm) through most of it
- up to 10% granules upper **sandstone**; there are pink, lesser red, grains ≤1%
- **conglomerate** comprises ~ 10% of interval - contains 2-6mm white quartz and feldspar granules, quite angular; very sandy (matrix supported); 5-10% black rounded shale fragments
- a 50cm **conglomerate** dominated interval (@ 211.9m) has dirty green and dirty greenish grey "seams" and "waves" which permeate the conglomerate - appear to be late alteration as they isolate conglomerate fragments
- many grey-greenish chloritic? to clayey seams & veins throughout 30-50% of conglomerate and granule-rich **sandstone**
- calcite **sandstone** dolomite veining, but not very abundant - vary from ≤1mm, to 'pinch & swell' fractured (& vug?) filling discontinuous veins, up to 5mm - also 5 or 6 veins up to 1cm wide - shiny black veins present as well (not heavy)
  Fluorescence: @ 211.2m - <1mm bright yellow lines, 5-15mm dull yellow patches - in conglomerate with calcite veins
  @ 211.4m - bright yellow ≪1mm (on very thin fracture?)

- dull yellow on calcite vein (3-4mm) - staining adjacent to vein
@ 215.6-216.1m - ½ dozen or more bright white 2-4mm wide bands, some with adjacent dull yellow patches (staining) CUT - fast, moderate stream - associated with white calcite vein and pink, vuggy dolomite vein
@ 216.2m - 1-2mm hz yellow (bright) band, 45° bright white bands - some staining (?) - associated with calcite veins
@ 216.7m - mostly yellow with some bright white patches - no cut

216.9m (711.61')- 218.1m (715.55')

- **conglomerate** - speckled white and black with green grey sandy matrix
- displays grading up from clast supported to matrix supported, <20-35cm sequences - well cemented no porosity
- cut by white dolomite veins (slightly calc.), 1-5mm wide
- several black, bituminous slickensides
- white quartz (and feldspar?) comprise up to 50% of granules, 2-8mm, angular to sub-rounded; 5-10% black shale? fragments, rounded to angular - rare pink and red granules

  Fluorescence: @ 216.9-217.4m - associated with dolomite veining - bright white bands and dull white to dull yellow patches 1-3cm wide - good staining up to 1cm away from vein; CUT - very slow, very thin stream
  @ 217.6m - bright white, adjacent to broken fracture in conglomerate - CUT - slow, moderate stream
  @ 217.8m - bright white 4mm band, bright yellow <1cm patches - associated with dolomite veins

218.1m (715.55')- 220.0m (721.78')

- green grey, black speckled **sandstone** with granule rich intervals
- the distinctive black speckles due to 1-3mm rock fragments? (<2%)
- interval grades UP from medium grain **sandstone** into a granule - dominated coarse **sandstone** (conglomerate?)
- tightly cemented, no/low porosity
- faint dark grey to black mottling in upper part

- calcite (to dolomite) veins, irregular ≤1mm veins widely spaced throughout interval
- a 15cm zone of concentrated white veining, and associated fluorescence

  Fluorescence: @ 218.2m - associated with white calcite/dolomite veining - bright white fluorescence to bright yellow - CUT - fast, thin streams
  @ 218.4-218.6m - bright white 2-4mm bands (10° dips) and 2-5mm moderately bright yellow patches - CUT - small, slow stream
  @ 219.10-219.25m - associated with heavy calcite veining moderately bright white with dull yellow patches up to 2cm - CUT - fast, thick stream

220.0m (721.78')-225.9m (741.14')

- conglomerate grading up into **sandstone**; 30-100^{+}cm cycles, with sandstone dominating top half of this interval
- conglomerate is moderately well sorted; 'granules' 3-5mm average in lower part of sequences - white to grey quartz ~ 50%, angular with lesser subrounded (some of white may be feldspar)
- 5-10% rock fragments (**shale?** fine grain **sandstone?**), subrounded to subangular, 3-5mm average
- scattered pink feldspar and red jasper, <1%
- coarse to medium sandy matrix, more granule rich at base of sequences
- contacts range from 30° - 45° (from hz)
- **sandstone** is greenish grey, poorly sorted, 2-5% granules even at top of sequences
- calcite veins, 1-2mm typical, every 10-20cm in **sandstone**, fewer in conglomerate
- **sandstone** is massive, hard, low/no porosity - conglomerate has weathered out veins? fracture? giving some porosity in lower part
- occasional black slickenside

  Fluorescence: @ 221.2m - dull yellow patches, not many
  @ 221.5m - dull yellow fluorescence - in sandstone
  @ 222.0m - a single 2mm bright white band, 1.5cm medium bright white patch - in sandstone
  @ 222.4m - yellow with small patches of bright white CUT - (fast, but very thin

stream) - in sandy conglomerate
@ 225.4m - dolomite vein, faint white, small specs of yellow
@ 225.6m - in conglomerate (broken up) - thin bright yellow band (1mm) on fracture

225.9m (741.14')-229.9m (754.27')

- green grey to grey **sandstone** with moderate to heavy "black veining" and lesser dolomite/calcite veining; shale splits (poker chip shale)
- **sandstone**, medium → fine, lesser coarse, rare granules - medium to strong fracturing
- calcite to dolomite veining (may be 2 different sets), white to translucent, typically ~ 1mm thick, but occasional discont. veins (vug or fracture infilling?) and a 2cm thick vein, white, brecciated, @ 229.0m
- core is cut by "black veins", very heavy in some 5-25cm intervals
- when core is broken in above intervals, black bituminous slickensides,

  @ 227.8-228.2m - very heavy 'black veining', also white calcite/dolomite veins, in a disrupted conglomerate/sandstone/shale interval
- **shale** splits/intervals, 2-10cm wide, grey to grey green, waxy, slickensided; disrupted bedding in one zone

  Fluorescence: @ 226.6m moderate to bright white - CUT - slow, small stream
  @ 227.9m - minor, very dull white
  @ 229.6m - bright white and yellow - CUT - very small light thin stream

229.9m (754.27')-232.9m (764.11')

- grey to green grey fine to medium grain **sandstone** with light/dark banding or mottling; shale splits
- top half of interval has diffuse banding, ~ 35°-45° (to hz) and on a 1-3cm scale - may be due to sandstone composition, (i.e. "clean/dirty"); core readily breaks parallel to these bands
- lower half **sandstone** in interval has very irregular/contorted colour banding/mottling - also due to compositional change, thus can be described as small scale soft sed deform/diapirs
- **shale** 'splits' 1-5cm, very broken, grey black, waxy, slickensided - also grey green shale, waxy, as deformed inclusions in sandstone, 'squeezed bands'

  Fluorescence: @ 231.8m white band, (dolomite vein)

- calcite to dolomitic veining, white, 1-2mm thick, cross-cutting, and often weathered out leaving fractured porosity?

232.9M (764.11')-240.0m (787.40')

- mixed **sandstone/shale** interval, shale > sandstone
- **sandstone** is very fine → medium grain, much less coarse grain with occasional granule
- greenish grey to very dark green-grey - one 60cm interval fines upward
- faint 'black veins/lines' in 50% of **sandstone** - heavy in 2-5cm intervals (3)
- **shale** is light grey green, dark grey green, and charcoal grey
- moderate to extremely broken - waxy, slickensided, deformed contacts common - in places where contacts aren't deformed, 40°-50° (to hz)
- relatively little white veining - single 7mm slightly calcite vein in shale; two zones of heavy black lines have associated dolomitic veining

240.0m (787.40')-242.5m (795.60')

- grey to greenish grey coarse **sandstone**, much less fine -medium - quartz granules (1-3mm) common, rare 5-8mm shale fragmented; rare pink feldspar and red jasper grain
- 1 **shale** split, broken, < 1cm?
- upper **sandstone** contact with **shale** (@ 240.0m) is very abrupt, and undulating - erosional? which would mean overturned bedding? also @ 241.7m, despite broken rock, it appears to be sandstone fining <u>down</u> into shale, and underlain by coarse sandstone??

@ 241.4m a 2 to 5mm wide dolomitic vein (slightly calcareous) @ 70° with many splays and associated black veining

Fluorescence: @ 241.4m - bright white on above noted dolomitic vein - no cut

242.5m (244.6')-244.6m (802.49')

- medium to coarse **sandstone**, light mottling, bituminous slickensides little fluorescence
- **sandstone** is grey, occasional quartz grains up to 3mm, rare pink feldspar and very rare red jasper grain
- light grey to white mottling appears due to higher percentage of translucent to white quartz grains, i.e. lithology change - but contacts are extremely modified, angular to rounded patches, possibly soft sed. deformed?? occasional pyrite in these patches
- irregular black lines/veins - discont, at high angles (to hz) and in two locals they are "bunched" together in lenses 1cm-2cm with dolomitic patches - on breaks black

	lines/veins look shiny, bituminous, ± disseminated pyrite • dolomitic veins (sometimes a slight fizz), 20•≤° to 70•≤° (to hz) rarely up to 1cm wide, discontinued to 'lensey' • one dolomitic vein has 2 Fluorescent spots, 2mm x 3mm in size
244.6m (802.49')-245.3m (804.79')	• crushed zone - this may be where they started again after Christmas break • green grey, and black shale chips, grey sandstone pieces, dolomitic fragments, grey sandy mud
245.3m (804.79')-251.5m (825.13')	• mixed bag of variably textured and veined **sandstone** • initial 1.5m, as before crushed zone - grey **sandstone**, coarse grain, lesser medium grain, white mottling & dolomitic veins • change to medium grain, green grey **sandstone** with rounded shale fragments up to 2cm diameter - both green grey & black this 50cm interval is broken and crushed for 5-10cm, just before end • @ 247.4m a sharp, but undulating contact, 30°-45° (to hz) with coarse grain **sandstone**, with 1-3mm quartz 'granules' below contact (overturned bedding???) - below this contact 1.5m of medium grey, coarse grain sandstone, abundant black veining varying from 'net veining' to 2cm wide black veins with sandstone fragments (brecciated) • at least 2 generations of dolomitic veining; <1-3mm wide, low to high angle, discont white veins in turn cut by 3-15mm wide, white, hz to low angle veins - just a few 2 to 4mm patches of weak Fluorescence in these veins • below this is crushed or broken green grey **sandstone**, 80 cm, weak Fluorescence associated with one small dolomitic vein within this broken interval is a vuggy weathered vein of black bituminous-looking, shiny, crystalline material this vein is 1-2mm wide, and easy to sample - the material CUT - slow, steady stream • remaining 1.5m is coarse grain, medium grey **sandstone** with 1-2mm quartz granules which give a white speckled appearance • abundant thin black veins, <1m to 2mm wide, at times net veined • bedding looks 'disturbed', in part due to 2 or 3 zones of 'squeezed' green grey **shale**, 1-5 cm wide, which appear to truncate black veining - similarly 'squeezed'/deformed green grey **siltstone** with quartz granules, shale fragments, and lighter coloured green grey; stringy veinlets - (modified

small scale fault contact??)
- interval ends in broken green grey **shale**

251.5m (825.13')-258.9m (849.41')

- as above, mixture of variably textured and veined **sandstone**, with more **shale** intervals than above, including deformed 'forest-green shale'
- initial 30cm of broken **shale** - brown green to forest green - unusual in that the shale is net veined with 5 1mm wide black veins; occasionally brecciated shale in laminated veins - dissem. pyrite <1%; - hz contact with sandstone slickensided
- next 1.4m down, light to medium grey **sandstone**, medium to coarse grain, light green shale fragments, subrounded, up to 2cm; rare pink feldspar - weakly to strongly mottled appearance due to presence or absence of white cement, mildly calcite - middle of this zone has faint banding (2.7mm scale) due to degree of white cement present (~60° to hz)
- early calcite veins, white with brown patches, 1-3mm wide, not common - cut by 1-2mm black veins which are generally wide spaced, but occasionally close spaced
- black veins are occasionally 1cm wide and brecciated
- later, white dolomitic veins (discontinuous) and translucent dolomitic veins (continuous) both types are 1-3mm wide
- several spots of very weak Fluorescence
- approximately 25cm of forest green **shale** below mottled zone
- sharp, subhz upper contact, a gradational lower contact with wispy interlaminations in dark grey, fine grained **sandstone**; these persist for 5-10cm; lower contact steep to vertical - shale is faintly laminated - black veins in above sandstone, stop abruptly at upper contact, rarely cutting through shale
- 10cm below green **shale** is charcoal grey to black shiny, waxy to weakly slickensided, and having green shale at lower contact
- next 45cm below, consist of dark grey **sandstone**, medium grain, faint banding @ 50° to hz - occasional <1-3cm patch of sandstone with white, slightly calcite cement & heavily net veined (black)
- remainder of **sandstone** with moderate to heavy black veining, very irregular, often thin splays off of a thicker vein (2-4mm), thick black vein rarely continuous, may end in zone of brecciation
- lower contact of this zone is near vertical, deformed/disrupted, with shale fragments in sandstone, and

10cm of broken dark grey shale

- below is approximately 60cm of broken **sandstone** with large angular dark grey shale fragments; ending in crushed waxy, green, grey and black shale
- followed by 80cm of light grey coarse **sandstone** with a small number of thin dolomitic veins and very thin black veins
- 2 contacts of coarse grain, granule **sandstone** and coarse sandstone - appear to fine upwards
- in top of this zone, good white and yellow Fluorescence associated with fractures and dolomitic veins - under black light can see yellow fluorescence fading away from fractures CUT - fast, moderate stream (@ 254.9m)
- next 60-70cm consists of grey **sandstone**, medium to coarse grain with quartz granules - moderate to very heavy black veining, very brecciated appearance
- 3-5cm shale "fragments'? or squeezed out shale bed
- below is 1-2m of medium grain grey to light grey **sandstone**, medium to coarse grain
- bottom ⅓ of this zone appears 'very disturbed', with psuedo folds and faults, very irregular mottling due to changes in colour of cement
- irregular, discont, white dolomitic veins/lenses, <1-5mm wide
- rare pink feldspar and red jasper granules, rounded black shale fragments up to 2cm, and <1-2mm black shale fragments 'speckle' parts of this zone
- remaining 1.5m consists of green grey **sandstone** & **shale**
- **sandstone** is medium to coarse grain, ±1-3mm quartz granules, rare pink feldspar – in places the sandstone appears to 'fine downwards'?
- grey black **shale**, interlaminated with green shale, and overall interbedded with dark grey **siltstone** & fine sandstone – contacts irregular often vertical, or broken
- **shale** is waxy on broken surfaces, some slickensides with yellow soapy sheared surfaces to shiny black
- several black veins intermixed with dolomitic veins, up to 1cm wide

258.9m (849.41')-
262.4m (860.89')

- grey to green grey **sandstone** with light grey to white mottled look due to 'patches' of white cement/matrix - with the white matrix it's easier to see textures → poorly sorted medium to coarse sandstone; rounded to subangular grains; quartz dominates (80-90%?)
- grains not tightly packed, but very tightly cemented

- common granules, up to 4mm - white quartz, rare blue quartz, pink feldspar, red jasper - ~1% rock fragments, ≤1mm black most common, also rounded 2-5mm green, grey and black shale fragments
- 2-4mm granule-rich **sandstone** at base - a 3-4cm thick zone, grades up into green grey sandstone - there is a 1-2mm wide 'seam' at the granule/sandstone "contact" , grey green "chloritic'? 'clayey'-looking, with <<1mm broken grains within - contact looks gradational
- white dolomitic veins present but wide spaced (3-10cm)
- veins are 1-3mm wide, irregular, discont.
- black <1-2mm thick veins, also irregular & discont, even wider spaced than dolomitic veins

262.4m (860.89')-
269.5m (884.19')

- green to black, laminated **shale**, lesser fine grain sandstone and siltstone
- initial black & dark green **shale**, laminated, disturbed bedding, coarsens down into fine grain sandstone (2-5cm bands) then broken grey black waxy shale – return to

270.2m (886.48')-
277.2m (909.45')

- light to dark green grey with **shale** interbeds
- **sandstone** is initially medium-coarse grain with occasional rounded shale fragments (3-8mm) and black rock fragments (1-2mm), rare pink feldspar grain
- just a few light coloured patches (1-2cm) and discont. white dolomitic veins (1-5mm wide); 1 or 2 white veins have moderate fizz (calcite) - several very pale green 1-3mm wide veins??
- the 20cm directly below **shale** has 6 or more black veins, 1-4mm wide, tapered ends – associated with Fluorescence - moderate to dull yellow 'cores', moderate to dull white fuzzy 'outsides' (2-5mm wide)
- hard to get sample to try CUT - possibly a very faint, slow stream
  @ 271.2m - 10cm of broken green grey shale pieces, <1-3cm, subrounded pieces
- @ 271.4m - 10cm of waxy, green grey **shale**, partially sheared & mixed with sandstone - contact 60° (to hz)
- below is approximately 3m of medium grey to green grey, medium to coarse grain **sandstone** with light grey to white mottling (due to white matrix/cement) in very irregular patterns (including 'doughnut-shaped') up to 5cm in diameter - mildly calcitic cement – greyish fragments, angular, up to 1.5cm; a couple light green shale fragments, biggest is 4cm x 0.5cm
- white dolomite & calcite veins, 1-3mm, often discont., one vein runs about 50cm along length of core, pinching & swelling
- @ 272.7m - a 1cm thick vein, mixed dolomite/calcite/and black veining - very dull Fluorescence
- @ 274.3m - very dull yellow Fluorescence, <u>no</u> cut
- remainder of this interval is medium grey, medium to coarse grain **sandstone** with quartz granules, occasional pink feldspar grain; rounded to angular shale clasts, 2-10mm
- widely spaced 1-3mm white dolomitic veins
- 276.6m - large, elongated **shale** fragments? or squeezed band? - 1.5 x 8cm, grey black
- 276.7m - ~ 50cm black **shale** with green grey laminations (1-3mm) - bedding is 70° to hz - shale is quite massive at lower contact

277.2m (909.45')-
284.1m (932.09')

- medium grey, medium-coarse grain, massive **sandstone**, with subtle fining up sequences over 50cm to 2m intervals
- generally poorly sorted, granule of quartz appearing irregularly - tightly cemented - no/low porosity

- distinctive blue quartz granules (1-3mm) in coarse **sandstone**, ≤1%, rare pink feldspar
- **shale** fragments common throughout (but only 1-2%), they range from 2mm to 2cm in diameter, the larger the more rounded - generally grey, also black and light green
- light grey calcareous mottling in medium green **sandstone** in top 50cm
- thin white calcite veins (≤1-3mm) at all angles, generally wide spaced, but in two 10-20cm zones, they are closely spaced
- a 1cm calcite vein just below mottled zone, associated with black veining – irregularly spaced black veins, ≤1mm, generally wide spaced, often cross-cutting when they do occur in clusters, where they may form thicker veins
- @ 280.25m & 280.35m - there are 2-7mm wide veins, often with black rims, white calcite centres, and with black shiny inclusions
  1-3mm - <u>CUT</u> small slow stream
  Fluorescence: @ 280.1m - associated with calcareous vein - bright white with patches of yellow - CUT - very small light stream
  @ 281.8m - associated with calcareous vein - very pale yellow
  @ 281.5m - small dot of white (associate with calcareous vein) and a very small yellow speck - no cut from here, but a black vein 20cm above did <u>CUT</u>, moderate slow stream

284.1m (932.09')-
292.3m (958.99')

- mixed interval of medium, to coarse, and granule-rich **sandstone**, medium grey to medium greenish grey in colour
- many large scale graded sequences, usually fining up, over 50cm to 2.0m
- **sandstone** is very massive, ~ 60% granule rich
- interval begins with sharp contact, 70° to hz, granule - dominated coarse sandstone underlying massive medium grained sandstone
- the granule **sandstone** almost looks to be fining down?
- very poorly sorted overall
- 285.8-287.5m - medium grained **sandstone** with granule-rich bands, and vice-versa - contacts irregular, lensoid, possibly soft-sediment deformed?
- 287.5-289.1m - massive medium grain **sandstone**
- lower 3m, lighter grey, granule-rich to small pebble-rich

coarse **sandstone** - rounded shale pebbles, blue quartz granules, and less common pink feldspar grains

- slightly calcareous matrix @ 289.5m, becoming moderately calcareous by 291.5m, and intermittently calcareous till 292.0m - mostly in granule-rich sandstone
- wide spaced white veining, mostly calcareous, 1-3mm, except at 289.3m, a group off 3 calcareous veins 3-10mm
- irregular spaced black veins, generally 1-2mm, except networks of black veins @ 285.6m, 286.7m and 289.4m

Fluorescence: @ 284.4m - associated with calcareous vein, a small patch of white and yellow - CUT, thin, slow, stream
@ 285.7m - white dot associated with black vein network and calcareous veins - CUT - thin moderate stream
@ 290.4m - faint dull yellow (grease?)
@ 290.7m - associated with vein - bright white and dull yellow - CUT? - possible faint stream

- a 10cm sliver of white matrix **sandstone** on one side of core at end of interval - very calcareous - consists of very coarse sandstone and is overlain by medium grain sandstone - 70° (to hz) contact

292.3m (958.99')- 299.3m (981.96')

- dark grey to medium grey, medium to coarse **sandstone**
- 292.3m to 295.1m - dark grey coarse **sandstone** with white quartz granules; also less common blue quartz, grey & grey shale fragments, and rare pink feldspar
- abundant black veins in this zone, in 3, 10cm zones in upper half - net veined & brecciated textures
- very wide spaced calcareous veins (≤1mm thick), except at 292.4m, contorted 2cm wide vein, mixed with black veins
- in contrast, below is light grey, medium to coarse grain **sandstone**
- fining up sequences, 50cm-100cm, with fine **sandstone** at top of some sequences
- faint black veins, ≤1mm, with irregular orientation
- slightly calcareous veins, 1-3mm, occurring 3 to 5 at a time in bunches, which in turn are wide spaced
- @ 297.5m - broken up **shale**, interlaminated green & grey, bedding at 60° (to hz) - waxy and partially slickensided approximately 30cm of shale, but some core missing
- remaining 1.5m is massive dark grey **sandstone**, dominantly medium grain
- a 1cm pink vein, slightly calcareous, several 1-2mm white

veins, and bottom 50cm looks slightly fractured, with many <<1mm irregular veinlets? at sharp angles

- few, discontinuous black veins
- no fluorescence

TD - 299.3m

Appendix II

Petrography

Thin Section Analyses of Samples from Western Newfoundland III

Report to Mobil Oil

by Louise Quinn, Department of Geology, Brandon University, Brandon, MB

Submitted March 18th 1997

Executive Summary

It can be concluded from the investigations carried out here, that the entire core collected by Mobil Oil from the York Harbour area, western Newfoundland, in December, 1996, is composed of lithologies of the Blow me Down Brook Formation. Dolomite appears to be associated with some mineral fluorescence, whereas calcite is associated with a distinct pink fluorescence. A sequence of diagenetic events can be established, which is as follows:

1. Induration of the sandstone

2. Development of crush zones

3. Opening of fractures associated with crush zones

4. Early bitumen which may or may not be associated with quartz growth on walls of fractures

5. Major phase of euhedral quartz growth on fractures

6. Infilling of fractures with bitumen

7. Infilling of fractures and replacement of framework with carbonate - multiple generations, associated with continued opening of veins.

8. Dissolution porosity developed in dolomite.

Samples analyzed:

Samples from core through the Blow me Down Brook Formation (drilled December 1996), at levels 17.88, 36.7, 63.1 (62.2 on original Mobil photo set), 64.6 (62.9 on original Mobil photo set), 113.9 (113.5 on original Mobil photo set), 152, 285.7 (288.6 on original Mobil photo set). Note that the corrections are necessary because the core has been replaced in boxes slightly out of alignment with its original boxing.

Sample Collection:

Samples were collected with a view to better establishing paragenesis, and an understanding of the timing of emplacement of bituminous material. Overall the suite of samples collected appears to represent the major macroscopically visible diagenetic features. Specifically:

17.88 was collected because it appeared to contain fluorescing carbonate.

36.7 was collected because it contained fluorescing carbonate.

63.1 was collected because it contains a surface coated with bituminous material.

64.6 was collected because it contains a network of veins filled with bituminous material.

113.9 was collected because it contains irregular dark and light patches within the sandstone.

152 was collected because it appeared to contain a network of veins filled with shaly material.

285.7 was collected to establish that the lowermost part of the core was still within the Blow me Down Brook Formation, and to evaluate the vein filling, pink fluorescing carbonate material.

Methodology:

Thin sections of the samples were prepared by Calgary Petrographics. They were ground to standard thickness, impregnated with blue epoxy, stained with alizarin red, and prepared without coverslips. No samples were point counted for this study. The samples were examined in thin section for qualitative evaluation of specific diagenetic features. Sample 63.1 was not thin sectioned but instead a number of stubs were prepared and the bituminous surface was examined under the Scanning Electron Microscope. Given the specified time limitations, I was instructed to concentrate on paragenesis, focusing on the timing of emplacement of bitumen. Given these limitations, I have recommended further work, should more information on diagenesis be required.

Qualitative Descriptions:

It should be noted that the sandstone in all samples is typical of the Blow me Down Brook Formation. That is, all samples are coarse sandstone, poorly sorted, with a high percentage of matrix. The framework grains are dominated by monocrystalline quartz, potassium and plagioclase feldspar. Few rock fragments are present. The matrix is dominated by chlorite and mica, somwhat recrystallised. Most samples contain crush zones. The lithology is tight. These characteristics can be seen in most of the accompanying plates (note that all samples collected were impregnated with blue epoxy).

