WATER POTENTIAL OF THE MISSISSIPPIAN DEBOLT FORMATION IN THE HORN RIVER BASIN, NORTHEASTERN BRITISH COLUMBIA

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ABSTRACT

Water demand in the Horn River Basin is increasing rapidly as a result of shale gas exploration and development. The British Columbia Ministry of Energy, Mines and Petroleum Resources is studying the suitability of shallow subsurface strata, the Debolt Formation in particular, to supply the water needs of industry. There is little known of the geology or hydrogeology relative to the size of the area. The Debolt Formation subcrops against an unconformity throughout the basin. Water has been produced from the Mattson Formation in association with gas production. Drill-stem tests indicate there are highly permeable zones in the Mattson, Golata, Bluesky, and Debolt formations. The lithology and stratigraphy studies at the contact may help locate highly permeable zones in the Debolt.

Johnson, E. (2009): Water Potential of the Mississippian Debolt Formation in the Horn River Basin, Northeastern British Columbia; Geoscience Reports 2009, *BC Ministry of Energy, Mines and Petroleum Resources,* pages 39–47.

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Key Words: aquifer, groundwater, disposal, 94O, Debolt, Mattson, Golata, Scatter, Bluesky, Bullhead

INTRODUCTION

Water demands in the Horn River Basin are expected to escalate dramatically as the regional shale gas exploration and development accelerates. The British Columbia Ministry of Energy, Mines and Petroleum Resources has initiated studies to establish the availability of subsurface water sources to support industry activity. The Mississippian Debolt Formation of the Rundle Group is considered one of the most likely near-surface stratigraphic units capable of providing large volumes of water.

The Horn River Basin is located in northeastern British Columbia between Fort Nelson and the Northwest Territories border (mostly in NTS map sheets 94O eastward into 94P and southward to 94J). Located in the Fort Nelson Lowland of the Alberta Plateau, the area has very low relief (300 to 730 m above sea level), with the Etsho Plateau forming a minor upland, oriented northwest to southeast in the central region (Figure 1) (Holland 1976). There are two major drainage systems incised up to 150 m below the general level of the lowland: the Fort Nelson River and the Petitot River (which are tributaries of the Liard and Mackenzie River systems). For the most part, the study area is defined by the Devonian Slave Point reef on the east and south and the Bovie Fault on the west; the Northwest Territories border forms the northern limit.

CURRENT ACTIVITY

Recent drilling activity has increased rapidly as shale gas and tight gas exploration and development progresses (Figure 2). Currently, there are 1547 wells in the study area. This is a five-fold increase since 2000. Data from over fifty wells are confidential as they are classed as experimental schemes, and the standard period of confidentiality is extended to three years from rig release. The majority of wells along the east margin of the basin are associated with development of the Jean-Marie Formation.

The increased demand for water is primarily owed to hydraulic fracturing , the stimulation technique necessary for the economic development of tight and shale gas. To develop shale gas plays, hydraulic fracturing (herein referred to as "fracs" or "fracing") is used to create fractures in the shale that increase well-bore access to the gas trapped in the rock. Fracing requires high pressures and injection rates up to 100 MPa and 256 L/s to create fractures around the well bore. A proppant such as sand is added to the water to prevent the fractures from closing again. Substantial volumes of water are required for this process. Estimates vary by producer from 1,200 m^3 to over 2,500 m^3 of water per frac[1,2,3]. An average well may contain six to twelve fracs, so the water requirement for one well could be as low 7,000 m^3 or more than 30,000 m^3. Well configuration estimates place 3 to 8 wells

[1] Based on current industry estimates

[2] Slick water fracing of a vertical well completion can use over 5,500 m^3 (1.2 million gallons) of water, while the fracturing of a horizontal well completion can use over 16,000 m^3 (3.5 million gallons) of water. In addition, the wells may be re-fractured multiple times after producing for several years (Railroad Commission of Texas 2008)

[3] An entire frac job may take a day and uses 9,500 to 13,600 m^3 (2.1 to 3 million gallons) of water (Veil 2007)

