# Preliminary Study of Reservoir Distribution in the Middle Jurassic Upper Shaunavon Member, Southern Shaunavon Oil Field Trend, Southwestern Saskatchewan

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## *Abstract*

*Oil production from the Middle Jurassic reservoirs of the Upper and Lower members of the Shaunavon Formation in southwestern Saskatchewan has been well known for several decades. Technological advancements in drilling and completion techniques in recent years have resulted in renewed interest by industry in these strata. Initially, this rekindled interest in the Shaunavon Formation was focussed on its Lower Member; however, even with the focus, the majority of the production to date from the Shaunavon Formation in southwestern Saskatchewan has been limited to mixed clastic/carbonate reservoirs of the Upper Member.*

*This paper focusses on four reservoirs (in descending order E, D, C, and B) within the Upper Shaunavon Member in the Dollard, Eastend, Eastbrook, and Rapdan pools, as well as on a regional unconformity underlying the uppermost two reservoirs (E and D). An objective of this study was to perform detailed descriptions of core from the Upper Shaunavon Member and correlate this with data from geophysical well logs. These data would then be used to create a series of maps showing the distribution and thickness of each of the reservoirs, plus a map showing the morphology of the unconformity underlying reservoirs E or D and the distribution of reservoirs E and D where they are greater than 4 m. The distribution of each of the Upper Shaunavon reservoirs, and their relationship with each other and the regional mid Upper Shaunavon Member unconformity could then be defined within the study area. The preliminary delineation of these reservoirs of the Upper Shaunavon Member within this study area (Townships 3 to 7, Ranges 19 to 21W3) could then be used in future studies as a model for other areas of southwestern Saskatchewan where the Upper Shaunavon Member is present and prospective for oil production.*

**Keywords:** *Jurassic, Shaunavon, Dollard, Eastend, Eastbrook, Rapdan, southwestern Saskatchewan, oil field trend, isopach map, structure map.*

## 1. Introduction

The Middle Jurassic Shaunavon Formation (Figure 1) has been a known oil producer in southwestern Saskatchewan since the early 1950s. Initial production came from the Delta field (Township 15, Range 19W3) in mid 1952, and was followed by a second producer in the Eastend field (Township 6, Range 20W3) later in the same year. Cumulative oil production from the Shaunavon Formation to the end of 2013 is approximately 65.2 million cubic metres (approximately 410.4 million barrels) from 3011 wells. Interest in the Shaunavon Formation, in particular the Lower Member, was renewed in recent years with the advancement of completion techniques; specifically, hydraulic fracturing. However, even with this recent interest in the low permeability reservoirs of the Lower Member, most of the production from the Shaunavon Formation in southwestern Saskatchewan is still limited to the highly complex reservoirs of the Upper Member. To the end of 2013, there have been 2622 wells drilled into, and that have at some point produced oil from, the highly heterogeneous Upper Shaunavon Member in the southwest of the province. Cumulative production from the Upper Member is in the order of 63.2 million cubic metres (397.6 million barrels) of oil since 1952, which accounts for 97% of the production from the entire formation. In the last two years alone there has been an increase in production of 2.6 million cubic metres (16.5 million barrels).

The primary focus of this paper is the distribution and thickness of four Upper Shaunavon Member reservoirs in and around the Dollard, Eastend, Eastbrook, and Rapdan pools (Figure 2). Also of interest in this paper is the regional unconformity that was initially identified in core, which underlies the uppermost two reservoirs. The current study area is limited to Townships 3 to 7, Ranges 19 to 21W3 (Figure 2), although it is recognized by the authors that various Upper Shaunavon Member reservoirs do extend throughout much of southwestern Saskatchewan, in the area south of the Shaunavon Formation subcrop edge.

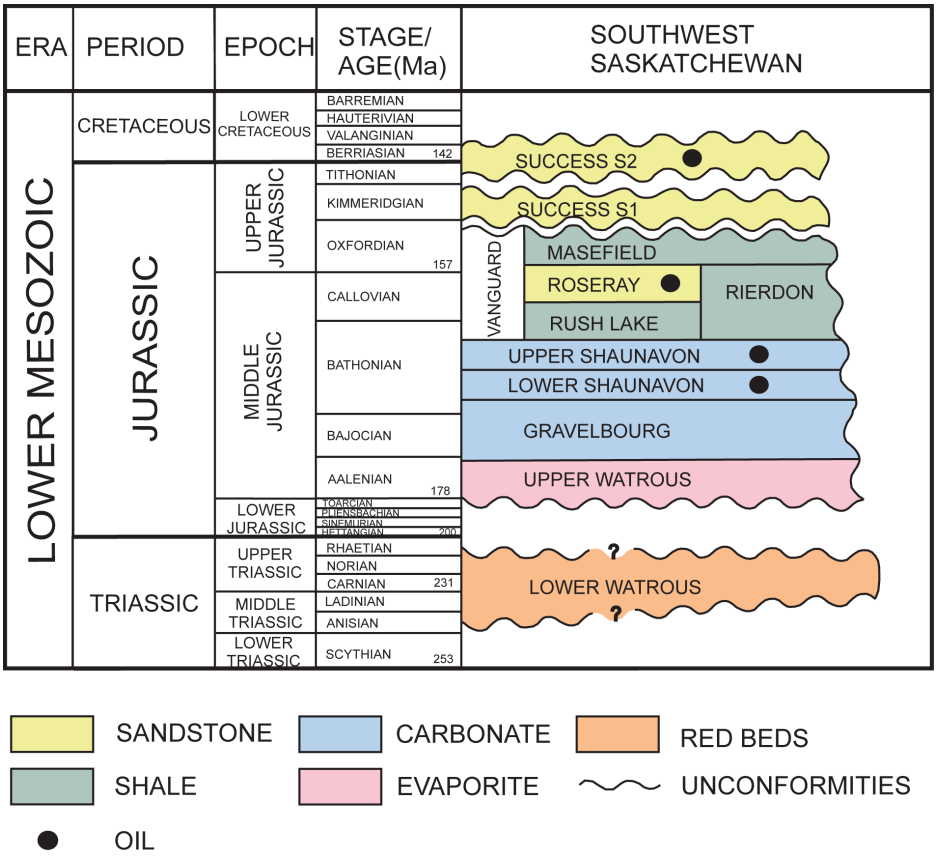


***Figure 1 – Stratigraphic chart showing the general stratigraphic relationship of the Upper Shaunavon Member with other Lower Mesozoic intervals in southwestern Saskatchewan* (modified from *Saskatchewan Ministry of the Economy, 2011). Erosional truncation of the Shaunavon Formation in southwestern Saskatchewan by the Lower Cretaceous sub-Cantuar unconformity (sub-Mannville Group) occurs north of the current study area, from Township 19 at the Alberta border to Township 25 at Range 17 west of the Third Meridian.***