Sample 17.88:

Diagenetic features: (Plates 6 and 7) The focal feature in this thin section is a vein, which in hand specimen is light coloured in places and dark coloured in others. The light coloured part, which in hand sample fluoresces yellow, is associated with carbonate. In thin section this is dolomite with undulose extinction (saddle dolomite). It shows some dissolution porosity along cleavage planes. It also contains small blebs which have taken the alizarin red stain, but this is probably an anthropogenic effect. The dark coloured part of the vein is the typical crush zone seen in many Blow me Down Brook samples, with recrystallisation of quartz along the crush zone. Early recrystallisation of quartz has occurred along the crush zone, and carbonate is a later pore filling material..

Sample 35.7:

Diagenetic features: (Plates 14 and 15) This sample is dominated by a dolomite filled vein. The vein is associated at its margins with euhedral quartz crystals, which are also found 'floating' in the dolomite. The floating quartz crystals are presumably protruding up from the wall of the vein below. They are earlier than the dolomite. The vein exhibits vuggy porosity with zoning in the dolomite crystals close to the margins of the vugs. The dolomite is cloudy with undulose extinction, which is typical of saddle dolomite, a high temperature form of dolomite. Patches of matrix material are also found floating in the vein, suggesting that the dolomite has also replaced part of the original framework.

Sample 63.1:

Diagenetic features: (Plates 21, 22, 23) This sample was examined under the Scanning Electron Microscope only. The bituminous material on the exposed fracture surface is brittle, and was broken easily into conchoidal fragments. The relationship to the host rock is obscure in the SEM images, but in places the bituminous material appears to be associated with calcite and mg-rich calcite. In other examples the conchoidal fracture of the material is the most prominent feature. Analysis using the Kevex feature confirms the organic nature of the material, since only trace amounts of heavy elements were detected.

Sample 64.6:

Diagenetic features: (Plates 16, 17, 18)This sample contains a prominent 2 mm thick bitumen filled fracture associated with it. Throughout most of the sample the bitumen is not associated with any identifiable diagenetic feature, but in part of the vein, it is associated with a typical Blow me Down Brook crush zone. The lack of quartz recrystallisation along the vein may indicate that migration of the hydrocarbon took place at a relatively early stage, before quartz had a chance to grow along the walls of the open fracture.

Sample 113.9:

Diagenetic features: (Plates 19, 20) The lighter patches which were identified in hand specimen are not associated with any obvious cementation feature. They appear to represent patches in which there are fewer green minerals in the matrix, possibly indicating a higher degree of recrystallisation in these parts of the matrix, and there may be a slightly higher proportion of carbonate. The grey-green areas appear to contain higher proportions of aligned green sheet silicates (biotite/chlorite).

Sample 152:

Diagenetic features: (Plates 8, 9, 10, 11, 12) In this sample bitumen clearly fills in pores subsequent to growth of euhedral quartz. Closer inspection show that some bitumen is situated adjacent to the wall of the vein, suggesting two generations of hydrocarbon migration. The early generation has taken place prior to most of the quartz growth, the second generation has taken place subsequent to the major phase of quartz growth. Other views clearly show bitumen associated with crush zones, and still others show one fracture associated with bitumen offset by another associated with bitumen, again suggesting multiple generations of hydrocarbon movement. In yet another view, quartz, bitumen and dolomite are shown associated with a crush zone, and in this case the bitumen clearly appears to be later than the quartz, but earlier than the dolomite.

Sample 285.7:

Diagenetic features: (Plates 1, 2, 3, 4, 5) This is the only sample collected which contains unequivocal sparry calcite with well developed lamellar twinning. This is the mineral which fluoresces a distinct pink in hand specimen. It is developed in a vein which is the focal feature of this thin section. Relationships clearly show that the original structure was a crush zone, which later became an open fracture. As the fracture opened, euhdral crystals of quartz grew into it, with the calcite undoubtedly being a later phase. The calcite in this major fracture contains lamellar twinned crystals which are broken and cut by more calcite, indicating multiple generations of carbonate have filled this vein. No bitumen is associated with this major fracture, but the fracture cross cuts another which is associated with bitumen.. In the earlier vein, which has quartz, calcite and bitumen associated with it, the relationships are not unequivocal, but the bitumen is clearly later than the quartz, and presence of bitumen surrounded by carbonate indicates bitumen is earlier than the calcite.

Overall interpretation and conclusions:

1. The mineral which shows yellow fluorescence is dolomite. Some of this may be mineral fluorescence. However any light oil present in the core is likely to also be associated with dolomite, since carbonate fractures are the only features showing any porosity.

2. The mineral which shows pink fluorescence is calcite.

3. The lowest sample collected (285.7) is clearly identical in terms of composition to all other samples collected and examined by the author in the various phases of this study. Therefore the entire core is composed of sandstones of the Blow me Down Brook Formation, and the deepest part of the core has not intersected any other formation.

4. The relative order of diagenetic events appears to be as follows (from earliest to latest)

1. Induration of the sandstone

2. Development of crush zones

3. Opening of fractures associated with crush zones

4. Early bitumen associated which may or may not be associated with quartz growth on walls of fractures

5. Major phase of euhedral quartz growth on fractures

6. Infilling of fractures with bitumen

7. Infilling of fractures and replacement of framework with carbonate - multiple generations, associated with continued opening of veins.

8. Dissolution porosity developed in dolomite.

Note that since calcite and dolomite were not observed in relation to each other, the relative timing of their emplacement cannot be determined.

Recommendations for other work

1. The phenomenon of mineral fluorescence was not very thoroughly investigated in this study. Fluorescence microscopy is recommended to study this phenomenon further.

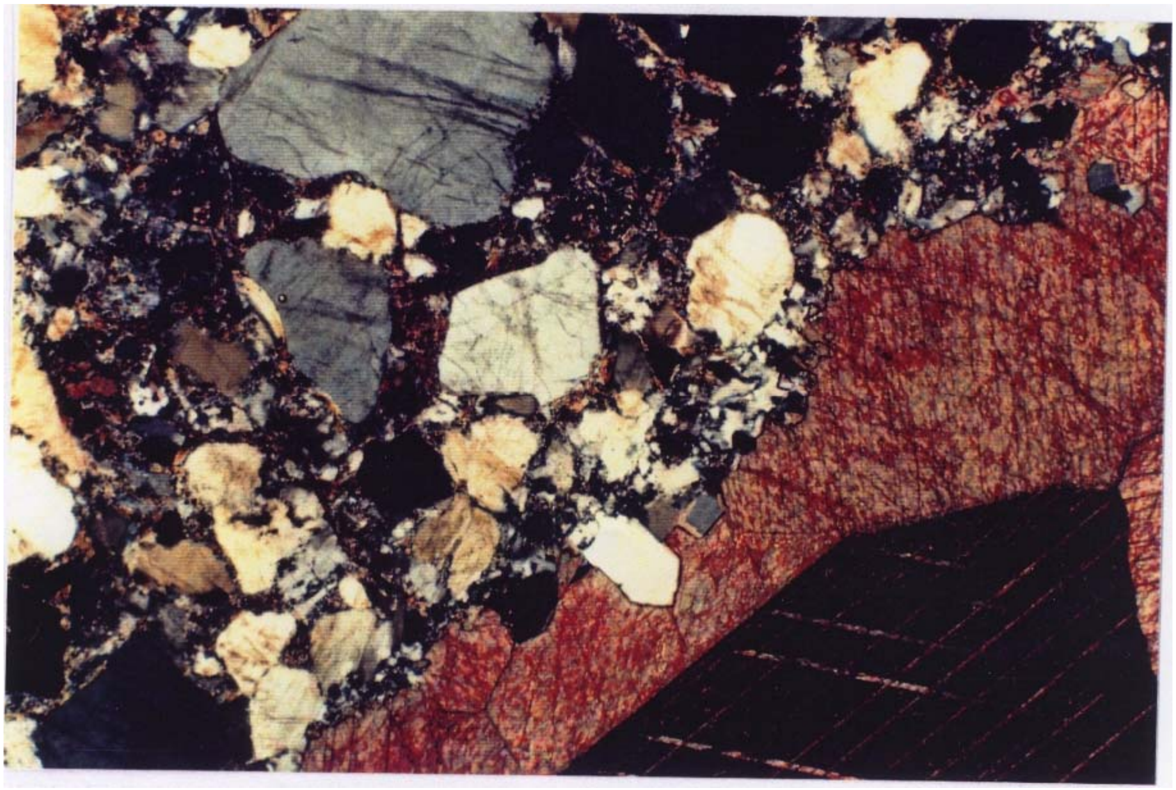
2. The study throws little light on the maturity or other characteristics of the bituminous material. It is recommended that reflectance studies be carried out by the Geological Survey of Canada to determine this.

3. While it is clear that multiple generations of cementation have occurred, more information can be derived from cathodeluminescence studies.

If required, the author of this report can carry out projects 1 and 3.

Plate 1, 285.7: Euhedral quartz protruding into the major calcite vein present in this sample. Note that calcite vein (stained pink) appears to have opened along a crush zone in sandstone. The formation of the crush zone was the earliest event, and was followed by opening of a fracture along the zone and formation of euhedral quartz along the fracture walls. Subsequently the fracture was filled with calcite. The fracture continued to open and fill with calcite as multiple generations are present in the vein (not shown here). Crossed polars, x50.

Plate 2, 285.7. The major calcite vein shown in plate 1 cuts across a smaller vein (shown here) in which quartz, bitumen (black) and calcite are intimately associated. Quartz is clearly the earliest feature, with its euhedral terminations. Calcite is considered to be later than bitumen as it clearly surrounds bitumen in places.
Plane polarised light, x100



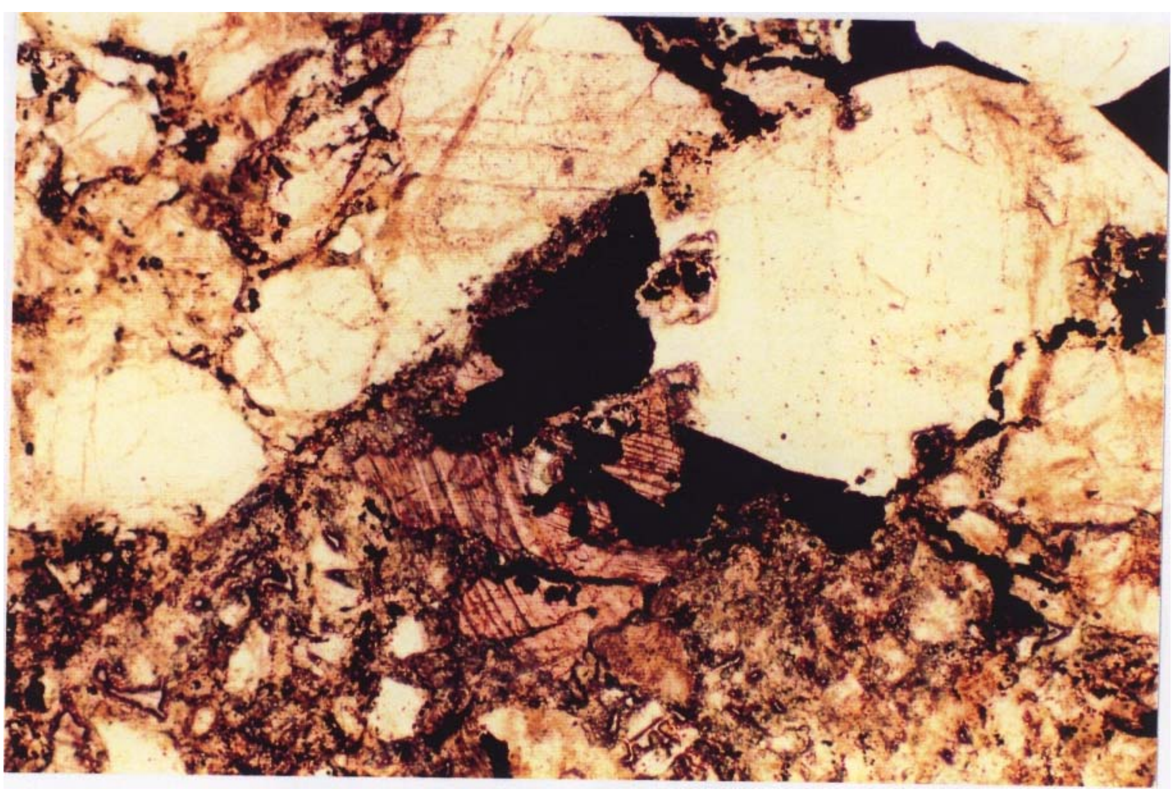
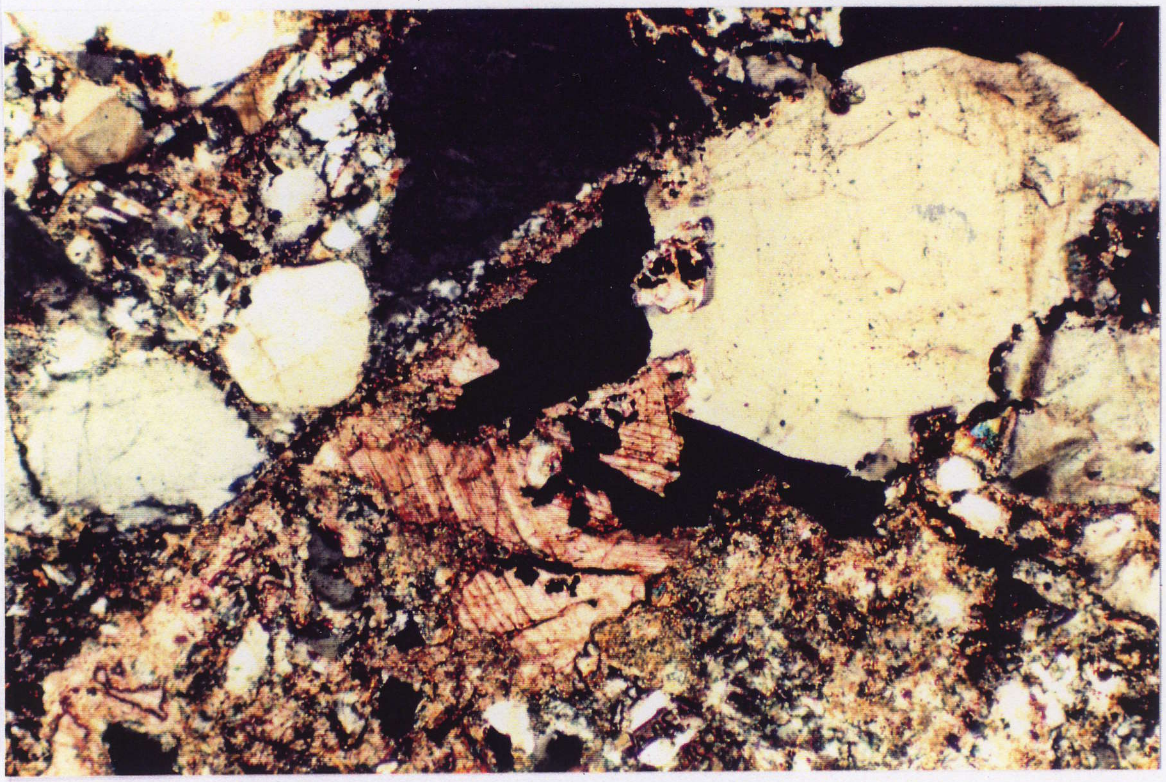


Plate 3, 285.7: Same view as plate 2. Crossed polars. x 100.

Plate 4, 285.7: Same vein as in plates 2 and 3, but at a different location, showing clear association of the vein with crushing (note broken quartz grain). Crossed polars, x100



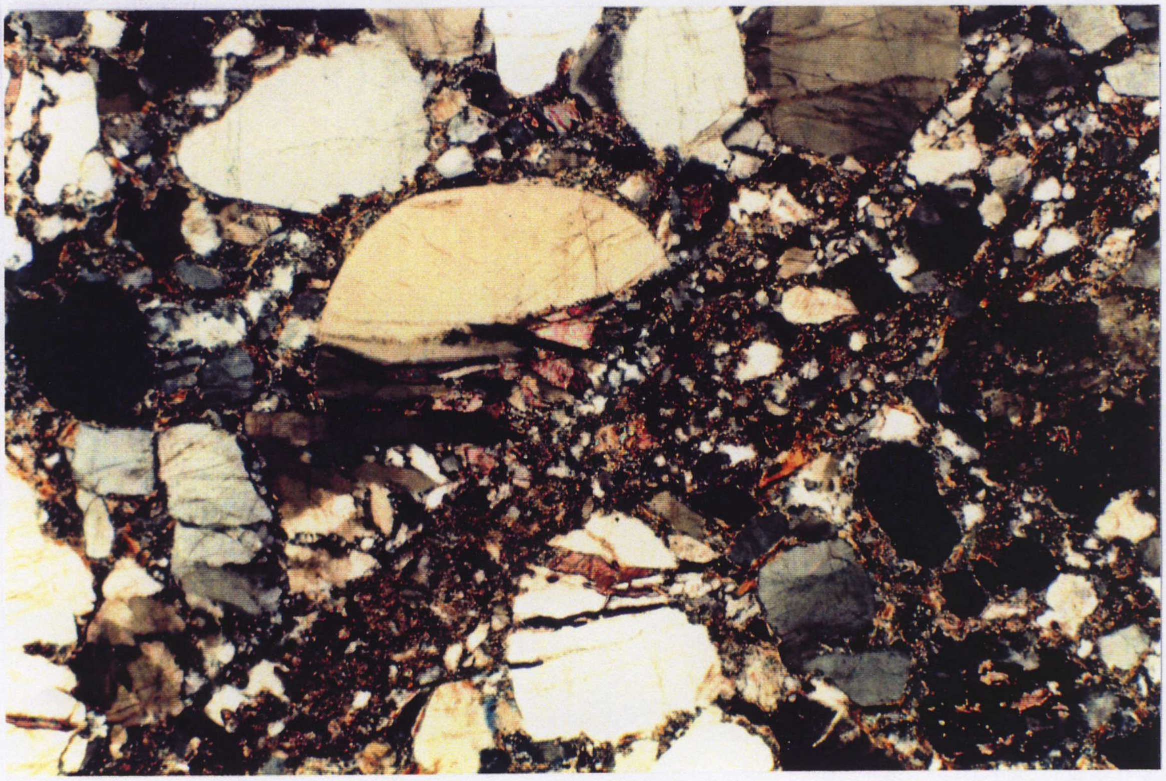
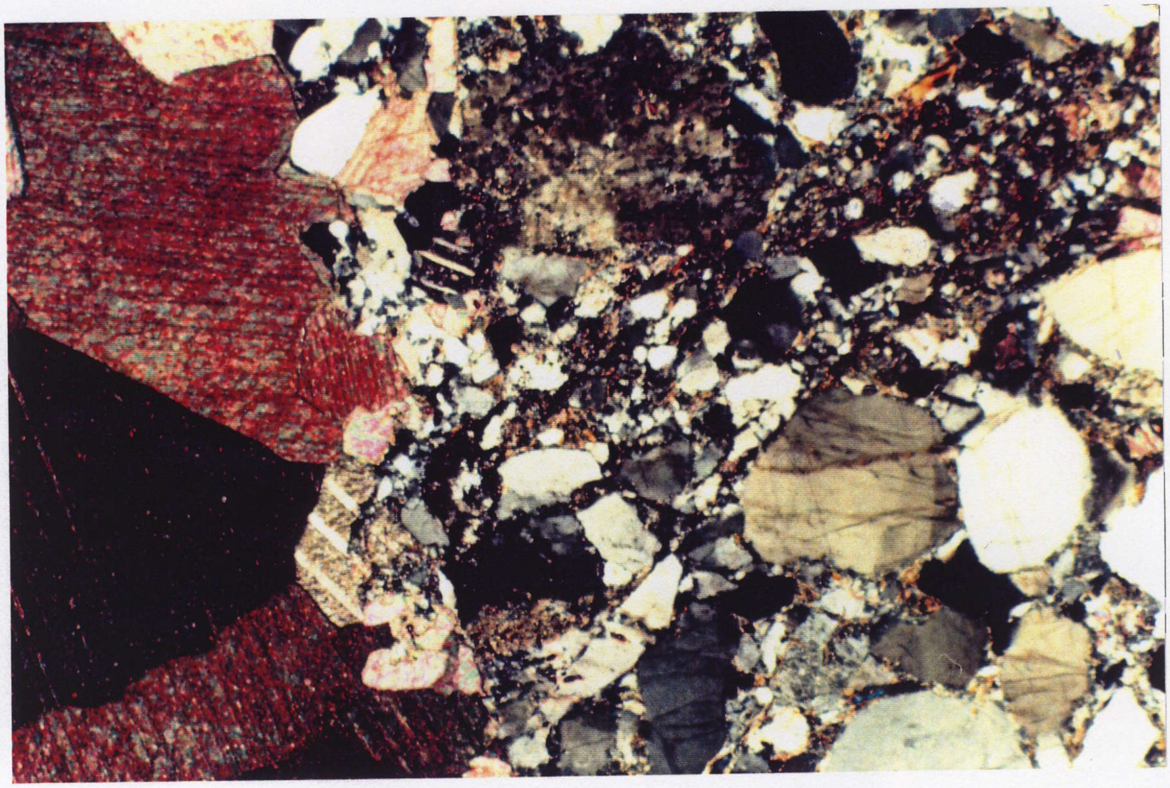


Plate 5, 285.7: Shows how the main calcite vein clearly cross cuts the vein (trending NE/SW in this photo) which is the subject of plate 4. Crossed polars, x50.

Plate 6, 17.88: Typical crush zone showing recrystallisation of quartz along the zone of deformation. Potassium feldspar is also visible in the upper part of the photo. Crossed polars. x50.



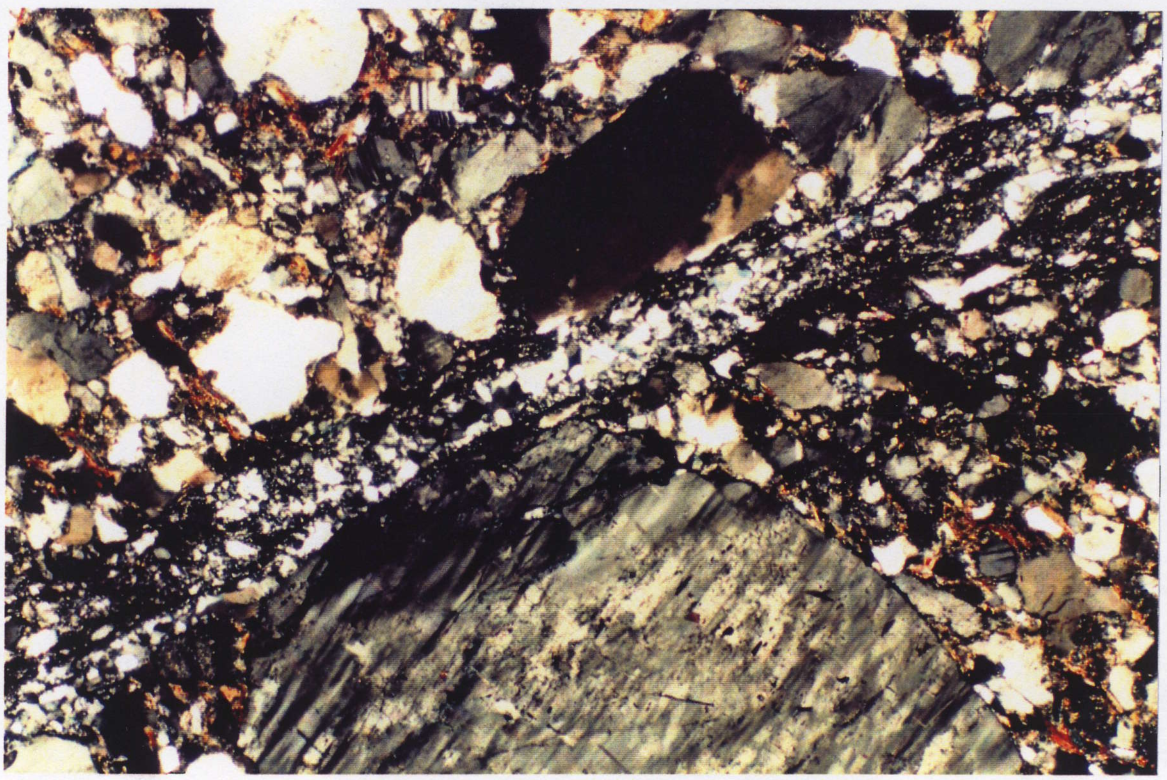
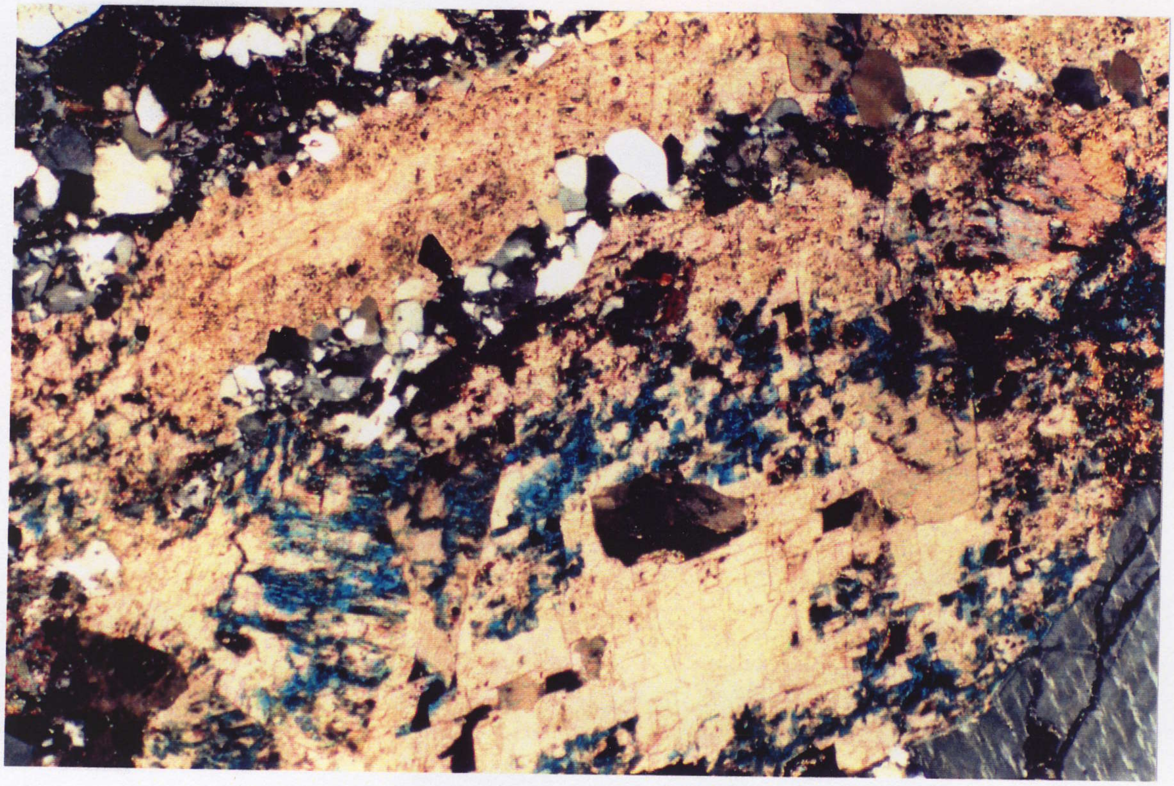


Plate 7, 17.88: The same crush zone as in plate 6, but at a different location. Shows early quartz growth in fracture space, with later dolomite filling remaining space in fracture. Dissolution porosity (blue) is also present in the dolomite. Crossed polars, x50.