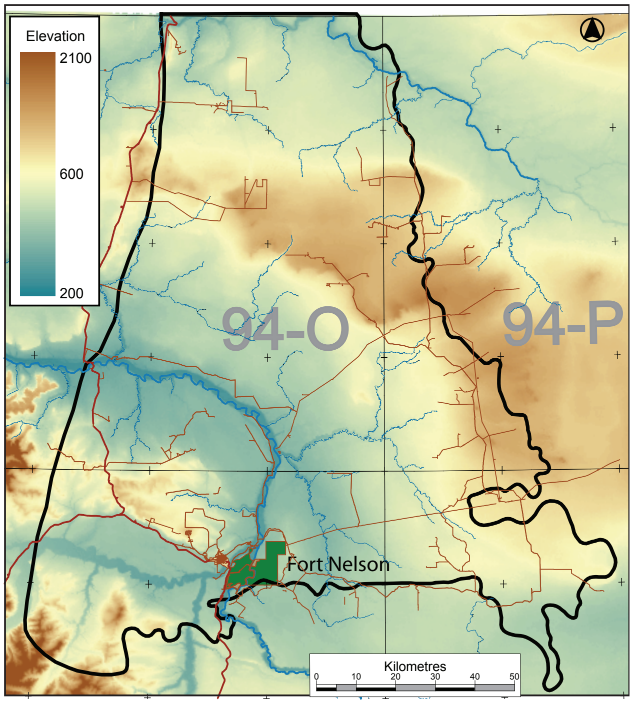

Figure 1. Topography of the Horn River Basin. The outlined area shows the geologically defined basin. Elevation in metres above sea level.

per gas spacing unit (approximately 240 ha). Producers hope to recover one quarter to one third of frac water used and recycle 100% of the return.

Industry activities initially used surface water from small lakes and borrow pits[4], which were easily accessible since much of the region is covered with small lakes, muskeg, and black spruce forests. However, an average-sized borrow pit can supply the water needs for only one or two wells. Surface water has been rejected as a long-term option as this supply is not likely to sustain prolonged industry activity and poses an environmental concern. As a consequence, subsurface water bodies being targeted include (a) fresh water from large buried valleys filled with Quaternary sediments and (b) saline waters in Mississippian Debolt Formation limestone or overlying sandstones from the Mattson, Bluesky, or Gething formations. Buried valleys are discussed elsewhere (see Hickin, this volume). This study focuses on the Debolt Formation for two reasons. First, the Debolt Formation is a possible candidate for both source and disposal water; it is a thick, continuous, locally porous calcareous unit known to contain saline water and small gas pools. Second, at present there is more data available for the Debolt than other horizons. This is an important factor as there are fifteen hundred wells with publicly released data that intersect the Debolt Formation in an area of greater than 1.3 million ha. The majority of these data are from the periphery of the Horn River Basin, especially along the eastern boundary where the target horizon is the stratigraphically lower Jean Marie Formation (Devonian).

[4]A borrow pit is the hole created when material is excavated to be used as road fill

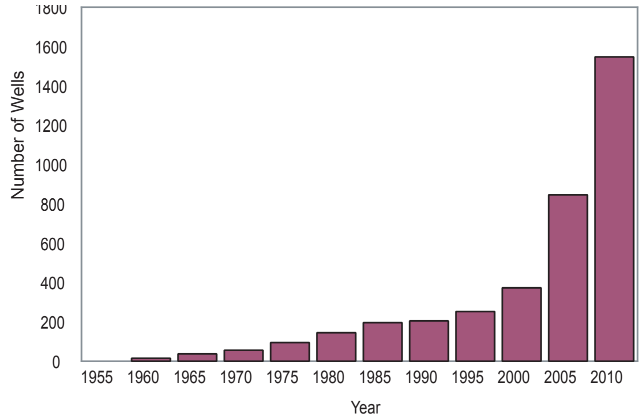

Figure 2. Increased drilling in the Horn River Basin over time.

STRATIGRAPHY

The Banff Formation forms the base for the sequence of interest. It is a 400 to 500 m thick Upper Devonian to Mississippian horizon consisting of interbedded calcareous shale and argillaceous limestones (Member B) (Glass 1997; Monahan 1999). Atop the Banff Formation is the Rundle Group, which is unconformably overlain by Cretaceous strata in much of the study area. The Rundle Group includes the Pekisko, Clausen, Debolt, Shunda, and Flett formations (Table 1). The Flett Formation in the District of Mackenzie is equivalent to Debolt in northeastern British Columbia (Richards et al. 1994). The assemblage consists of carbonate platform lithofacies with subordinate carbonate ramp lithofacies and basinal to supratidal siliciclastics. They form a shallowing upward succession over several transgressive/regressive cycles (Richards et al. 1994). At the base of the Rundle Group is the Pekisko Formation, a 25 m thick unit of clean bioclastic limestone indicative of a shelf setting. The Shunda Formation consists of argillaceous limestone and calcareous shale, and the Debolt consists of limestone with dolomite, chert, and argillaceous units (Monahan 1999). The limestone commonly has light brown mottled colouring and fine to medium granular texture and is bioclastic with crinoids, ostracods, and brachiopods.

The Debolt Formation is informally divided into lower, middle, and upper members. The Elkton forms a lower submember of the Debolt. It is capped by a distinctive argillaceous unit. The middle Debolt member has a greater argillaceous content, which is visible on gamma ray logs (Monahan 1999). Dolomites up to 60 m thick occur in the upper Debolt (Monahan 1999).

Within the geological outline of the basin, Cretaceous sediments unconformably overlie Mississippian Debolt carbonates. The surface of the Debolt is erosional and is relatively flat, with approximately 200 m total relief (Figure 3). The Debolt-Shunda-Pekisko package (Rundle Group) thins eastward (Figure 4). The upper Debolt occurs mostly in the west but has been eroded to the east.