## 2. Geological Framework and Study Area

The Shaunavon Formation is divided into two members: the Upper Member contains a mixture of clastic and carbonate sediments, and the Lower Member is a fairly homogeneous carbonate deposit. As a whole, the Shaunavon Formation is a highly heterogeneous stratigraphic interval that was deposited in warm shallow seas during the Middle Jurassic (Milner and Thomas, 1954; Francis, 1956). The heterogeneous layers within the Upper Shaunavon Member form sheet-like lenticular beds, separated typically by shales that were deposited on a low gradient monoclinal shelf (Christopher, 1964). These regional lenses are also often dissected by trough-like deposits that filled incised valley systems throughout the area (Christopher, 1964). In southwestern Saskatchewan, the oil fields that produce from the Shaunavon Formation are found along a north-northeast to south-southwest curvilinear trend that has been identified in the literature as the Shaunavon Linear or the Shaunavon Syncline (Christopher, 1984, 2003), which formed along the western flank of the northern extension of the Coburg Syncline from Montana (Milner and Blakslee, 1958). This linear trend of oil fields that extends from Townships 3 to 19, Ranges 16 to 21W3 is commonly identified as the Shaunavon oil field trend. For the purpose of this study, only the southernmost five townships (Townships 3 to 7) and three ranges (Ranges 19 to 21W3) of the Shaunavon oil field trend have been considered (Figure 2). This area includes wells from the Dollard, Eastend, Eastbrook, and Rapdan oil pools, in addition to wells from the area surrounding these pools. It should be noted that the Dollard pool contains the three most prolific Shaunavon Formation wells drilled in Saskatchewan to date (101/07-22-007-20W3/00; 55G093, 101/13-22-007-20W3/00; 54K075 and 101/13-23-007-20W3/00; 55B071), all of which were drilled in the mid 1950s, and all were perforated in the uppermost Upper Shaunavon Member reservoir that is to be discussed in this paper. These three wells have currently each produced over 800 thousand cubic metres (over 5.2 million barrels) of average 22° API gravity oil.

## 3. Methodology

The well data used in this paper are primarily derived from the study of core that are correlated to the geophysical well logs from each cored well. In wells that were not cored, correlations were made based on the suite of geophysical well logs that were available for each particular well. The dataset used to create the isopach maps of the Upper Shaunavon Member reservoirs, and the structure map of the unconformity underlying the uppermost two reservoirs (see figures in '*Discussion*'), contains 754 well points. Of the 754 wells, 110 were cored through at least part of the Upper Shaunavon Member, and that core was logged in detail as part of this study. All of the maps for this study were created using Golden Software's Surfer® 9 using the kriging algorithm with a 2000 m grid spacing.

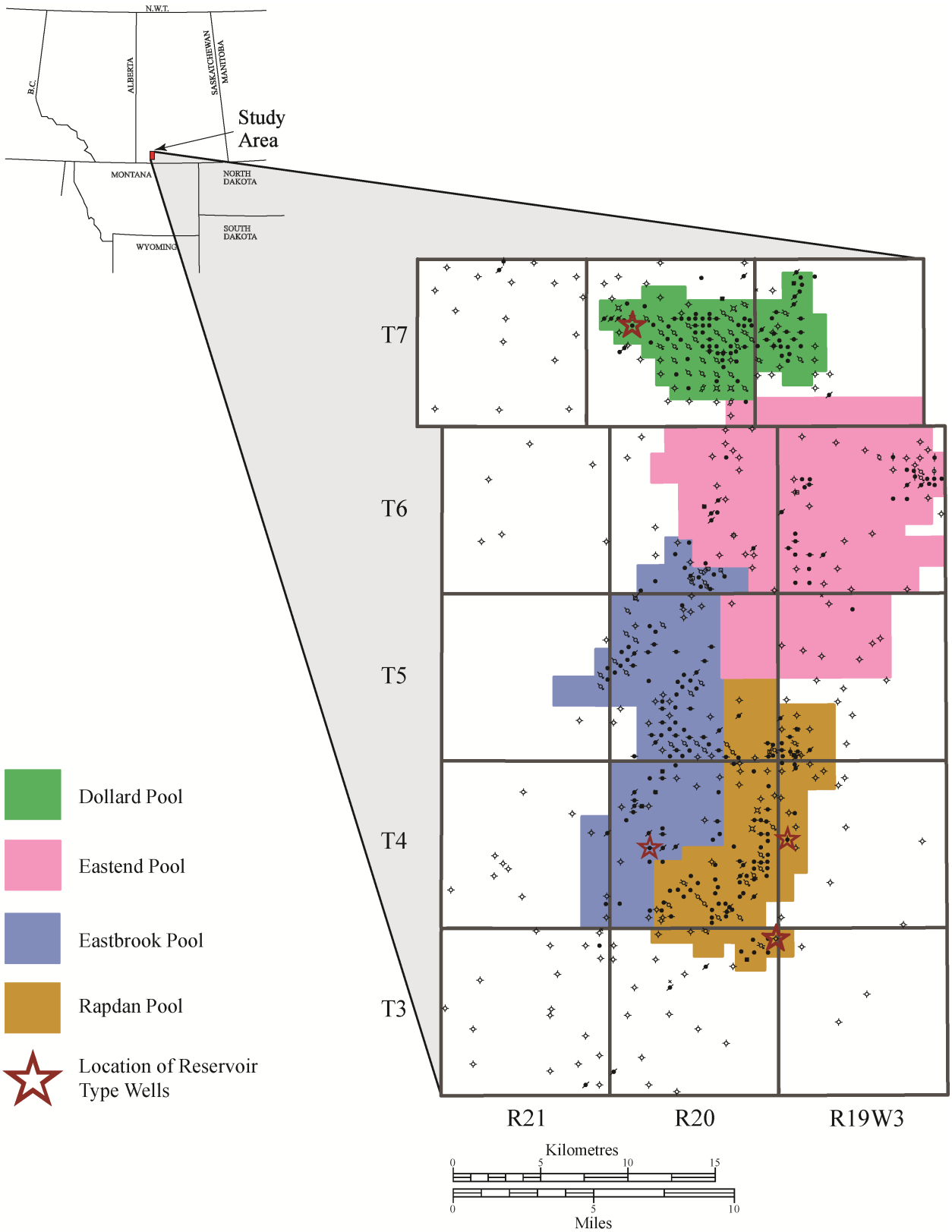


***Figure 2 – Top left: map showing the location of the study area within southwestern Saskatchewan; bottom right: a more detailed map of the study area showing the locations of all of the wells used for this paper, the pools within the study area, and the location of the 4 type wells (red stars) used to show the geophysical well log signatures for each of the reservoirs.***

## 4. Discussion

For the purpose of this study the authors have identified five Upper Shaunavon reservoirs present in the study area as reservoirs E, D, C, B, and A, in descending order (Figure 3). These five reservoirs vary greatly in both areal distribution and thickness, while lithologies of each of the reservoirs are similar. In general terms, each reservoir is composed of a mixture of carbonate and clastic material that typically becomes coarser towards the top of the Upper Shaunavon Member. For the purpose of this paper only four (E, D, C, and B) of the five reservoirs will be discussed. The fifth and lowermost reservoir (Reservoir A) directly overlies the Lower Shaunavon Member and requires further investigation. The characteristics and distribution of each of the four reservoirs studied are discussed in more detail below.