Plate 8, 152: Quartz and bitumen filled vein. Note that two generations of bitumen fill are apparent here. The early phase has occurred prior to the main phase of quartz crystallisation, with bitumen present in small stringers near vein walls. The bulk of the hydrocarbon migration has taken place subsequent to the main phase of quartz crystallisation and fills in voids remaining in the vein after quartz crystallisation. Crossed polars, x50



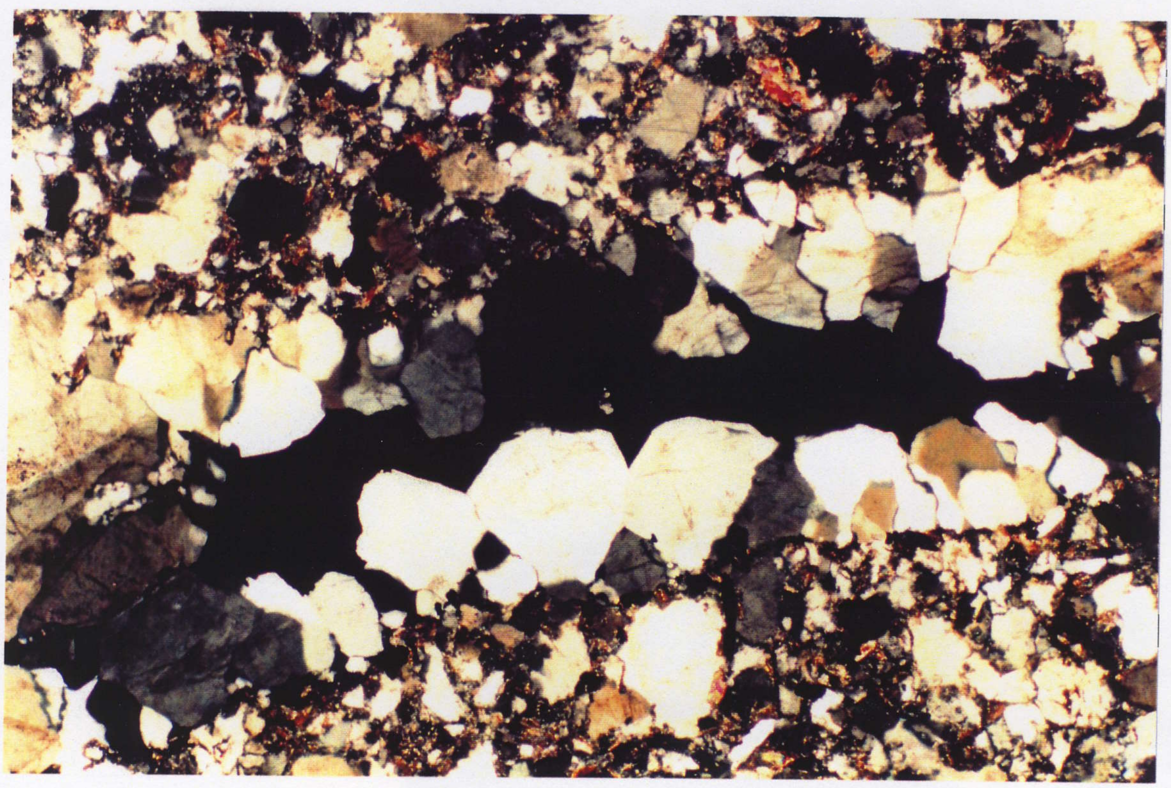
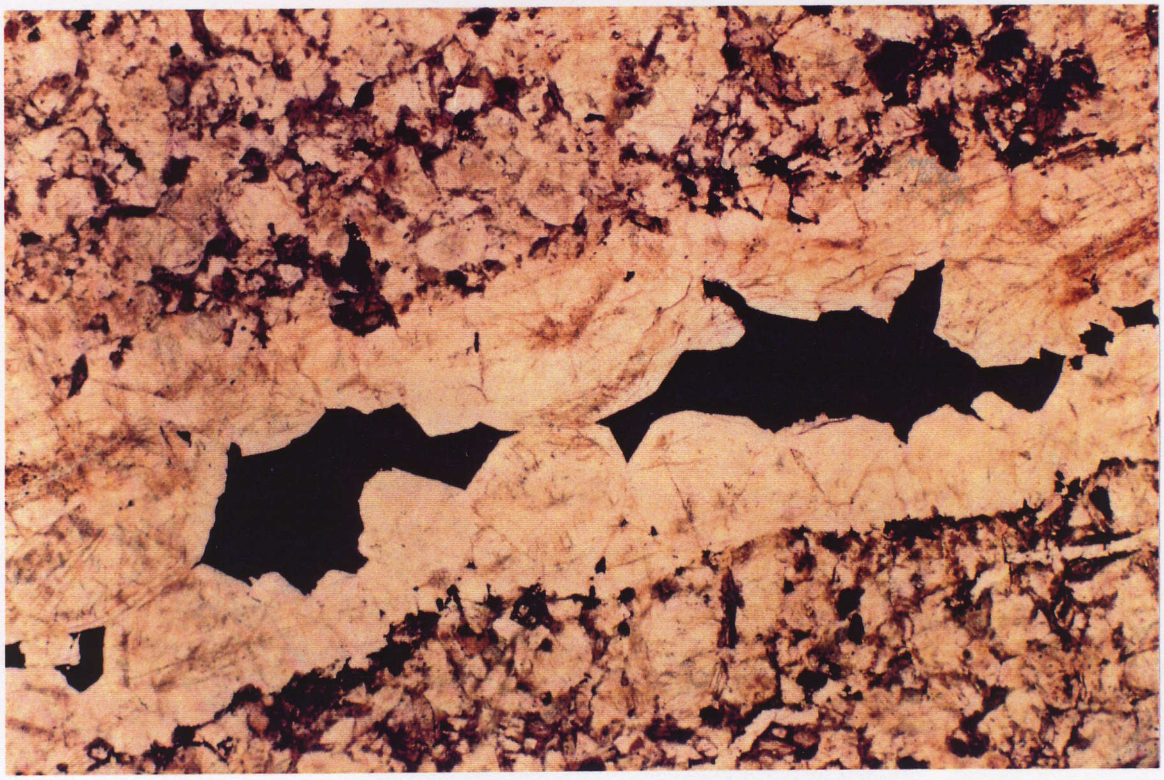


Plate 9, 152: Same view as in plate 8. Plane polarised light, x50.

Plate 10, 152. Major crush zone associated with quartz and bitumen. Crossed polars, x50



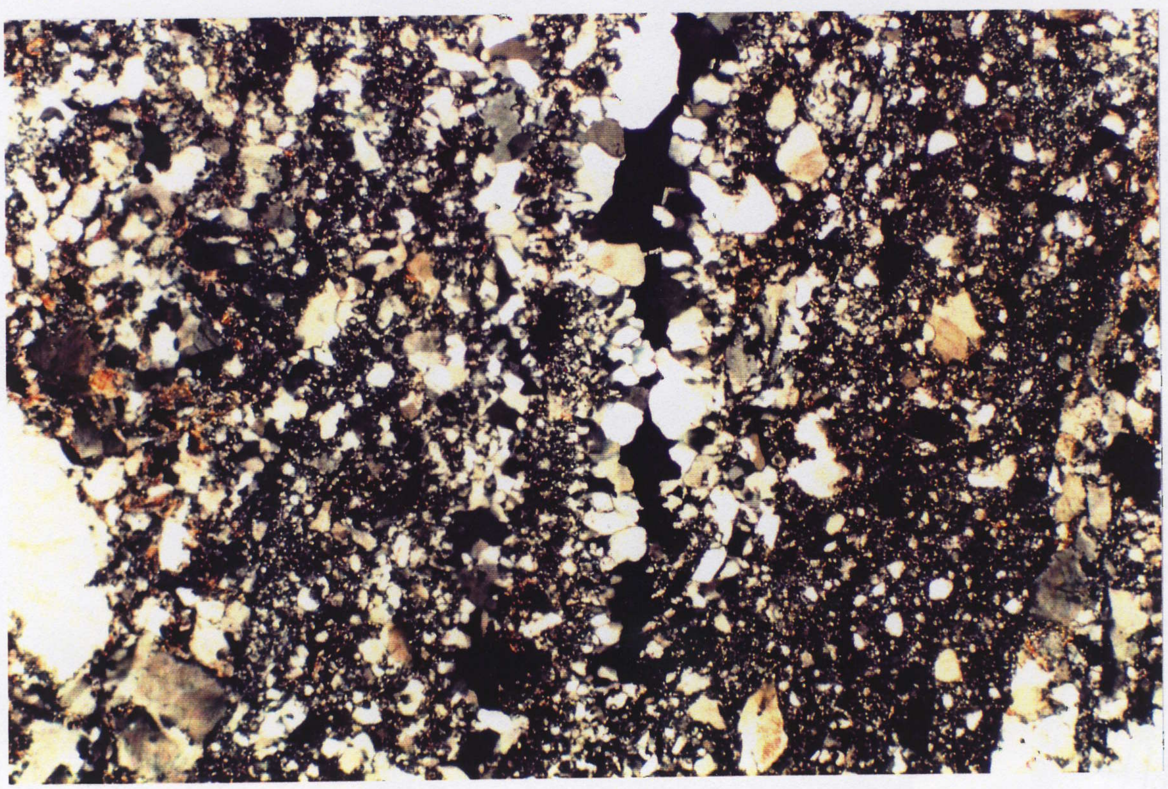
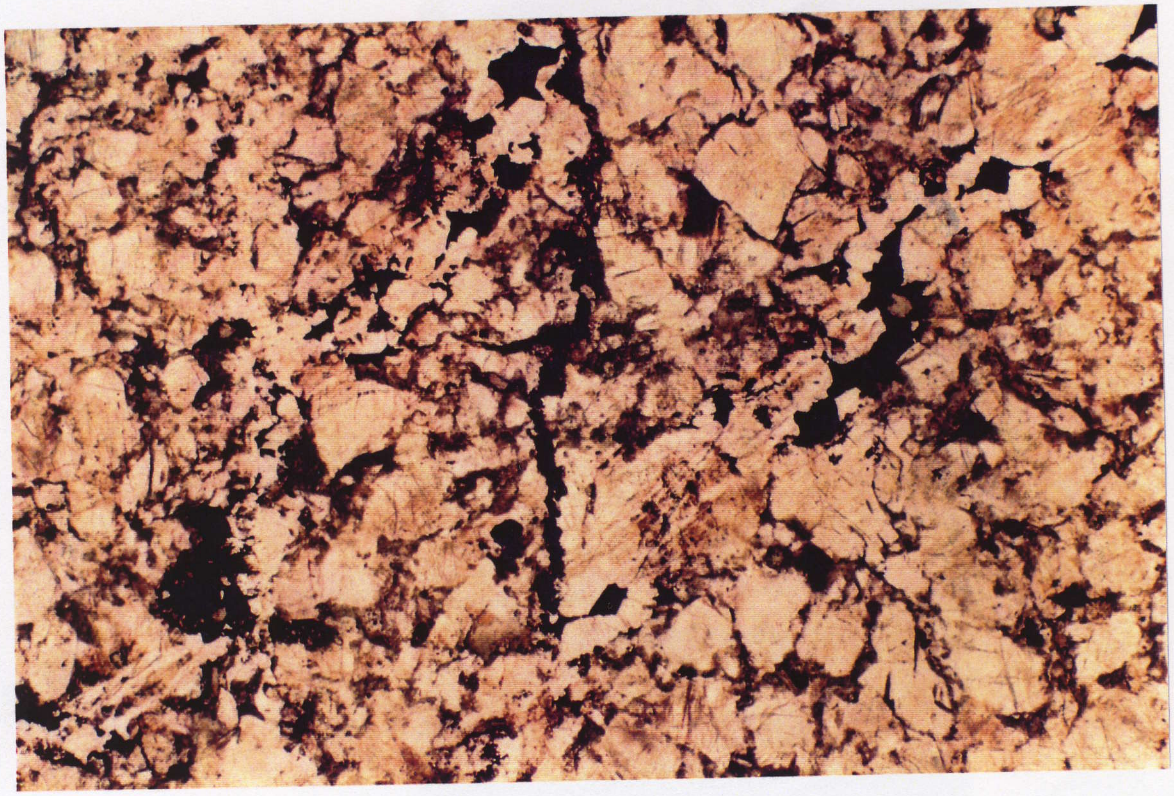


Plate 11, 152: Shows offset of one bitumen filled fracture (NE/SW trending) by another bitumen-filled fracture (NS trending), indicating more than one generation of hydrocarbon filling. Plane polarised light, x50.

Plate 12, 152: Shows quartz, dolomite and bitumen in a crush zone, with bitumen (closer to vein walls) clearly appearing as an earlier feature than dolomite. Crossed polars, x50.



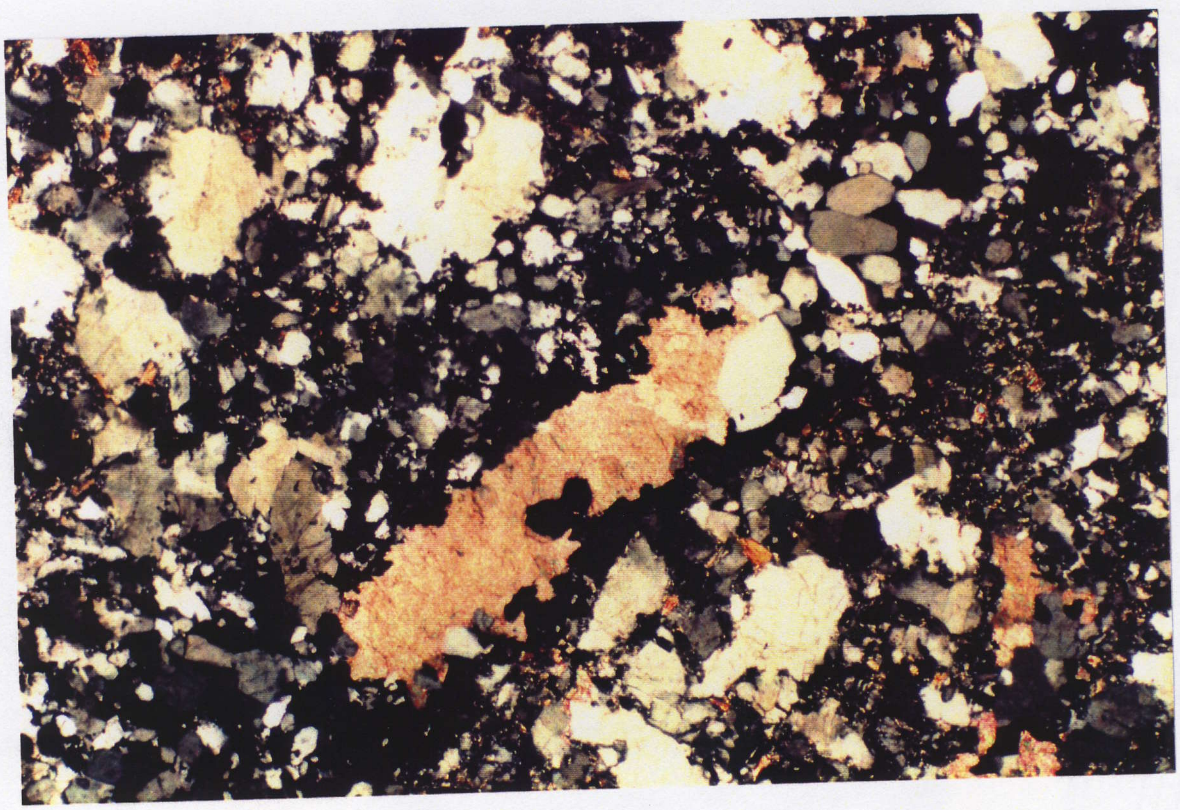
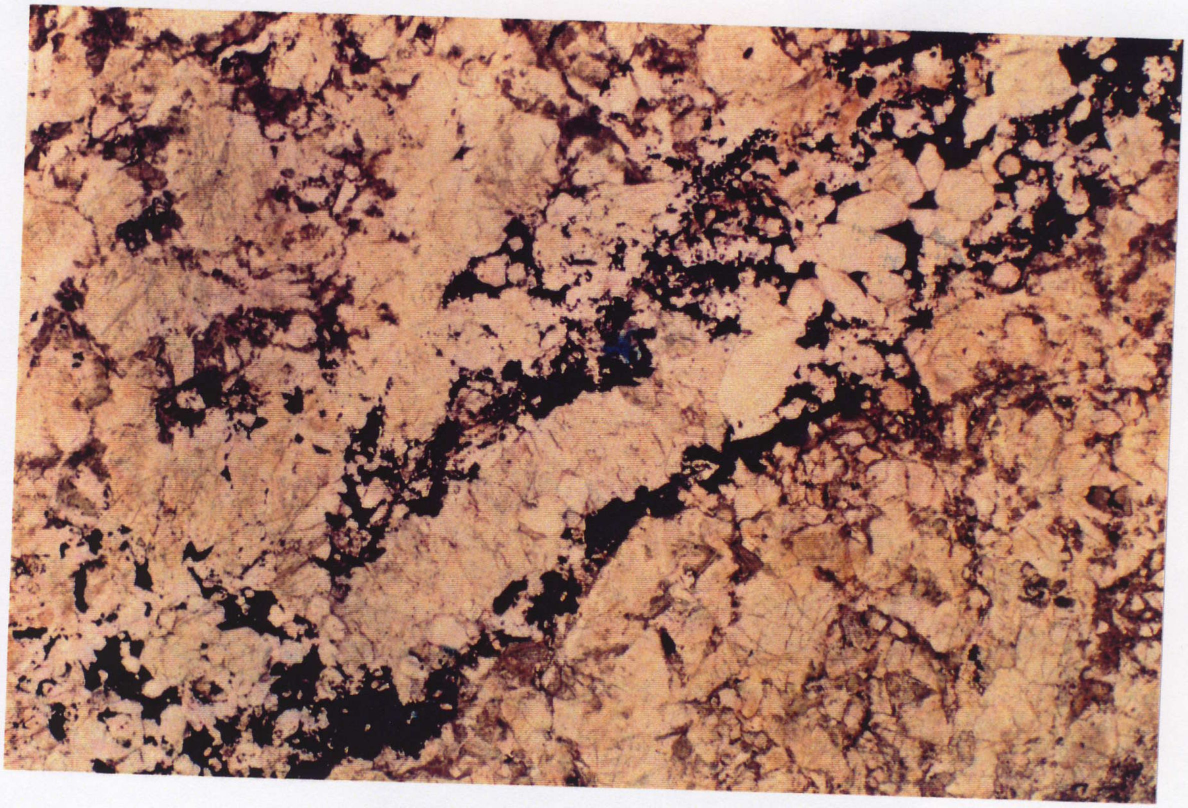


Plate 13, 152: Same view as in Plate 12. Plane polarised light, x50.

Plate 14: 35.7: Major vein filled with dolomite showing vuggy porosity. Euhedral quartz crystals evidently grew on fracture walls prior to filling with dolomite. Dolomite shows euhedral extinction and is hence saddle dolomite. Plane polarised light, x50.



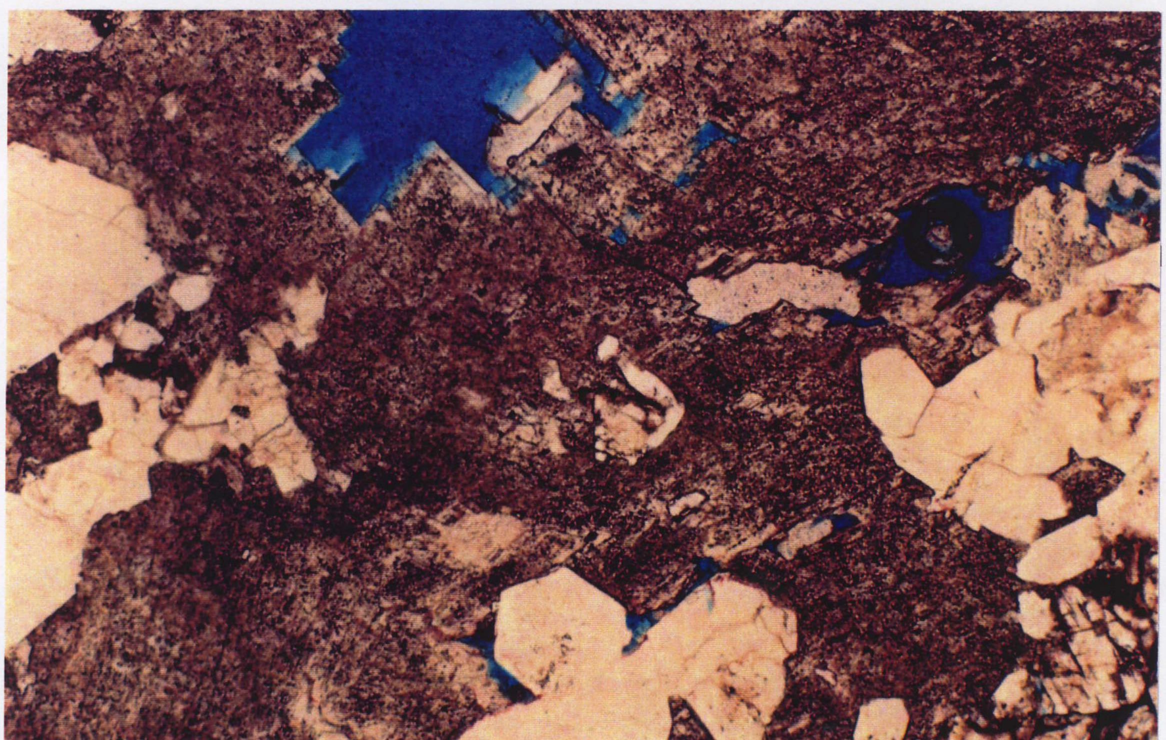
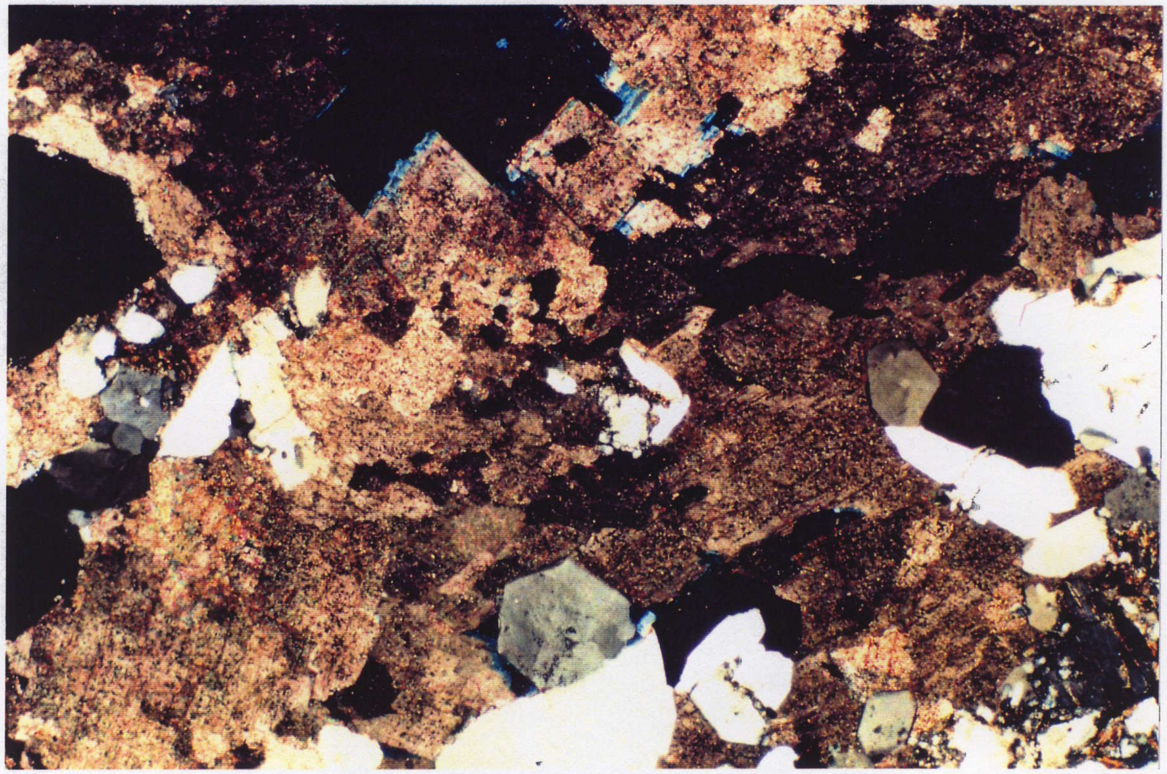


Plate 15, 35.7: Same view as in plate 14. Plane polarised light, x50.

