# DEEP SUBSURFACE AQUIFER CHARACTERIZATION IN SUPPORT OF MONTNEY TIGHT GAS DEVELOPMENT

# GEOLOGICAL REPORT

*Prepared for*

**GEOSCIENCE BC**

June 2011

**GEOSCIENCE BC REPORT 2011-11**

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# EXECUTIVE SUMMARY

Horizontal wells and multiple hydraulic fracture (frac) stimulation technology have unlocked immense gas resources in the Montney tight gas / shale gas play fairway of northeastern British Columbia. These operations require large quantities of water – up to several thousand cubic metres per wellbore. In addition, safe disposal must be ensured for substantial volumes of contaminated produced and flow-back water.

Deep subsurface aquifers carrying saline waters are ideal sources and sinks for the water volumes required. Following upon successful completion of the Horn River Basin Deep Subsurface Aquifer Characterization Project, Geoscience BC commissioned Petrel Robertson Consulting Ltd. and Canadian Discovery Ltd. to undertake a similar study of deep saline aquifers in the Montney play fairway, as a component of the regional Montney Water Project. To date, operators in the Montney play have not made systematic use of deep subsurface water source or disposal capacity.

The fairway was divided into Plains and Foothills study areas, based primarily on subsurface stratigraphic and structural aspects. In the Plains, potential aquifers ranging from Middle Triassic Halfway to Upper Cretaceous Cardium were assessed. The best aquifer characteristics – thick net porous sandstones, high storativity, good to excellent potential deliverability, moderate to low salinities, and little or no $H_2S$ – were found in the Cadomin and Nikanassin aquifers. The Baldonnel, Bluesky, and Peace River formations offer more modest aquifer characteristics, but may still have local importance.

In the Foothills, potential aquifers range from the Mississippian Debolt to the Lower Cretaceous Bluesky; younger Cretaceous strata have shaled out in this area. In general, more extensive diagenetic degradation has reduced aquifer quality in the sandstone reservoirs, compared to the Plains Study Area. Aquifer quality in Debolt and Baldonnel carbonates is difficult to assess from logs, but test data indicate variable aquifer quality, with waters of moderate salinity and some $H_2S$ present. Foothills drilling and gas production are focused on the crests of regional northwest-southeast structural (anticlinal) trends, so there are insufficient data to adequately characterize aquifer quality off-trend.

Key observations arising from the project include:

- Deep subsurface aquifers with sufficient quality to support Montney water requirements are distributed unevenly across the play fairway.

- The northern Plains Study Area contains substantial stacked aquifer potential, while there is much less potential in the southern Plains area, where a Deep Basin (gas-saturated) regime occurs in many of the units.

- Good aquifer potential is present only in the southeastern Foothills area. More detailed work is required to determine whether gas production along regional anticlinal trends can be linked to fracturing, and whether such fractured reservoirs are capable of water production outside of established pool areas.

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# INTRODUCTION

The Triassic Montney Formation in northeastern British Columbia is one of North America's newest and hottest gas plays (Fig. P-1). Ten years ago, the deep Montney was regarded as a thick body of non-prospective siltstones and shales. Today, however, horizontal well technology and multiple hydraulic fracture (frac) stimulations have unlocked huge potential for gas production. Low development risk, large reserves, and high flow rates make the N.E.B.C. Montney play one of the most economic gas resource plays on the continent.

Since 2005, hundreds of horizontal wells have been drilled into the Montney, and current production exceeds 500 MMCF/D (14 $e^6m^3$/d) – or about 3% of Canada's daily total. A variety of hydraulic fracture stimulation techniques have been used to stimulate Montney reservoirs, and experimentation continues to optimize these treatments according to local burial depth, rock composition, and economic parameters. Regardless of specific technique, all of these treatments require large quantities of water – up to thousands of cubic metres per wellbore. In addition, safe disposal must be ensured for substantial volumes of contaminated produced water.

Deep subsurface aquifers, carrying saline (non-potable) water and lying far below the water table and domestic water wells, are ideal sources and sinks for the water volumes required. Shallower aquifers, such as shallow bedrock, and buried valley fills associated with Quaternary glaciation and drainage, are alternate targets. Surface waters may serve as short-term water sources, but produced water cannot be disposed of at surface.

In 2008, members of the Horn River Basin Producers Group asked Geoscience BC to investigate deep subsurface aquifers as sources and disposal sites for frac waters, to support the emerging Devonian shale gas play in the Horn River Basin. This study was completed and is documented as Geoscience BC Report 2010-11 (Petrel Robertson Consulting Ltd., 2010). As a result of the success of the HRB study, a group of producing companies approached Geoscience BC in 2009 to undertake a similar assessment of potential water sources and sinks in the Montney play area. In response, Geoscience BC assembled a project team to characterize deep subsurface, shallow subsurface, and surface water distribution and availability for drilling and completions operations. Petrel Robertson Consulting Ltd. and Canadian Discovery Ltd. have been commissioned to undertake and report upon the technical assessment of deep subsurface aquifers, and this report summarizes their work.

Note that the results of this study are regional in scope. They are intended to provide guidance regarding distribution and characteristics of prospective aquifers. More detailed local study will be required to assess aquifer characteristics at specific locations in order to plan water production and disposal operations.

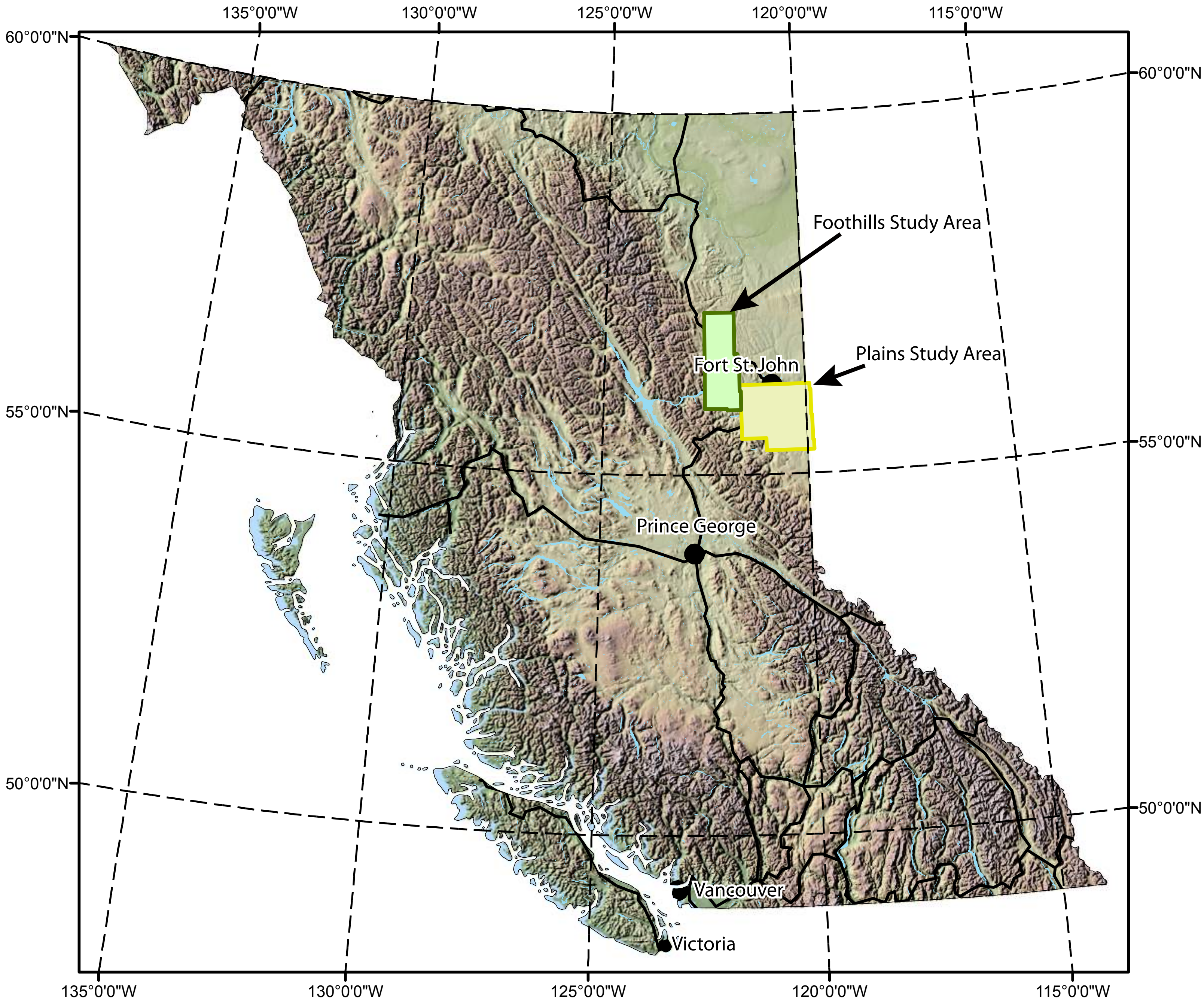


**Figure P-1.** Location map showing the Montney play areas in the Peace River Plains and adjacent Foothills of northeastern British Columbia.

# STUDY PARTICIPANTS

GEOSCIENCE B.C. initiated and managed the Montney Aquifer Characterization Project. Geoscience BC is an industry-led, not-for-profit, applied geoscience organization. It works in partnership with industry, academia, government, First Nations, and communities to fund applied geoscience projects with the objective of attracting mineral and oil and gas exploration to British Columbia. Geoscience BC's mandate includes the collection, interpretation, and delivery of geoscience data and expertise, to promote investment in resource exploration and development in British Columbia. Geoscience BC's activities have been supported by grants from the Province of British Columbia.

Industry partners ARC RESOURCES, CONOCOPHILLIPS CANADA, DEVON ENERGY, ENCANA CORPORATION, PROGRESS ENERGY, SHELL CANADA, and TALISMAN ENERGY have worked with Geoscience BC to define the scope of the Montney Aquifer Project (surface, shallow, and deep components), and to direct its progress. These partners also provided 50% of project funding, which was matched by Geoscience B.C. Additional project funding has been provided by the Science and Community Environmental Knowledge (SCEK) Fund.

PETREL ROBERTSON CONSULTING LTD. (PRCL) managed geoscience work for the deep subsurface component of the Project, creating the stratigraphic framework and mapping, then folding in hydrogeologic contributions from affiliated consultants, and producing this final report. PRCL is Canada's leading petroleum exploration consultancy. Working with several affiliated consultants, PRCL leads projects ranging from regional exploration assessments to local reservoir characterization and mapping.

CANADIAN DISCOVERY LTD. compiled and interpreted reservoir test data, to provide an integrated hydrogeologic framework for the Project. Canadian Discovery provides fully-integrated geoscience services to a diverse range of resource sector stakeholders including multi-client projects, information products, geoscience consulting, and data/software.

# BACKGROUND AND REGIONAL SETTING

Montney strata subcrop beneath various unconformities along the western flank of the Western Canada Sedimentary Basin, and equivalent strata crop out along the eastern edge of the adjacent Rocky Mountains (Davies, 1997a) (Fig. P-2). In the Deep Basin, immediately east of the Foothills, the Montney consists primarily of siltstones deposited in distal shelf settings (Davies et al., 1997). Although pervasively gas-saturated, Montney siltstones exhibit porosities of less than 10% and very low permeabilities – and thus are considered “tight gas” reservoirs.

Systematic development of Montney tight gas began in 2003 in the Dawson Field near Dawson Creek, with the drilling of numerous closely-spaced vertical gas wells. In 2005, the first horizontal well was drilled into the play, and the gas rates obtained sparked a massive land rush and horizontal drilling in several areas across the B.C. Peace River Plains. As play activity progressed, some operators began to experiment with horizontal wells in thicker, more argillaceous Montney strata in the outer Foothills. Today, Montney tight gas drilling extends northwestward in the Foothills to near Pink Mountain.

Figure P-3 shows the Montney exploration and development play fairway. We have subdivided it into Plains and Foothills study areas, reflecting differences in the Montney reservoir (siltstone-dominated in the Plains, more argillaceous in the Foothills), and differences in the deep subsurface aquifers available for water source and disposal.

The Montney tight gas play fairway includes several cities and towns, and extensive areas of agricultural, forestry, and other human development (Fig. P-3). Thus, fresh (non-saline) water resources are in high demand by other users, who are sensitive to potential disruptions in water quality and supply. Deep subsurface aquifers carrying saline waters offer the greatest potential to supply both substantial sources of water for drilling and completions and water disposal sites, without threatening non-saline water supplies.

The top of the Montney ranges from 2000 to almost 3000 metres deep across the play fairway. Several deep subsurface aquifers occur above the Montney, and we have considerable well control with which to map these units. While some aquifer potential exists in deeper strata, aquifer quality (porosity and permeability) tends to be poorer, and deep well control is scarce in most areas. To date, producers have used little or no water from deep subsurface aquifers to support Montney operations. It is difficult to know whether Montney flow-back and production waters have been injected into deep subsurface aquifers anywhere, but there appear to have been few, if any, new injectors put on stream in recent years for this purpose. Tables P-1 and P-2 summarize existing deep water source and disposal wells in the Plains and Foothills study areas, respectively.