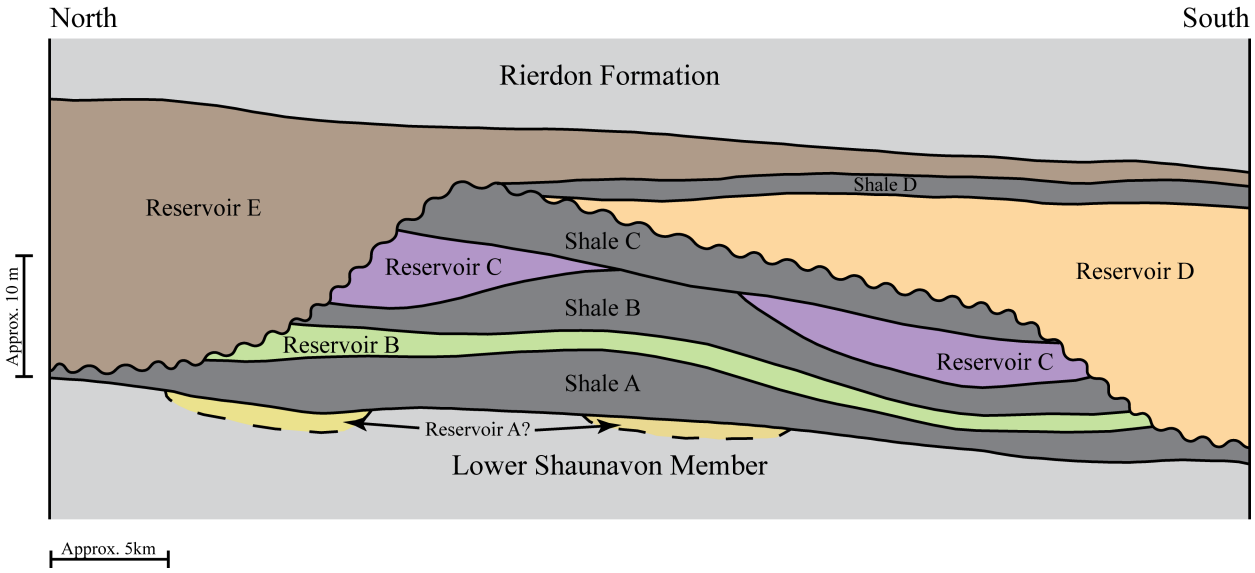


***Figure 3 – Schematic cross section from north to south showing the general relationships of each of the reservoirs studied, the shales confining each of the reservoirs, and the regional unconformity that underlies reservoirs E or D, which has been identified in core and correlated regionally using geophysical well logs. This unconformity surface was originally identified by Christopher in 1964 and was considered to be a surface that incised his unit $U_2$, and created accommodation space for his unit $U_3$.***

### a) Reservoirs E and D

A regional unconformity identified in core is present underlying Reservoir D in the Eastbrook and Rapdan pools and part of the Eastend pool, and Reservoir E in part of the Eastend pool and in the Dollard pool, where Reservoir D is absent (Figure 3). This unconformity and its paleotopographic expression appears to play a key role in the distribution and greatest thickness of both reservoirs D and E. This unconformity was defined by Christopher in 1964 as the paleotopographic surface separating his unit $U_2$ from his overlying unit $U_3$. The paleotopographic surface of the unconformity that underlies reservoirs D or E in the study area generally dips to the southeast. Approximately along strike of the surface of the unconformity are a series of several southeasterly plunging incised valley systems (Figure 4).

#### Reservoir E

Reservoir E is the most prolific Upper Shaunavon Member reservoir in the study area. To date, the best production from any Shaunavon Formation well is from this reservoir in the Dollard pool, which is also where this reservoir reaches its maximum thickness within the study area. In general, this reservoir varies from 0.5 to 20.1 m (Figure 5) with an average thickness of 3.6 m, and is present in 517 of the wells studied. Throughout the Dollard pool and in the Eastend pool where Reservoir E is productive, this reservoir is typically greater than 8 m thick (Figure 6) and is composed of massive to crossbedded sandstone units (Figure 7A) with fairly good porosity and permeability. These deposits are interpreted as incised valley fills associated with the regional unconformity. This interpretation is based on the identification in core of a pebble lag that is typically found immediately overlying the unconformity surface, as well as the relationship of Reservoir E to the underlying strata, particularly in the Dollard pool. Outside the Dollard and Eastend pools, Reservoir E is commonly present as a thin (less than 4 m) coquina (Figure 7B) or carbonate-cemented sandstone.

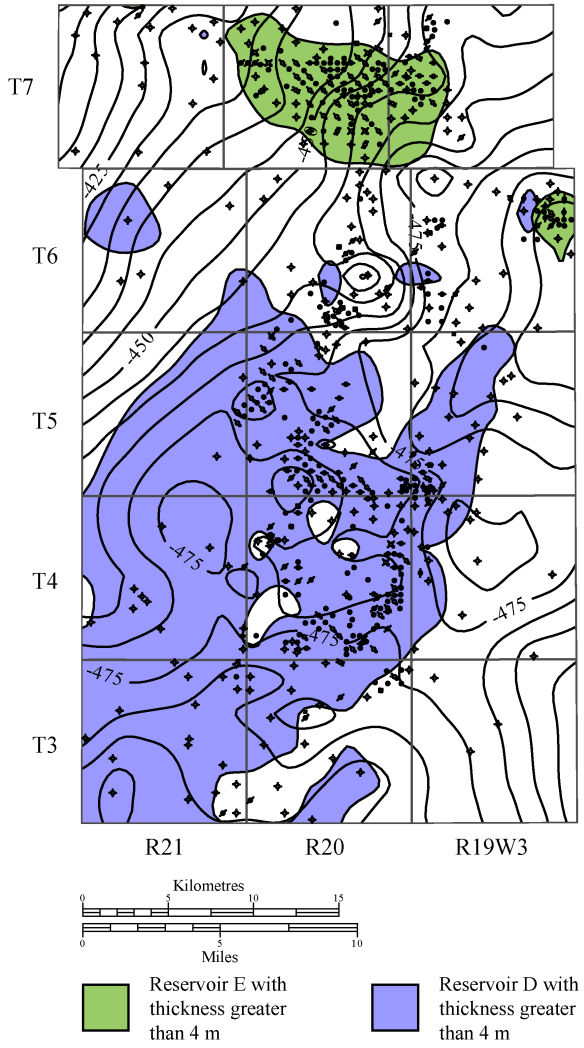


***Figure 4 – Structure map of the unconformity underlying reservoirs E or D. Also shown on the map is the distribution within the study area of where reservoirs E and D have thicknesses greater than 4 m. Contour interval is 5 m.***