Plate 16: 64.6: Bitumen associated with crush zone. Note that in this case bitumen is not obviously associated with any other diagenetic feature (e.g. euhedral quartz). This may indicate that hydrocarbon migration occurred relatively soon after opening of the fracture. Crossed polars, x50.



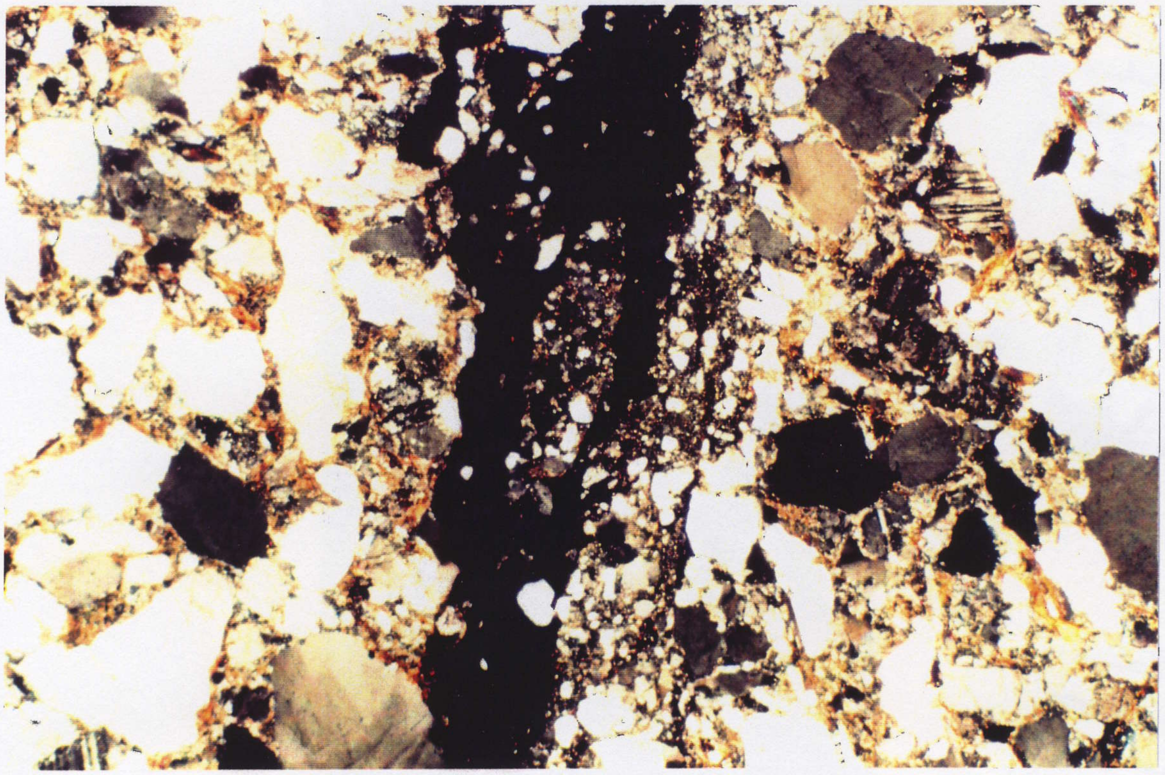
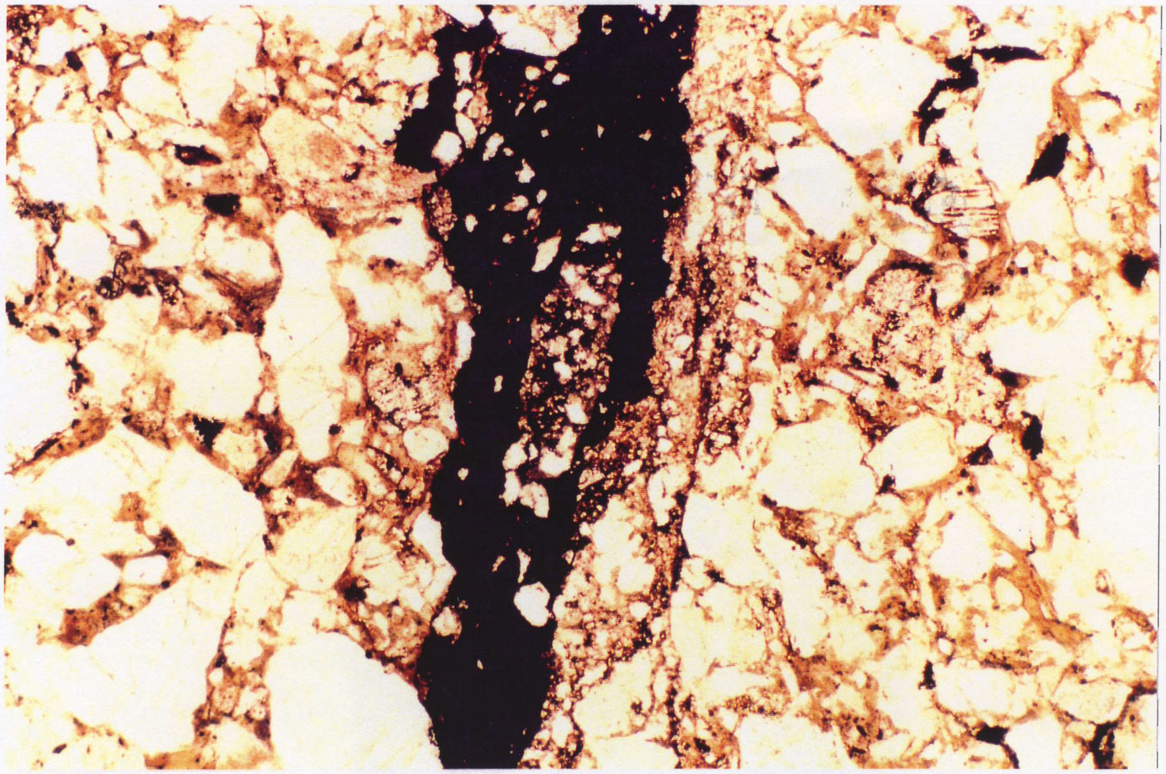


Plate 17, 64.6: Same view as plate 16. Plane polarised light, x50.

Plate 18, 64.6: Same fracture as in plates 16, 17, at a different location. Crossed polars, x50



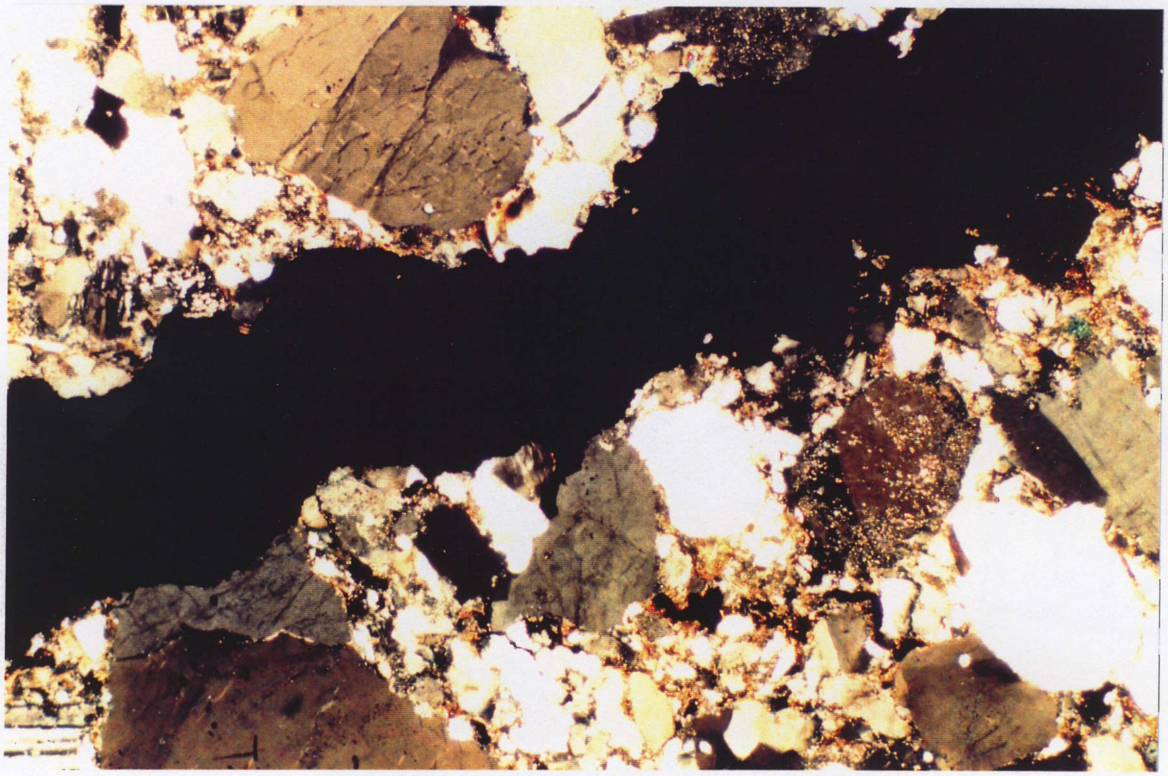
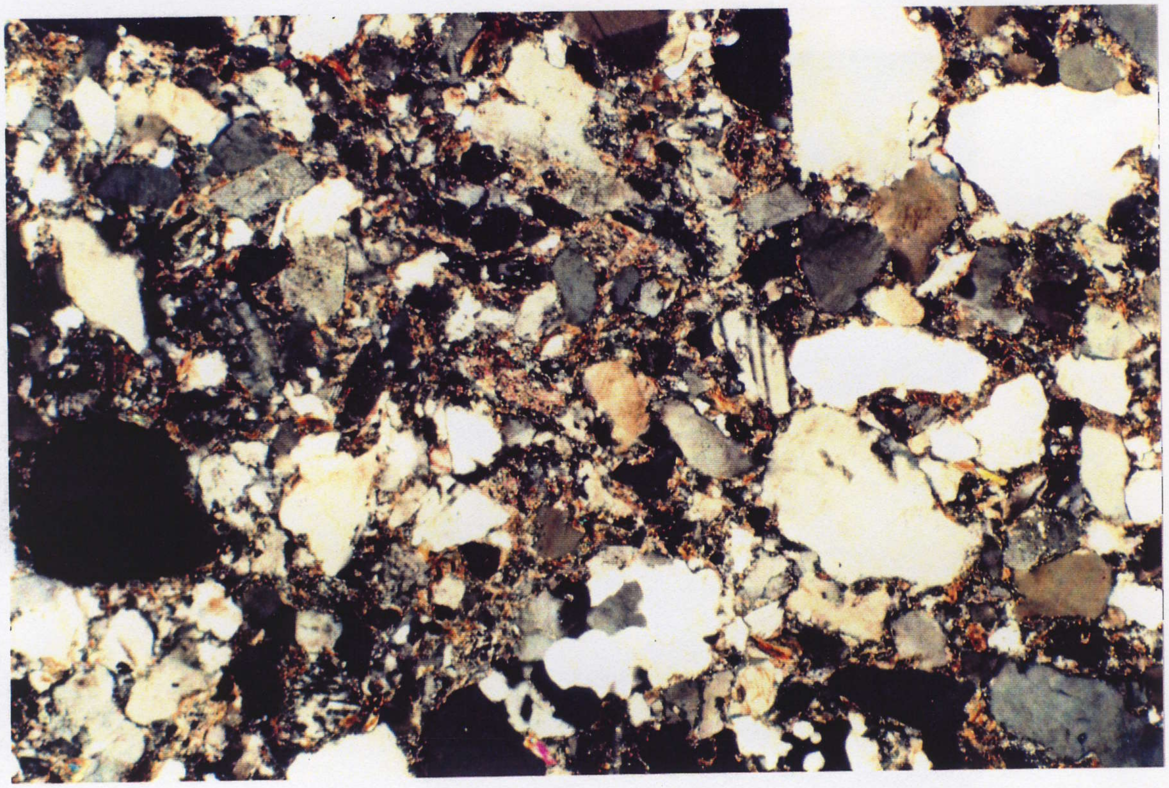


Plate 19, 113.9: General view of area which in hand specimen appears as whiter patch in generally grey green sandstone. While some carbonate is present, it still represents a fairly minor proportion of the inter-framework material. Crossed polars, x50.

Plate 20, 113.9: General view of area which in hand specimen is normal grey green colour. Note high percentage of elongate ferromagnesian sheet silicates and lack of carbonate. Crossed polars, x50.



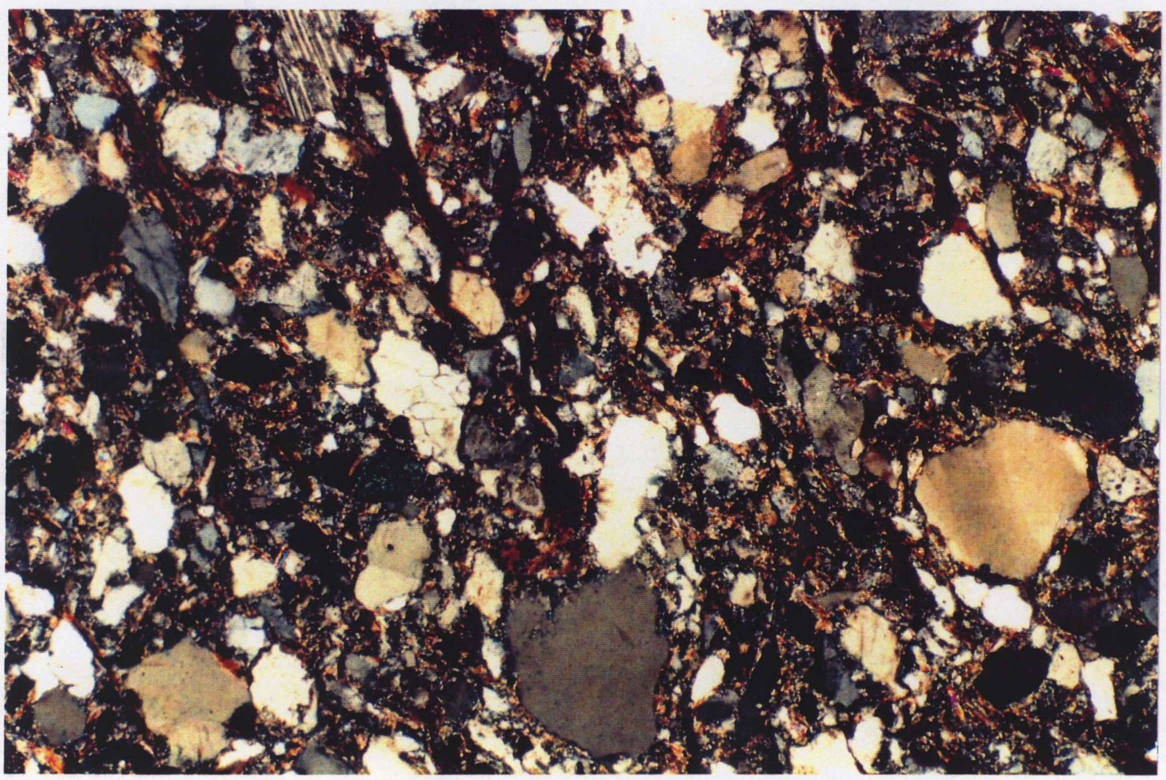
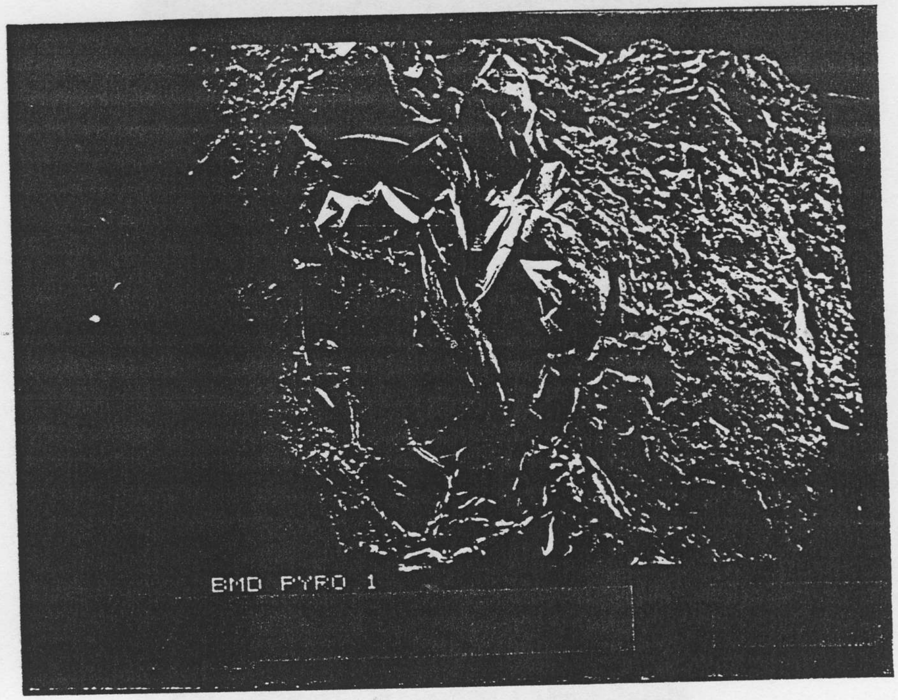


Plate 21, 63.1: Scanning electron microscope image of bituminous material on surface of fracture. Note smooth surface and conchoidal fracture.

Plate 22, 63.1: Scanning electron microscope image of fragmented bituminous material, showing conchoidal fracture.


BMD PYRO 1

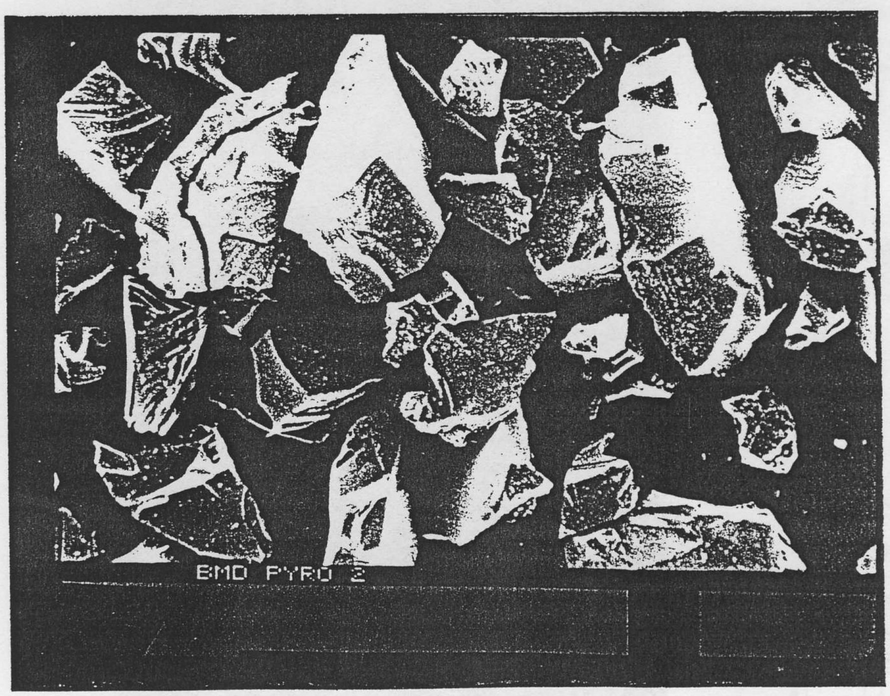
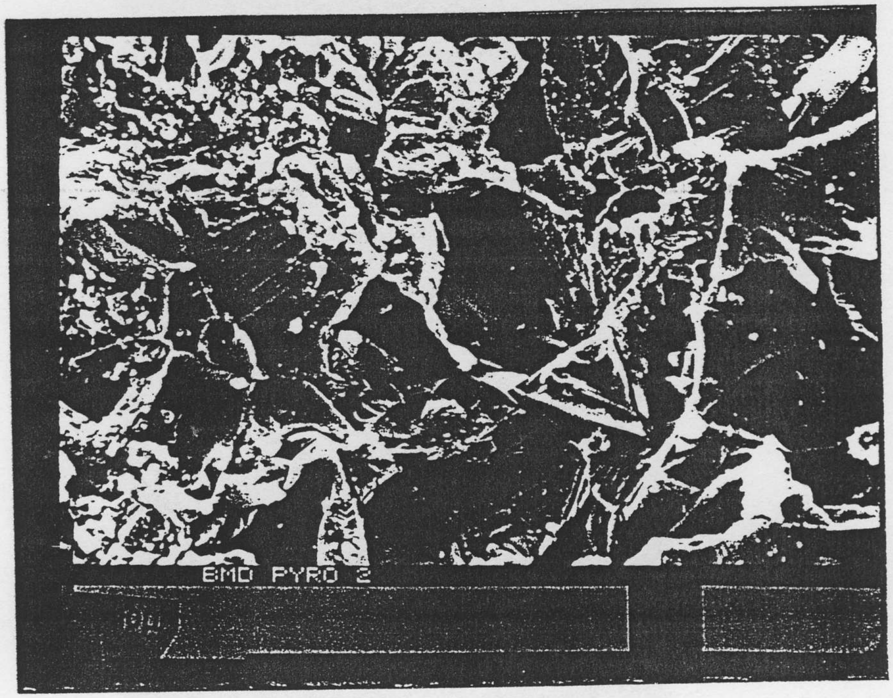

BMD PYRO 2

Plate 23, 63.1: Scanning electron microscope image of bituminous material (smooth, dark), surrounded by carbonate (light, rough).


BMD PYRO 2

Appendix III

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.