West of the Bovie Fault, in the Liard Basin (see Figure 3 for location), Permian sediments are present, as are younger Mississippian strata such as the Mattson and Golata formations, so the elevation of the sub-Cretaceous unconformity is significantly higher than the Debolt. Figure 5 shows the thickness of sediment between this unconformity and top of Debolt and outlines the subcrop edge of the Mattson, Golata, and Fantasque formations. Wells on the map indicate the formation that subcrops against the unconformity. There are rare occurrences of these younger sediments within the basin, mostly near the Bovie fault but also along a central northeast to southwest trending features. This feature may be a splay along the Bovie Fault or related fault structures associated with the Dilly and Petitot faults (Petrel Robertson 2003).

WATER-BEARING STRATA

Little more than 100,000 m^3 of water has been produced from multiple wells in the Debolt (Flett), Mattson, and Bluesky formations (Table 2). A 15 m thick porous dolomite at the top of the Elkton has produced water in several drill-stem tests just southwest of the HRB boundary (e.g., b-6-G/94-O-7) (Monahan 1999).

Within the geologically defined basin at shallower depths (above the Banff Formation), drill-stem tests were performed in the Cretaceous sediments (10 tests) and the Mississippian Golata (1 test), Mattson (20 tests), and Debolt (61 tests) formations (Figure 6). Highly permeable formations are distinguishable from low permeability

TABLE 1. TABLE OF FORMATIONS FOR NORTHEASTERN BRITISH COLUMBIA.

ERA	PERIOD & EPOCH		N.W.T.& YUKON — LIARD RIVER AREA	NORTHERNMOST NEBC — PLAINS
CENOZOIC	QUATERNARY		BOULDER CLAYS, SAND AND GRAVEL VARVED CLAY, SILT	BOULDER CLAYS, SAND AND GRAVEL VARVED CLAY, SILT
CENOZOIC	TERTIARY			
MESOZOIC	CRETACEOUS	UPPER	WAPITI	WAPITI
MESOZOIC	CRETACEOUS	UPPER	KOTANEELEE	KOTANEELEE
MESOZOIC	CRETACEOUS	UPPER	FORT NELSON	
MESOZOIC	CRETACEOUS	UPPER	FT. ST. JOHN GROUP: SULLY	FT. ST. JOHN GROUP: SULLY
MESOZOIC	CRETACEOUS	LOWER	FT. ST. JOHN GROUP: SIKANNI	FT. ST. JOHN GROUP: SIKANNI
MESOZOIC	CRETACEOUS	LOWER	FT. ST. JOHN GROUP: BUCKINGHORSE: LEPINE	FT. ST. JOHN GROUP: BUCKINGHORSE: LEPINE
MESOZOIC	CRETACEOUS	LOWER	FT. ST. JOHN GROUP: BUCKINGHORSE: SCATTER	FT. ST. JOHN GROUP: BUCKINGHORSE: SCATTER
MESOZOIC	CRETACEOUS	LOWER	FT. ST. JOHN GROUP: BUCKINGHORSE: GARBUTT	FT. ST. JOHN GROUP: BUCKINGHORSE: GARBUTT
MESOZOIC	CRETACEOUS	LOWER	CHINKEH	GETHING
MESOZOIC	JURASSIC	UPPER		
MESOZOIC	JURASSIC	MIDDLE		
MESOZOIC	JURASSIC	LOWER		
MESOZOIC	TRIASSIC	UPPER		SHROEDER CR. GROUP: BLDN.
MESOZOIC	TRIASSIC	UPPER / MIDDLE		SHROEDER CR. GROUP: CHARLIE LAKE
MESOZOIC	TRIASSIC	MIDDLE		SHROEDER CR. GROUP: HLFY.
MESOZOIC	TRIASSIC	LOWER		DIABER GROUP: DOIG
MESOZOIC	TRIASSIC	LOWER		DIABER GROUP: MONTNEY
PALEOZOIC	PERMIAN		FANTASQUE	NW PART OF AREA FANTASQUE?
PALEOZOIC	PENNSYLVANIAN		MATTSON	MATTSON
PALEOZOIC	MISSISSIPPIAN	UPPER	MATTSON	MATTSON ?
PALEOZOIC	MISSISSIPPIAN	UPPER	ETANDA / FLETT	RUNDLE GROUP: DEBOLT
PALEOZOIC	MISSISSIPPIAN	UPPER	ETANDA / FLETT	RUNDLE GROUP: SHUNDA
PALEOZOIC	MISSISSIPPIAN	UPPER	ETANDA / FLETT	RUNDLE GROUP: PEKISKO
PALEOZOIC	MISSISSIPPIAN	LOWER	ETANDA / CLAUSEN	BANFF
PALEOZOIC	MISSISSIPPIAN	LOWER	ETANDA / YOHIN	EXSHAW

