# Preliminary Core Description and Lithofacies Analysis of the Ordovician Coronach Member, Herald Formation, Southeastern Saskatchewan

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## *Abstract*

*Upper Ordovician Red River strata in the northern Williston Basin (southeastern Saskatchewan) consist of three brining-up, carbonate-evaporite cycles. The Coronach Member of the Herald Formation makes up the middle carbonate-evaporite cycle and is widely capped by the Coronach Anhydrite. Although the Coronach Member has not produced economic quantities of oil in Saskatchewan, the time-equivalent stratigraphic unit in North Dakota, the Red River "B", is a significant producer. This report contains the preliminary analyses of petrography and lithofacies of the Coronach Member in two wells (12-2-7-11W2 and 8-16-2-14W2) in southeastern Saskatchewan. Three major facies assemblages were recognized: 1) a basal limestone package with a high diversity of skeletal grains, depositional textures, and diagenetic minerals; 2) a middle, commonly dolomitized, laminated assemblage; and 3) an upper, dense anhydritic dolomudstone to nodular anhydrite assemblage. The discontinuous laminate facies within Facies Assemblage 2 is, potentially, a prospective reservoir within the Coronach Member in southeastern Saskatchewan.*

**Keywords:** *Ordovician, Saskatchewan, Red River, Herald Formation, Coronach Member, core description, Williston Basin, carbonates, evaporites, hydrocarbons.*

## 1. Introduction

Upper Ordovician Red River strata in the northern Williston Basin (southeastern Saskatchewan) have commonly been interpreted as consisting of three brining-up, carbonate-evaporite cycles (Kendall, 1976; Longman *et al.*, 1983). Hydrocarbon production from Red River carbonate reservoirs in southeastern Saskatchewan is restricted to the lowest of these cycles: a combination of the Yeoman and lower Herald formations. The Coronach Member of the Herald Formation is the middle carbonate-evaporite cycle (Table 1). Although it has not produced economic quantities of oil in Saskatchewan, the time-equivalent Red River "B" in North Dakota accounts for 4.4% of the state's cumulative production through 2006 (>68 million barrels [$10.8 \times 10^6$ $m^3$], North Dakota Oil and Gas Division, 2007; Table 2), and, in the past two years, has been the highest producer (33.7% and 39.6% in 2005 and 2006, respectively, Table 3). Recent production increases have stemmed from infill drilling and enhanced recovery methods (Ross Smith Energy Group Ltd., 2007).

Petrography and lithofacies of the Coronach Member in southeastern Saskatchewan were described and analyzed in 18 cores in order to try to understand the large disparity in production across the international border (Figure 1). This preliminary report describes two cores, one (12-2-7-11W2) in which the Coronach Member is completely represented, and the other (8-16-2-14W2) in which the Coronach Member is almost complete. Both cores display the full range of lithofacies. Porosity is reported from core analyses or from visual estimates.

## 2. Core Description and Lithofacies Analyses – Advantage et al Midale 12-2-7-11W2

### a) Lithology Summary

Advantage et al Midale 12-2-7-11W2 is located in the central part of the study area (Figure 1). In this well, the Coronach Member (including the Coronach Anhydrite) was completely cored with a total thickness of 12.2 m from 2555.7 to 2543.5 m. Three major facies' assemblages were recognized: 1) a basal 6.7 m-thick limestone and

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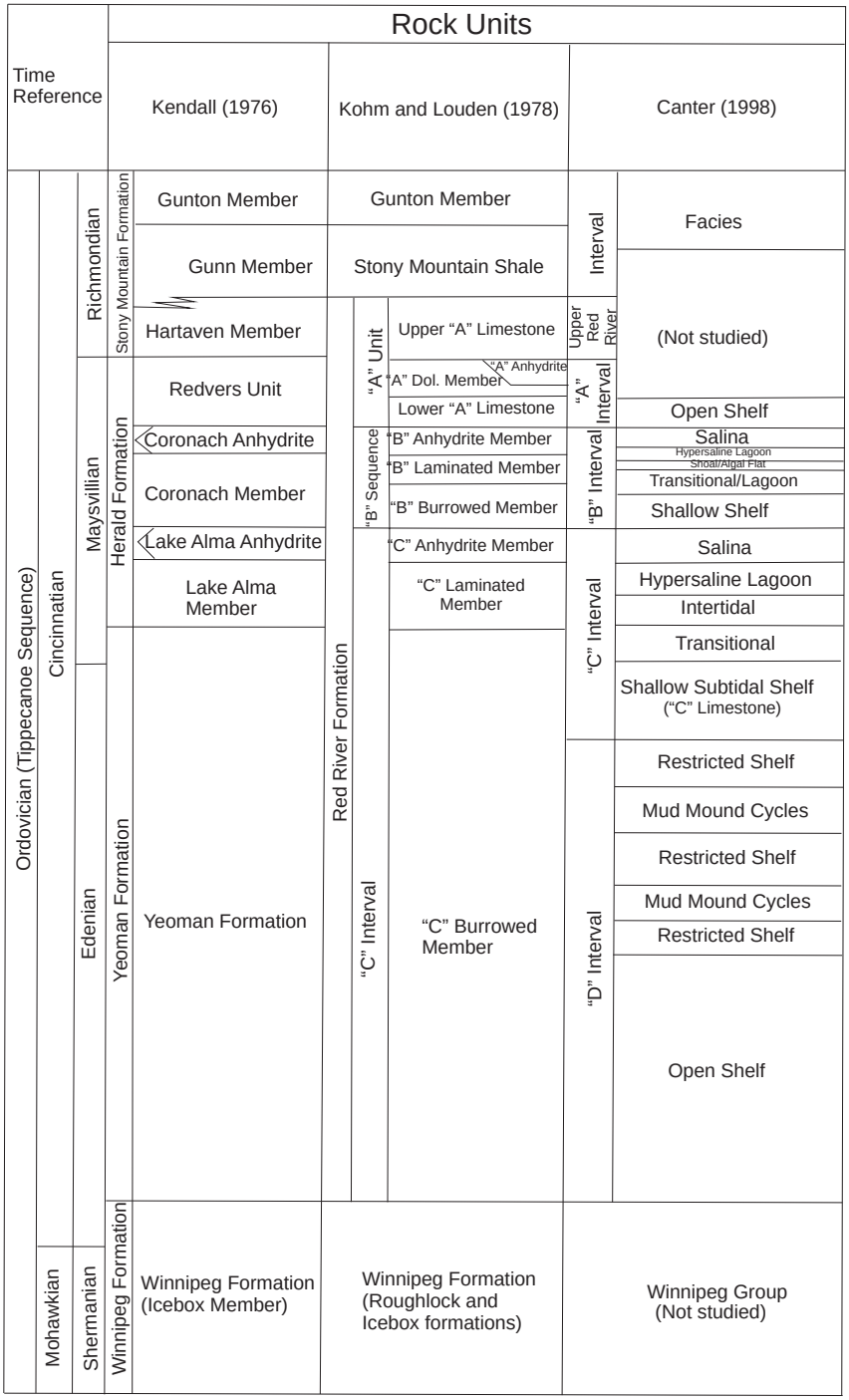
***Table 1 - Stratigraphic terminology of Red River and adjacent strata in the Williston Basin (modified from Canter, 1998).***




dolostone package with a high diversity of skeletal grains, depositional textures, and diagenetic minerals; 2) a 2.2 m-thick, commonly dolomitized, laminated package with slight, but variable, changes in depositional textures and organic matter; and 3) an upper, 3.3 m dense anhydritic dolomudstone and anhydrite package.

