**Objectives:**

The objectives of the well evaluation are to review test and log data to describe the main reservoir properties and lithologies encountered in the formations. The quantified results can then help to better constrain the gross depositional environment maps. A deterministic petrophysical evaluation for shale content (VSH), effective porosity (PHIE) and water saturation (SW) has therefore been carried out for three (3) wells. Secondly, the determination of lithologies from log data is performed through statistical electrofacies and density cross-plot methodology as we described on Plate 2.1.2 and detailed in Plate 2.1.4.

**Well Database:**

The log database consists in a full set of logs in wells Bandol and Heron and partial data and low log quality in East Wolverine (Table 2). Log mnemonic equivalence as used in this project is listed in Table 2 together with the top and base depths (in MD) for the interpreted intervals. Database homogenization has been performed, including Neutron limestone calibration (originally already limestone calibrated NPLS in Heron) and recalibration of neutron from sandstone (NPOR_SAN in Bandol and East Wolverine).

Dislocation and loading of mudlogging lithology as lithologies (Sandstone, Limestone, Dolomite, Chalk, Claystone, Shale, Marl, Siltstone, Salt, Coal and Anhydrite).

**Well Results:**

The wells have locally been side-wall cored (Table 3) and tested (Table 4). The results, integrated with log analysis results are described on Plate 2.1.2 and detailed in Plate 2.1.4.

<table>
<thead>
<tr>
<th>Well</th>
<th>GR (GAPI)</th>
<th>DT (µR)</th>
<th>NPHI (kV)</th>
<th>RHOB (g/cc MD)</th>
<th>PEF (l/sec)</th>
<th>RESD (Ohm.m)</th>
<th>Top (m MD)</th>
<th>Base Interval (m MD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandol B-1</td>
<td>G</td>
<td>DT45</td>
<td>NPOR_SAN</td>
<td>RHOB2</td>
<td>PEF2</td>
<td>AHT90</td>
<td>1230</td>
<td>2405</td>
</tr>
<tr>
<td>East-Wolverine G-37</td>
<td>GR</td>
<td>DT47</td>
<td>NPOR_SAN</td>
<td>RHOB2</td>
<td>PEF2</td>
<td>AF91</td>
<td>* 3500</td>
<td>* 6780</td>
</tr>
<tr>
<td>Emerillon C-M</td>
<td>GR</td>
<td>DT</td>
<td>NPLS</td>
<td>RHOB</td>
<td>-</td>
<td>LID</td>
<td>1190</td>
<td>3250</td>
</tr>
<tr>
<td>Heron H-73</td>
<td>GAM</td>
<td>DT</td>
<td>NPL3</td>
<td>RHOB</td>
<td>-</td>
<td>LID</td>
<td>770</td>
<td>3562</td>
</tr>
</tbody>
</table>

**Table 2: List of logs in wells and interpretation intervals.

* Edited

° Gap

<table>
<thead>
<tr>
<th>Well</th>
<th>Sidewall core/full-hole core</th>
<th>Core Porosity</th>
<th>Core Permeability</th>
<th>Core Grain density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandol B-1</td>
<td>No</td>
<td>Full-hole core, side wall core available</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>East-Wolverine G-37</td>
<td>No core measurements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emerillon C-M</td>
<td>No</td>
<td>Full-hole core, side wall core available</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**Log Analysis Methodology:**

A deterministic workflow was applied to identify the shaliness, porosity and water saturation. Log signatures in specific intervals and lithologies (based on cuttings data) were compared and analyzed in order to define specific interpretation parameters suitable for each interval (Figure 2). 11 lithologies were thus determined: Sandstone, Limestone, Dolomite, Chalk, Claystone, Shale, Marl, Siltstone, Salt, Coal and Anhydrite.

Shale volume evaluation was performed by calculating the shale content based on the neutron-density cross-plot methodology as well as gamma-ray. A good correspondence was obtained between GOR-based and Neutron-Density based shale volume curves. The minimum curve of these two was retained as final shale volume (Figure 3).

