Drill Bits

Cardium – Still Sexy at 70!

BMO Capital Markets – Energy – A&D Advisory

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The Cardium is estimated to contain over 12 billion barrels of original oil in place.

- First vertical well produced in 1953 in Pembina and is still producing at ~10 bbl/d
  - Since 1953, ~19,500 wells drilled

- Vertical infill drilling, unitization and waterfloods were implemented in the mid 1960s with further infill drilling during 1970s/80s/90s

- As horizontal drilling became more commercial in the late 2000s, operators shifted focus to halo areas of the Cardium, which spurred significant production growth in the play, and has added a further 1 to 3 billion barrels of OOIP

- Activity slowed in 2015 due to commodity price downturn but increased again in 2017-2018

- Current production is ~200 Mboe/d of which 38% is oil, and post 2008 wells account for ~80%

- Cumulative production includes 2.1 Bbbl of oil and 8.8 Tcf of gas; in addition 2.9 Bbbl of water has been produced while 5.2 Bbbl of water has been injected

Long history of development stretching back to the early 1950s
Several development phases have kept the Cardium contributing over ~70 years
At YE 2008, recovered liquids totalled 1.7 Bbbl, almost 100% from vertical wells. Since then, an additional 0.3 Bbbl was produced, mostly (76%) from horizontal wells.
By 2009, 6 Tcf of gas was recovered, which represents 33% of total produced hydrocarbons. Since then, gas production increased by over 40%, recovering an additional 2.8 Tcf.
This Drill Bit examines four areas which have distinct geologic features that make them unique. This uniqueness is derived from the depositional history of the Cardium Formation which evolved over time in response to rising and falling sea levels and changing sediment sources and volumes. Comprised of six upward-coarsening cycles capped by erosional surfaces, the Cardium shoreline trends northwest-southeast and migrated eastward. Nomenclature of the strata is complex with two of the key areas and members shown schematically. Sedimentological features identified within the formation indicate that accumulation took place in muddy and sandy inner and outer shelf, shoreface, lagoon, tidal, estuarine and coastal plain settings.

The deposits alternated between coarse and fine-grained stages that were controlled by estuarine and lagoonal settings to conventional shorelines. Other depositional features in this play include delta avulsion, compaction-driven subsidence, tectonically driven subsidence, tectonically controlled sediment sources, and tectonic and eustatically controlled changes in sea level. These processes contributed to the development of a complex sedimentary mosaic containing varied and abundant stratigraphic traps and reservoirs. Hydrocarbons stored in these reservoirs appear to have been derived from organic-rich Colorado Group shales and are typically light and sweet. Reservoirs are at drilling depths ranging between 1,200 and 2,700 m.
STUDY AREAS

**WAPITI, KAYBOB, SUNDANCE & ANDERSON**
- Deep Basin Cardium has characteristically low permeability and is pervasively gas-saturated; operators have historically targeted oil pools at Wapiti & Kaybob
- Narrow shoreface sands have been eroded and deformed to create thick sandstone domes with limited areal extent

**PEMBINA**
- Highest-quality reservoir is found in the core of the Main Pembina pool in Cardium shoreface sand and conglomerate deposits; halo areas consist of interbedded and bioturbated Lower Cardium sand and shale
- Activity has been steady since 1950. Production transitioned from conventional to waterflood and expansion into the halo areas, accessing the tighter oil-charged sands with horizontal wells and multi-stage fracture technology. Lower sand is a key target for horizontal drilling and waterflood

**FERRIER & WILLESDEN GREEN**
- Recent horizontal wells have targeted the halo region of the legacy pools
- Operators gaining additional production by drilling the bioturbated zones and fracturing into adjacent cleaner sands
- Local faulting separates the gas and oil, creating areas that preferentially produce gas; gas also found in dome structures