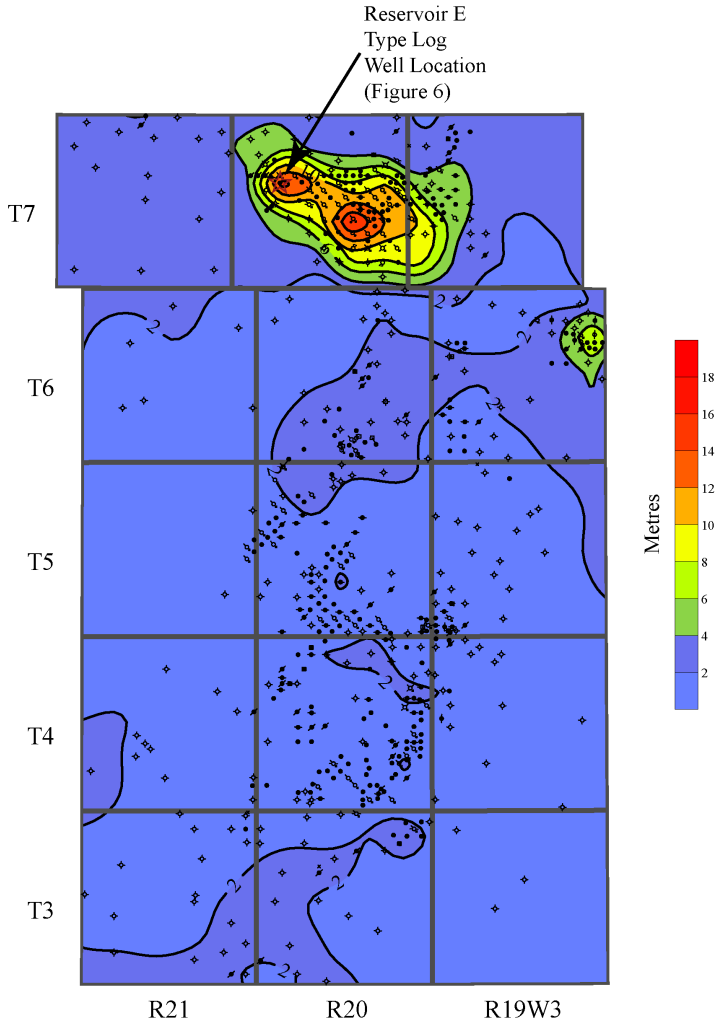


***Figure 5 – Isopach map of Reservoir E. The red star indicates the location of well 101/10-20-007-20W3/00; 96G206, the location of the type log for Reservoir E (Figure 6). Contour interval is 2 m.***

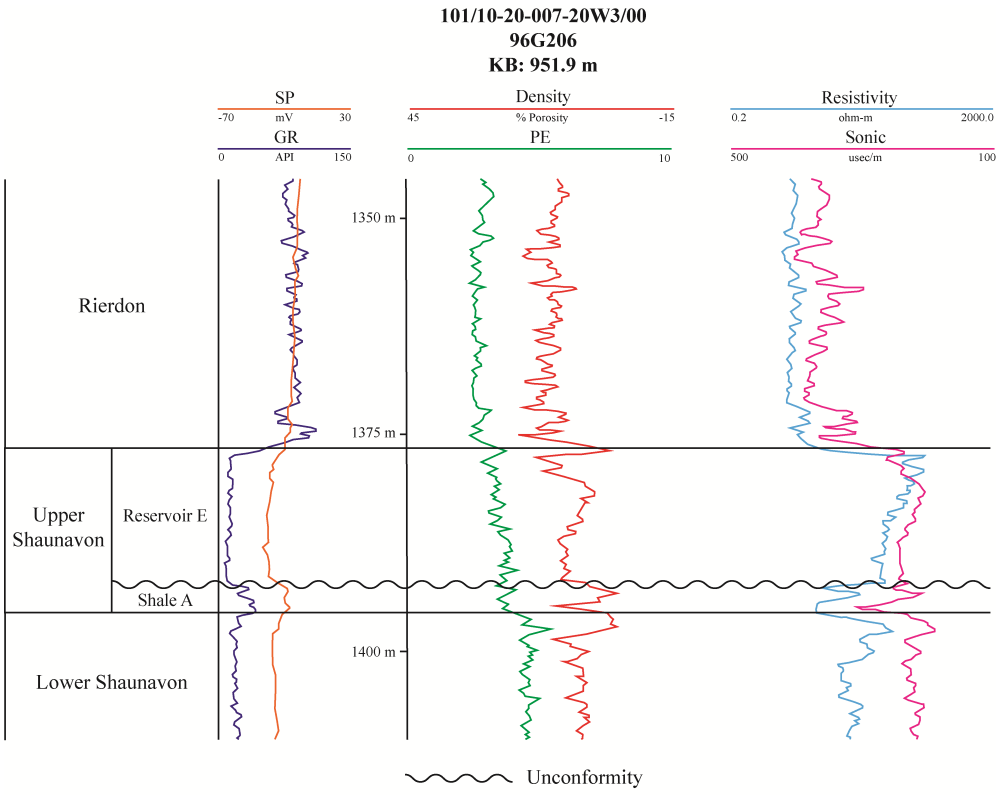


***Figure 6 – Geophysical type logs for Reservoir E from well 101/10-20-007-20W3/00; 96G206 in the Dollard pool. In this well the Upper Shaunavon Member has been deeply incised by the regional unconformity down to Shale A, which is the lowermost shale in the study area (Figure 3). Up to the end of 2013 this well has produced 7582 $m^3$ (47 712 bbl) of oil. KB= kelly bushing; SP = spontaneous potential; GR= gamma ray; PE= photoelectric effect.***

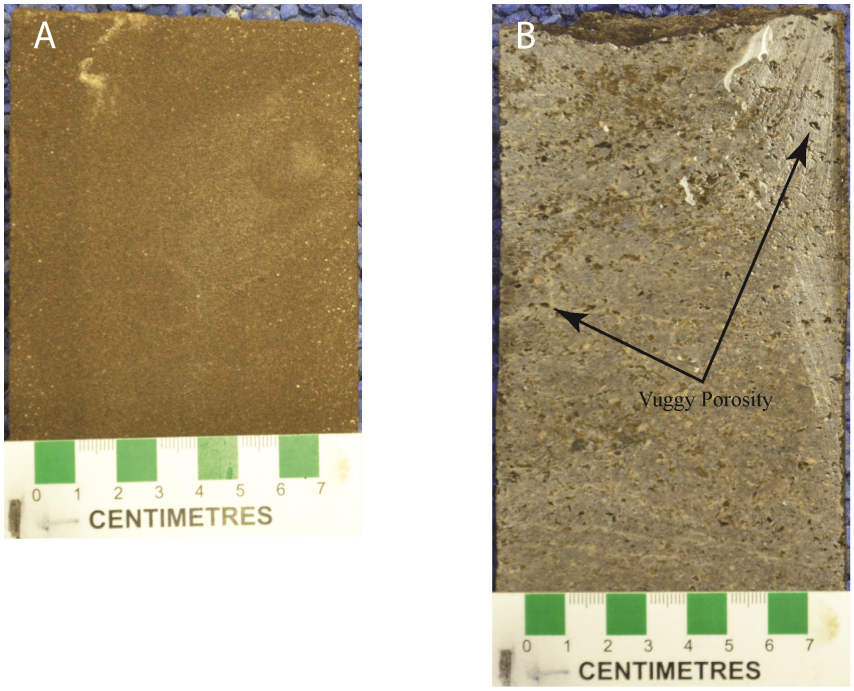


***Figure 7 – Core photographs of Reservoir E lithologies: A) moderately oil-stained massive sandstone from well 111/09-18-007-19W3/00; 72F077 at a depth of 1409 m; B) weakly oil-stained coquina with interparticulate and vuggy porosity from well 141/05-19-007-19W3/00; 71J027 at a depth of 1391 m.***