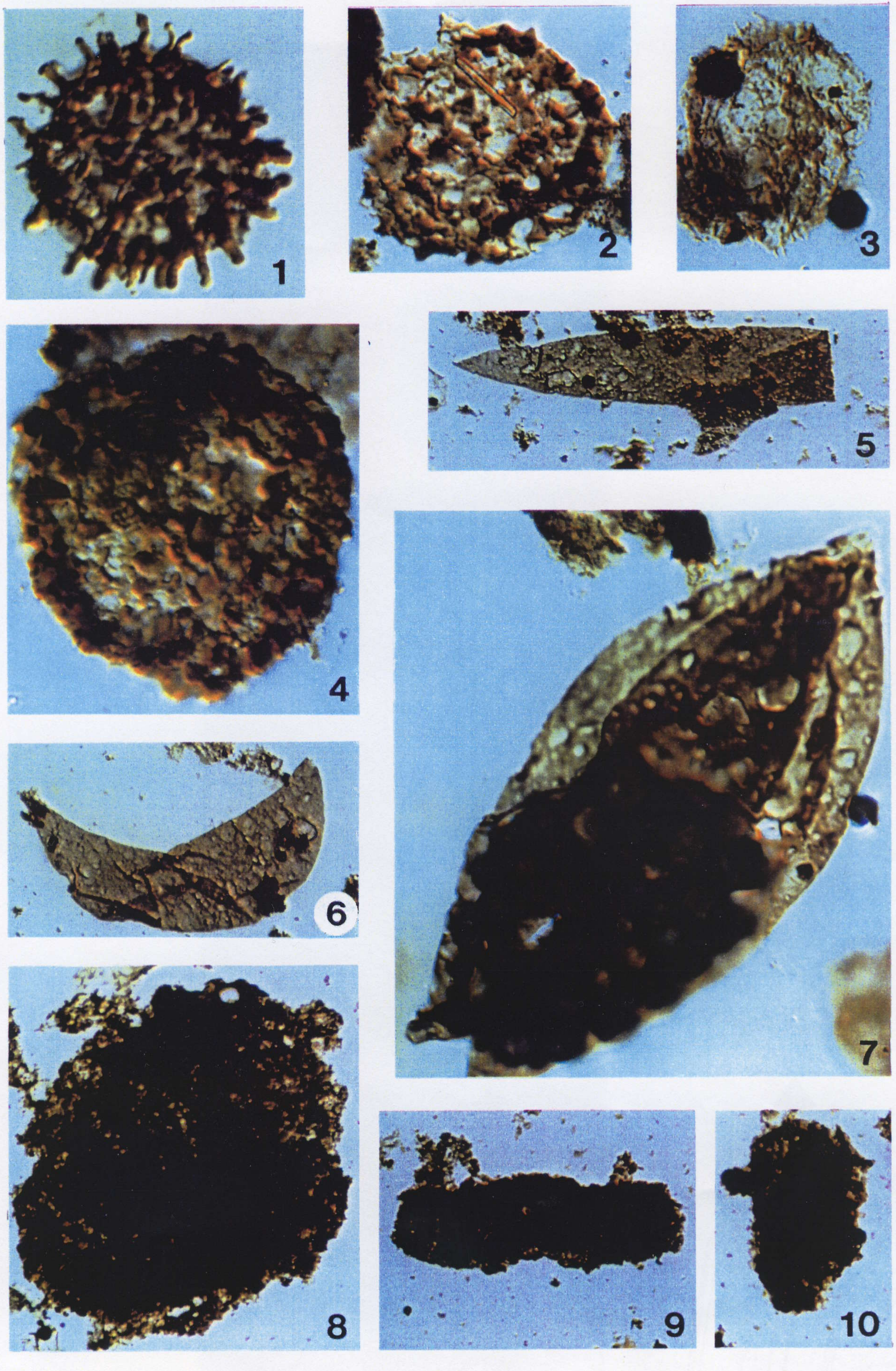

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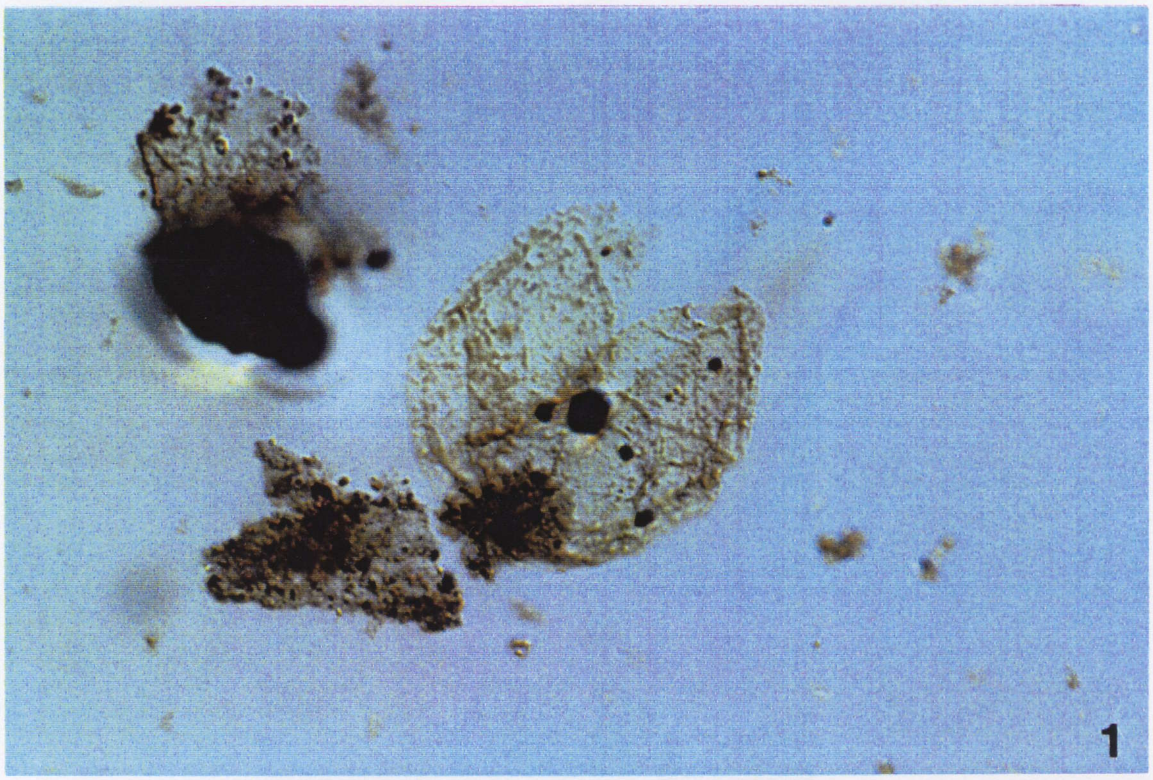
PLATE 2

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).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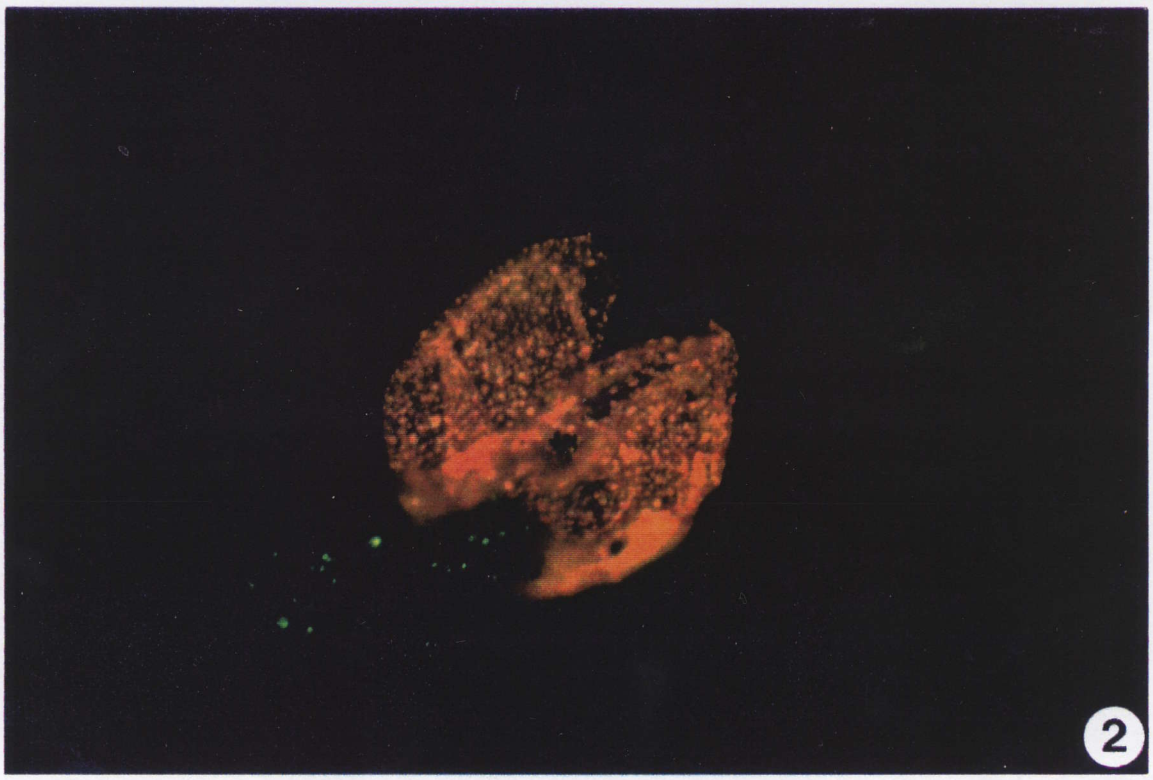
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PLATE 3

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.

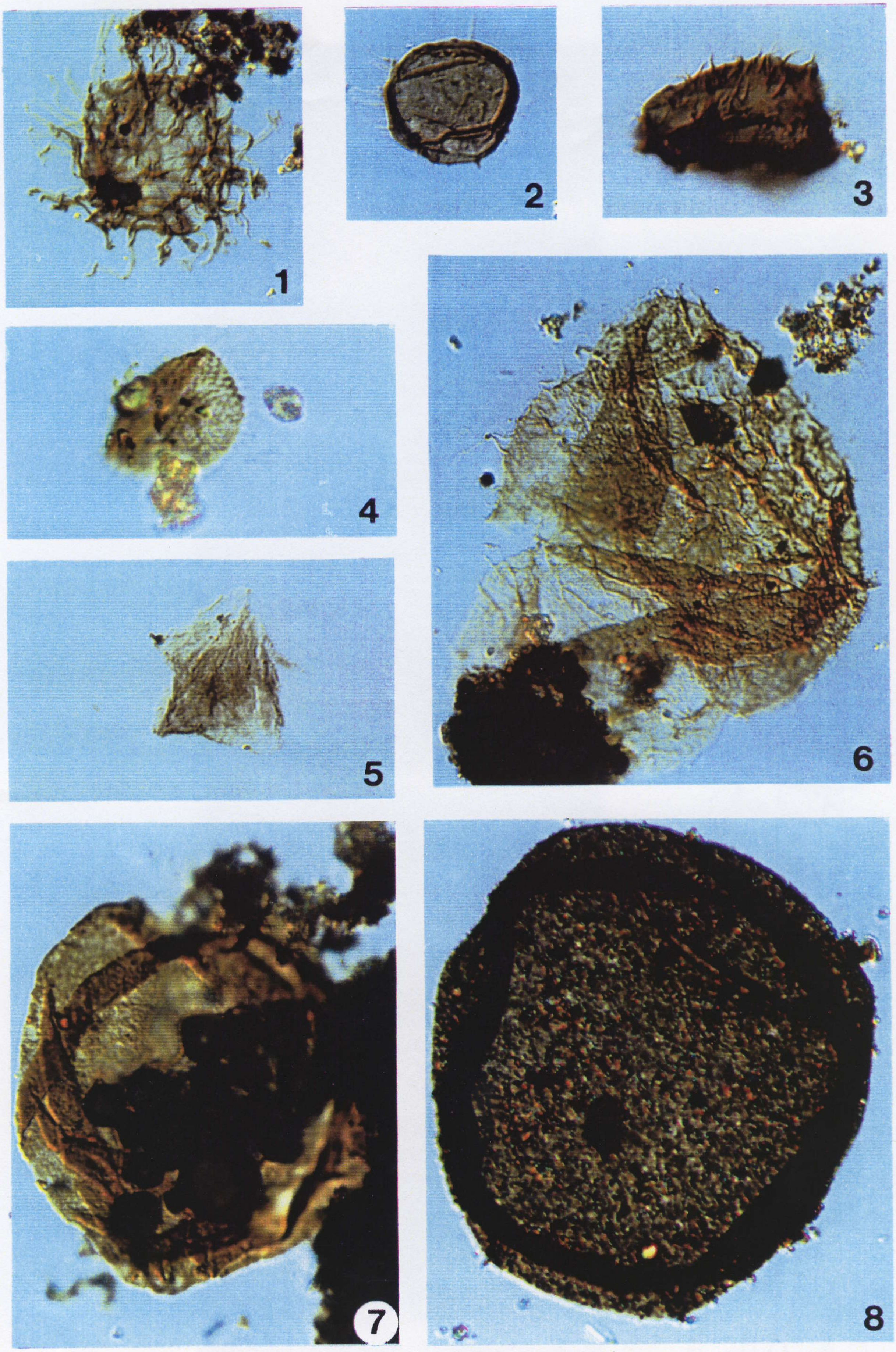
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PLATE 4

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.

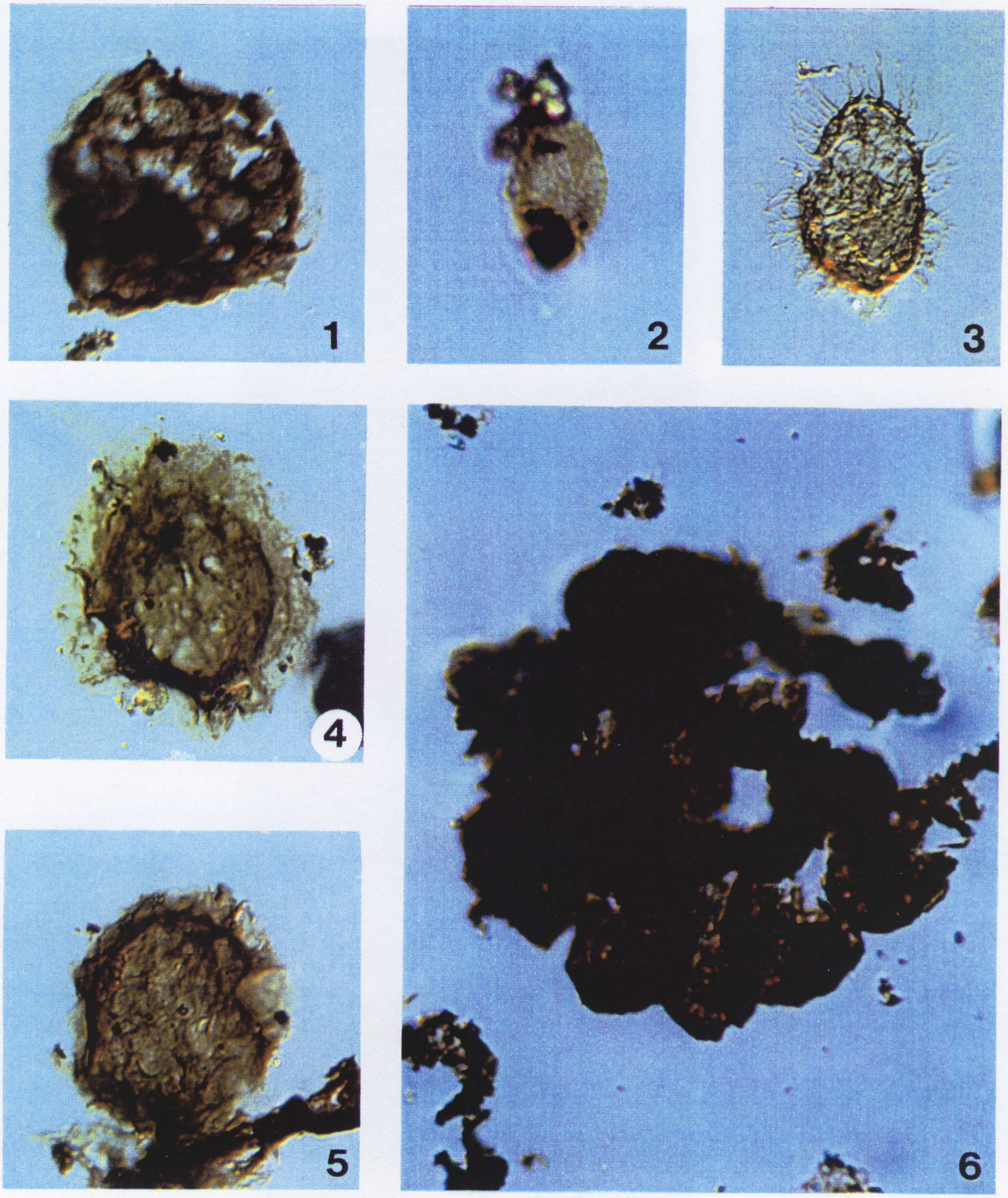
2. *Micrhystridium minutum* WW-3; 85-95m; 5.0, 83.3; x1,900.

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 (16μm) sphaeromorphs medium (32μm) sphaeromorphs large (48μm) sphaeromorphs *Baltisphaeridium* sp. A *Baltisphaeridium* sp. B *Baltisphaeridium cerinum* *Lophosphaeridium* sp. (granulate) *Lophosphaeridium* sp. (verrucate) *Leiofusa.* sp. B of sample M102 (large > 120μm) cf. *Lunulidinium*? sp. of sample M102 (small ~ 200μm) *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 (16μm) sphaeromorphs medium (32μm) sphaeromorphs large (48μm) 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.

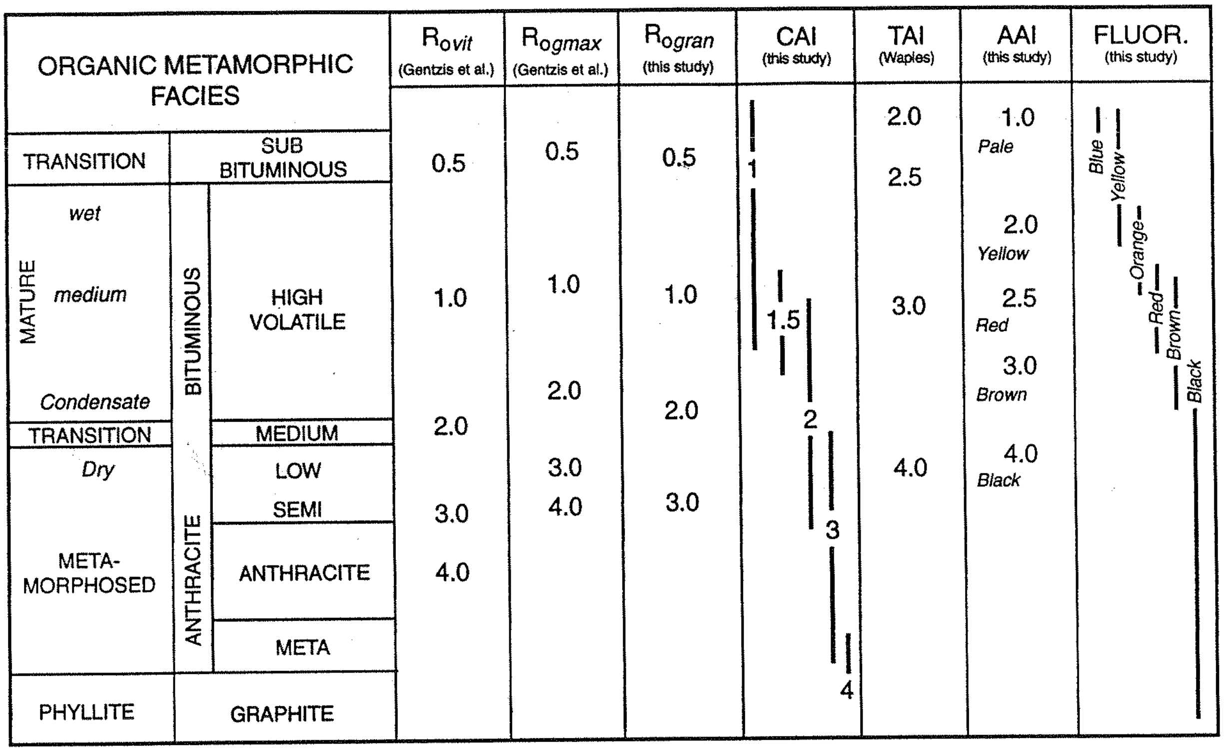

Figure 1. Correlation of thermal maturity indices discussed in text.

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

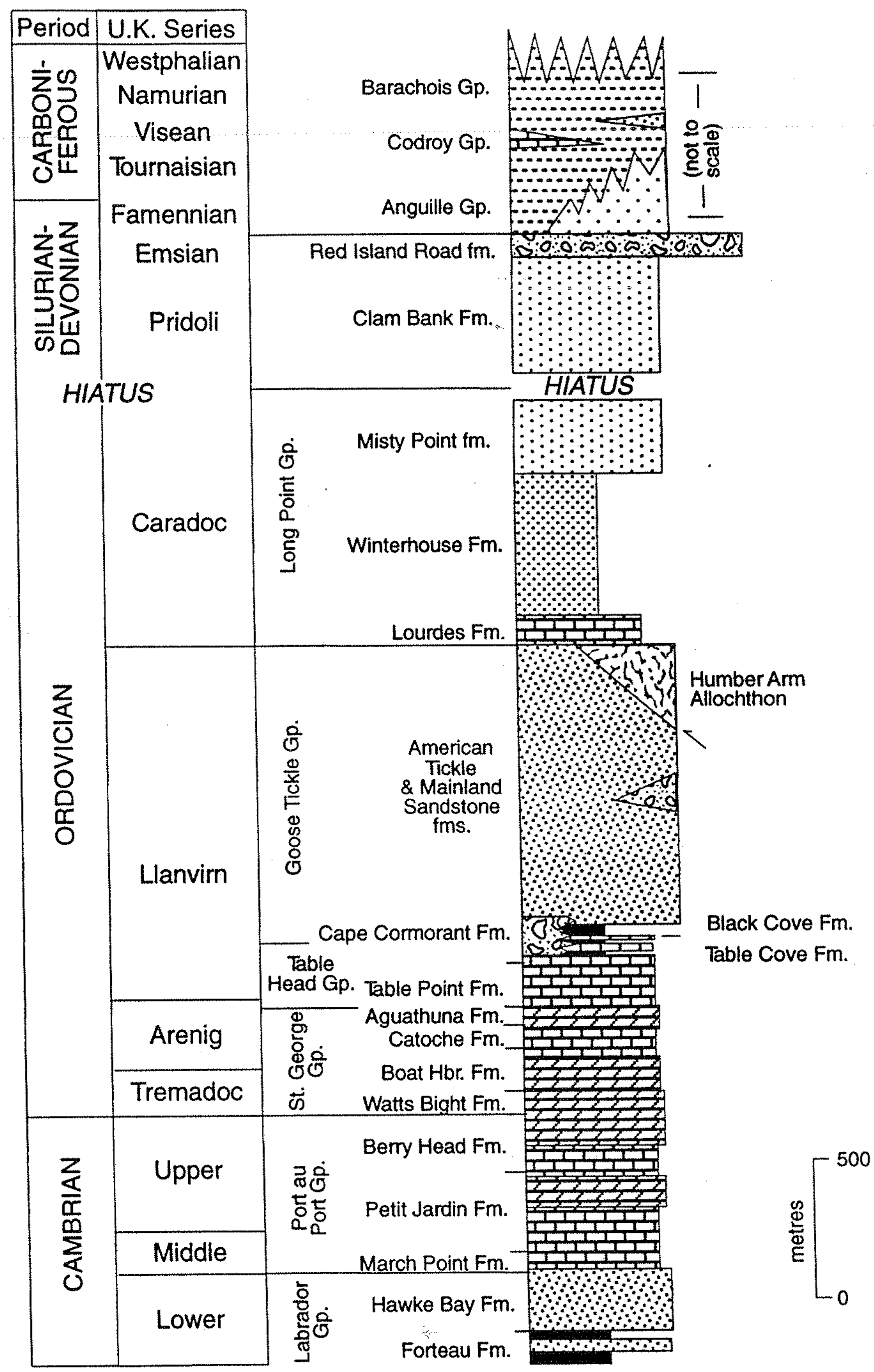

Figure 2. Paleozoic stratigraphy of autochthonous strata in western Newfoundland

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

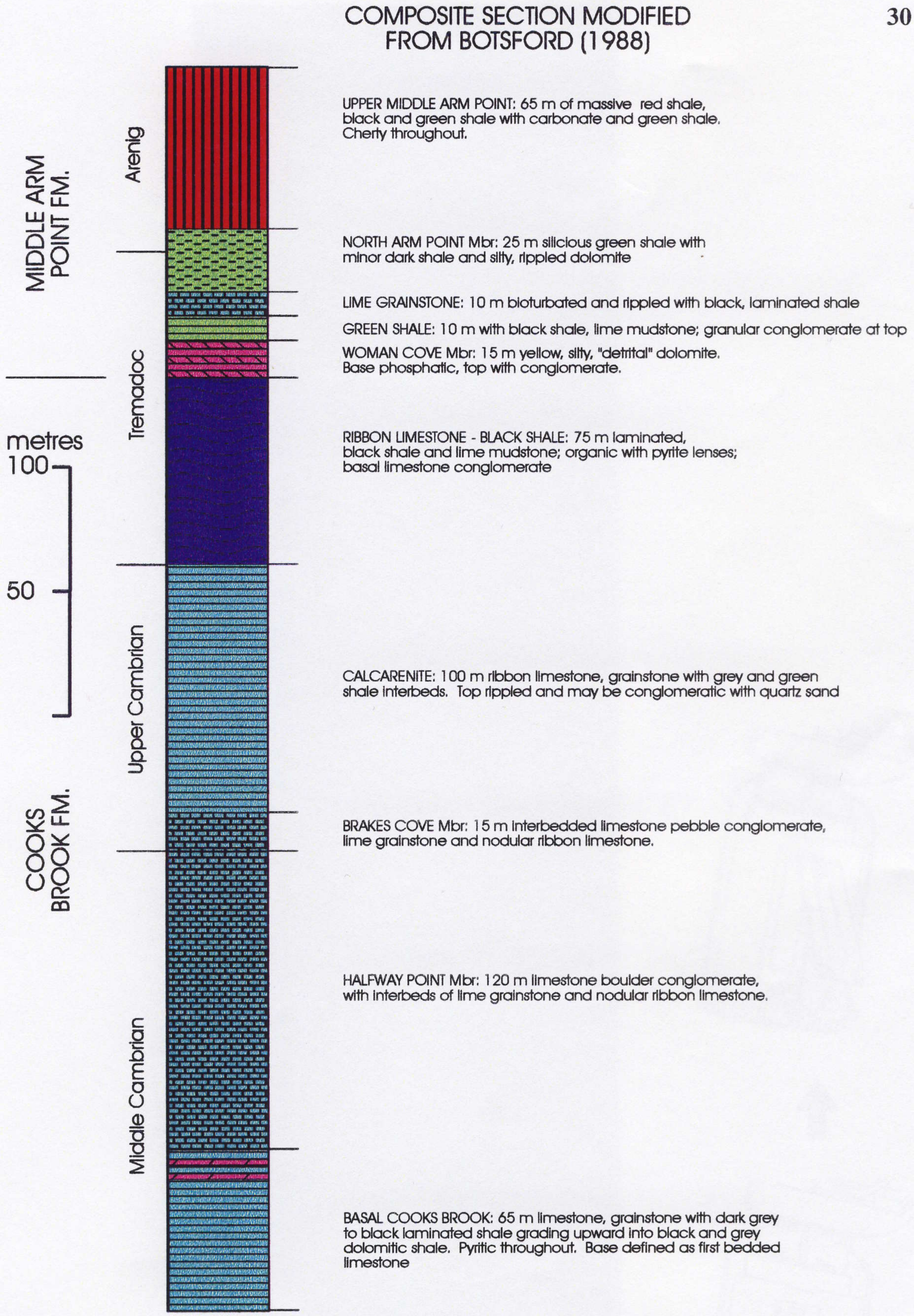

Figure 3. Composite section for allochthonous strata in the Bay of Islands region.