**LOCHEND, HARMATTAN & GARRINGTON**
- Deposition of sands further from sediment source; quieter depositional environment with higher shale
- Operators indicate sands are cleaner with higher porosity than appears on logs
- Conventional interpretation of Cardium logs can lead to underestimated original-oil-in-place (OOIP) calculations

Understanding the variable geology is the key to unlocking the resource
Geology commentary and how it impacts production

- New discoveries are still happening; not considered to be a resource style of play
- Narrow shoreface sands have been eroded to create thick clinoforming sandstone domes/duplexes that have limited areal extent
- Productive thick linear sands can be anywhere from 1 mile$^2$ to nearly a township wide (Wapiti)
- Great reservoir when you can find the sands
- Completing effective wells can be challenging because of the principle stress direction (NE) vs. deposition orientation (SE)
- Deep Basin hydrodynamics where water is over oil is over gas

**CARDIUM CORE AND OPEN HOLE LOG FOR 100/14-33-066-08W6 (WAPITI POOL)**

- Overlying coal bed
- Massive sand with cross-bedding and fine laminae
- Localized 15-cm-thick cemented shale zone
- Massive sand with cross-bedding and laminated zones

**TYPE LOG LOCATION MAP**

Source: geoSCOUT, GeoEdg

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Wapiti, Kaybob, Sundance, Anderson | Cardium Geology
Light oil and liquids-rich gas sub-plays continue to attract capital

- Modern, Whitecap and TORC are actively drilling in the Wapiti and Kaybob light oil play
- Peyto and Tourmaline are active in the liquids-rich gas plays of Sundance and Anderson where initial liquids yields have averaged as high as >85 bbl/MMcf in Sundance
Pebble conglomerate with sand matrix
Upper sandstone with interbedded laminar shale
Cardium shale with minor coal and bioturbation
Bioturbated sandstone and shale

- Pembina Cardium is the typical section seen, with a pebble conglomerate cap over shoreface sands that increase shale content and bioturbation with depth
- Historically the conglomerate was targeted for production and waterfloods
- Geological areas that have the strong laminar bedding at separating the upper conglomerate and middle sandstone have compartmentalization between upper and lower reservoirs and thus do not water out
- Highly mature pools that are in secondary and tertiary recovery stage of life
- High OOIP remains in the bioturbated zone
Successful waterflood strategies have been deployed in several units resulting in shallow decline for legacy production.

- Drilling continues in the upper sands of the halo regions around the legacy pools with some companies testing the tighter lower/bioturbated sands.
- Companies are developing strategies to optimize fluid handling, manage voidage replacement ratios in smaller units/areas and develop area-based abandonment strategies to capitalize on economies of scale.

**LAND OWNERS AND ACTIVITY**

- TORC 14-14-054-16W5  IP30: 205 bbl/d
- Whitecap 09-12-050-10W5  IP30: 288 bbl/d
- ARC 15-14-049-07W5  IP30: 357 bbl/d
- Bonterra 02/06-046-07W5  IP30: 295 bbl/d

**AREA RAW PRODUCTION BY OPERATOR**

**HALO REGION TYPE CURVE ECONOMICS**

- **IP30 (bbl/d)** 254
- **Ult Rec (Mboe)** 186
- **% Liquids** 74%
- **C2 - C4 (bbl/MMcf)** 17
- **C5+ (bbl/MMcf)** 12
- **GOR (scf/bbl)** 3,000
- **Lateral Length (m)** 1,600
- **C* ($MM)** 3.5
- **Capital ($MM)** 3.0
- **Opex ($/boe)** $16.05
- **TVD (m)** 1,800
- **BT-NPV@10% ($MM)** $0.6
- **IRR (%)** 21%
- **Payout (yrs)** 3.4
- **P/I (@10%)** 0.2

Source: BMO Capital Markets, geoSCOUT, Geodges, Corporate Disclosure.