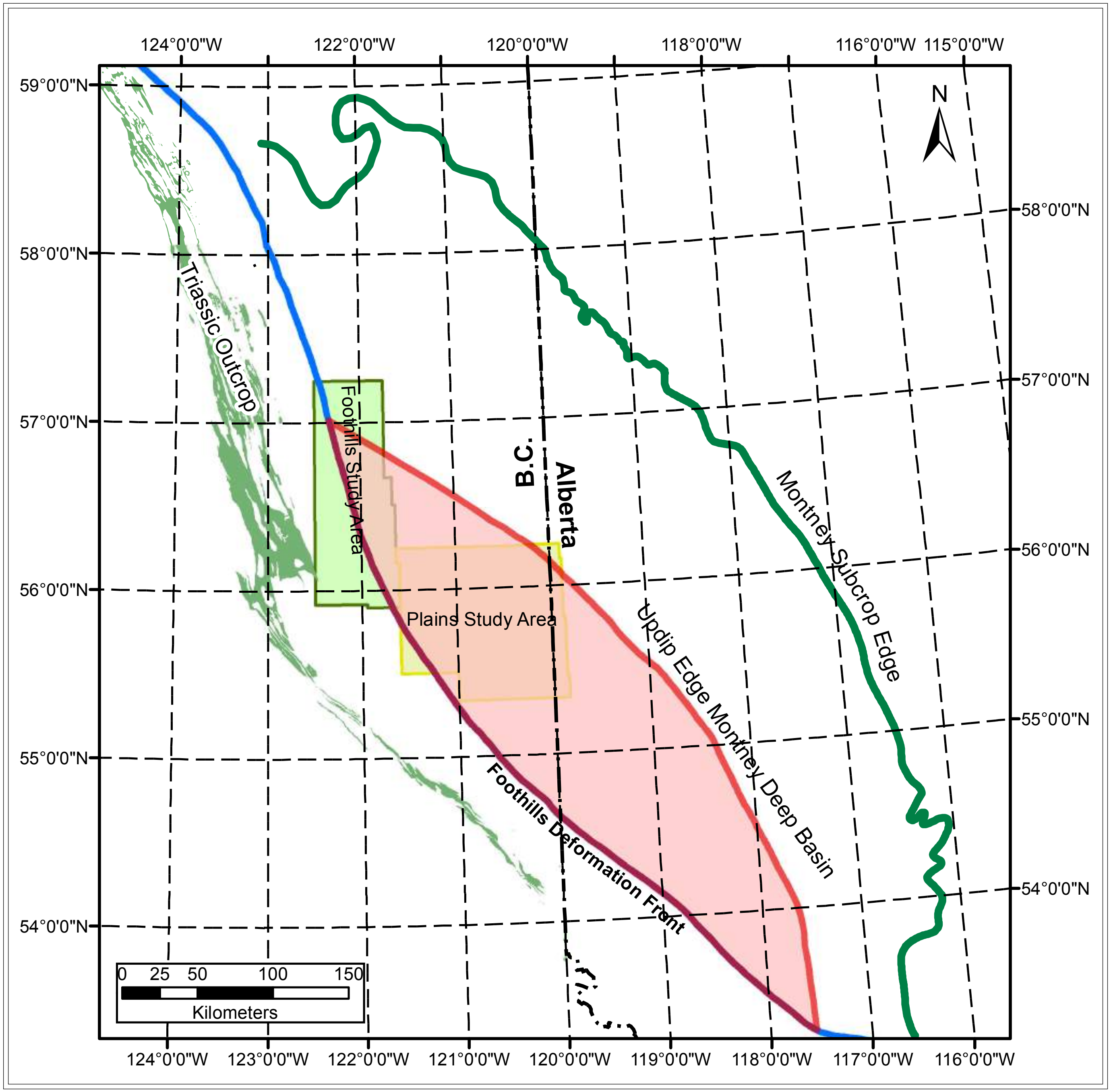


**Figure P-2.** Location map showing the Montney subcrop in the Western Canada Sedimentary Basin, the Montney Deep Basin, and outcrops in the adjacent Rocky Mountains.

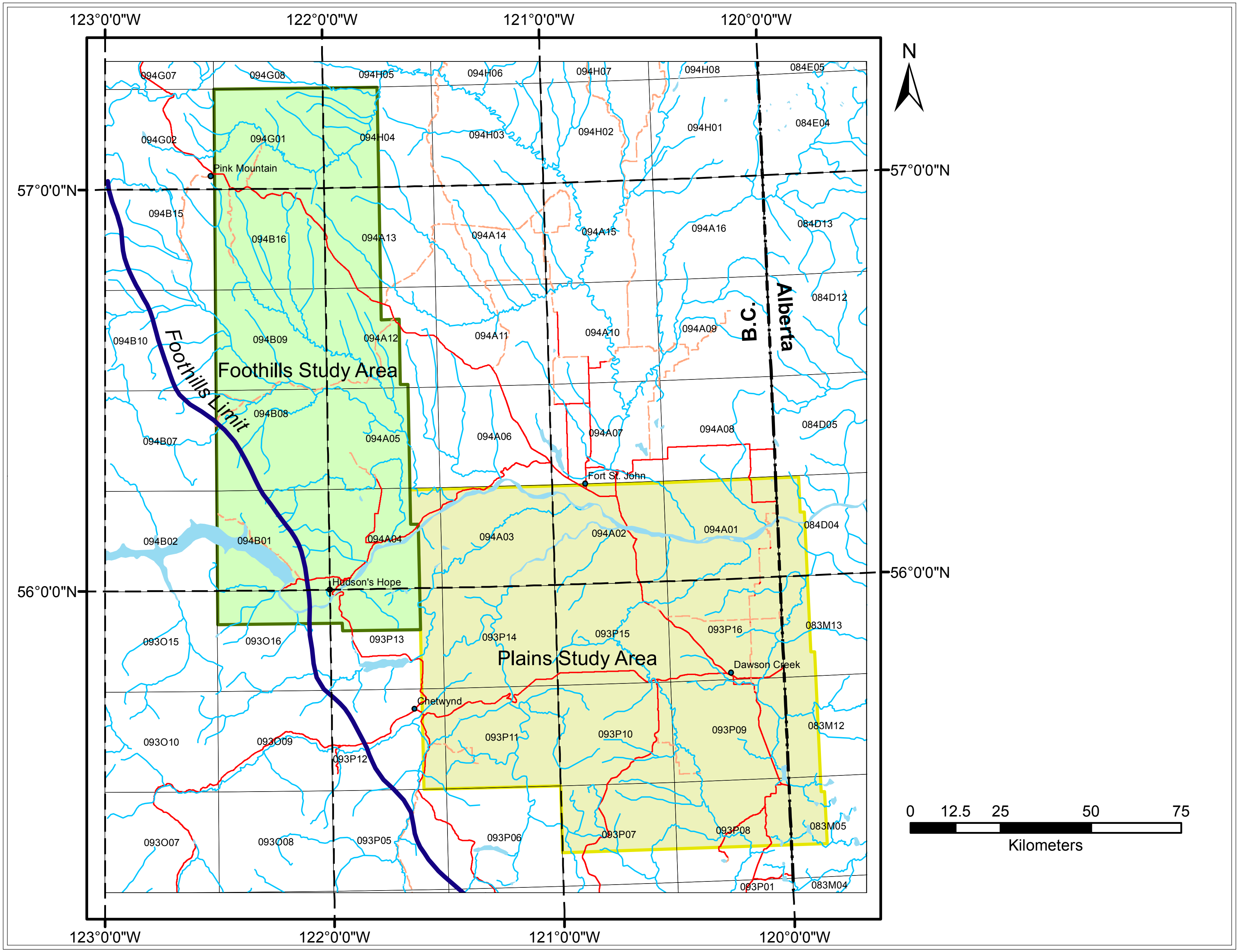


**Figure P-3**. Location map showing Plains and Foothills play areas for Montney tight gas drilling.

| Well ID | Type | Well Status | Prod./Inject. Frm | TVD (m) | Comments |
|---|---|---|---|---|---|
| 1F1/07-01-074-13W6/00 | Source | WTR Source | Peace River - Cadotte | 1554 | Cum 354 $e^3m^3$ (2002-2009) |
| 100/16-03-078-13W6/00 | Disposal | ABD WTR Disp | Peace River - Paddy | 1052.8 | Inj 14.7 $e^3m^3$ (1961-1974) |
| 100/14-14-080-13W6/02 | Disposal | WTR Disposal | Baldonnel | 1692.6 | Inj 141 $e^3m^3$ (2003-2011) |
| 100/10-28-080-13W6/00 | Disposal | ABD WTR Disp Zone | Bluesky | 1464 | Inj 55.7 $e^3m^3$ (1998-2003) |
| 102/04-30-080-13W6/00 | Source | ABD WTR | Peace River - Paddy | 661.8 | Never on stream; abandoned |
| 100/07-05-080-18W6/03 | Source | Potential WTR | Cadomin | 1823.3 | Swabbed water after frac; never on stream |
| 100/16-06-080-18W6/00 | Source | WTR Source | Cadomin | 2030 | Swabbed water after frac; never on stream |
| 100/16-06-080-18W6/02 | Source | Pot WTR Source | Nikanassin | 2030 | Swabbed water after frac; never on stream |
| 100/12-20-081-16W6/05 | Disposal | WTR Disposal | Cadomin | 2592 | Inj 64.2 $e^3m^3$ (2005-2011) |
| 100/04-12-081-17W6/03 | Disposal | Susp WTR Disp | Cadomin | 1937 | Injection test; no substantial injection |
| 100/04-12-081-17W6/04 | Disposal | WTR Disposal | Bluesky | 1937 | Injection test; no substantial injection |
| 100/16-34-083-14W6/02 | Source | ABD WTR | Cadomin | 1382.3 | Recompleted after Tr abandoned; never on stream |
| 100/10-05-083-16W6/00 | Disposal | ABD WTR Disp | Charlie Lake | 1633.1 | Inj 9.2 $e^3m^3$ (1993-1995) |
| 100/10-18-083-16W6/00 | Disposal | ABD WTR Disp | Halfway | 1631.3 | Inj 130 $e^3m^3$ (1972-1995) |
| 100/15-05-083-17W6/00 | Disposal | WTR Disposal | Cadomin | 1090 | Inj 731 $e^3m^3$ (1994-2011) |
| 100/12-10-083-17W6/02 | Disposal | WTR Disposal | Cadomin | 4175 | Inj 577 $e^3m^3$ (1989-2011) |
| 100/06-20-083-17W6/03 | Disposal | ABD WTR Disp | Cadomin | 1160 | Inj 2.6 $e^3m^3$ (1999-2001) |
| 100/14-15-083-18W6/02 | Source | ABD WTR Source | Cadomin | 1454.8 | Swabbed water after frac; never on stream |
| 100/10-30-083-18W6/00 | Disposal | Susp WTR Disp | Halfway | 1495 | Inj 278 $e^3m^3$ (1972-2004) after gas production |
| 100/10-35-083-18W6/00 | Source | Potential WTR | Baldonnel | 1420 | Swabbed water after acid; never on stream |
| 100/11-17-083-19W6/02 | Disposal | Susp WTR Disp | Halfway | 2019 | Inj 64.1 $e^3m^3$ (1982-1997) |
| 100/07-30-083-19W6/02 | Disposal | ABD WTR Disp | Nikanassin | 1834.9 | Inj 111 $e^3m^3$ (1971-1981) |
| 100/06-26-083-21W6/00 | Disposal | Susp WTR Disp | Halfway | 1542 | Perfed, never on stream |
| 200/d-039-A 093-P-09/00 | Disposal | WTR Disposal | Baldonnel | 2132.2 | Inj 56.4 $e^3m^3$ (2009-2011) |

**Table P-1.** Water source and disposal wells, Plains Study Area.

| Well ID | Type | Well Status Text | Prod./Inject. Frm | TVD (m) | Comments |
|---|---|---|---|---|---|
| 100/06-25-088-25W6/00 | Disposal | Susp WTR Disp | Debolt | 2005.9 | Inj. 585 $e^3m^3$ (1973-1993) after oil production |
| 200/a-020-D 094-A-04/02 | Disposal | WTR Disposal | Baldonnel | 1610 | Inj. 79.2 $e^3m^3$ (2008-2010) |
| 200/a-100-D 094-A-04/02 | Disposal | WTR Disposal | Bluesky | 860 | Inj. 7.1 $e^3m^3$ (2005-2007) |
| 200/d-030-K 094-A-12/00 | Disposal | WTR Disposal | Debolt | 2040 | Inj. 282 $e^3m^3$ (1996-2011) after oil production |
| 200/d-096-K 094-A-12/02 | Disposal | Susp WTR Disp | Nikanassin | 2224 | Inj. 189 $e^3m^3$ (2003-2007) |
| 200/b-007-L 094-A-12/00 | Disposal | WTR Disposal | Debolt | 2244 | Inj. 180 $e^3m^3$ (2000-2011) after oil production |
| 200/d-019-L 094-A-12/00 | Disposal | ABD WTR Disp | Baldonnel | 2486.6 | Inj. 23.7 $e^3m^3$ (1974-1981) after gas production |
| 200/d-031-L 094-A-12/03 | Disposal | WTR Disposal | Debolt | 2074 | Inj. 325 $e^3m^3$ (1997-2011) |
| 200/d-041-L 094-A-12/00 | Disposal | WTR Disposal | Debolt | 2035.1 | Inj. 339 $e^3m^3$ (1992-2011) after oil production |
| 200/d-093-L 094-A-12/00 | Disposal | WTR Disposal | Debolt | 2054.4 | Inj. 310 $e^3m^3$ (1994-2011) after oil production |
| 200/d-042-J 094-A-13/00 | Disposal | Susp WTR Disp | Baldonnel | 1331 | Inj. 7.1 $e^3m^3$ (1992-1994) after oil production |
| 202/d-006-C 094-B-09/00 | Disposal | WTR Disposal | Debolt | 2689.3 | Inj. 913 $e^3m^3$ (2002-2011) |
| 200/d-077-G 094-B-09/00 | Disposal | WTR Disposal | Debolt | 2298 | Inj. 178 $e^3m^3$ (2005-2011) |
| 200/a-076-A 094-B-16/00 | Disposal | ABD WTR Disp | Baldonnel | 1361.5 | Inj. 4.0 $e^3m^3$ (1977) |
| 200/b-079-I 094-B-16/00 | Disposal | WTR Disposal | Debolt | 2177 | Inj. 156 $e^3m^3$ (1999-2011) |
| 200/c-092-L 094-B-16/00 | Disposal | Susp WTR Disp | Baldonnel | 2590.8 | Inj. 37.3 $e^3m^3$ (1978-1995) |
| 200/a-083-A 094-G-01/00 | Source | Susp WTR | Baldonnel | 1603 | Perfs and acid, never on stream |
| 200/b-094-C 094-G-01/05 | Source | Susp WTR | Baldonnel | 2297 | Acid, flowed water, never on stream |
| 200/b-042-F 094-G-01/02 | Disposal | ABD WTR Disp | Halfway | 1559.4 | Inj. 19.9 $e^3m^3$ (1970-1987) after gas production |
| 200/d-025-G 094-G-01/02 | Disposal | WTR Disposal | Baldonnel | 1675 | Inj. 81.2 $e^3m^3$ (2002-2011) |
| 200/d-055-I 094-G-01/00 | Disposal | WTR Disposal | Baldonnel | 1399.3 | Inj. 197 $e^3m^3$ (1970-2011) |
| 200/b-068-J 094-G-01/00 | Disposal | WTR Disposal | Baldonnel | 1739.2 | Inj. 689 $e^3m^3$ (1969-2011) after gas production |
| 200/a-031-F 094-H-04/00 | Disposal | WTR Disposal | Baldonnel | 1553 | Inj. 507 $e^3m^3$ (1969-2011) after gas production |

**Table P-2.** Water source and disposal wells, Foothills Study Area.

# METHODOLOGY

## Geologic Methodology

Several deep subsurface aquifers overlying the Montney occur throughout the Plains and Foothills play areas (Fig. P-4). Aquifers lying below the Montney were not considered in the Plains area, as well control is too poor for reasonable characterization. In the Foothills area, however, Debolt carbonates underlying the Montney were also included, as they contain substantial hydrocarbon reservoirs, and thus viable aquifer targets.