***Table 2 - Cumulative oil production in North Dakota, by formation, through December 2006 (data source is North Dakota Oil and Gas Division, 2007).***

| Formation | Cumulative Oil (barrels) | Percent | Well Count |
|---|---|---|---|
| Bakken | 35,668,213 | 2.2902 | 500 |
| Bakken/Three Forks | 721 | 0.0000 | 4 |
| Birdbear | 15,380,085 | 0.9875 | 156 |
| Cambro/Ordovician | 351,640 | 0.0226 | 5 |
| Dawson Bay | 3,954,187 | 0.2539 | 14 |
| Deadwood | 953 | 0.0001 | 1 |
| Devonian | 96,192,973 | 6.1764 | 135 |
| Duperow | 47,551,840 | 3.0532 | 332 |
| Gunton | 212,236 | 0.0136 | 10 |
| Heath | 65,330,267 | 4.1948 | 197 |
| Interlake | 8,568 | 0.0006 | 1 |
| Lodgepole | 52,349,991 | 3.3613 | 45 |
| Lodgepole/Bakken | 5,883 | 0.0004 | 1 |
| Madison | 873,292,115 | 56.0728 | 5,348 |
| Midale/Nesson | 1,464,454 | 0.094 | 31 |
| Mission Canyon | 13,001 | 0.0008 | 1 |
| Ordovician | 30,502,986 | 1.9586 | 120 |
| Ratcliffe | 154,006 | 0.0099 | 4 |
| Red River | 98,858,830 | 6.3476 | 657 |
| *Red River B* | *68,738,942* | *4.4136* | *444* |
| Red River C | 11,829 | 0.0008 | 1 |
| Sanish | 12,737,572 | 0.8179 | 53 |
| Silurian | 61,821,297 | 3.9695 | 216 |
| Souris River | 58,090 | 0.0037 | 2 |
| Spearfish | 548,935 | 0.0352 | 20 |
| Spearfish/Charles | 48,182,874 | 3.0938 | 206 |
| Spearfish/Madison | 4,312,392 | 0.2769 | 93 |
| Stonewall | 14,052,295 | 0.9023 | 119 |
| Stony Mountain | 5,668 | 0.0004 | 1 |
| Three Forks | 2,003 | 0.0001 | 1 |
| Tyler | 14,022,672 | 0.9004 | 79 |
| Tyler A | 2,853,526 | 0.1832 | 7 |
| Winnipeg | 138,542 | 0.0089 | 3 |
| Winnipeg/Deadwood | 28,267 | 0.0018 | 5 |
| Winnipegosis | 8,616,381 | 0.5532 | 51 |
| **Totals** | **1,557,424,234** | **100** | **8,863** |

## b) Detailed Lithology

### Facies Assemblage 1

2555.7 to 2555.5 m: Dark brown to black anhydritic dolomudstone with a 1 cm-thick pebble-lag deposit at the base (Figure 2). This interval is a transition facies from the interbedded anhydrite and dolomudstones of the Lake Alma Member below. The Coronach lower contact is a flooding surface as indicated by the pebble-lag deposit, which in this core overlies a 15 cm-thick dolomudstone bed. The upper contact is a sharp conformable facies change.

2555.5 to 2555.45 m: Massive, organic-rich, black lime mudstone with no skeletal grains. Porosity is low, but facies has a moderate petroliferous odour. The upper contact is a gradational lithology change.

2555.45 to 2553.35 m: Brown lime wackestone with secondary siliceous cement (5 to 10%), bladed anhydrite (5%), and disseminated pyrite (5%). Skeletal grains include fragmented crinoids (7%), brachiopods (3%), and ostracods (2%). Porosity is intercrystalline at about 2% and there is a faint petroliferous odour throughout. The upper contact is a gradational lithology change.

2553.35 to 2550.5 m: This interval is characterized by brown organic-rich lime wackestones (70%) to packstones (30%) with fractures throughout. Minor replacive anhydrite (3% of mineralogy). Observed skeletal grains include crinoids, brachiopods, stromatoporoids (several laminar varieties), ostracods, bryozoans, and a single coral. Porosity is 3% and includes intercrystalline and moldic types. This interval has a very faint petroliferous odour. The upper contact is gradational into a similar facies, but with mottled textures.

2550.5 to 2549.6 m: Light to dark brown dolowackestone with crinoids (10%), bivalves (10%), and calcite matrix (40%). This interval has a mottled fabric (Figure 3) which is increasingly well developed upwards. Mottling consists of light brown dolomite nodules within a dark brown limestone matrix. Dolomite mottles are tight, while intercrystalline porosity in the matrix is estimated to be about 2%. Light hydrocarbon staining is only present in the matrix. The upper contact is a sharp, conformable lithology change.

2549.6 to 2549.0 m: Dark brown, organic-rich lime wackestone with crinoids (5 to 15%), and *Planolites* burrows (10%). Intercrystalline-type porosity is estimated at about 2%. A faint petroliferous odour was detected in this interval. The upper contact is a sharp lithology change into laminites.

***Table 3 - Oil production in North Dakota for 2005 and 2006, by formation, highlighting Red River "B" (data source is North Dakota Oil and Gas Division, 2007).***

| Formation | 2005 North Dakota Oil Production by Formation | | | 2006 North Dakota Oil Production by Formation | | |
|---|---|---|---|---|---|---|
| | Oil Produced (barrels) | Percent | Wells | Oil Produced (barrels) | Percent | Wells |
| Bakken | 985,496 | 2.7902 | 226 | 2,245,411 | 5.6740 | 300 |
| Birdbear | 1,305,418 | 3.696 | 96 | 1,242,060 | 3.1386 | 109 |
| Cambro/Ordovician | 15,214 | 0.0431 | 2 | 15,754 | 0.0398 | 2 |
| Dawson Bay | 35,759 | 0.1012 | 3 | 34,061 | 0.0861 | 3 |
| Devonian | 1,098,339 | 3.1097 | 58 | 962,058 | 2.4311 | 59 |
| Duperow | 904,296 | 2.5603 | 119 | 901,638 | 2.2784 | 121 |
| Gunton | | | | 18,822 | 0.0476 | 1 |
| Heath | 194,320 | 0.5502 | 43 | 220,369 | 0.5569 | 40 |
| Lodgepole | 2,076,906 | 5.8803 | 29 | 1,596,325 | 4.0338 | 29 |
| Madison | 11,732,155 | 33.2172 | 2,069 | 11,680,192 | 29.5151 | 2,107 |
| Midale/Nesson | 76,068 | 0.2154 | 22 | 155,200 | 0.3922 | 30 |
| Mission Canyon | 2,879 | 0.0082 | 1 | 2,213 | 0.0056 | 1 |
| Ordovician | 593,650 | 1.6808 | 57 | 533,782 | 1.3488 | 55 |
| Ratcliffe | 13,555 | 0.0384 | 4 | 11,876 | 0.0300 | 4 |
| Red River | 1,911,464 | 5.4119 | 200 | 1,871,889 | 4.7301 | 203 |
| *Red River B* | *11,922,208* | *33.7553* | *239* | *15,706,913* | *39.6903* | *269* |
| Sanish | 65,811 | 0.1863 | 13 | 67,118 | 0.1696 | 13 |
| Silurian | 584,537 | 1.655 | 56 | 593,657 | 1.5001 | 55 |
| Spearfish | 15,766 | 0.0446 | 11 | 15,465 | 0.0391 | 9 |
| Spearfish/Charles | 439,246 | 1.2436 | 105 | 416,980 | 1.0537 | 106 |
| Spearfish/Madison | 48,149 | 0.1363 | 36 | 63,128 | 0.1595 | 36 |
| Stonewall | 512,509 | 1.4511 | 49 | 463,033 | 1.1701 | 51 |
| Tyler | 482,040 | 1.3648 | 43 | 433,896 | 1.0964 | 45 |
| Tyler A | 32,881 | 0.0931 | 3 | 31,035 | 0.0784 | 4 |
| Winnipeg | 40 | 0.0001 | 1 | | | |
| Winnipeg/Deadwood | 1,101 | 0.0031 | 2 | 1,267 | 0.0032 | 2 |
| Winnipegosis | 269,703 | 0.7636 | 16 | 289,508 | 0.7316 | 16 |
| **Total** | **35,319,510** | **100** | **3,503** | **39,573,650** | **100** | **3,670** |