1. BMO Capital Markets interpretation Economics based on flat WTI US$50/bbl, Edm MSW Diff (C$7/bbl), AECO C$2.25/MMBTU; Fx USD/CAD 0.76
A Massive oil-stained sandstone capped by conglomerate
B Bioturbated sand and shale
C Interbedded quartz sand and argillaceous shale
D Bioturbated shale and sand

- Massive resource in place; even after 70 years of production operators still cannot draw down the gas fast enough to enable oil production
- Geologically very similar to Pembina (nothing directly influencing the gas vs. oil)
- Locally we see regional faulting separating the gas and oil, creating areas that preferentially produce gas; gas also found in dome structures
- Production variability is a function of the different play types (waterfloods, banked oil, bioturbated zones)
- Rock mechanics still control production rates and need to be understood by operators (parallel or perpendicular to sigma 1). Most fractures propagate along bedding planes

Source: geoSCOUT, GeoEdges, BMO Capital Markets
1. Personal Comm. Feb 2020, Dr Per Pedersen
Ferrier, Willesden Green | Activity and Economics

Variety of operator strategies to develop the play resulting in the area’s best ever initial production rates in the most recent wells.

- Obsidian is targeting EOR banked oil east of the North Saskatchewan River and primary production to the west.
- Yangarra and InPlay are driving higher recoveries by drilling into the lower permeable bioturbated zone and fracking into adjacent cleaner sands.
- Type curve shown is more conservative than top rate wells.

Source: BMO Capital Markets, geoSCOUT, GeoEdges, Corporate Disclosure
Lochend, Harmattan, Garrington | Cardium Geology

**CARDIUM CORE AND OPEN HOLE LOG FOR 100/06-28-036-03W5/00**

- **A** Attic
- **B** Pebby conglomerate
- **C** Highly bioturbated sand with minor argillaceous shale
- **D** Bioturbated shale with minor quartz sand
- **E** Bioturbated with increased shale and minor oil-stained sand

- Pools in the southern Cardium can change dramatically depending on proximity to the sediment source; further from source increases bioturbation and vertical permeability allowing for greater deliverability.

- Interbedded sandstones are more difficult to identify on logs; but key as they cause permeability barriers to the bioturbated zone and cleaner upper sandstone, which aid production.

- Massive resource is still in-place, but vertical heterogeneity makes well targeting challenging.

**TYPE LOG LOCATION MAP**

Source: geoSCOUT, GeoEdges, BMO Capital Markets
**LAND OWNERS AND ACTIVITY**

- **Shale Petroleum testing hz 11-05-035-08W5 Spud Feb 6, 2020**
- **TransGlobe testing in between pool boundaries 02-20-029-03W5 IP30: 300 bbl/d Spud 13-16-029-03W5 March 2020**

**Area Raw Production by Operator**

- **Tamarack**
- **ExxonMobil**
- **Yangarra**
- **Orlen**
- **TransGlobe**
- **TAQA**
- **Whitecap**
- **Ridgeback**
- **Bonavista**
- **NAL**
- **Other (28)**

**Type Curve Economics**

- **IP30 (bbl/d) 226**
- **BT-NPV@10% ($MM) $0.6**
- **Ult Rec (Mboe) 174**
- **IRR (%) 21%**
- **% Liquids 76%**
- **C2 - C4 (bbl/MMcf) 22**
- **C5+ (bbl/MMcf) 12**
- **GOR (scf/bbl) 3,000**
- **Capital ($MM) $2.9**
- **Opex ($/boe) $16.32**
- **TVD (m) 2,000**
- **Lateral Length (m) 1,600**
- **P/I (@10%) 0.2**
- **C* ($MM) 3.5**
- **Payout (yrs) 3.2**
- **Total Proppant (t) 400**
- **50% Reduction in Production**
- **Renewed Interest**

**.operator are testing the limits with NAL drilling two wells with lateral lengths >4,600 m, TransGlobe extending the South Harmattan area and Shale Petroleum testing a horizontal well at Ricinus**