Stratigraphic mapping and reservoir characterization were supported by interpretation of well logs, cores, sample cuttings logs (from wellsite) and well test data. The Plains area stratigraphic database comprises data from approximately 1300 wells distributed relatively evenly across the map sheet (Enclosure P-1). In the Foothills area, approximately 900 wells were used; note that many of these were drilled along tight northwest-southeast anticlinal trends, where development has historically focused (Enclosure P-2). Wells with modern log suites, including neutron-density logs, were selected for inclusion in the study, while some older wells with less complete log suites, but with relevant core or test data, were added. Thus, there are a substantial number of wells, most of them older and with less complete log suites, that were excluded. Some of these would be useful to include in more local, detailed follow-up studies.

To establish a stratigraphic framework, eight regional cross-sections for the Plains Study Area (Cross-sections A-A' to D-D' and AA-AA' to DD-DD') and nine regional cross-sections for the Foothills Study Area (Cross-sections E-E' to H-H' and EE-EE' to II-II') were constructed (Enclosures P-1, P-2). In addition, a separate set of four cross-sections was constructed to illustrate correlation of the Debolt Formation and deeper strata in the Foothills Study Area (Cross-sections D1-D4). Cross- sections were used to tie to correlations from the literature and previous studies, and to calibrate observations from cores and sample cuttings logs.

Logs from each well were tied to the cross-section grid to interpret stratigraphic tops, which are tabulated in Appendix P-1. All full-diameter cores were assigned to the correct stratigraphic unit, and core analysis (porosity / permeability) data were tabulated by formation (Appendix P-2). Numerous core descriptions from PRCL files and the literature were used for reservoir characterization, and several new cores were logged at the MEMPR core storage facility in Charlie Lake. Core descriptions are presented in Appendix P-3. Incorporating all these data and interpretations, PRCL produced regional maps of key stratigraphic surfaces and intervals throughout the aquifer section. Core and sample data were tied to logs to estimate reservoir quality, which was also systematically mapped.

Regional hydrostratigraphy and flow characteristics were examined as stratigraphic work progressed. Results are combined with the stratigraphic mapping to produce a regional characterization of each aquifer unit.

## Hydrogeologic Methodology

### Data Screening

#### *DST Quality Coding*

Fluid pressures measured by DSTs may not reflect true undisturbed formation pressures for a variety of reasons, including:

1. Mechanical error/failure during the test.
2. Inaccurate or incomplete recording of test data.
3. Formation pressure modification during drilling (e.g., supercharge).
4. Improper extrapolation of the pressure test data.
5. Production induced drawdown.

Pressures exhibiting effects 1 through 4 can be recognized and screened-out by using strict quality control guidelines. Quality codes, which relate to the success of the test and the confidence that can be placed in the accuracy of the pressure, have been assigned to the DSTs and allow the interpreter to quickly and easily differentiate between the highest quality pressures (coded as A and B quality), those which are less reliable (coded as C to D quality), and those which are not usable (coded as E, F and G quality). The good quality pressures are favoured when building an interpretation, and the less reliable pressures are only used when absolutely necessary, in areas where data density is sparse. For most of the pressure tests, initial reservoir pressures were determined by Horner analysis, where there were sufficient shut-in pressure build-ups for extrapolation. Table C-1 provides a summary of drillstem test quality codes.

Once the initial pressure screening was complete, formation pressure data were converted to hydraulic head and mapped. It was during this stage that pressure data affected by production were identified and removed from the dataset. Also during this stage, pressures overestimating hydraulic head due to their tested interval location in gas pools were identified and removed.

Appendices C-1a and C-1b include all pressure data for hydraulic head mapping for the Plains Study Area and Foothills Study Area, respectively.

| QUALITY CODE | QUALITY RATING | TEST CHARACTERISTICS |
|---|---|---|
| A | High Quality | Test mechanically sound, both shut-in pressures have stabilized. |
| B | Requires Extrapolation | Slight mechanical difficulties, shut-in pressures not fully stabilized, but pressures have been extrapolated and should be accurate. |
| C | Requires Extrapolation, use with caution | Some mechanical difficulties apparent, shut-in pressures not fully stabilized, but pressures have been extrapolated and can be used with caution. |
| D | Test Results Questionable | Test not mechanically sound and pressures have not stabilized enough to obtain reasonable extrapolation, thus the results are questionable. |
| E | Low Perm, High Pressure, Low Quality | Low permeability, low pressure but problems encountered throughout test and/or unable to extrapolate. Pressure should NOT be used. |
| F | Low Perm, High Pressure, Low Quality | Low permeability, high pressure but problems encountered throughout test and/or unable to extrapolate. Pressure should NOT be used. |
| G | Misrun, Low Quality | Severe mechanical difficulties: packer failure, tool failure, plugged tool. Pressures invalid if present. |
| E, F, G | Low Quality | See E, F, G above. |

**GEOSCIENCE B.C MONTNEY BASIN**

| | | | |
|---|---|---|---|
| Project | GBMB | Author | Sheldon Thistle |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Summary of Drillstem Test Quality Codes**

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Table C-1

## *Water Chemistry*

Water analyses within both the Plains Study Area and the Foothills Study Area were obtained from the geoFluids® database. This resulted in 6,836 water analyses identified in the Plains Study Area and 3,697 in the Foothills Study Area, which included duplicate water analysis files and multiple sampling events from the same well. Each water analysis identified has undergone a rigorous screening procedure in an attempt to distinguish contaminated water samples from true formation water. In order to systematically screen this large volume of geochemical data, a multiple phase screening approach was developed. Each screening phase is described as follows:

- Phase One: The initial phase consisted of screening out analyses that were incomplete in terms of the cations and anions reported. If no values existed for ions routinely analyzed (Na, K. Mg, Ca, Cl, $SO_4$, $HCO_3$, and $CO_3$) the water analysis was removed and not included in the interpretation. Additionally, ion ratios were calculated by converting ion concentrations from milligrams per litre (mg/L) to milliequilvalents per litre (Meq/L) and dividing the sum of the cations by the sum of the anions. If the resulting ion ratio was out of range by more than 10% (<0.90 or >1.10), the analysis was considered unreliable and removed.

- Phase Two: A number of parameters were screened according to their values that potentially indicate contamination by a variety of fluids introduced during well drilling and completion activities. Specific parameters and their acceptable criteria include:
  - pH range between 6.0 – 8.5
  - OH ion less than 0
  - $CO_3$ ion greater than 0; if pH is 8.1 or greater

- Phase Three: A multi-variant cluster analysis was constructed consisting of a cross plot of sodium over chloride ratio (Na/Cl) versus magnesium over sulphate plus bicarbonate ratio ($Mg/SO_4 + HCO_3$). The multi-variant cluster analysis is effective in characterizing formation water and distinguishing samples from several types of contamination including gelchem and potassium chloride (KCl) drilling fluids. The cut-off values for the Na/Cl ratio presented on the cross plots ranged from 0.8 to 3.5. A cross plot of Na/Cl ratio versus $Mg/(SO_4 + HCO_3)$ was constructed for each stratigraphic unit. These cross plots illustrate where selected formation water analyses used for TDS mapping control points for a specific formation plot in relation to all screened analyses for all formations.

All water analyses remaining after this multi-phase screening procedure were further evaluated using the cross plot as a tool to identify samples that may still be unrepresentative of formation water. Table C-2 summarizes the resultant analyses screened out during each phase.

| STUDY AREA | NO. OF RAW ANALYSES | NO. OF ANALYSES AFTER PHASE ONE | NO. OF ANALYSES AFTER PHASE TWO | NO. OF ANALYSES AFTER PHASE THREE | PERCENT OF RAW ANALYSES REMAINING PRIOR TO TDS MAPPING |
|---|---|---|---|---|---|
| Plains Study Area | 6,836 | 3,453 | 2,191 | 1,259 | 18% |
| Foothills Study Area | 3,697 | 1,586 | 809 | 499 | 13% |

**GEOSCIENCE B.C MONTNEY BASIN**

| | | | |
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| Project | GBMB | Author | Sheldon Thistle |
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| File | *.idd | Reviewer | David Hume |

**Summary of Resultant Analyses Screened Out During each Screening Phase**

Canadian Discovery Ltd.

Table C-2

Total dissolved solids (TDS) in mg/L were mapped as an indicator of formation water salinity and potability. TDS data were plotted and contoured based on water analyses screened as described in the previous section. Water analyses were correlated stratigraphically based on test interval depths and categorized by PRCL geologists. For water analyses that were not categorized by PRCL, formations identified in geoFluids® by IHS were used. TDS maps were constructed for each formation or group of formations within the Plains and Foothills study areas. At this stage, a final screening of TDS values was performed by observing plotted values for a particular map unit and investigating suspect values that were orders of magnitude different from adjacent control points. Points that were determined to be unreliable were removed. When one well had multiple TDS values, the value that best fit the observed trend was honoured and the other values ignored. Furthermore, recovery descriptions were used when the water analysis chemistry was questionable, whereby larger recoveries (100s of metres) were assumed to represent formation water, while small recoveries (10s of metres) were often classified as mud filtrates. Finally, duplicate water analysis files for each map unit were removed prior to finalization of the TDS maps. Table C-3 provides a summary of water analyses used as control points for TDS mapping.

### *Piper Plots*

All of the screened water chemistry analyses were plotted on a modified ternary diagram, a Piper Diagram, which enables the comparison of all major ions on the same graph. Piper diagrams were constructed for each formation or group of formations to accompany the TDS map. The Piper diagram is a useful tool for hydrogeologists to assist in establishing groundwater origin and hydrochemical facies. The cations and anions presented on the diagram are plotted as a percentage in Meq/L and projected onto the upper portion of the diagram where the formation water may be categorized.

To ensure only representative formation waters were used to construct the Piper diagrams, the screened water analyses used as control points to create the TDS maps were also used to create the Piper diagrams.

### *Formation Water Grouping Cross Plot*

A second multi-variant cross plot using ion ratios was constructed to illustrate formation water grouping and mixing trends. The cross plot consisted of $HCO_3$/Cl ion ratio versus Na + Cl ions, and is designed to demonstrate the trend from meteoric-influenced groundwater to connate-type groundwater having longer residency time and fluid-rock interaction.

Appendices C-2a and C-2b include all water chemistry data used in the Plains Study Area and Foothills Study Area, respectively.

| PLAINS STUDY AREA | | FOOTHILL STUDY AREA | |
|---|---|---|---|
| MAP UNIT | NO. OF CONTROL POINTS | MAP UNIT | NO. OF CONTROL POINTS |
| Peace River Grp. (Paddy & Cadotte Fms.) | 55 | N/A | - |
| Bluesky Fm. | 16 | Bullhead Group (Bluesky & Gething Fms.) | 14 |
| Gething Fm. | 13 | | |
| Cadomin Fm. | 62 | | |
| Nikanassin Fm. | 18 | Nikanassin Fm. | 6 |
| Baldonnel Fm. | 39 | Baldonnel Fm. | 80 |
| Halfway Fm. | 62 | Halfway Fm. | 28 |
| N/A | - | Debolt Fm | 25 |
| Total Analyses used for Control Points | 265 | Total Analyses used for Control Points | 153 |

**GEOSCIENCE B.C MONTNEY BASIN**

| | | | |
|---|---|---|---|
| Project | GBMB | Author | Sheldon Thistle |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Summary of Water Analyses used as Control Points for TDS Mapping**

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Table C-3

### *$H_2S$ Chemistry Mapping*

Hydrogen sulphide gas is a potential by-product of water production in the area. For this reason, $H_2S$ concentrations from publicly available gas chemistry analyses were plotted.

Appendices C-3a and C-3b contain the gas chemistry data used in the Plains Study Area and Foothills Study Area, respectively.

### *PE Graphing*

A Pressure versus Elevation (PE) graph is a tool which helps in determining pressure connections between formations, and also provides an idea of the magnitude of hydraulic gradient for an aquifer in an area. It also is used to define the limits of under-pressured, gas charged deep basin systems

Good quality pressures and elevations (mASL) that were recorded for the various units are plotted on the PE Graph. Water and gas gradients can then be defined to identify the various systems.

### *Hydraulic Head Mapping*

Hydraulic head was calculated using the following equation:

Hydraulic head = P/g + E

*Where:*

P = Pressure (kPa)

g = Pressure Gradient (kPa/m)

E = Elevation of the pressure recorder (mASL)

Although many pressure values recorded are gauge pressures, in the pre-digital era (circa 1980), pressures were recorded as gauge pressure with atmospheric pressure equal to zero. Later digital gauge pressures may be absolute or gauge. For this reason, all pressures are considered to be absolute, fully realizing that some pressures may be gauge and others absolute. Normal atmospheric pressure is approximately 100 kPa and using an approximate pressure gradient of 10 kPa/m, this could possibly represent and a calculation error of 10 m. Knowing this error could exist, the lowest contour interval used was 20 m when mapping hydraulic head across the study area, in order to minimize the effect it could have on the contour distribution.

### *Available Head Mapping*

Available head is a measure of the water column height that is available for pumping before the potentiometric surface is drawn down enough that it intersects the top of the completed zone. For the purposes of this study, the available head was calculated as the difference in elevation between the potentiometric surface and the top of the completed formation at the wellbore.

Total available head was estimated for each well using the hydraulic head contour map generated for that unit.

Appendices C-4a and C-4b contain tabulated available head data used in the Plains Study Area and Foothills Study Area, respectively.

### *Aquifer Storativity Mapping*

The volume of water in a confined aquifer is contained in the primary and secondary pore spaces, and is released from storage by dropping the pressure at the sandface of a well. In cases where aquifers or reservoirs are unconfined, the pore spaces can be pumped dry as the water level drops below the completed interval on an area-wide basis, but in confined aquifers, pore spaces cannot be pumped dry until all water contained in storage is first released.