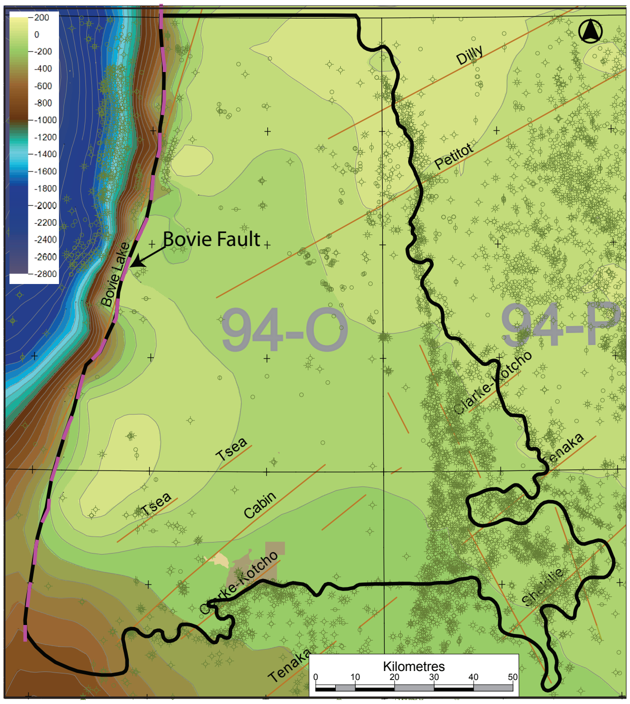

Figure 3. Elevation (in metres above sea level) of the surface of the Debolt Formation. Brown lines indicate inferred locations of regional faults.

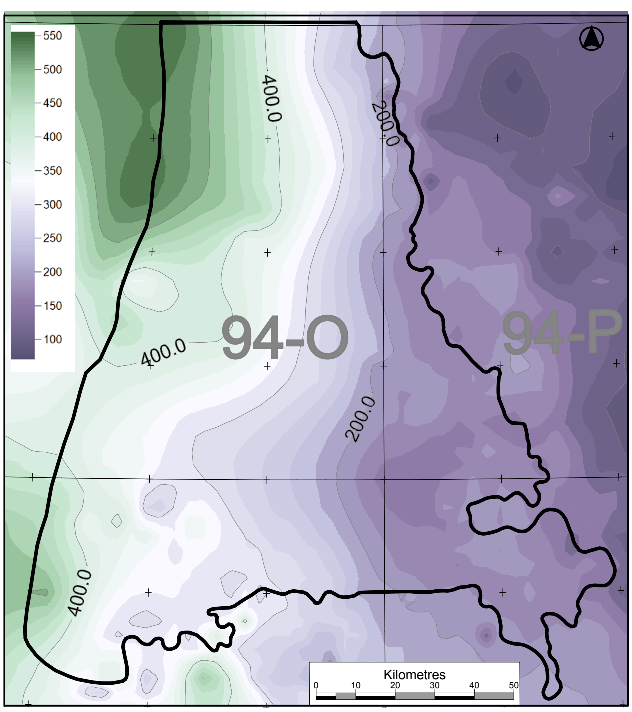

Figure 4. Isopach map for thickness (in metres) of the Rundle Group from the top of the Debolt formation to the top of the Banff Formation.

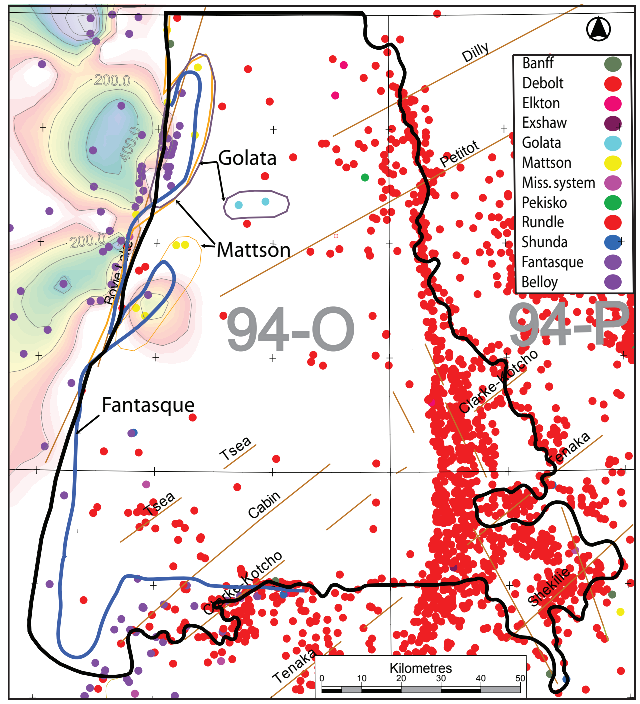

Figure 5. Kriged isopach of sediment thickness (in metres) of Paleozoic sediments younger than the Debolt Formation. Well coloration indicates the first unit intersected below the Permo Triassic unconformity. Coloured lines indicate the approximate location of the subcrop contact.