**Reservoir D**

Reservoir D is common throughout much of the southern two-thirds of the study area (Figures 3, 8, and 9), and is the main reservoir within the Eastbrook and Rapdan pools (Figure 2). Reservoir D is also present in the Eastend pool, but is typically less than 4 m thick (Figure 8). The thickness of Reservoir D within the pools in the study area generally ranges from 2 to 18 m. This reservoir varies lithologically from a laminated to crossbedded bioturbated sandstone (Figure 10A) to a coquina (Figure 10B). However, in the Dollard pool, Reservoir D is absent due to erosion and is replaced by an over-thickened Reservoir E. The thickness of Reservoir D within the study area varies from 0.7 to 18.6 m, with an average thickness of 5.6 m, and is present within 411 of the wells studied. Production from Reservoir D is more commonly found as deposits preserved within embayments that are somewhat parallel to the strike of, as well as infilling incisions on, the regional unconformity surface. Except within the Dollard pool, Reservoir D directly overlies the regional mid Upper Shaunavon Member unconformity. The basal few centimetres of Reservoir D outside of the Dollard pool is marked by a pebble lag.

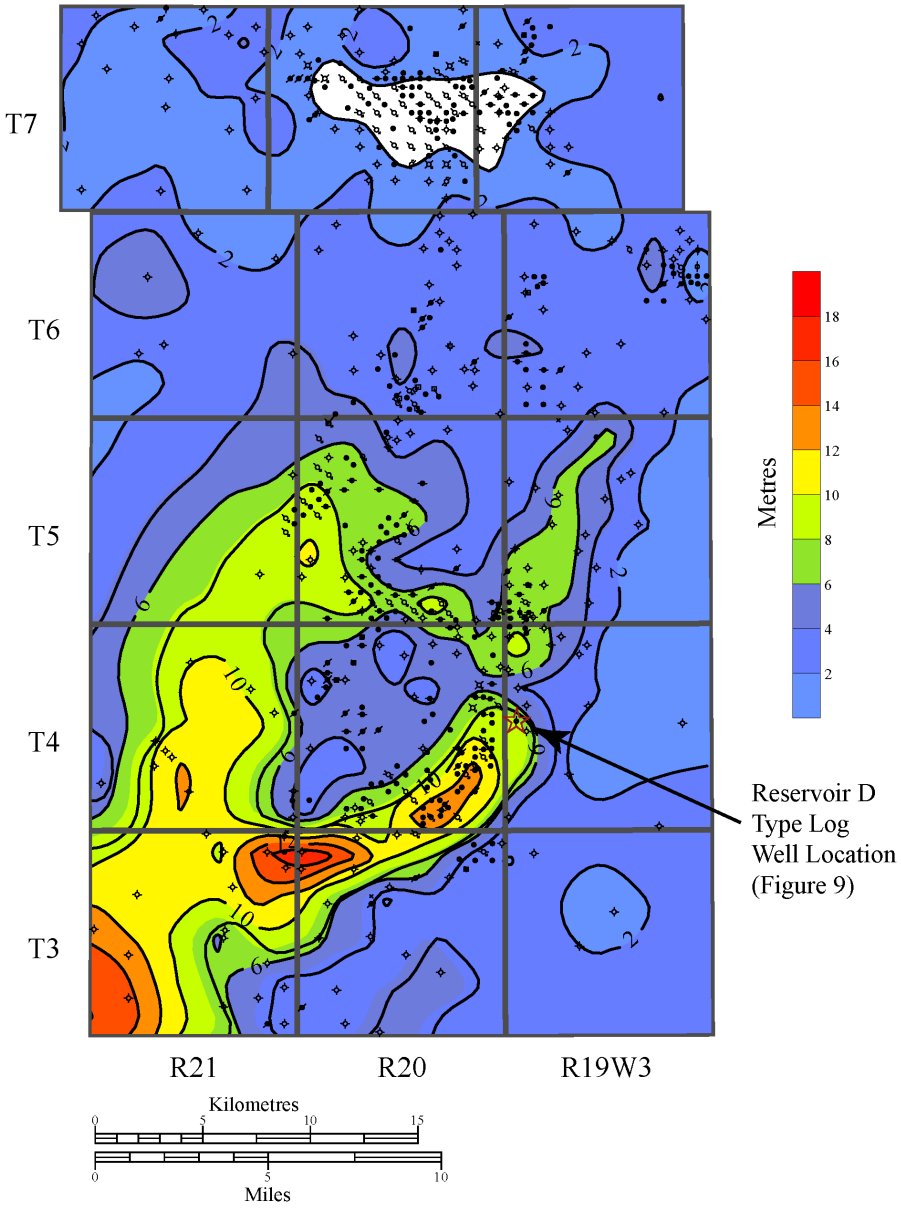


***Figure 8 – Isopach map of Reservoir D. It should be noted that Reservoir D is absent in the Dollard pool due to erosion. Typically where Reservoir D is not present, it has been replaced by Reservoir E. The red star indicates the location of well 131/03-19-004-19W3/00; 97A222, the location of the type log for Reservoir D (Figure 9). Contour interval is 2 m.***