#### *Water Volume Contained in Storage*

Specific storage ($S_s$) is the volume of water per unit volume of a saturated formation that is expelled from storage due to the compression of the aquifer and expansion of water per unit change in hydraulic head, as the aquifer pressure declines due to production.

The following equation developed by Jacob (1940) and Cooper (1966) expresses specific storage as:

$$S_s = \Upsilon(\alpha + \Phi\beta)$$

*Where:*

$\Upsilon$ = specific weight of water or density pressure gradient ($kg/m^2s^2$ or $N/(m^2 \cdot m)$)

$\alpha$ = aquifer compressibility ($m^2/N$ or $Pa^{-1}$)

$\Phi$ = porosity

$\beta$ = water compressibility ($m^2/N$ or $Pa^{-1}$)

Aquifer (rock) compressibility varies with aquifer porosity. As such, a table was generated (Table C-4) assigning an aquifer compressibility term to aquifer porosity values as mapped by PRCL. Water compressibility is weakly a function of aquifer temperature, salinity and pressure; therefore, an average of these

| CONSOLIDATED SANDSTONES (HALL'S CORRELATION) | | CONSOLIDATED LIMESTONES (VAN DER KNAAP'S CORRELATION) | |
|---|---|---|---|
| POROSITY (%) | ROCK COMPRESSIBILITY, $\alpha$ (1/kPA) | POROSITY (%) | ROCK COMPRESSIBILITY, $\alpha$ (1/kPA) |
| 5 | 9.86E-7 | 3 | 2.32E-6 |
| 7 | 8.27E-7 | 5 | 1.74E-6 |
| 9 | 7.37E-7 | 7 | 1.16E-6 |
| 11 | 6.67E-7 | 9 | 9.43E-7 |
| 13 | 6.32E-7 | 11 | 7.83E-7 |
| 15 | 5.96E-7 | 13 | 6.96E-7 |
| 17 | 5.66E-7 | 15 | 5.66E-7 |
| 19 | 5.40E-7 | 17 | 4.79E-7 |
| 21 | 5.18E-7 | 19 | 4.21E-7 |
| 23 | 4.99E-7 | 21 | 3.92E-7 |
| 25 | 4.82E-7 | 23 | 3.48E-7 |
| 27 | 4.67E-7 | 25 | 3.05E-7 |

**GEOSCIENCE B.C MONTNEY BASIN**

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|---|---|---|---|
| Project | GBMB | Author | Sheldon Thistle |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Summary of Rock Compressibility vs. Porosity**

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Table
C-4

three parameters was calculated, and a specific water compressibility value was assigned to each formation. Table C-5 summarizes terms used to calculate Specific Storage.

### *Storativity*

The storativity of a confined aquifer is a product of the specific storage ($S_s$) and the aquifer thickness. This accounts for all water released by the compressibility of the aquifer and by the expansion of formation water across the entire thickness of the aquifer. For the purposes of this study, the aquifer thickness was determined using net porous reservoir maps as provided by PRCL. If a net porous reservoir map was not provided, a representative average thickness was assumed based on examination of borehole wireline logs. The equation for storativity is as follows:

$$S = hS_s$$

*Where:*

h = aquifer thickness (m)

$S_s$ = Specific Storage

### *Total Water Volume*

Total water volume released from storage assuming all available head is drawn down during pumping.

$$V_w = SAdh$$

*Where*:

A = area

S = storativity

dh = change in hydraulic head (m) – available head (in this case dh represents all available head).

For the purpose of this study, the area used was equal to 2,589,988 $m^2$, which is equal to the area of one DLS section (1 $mile^2$), a standard area used in the oil and gas industry when calculating drainage of hydrocarbon pools. A total water volume summary table is provided in the Conclusions and Recommendations section of both study areas.

| PLAINS STUDY AREA | | | | | |
|---|---|---|---|---|---|
| FORMATION | AVERAGE TDS (mg/L) | AVERAGE FORMATION TEMPERATURE (ºC) | AVERAGE FORMATION PRESSURE (kPA) | SPECIFIC WEIGHT OF WATER, $\gamma$ (kPA/m) | WATER COMPRESSIBILITY, $\beta$ (1/kPA) |
| Peace River | 19,200 | 47 | 8,700 | 9.870 | 4.21E-7 |
| Bluesky | 18,800 | 48 | 8,500 | 9.862 | 4.15E-7 |
| Cadomin | 22,900 | 60 | 12,000 | 9.846 | 4.12E-7 |
| Nikanassin | 26,000 | 56 | 10,300 | 9.880 | 4.09E-7 |
| Baldonnel | 36,000 | 44 | 12,500 | 10.012 | 3.99E-7 |
| Halfway | 152,600 | 54 | 15,300 | 10.789 | 3.31E-7 |

| FOOTHILLS STUDY AREA | | | | | |
|---|---|---|---|---|---|
| FORMATION | AVERAGE TDS (mg/L) | AVERAGE FORMATION TEMPERATURE (ºC) | AVERAGE FORMATION PRESSURE (kPA) | SPECIFIC WEIGHT OF WATER, $\gamma$ (kPA/m) | WATER COMPRESSIBILITY, $\beta$ (1/kPA) |
| Bluesky | 22,000 | 40 | 9,500 | 9.921 | 4.16E-7 |
| Gething | 21,800 | 41 | 10,500 | 9.920 | 4.14E-7 |
| Nikanassin | 25,000 | 40 | 11,000 | 9.948 | 4.11E-7 |
| Baldonnel | 20,400 | 49 | 12,400 | 9.885 | 4.10E-7 |
| Halfway | 116,000 | 56 | 14,000 | 10.511 | 3.51E-7 |
| Debolt | 62,000 | 86 | 21,300 | 9.994 | 3.85E-7 |

GEOSCIENCE B.C MONTNEY BASIN

| | | | |
|---|---|---|---|
| Project | GBMB | Author | Sheldon Thistle |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

Summary of Terms used to Calculate Specific Storage

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Table C-5

### *Permeability Analysis*

Permeability values were obtained from publicly-available core analyses, and analyses of publicly available DST flow and build-up curves.

### *DSTS*

Drillstem tests were analyzed to determine the permeability of the aquifer within a volume that was sufficiently large enough to give a reasonable estimate of the permeability and deliverability of the reservoir.

Initially, information pertaining to each drillstem test was collected by looking at the available DST reports and charts, and summarizing the information so the test could be analyzed. An assessment of test quality was performed as well as a verification of the fluid recovered and flow periods during the test. Values for productive thickness and porosity were determined from borehole well logs. Finally, increments for the test charts were entered into a separate table and were transferred to the Fekete F.A.S.T. WellTest program for aquifer evaluation and simulation.

### *Deliverability Estimates*

Well deliverability is difficult to estimate due to uncertainties in development plans. Variables such as how many wells and their spacing distance will greatly affect how much water can be produced or injected into a formation. In order to be able to accurately estimate deliverability, different development scenarios would need to be run in a detailed numeric groundwater or reservoir model. However, in order to come up with a ballpark estimate of deliverability, CDL ran some test case scenarios that are detailed below.

Deliverability was determined for reservoir models that are based on the DST analyses from the aquifer and represent likely reservoir types for the various aquifers. The two scenarios modeled are as follows:

- one well centred within one section, with the four sides of the section representing no-flow boundaries (1609 metres by 1609 metres), and;
- one well centred within one township that is essentially unbounded, with the township representing no-flow boundaries (9654 metres by 9654 metres).

Using Fekete's F.A.S.T WellTest software, each scenario produced up to three forecast deliverability curves. If a skin due to damage ($s_d$) was calculated much greater than 0.00, then second and third deliverability curves were added to the forecast, representing no near-wellbore damage ($s_d$ = 0.00), and a stimulated wellbore ($s_d$ = -4 .00), respectively. If a skin due to damage was calculated near 0.00, then only a second deliverability curve was added, representing a stimulated wellbore ($s_d$ = -4 .00).

Appendices C-5a and C-5b contain the estimated water deliverability curves for the Plains Study Area and Foothills Study Area, respectively.

# GEOLOGY AND RESERVOIR CHARACTERIZATION OF POTENTIAL AQUIFER UNITS

## Regional Geology

A thick section of Paleozoic and Mesozoic strata were deposited and are preserved in the Montney play areas of northeastern British Columbia (Fig. P-4). Our focus will be on aquifers in the Jurassic / Cretaceous section overlying the Montney reservoir, and on the Mississippian (Debolt) aquifer immediately underlying the Montney in the Foothills study area.

The Debolt Formation forms the uppermost subdivision of the Mississippian Rundle Assemblage, a thick package of platform carbonate ramp deposits mappable throughout the Montney play area (Richards et al., 1994). Some studies have subdivided the Debolt section stratigraphically, and have interpreted broad regional facies trends (e.g., PRCL, 1995, 2000). This level of detail is beyond the scope of the current study, particularly as there are relatively few complete Debolt penetrations in the Foothill Study Area (Cross-sections D1-D1’ to D4-D4’).

Triassic and Jurassic strata in northeastern British Columbia were deposited in marine to marginal marine environments in a passive margin setting on the western edge of the North American craton (Davies, 1997a; Poulton et al., 1994).

During Late Jurassic and Cretaceous time, discrete landmasses termed allochthonous terranes collided with the western edge of the North American craton, causing mountain building to occur. Rapidly-subsiding foredeeps formed between the western orogenic belt and the eastern stable craton, and were filled with thick clastic successions shed from the rising orogen during Cretaceous and Tertiary time (Stott, 1984).

Tertiary to Recent erosion has removed the upper part of the westerly-derived clastic wedge, such that predominantly Upper Cretaceous strata crops out in the Plains Study Area, and in the eastern part of the Foothills Study Area (Enclosures P-3, P-4). Westward, thrust faulting in the Rocky Mountain deformed belt brings older strata to surface, removing some of the younger potential aquifer, particularly in the Foothills Study Area.

In the following discussion, we review, from oldest to youngest, each deep subsurface unit with substantial regional aquifer potential. Units with little or areally-limited aquifer potential are not discussed, or are summarized briefly. Basic regional correlations are illustrated in the various regional cross-sections.

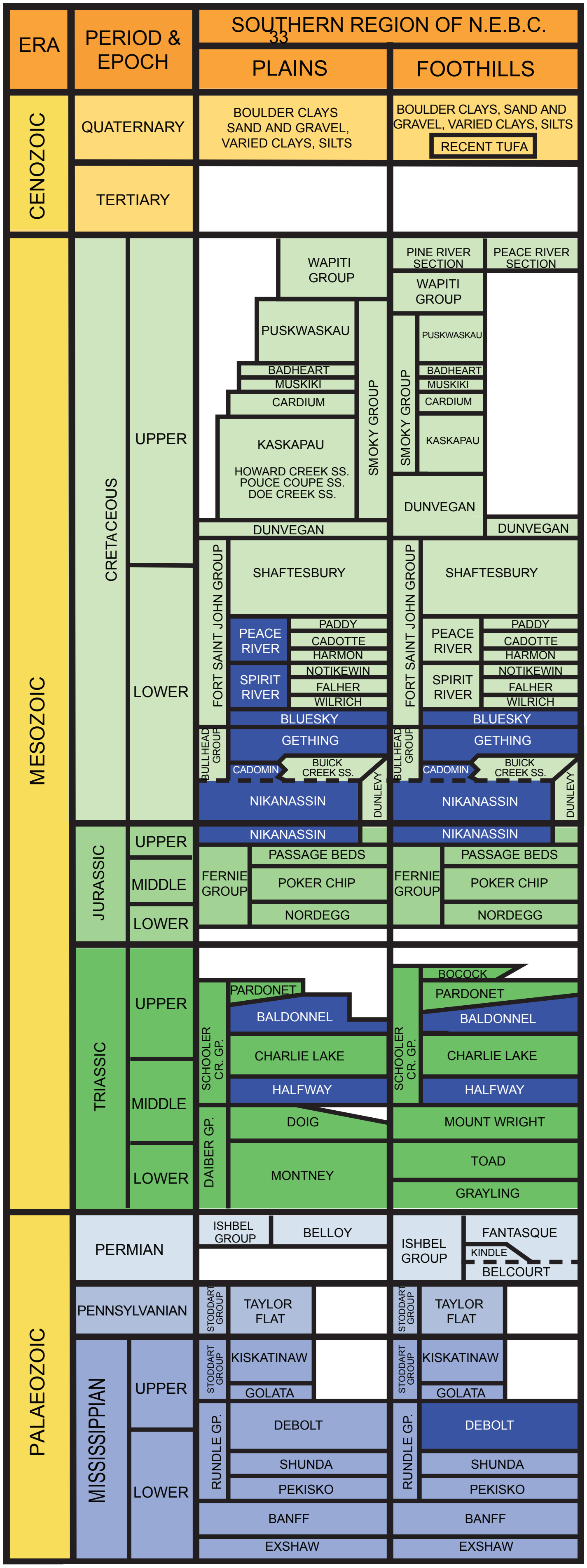



**Figure P-4.** Stratigraphic columns, N.E.B.C. Peace River Plains and Adjacent Foothills. Potential aquifers are shown in dark blue with white text.

## Debolt Formation

### Definition and Distribution

Mississippian strata of northeastern B.C. were deposited over an active and complex basement framework. PRCL (1995) documented three major depositional phases, after the Late Devonian to Mississippian Antler Orogeny:

1. Early progradation, where dominantly argillaceous sediments of the Banff Formation clinoformally fill an open basin. These strata were succeeded by a stable carbonate ramp setting, which saw deposition of the Pekisko, Shunda, and lower Debolt.

2. A renewal of tectonic activity at the close of lower Debolt time caused widespread erosion, followed by unconformable onlap of the upper Debolt. The upper Debolt section can be mapped in five depositional successions featuring initial transgressive subtidal deposits grading up to proximal carbonate ramp facies.

3. Increased subsidence linked to a regional extensional regime provided accommodation space for deposition of the Stoddart and Ishbel groups in the Peace River Embayment / Dawson Creek Graben Complex (Barclay et al., 1990; PRCL, 1995).

While Stoddart and Ishbel strata contain productive facies and mappable reservoir trends in Alberta (Barclay and Krause, 2002), they are buried deeply beneath the Plains and Foothills study areas, and there are relatively few penetrations. Therefore, we have not attempted to assess their aquifer potential for this study.

