Integrated geological reservoir characterization of the Cardium Wapiti Halo Play, Alberta

John-Paul Zonneveld[1,2], Barbara Rypien[2], Eric Keyser[2], and Darren Tisdale[2]

[1]Ichnology Research Group, Department of Earth & Atmospheric Sciences, University of Alberta, Edmonton, Alberta, Canada, T6G2E3

[2]Modern resources Inc., Suite 200, 110 – 8th Avenue SW, Calgary, Alberta, Canada, T2P 1B3

Summary

The Cardium Formation was deposited on the eastern margin of the rising Canadian Cordillera during the Late Cretaceous (Turonian to Coniacian). It is one of the most prolific producers of liquid hydrocarbons in western Canada. Between the 1970's and 1990s this unit was the focus of extensive vertical well development (eg. Krause et al., 1994; Hart and Plint, 2003). The last few years have seen a resurgence of interest in this unit as a horizontal drilling target (eg. Baranova and Mustaqeem, 2011; Kuntz et al., 2012; Pedersen et al., 2013; Grey and Cheadle, 2016.Rojas-Aldana, 2016). Recent exploration has targeted the 'halo'; the tighter, but still hydrocarbon-bearing lithologies on the periphery of older conventional legacy plays. Although typically characterized by lower porosities and permeabilities than legacy pools, the halo plays commonly extend the size of the original reservoir by an order of magnitude or more. In these plays an understanding of lateral changes in reservoir parameters (porosity, permeability, mineralogy of grains and cements) is essential for successful well development and stimulation.

The Wapiti pool occurs at the northwestern limit of Cardium deposition (Krause et al., 1990; Deutsch, 1992). Exploration in the Wapiti Cardium halo play is currently focused on the main Cardium Sandstone (Kakwa Member) although historically both the Kakwa Member sandstone and Cardium zone sandstone and conglomerate have formed exploration targets. The Wapiti Halo play has an estimated 500,000,000 Barrels, with >10% recoverable at current proposed well spacing. It is thicker and has a much lower proportion of interspersed and interbedded clay /mudstone than the more well known Cardium Halo play at Pembina (eg. Kuntz et al., 2012; Pedersen et al., 2013; Grey and Cheadle, 2016.Rojas-Aldana, 2016). The Cardium at Wapiti forms a deep basin hydrocarbon trap with downdip hydrocarbon-bearing strata segueing towards the east into updip water-filled strata (Murray et al., 1994).

The Cardium Sandstone in the study area was deposited in a prograding strandplain setting resulting in an approximately continuous sheet of sandstone, 6 to 14 metres thick, on the western side of the legacy pool. The Wapiti Halo light oil play (40-42 API) comprises a NW-SE trend encircling the legacy play. It is approximately 15 kms by 35 kms, similar in areal extent, thickness and grain size to the classic Nayarit strandplain on the Pacific coast of Mexico (Curray, et al., 1964; Curray, 1969).

Throughout the halo play the sandstone unit can be subdivided into upper and lower subunits, with distinct lithological and reservoir characteristics. The lower unit comprises a variably sideritic, hummocky cross-stratified, very fine-grained sandstone characterized by median porosities of 5-9% and permeabilities of ~0.1 to 0.25 millidarcies. The upper sandstone unit comprises a cryptically bioturbated, planar to trough cross-stratified fine to medium-grained sandstone characterized by median porosities of 6 to 10% and permeabilities ranging between 0.3 and 12 millidarcies.

Rather than two distinct stratigraphic units separated by a regional unconformity as has been previously proposed (the E3 surface of Hart and Plint, 1993), the lower and upper Ram Members in the study area are interpreted as facies end-members within a single depositional system. Although the transition is commonly abrupt, the two facies interfinger near their contact in many wells. Sharp contacts, interpreted as wave-induced ravinement surfaces, subdivide the Cardium succession into a series of

offlapping sandstone-dominated shingles. These ravinement surfaces record major storm events and associated erosion. The Kakwa Member of the Cardium Formation at Wapiti records an interval of overall rapid basinward progradation punctuated by periodic 'back-steps' during intervals of increased storm intensity.