Porosity was evaluated by implementing the neutron-density cross-plot method, allowing the matrix composition effect on porosity to be discounted. The porosity interpretation was compared to the occasionally available sidewall core porosity. The porosity interpretation defined total porosity and effective porosity, the latter corrected for the shale effect as well as the microporosity in chalks (Figures 4 & 5). No effective porosity is considered present in the chalks, albeit high plug porosity (measured under ambient conditions), knowing microporosity is reported in core description and compaction of the chalks in reservoir condition. The low resistivity and absence of staining or gas in mud reports confirms the view that these chalks represent tight reservoir. In the porosity interpretation QC, the computed matrix density was also compared to core grain densities and porosity interpretation showing good coherency and supporting the interpretation results.

The water saturation in the formation is calculated using a modified Archie, Indonesia method, accounting for the influence of shale on the resistivity measurement. Formation water resistivity was determined based on the measured salinity of the water. The value for water salinity has been determined as an average from DST sampled formation water (Table 4) at 81 kppm NaCl, corresponding to an Rw of 0.045 @ 67°C. This value may be expected to vary somewhat over the area and interval of the Atenaki. The evolution of this resistivity with the temperature has been related to the thermal gradient defined for the formation. Quality control of the saturation results has included review of starting and shows listed in mud reports and low resistivity to verify high interpreted water saturation in specific intervals.
Well-by-Well Review

Bandol-1
Very good porosity in sandstone (22% average); very high water saturation (>80%); No shows No stains.
Interval: 1200-4050 m MD
Interval 1210-1644 m MD (marker T29-T50): bad log interval quality with very high Neutron and Density values. Very shaly interval (GR=60) described as clayslate in striplog.
Interval 1645-1955 m MD (T50-K94): Chalky interval (1645-1918m MD) with low argillaceous content (1730-1740 m MD & 1790-1810m MD for example), grading to marl at base.
Interval 1955-2060 m MD (K101-K137): high Clayslate content with some quartzose layer of fair good porosity (18-20%) (1955-1990 m MD).
Blocky shale at base (1990-2060m MD).
Interval 2060-2378m MD (K101-K137): increase of sandstones interval thickness becoming less argillaceous intercalated with thin shale intervals. From poor porosity (2060-2075 m MD) to good porosity in base (2370-2375 m MD).
Interval 2375-2446m MD (K101-K137): thin intercalation of a shale and sandstone with good porosity.
Interval 2445-2496: 2 Thick chalky limestone intervals with porosity showing a high density and separated by a shaly interval.
Interval 2496-2830 m MD (K137-K163): intercalation of sandstone with kaolinitic matrix with porosity becoming more permeable (2630 m MD) grading toblocky Shale. Few chalky Lime-. Stoned interbeds.
Interval 2830-3542 m MD (K163): intercalation of sandstone slightly argillaceous with blocky shales. Very Good core porosity (22 to25%) slightly lower than computed porosity due to presence of axial.
Interval 3589-3702 m MD (K163): intercalation of limestone, chalky in top and soft and crumbly in base, and Shale. Good to Very good porosity.
Interval 3702-4023m MD (K163): clean sandstone with very low amount of sand grading to shale. Good to fair core porosity (15-20%). At 3985 m MD presence of black carbonaceous partings were core porosity is lower than computed porosity.
There is neither oil show nor fluorescence in this well. Deep resistivity deep is always lower than the shallow resistivity. No HC reservoirs are available in this well.
OBM in interval 1221-4046 m MD