Debolt strata produce gas and oil in the northern part of the Foothills Study Area, and thus we can make some assessment of their potential in that area. Debolt penetrations in the Plains Study Area are scattered, relatively deep, and with little or no production – so we have not attempted to assess the Debolt in the Plains Study Area.

Enclosure P-5 is a gross isopach map of the Debolt (Debolt to Shunda interval on Cross-sections D1-D1' to D4-D4') for the Foothills Study Area. We have displayed computer-generated contours, as there are too few full Debolt penetrations to support reasonably interpretive hand contouring. Note that many of the producing wells penetrate only the upper part of the Debolt, and thus do not provide isopach values. Reservoir-quality rock and hydrocarbon production tend to occur toward the top of the formation, so gross thickness is not a good measure of aquifer potential.

Enclosure P-6, Depth to top Debolt in the Foothills Study Area, shows a range from 1950 m in the northeast to greater than 3000 m in the west. The map does not adequately illustrate the structural complexity of the Debolt surface, as well control is concentrated along northwest-southeast anticlinal trends.

### Aquifer Lithologies and Reservoir Quality Assessment

Stacked, shoaling-upward carbonate successions are evident on well logs in Cross-sections D1-D1' to D4-D4'. Where structurally deformed in the Foothills Study Area, Debolt carbonates exhibit substantial reservoir quality in clean, grain-supported shallow water facies, and where dolomitized, either through low-temperature alteration, or through higher-temperature hydrothermal dolomitization. For example, core from well d-50-K/94-A-12 (Appendix P-3) recovered porous dolopackstones; Figure P-5 illustrates porosity development through dolomitization. Durocher and Al-Aasm (1997) interpreted diagenetic processes in the Debolt at Blueberry Field (94-A-12).

Unfortunately, a systematic regional assessment of Debolt aquifer distribution and quality cannot reasonably be made, given the scant distribution of wells and core. The spectrum of facies and sorting, and the variable limestone/dolomite content make it difficult to assess reservoir quality from logs alone, particularly in older wells lacking modern log suites. Where core data are available, we have attempted to represent the distribution of carbonate lithologies (in the cored sections only) using average grain densities (Enclosure P-7). Purple hues, representing higher grain densities (and thus dolomite) are predominant in a west-east trend through Blueberry Field, while blue hues, representing lower grain densities (limestone) are more dominant elsewhere. Similarly, Enclosure P-8 shows average porosities for cored intervals in the Debolt; note that porosities are greatest along the same west-east dolomitized trend.

Local assessment of Debolt aquifer potential must build upon this regional knowledge, combined with an intensive examination of local well control, core, sample cuttings, and production / test data.

## Doig Formation

The Lower to Middle Triassic Doig Formation overlies the Montney directly, and can be mapped throughout the Montney play fairway (see Cross-sections). However, it is dominated by argillaceous strata. Sandstone bodies, while locally thick and continuous, generally exhibit relatively low porosity and permeability, and are hydrocarbon-saturated through much of the study area.

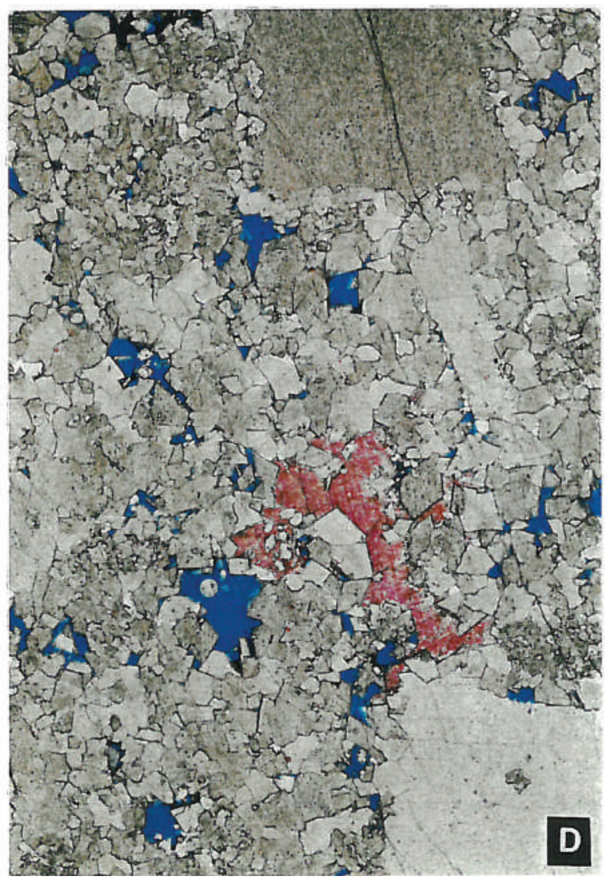
As regional aquifer potential is limited, we have not assessed the Doig Formation in this study.

A

Core: leached pellet skeletal grainstone with moldic vuggy porosity after pellets and skeletal particles in fine crystalline dolomite with some intercrystalling porosity. White calcite vug and fracture fill. Slight oil stain. 7144 ft.


Very fine to fine crystalline euhedral and planar-S dolomite. Relict Texture after leaching of pellet skeletal grainstone. Moldic and intercrystalline porosity. 7140 ft.; X25


Very fine to fne crystalline dolomite, abundant planar-E interlocked with mosaics planar-S primarily intercrystalline porosity with scattered calcite void filling. 7107 ft.; X25




Fine to medium crystalline dolomite with large crinoid plates top and bottom. Intercrystalline and vuggy porosity with some late calcite void filling which is possibly of late vadose meteoric origin. 7140 ft.; X25

**Figure P-5.** Core and thin-section photo montaged-59-I/94-B-9 Upper Debolt Unit B

## Halfway Formation

### Definition and Distribution

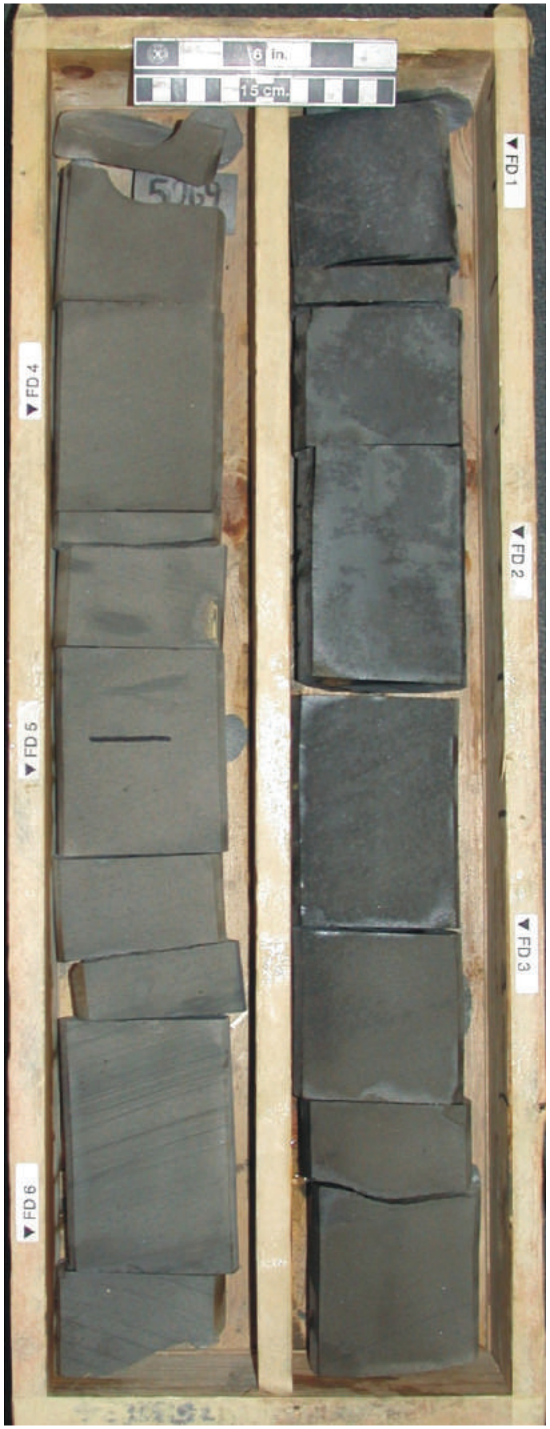
The Halfway encompasses shallow marine sandstone parasequences, deposited along the western margin of the North American craton in barrier island, shoreface, and tidal inlet channel environments (Gibson and Edwards, 1990). It occurs west of the Sixth Meridian in Alberta and adjacent B.C., thinning to a northern subcrop edge in 94G and H. Halfway sand bodies are stratigraphically isolated in updip areas, but pass southwestward into a broad, continuous shelfal sandstone complex, which spans the entire Montney play fairway.

Numerous papers have been written on conventional Halfway reservoirs (e.g., Caplan and Moslow, 1999; Norgard, 1997; Spence and Evoy, 1997; Willis and Moslow, 1994; Zonneveld et al., 1998). Zonneveld et al. (1997) documented outcrop equivalents in the B.C. Foothills, which include more distal clastics and a greater proportion of bioclastic carbonates.

In the Plains Study Area, Halfway sandstones form a blanket, thinning eastward from more than 100 metres thick in the far west, to less than 10 metres in the northeastern corner (Enclosure P-9). Burial depths range from less than 1400 metres in the north and northeast, to greater than 3200 metres in the southwest (Enclosure P-10). In the Foothills Study Area, the Halfway ranges from less than 20 to more than 80 metres thick, but lies generally between 30 and 50 metres (Enclosure P-11). Burial depths in the Foothills range from less than 1400 metres in the northeast to greater than 2100 metres in a few wells in the south (Enclosure P-12). It is more difficult to pick the Halfway consistently to the west, as the entire Charlie Lake / Halfway succession becomes sandier (e.g., Cross-sections GG-GG', HH-HH'). Consequently, some variability in isopach values may arise from inconsistencies in stratigraphic picking.

### Aquifer Lithologies and Reservoir Quality Assessment

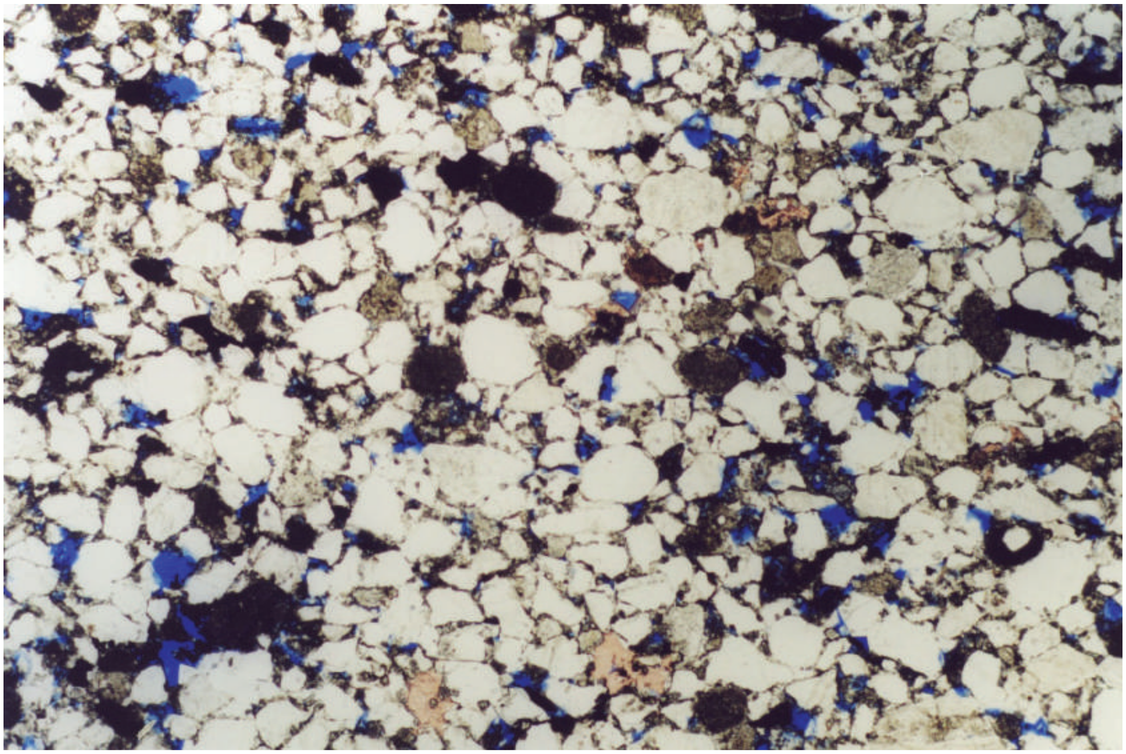
Halfway sandstones are primarily quartzarenites and sublitharenites, with local bioclastic (shell debris) sandstones and coquinas (Figs. P-6, P-7; Appendix P-3). Major cements include silica, carbonates, and anhydrite. At Tommy Lakes, just north of the Foothills Study Area (present depth about 1000 metres), Zonneveld et al. (1998) described Halfway shoreface strata as quartzose, well-sorted, trough to planar cross-stratified, very fine- to medium-grained sandstone, with porosities of 3-12%, and permeabilities ranging between 0.1 and 3 mD. Coquinoid tidal inlet channel fills provide reservoir sweet spots, with porosities of 12-19% and permeabilities ranging between 15 and 90 mD (Core log d-55-A/94-G-9, Appendix P-3). At Monias in the Plains Study Area, (present depth about 1500 metres), Norgard (1997) calculated average porosity of 8.8% and average permeability of 5.2 mD in quartzose sandstones with secondary solution porosity.