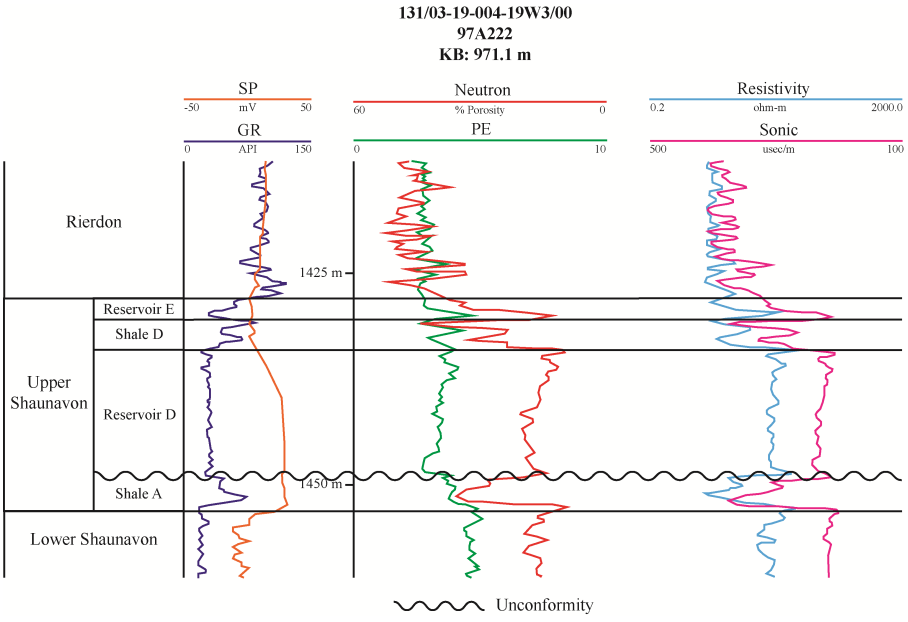


***Figure 9 – Geophysical type logs for Reservoir D from well 131/03-19-004-19W3/00; 97A222 in the Rapdan pool. In this well Reservoir E is present, but is much thinner (1.2 m) than in well 101/10-20-007-20W3/00; 96G206 (Figure 6). Reservoir D in this well is seen filling the incision created by the regional unconformity, which in this location is directly underlying Reservoir D. Similar to the well in Figure 6, the incised surface has once again cut down through most of the Upper Shaunavon Member sediments to Shale A. It should be noted that this well has been perforated from 1440 to 1444 m; however, the well is suspended and is yet to go on production. KB= kelly bushing; SP = spontaneous potential; GR= gamma ray; PE= photoelectric effect.***

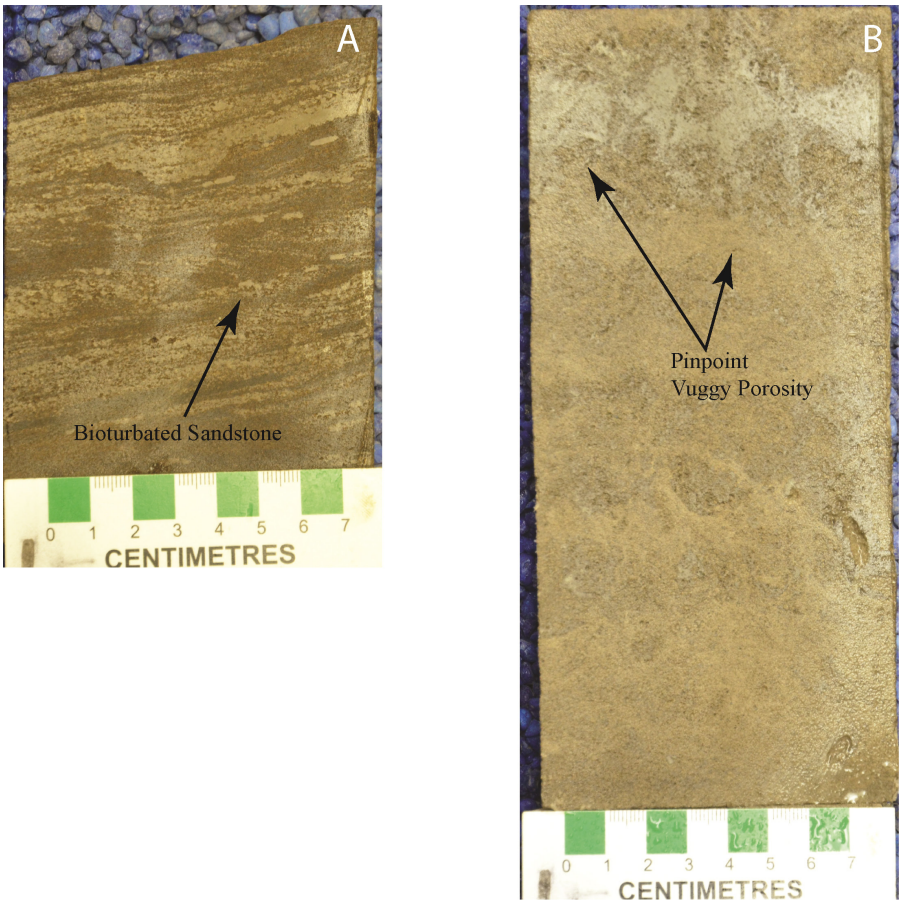


***Figure 10 – Core photographs of Reservoir D lithologies: A) moderately oil-stained, crossbedded, moderately bioturbated sandstone from well 101/06-13-004-20W3/00; 76H012 at a depth of 1409.5 m; B) weakly oil-stained, bioturbated coquina with pinpoint vuggy porosity from well 101/08-05-005-20W3/00; 79E110 at a depth of 1423 m.***

## b) Reservoirs C and B

Below the mid Upper Shaunavon Member unconformity in the study area are the lower three Upper Shaunavon reservoirs (C, B, and A), which are less productive and generally thinner in this area than reservoirs E and D. The lowermost reservoir (Reservoir A) requires further investigation and has not been included in this paper.

### Reservoir C

Reservoir C is present as a thin veneer (typically less than 2 m) throughout most of the east and north of the study area, with its thickest point being west of Dollard in the northwest corner of the study area (Figures 11 and 12). The lithology of Reservoir C is typically a coquina with vuggy to moldic porosity (Figure 13). Reservoir C is absent in areas where reservoirs E or D are at their thickest. This absence of Reservoir C is due to the incision of the regional unconformity, which also created accommodation space for reservoirs E and/or D. The thickness of Reservoir C varies from 0.4 to 6.7 m, with an average of 1.7 m and the reservoir is present within 297 wells in the study area.