Heron H-73
Maury limestone with low to poor porosity. High water saturation (>60%); few gas shows in tight limestone @2300-2600 m and stains @2371 m.
Interval 1500-1740 m MD (T29-T50): claystone with high GR, few interbeds of sandstone
Interval 1740-1765 m MD: Chalky limestone without macroporosity porosity. High Microporosity content visible in total porosity calculation.
Interval 1765-2033m MD (T50-K94): clayslate grading to shale. Occasional sand stringers. Some badhole area seen on Neutron Density impacting porosity calculation.
Interval 2203-2371 m MD (T50-K101): On top Chalky limestone with few dark brown oil staining grading to micritic limestone in base. There is no macroporosity in chalky limestone, only microporosity. Microporosity is seen on total porosity and on Core porosity measurements. At base Micritic limestone shows a poor to fair macroporosity (5-10%) with some live oil staining and gas in the mud record (2295-2365m MD). Interval 2371-2462m MD (K101-K137): coarse unconsolidated sandstone with good porosity (20% in average), no shows or stain in this interval. High GR reveal presence of sandy shale and low RD the absence of hydrocarbon in formation.
Interval 2462-3044m MD (K137-J166): thick micritic limestone interval with live oil stain and poor to fair porosity (0-10%). Cuttings reveal no visible porosity and very good porosity. Total porosity calculated between 6-10%.
Interval 3050-3244m MD (J166-J188): sandstone interval. It present a high GR seen on shale volume. Proxys wasn't calculated in this interval do to badhole log problem. Density is missing. No stain nor gas show.
Interval 3048-3375 m MD (J166-J188): intercalation of shale and limestone interbedded grading to thick shale layer in base. Facies is changing with fine crystalline porosity at top to intercrystalline porosity at base. Calculated porosity reflects these changes with values from 15% in top to 5% in base. No gas was seen in mud log and trace of dead oil.
Interval 3375-3502 m MD (J166-J188): dolomite interval described as 5-10% of intercrystalline porosity. Density not available in this interval. Oil stains are visible and gas in mud logs RD are increasing in this area with few peaks at 2000 ohm m. Salt layers below may affect resistivity. After 3502m : salt layer

East Wolverine G-37
Mainly claystones with very few reservoir intervals; few gas shows @5140 m and @6313 m; no stains.
Interval 3750-4255 m MD (T29-T50): intercalation of clayslate slightly calcareous and limestone. Limestone layers are becoming thicker in base. GR present regular values in clayslate (between 50 and 60API). Limestone is revealed by decrease of Gamma-Ray. Neutron log is not relevant in this interval showing irregular values. Porosity is poor (0 - 10%) in limestone intervals. There are no relevant shows in this formation.
Interval 4250-5200 m MD (T50-K137): clayslate interbedded with few sandstones. Neutron and density are missing between 4800-5220m MD and Gamma-Ray shows inconsistent values in this same interval. A badhole flag was created to highlight this area. A gas peak was observed (29.6% maximum total gas) 4982 m MD.
Interval 5220-6620 m MD (K137-J170): Claystone interbedded with thin beds of sandstone. Claystones are seen in Neutron and Density with a clear separation. Inflow in GR and Neutron density signature reveals 4 main sandstone layers visible at 5330 m MD, 5925 m MD, 6220 m MD and 6423 m MD. No major variation in resistivity and no major gas show have been identified. Porosity is poor (below 5%) in all interval.
No core data were available in this well. Absence of stain or gas in the mud record confirms that the well does not contain hydrocarbons.
Interval T50-K94

Heron H-73  |  Bandol-1  |  East-Wolverine G-37

Interval K94-K101

Heron H-73  |  Bandol-1  |  East-Wolverine G-37

Figure 6: Neutron-Density and Neutron-Sonic crossplots and composite log display for interval T50-K94 in wells H-73, B-1 and G-37

Figure 7: Neutron-Density and Neutron-Sonic crossplots and composite log display for interval K94-K101 in wells H-73, B-1 and G-37

Logs in intervals T50-K94 and K94-K101
**WELL EVALUATION - PETROPHYSICS**
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**Figure 8:** Neutron-Density and Neutron-Sonic crossplots and composite log display for interval K137-J163 in wells H-73, B-1 and G-37

**Interval K137-J163**

- **Heron H-73**
- **Bandol-1**
- **East-Wolverine G-37**

**Figure 9:** Neutron-Density and Neutron-Sonic crossplots and composite log display for interval K101-K137 in wells H-73, B-1 and G-37

**Interval K101-K137**

- **Heron H-73**
- **Bandol-1**
- **East-Wolverine G-37**

Logs in intervals K101-K137 and K137-J163

**PLATE 6.1.4**
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Interval J163-J166

Heron H-73

Bandol-1

East-Wolverine G-37

Log in intervals J163-J166 and J166-J188

Figure 10: Neutron-Density and Neutron-Sonic crossplots and composite log display for interval J163-J166 in wells H-73, B-1 and G-37