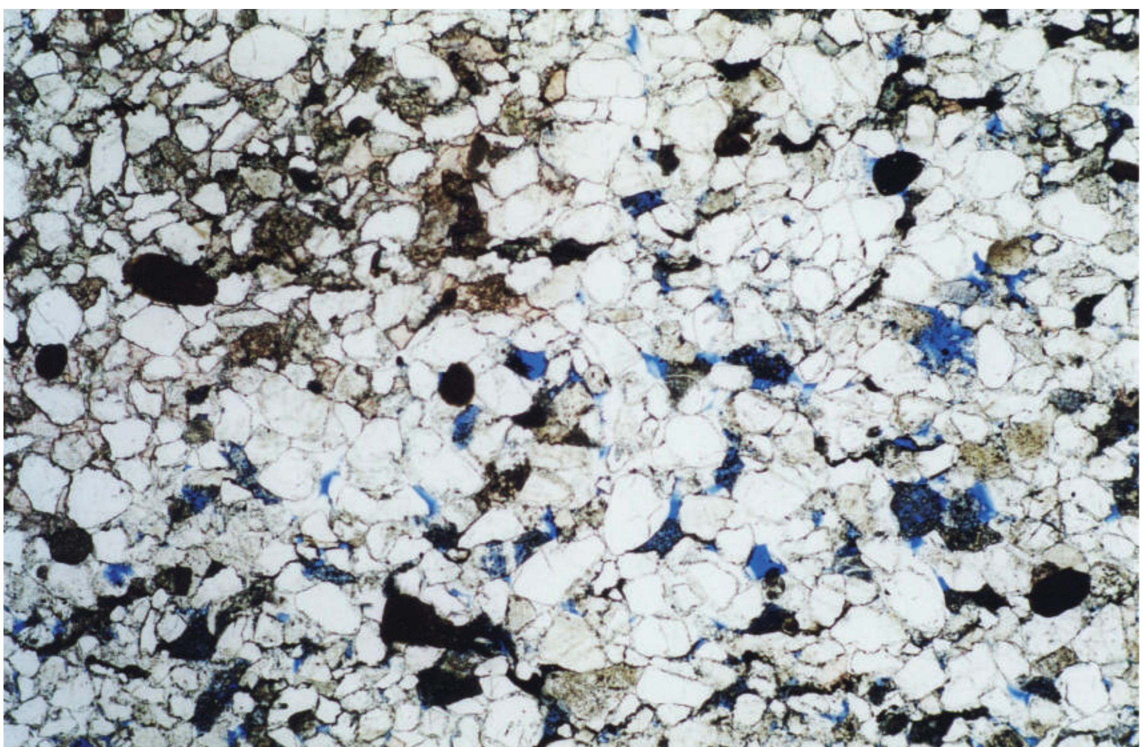

Very fine-grained, tight, cemented Halfway shoreface sandstone. d-99-I/93-P-8; 2587 m

Laminated medium-grained shoreface sandstone in Halfway Formation at Blueberry. White "specks" are leached lithic sand grains, yielding limited secondary solution porosity. b-44-D/94-A-13, 1655.9 m

**Figure P-6.** Core photo montage, Halfway Formation



Thin section, Halfway shoreface sandstone at Elmworth. Note solution of some larger grains, creating secondary porosity. 12-9-70-10W6M; 2677.2 m



Thin section, Halfway shoreface sandstone, tightly carbonate cemented. d-99-I/93-P-8; 2589.1 m

**Figure P-7.** Thin section photo montage, Halfway Formation.

Even deeper, at Tupper d-99-I/93-P-8 in the southeastern Plains Study Area (present depth 2600 metres), the shoreface succession is finer-grained, and tightly cemented by silica, calcite, and anhydrite (Core log d-99-I/93-P-8, Appendix P-3; Fig. P-7). There is patchy solution porosity, but core analysis porosities are 5-7%, and permeabilities <0.5 mD.

Appendix P-2 contains porosity-permeability cross-plots for Halfway core analyses in both the Plains and Foothills, which show reasonably linear relationships (on a semi-log plot). In the Foothills, a porosity of 12% should correspond to a permeability of about 10 mD whereas in the Plains, a permeability of 2-3 mD is indicated. We selected 6% and 12% cutoffs on sandstone density porosity logs to illustrate the distribution of porous sandstones within the Halfway.

In the Plains Study Area, porous sands meeting the 6% cutoff are relatively continuous and greater than 10 metres thick only in Twp. 79 and northward (Enclosure P-13). Applying the 12% cutoff, we see only isolated porous sandstone bodies (Enclosure P-14). In the Foothills Study Area, porous sands exceeding the 6% porosity cutoff are continuous and relatively thick in the northeastern half of the map sheet, but are absent in deeper, southwestern areas (Enclosure P-15). Very little sandstone meets the 12% porosity cutoff (Enclosure P-16), although one must note that generally poor log quality (washed out hole) is common across the Halfway, and that we thus could not assess reservoir quality in many wells (indicated as PL (poor logs) on the maps). Enclosures 17 through 20 show average porosity values for the sandstones that meet or exceed the different porosity cutoffs in both areas.

We conclude that Halfway sandstones, although thick and continuous throughout the Montney play fairway, generally suffer diagenetic degradation with depth, and represent potential aquifer targets only where burial depths are relatively shallow.

## Charlie Lake Formation

Above the Halfway, Charlie Lake strata comprise a succession of intercalated sandstones, siltstones, dolomites and anhydrite, deposited in nearshore-marine, shoreline, tidal flat, lagoon, sabkha, and aeolian environments (Edwards et al., 1994). Several formal and informal stratigraphic members are correlated within the formation, many of which are relatively thin and regionally discontinuous sandstone reservoirs.

Charlie Lake reservoirs host significant oil reserves and some gas in northeastern B.C., and are locally prolific producers. Some members may offer aquifer potential locally, but are too thin and discontinuous to have sufficient capacity and deliverability to support Montney drilling and completions operations on a regional basis.

## Baldonnel and Pardonet Formations

### Definition and Distribution

Upper Triassic Baldonnel and Pardonet strata subcrop the pre-Jurassic and pre-Gething unconformities beneath much of the Montney play fairway. They comprise a series of shallowing-upward bioclastic marine carbonate parasequences, variably dolomitized, and exhibiting good reservoir quality over large areas. Davies (1997b) illustrated a number of stratigraphic units and internal unconformities that he correlated regionally (Fig. P-8).

For the purposes of this study, we did not attempt to correlate and map the Baldonnel and Pardonet Formations exactly as defined by Davies (1997b). Instead, we mapped the uppermost Triassic clean carbonates bearing significant porosity, as we considered this to be the target interval containing regional aquifer potential (see regional Cross-sections). The pick of the base of the interval varies according to the porosity development at each location, but generally lies within the lower Baldonnel Formation or uppermost Charlie Lake Formation as defined by Davies (1997b). Our picks were guided by inspection of several cores in the study areas (Appendix P-3). Unfortunately, many of the wells with Baldonnel core were drilled in the 1950's and 60's, and hence lack modern log suites that can be tied into the regional reservoir quality assessment.

Regionally, the Baldonnel aquifer interval thins from more than 100 metres thick on the western side of the Plains Study Area to less than 20 metres in the east, reflecting general eastward bevelling beneath an unconformity underlying the Jurassic Gordondale ("Nordegg") Member (Enclosure P-21; Plains regional cross-sections). Burial depths range from less than 1000 metres in the north and northwest, to greater than 3000 metres in the southwest (Enclosure P-22). Regional isopach patterns in the Foothills Study Area are less systematic, reflecting more variable porosity development in the Pardonet and Baldonnel, and significant relief beneath the pre-Cretaceous unconformity (Enclosure P-23). Burial depths range from less than 1200 metres on anticlines in the centre and east, to greater than 1800 metres in the west (Enclosure P-24).

### Aquifer Lithologies and Reservoir Quality Assessment

Regional work by Davies (1997b) and our own core observations show the Baldonnel aquifer unit to include a variety of interbedded limestones, dolostones, and fine-grained siliciclastics, with common mixed lithologies (Appendix P-3). It is thus difficult to characterize reservoir lithologies and porosities from well logs, even those with modern log suites containing a photoelectric (PE) curve. As for the Debolt Formation, we have used grain densities from core analysis data to characterize Baldonnel lithologies in terms of limestone vs. dolomite (ignoring any clastic fraction present).

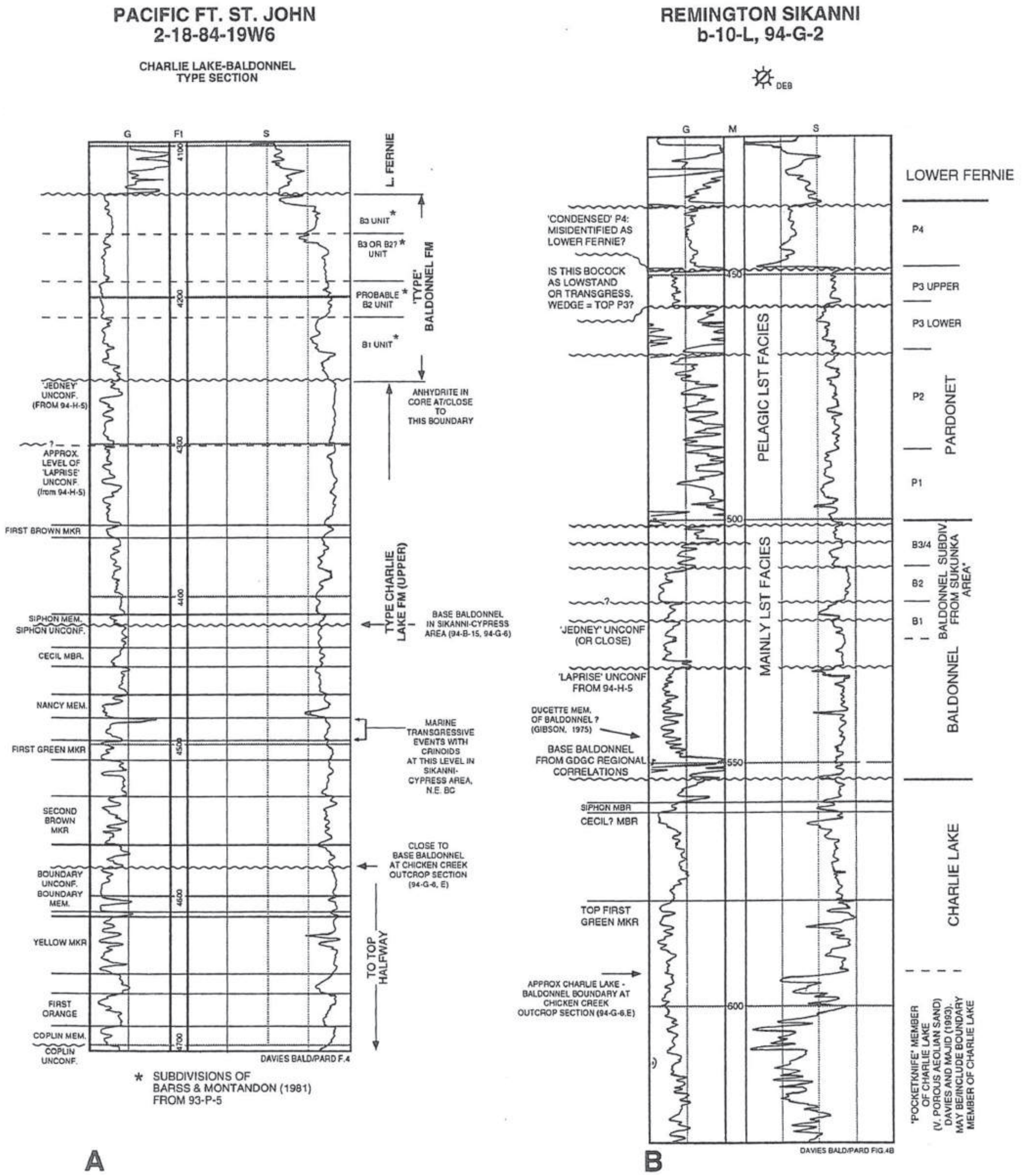



**Figure P-8. (from Davies, 1997b)**

**A.** Type section of the Charlie Lake and Baldonnel formations in Pacific Fort St. John No. 16 well in 2-18-84-19W6 (Hunt and Ratcliffe, 1959), with addition of Charlie Lake members, markers and unconformities. The high degree diachroneity of the Baldonnel-Charlie Lake boundary for different areas is indicated down the right side of the log. Approximate correlations of Baldonnel subdivisions of Barss and Montandon (1981), extended from the Bullmoose-Sukunka area 120 km to the southwest, are shown at upper right.

**B.** Reference well log b-10-L, 94-G-2 for the Upper Charlie Lake, Baldonnel and Pardonet formations in a western Foothills setting in the Sikanni area of northeastern British Columbia. The plot shows correlations to the subdivisions of Barss and Mantandon (1981) for the Baldonnel and Pardonet and the positions of the Jedney and Laprise unconformities correlated from the east. In this northwestern setting, most of the Baldonnel is in a limestone facies and the Pardonet is in its "type" pelagic limestone facies. Note the occurrence of a clean skeletal carbonate at "upper Pardonet P3" level.

Enclosures 25 and 26 show that core coverage is sufficient to map lithologies over only parts of the Plains and Foothills Study Areas (keeping in mind that the lithologies shown are for the cored part of the section only). We conclude from the lack of clear lithological trends that there are no systematic controls pointing to specific areas as having particular reservoir properties associated with preferential dolomitization or other porosity-enhancing processes. Average porosity maps (Enclosures 27, 28) derived from core analysis data show a range of average porosities from about 4% to greater than 14%, but it is difficult to be confident of geographic or stratigraphic trends, given the scarcity of core analysis data. However, the highest porosities appear to occur in shallower, updip positions in the Plains Study Area.

Porosity / permeability cross-plots, shown on Enclosures 27 and 28 and in Appendix P-2, indicate that matrix permeabilities range up to 10 mD in the Foothills Study Area and up to nearly 100 mD in the Plains Study Area. Average values are much lower, but we judged that rigorous statistical analysis of the data was not justified, given their scarcity and distribution. In the Foothills Study Area, it is generally accepted that fracturing associated with structural deformation is an important component of overall reservoir permeability in the Baldonnel and other reservoir units.

## Minnes Group / Nikanassin Formation / Buick Creek Sandstone

### Definition and Distribution

Nikanassin strata comprise a thick (in places >1000 metres), easterly-thinning wedge of clastics, deposited during latest Jurassic and earliest Cretaceous time. They grade up from marine Fernie shales at the base, and are capped by the widespread pre-Mannville unconformity. Equivalent strata include the Minnes Group in the Foothills to the west (Stott, 1998), the Buick Creek sandstone to the north (PRCL, 1997, 2004), and Upper Fernie sandstones and shales in west-central Alberta to the south (Poulton, et al., 1994).

During Nikanassin time, the Jurassic Fernie Sea retreated northward from the Western Canada Sedimentary Basin, in response to eustatic sea level fall and immense volumes of sediment being shed from the rising Columbian Orogen to the west. Additional sediment supply from the craton to the east is evident in the highly quartzose nature of Buick Creek sandstones in the Rigel-Buick Creek areas on the eastern flank of the Foothills Study Area. With further marine retreat and orogenic uplift, deposition was terminated and uppermost Nikanassin strata were eroded.