### Facies Assemblage 2

2549.0 to 2547.9 m: Black to grey laminated lime mudstone. Laminations are horizontal and planar (Figure 4). No skeletal grains are observed. Organic content, as indicated by colour, gradually increases upwards. Intercrystalline porosity is low at an estimated 2%. This interval has a very strong petroliferous odour. The upper contact is not preserved.

2547.9 to 2546.8 m: Light brown dolomudstone with a laminated texture. Laminites at basal 10 cm are discontinuous; changes to more "wispy" at 2547.55 m; gradational upwards into sub-horizontal, parallel laminations to the top. No skeletal grains are observed in this interval. Porosity is intercrystalline, ranging from about 5 to 7%. Laminites are faintly oil stained (Figure 5A) and have a strong petroliferous odour. Under UV light, hydrocarbons give off a bright yellow fluorescence (Figure 5B). Upper contact is a very sharp lithological change at a 15° angle.

### Facies Assemblage 3

2546.8 to 2545.2 m: Light brown massive dolomudstone with local small (less than 0.5 cm) radiating crystals of anhydrite. No skeletal grains were observed. A massive anhydrite bed occurs at 2546.6 m. The upper boundary is gradational into anhydritic dolomudstones.

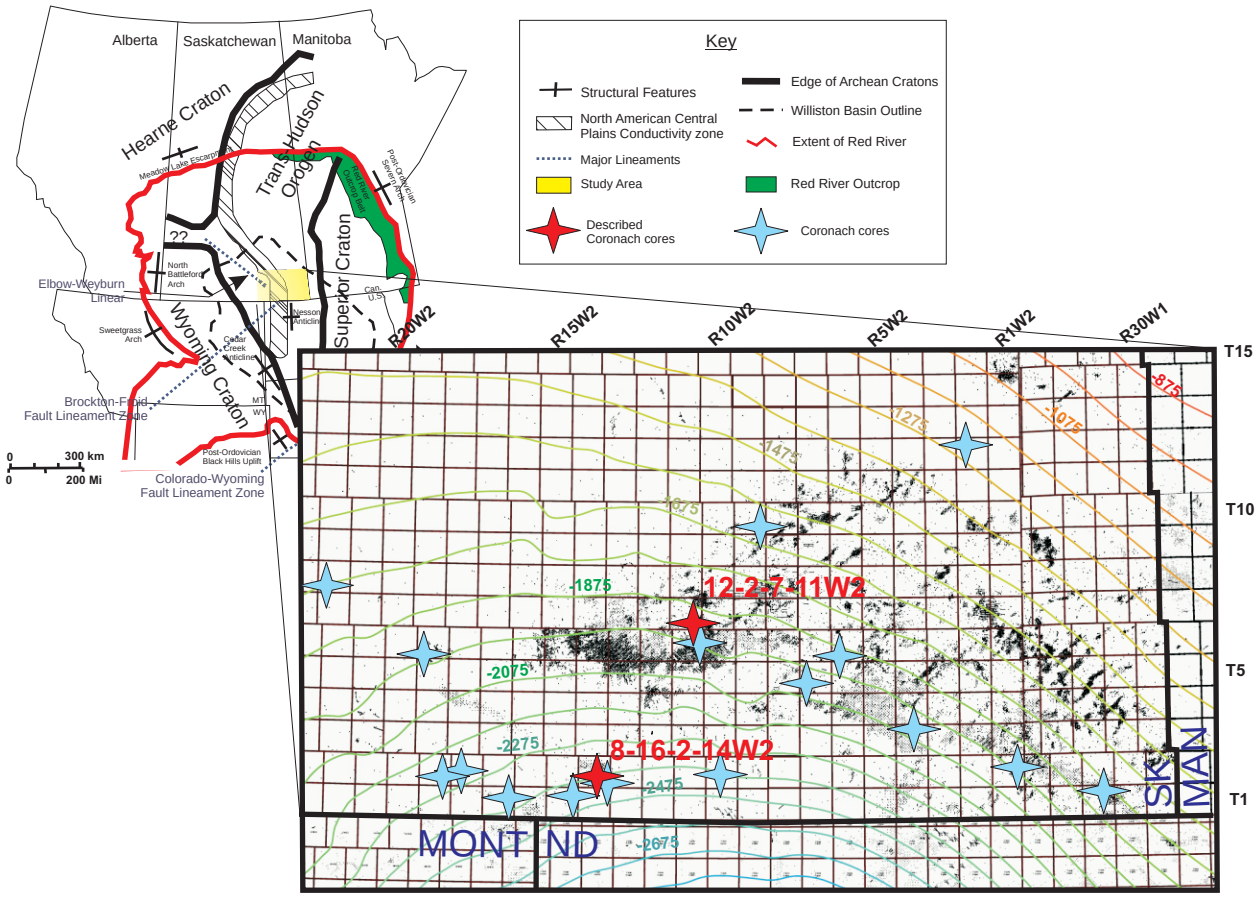



***Figure 1 - Location map of the study area in southeastern Saskatchewan showing structure contours on top of the Coronach Member (C.I. = 100 m ) and location of cores described in this study. Inset map shows the outline of the present day Williston Basin, and the location of major lineaments and other structural features.***

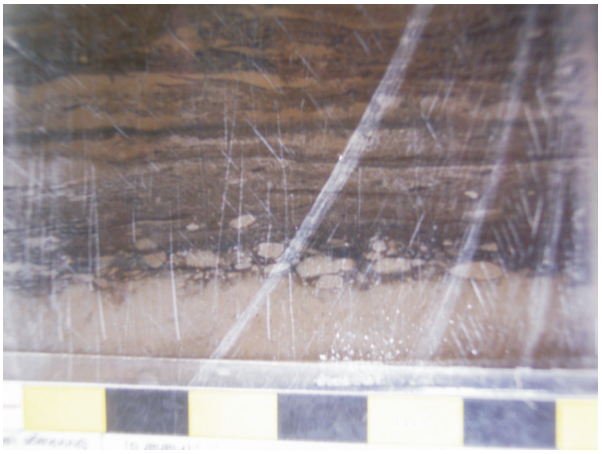


***Figure 2 - Base of the Coronach Member; picked at the contact between 1 cm-thick pebble lag deposit composed of sub-angular, 0.5 cm-sized clasts and underlying light brown dolomudstone of the Lake Alma Member. Interpreted to record a flooding event which initiated Coronach deposition. Overlying strata are composed of anhydritic dolomudstone. From well 12-2-7-11W2; depth at contact is 2555.7 m.***

2545.2 to 2544.1 m: Grey bedded anhydrite (50%) and tan dolomudstones (50%) grade upwards into massive anhydrite with nodular texture. Upper contact is a sharp lithological change into dolomudstones.