**Encouraging results from Orlen’s most recent wells at Lochend with IP30 rates of almost 750 bbl/d oil**

**Refocus of capital in the area; early results are promising**

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Source: BMO Capital Markets, geoSCOUT, GeoEdges, Corporate Disclosure

1. BMO Capital Markets interpretation Economics based on flat WTI US$50/bbl, Edm MSW Diff (C$7/bbl), AEOC C$2.25/MMBTU; Fx USD/CAD 0.76
**Cardium | Unitized Production & Waterfloods**

**CARDIUM UNITS**

- All of the 65 producing Cardium Units are for P&NG rights
  - There are two Cardium gas storage Units at Mcleod
- Until the mid 1990s unitized production was greater than non-unitized
  - Trend continues today where non-unitized horizontal wells produce well above unitized production rates
- Units are present where we have high quality reservoir (often porous and permeable) which were exploited early (1960s – 1980s) with vertical wells
- Unitizing pools allows operators and their partners to best manage the resource with a singular objective to economically produce oil
  - Many Units have gone from primary to secondary (waterflood) recovery, slowing the decline
  - In 2010 production increased significantly with horizontal wells drilled into mature Units and halo areas, effectively arresting the decline
- Halo areas with lower porosity and permeability adjacent to waterfloods also benefit from the increased pressure support

**HISTORICAL PRODUCTION – UNITS AND NON-UNITS**

- Cardium production was primarily unitized until early-1997
  - Unitized horizontal production and injection arrests decline

Unitized pools permit better exploitation of the reservoir
Cardium Waterflood | Started in the 1960s and continues to this day

- Waterfloods re-pressurize mature reservoirs and “push” oil to the producing wells
- A normally pressured reservoir with continued pressure maintenance has flat Gas-Oil-Ratio (GOR)
- At Willesden Green Cardium Unit No.9, injection began in 1970 and continues in vertical and horizontal wells; 90 of the 99 wells drilled into the Unit since 2008 are horizontal and include producers and injectors
- Horizontal wells drilled up-dip (east) of the unitized injection wells have had exceptional IP rates, and are capturing banked oil

Unitized waterfloods help to increase long-term production from the reservoir

**Willesden Green Cardium Unit No.9 Production and Injection History**

- First Injection 1970
- Increased injection causing GOR to fall
- Incremental oil and gas production realized from horizontal wells

**Wellesden Green Cardium Unit No.9 Production and Injection History**

- PRD Monthly GAS Mcf
- PRD Monthly Oil & Cond
- INJ Monthly Water Bbl
- Ratio: GAS/OIL Scf/Bbl
- Percent: OIL Cut %
- PRD Well Count

**SCHEMATIC OF A WATERFLOOD(1)**

- Beam pumping unit
- Water-injection site
- Injection wells
- Production well
- Waterfloods re-pressurize mature reservoirs and “push” oil to the producing wells
- A normally pressured reservoir with continued pressure maintenance has flat Gas-Oil-Ratio (GOR)
- At Willesden Green Cardium Unit No.9, injection began in 1970 and continues in vertical and horizontal wells; 90 of the 99 wells drilled into the Unit since 2008 are horizontal and include producers and injectors
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Source: BMO Capital Markets, geoSCOUT, GeoEdges

Well design continues to increase in lateral length, proppant placed and number of stages

Source: BMO Capital Markets, FracDB

1. Successful (actual) stages recorded, not design stages planned
Since 2015 operators have continued to optimize the formula for cost-effective completions

**Comments**

- Wapiti, Kaybob operators are pumping the most fluid per stage
  - Overall operators have kept fluid pumped/stage relatively flat and within the range of 110 - 165 m³/stage

- Operators at Ferrier continue to pump the most proppant per well
  - Proppant pumped per stage across all areas remains at 15-30 tonnes/stage
  - Proppant intensity since 2010 has remained relatively flat while operators are largely focused on fracture spacing