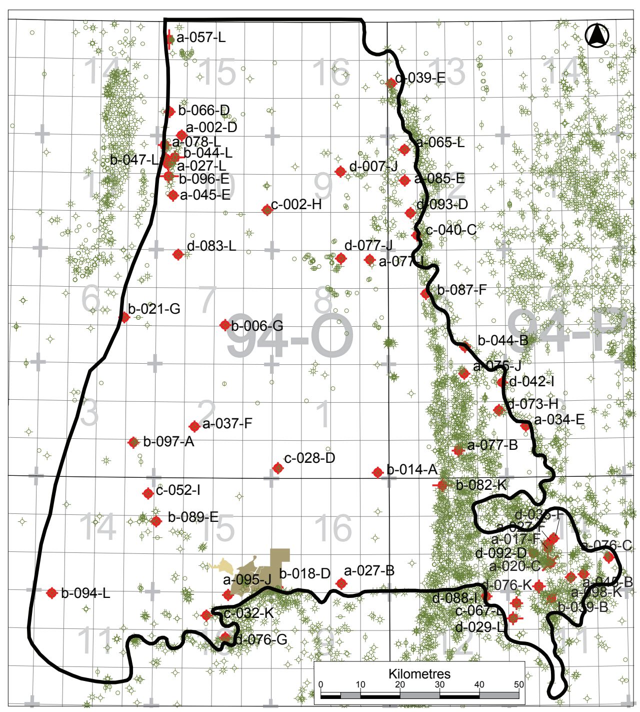

Figure 6. Locations of wells in the Horn River Basin (green dots). Wells with drill-stem tests in formations above the Banff Formation (listed in Table 3a) are indicated in red.

TABLE 2. WELLS WITH PRODUCED WATER GREATER THAN 1000 M³.

Well ID	Water Rate First 4 mo. (m3/d)	Water Rate Last 4 mo. (m3/d)	Cum. Water Prod. (m3)	Formation	Total Prod. (hours)	Date of Last Prod. (month-year)
b-015-F/094-I-14	0.03	0.05	1455	Bluesky	14681	Oct-08
b-015-F/094-I-14	0.03	0.05	1455	Bluesky	14681	Oct-08
b-037-G/094-P-04	2.4	0.51	3717	Bluesky	37534	Oct-08
c-006-F/094-I-14	1.21	2.03	8700	Bluesky	73250	Oct-08
c-006-F/094-I-14	1.21	2.03	8700	Bluesky	73250	Oct-08
c-028-F/094-I-14	1.57	23.13	11968	Bluesky	24312	Feb-04
c-028-F/094-I-14	1.57	23.13	11968	Bluesky	24312	Feb-04
d-008-F/094-I-14	0.36	0.83	1497	Bluesky	11909	Dec-03
d-008-F/094-I-14	0.36	0.83	1497	Bluesky	11909	Dec-03
a-025-L/094-O-10	0.12	-	5506	Debolt	27204	Sep-06
a-025-L/094-O-10	0.12	-	5506	Debolt	27204	Sep-06
a-025-L/094-O-10	0.05	-	13809	Mattson	62539	Oct-08
a-025-L/094-O-10	0.05	-	13809	Mattson	62539	Oct-08
a-078-L/094-O-10	0.18	-	5848	Mattson	33754	Sep-06
a-078-L/094-O-10	0.18	-	5848	Mattson	33754	Sep-06
b-025-L/094-O-10	-	0.9	1552	Mattson	26030	Dec-04
b-025-L/094-O-10	-	0.9	1552	Mattson	26030	Dec-04
b-044-L/094-O-10	-	0.2	1674	Mattson	78000	Oct-08
b-044-L/094-O-10	-	0.2	1674	Mattson	78000	Oct-08

horizons by lower final hydrostatic pressures, smaller pressure changes, a lower rate of recovery on the second phase of the test (slope), lower salinity, and higher electrical resistance (Table 3). The Rundle Group overall has average to high permeability in drill-stem tests but has localized horizons of low permeability. The Mattson, Golata, and Bluesky also indicate average to high permeability in a small number of tests. As mentioned, upper Mississippian and Permian sediments occur mostly along the western edge of the basin boundary. The Cretaceous Bullhead Group (Bluesky Formation) occurs only along the east side with the exception of a small zone west of Fort Nelson. Salinity for the various formations is generally in the 10,000 to 20,000 ppm range. There are occurrences of fresh to slightly saline water (less than 3000 ppm) in drill-stem tests of the Bullhead Group, Scatter, and Debolt formations. A review of the water analyses for these occurrences indicates that the samples are all affected by mud filtrate. Evidence of mud filtrate includes low recovery volumes, skewed ion proportions, and physical observations.