2544.1 to 2543.5 m: Greenish grey dolomudstone becoming an orange colour at top. About 15 cm of floating breccia are present at the top of this interval (Figure 6). Brecciated grains are 1 cm x 1 cm sub-angular to sub-rounded mud clasts. Orange mudstones contain smaller, sub-angular brecciated grains about 0.2 cm x 0.2 cm in size, and also appear to have mudcracks. The upper boundary is an exposure surface, as indicated by mudcracks. Lime mudstones of the Redvers Member sharply overlie this contact.


*Figure 3 - Mottled texture from light brown dolomite nodules (D) in a dark brown limestone matrix. Core is 9 cm wide. Sample from 12-2-7-11W2, 2550.4 to 2550.2 m.*


*Figure 4 - Black, organic-rich, horizontal laminites from the base of Facies Assemblage 2. This facies has a very strong petroliferous odour and is a potential source rock in the Coronach Member. Sample is 9 cm wide, from well 12-2-7-11W2, 2548.05 to 2547.9 m.*

## c) Preliminary Interpretations

The base of the Coronach Member is picked at the top of dolomudstone beds in the Lake Alma Anhydrite. This contact is interpreted as a sharp flooding surface as evidenced from a thin pebble lag deposit at the base of the Coronach (Figure 2). This transition facies (2555.7 to 2555.5 m) exhibits similar lithology to the Lake Alma Member. Other cores exhibit mudcracks at the top of this facies indicating an element of exposure prior to flooding. The deepening event is recognized by subsequent deposition of organic-rich lime mudstones with overlying subtidal lime wackestones and packstones (2555.5 to 2549 m) of Facies Assemblage 1.

Dolomite nodules, about 2 to 5 cm long by 2 cm wide, within a limestone matrix have created mottling textures near the top of Assemblage 1. The nodules may contain skeletals of crinoids and bivalves, and appear to be unrelated to dolomitization of *Thalassinoides* burrows, as reported for the Yeoman Formation (*e.g.*, Kissling, 1999; Gingras *et al.*, 2004). Further investigation is required to verify the nature of the mottling textures and their implication for dolomitization.

Facies Assemblage 2 consists of lime or dolostone laminites with variable depositional textures. The black, basal lime mudstones with horizontal laminations are a potential source rock for petroleum. This organic-rich facies grades sharply into laminated dolomudstone. These laminites appear to be stromatolitic – the producing lithofacies in the Red River "B" of North Dakota and South Dakota (Kohm and Louden, 1988). The textures display an upward trend from discontinuous laminations at the base, to wispy or irregular laminations, to sub-horizontal, parallel laminations at the top. A similar trend is observed in other wells, where stromatolites are present. The origin and nature of laminations in Facies Assemblage 2 is under further investigation.

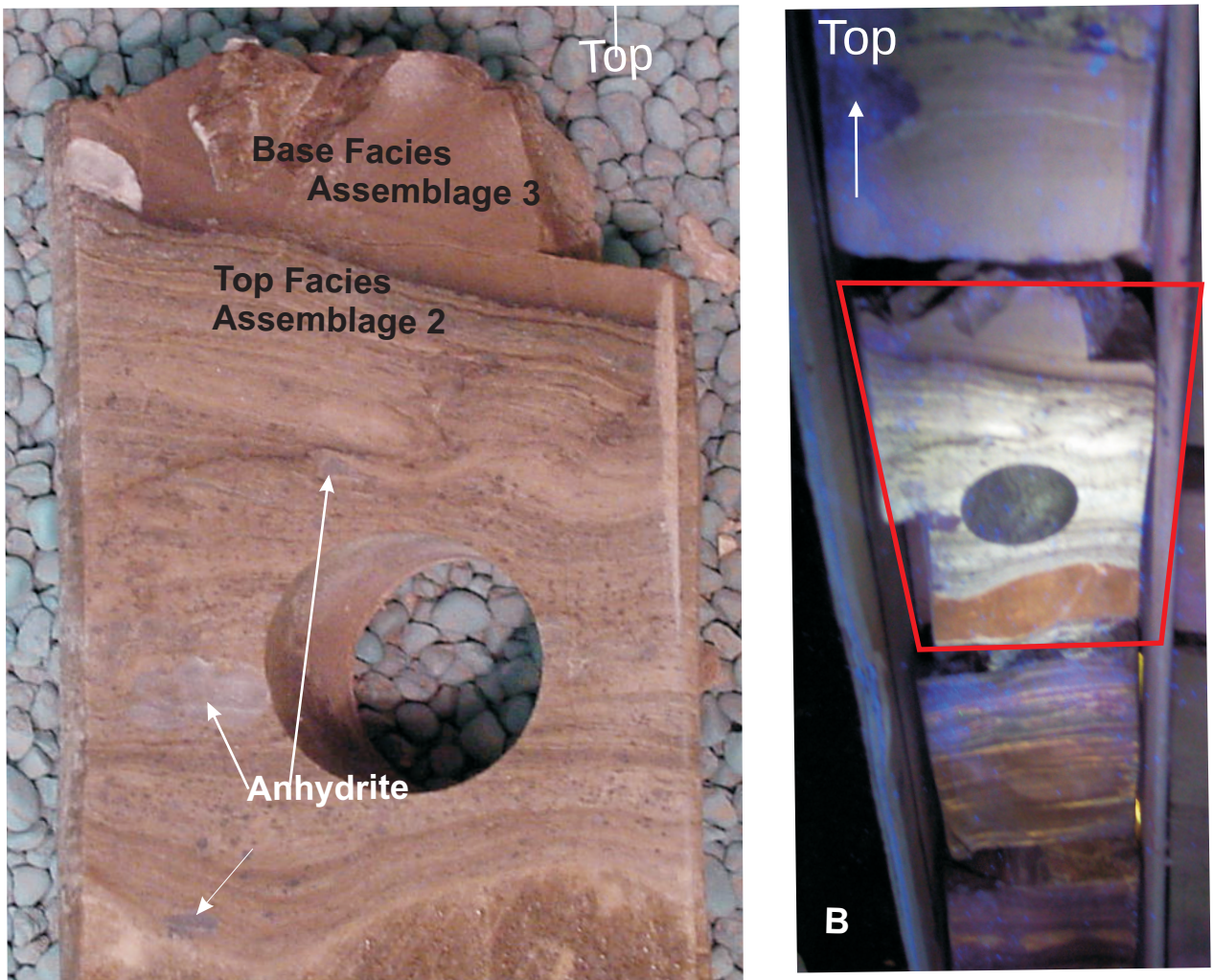



***Figure 5 - A) Top of laminite facies (from Assemblage 2) showing displacement of laminations due to growth of nodular anhydrite. Facies has a sharp, 15° angle contact with tight massive dolomudstones above (Assemblage 3). Sample from 12-2-7-11W2, 2546.95 to 2546.8 m. Core is 9 cm wide. B) The same sample (outlined by red box) under UV light showing bright yellow to orange fluorescence in laminite facies.***

The presence of anhydrite needles in massive dolomudstones and a thick succession of nodular anhydrite (Facies Assemblage 3) are interpreted as an indication of increasing salinity during late Coronach time. This facies assemblage was likely deposited in a supratidal environment, and makes an effective cap for hydrocarbon-bearing laminites below.