Nikanassin strata beneath the Montney play fairway consist of:

- A basal massive sandstone, equivalent to the basal Monteith Formation of the Minnes Group in outcrop, and to the Buick Creek sandstone of the Buick Creek /

Fireweed area (94-A-13, 14). This unit can be recognized across most of the Montney play fairway, although it loses character in the southern part of the Plains Study Area. Where it lies directly beneath the pre-Cretaceous unconformity, it is locally difficult to distinguish from overlying Cadomin or basal Gething sandstones. Dominantly quartzose lithologies reflect deposition in a regional deltaic system sourced from the east and northeast (PRCL, 1997; Stott, 1998).

- Overlying interbedded lithic to quartzose sandstones, siltstones, and shales with minor coals, equivalent to the Beattie Peaks Formation in outcrop (Stott, 1998). Deposition took place in marginal marine to continental settings, within which regional stratigraphic markers and significant depositional trends have not been recognized. However, Miles et al. (in review) have mapped a series of stacked delta / shoreline systems in equivalent strata in west-central Alberta.

In the Montney play area, Nikanassin strata are beveled northward and eastward beneath the pre-Cretaceous unconformity (see regional cross-sections). In the Plains Study Area, the Nikanassin is more than 450 metres thick in the far southwest, but is eroded to a subcrop edge in the northeastern corner of the map (Twp. 83-13W6) (Enclosure P-29). Burial depths range from less than 900 metres in the northwest, to greater than 2500 metres in the southwest (Enclosure P-30). In the Foothills Study Area, Nikanassin strata are up to 790 metres thick in the subsurface, adjacent to outcrop brought to surface by thrust faults in the southwest, but are eroded northward to a zero edge in northern 94-B-16 (Enclosure P-31). Burial depths range from less than 900 metres adjacent to outcrop, to greater than 1500 metres in the west, between anticlinal structures (Enclosure P-32).

## Aquifer Lithologies and Reservoir Quality Assessment

*Basal Massive (Buick Creek) Sandstone* – the basal massive unit comprises clean, moderately- to poorly-sorted, fine-grained to pebbly quartz sandstones, interbedded locally with organic shales and argillaceous coals. Cored sections are heterogeneous in appearance, and commonly lack well-defined grain size or bedding trends (Cores d-55-G/94-A-13 and 02/7-33-86-16W6, Appendix P-3; Fig. P-9). Where preserved, sedimentary structures consist predominantly of large-scale cross-beds, and locally, convoluted or slumped beds. Finer-grained intervals may show wispy carbonaceous partings and flasers. Root traces occur beneath many organic shale and coal beds, within the Buick Creek or beneath the pre-Gething unconformity. Mud clasts up to several centimetres long are common locally; their angular, plastically-deformed aspect indicates that they originated as rip-ups, and were transported only short distances (Fig. P-9). Wood clasts and disseminated carbonaceous debris are also common accessories, normally accompanied by pyrite crystals or masses.

Chert and sedimentary rock fragments generally make up less than 10% of the bulk rock volume, but range up to 19% in cores a few townships north of the Plains Study

Buick Creek sandstone. Coarse-grained quartzarenite, exhibiting vague large-scale bedding interpreted as trough cross-bedding.
Diasham West Stoddart 6-6-87-20W6; 1205.5 m.

Fine- to medium-grained quartzarenite, with large-scale cross-bedding highlighted by wispy carbonaceous partings and flasers.
Diasham West Stoddart 6-6-87-20W6; 1211.8 m,

Buick Creek sandstone. Thin, flat, brown-grey mud clasts within massive Buick sandstone, interpreted as rip-up clasts transported only a short distance.
Pacific East Siphon 6-4-87-15W6; 3668.5 ft.

Buick Creek sandstone. Heterogeneous sandy mudstone featuring pyrite-lined root traces. Bedding has been destroyed by pervasive rooting.
Monsanto et al Rigel 14-14-87-17W6; 1095.5 m.

**Figure P-9.** Core photo montage, Nikanassin (Buick Creek).

Area (Fig. P-10) (PRCL, 2004). PRCL (1997) attributed the near-complete absence of non-quartz grains in the Buick Creek area (94-A-14) both to an eastern provenance, and to secondary solution of lithic fragments and chert. To the east, secondary solution may not have proceeded to the same degree as in the more deeply-buried western sections.

Reservoir quality ranges from poor to very good. Porosity includes both modified primary intergranular pores and secondary solution pores, and is best developed in medium- to coarse-grained sandstones. Quartz overgrowths form the primary cement, with some kaolinite and localized bitumen and calcite. Extensive quartz overgrowths have filled almost all porosity in many sections further to the west (Fig. P-10).

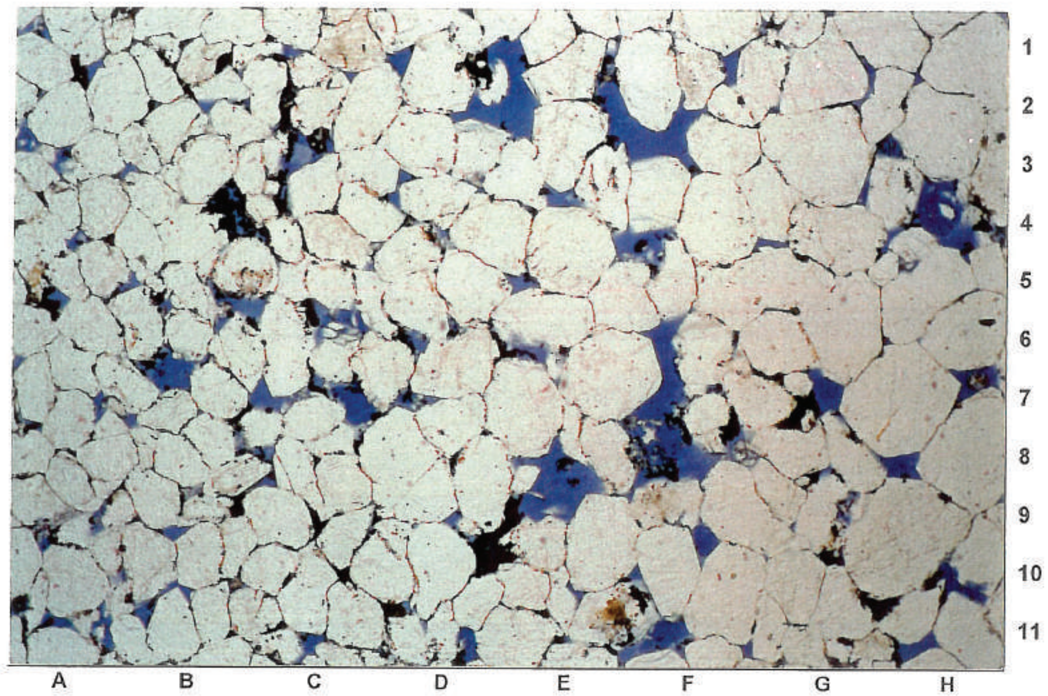
*Upper Nikanassin (Beattie Peaks)* – reservoir sandstones consist primarily of fine- to medium-grained litharenites, deposited as channelized bodies on the order of 5 to 15 metres thick, although individual channels may stack into thicker bodies (see regional cross-sections). Cored sections are relatively few, and do not generally exhibit surfaces that appear to have regional correlative value (Core a-23-H/93-P-8, Appendix P-3). Reservoir quality is generally poor in cored sections we have logged in the B.C. Deep Basin and southern (93P) Foothills. In hand section, sandstones are glassy and brittle, and break across individual grains, indicating strong and pervasive cementation. Silica cement dominates, reducing porosities to the 3-8% range in most places (Fig. P-11). Permeability values generally measure less than 1 millidarcy (standard air-permeability core analysis measurements), and are less than 0.1 mD in many places. Secondary solution porosity is generally not observed. However, we have not logged upper Nikanassin cores in the central and northern Plains Study Area, where logs indicate better porosities.

*Aquifer Maps* – Enclosures P-33 and P-34 show thickness of net clean sandstone (applying a 60 API gamma log cutoff) across the Plains and Foothills Study Areas, respectively. Overall northeastward beveling of the formation, channelized sandstones in the upper (Beattie Peaks) portion of the Nikanassin, and erosion beneath the pre-Cretaceous unconformity account for the variability seen in each map.

Porosity-permeability crossplots (Appendix P-2) show considerable scatter, but 6% porosity equates to about 0.1 mD permeability in the Plains, and about 0.5 mD in the Foothills. At 12% porosity, we see permeabilities of 2-3 mD in the Plains and up to 20 mD in the Foothills. As for the Halfway Formation, porosity cutoffs of 6% and 12% were mapped in order to demonstrate the distribution of sands of poor and moderate reservoir quality, respectively. Enclosures P-35 and P-36 show northwest-southeast maximum thickness (up to 50 m) trends of net porous reservoir in the northern part of the Plains Study Area, reflecting the full presence of the basal Monteith-equivalent sandstones in updip positions where least diagenetically degraded. In the Foothills (Enclosures P-37, P-38), there are substantial thicknesses of sandstone making the 6% cutoff, but only a single northwest-southeast thick porous trend is evident in the southeastern part of the 12% map.

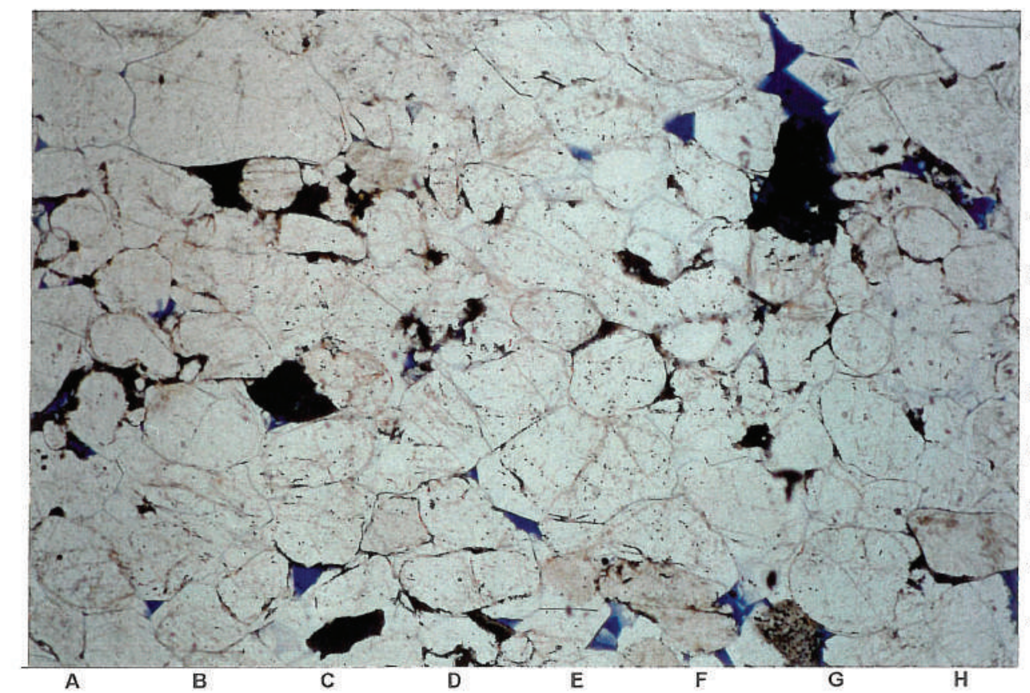
| | | | |
|---|---|---|---|
| Well: c-16-B/94-A-14 | Depth: 3641.0 ft. | Magnification: 31.25 | Polarization: |

A



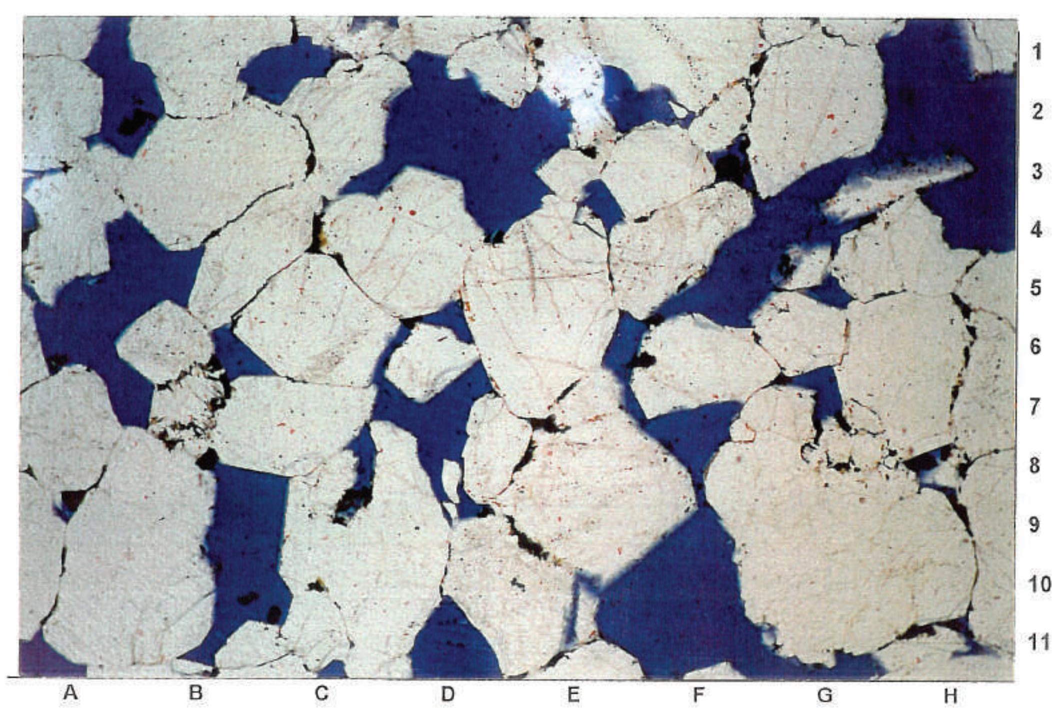

| | | | |
|---|---|---|---|
| Well: a-8-H/94-B-16 | Depth: 4442.0 ft. | Magnification: 25 | Polarization: |