The lithologic logs of most wells do not allow for the differentiation of subunits within the Debolt. Lithologic descriptions indicate that the Debolt is tight over broad intervals. In well D-079-G/094-O-16 (WA 6239), core analysis in the Debolt Formation from three porous horizons showed that the porosity can spike from generalized low values of 1% to 5% to high values of 10% to 28% and back to low values over short vertical thicknesses of less than a meter. In well D-090-K/094-O-07 (WA 13894), the Debolt Formation has consistently poor to no porosity through a 120 m section that is followed by a 120 m section of undifferentiated limestone averaging 3% to 5% porosity. This lower porous zone may be the lower Debolt, the Elkton submember, or (most probably) the Shunda Formation. There are many other instances, especially in the central east side of the study area, where the Shunda Formation is not differentiated from the Debolt. Similarly, the Pekisko Formation is not always identified in drill holes despite strong lateral correlation of stratigraphy from surrounding wells. A thorough review of the lithology sequence stratigraphy and a common nomenclature would be helpful to developing an integrated understanding of the porosity distribution within the basin.

The Debolt Formation is present across the basin and therefore is a prospective targets as a water source or disposal horizon. Widespread regions of very low permeability, however, may limit its utility. Thinner porous dolomite intervals in the upper, middle, and lower Debolt provide traps at the sub-Cretaceous unconformity for gas shows and small gas pools (Monahan 1999). Porosity is often increased in carbonate horizons underlying unconformities from secondary processes including (a) shallow subsurface solution by meteoric fluids and (b) increased solution by circulating fluids under a confining layer at the unconformity. Porosity is also increased with dolomite content. Careful mapping of the unconformity surface and juxtaposition of lithologies across the unconformity would be helpful in finding zones of the Debolt Formation that would yield more water.

TABLE 3A. DRILLSTEM TEST RESULTS FOR FORMATIONS ABOVE THE BANFF FORMATION.

UWID	Formation	Depth (m)	Hydro. Press. Initial (kPa)	Hydro. Press. Final (kPa)	Rate Recov. Phase 2, Test 1 (kPa/min)	Rate Recov. Phase 2, Test 2 (kPa/min)	Bore Hole Temp. (°C)	Fluid Salinity (ppm)	Resistivity of water (Ohms)	Perme-ability
d-092-D/094-I-14	Bluesky	616	6467	6322	2	1		17,729	0.419	`
a-085-E/094-P-12	Bluesky	525	6050	5963	2	2	37.8	12,638	0.475	3
a-017-F/094-I-14	Bluesky	605	5976	5748	1	1	34.6	27,400	0.240	`
c-086-A/094-I-14	Bluesky	550	6320	6414			38.0			`
a-027-F/094-I-14	Bullhead	607	6260	6150	2	4	30.0			`
a-027-F/094-I-14	Bullhead	599	6109		10	2	40.6	10,000	0.580	`
a-045-B/094-I-14	Bullhead	578	6033	6019	5	2	46.1	1,690	4.998	`
d-035-F/094-I-14	Bullhead	607	6805	6860	4	2		53,333	0.130	1
a-045-E/094-O-10	Scatter	780	8729	8687	20	10	22.8	1,583	4.880	`
b-044-B/094-P-05	Spirit River	565	5833	5833	50	25	21.1	16,791	0.363	`
d-088-I/094-I-12	Debolt	613	7102	6729			32.2			`
d-088-I/094-I-12	Debolt	613	7053	6453	2		32.2			`
a-027-B/094-J-16	Debolt	520	6322	6322	2	1	28.3	23,824	0.318	3
a-027-F/094-I-14	Debolt	700	7460	7357	40	20	36.7			`
a-034-E/094-P-03	Debolt	700	8991	8874	2	5	37.8	32,404	0.255	`
a-045-B/094-I-14	Debolt	594	6288	6288	2	1	46.1			`
a-065-L/094-P-12	Debolt	358	3813	3436				4,300	1.520	`
a-075-J/094-P-04	Debolt	638	6989	6860	8	5	36.2	20,000	0.310	2
a-076-C/094-I-14	Debolt	603	6674	6509	15	5		28,682	0.257	`
a-076-C/094-I-14	Debolt	618	6667	6681						`
a-076-C/094-I-14	Debolt	603	6674	6509	15	5		28,682	0.257	`
a-076-C/094-I-14	Debolt	618	6667	6681						`
a-077-B/094-P-04	Debolt	603	6694	6672	10	2	37.3	10,000	0.585	3
a-077-I/094-O-08	Debolt	650	6667	6529				2,310	2.550	`
a-095-J/094-J-10	Debolt	536	6481	6481	40	45	37.8	26,263	0.273	`
b-006-G/094-O-07	Debolt	528	5709	5681	5	10	28.9			`
b-006-G/094-O-07	Debolt	627	6778	6771	2	1				`
b-014-A/094-O-01	Debolt	581	6840	6709	10	10	27.8	19,000	0.310	3
b-018-D/094-J-16	Debolt	565	7474	7474	5	10	32.2	24,713	0.303	`
b-021-G/094-O-06	Debolt	555	5840	5840				1,754	4.802	`
b-039-B/094-I-14	Debolt	588	6391	6356	10	10	21.1	26,700	0.234	2
a-020-C/094-I-14	Debolt	574	6567	6223	2	1	36.7	31,787	0.227	3
b-082-K/094-I-13	Debolt	608	6440	26424	8	5	33.8	14,000	0.430	2
b-087-F/094-P-05	Debolt	707	6743	6647	2	1	33.3			`
b-089-E/094-J-15	Debolt	567	6474	6474	50					`
b-094-L/094-J-11	Debolt	1044	11232	11107	2	1	37.2	20,934	0.287	3
b-096-E/094-O-10	Debolt	724	7508	7412	1	1		10,575	0.681	`
d-093-D/094-P-12	Debolt	536	5530	5530						`
d-093-D/094-P-12	Debolt	515	5612	5612	5	2		5,760	0.990	3
b-096-E/094-O-10	Debolt	724	7508	7412	1	1		10,575	0.681	`
b-097-A/094-O-03	Debolt	347	3868	3820	2	20	12.2			`
c-028-D/094-O-01	Debolt	365	3544	4137	2		37.8			`
c-032-K/094-J-10	Debolt	589	6822	6822	10	10				`
c-040-C/094-P-12	Debolt	611	6788	6490	10	10	47.0	3,858	1.680	`
c-067-L/094-I-11	Debolt	592	6674	6571	2	1	38.0			`
d-007-J/094-O-09	Debolt	463	5281	5171	2	1				`
d-029-L/094-I-11	Debolt	557	6109	6116	2	2		30,400	0.210	`