The top of the Coronach Member was not picked at the last occurrence of anhydrite, but at the top of an overlying dolomudstone (Figure 6), which is tentatively interpreted to be the paleosol that signifies the end of the overall, shallowing cycle which began with a flooding surface at the base of this core.

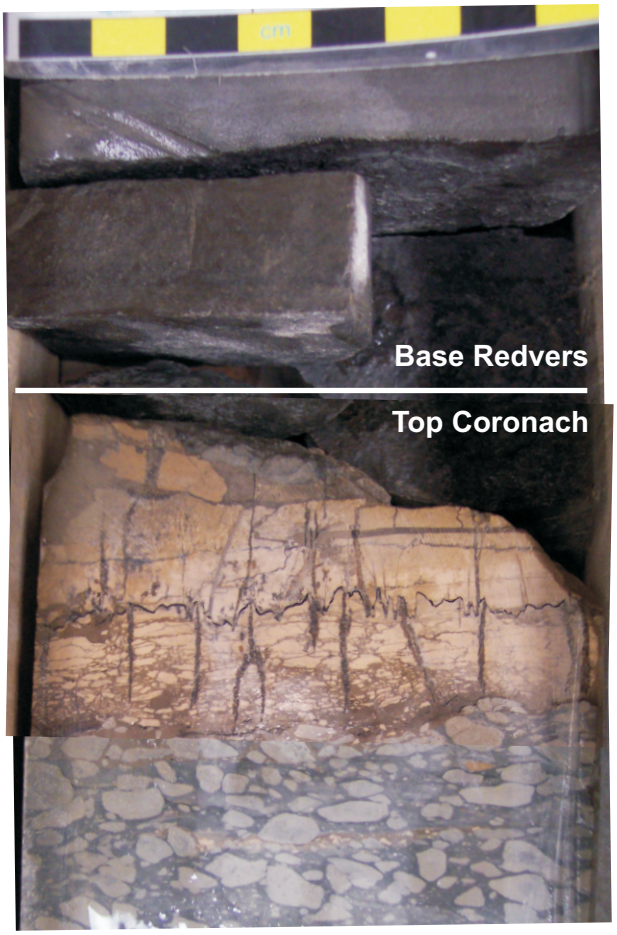



***Figure 6 - Sharp transition between Coronach Member and Redvers Unit. The top Coronach has mudcracks and brecciated grains. Preliminary interpretation is that this is a paleosol, which represents maximum sea-level drawdown, ending Coronach deposition. Black lime mudstones overlying the paleosol represent initial deposits of the Redvers Unit. Sample from 12-2-7-11W2 at 2543.6 to 2543.5 m.***

### d) Petrophysical Analysis

Core analysis of this core generally indicates a very tight rock throughout (Table 4). Nearly every facies has faint to moderate hydrocarbon staining and petroliferous odour except for Facies Assemblage 3. Facies Assemblage 2 showed the best porosity, up to 9%, but permeability is low, only reaching 2.6 mD. The discontinuous laminites, which showed the best oil staining and fluorescence in Facies Assemblage 2, were not, however, sampled for analysis. The laminations likely act as individual permeability barriers, but where these barriers are broken, as in the discontinuous laminites, permeability should be higher. The highest permeability in this sampled core interval is 2.6 mD; it occurs in the black, laminated lime mudstones (2549 to 2547.9 m). Its corresponding porosity is less than 2%, probably related to the absence of dolomitization.

## 3. Core Description and Lithofacies Analyses – Suncor Oungre 8-16-2-14W2

### a) Lithology Summary

In the Suncor Oungre 8-16-2-14W2 well (Figure 1), the Coronach Member is 11.6 m thick. True vertical depths are 3023.4 to 3011.8 m based on logs. In this well, the core is 1.4 m lower relative to logs, and about 0.8 m of the Coronach Anhydrite was not cored. Similar to 12-2-7-11W2, three major facies assemblages were recognized: 1) a 5.8 m-thick basal, dominantly limestone, package with a high diversity of skeletal grains, depositional textures, and diagenetic minerals; 2) a laminated, 2.7 m-thick, dolomitized zone; and 3) an upper, 2.3 m-thick (not including ~0.8 m of un-cored section), anhydritic dolomudstone to nodular anhydrite package.

### b) Detailed Lithology

**Facies Assemblage 1**

3024.8 to 3024.6 m: Grey dolomitic mudstone with clasts of mud interpreted to be rip-ups. Main fabrics range from laminations to deformed bedding, possibly weathering textures (Figure 7). No skeletal grains are observed. Porosity is low. This interval includes the basal Coronach contact and is marked by: 1) a zone of mud rip-ups (presumably from the underlying Lake Alma); 2) weathering textures that also extend down into the Lake Alma Member; and 3) a grey, 1 cm-thick faintly laminated speleothem interval interpreted to be a flowstone, which marks the upper contact of this facies.

3024.6 to 3022.7 m: Organic-rich, dark brown lime wackestone with *Planolites* burrows that grade up into slightly less argillaceous wackestones with crinoids (12%). Chert nodules and secondary bladed anhydrite grains up to 2.5 cm long each account for 5 to 10% of this facies. The upper contact was not preserved.

3022.7 to 3022.2 m: Missing core.

3022.2 to 3019.0 m: Dark brown, variably mottled, lime wackestone to packstone. Skeletal grains include numerous laminar and low-relief hemispheroidal stromatoporoids (B. Pratt, pers. comm., 2007, see Figure 8), crinoids, one colonial coral (*Syringopora* sp.?), red algae, and small, centimetre-sized laminar labechiid stromatoporoids, *Planolites* burrows, and *Teichichnus* (?) burrows, at the top 20 cm (Figure 9). Porosity is low (2%) and characterized by intercrystalline porosity. The upper contact is an erosional surface as evidenced by the sharp, irregular change into overlying cross-laminated grainstone dipping at 20º (Figure 9).