Figure 11: Neutron-Density and Neutron-Sonic crossplots and composite log display for interval J166-J188 in wells H-73, B-1 and G-37
### Laurentian sub-basin study – CANADA – June 2014

#### Overview of well results

**Table 5: Overview of well results**

<table>
<thead>
<tr>
<th>Interval</th>
<th>Heron H-73</th>
<th>Bandol B-72</th>
<th>East Wolverine G-37</th>
</tr>
</thead>
<tbody>
<tr>
<td>T29 – T50</td>
<td>Shales with occasional beds of shaly sand or limestone, no PHIE or shows. At base interval a porous limestone (PHIE 15-20 %) with gas shows but no log saturation.</td>
<td>Down to Intra Campanian UC: shales with very thin (&lt;1m) levels of slightly porous dolastics, no shows.</td>
<td>Shales with occasional limestone intervals (~20m thick), with low porosity (&lt;10%) and without HC saturation.</td>
</tr>
<tr>
<td>T50 – K94</td>
<td>250m of shales overlying 100m of clean tight limestone, no log saturation and a minor gas show at the very base of the interval.</td>
<td>Intra Campanian UC to 1925m MD: chalks with no PHIE or shows. Overlying 40m thick shale interval.</td>
<td>Shales and porous list: PHIE ~10-15%, no HC sat.</td>
</tr>
<tr>
<td>K94 – K101</td>
<td>Shale bed (~10m) overlying tight clean limestones, no saturation, no shows.</td>
<td>Mainly shales with several 10 to 20m thick shaly sand layers (PHIE &gt; 20%) no HC saturation or shows.</td>
<td>Tight limestones: PHIE &lt;10%, no HC sat.</td>
</tr>
<tr>
<td>K101 – Alb/Apt MFS</td>
<td>Porous sandstone interval between two shaly layers. Sands with PHIE ~20-25% showing no saturation on logs but some gas shows and oil staining.</td>
<td>50m thick Porous clean sands (PHIE ~25%) no HC saturation or shows overlying section of alternating metric shales and sands. Low porosity limestone interval around 2450m, occassional thin porous layers (~1-2m, PHIE &gt; 20%) without shows or saturation.</td>
<td>Shales with occasional metric thick shaly-sand bodies (no PHIE).</td>
</tr>
<tr>
<td>Alb/Apt MFS – IntraApt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IntraApt – Mississauga</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mississauga – K130</td>
<td>Tight clean limestones with: • 10m thick porous limestone interval (caved, hence logs not reliable) where gas shows and oil staining are observed. • Below that three thin porous intervals (~2-4m thick, ~10% PHIE) with some gas shows and oil staining.</td>
<td>Shales with occasional thin beds of moderate porosity sandstones or limestones (PHIE 10-15%) without HC saturation or shows.</td>
<td>Shales with one (~4m) thick sand body (PHIE not evaluated lacking logs but with gas shows). Sand interval at transition around Top K147 tested gas.</td>
</tr>
<tr>
<td>K130 – K137</td>
<td>Tight clean limestones with:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Alternating decametric beds of clean porous sands and shales. PHIE in sands 20-30%, no HC saturation or shows.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K137 – K147</td>
<td>Tight clean limestones with: • 10m thick porous limestone interval (caved, hence logs not reliable) where gas shows and oil staining are observed. • Below that three thin porous intervals (~2-4m thick, ~10% PHIE) with some gas shows and oil staining.</td>
<td>Shales with occasional thin beds of moderate porosity sandstones or limestones (PHIE 10-15%) without HC saturation or shows.</td>
<td>Shales with occasional few metre thick shaly-sand bodies (no PHIE). The lowermost of these shows minor PHIE (~5%) and had some supercharged gas shows.</td>
</tr>
<tr>
<td>K147 – Base Callovian</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Callovian – J163</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J163 – Intra Bathonian</td>
<td>Tight clean limestones, no PHIE or saturation</td>
<td>Below J163 to TD thick succession of clean porous sands (25-30% PHIE, no HC saturation or shows). Alternating with 5 to 20m thick shales; possible coal occurrence from cuttings not evidenced by logs. One interval of moderate porosity (~10%) clean limestone interval occurs between the sand succession at 3540-3680mMD.</td>
<td>Shales, on thin (~4m) thick sand body with low PHIE (&lt;10%).</td>
</tr>
<tr>
<td>Intra Bathonian – J166</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J166 – J170</td>
<td>Tight limestones overlying a thick (~40m) shale interval.</td>
<td>Shales, on thin (~4m) thick sand body with low PHIE (&lt;10%).</td>
<td>Not reached</td>
</tr>
<tr>
<td>J170 – J181</td>
<td>Shales</td>
<td></td>
<td>Not reached</td>
</tr>
<tr>
<td>J181 – J186</td>
<td>Low porosity (&lt;10%) limestones with thin shale interbeds, no significant HC saturation and no shows</td>
<td></td>
<td>Not reached</td>
</tr>
<tr>
<td>J186 – J188</td>
<td>Dolomite with 15-20% porosity, no HC saturation from logs or shows. Overlain by tight limestones and/or dry shales.</td>
<td></td>
<td>Not reached</td>
</tr>
<tr>
<td>J188 –</td>
<td>At top interval layer of non-porous dolomite with occasional thin shale beds, shows indicate heavy HC and gas (C3C4). Below, a thick salt column</td>
<td></td>
<td>Not reached</td>
</tr>
</tbody>
</table>
Objectives of the electrofacies analyses:
A log-based facies analysis is performed to complement the evaluation of shale and porous volumes from logs to better constrain geological model and facies maps. This allows us to (1) compare cuttings lithologies with log readings at different scales of observations, (2) positioned results to log depths and (3) compare results with petrophysical analyses.