TABLE 3A CONTINUED.

UWID	Formation	Depth (m)	Hydro. Press. Initial (kPa)	Hydro. Press. Final (kPa)	Rate Recov. Phase 2, Test 1 (kPa/min)	Rate Recov. Phase 2, Test 2 (kPa/min)	Bore Hole Temp. (°C)	Fluid Salinity (ppm)	Resistivity of water (Ohms)	Perme-ability
d-039-E/094-P-13	Debolt	301	3404	3371	1	1	29.3	8,000	0.740	3
d-042-I/094-P-04	Debolt	0	7267	7267			36.1			`
d-073-H/094-P-04	Debolt	680	7688	7564	2	1	48.9	22,732	0.307	`
d-076-G/094-J-10	Debolt	665	7308	7274						`
d-076-K/094-I-11	Debolt	594	7197	7197			35.0	24,506	0.276	`
d-077-J/094-O-08	Debolt	667	6564	6564			26.1	14,816	0.490	`
d-088-I/094-I-12	Elkton	649	7053	7164	10	15	36.7			`
a-037-F/094-O-02	Elkton	410	4854	4854			28.3			`
a-037-F/094-O-02	Elkton	399	5040	5026			28.3			`
a-045-E/094-O-10	Flett	930	10135	9832	20	30	31.1	6,190	0.949	`
a-057-L/094-O-15	Flett	1538	17633	17579	60	45	47.0			1
a-078-L/094-O-10	Flett	1092	12045	11935			45.0	15,623	0.459	`
b-044-L/094-O-10	Flett	520	5468	5378	1	1	41.7	13,470	0.460	3
c-002-H/094-O-10	Flett	805	9005	8963	20	10	33.3	20,173	0.331	`
a-002-D/094-O-15	Golata	505	5447	5323	2	2		4,000	1.240	`
c-052-I/094-J-14	Miss_sys	683	4109	4109						`
c-052-I/094-J-14	Miss_sys	598	6860	6736	5	2	52.2			`
a-027-L/094-O-10	Mattson	698	7097	6989	10	8				`
a-045-E/094-O-10	Mattson	863	9756	9632	5	5	30.0	20,314	0.311	`
a-057-L/094-O-15	Mattson	765	9134	9125	15	10	31.4	8,000	0.740	2
a-078-L/094-O-10	Mattson	770	8612	7784	5	2	40.6	9,756	0.771	`
a-078-L/094-O-10	Mattson	738	8039	7826	5	2		5180	1.348	`
a-078-L/094-O-10	Mattson	1035	11404	11342				24479	0.303	`
b-044-L/094-O-10	Mattson	396	4158	4116	10	5	18.9			2
b-047-L/094-O-10	Mattson	980	10996	10849	2	1	39.5			`
b-066-D/094-O-15	Mattson	993	11004	11004	30	20	28.9	4,480	1.370	3
b-096-E/094-O-10	Mattson	529	5447	5447			35.0			`
b-096-E/094-O-10	Mattson	530	5488	5612						`
b-096-E/094-O-10	Mattson	529	5674	5736	2	2	27.8			`
a-002-D/094-O-15	Mattson	494	5447	5447	5	2		12,497	0.582	2
b-096-E/094-O-10	Mattson	529	5674	5736	2	2	27.8			1
b-096-E/094-O-10	Mattson	530	5488	5612						`
d-083-L/094-O-07	Mattson	657	7037	6953	5	10	29.8	25,000	0.260	1
d-092-D/094-I-14	Shunda	668	7150	7205	5	4		28,983	0.187	`

TABLE 3B. SUMMARY OF DRILLSTEM TEST RESULTS BY FORMATION.