***Table 4 - Core analyses from the two cores described in this paper.***

| 12-2-7-11W2 Core Sample Analysis (data from Chemical & Geological Laboratories Inc.) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Depth (m) | Length (m) | Kmax (mD) | K90 (mD) | Kvert (mD) | Porosity (frac) | Grain Density (kg/m3) | Pore Vol Oil | Pore Vol Water | Lithology | Remarks |
| 1 | 2543 | 1 | | | | | | | | dolst, v f xl, lam-mot, anhy, pyr | not analysed |
| 2 | 2544 | 0.1 | 0.01 | | | 0.007 | 2750 | | 0.999 | dolst, v f xl, mot, anhy, pyr | |
| 3 | 2544.1 | 1.8 | | | | | | | | dolst, v f xl, lam-mot, anhy | not analysed |
| 4 | 2545.9 | 0.5 | 0.01 | | | 0.015 | 2820 | | 0.741 | dolst, v f xl, mas, pyr | |
| 5 | 2546.4 | 0.6 | 0.31 | | | 0.091 | 2870 | | 0.366 | dolst, v f xl, lam, anhy | |
| 6 | 2547 | 1.1 | | | | | | | | dolst, v f-f xl, lam, anhy | not analysed |
| 7 | 2548.1 | 0.25 | 0.01 | | | 0.012 | 2850 | | | dolst, v f xl, lam, anhy | |
| 8 | 2548.35 | 0.35 | 2.6 | 0.17 | 0.33 | 0.019 | 2720 | | | dolst, v f xl, lam, anhy, RF | fractured |
| 9 | 2548.7 | 1.55 | | | | | | | | dolst, v f xl, lam-brec, anhy | not analysed |
| 10 | 2550.25 | 0.25 | 0.01 | | | 0.019 | 2730 | | | ls, f xl, fos, anhy | |
| 11 | 2550.5 | 0.5 | 0.03 | | | 0.029 | 2670 | | 0.153 | ls, v f xl, fos, anhy, pyr | |
| 12 | 2551 | 1.5 | | | | | | | | ls, v f xl, fos, anhy, pyr | not analysed |
| 13 | 2552.5 | 0.5 | 0.01 | | | 0.005 | 2700 | | 0.444 | ls, v f xl, fos, anhy, pyr | |
| 14 | 2553 | 0.5 | 0.08 | | | 0.009 | 2700 | | | ls, v f xl, fos, anhy, pyr | |
| 15 | 2553.5 | 0.5 | | | | | | | | ls, v f xl, fos, anhy, pyr | not analysed |
| 16 | 2554 | 0.3 | 1.9 | | | 0.011 | 2700 | | 0.404 | ls, v f xl, fos, anhy, pyr, frac | fractured |
| 17 | 2554.3 | 0.4 | | | | | | | | ls, v f xl, fos, anhy, pyr | not analysed |
| 18 | 2554.7 | 0.25 | 0.01 | | | 0.003 | 2760 | | | ls, v f xl, fos, anhy, pyr | |
| 19 | 2554.95 | 0.15 | 0.01 | | | 0.009 | 2800 | 0.999 | | dolst, v f xl, lam, pyr, frac | |
| 20 | 2555.1 | 5.75 | | | | | | | | dolst, mic-v v xl, lam-mot, anhy | not analysed |
| 21 | 2560.85 | 0.15 | | | | | | | | lost core | missing |

| 8-16-2-14W2 Core Sample Analysis (data from Core Laboratories - Canada Ltd.) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Depth (m) | Length (m) | Kmax (mD) | K90 (mD) | Kvert (mD) | Porosity (frac) | Grain Density (kg/m3) | Pore Vol Oil | Pore Vol Water | Lithology | Remarks |
| 46 | 3014 | 1.5 | | | | | | | | dol anhy | dense |
| 47 | 3015.5 | 0.5 | 0.13 | 0.03 | 0.02 | 0.057 | 2840 | | 0.154 | dol i anhy frac | fractured |
| 48 | 3016 | 0.19 | 0.26 | 0.26 | -0.01 | 0.062 | 2850 | | 0.381 | dol i anhy frac | |
| 49 | 3016.19 | 1.55 | | | | | | | | dol anhy | dense |
| 50 | 3017.74 | 0.48 | 41.5 | 0.02 | 5.25 | 0.047 | 2820 | | 0.56 | dol i vfrac | fractured |
| 51 | 3018.22 | 0.38 | | | | | | | | dol | dense |
| 52 | 3018.6 | 0.4 | 0.05 | 0.03 | 0.01 | 0.06 | 2800 | 0.104 | 0.551 | dol i | |
| 53 | 3019 | 2.8 | | | | | | | | dol ls part rubble | broken |
| 54 | 3021.8 | 0.6 | | | | | | | | lost core | missing |
| 55 | 3022.4 | 10.85 | | | | | | | | ls anhy | dense |

**Abbreviations:** anhy, anhydrite (ic); brec, breccia (ted); dol, dolomite; dolst, dolostone; f, fine(ly); fos, fossil (iferous); frac, fracture (ed); i, intergranular; lam, laminated; ls, limestone; mas, massive; mic, micro; mot, mottled; pyr, pyrite (ic) (ixed); RF, random fracture; v, very; vfrac, vertical fracture; xl, crystal (line).

## Facies Assemblage 2

3019.0 to 3018.9 m: Light brown dolomudstone with basal, cross-laminated grainstone. This interval is fractured and exhibits a deformed texture, possibly from bioturbation. No porosity or skeletal grains observed. The upper contact is gradational into laminites.

3018.9 to 3016.3 m: Light brown dolostone with discontinuous laminations at the base, grading upwards to “wispy” laminations, which, in turn, grade up into sub-horizontal, parallel laminations (Figure 10). This interval contains about 5% anhydrite nodules at the top. The porosity is estimated around 4 to 5% and is characterized by intercrystalline porosity. This interval has light patchy oil staining. The upper contact is a sharp lithological change into anhydritic dolomudstone.

## Facies Assemblage 3

3016.3 to 3015.85 m: White to brown, bedded to laminated, anhydritic dolomudstone with local occurrence of anhydrite nodules. Porosity is low. The upper contact is sharp and is marked by a stylolite.

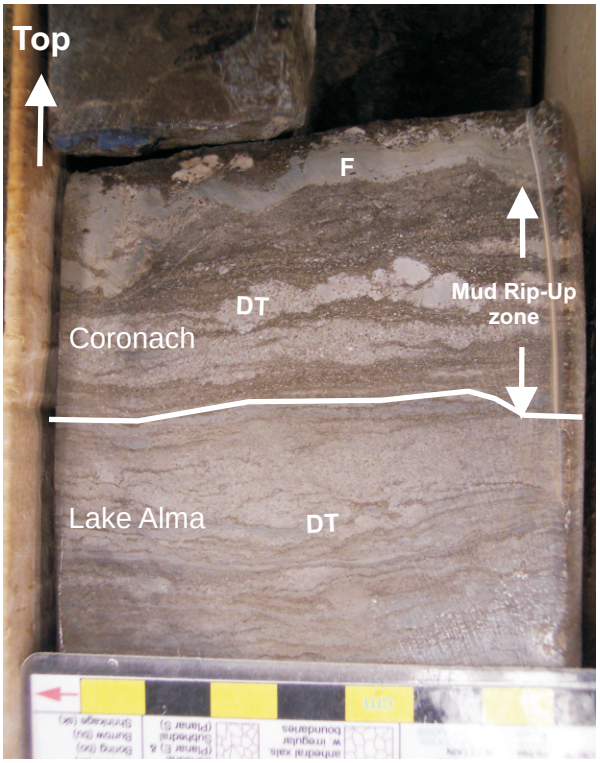



***Figure 7 - Transition facies from Lake Alma Anhydrite into basal Coronach deposits. Facies has deformed textures (DT), possibly from weathering, which extend down into the Lake Alma Member; a zone of mud rip-ups (minute white specks) possibly from the underlying facie; and a faintly laminated speleothem feature interpreted to be a flowstone (F). Above this transition facies are more normal-marine limestone deposits. Sample from 8-16-2-14W2, 3024.7 to 3024.6 m.***

3015.85 to 3014.6 m: Massive light brown dolomudstone with minor (5%) bladed anhydrite crystals. Local vertical fractures are lined with anhydrite. This interval has no porosity. The upper contact is sharp and marked by a stylolite.

3014.6 to 3014 m (top of core): Anhydritic dolomudstone grades upwards to massive evaporite. In the lower part of this interval, nodular anhydrite (50%) is mixed with dolomudstone (50%), but grades upward into 100% nodular anhydrite. This interval has no porosity. The upper contact was not cored.

## c) Preliminary Interpretations

The contact between the Lake Alma and Coronach members is marked by a flooding contact, as evidenced by mud rip-ups. Weathering textures below and above this contact, as well as a possible flowstone above the contact, is evidence that these rocks were also repeatedly subaerially exposed before being overlain by progressively more normal-salinity marine conditions.