In addition to clearly distinct grain sizes, the lower, finer-grained unit abundant siderite (4-16%), localized rhodochrosite (0-7%) and organic material (phytodetritus), all of which are absent to rare in the coarser-grained upper unit. The siderite occurs as reworked, sand-sized sideritic clasts, siderite-coated sand grains and sideritic cements in layers, lenses and laminae. Decreased grain size and the presence of authigenic siderite and rhodochrosite have resulted in slightly lower porosity and significantly lower (but more consistent) permeability in the lower unit. These minerals formed via early (syndepositional) precipitation due to degradation of phytodetritus, concomitant release of carbonate ions, and formation of reducing conditions just below the sediment-water interface (eg. Griffith,1980; Machemer and Hutcheon, 1988; Zymela, 996).

Both the finer-grained lower Kakwa Member and the coarser-grained upper Kakwa Member contribute to the Cardium reservoir in the study area. Although permeabilities are lower in the basal 30-40% of the member, porosities are similar and both form integral components of the Wapiti 'tank'. Economic exploitation of this resource requires an accurate seismic depth data set for the placement of horizontal wells. The seismic velocity model has proven accurate to within two meters for a target at 1200-1500 meters, providing enough confidence to steer the bit either up or down when the well pops out of zone. Fracing programs developed for horizontal wells in the Wapiti Cardium sandstone need to access both components to effectively drain the hydrocarbons

Acknowledgements

We are grateful to the contriubutions of Francois Legault and the entire Modern Resources team for their contributions to this truly collaborative project.

References

Baranova, C. and Mustaqeem, A. 2011. Unraveling Cardium tight sand paleo-depositional trends and subtle structural features using seismic reservoir characterization. Recovery- 2011 CSPG CSEG CWLS Convention, 3p.

Curray, J.R. 1969. Holocene history of a strandplain, lagoonal coast, Nayareit, Mexico. Lagunas Costeras, Un Simpposi. Mem. Simp. Intern. Lagunas Costeras, UNAM-UNESCO, 1967, p .p. 63-100.

Curray, J.R., Moore, D.G., Asgaard, K. (1964). Holocene regressive littoral sand, Costa de Nayarit, Mexico, in: Van Straaten, L.M.J.U. Deltaic and shallow marine deposits: Proceedings of the 6th International Sedimentological Congress The Netherlands and Belgium - 1963. Developments in Sedimentology, 1: pp. 76-82.

Deutsch, K.B. 1992. Sedimentology and stratigraphy of the Cretaceous Cardium Formation, Kakwa region, west-central Alberta. Unpublished M.Sc. thesis, University of Calgary 300p.

Griffith, L.A. 1980. Siderite textures in Cardium Formation, Ferrier Field, Alberta. AAPG Bulletin 64: 714-715.

Grey, K.E. and Cheadle, B.A. 2016. Stratigraphically-constrained variations in poroelastic properties in the Pembina Cardium Halo tight oil play: facies, fractures and fundamentals. Canadian Society of Petroleum Geologists International Core Conference. 172-176

Hart, B.S and Plint, A. G. 1993. Origin of an erosion surface in shoreface sandstones of the Kakwa Member (Upper Cretaceous Cardium Formation, Canada): importance for reconstruction of stratal geometry and depositional history. International Association of Sedimentologists Special Publication 18: 451-467.

Hart, B.S and Plint, A. G. 2003. Stratigraphy and sedimentology of shoreface and fluvial conglomerates: insights from the Cardium Formation in NW Alberta and adjacent British Columbia. Bulletin of Canadian Petroleum Geology 451: 437-464.

Krause, FF., Deutsch, K.B., Joiner, S.D., Barclay, J.E., Hall, R.I. and Hills, L.V. 1994. Cretaceous Cardium Formation of the Western Canada Sedimentary Basin. In Mossop, G. and Shetsen, I. (eds.) Atlas of the Western Canada Sedimentary Basin, Calgary, Canadian Society of Petroleum Geologists, Alberta Research Council, Geological Survey of Canada, pp. 375-385.

Kuntz, B., Pedersen, P.K. and Spila, M. 2012. Reservoir characterization of the Cardium Formation in the Carrot Creek Area, Geoconvention 2012, Calgary, 2p.