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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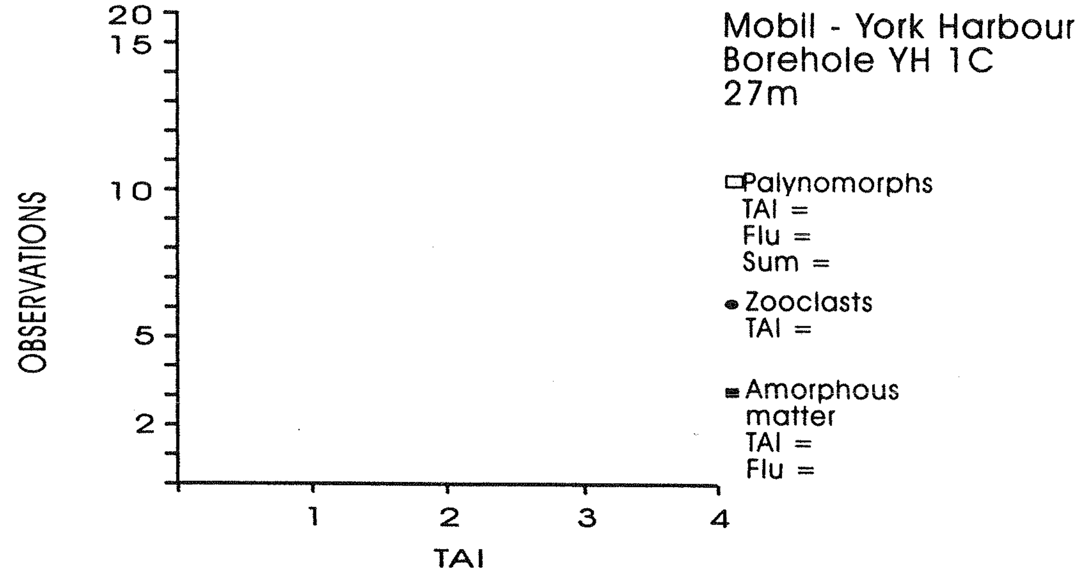
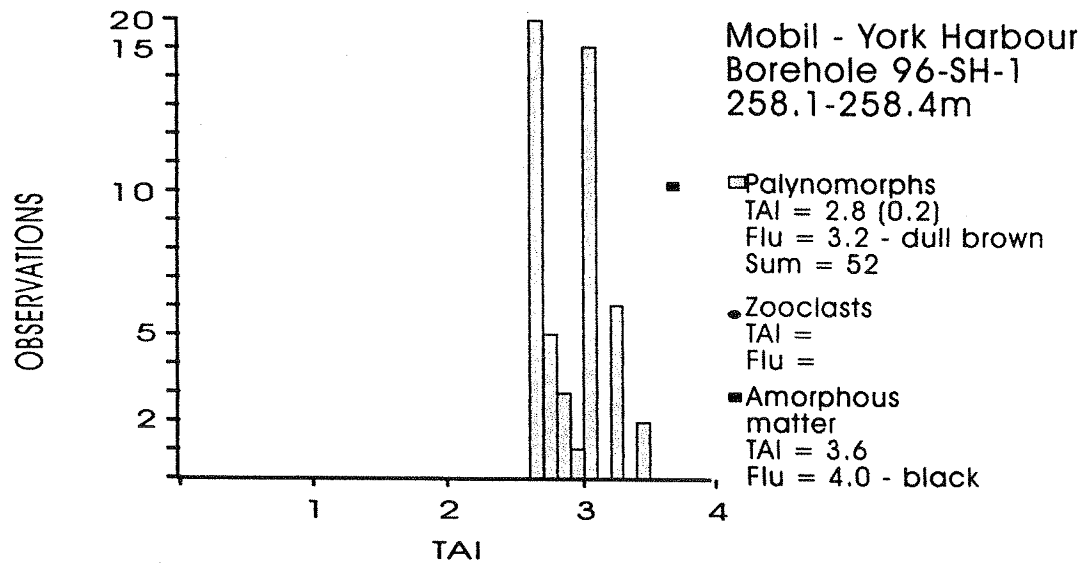
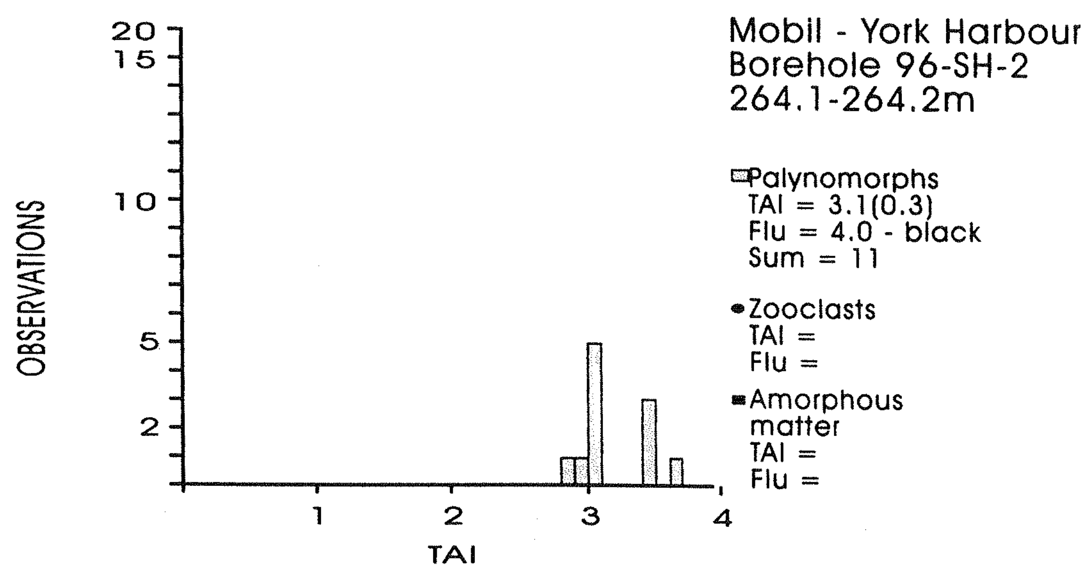


OBSERVATIONS
20
15
10
5
2
1
2
3
4
TAI
Mobil - York Harbour
Borehole YH 1C
27m
Palynomorphs
TAI =
Flu =
Sum =
Zooclasts
TAI =
Amorphous
matter
TAI =
Flu =



OBSERVATIONS
20
15
10
5
2
1
2
3
4
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
20
15
10
5
2
1
2
3
4
TAI
Mobil - York Harbour
Borehole 96-SH-2
264.1-264.2m
Palynomorphs
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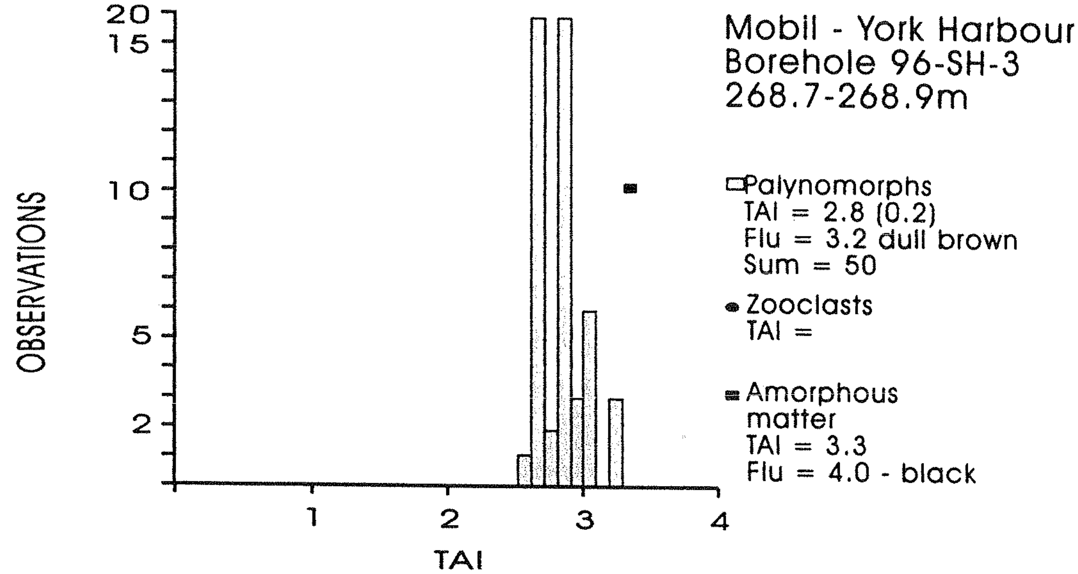
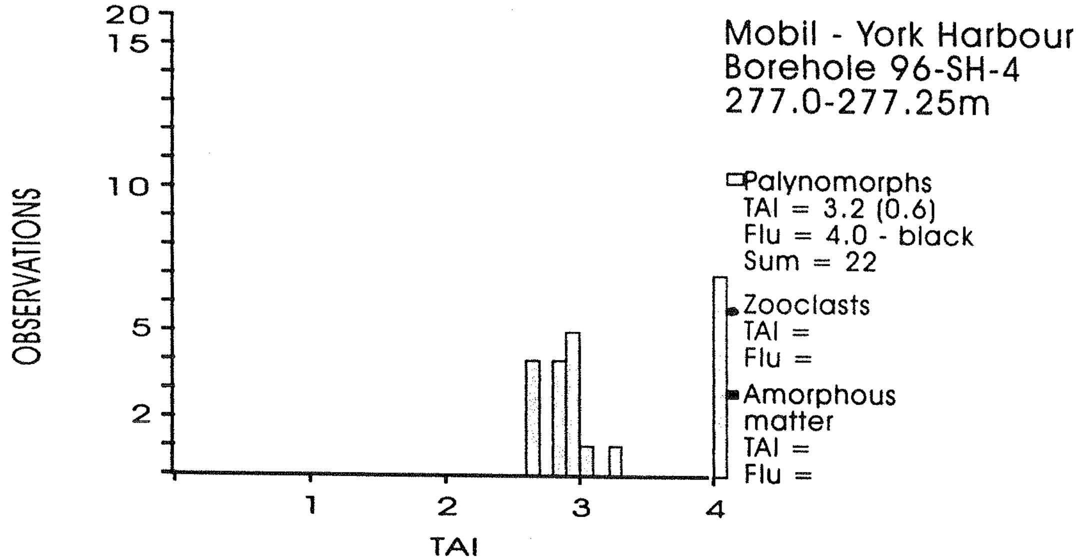
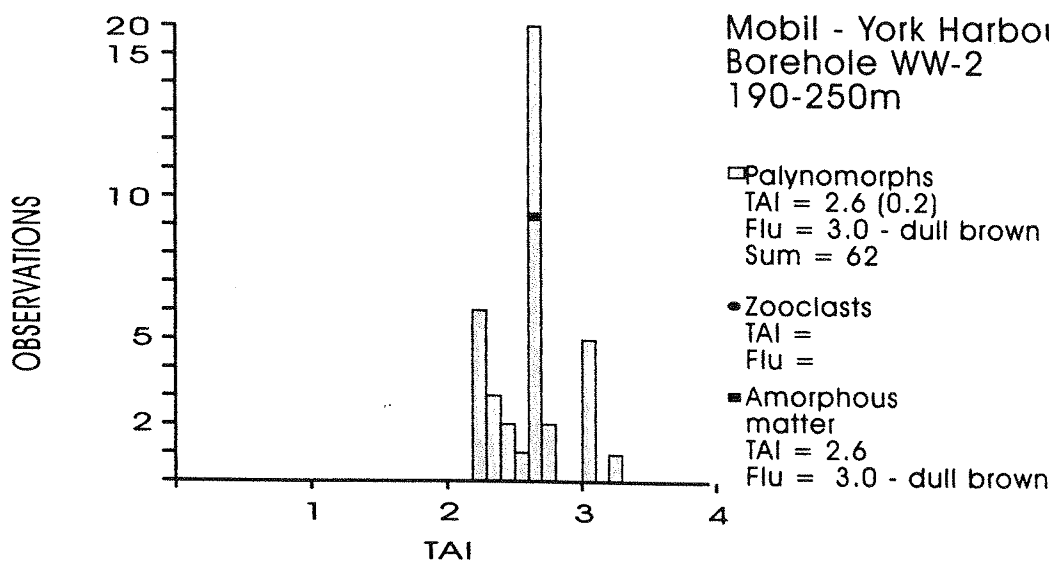
Flu = 4.0 - black
Sum = 11
Zooclasts
TAI =
Flu =
Amorphous
matter
TAI =
Flu =


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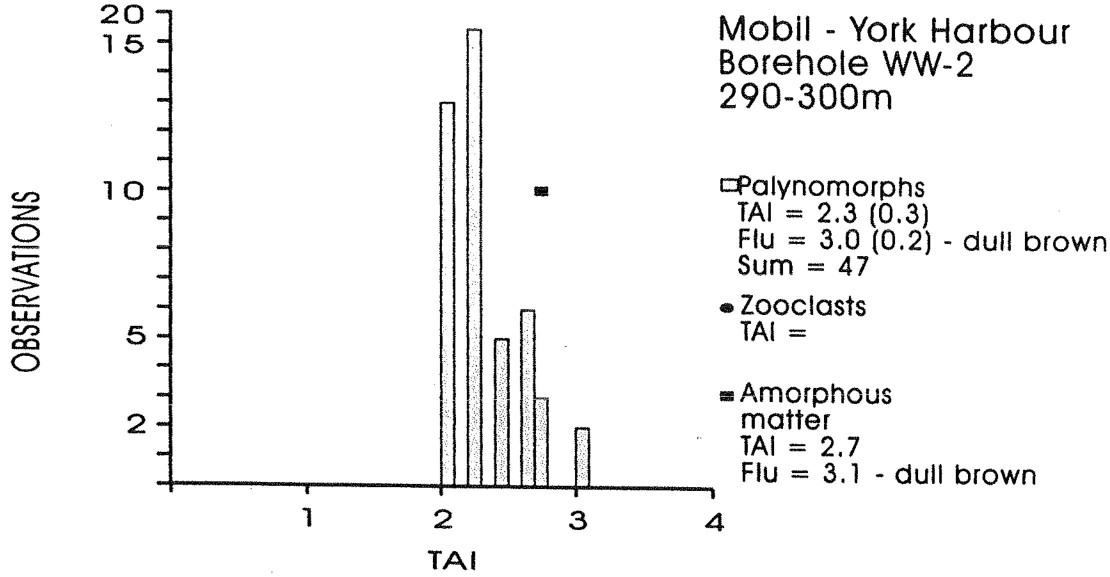
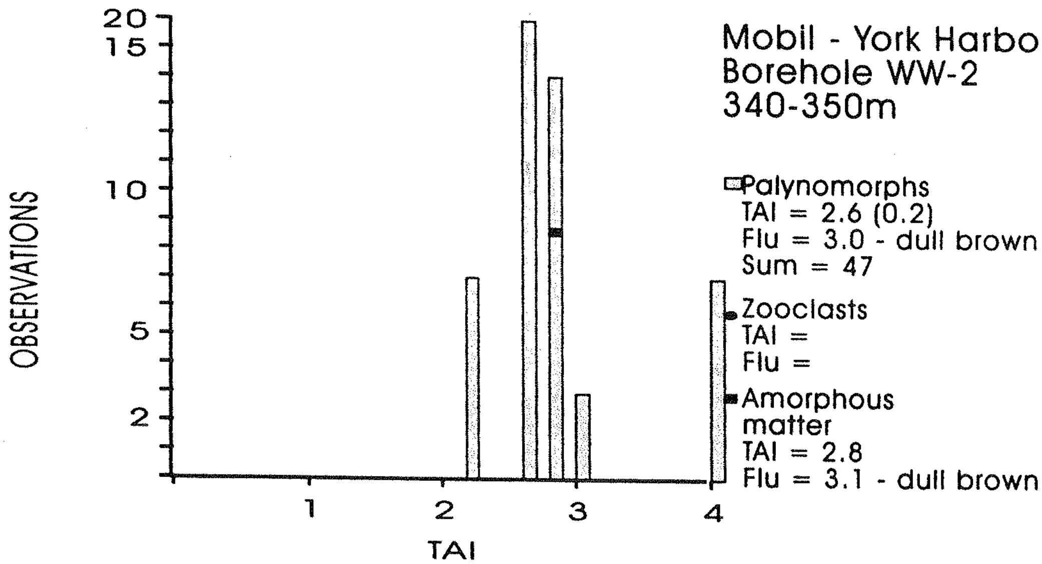
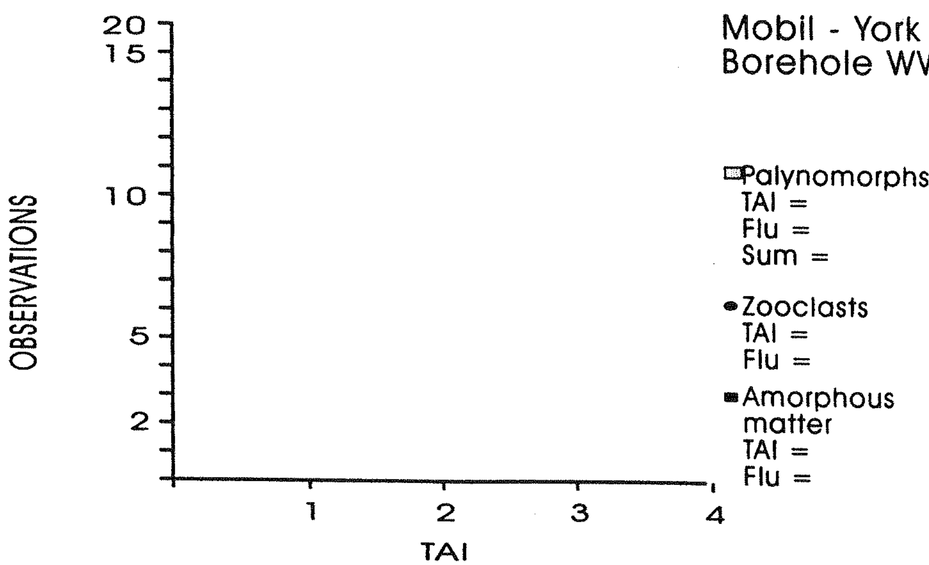
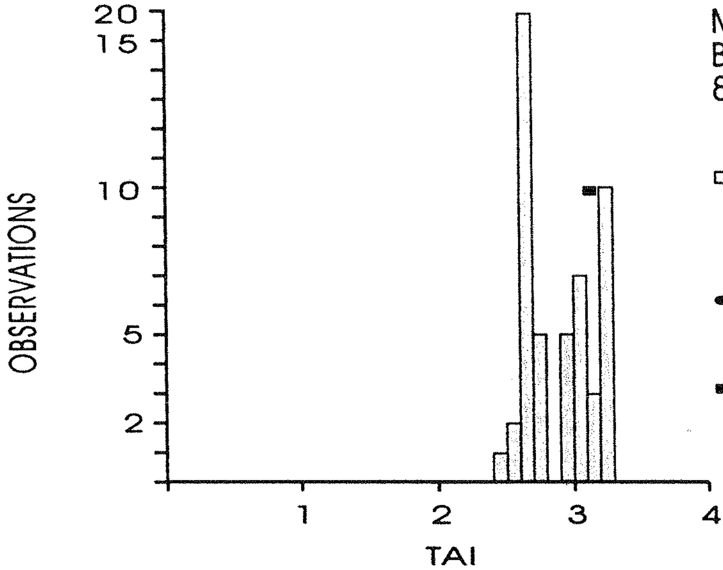
Borehole WW-2
190-250m
Palynomorphs
TAI = 2.6 (0.2)
Flu = 3.0 - dull brown
Sum = 62
Zooclasts
TAI =
Flu =
Amorphous matter
TAI = 2.6
Flu = 3.0 - dull brown
OBSERVATIONS
TAI
20
15
10
5
2
1
2
3
4


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
OBSERVATIONS
20
15
10
5
2
1
2
3
4
TAI


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
OBSERVATIONS
20
15
10
5
2
1
2
3
4
TAI


Mobil - York Harbour
Borehole WW-2
Palynomorphs
TAI =
Flu =
Sum =
Zooclasts
TAI =
Flu =
Amorphous matter
TAI =
Flu =
OBSERVATIONS
20
15
10
5
2
1
2
3
4
TAI

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

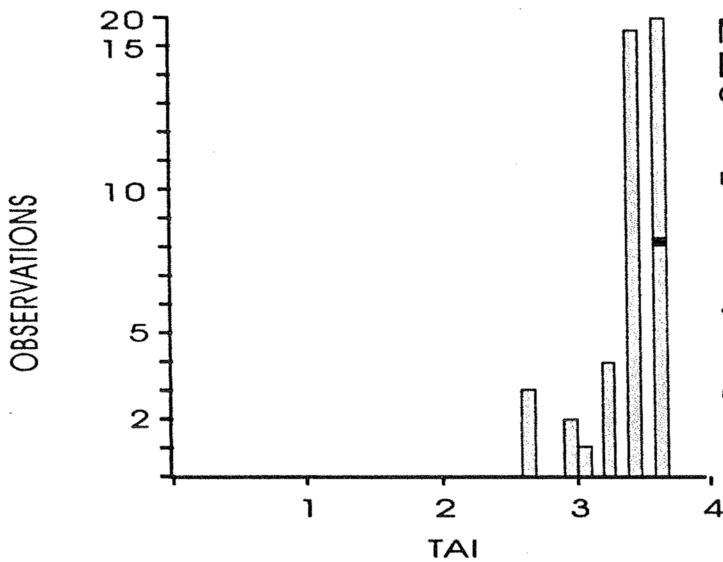


□Palynomorphs
TAI = 2.8 (0.3)
Flu = 3.1 (0.1) - dull brown
Sum = 54

•Zooclasts
TAI =

▪Amorphous matter
TAI = 3.2
Flu = 4.0 - black

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



□Palynomorphs
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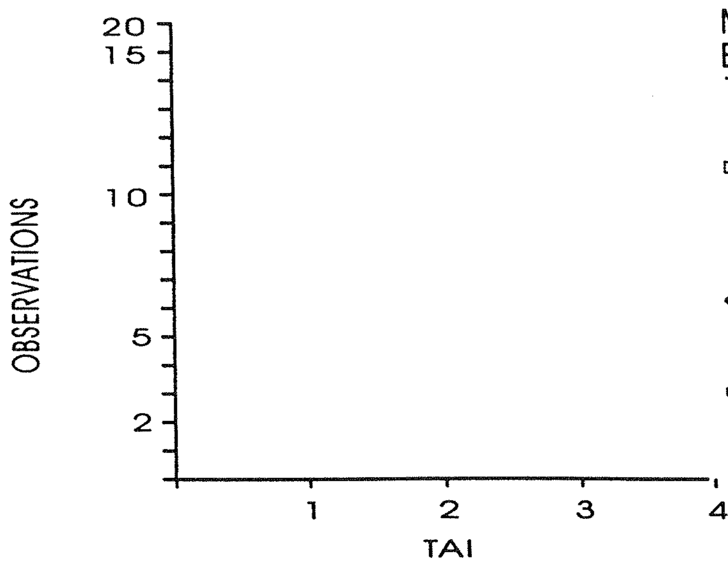
Flu = 4.0 - black
Sum = 48

•Zooclasts
TAI =
Flu =

▪Amorphous matter
TAI = 3.6
Flu = 4.0 - black

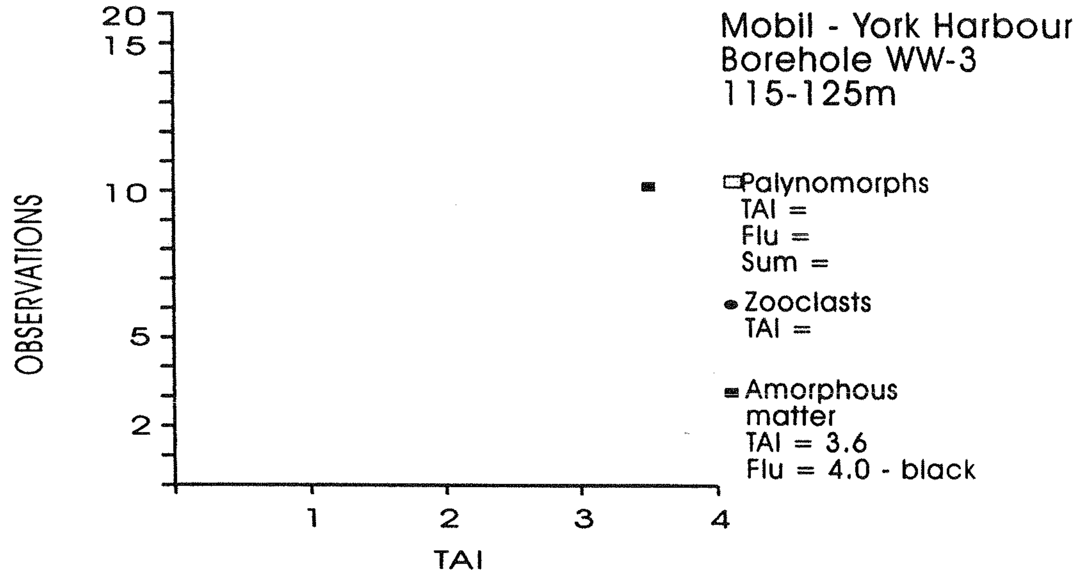
Mobil - York Harbour
Borehole WW-3
105-115m