- With the increase in number of stages, fracture stage spacing has decreased from ~110 m to ~35 m
  - Willesden Green has the closest fracture spacing at <20 m

**TOTAL FLUID PUMPED/STAGE (M³)**

- Few operators testing high fluid rates

**TOTAL PROPPANT PLACED/STAGE (T)**

- Anderson (Whitecap & InPlay) tested high proppant wells 2011-2012
  - Recent completions above 30 tonnes/stage have only occurred in the Wapiti Kaybob area

**FRACTURE STAGE SPACING (M)**

- Yangarra completing wells with fracture spacing below 20 m
Cardium has access to nearly all of Canada’s critical crude transportation pipelines:\(^1\):
- Aurora/Rangeland - Capacity: 45 Mbbl/d  
  - Delivery Point: Montana / Wyoming (PADD IV)
- Bow River/Milk River - Capacity: 98 Mbbl/d  
  - Delivery Point: Montana / Wyoming (PADD IV)
- Express - Capacity: 280 Mbbl/d  
  - Delivery Point: Wyoming (PADD IV) / Wood River (PADD II)
- Keystone - Capacity: 590 Mbbl/d  
  - Delivery Point: Cushing / Wood River (PADD II) or Houston (PADD III)
- Mainline - Capacity: 2,850 Mbbl/d  
  - Delivery Point: Chicago (PADD II) / Sarnia
- Trans-Mountain - Capacity: 300 Mbbl/d  
  - Delivery Point: Vancouver / Sumas (PADD V)

The Cardium is adjacent to Western Canada’s largest refining hub:
- Edmonton - Imperial: 191 Mbbl/d, Suncor: 142 Mbbl/d, Shell: 100 Mbbl/d, NW Refining (Sturgeon County): 79 Mbbl/d
- Hardisty - Husky Asphalt Plant: 29 Mbbl/d, Husky Upgrader: 82 Mbbl/d

Rail capable of transporting of 900 Mbbl/d has addressed some of the egress strain resulting from the lack of pipeline capacity

Additional Rail would require significant investment from the rail companies

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Source: geoSCOUT, GeoEdges, BMO Capital Markets, BMO Equity Research, CAPP Reported as of June 2019

1. Canadian Energy Regulator, reported as of June 2020
2. BMO Capital Markets Interpretation
Future Considerations

- Understanding the geologic complexity is key to operators’ success
- Land is tightly held within the mapped fairways
- Shallow depths, low-cost wells, and oil-weighted and liquids-rich focused production result in strong economic returns in many of the Cardium sub-play areas
- Low cost of entry with <$4MM to DCE&T well costs with continued efforts on drilling efficiencies and optimized completion designs

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<tr>
<th>WAPITI / KAYBOB / SUNDANCE / ANDERSON</th>
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<td>- Resurgence of interest (licensed wells) especially in the liquids-rich Sundance and Anderson sub-play areas where recent wells deliver some of the highest initial production rates</td>
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<td>- Historically operators produced from the hanging wall along thrust faults, now testing footwall where the section has been repeated</td>
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<td>- Continued development in Greater Pembina through optimization on well placement, waterflood strategies and water use</td>
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<td>- Recent focus on lower bioturbated zone where compartmentalization from upper high-permeability reservoir is in place</td>
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<td>- Step change in abandonment costs with area-based reclamations (field-based strategies and multi-company area efforts)</td>
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<td>- Optimized well placement via geosteering and completion design as operators improve their understanding of the target zone (Banked oil, Bioturbated)</td>
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<td>- Maximizing production rates resulting from longer laterals and best completion practices</td>
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<td>- Continued activity and focus with exceptional recent well results</td>
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<td>- Access to more reservoir with record lateral lengths – will the super-extended lateral-reach wells continue?</td>
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<tr>
<td>- Extensions to previously mapped pools</td>
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<td>- Horizontal drilling into previously vertically drilled pools</td>
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Even after 70 years of production, the Cardium play continues to captivate operators