Machemer, S.D. and Hutcheon, I. 1988. Geochemistry of Early carbonate cements in the Cardium Formation, central Alberta. Journal of Sedimentary Petrology 58: 136-147.

Murray, C., Ehrlich, R., Mason, E. and Clark, R. 1994. Evaluation of the diagenetic and structural influences on hydrocarbon entrapment in the Cardium Formation, Deep Basin, western Alberta. Bulletin of Canadian Petroleum Geology 42: 529-544.

Pedersen, P.K., Fic, J.D. and Fraser, A. 2013. Integrated geological reservoir characterization of the Cardium Light Tight Oil Play, Pembina Field in Alberta. Unconventional Resources Technology Conference, p. 807-813.

Rojas-Aldana, C, Krause, F.F., Meyer, R.O., DeBuhr, C., and Rojas-Aldana, A. 2016. Beyond the limits of the Pembina Oil Field – Cardium Formation Reservoir, Brazeau Area: A study of the geological characteristics of a highly heterogeneous rock formation. Permeability (Plug and Pdpk), geochemistry, cementation, diagenesis, XRF, XRD and E-FEG-SEM analyses, Canadian Society of Petroleum Geologists International Core Conference. 177-180.

Zymela, S. 1996. Carbon, Oxygen and Strontium isotopic composition of diagenetic calcite and siderite from the Upper Cretaceous Cardium Formation of Western Alberta. Unpublished Ph.D. Dissertation, McMaster University, 151p.