Facies Assemblage 1 consists mainly of subtidally deposited lime wackestones. Skeletal grains observed in this assemblage include laminar and low-relief hemispheroidal stromatoporoids and colonial corals, which are typical reef-builders (James and Bourque, 1992). However, the lack of a prominent *in situ* skeletal framework in the mud-dominated lithologies suggests this assemblage is not a reef-core facies (James and Bourque, 1992).

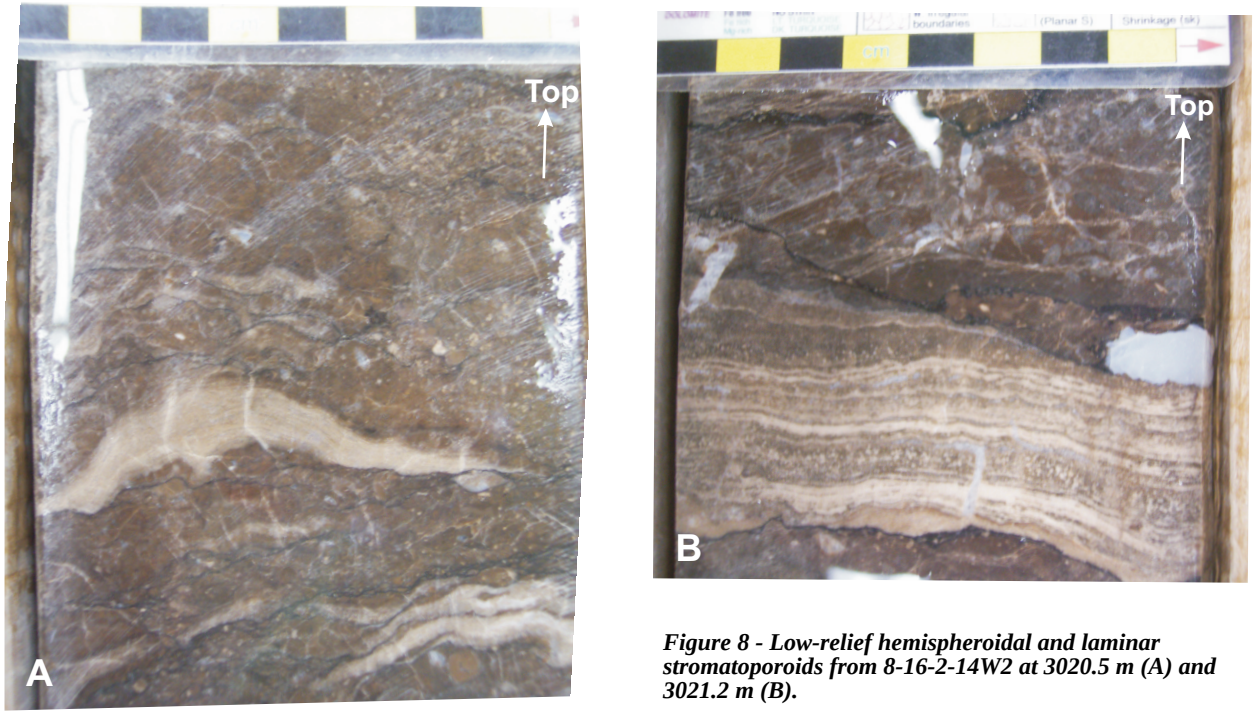



***Figure 8 - Low-relief hemispheroidal and laminar stromatoporoids from 8-16-2-14W2 at 3020.5 m (A) and 3021.2 m (B).***

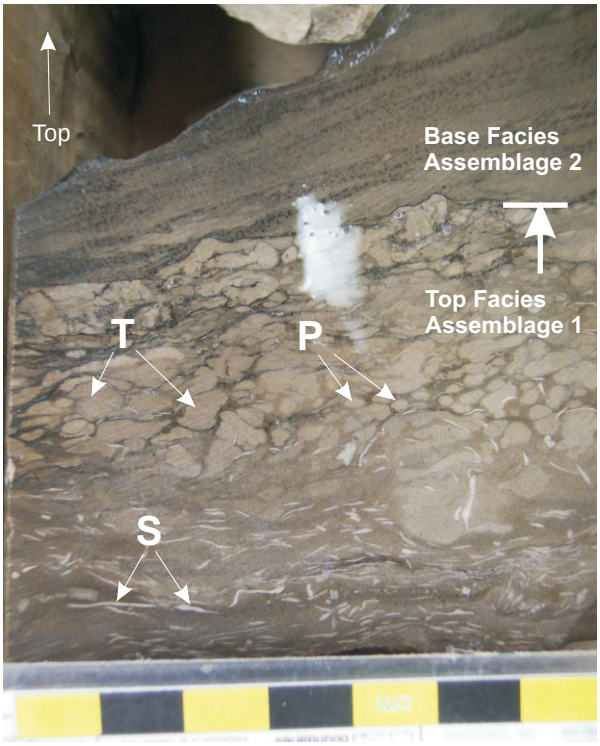



***Figure 9 - Top of Facies Assemblage 1 marked by sharp, irregular contact, probably an erosional surface. Below contact are small laminar labechiid stromatoporoids ('S'; B. Pratt, pers. comm., 2007) and sediment-filled* Planolites *(P) and, possibly,* Teichichnus *burrows (T). Contact is overlain by cross-laminated grainstone. Sample from 8-16-2-14W2, 3019 m.***

A dolomitized mottled texture was observed at the top of Assemblage 1. The contact between dolomitic nodules and limestone matrix is sharp and irregular (Figure 11) which is tentatively interpreted as infilling of cavities in the host limestone by dolomite. The source of the mottling fabrics will be investigated in the future.

Facies Assemblage 2 displays a general upward trend from discontinuous, to "wispy", to sub-horizontal, parallel laminations (Figure 10). Some discontinuous laminations are the result of mudcracks or larger prism cracks (Figure 12), but others could be water-escape structures. Though some laminites appear to be stromatolitic, further work is needed to explain their origin and textural significance.




***Figure 10 - Variations in fabric of the laminite facies. Basal, discontinuous laminations (A) grade up to irregular or "wispy" laminations (B) which grade up to sub-horizontal, more consistent laminations (C). Oil staining and fluorescence are best seen in laminites exhibiting textures like those in 'A'. Samples from 8-16-2-14W2 at depths of 3018 m, 3016.6 m, and 3016.2 m, respectively.***