□Palynomorphs
TAI =
Flu =
Sum =

•Zooclasts
TAI =
Flu =

▪Amorphous matter
TAI =
Flu =



Mobil - York Harbour
Borehole WW-3
115-125m
Palynomorphs
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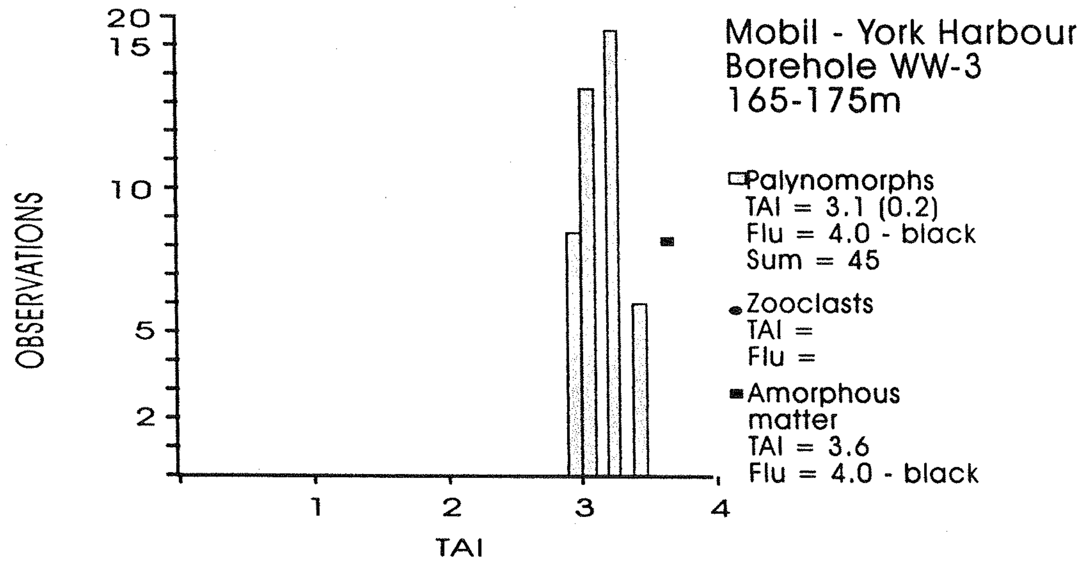
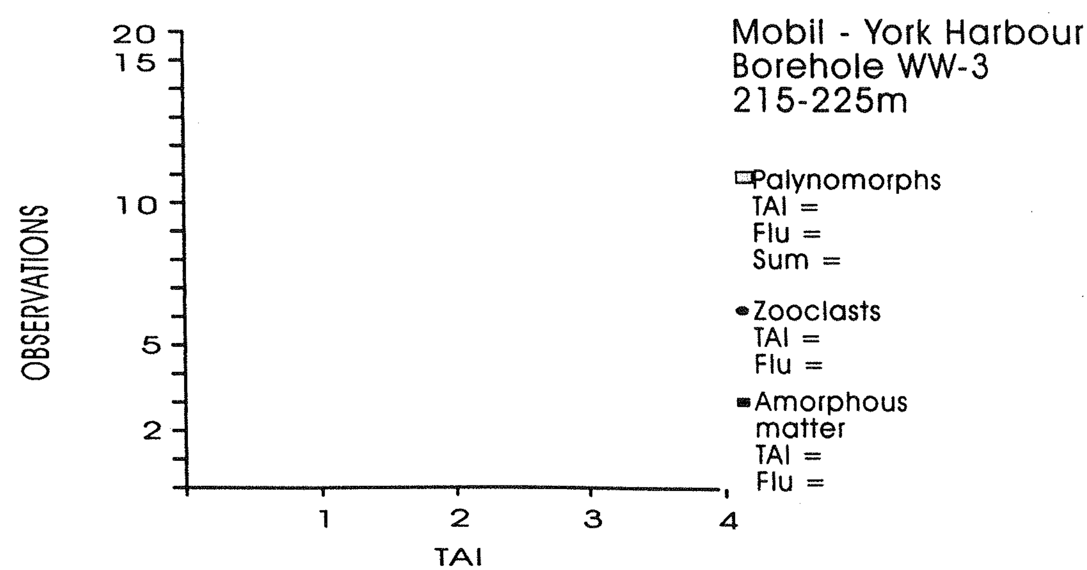
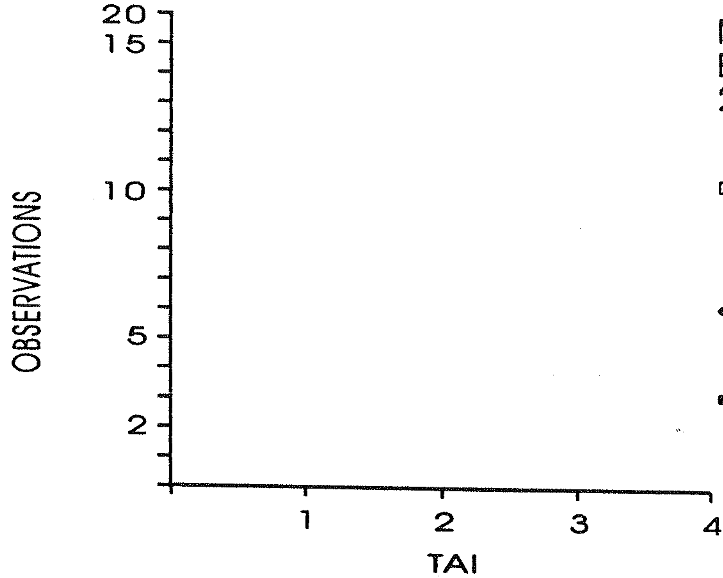
Flu =
Sum =
Zooclasts
TAI =
Amorphous matter
TAI = 3.6
Flu = 4.0 - black
OBSERVATIONS
TAI



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
OBSERVATIONS
TAI



Mobil - York Harbour
Borehole WW-3
215-225m
Palynomorphs
TAI =
Flu =
Sum =
Zooclasts
TAI =
Flu =
Amorphous matter
TAI =
Flu =
OBSERVATIONS
TAI

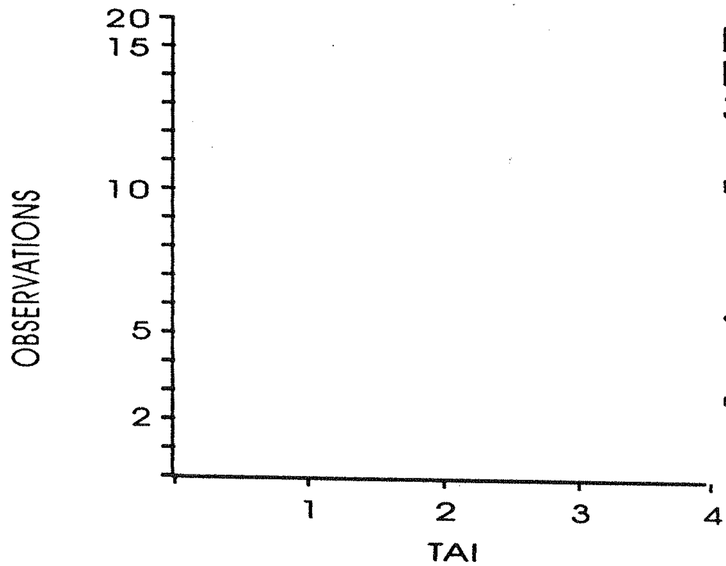


Mobil - York Harbour
Borehole WW-3
265-275m

□ Palynomorphs
TAI =
Flu =
Sum =

● Zooclasts
TAI =

■ Amorphous matter
TAI =
Flu =

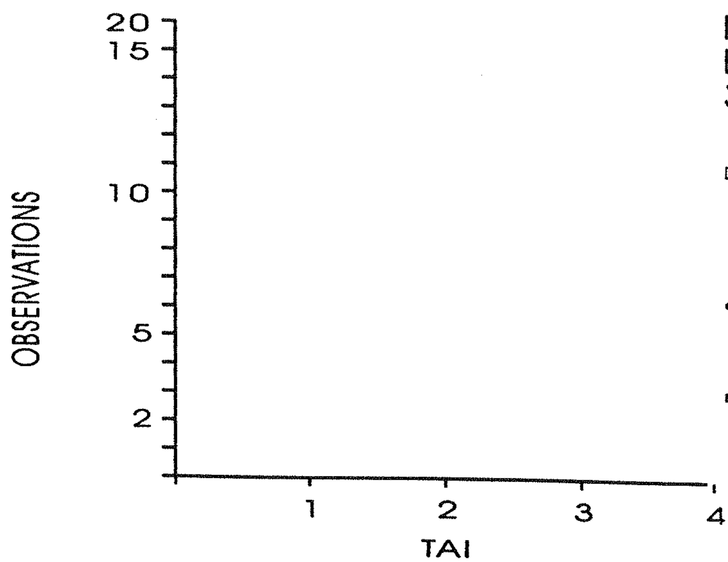


Mobil - York Harbour
Borehole WW-3
315-325m

□ Palynomorphs
TAI =
Flu =
Sum =

● Zooclasts
TAI =
Flu =

■ Amorphous matter
TAI =
Flu =

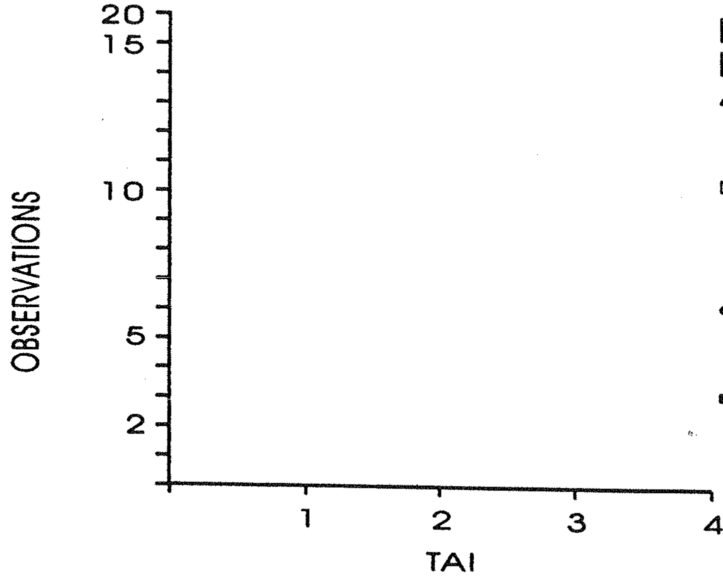


Mobil - York Harbour
Borehole WW-3
365-375m

□ Palynomorphs
TAI =
Flu =
Sum =

● Zooclasts
TAI =
Flu =

■ Amorphous matter
TAI =
Flu =

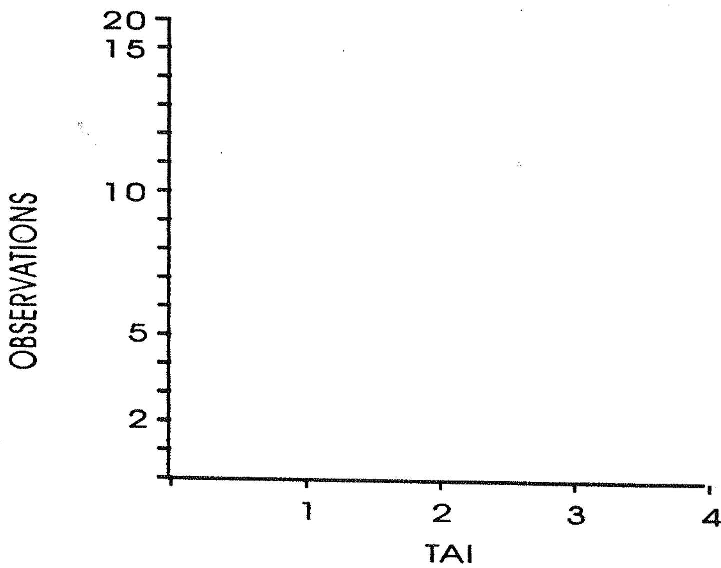


Mobil - York Harbour
Borehole WW-3
415-425m

□ 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 =

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

Appendix IV

Core Photos

Appendix V

Core Analysis

PETREL
ROBERTSON LTD.

CORE ANALYSIS REPORT
FOR

MOBIL YORK HARBOUR #C-1
, NF

Core # 1

Prepared for:	MOBIL OIL CANADA 330 - 5TH AVENUE S.W. CALGARY, AB, T2P 0L4		
Prepared by:	Petrel Robertson Ltd. 2801 - 18th Street N.E. Calgary, Alberta, T2E 7K5		
Project No.:	PRL/97027	Report date:	Tuesday, February 18, 1997

CONFIDENTIAL

PETREL ROBERTSON LTD.

Core Summary

Company:	MOBIL OIL CANADA	Core Received on:	Saturday, February 08, 1997
Attention:		Number of Boxes:	106
Well Name:	MOBIL YORK HARBOUR #C-1	Number of Full Diameter Samples:	5
Location:		Number of Small Plug Samples:	1
Province:	NF	Preliminary Analysis:	None
Formation:			

The following analysis was requested:

- Porosity measurements determined using calipered bulk volumes in conjunction with helium determined grain volumes.
- Three way permeabilities (horizontal Kmax, K90 and vertical KV) measured with a steady state permeameter using dry oil free nitrogen gas on 63 mm full diameter samples.
  (Full diameter samples sandblasted before permeability measurements)

Other services provided were:

- 2 sets of colour and 2 sets of ultra-violet (216 x 280 mm) photographs
- Core analysis supplied in digital format on 3½" diskette
- Prior to analysis, the core was cut with tap water and cleaned for 15 days in a vapour phase toluene extractor and dried for 48 hours in a gravity oven

Methods

Core Handling
When the core is received in our laboratory it is laid out on tables, checked for proper order and wiped clean to remove any residual drilling fluids.

Spectral Gamma Ray Log
The core is removed from the core boxes and fitted together on a variable rate conveyor belt. The core passes over a large volume NaI detector, shielded from background and cosmic radiation by lead. The detector gives off an electric pluse which is sent to a multi channel analyzer where a spectrum is created. The energy windows in the spectrum are used to measure gamma radiation and its constituents (potassium,uranium and thorium).

Sample Selection and Cutting
Samples are selected per the clients instructions and/or, by the discretion of one of our staff. Samples are drilled (small plugs) or cut (full diameter) using the appropriate fluids (water, brine, or oil base) depending on the nature of the core.

Sample Cleaning and Drying
The samples are cleaned with toluene in a CO2-toluene extractor (carbonates) or with a vapour phase extractor (most sandstones). Samples can also be cleaned using the Dean Stark distillation method if so desired. Samples are dried in a steam-heated oven at a temperature of approximately 108° Celsius. If necessary, samples can be dried in a humidity-controlled oven in order to control shrinkage of sensitive clays.

Residual Saturations - Fluid Summations
Residual fluid saturations are obtained from fresh core samples taken from the end pieces of full diameter samples or from adjacent core for small plug samples. Oil and water saturations are measured with a high temperature down draft retort using calibrated test tubes. The gas phase and bulk volume are measured with a mercury pump.

Porosity
Porosity values are obtained from full diameter (whole core) and/or small plug samples. Grain volumes is determined by the Boyle's Law helium expansion method. Bulk volumes are measured with digital calipers or by Archimedes Principle using mercury or water.

Permeability
Permeabilities are measured with a steady state permeameter using pre-purified nitrogen gas. Two horizontal permeabilities (Kmax and K90) and one vertical permeability (Kv) are measured on full diameter samples. A horizontal permeability (Kmax) is measured on small plug samples.

Comments

PETREL ROBERTSON LTD.

FINAL

WELL:	**MOBIL YORK HARBOUR #C-1**	**LOCATION:**	
COMPANY:	MOBIL OIL CANADA	FILE #:	97027
FIELD:	YORK HARBOUR	CORE(S):	1
FORMATION:		CORED INT:	1.37-298.60M
DATE:	Saturday, February 08, 1997	RECOVERY:	296.23M

CORE ANALYSIS DATA

Sample Number	Sample Interval [m]	Interval Thickness [m]	Gas Permeability [mD] Kmax	K90	Kv	Kmax x Thickness	Porosity (Boyle) [fraction]	Porosity x Thickness	Density [kg/m³] Bulk	Grain	Residual Saturation [fraction] Oil	Water	Descriptions and Remarks	
	CORE # 1: 1.37 - 298.60m Rec. 296.23m (106 boxes)													
NA	1.37 - 5.80	4.43											QUARTZITE	API's by REFRACTOMETER
1	5.80 - 6.40	0.60	**0.11**	0.09	<0.01	0.07	**0.034**	0.021	2600	2690	-	-	QUARTZITE	
NA	6.40 - 25.40	19.00											QUARTZITE	
2	25.40 - 25.85	0.45	**0.09**	0.04	0.02	0.04	**0.039**	0.018	2590	2700	-	-	QUARTZITE	API 35.0
NA	25.85 - 34.75	8.90											QUARTZITE	
3	34.75 - 35.15	0.40	**0.09**	0.07	0.01	0.03	**0.022**	0.009	2630	2690	-	-	QUARTZITE	
NA	35.15 - 71.15	36.00											QUARTZITE	
4	71.15 - 71.25	0.10	**0.32**	0.17	<0.01	0.03	**0.016**	0.002	2650	2690	-	-	QUARTZITE INF HFRAC	
NA	71.25 - 99.30	28.05											QUARTZITE	
5	99.30 - 01.70	2.40	**0.12**	0.10	0.03	0.28	**0.016**	0.040	2630	2680	-	-	QUARTZITE	
NA	101.70 - 98.10	96.40											QUARTZITE	
SP6	198.10 - 98.35	0.25	**0.04**	-	-	<0.01	**0.021**	0.005	2640	2700	-	-	QUARTZITE	API 26.0
NA	198.35 - 98.60	100.25											QUARTZITE	

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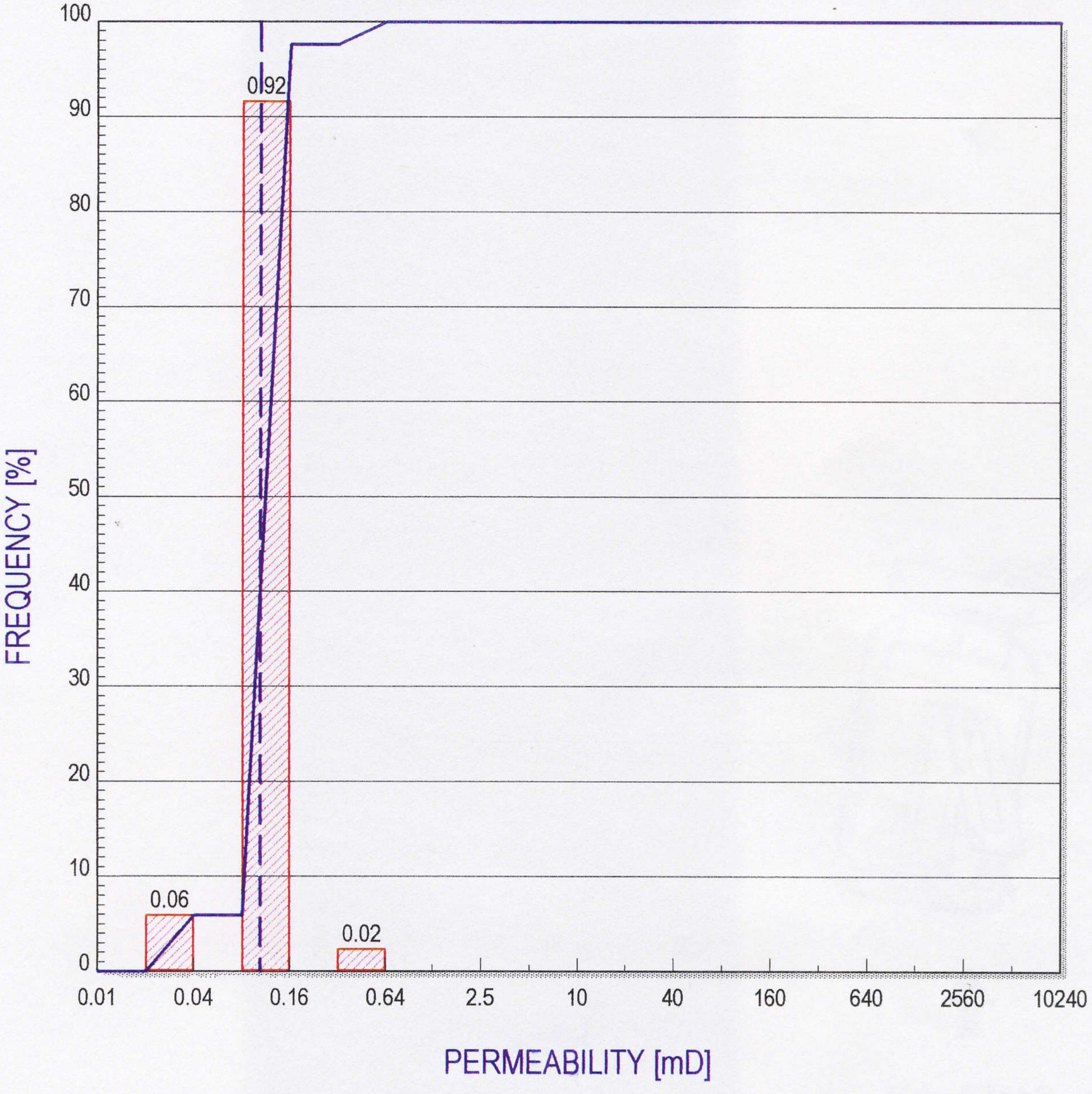
FINAL

WELL:	**MOBIL YORK HARBOUR #C-1**		
LOC:			
COMPANY:	MOBIL OIL CANADA	FILE #:	97027
FIELD:	YORK HARBOUR	CORE(S):	1
FORMATION:		CORED INT:	1.37-298.60M
DATE:	Saturday, February 08, 1997	RECOVERY:	296.23M

PERMEABILITY Kmax FREQUENCY DISTRIBUTION



CUMULATIVE FREQUENCY	————	GEOMETRIC MEAN	= 0.10
GEOMETRIC MEAN	— — — —	MEDIAN	= 0.11

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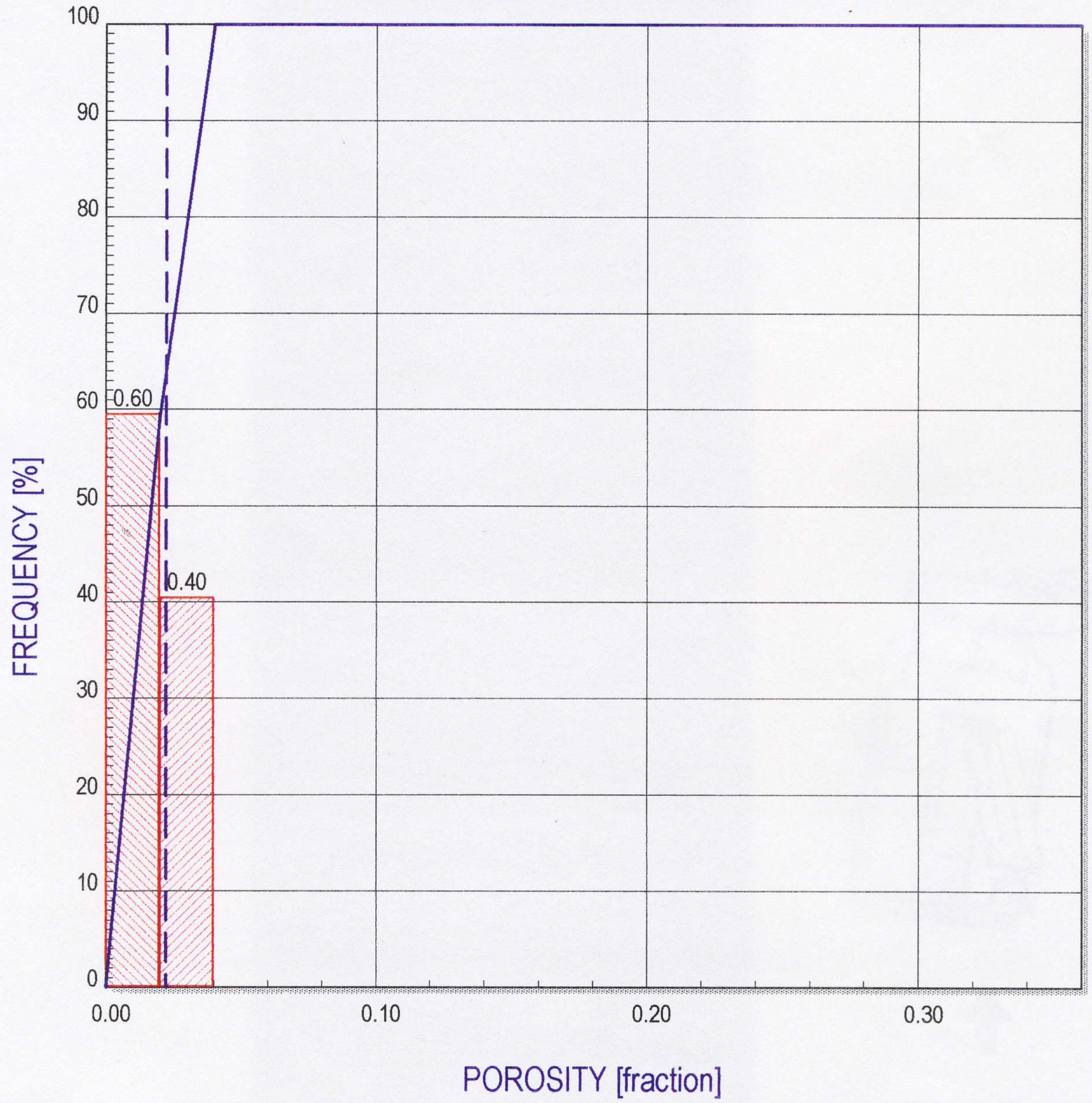
FINAL