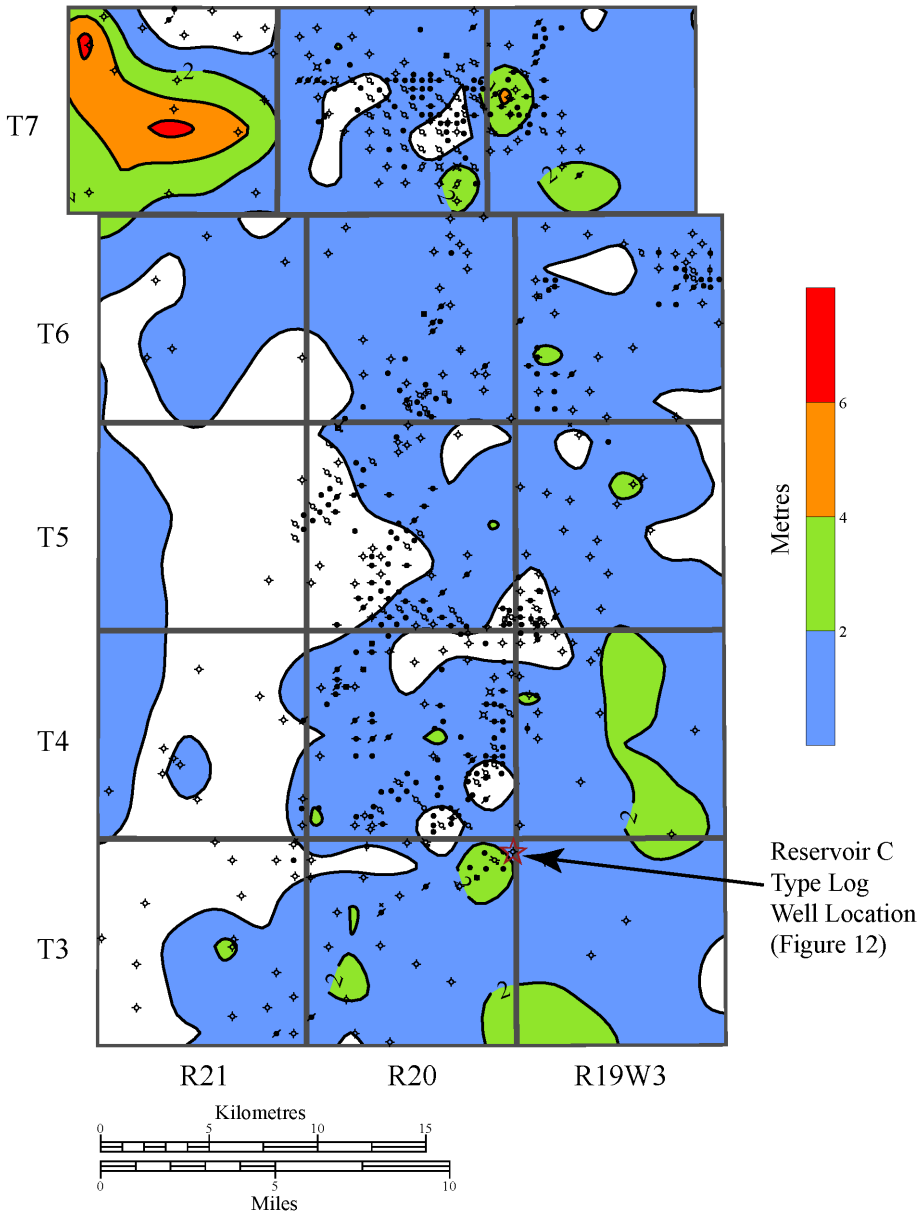


***Figure 11 – Isopach map of Reservoir C. The red star indicates the location of well 101/09-36-003-20W3/00; 67G117, the location of the type log for Reservoir C (Figure 12). Contour interval is 2 m.***

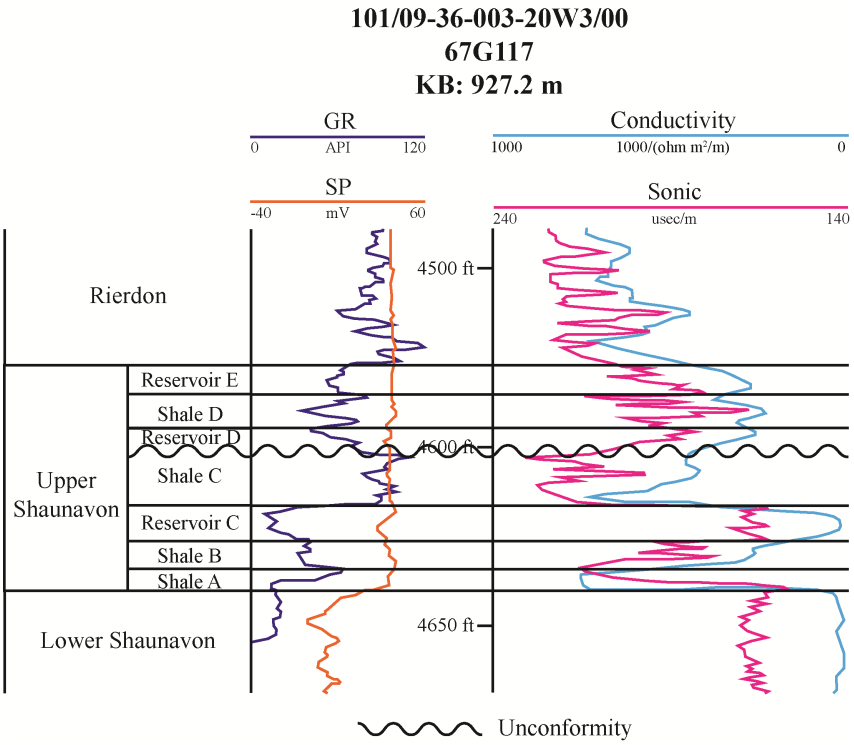


***Figure 12 – Geophysical type logs for Reservoir C from well 101/09-36-003-20W3/00; 67G117 in the Rapdan pool. The stratigraphy of the Upper Shaunavon Member is highly complex throughout southwestern Saskatchewan. The geophysical well log signatures for the Upper Shaunavon Member in this well are far more typical than those seen in the previous two examples (Figures 6 and 9) with both the log signatures and thickness (3.1 m) fairly typical of Reservoir C. This well had a drill stem test run from 1401.5 to 1417.3 m at the time it was drilled and returned 97.6 m of oil-cut mud and 39.7 m of oil-cut, saltwater-cut mud. The neighbouring well (101/10-36-003-20W3/00; 85E345) has produced 5705 $m^3$ (35 899 bbl) of oil to the end of 2013 from perforations that straddle reservoirs C and B. KB= kelly bushing; GR= gamma ray; SP= spontaneous potential.***

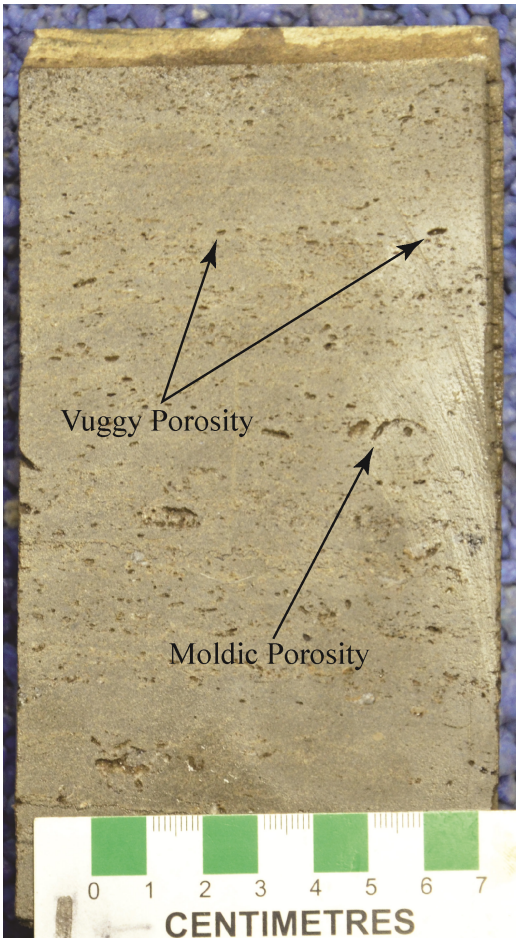


***Figure 13 – Core photograph of a Reservoir C coquina with vuggy and moldic porosity from well 101/14-06-004-20W3/00; 85E472 at a depth of 1397 m.***

**Reservoir B**

Reservoir B is present throughout most of the study area and is absent due to erosion only in the far southwest of the area, as well as in a few wells in the Dollard pool. However, similar to Reservoir C, Reservoir B thins to less than 3 m where it has been incised by the regional unconformity (Figures 14 and 15). Reservoir B is also lithologically similar to Reservoir C, as it is typically identified as a coquina with vuggy porosity (Figure 16). In some situations the lithological similarities of Reservoir B to Reservoir C make it difficult to accurately identify each of the reservoirs in core. Often, using the geophysical well log signatures and the relationship of these reservoirs to the shales by which they are confined is a more reliable method of identifying each of these reservoirs within a well. Reservoir B, which is present in 463 of the studied wells, varies from 0.5 to 5.2 m, with an average thickness of 1.8 m.