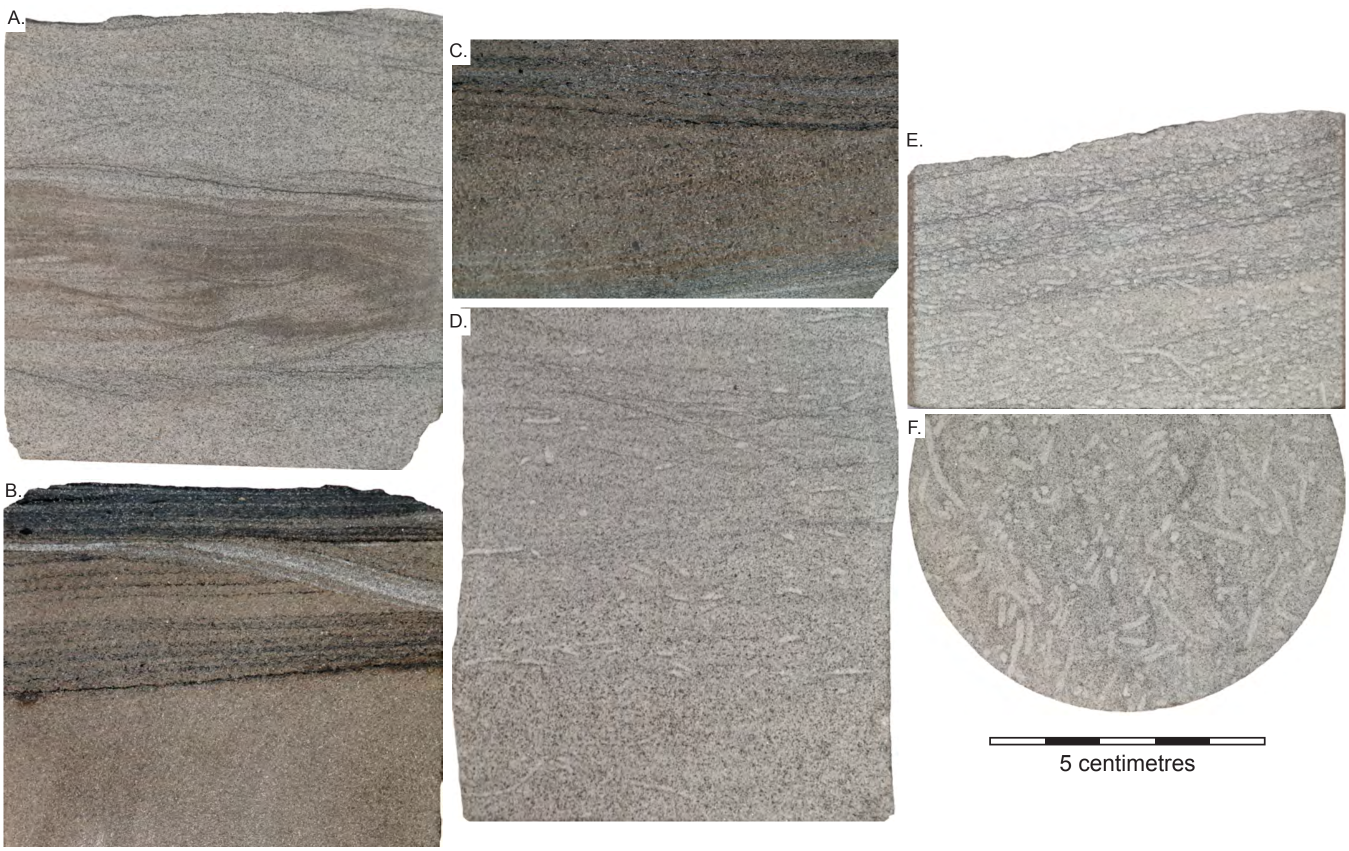
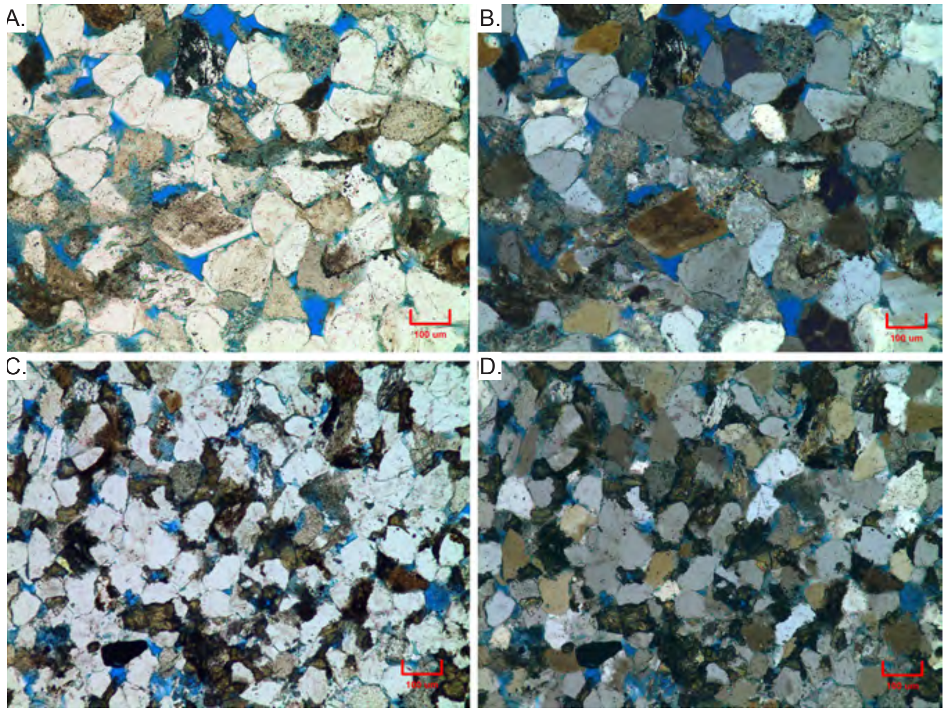


Figure 1. Core images from the Kakwa Member, Cardium Formation, Wapiti Field Alberta. A-C. Sideritic, current rippled and hummocky cross-stratified sandstone. Note the abundant disseminated phytodetritus in B and C. This material is accompanied by abundant muscovite flakes. The siderite in A occurs as siderite cement in a rippled horizon. The siderite in B and C includes detrital siderite clasts, siderite-coated sand grains and authigenic siderite cement. D-F. Bioturbated trough and planar cross-stratified fine-grained sandstone. The bioturbation in these images consists of a monotypic assemblage of *Macaronichnus segregatus*.

Figure 2. Thin section images from well 100-07-09-066-11W6 illustrating porosity distribution, mineralogy and grain size in the lower and upper Kakwa Member. A, B Fine-grained sandstone from the upper Kakwa Member (1518.4m) under normal light (A) and crossed polarizers (B). C,D. Very fine-grained sandstone from the lower Kakwa Member (1526.1m) under normal light (C) and crossed polarizers (D).