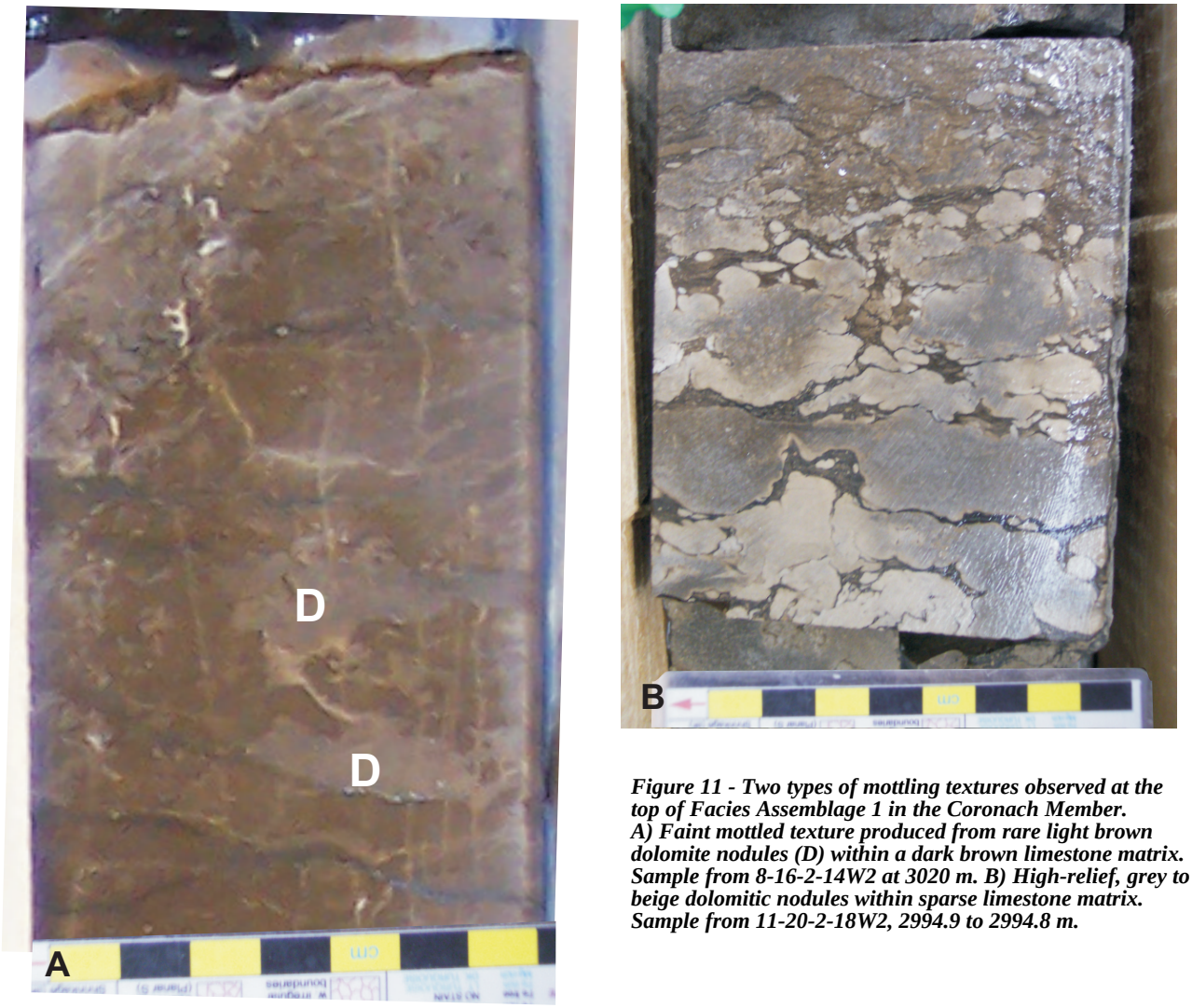



***Figure 11 - Two types of mottling textures observed at the top of Facies Assemblage 1 in the Coronach Member. A) Faint mottled texture produced from rare light brown dolomite nodules (D) within a dark brown limestone matrix. Sample from 8-16-2-14W2 at 3020 m. B) High-relief, grey to beige dolomitic nodules within sparse limestone matrix. Sample from 11-20-2-18W2, 2994.9 to 2994.8 m.***

Facies Assemblage 3 consists of three facies: 1) a dense dolomudstone with variable anhydrite needles and/or localized, nodular anhydrite; 2) bedded dolomudstone and nodular anhydrite; and 3) massive nodular anhydrite. All facies indicate high-salinity conditions, and were likely deposited in a supratidal environment.

### d) Petrophysical Analysis

Core analysis shows that the laminite facies (at 3017.74 m depth) has variable permeability, from over 40 mD to less than 0.1 mD (Table 4). Porosities for the same facies are fair at around 5 to 6%. Although data are sparse, permeability and porosity indicate a fair reservoir in the laminites only.

## 4. Summary

The lithofacies of the Coronach Member indicate an overall shallowing- and brining-upward trend. Based on lithology types and textures, skeletal grains, and exposure or erosional surfaces throughout both cores, preliminary interpretations suggest that the Coronach was deposited in relatively shallow to very shallow water.

The discontinuous laminate facies within Facies Assemblage 2 is potentially a prospective reservoir in the Coronach Member in southeastern Saskatchewan. The most important control on reservoir effectiveness appears to be permeability which is variable, ranging from 1 to 40 mD in the two cores described in this report. Exploration for this reservoir however, is high risk because it is thin and relatively deep, at 2400 to 3000 m. To help reduce the risk and address the production variances observed between Saskatchewan and the U.S. portion of the Williston Basin, this project will continue to study and analyze depositional and diagenetic controls on the lateral and vertical distribution of reservoirs in the Coronach Member.


***Figure 12 - Laminite facies showing large mudcrack, or prism crack, on right side of sample. Labelled are detached fragments of the original bedding that have fallen down into the opening. Sample from 14-26-6-11W2, 2555 m.***

## 5. Acknowledgments

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## 6. References

Canter, K.L. (1998): Facies, cyclostratigraphic and secondary diagenetic controls on reservoir distribution, Ordovician Red River Formation, Midale Field, southern Saskatchewan; *in* Bend, S.L., Christopher, J.E., Gilboy, C.F., and Paterson, D.F. (eds.), Eighth International Williston Basin Symposium, Core Workshop Volume, Regina, October 1998, Sask./North Dak./Mont. Geol. Socs., p41-65.

Gingras, M.K., Mendoza, C.A., and Pemberton, G. (2004): Fossilized worm burrows influence the resource quality of porous media; AAPG Bull., v88, p875-883.

James, N.P. and Bourque, P.A. (1992): Reefs and mounds; *in* Walker, R.G. and James, N.P. (eds.), Facies Models, Geol. Assoc. Can., p323-347.

Kendall, A.C. (1976): The Ordovician Carbonate Succession (Big Horn Group) of Southeastern Saskatchewan; Sask. Dep. Miner. Resour., Rep. 180, 185p.

Kissling, D.L. (1999): Life and death roles of Red River *Thalassinoides*; AAPG Bull., v83, p1184-1185.

Kohm, J.A. and Louden, R.O. (1978): Ordovician Red River of eastern Montana–western North Dakota: Relationships between lithofacies and production; *in* Montana Geological Society 24th Annual Conference Guidebook, Williston Basin Symposium, Mont. Geol. Soc., Billings, p99-117.

_____ (1988): Red River reservoirs of western North Dakota and eastern Montana; *in* Goolsby, S.M. and Longman, M.W. (eds.), Occurrence and physical properties of carbonate reservoirs in the Rocky Mountain region, 1988 Carbonate Symposium, Rky. Mtn. Assoc. Geol., p275-290 (with plates, p451-455).

Longman, M.W., Fertal, T.G., and Glennie, J.S. (1983): Origin and geometry of Red River dolomite reservoirs, western Williston Basin; AAPG Bull., v67, p744-771.

North Dakota Oil and Gas Division (2007): North Dakota Oil and Gas Division, General Statistics; <http://www.dmr.nd.gov/oilgas/stats/2006Formation.pdf> and <http://www.dmr.nd.gov/oilgas/stats/2006CumulativeFormation.pdf>, accessed 1 June 2007.

Ross Smith Energy Group Ltd. (2007): Waiting For the Encore; URL <http://www.rseg.com>, accessed 8 Jan 2007.