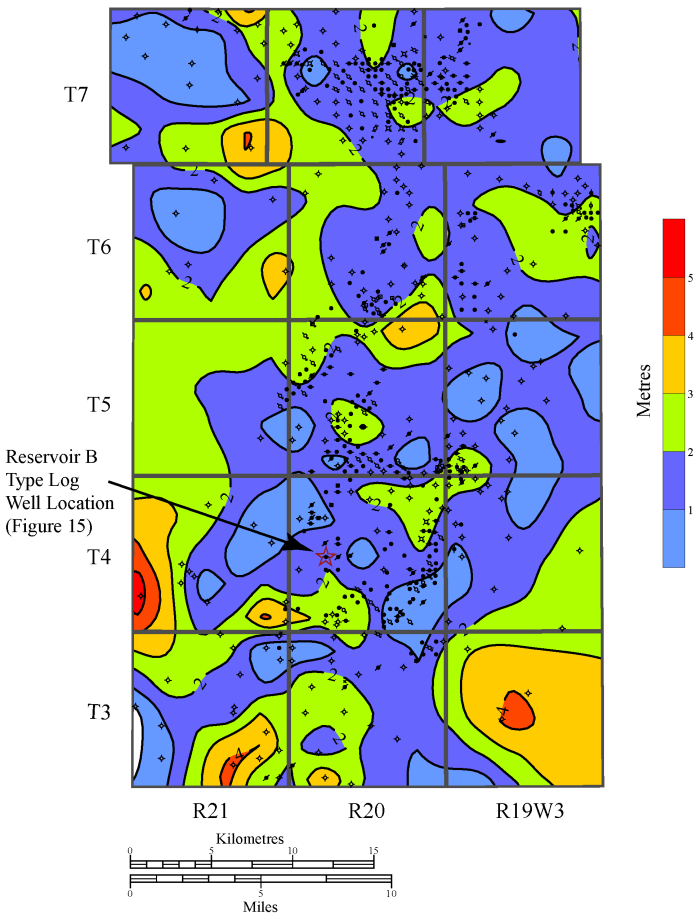


*Figure 14 – Isopach map of Reservoir B. The red star indicates the location of well 150/14-17-004-20W3/00; 84I123, the location of the type log for Reservoir B (Figure 15). Contour interval is 1 m.*

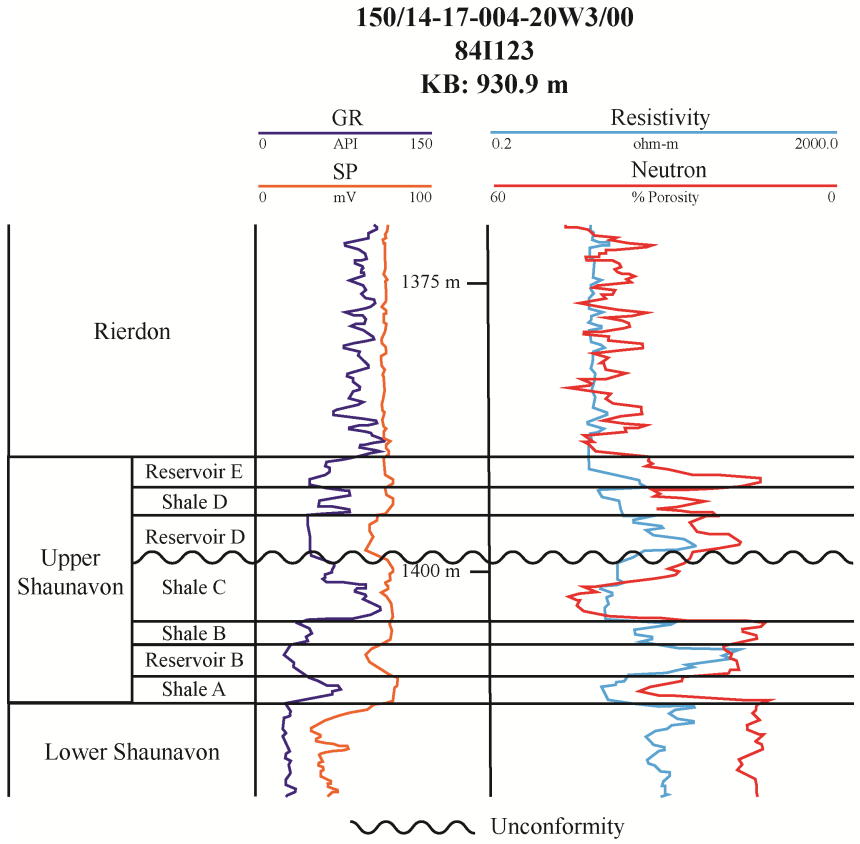


*Figure 15 – Geophysical type logs for Reservoir B from well 150/14-17-004-20W3/00; 84I123 in the Eastbrook pool. Similar to Figure 12, the geophysical well log signature for the Upper Shaunavon Member is fairly typical, as are the signature and thickness (2.5 m) for Reservoir B throughout much of the study area. This well is currently suspended, but from the time it was completed in November 1984 until March 2008 it produced 4107.4 $m^3$ (25 847.3 bbl) of oil. KB= kelly bushing; GR= gamma ray; SP= spontaneous potential.*


***Figure 16 – Core photograph of a coquina with vuggy porosity from Reservoir B in well 131/14-09-005-20W3/00; 85A260 at a depth of 1435 m.***

## 5. Summary

Oil production from the four Upper Shaunavon Member pools (Dollard, Eastend, Eastbrook, and Rapdan) of the southern Shaunavon oil field trend in southwestern Saskatchewan is primarily from two reservoirs (reservoirs E and D). The thickness of these reservoirs varies depending on the accommodation space created by erosional events that formed the underlying unconformity surface. In a handful of wells within the study area, oil production can be attributed to two thinner reservoirs (reservoirs C and B) that underlie the unconformity. The basal Upper Shaunavon Member reservoir (Reservoir A) within the study area directly overlies the Lower Shaunavon Member and requires further investigation in order to define it effectively.

Further studies to delineate the Upper Shaunavon Member reservoirs to the north along the Shaunavon oil field trend within known pools will be useful. However, based on the on-trend reservoir distribution, a key to further development of the Upper Shaunavon will be to investigate areas to the west of the main oil field trend.

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