Formation	No. tests	Depth (m)	Hydrostatic Pressure Initial(kPa)	Hydrostatic Pressure Final(kPa)	Pressure Change Test1	Pressure Change Test2	Rate Recov. Phase 2, Test 1 (kPa/min)	Rate Recov. Phase 2, Test 2 (kPa/min)	Bore Hole Temp. (°C)	Fluid Salinity (ppm)	Resistivity of water (Ohms)	Permeability
Bullhead	8	585.9	6,253	6,211	3,648	1,973	4	2	37.85	20,465	1.14	Variable
Scatter	1	779.7	8,729	8,687	1,627	986	20	10	22.8	1,583	4.880	
Spirit river	1	565.4	5,833	5,833	751	213	50	25	21.1	16,791	0.363	Low
Golata	1	505.4	5,447	5,323	2,338	1,965	2	2		4,000	1.240	High
Mattson	20	642.6	7,328	7,257	2,888	1,631	8	6	30.4	13,341	0.672	Average
Debolt	51	601.7	6,404	6,738	2,207	1,092	8	6	33.3	17,700	0.758	Average
Elkton	4	464.3	5,490	5,514	2,561	1,389	15	15	31.0			
Shunda	1	667.5	7,150	7,205	3,420	3,723	5	4		28,983	0.187	Low

Additionally, there are occurrences of increased porosity from hydrothermal brecciation in Devonian carbonates where they are spatially associated with deep-seated fault structures across northeastern British Columbia. The Debolt Formation may also exhibit increased porosity from hydrothermal brecciation in association with faults like the Dilly and Petitot faults.

The Debolt Formation may not act well as a water-disposal formation. It is too shallow in some localities. The total vertical depth to the top of the Debolt Formation ranges from 280 m to more than 700 m (Figure 7). In general, areas of greatest and least depths are inversely spatially correlated with elevation. Additionally, specific locations for disposal in the Debolt need to be studied because in places the Debolt directly underlies the Quaternary sediments or subcrops against an unconformity.

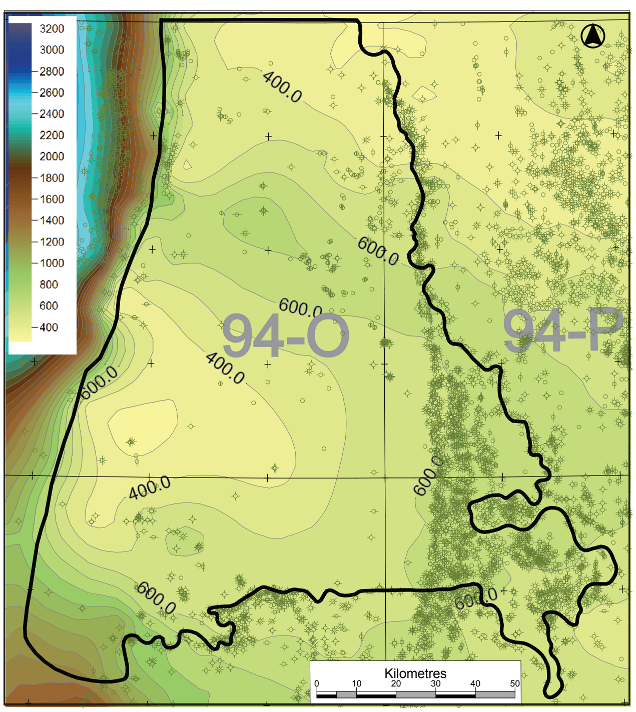

Figure 7. Total vertical depth (in metres) to the top of the Debolt Formation.

CONCLUSIONS AND RECOMMENDATIONS

Water demand in the Horn River Basin is expected to increase dramatically with increasing gas production. Cretaceous and Mississippian sandstones and limestones are considered the most likely source rocks for water in sufficient quantity to meet drilling and hydraulic fracturing requirements. Drilling has increased rapidly, but geologic knowledge is still highly limited, especially in the centre portion of the basin. The Mattson and Golata provide a potential source along the far west of the basin boundary, but the Debolt is the primary horizon of interest as it is a thick, basin-wide, porous unit. While the Debolt has good permeability in some areas, there are also broad regions of very low permeability. Knowledge of which portion of the Debolt is in contact with the unconformity, its porosity characteristics, and which formations are proximal will aid in determining zones of secondary porosity with increased permeability. Better control is needed to understand depositional and diagenetic controls on porosity and permeability.

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