Electrofacies Methodology and Results
A clustering technique (developed in EasyTrace™ software) in a multidimensional space generated by selected input logs is used to group facies based on their characteristic log signatures. Cluster analysis of log data was performed for the 3 wells, Bandol, East Wolverine and Heron, using the following logs: RHOB, NPHI, DT, VSHfin, PHIEfin.

Non-supervised approach is applied. Interpretation was controlled based on the petrophysical signatures and cuttings analysis results. From cluster analysis 10 electrofacies are defined as training samples. This is illustrated by the probability density function (PDF) shown in Figure 12. The PDF is estimated in the multidimensional space generated by the 5 considered logs. Then it is plotted to produce the graphics which are displayed here. Peaks or “modes” of the pdf correspond to different electrofacies. Colored peaks shown here serve as “training samples”. These are subsequently assigned to all relevant log samples in the wells (Figure 14).

Lithologies from Cuttings description match fairly well with electrofacies (Figure 15):
- Coal is not seen in log signatures and is usually associated to sands (coal only sporadically present?)
- No dolomite observed in logs: these are characterized as limestone in the electrofacies.
- Some overlap between clean porous limestone and siltstones is observed as NPHI−RHOB signature for both not very different (function of minor shale content)
- Chalks well identified; two main types are distinguished by electrofacies

Electrofacies have been determined in the Bandol-1, East-Wolverine (G-37) and Heron (H-73) wells. This has allowed defining main log-based facies in all three wells. It is observed that the electrofacies match rather well with cuttings lithologies and show a higher degree of facies bedding notably the sand−shale layering in Bandol B-73 (Plate 2.1.8)
Total Organic Carbon Estimation Test (TOC)

A TOC detection method based on log data has been attempted in the wells in order to illustrate the potential variation of organic carbon (or organic matter volume) present in the formation intervals along the wells.

The method applied is Carbolog® as determined by Carpenter et al. (1991) and implemented in EasyTrace™. The method is based on the comparison between sonic and resistivity logs to indicate the vertical variation of organic carbon contents of the formation. The method uses ternary diagram on sonic and 1/Rn basis between the matrix, shale and organic matter poles to determine the content of TOC in the formation (Figure 17). The calibration has been performed on log data, lacking core or cuttings TOC measurements (RockEval) to calibrate to and should therefore be considered qualitatively. The resulting TOC curves (shown in Figure 18 for Bandol B-1 and Heron H-73) show that some intervals could potentially contain higher TOC, notably in the shales above T29 horizon, and for Heron in the tighter limestones of J166-J170 interval. The higher TOC readings computed at the base of well Heron should be considered as highly uncertain, lacking full log coverage and may be influenced by end-of-run effects.