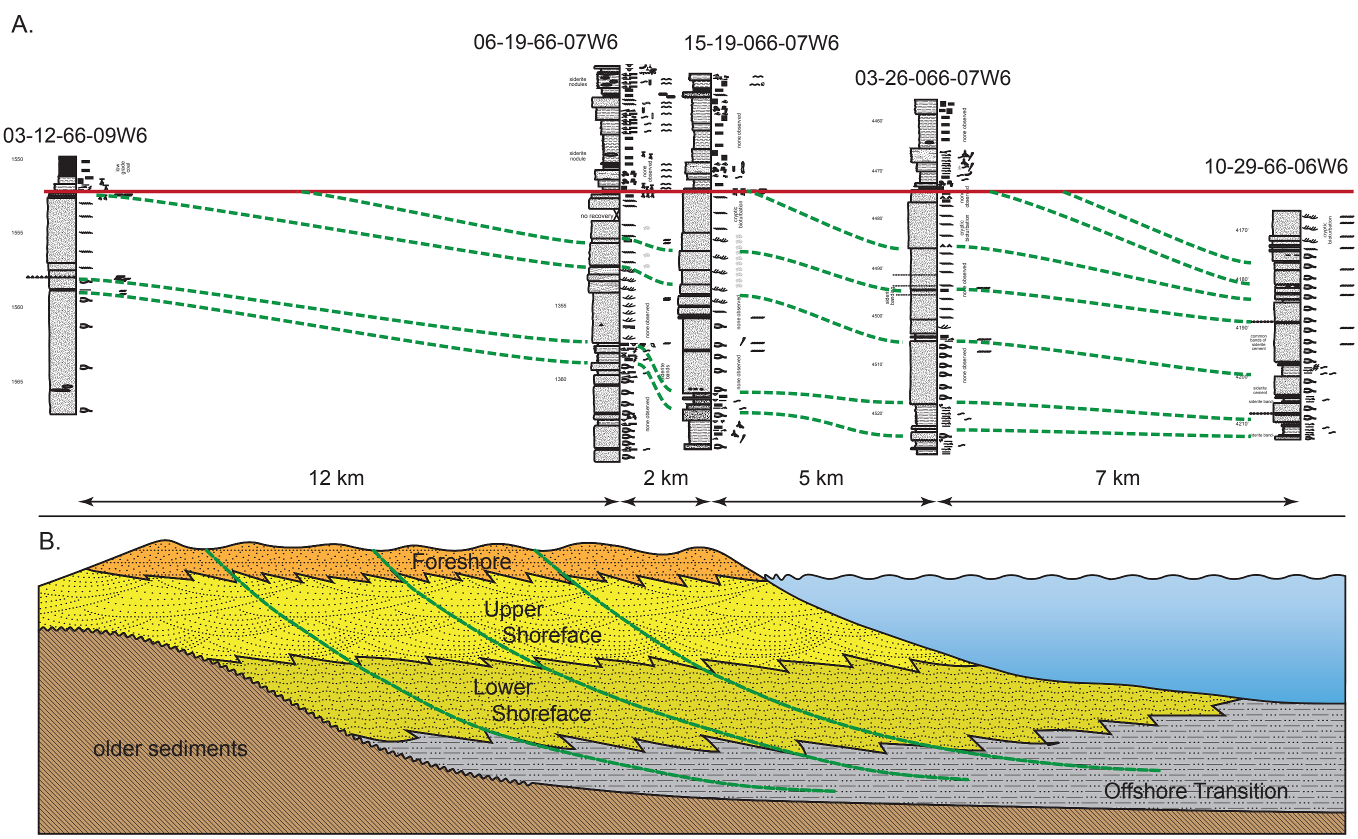


Figure 3. A. Dip-oriented core-based cross-section through the centre part of the Wapiti pool showing the architecture of the Kakwa Member (Cardium Sandstone) in the study area. The dashed green lines denote erosional surfaces interpreted as storm-induced ravinement surfaces. B. Schematic model of the Cardium strandplain shoreface succession at Wapiti.