WELL:	**MOBIL YORK HARBOUR #C-1**		
LOC:			
COMPANY:	MOBIL OIL CANADA	FILE #:	97027
FIELD:	YORK HARBOUR	CORE(S):	1
FORMATION:		CORED INT:	1.37-298.60M
DATE:	Saturday, February 08, 1997	RECOVERY:	296.23M

POROSITY FREQUENCY DISTRIBUTION



CUMULATIVE FREQUENCY	———	ARITHMETIC MEAN	= 0.022
ARITHMETIC MEAN	— — —	MEDIAN	= 0.017

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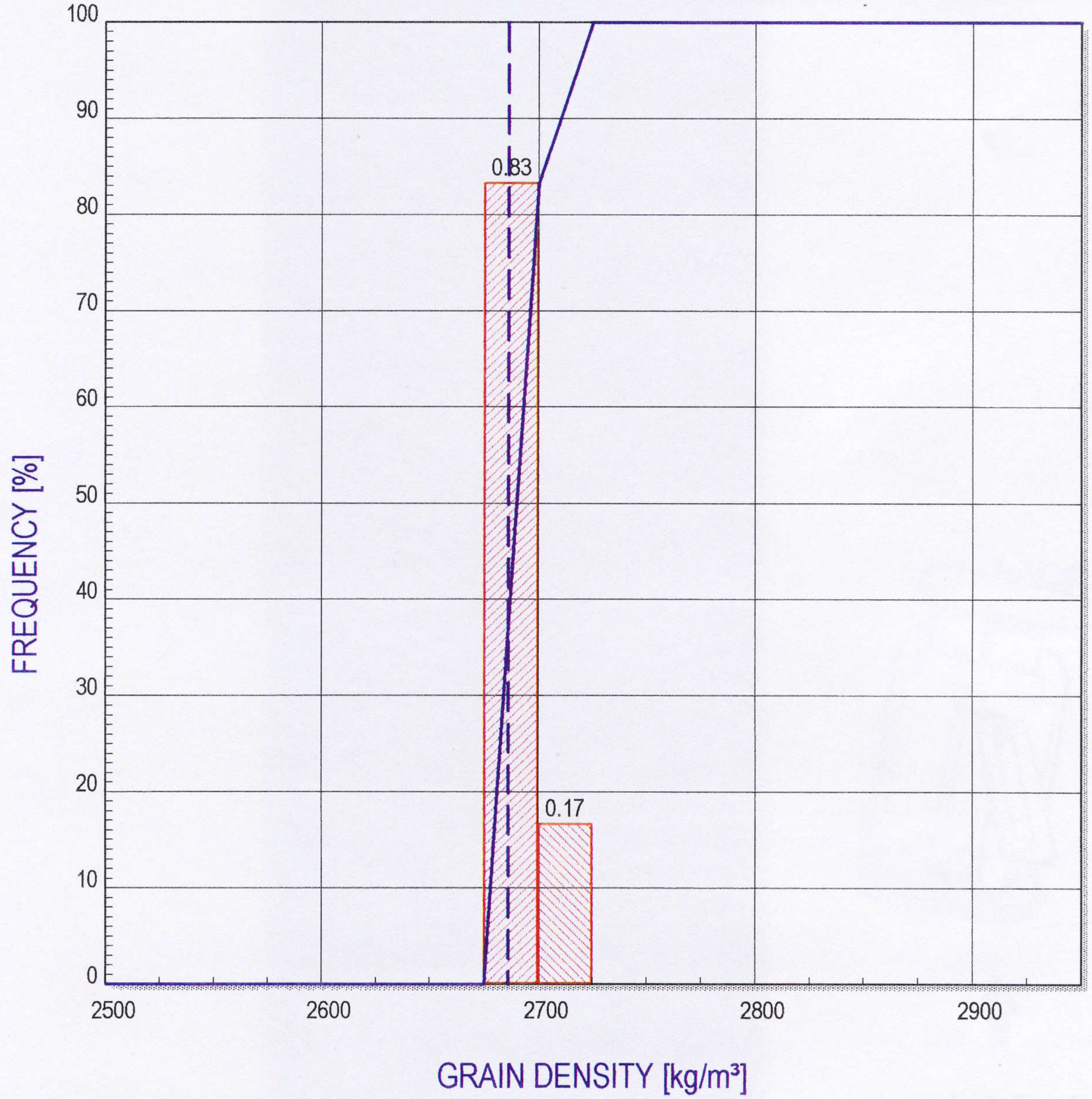
FINAL

WELL:	**MOBIL YORK HARBOUR #C-1**		
LOC:			
COMPANY:	MOBIL OIL CANADA	FILE #:	97027
FIELD:	YORK HARBOUR	CORE(S):	1
FORMATION:		CORED INT:	1.37-298.60M
DATE:	Saturday, February 08, 1997	RECOVERY:	296.23M

GRAIN DENSITY FREQUENCY DISTRIBUTION



CUMULATIVE FREQUENCY	————	ARITHMETIC MEAN	= 2686
ARITHMETIC MEAN	— — —	MEDIAN	= 2690

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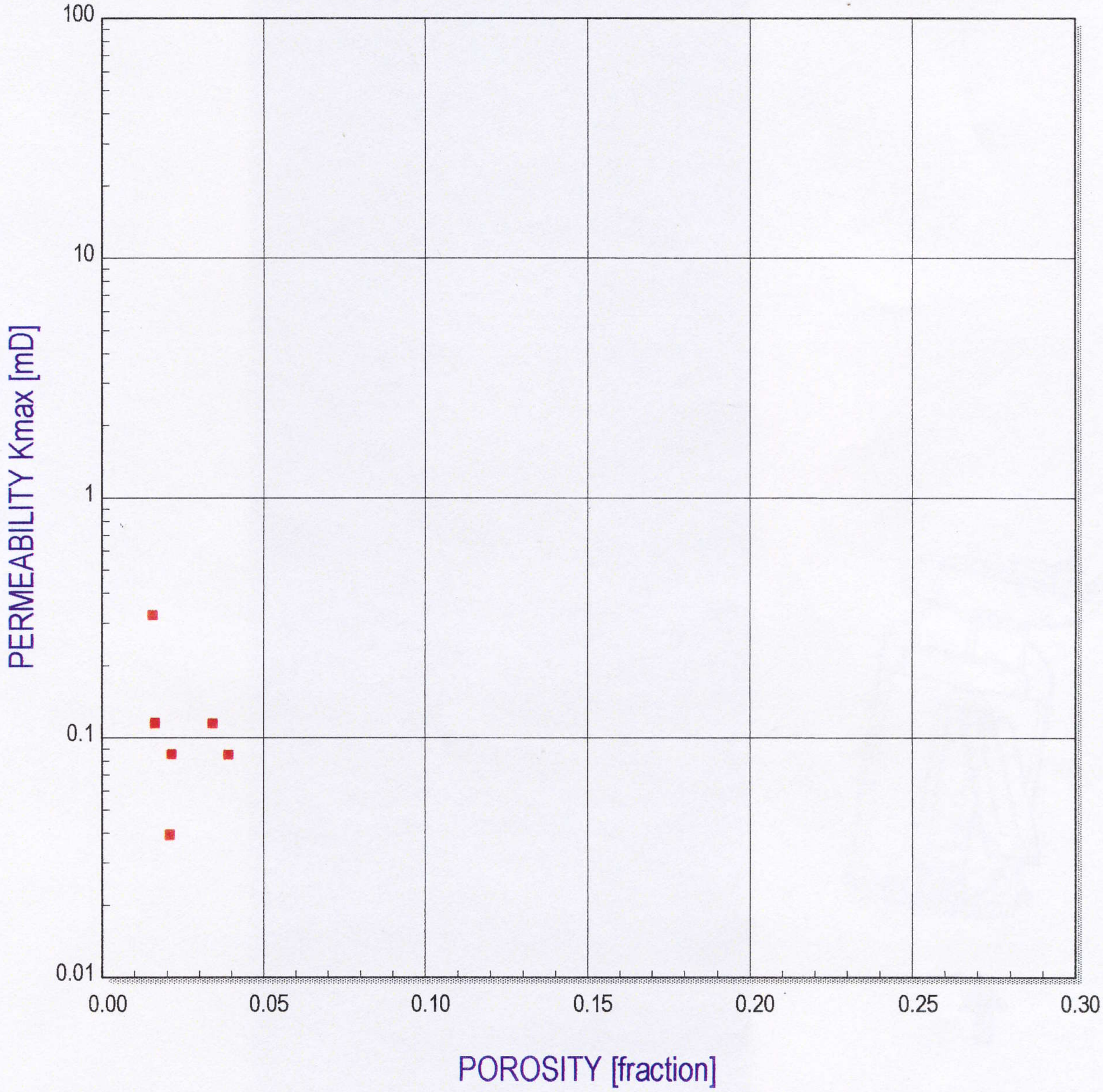
FINAL

WELL:	**MOBIL YORK HARBOUR #C-1**		
LOC:			
COMPANY:	MOBIL OIL CANADA	FILE #:	97027
FIELD:	YORK HARBOUR	CORE(S):	1
FORMATION:		CORED INT:	1.37-298.60M
DATE:	Saturday, February 08, 1997	RECOVERY:	296.23M

POROSITY - PERMEABILITY (Kmax) CORRELATION



PETREL ROBERTSON LTD.

FINAL

WELL:	**MOBIL YORK HARBOUR #C-1**		
LOC:			
COMPANY:	MOBIL OIL CANADA	FILE #:	97027
FIELD:	YORK HARBOUR	CORE(S):	1
FORMATION:		CORED INT:	1.37-298.60M
DATE:	Saturday, February 08, 1997	RECOVERY:	296.23M

ABBREVIATIONS

AST	Appears similar to	INF	Infilled
FD	Full diameter sample	NA	Not analyzed
HFRAC	Horizontal fracture	SP	Drilled plug sample

Appendix VI

Oil Analyses

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 OIL FROM YORK HARBOUR TEST WELL CORE, WESTERN NEWFOUNDLAND, CANADA JOB NO. MBJJ17A

We have completed geochemical analysis of the oil thermally extracted from core from the York Harbour test well drilled in Western Newfoundland. Whole-oil GC analysis found evidence of toluene contamination and the addition of a refined product. The remaining hydrocarbons appear to be a severely biodegraded light oil. Biomarker distributions indicate that the extracted oil was derived from a mature, carbonate source and not from Green Point shale. However, the biomarkers also may be contaminants. The biodegraded hydrocarbons from C_7 to C_{14} may be from a Green Point source as indicated by the $\delta^{13}C$ value.

These possible conclusions, however, cannot be confirmed with the present sample because of the organic contamination that may have been introduced while drilling or in the thermal extraction apparatus used to obtain the fluid samples. We recommend that a non-extracted core sample from the York Harbour test well be sent to MEPTEC for further analysis.

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 Oil from York Harbour Test Well Core 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 samples thermally extracted from core from the York Harbour test well. This well was drilled as part of MOCAN 1996 exploration program on western Newfoundland.

SAMPLES

Samples. Three samples were provided for analyses. Two samples contained only clear fluid while one sample had a thin light brown layer over a clear liquid. All samples had a strong organic odor.

Upon inspection, the clear liquids proved to be water and were not subsequently analyzed. The think film of oil was removed from the third sample and treated as a petroleum sample. Because of the limited amount of material available for study, only analyses requiring minimum sample amounts and preparation were conduction.

WHOLE-OIL ANALYSIS

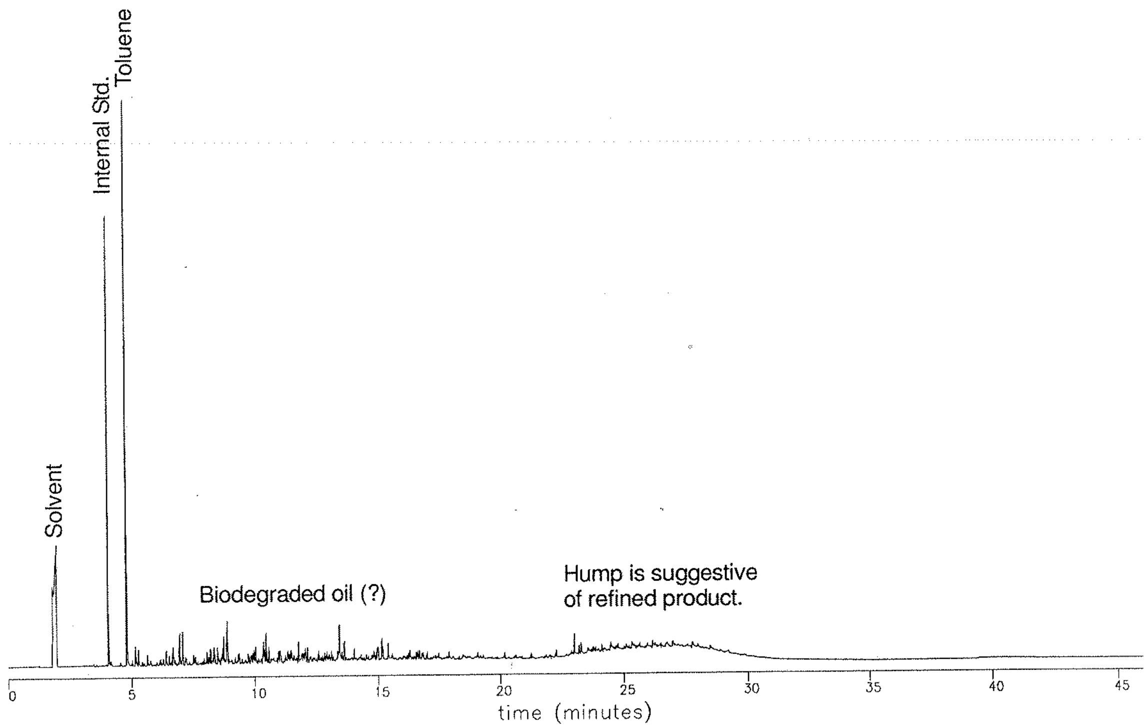


Figure 1. Whole-oil gas chromatographic analysis of oil extracted from York Harbour core.

Whole-oil gas chromatographic analysis shows that the oil extracted from the York Harbour core is contaminated with toluene, which apparently was used in cleaning the extraction apparatus. A mixture of hydrocarbons between 5-20 minutes (corresponding from ~n-C_7 to ~n-C_{14}) is revealed that resembles a severely biodegraded light oil. Within the range of 22 to 32 minutes, there is a "hump" of unsolved material that suggests that this may be the biodegraded residue of a refined product (e.g. diesel).

Toluene contamination can explain the petroliferous odor emitting from the water samples. Toluene is relatively soluble in water and a solvent residue from instrument clean-up would be present in both hydrocarbon and aqueous phases.

$\delta^{13}C$ Whole Oil

The stable carbon isotopic ratio of the extracted oil was measured at –28.45‰. This is slightly heavier than oils derived from the Green Point Formation, but the enrichment could be due to the advanced state of biodegradation.

SATURATE BIOMARKERS

Saturated biomarker compounds were analyzed on the unfractionated oil using standard GC/MS methods. The results of the analyses are shown in Figures 2-4. The data quality is below our typical standards because the sample was not fractionated into C_{15+} group types prior to biomarker analysis.

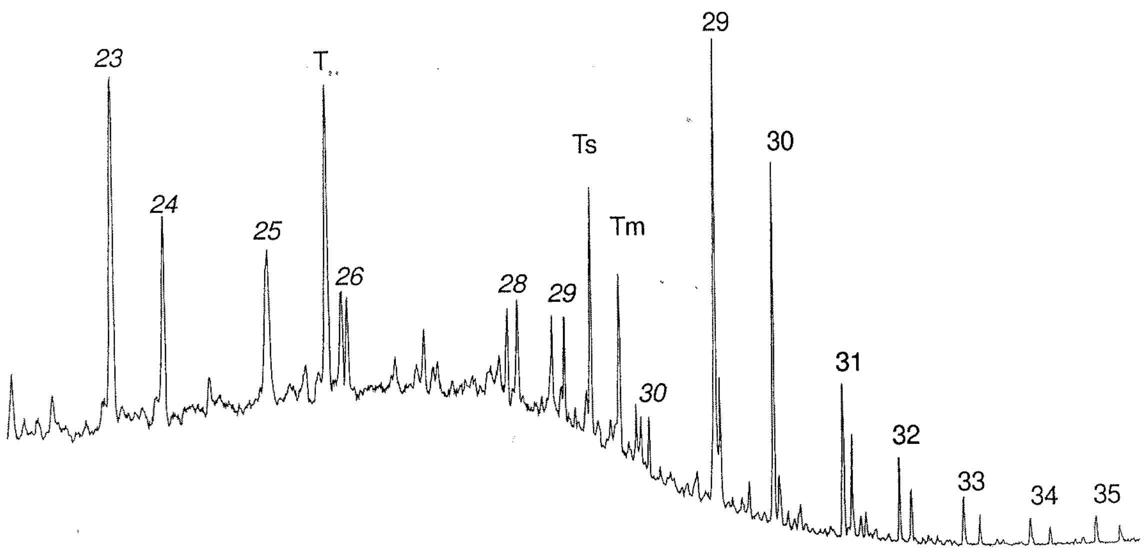


Figure 2. Reconstructed ion chromatograph (m/z 191) showing distribution of tricyclic terpanes (indicated by carbon number in italic) and hopanes (indicated by carbon number).

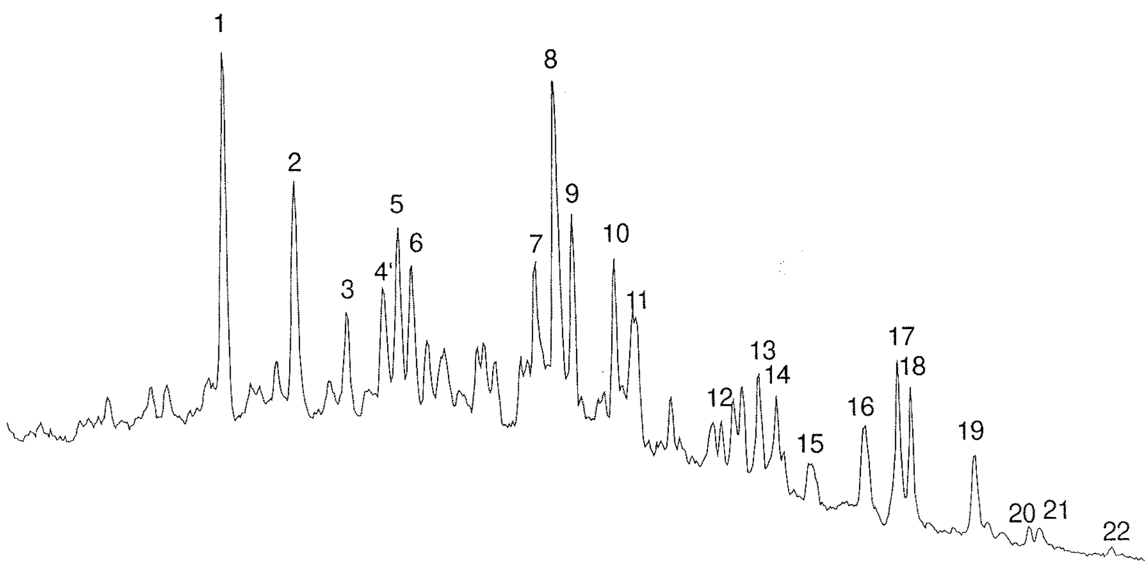


Figure 3 Reconstructed ion chromatogram (m/z 217) showing the distribution of steroidal hydrocarbons. Peaks are identified in Table 1.

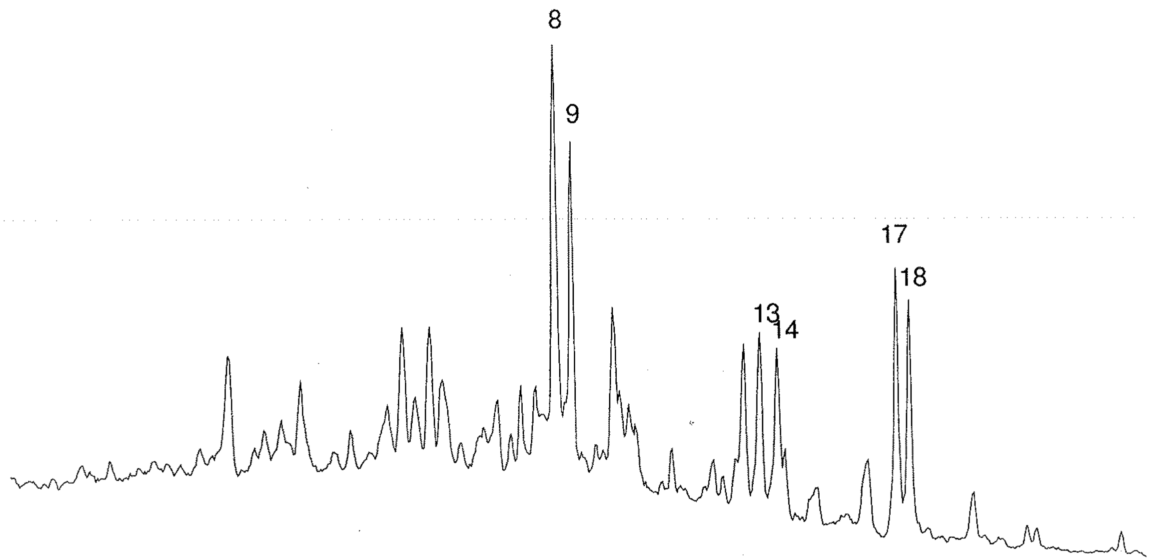


Figure 4. Reconstructed ion chromatogram (m/z 218) which is characteristic of the αββ-steranes. Peaks are identified below in Table 1.

Table 1. Sterane and diasterane compound identification for Figures 3,4

Peak Number	Name	Carbon Number
1	13β,17α-diacholestane 20S	27
2	13β,17α-diacholestane 20R	27
3	13α,17β-diacholestane 20S	27
4	13α,17β-diacholestane 20	27
5	13β,17α-24-methyldiacholestane 20S	28
6	13β,17α-24-methyldiacholestane 20R	28
7	5α,14α,17α-cholestane 20S	27
8	5α,14β,17β-cholestane 20R + 13β,17α-24-ethyldiacholestane 20S	27 + 29
9	5α,14β,17β-cholestane 20S	27
10	5α,14α,17α-cholestane 20R	27
11	13β,17α-24-ethyldiacholestane 20R	29
12	5α,14α,17α-24-methylcholestane 20S	28
13	5α,14β,17β-24-methylcholestane 20R	28
14	5α,14β,17β-24-methylcholestane 20S	28
15	5α,14α,17α-24-methylcholestane 20R	28
16	5α,14α,17α-24-ethylcholestane 20S	29
17	5α,14β,17β-24-ethylcholestane 20R	29
18	5α,14β,17β-24-ethylcholestane 20S	29
19	5α,14α,17α-24-ethylcholestane 20R	29
20	5α,14β,17β-24-*n*-propylcholestane 20R	30
21	5α,14β,17β-24-*n*-propylcholestane 20S	30
22	5α,14α,17α-24-*n*-propylcholestane 20R	30

The distribution of saturated biomarkers in the York Harbour core extract is unlike any published or in-house analysis of oil or source-rock extract from western Newfoundland. It has numerous characteristics that suggest that it is derived from a carbonate or evaporitic source facies. These characteristics include:

1. High C_{23} tricyclic terpane
2. High C_{24} tetracyclic/C_{26} tricyclic ratio
3. High C_{29}/C_{30} hopane ratio
4. High C_{35}/C_{34} homohopanes ratio
5. High $\alpha\beta\beta/\alpha\alpha\alpha$ sterane ratios

The oil is indicated to be relatively high maturity (peak to post-peak oil generation) as revealed by:

1. High Ts/Tm ratio (C27 hopanes)
2. High tricyclic/hopane ratio
3. High 20S/20R sterane ratios
4. High diasterane/sterane ratio

CONCLUSIONS & RECOMMENDATIONS

There is little doubt that the water and oil samples were contaminated with toluene. Secondary contamination of C_{15+} hydrocarbons is indicated as well. Hence, the biomarker compounds, which occur only in trace quantities, also are suspect. If we assume that the biomarkers are representative of an indigenous subsurface fluid, we would conclude that the extracted oil was derived from a mature, carbonate source and not from Green Point shale. On the other hand, if we assume that the only indigenous fraction in the extracted oil sample is the biodegraded hydrocarbons from C_7 to C_{14} and that the $\delta^{13}C$ value for the whole-oil sample is representative of these biodegraded hydrocarbons, a Green Point source is possible. This conclusion, however, cannot be confirmed with the present sample because of the contamination.

We recommend that a core sample from the York Harbour test well be sent to MEPTEC for solvent extraction using the standard procedures designed to minimize contamination. Ideally, the core sample should be consolidated and free of drilling mud. Thermal extraction-GC analysis can characterize the volatile hydrocarbons directly with no introduction of cleaning solvents such as toluene. Solvent extraction will liberate the C_{15+} hydrocarbons for biomarker analysis.

YH 1C

YORK HARBOUR 1C

Figure 2

YH1C26114757 drrae 26-Mar-1997 12:20
drrae /data4/frontier/stratlog/wnfld/YH1C.cgm