C



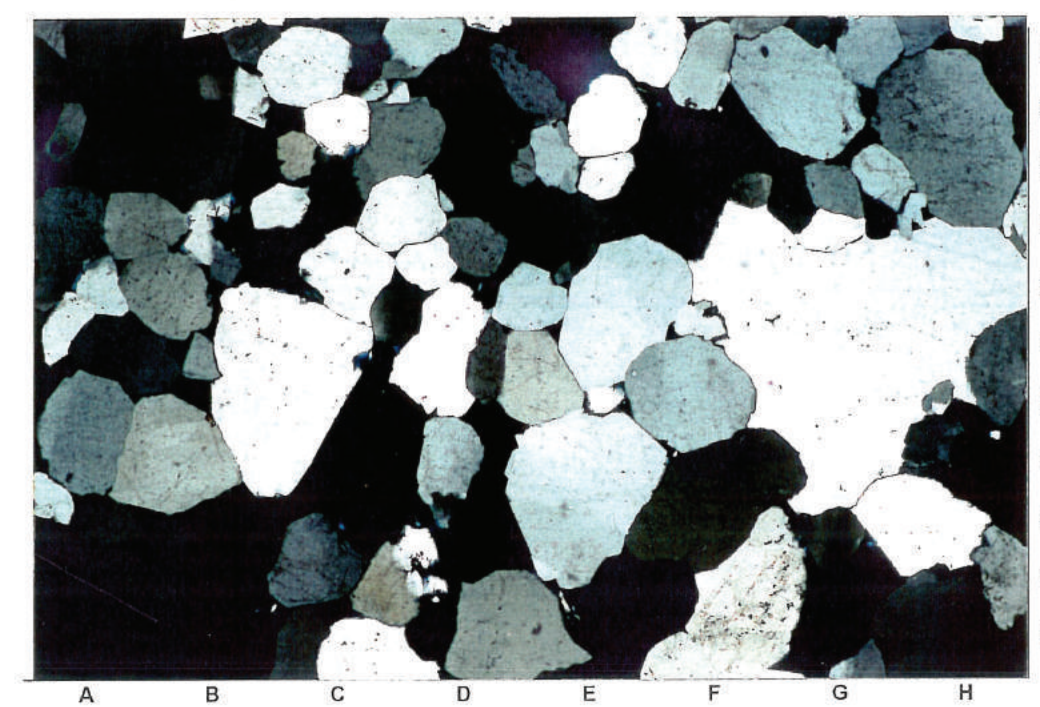

| | | | |
|---|---|---|---|
| Well: c-16-B/94-A-14 | Depth: 3650.0 ft. | Magnification: 31.25 | Polarization: |

B




| | | | |
|---|---|---|---|
| Well: d-79-B/94-A-14 | Depth: 3789.0 ft. | Magnification: 31.25 | Polarization: X |

D




**A.** Quartz arenite, grading from coarse-grained (right) to fine-grained (left). Rock is well cemented by quartz overgrowths, but substantial primary porosity (F2) remains. There is also a component of secondary porosity (F8), arising from dissolution of the minor original component of lithic and/or chert fragments. Core analysis: ø13.3%, K 45 mD. Dunlevy et al Buick Creek c-16-B/94-A-14.

**B.** Excellent primary porosity, some secondary porosity in coarse-grained Buick Creek sandstone. Small percentage of bitumen (black) does not affect reservoir quality. Core analysis: ø 11.5%, K 500 mD. Dunlevy et al Buick Creek c-16-B/94-A-14.

***C.*** Fine- to medium-grained quartz arenite, tightly cemented by quartz overgrowths. Remaining primary porosity consists of small, relatively isolated pores. Very few non-quartz grains are available for solution and development of secondary porosity. Patchy bitumen (C7) fills some of porosity. Core analysis: ø 5.4%, K 0.69 mD. Coseka et al Gundy a-8-H/94-B-16.

**D.** Poorly-sorted quartz arenite, also tightly cemented; view under crossed nicols. Interpenetrated contacts (C5) document silica solution, while straight contacts (F5) arise from quartz overgrowths growing together. Core analysis: ø 7.4%, K 8.6 mD. Pacific West Prod N. Buick d-79-B/94-A-14.

**Figure P-10.**

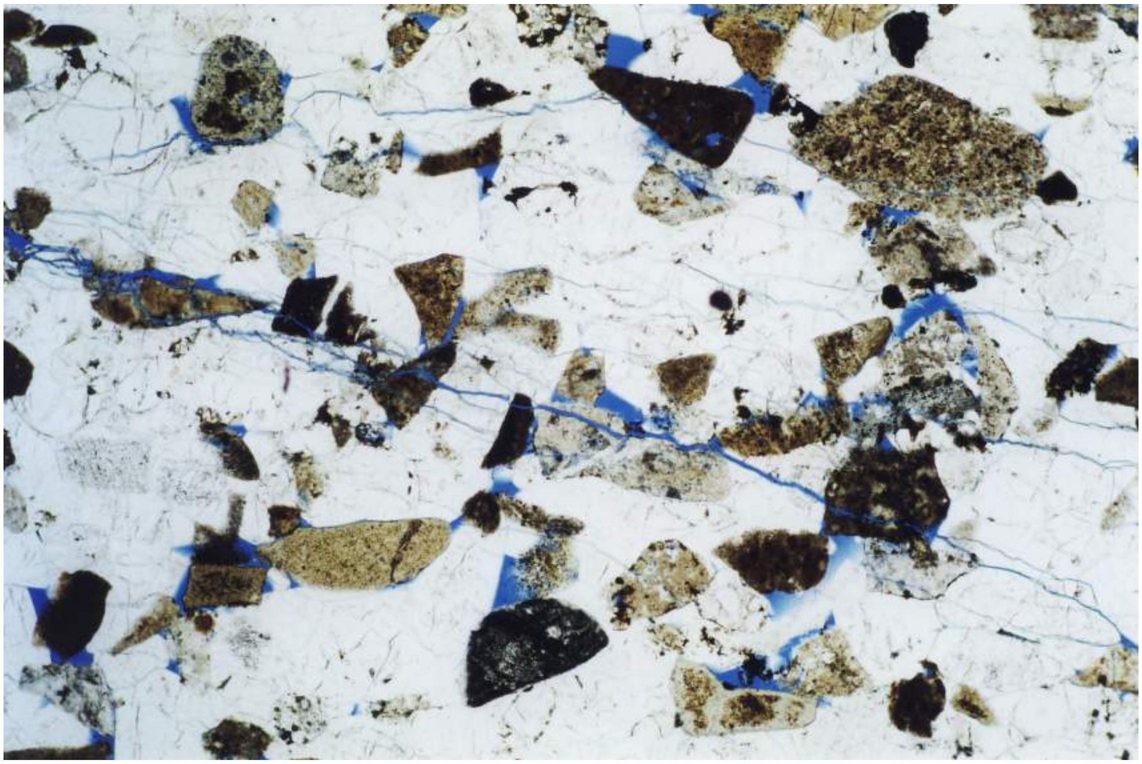


**Figure P-11.** Thin section, well-compacted Nikanassin litharenite; note extensive silica cementation. Small-scale fracturing may provide some permeability, but it is not clear whether these fractures are natural, and if they are, whether they would be large enough to provide appreciable permeability under reservoir conditions. a*23-H/93-P-8; 2247.4 m.

Enclosures P-39 through P-42 show average porosity in the net porous sections of the Nikanassin in the Plains and Foothills, using the two different porosity cutoffs. Note the strong trend of better porosities in the most updip sands in the Plains study area, which have experienced the least burial diagenesis. No similar relationships are observed in the Foothills maps, where more complex burial and structural histories have taken place.

## Cadomin Formation

### Definition and Distribution

The Cadomin is a widespread sandstone and conglomerate, thickening locally to 100 metres or more near depocentres in the Foothills (McLean, 1977). In northeastern B.C., Stott (1973) has described and mapped the Cadomin in outcrop, while Smith et al. (1984), Gies (1984), and Varley (1984) have described it in the subsurface. The Cadomin lies sharply on the pre-Mannville unconformity in the Spirit River Valley, west of the Fox Creek escarpment, and is sharply or gradationally overlain by Gething strata.

Cadomin strata represent an initial outwash of alluvial fan to alluvial plain sedimentation in Early Cretaceous time, following renewed uplift of the Columbian orogenic highlands to the west. Pronounced subsurface and outcrop thicks, particularly evident in northeastern B.C. at Mount Belcourt and Peace River, marked sediment depocentres.

Enclosure P-43 shows the distribution of the Cadomin across the Plains Study Area. The thick area in the northwest represents deposition in the Peace River depocentre, with channelized thicks branching away from the main alluvial fan region. Cross-section B-B' illustrates the thick, blocky nature of the Cadomin, but also illustrates that picking the top of the Cadomin / base Gething can be difficult where channel sandstones occur in the lower Gething (e.g., well 12-29-80-22W6). Where the boundary was unclear, we picked the uppermost reasonable choice for the Cadomin top, in order to include the maximum possible amount of potential aquifer rock in the Cadomin map unit. Burial depths range from about 750 metres in the northwest to greater than 2500 metres in the south (Enclosure P-44).

We did not map the Cadomin as a separate unit in the Foothills Study Area. By definition, it is confined to the westerly Spirit River Valley system: PRCL (2004) and Hayes (2005) mapped the escarpment defining the eastern margin of the Spirit River Valley to trend northwesterly, just north of the Plains Study Area (Fig. P-12). Although some Cadomin may be present in the southeastern corner of the Foothills Study Area, we have included it within the Gething map unit.

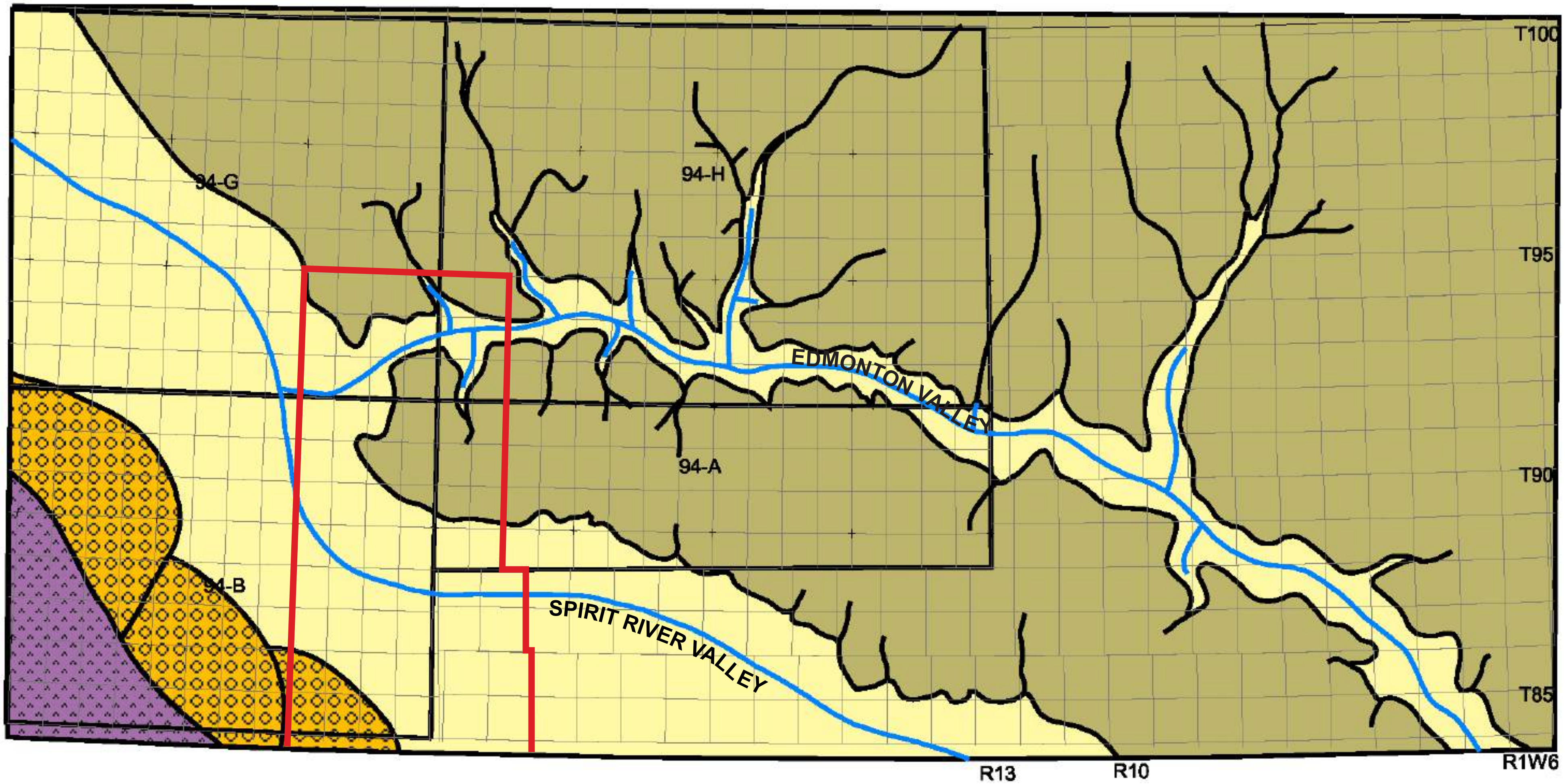



**Figure P-12.** Paleogeography at Cadomin time, showing Spirit River and Edmonton Valley systems converging in the Foothills Study Area (red outline). Cadomin deposition is confined by definition to the Spirit River Valley.

## Aquifer Lithologies and Reservoir Quality Assessment

Poorly-sorted sandstones and conglomerates characterize the Cadomin (see core logs, Appendix P-3; Fig. P-13). Alluvial fan to fluvial environments of deposition are demonstrated by large-scale, high-energy cross-bedding, poor sorting, lack of marine indicators, and association with the pre-Mannville unconformity. Although some finer-grained continental sediments may have been deposited during Cadomin time, these are generally assigned to the overlying Gething Formation. Regional stratigraphic markers therefore do not occur in the Cadomin.

Reservoir quality is generally poor in the southern portion of the Plains Study Area. Pervasive silica cement occludes most sand-supported porosity, while white (kaolinitic) clays fill much pebble-supported porosity, although interpebble pores and open fractures are found as well (Fig. P-14). Core analysis and well log porosities generally range from 2 to 6% (Appendix P-2). The Cadomin is thus characteristically glassy and brittle, and has locally developed considerable permeability as the result of small- to moderate-scale fracturing. However, we have not logged upper Cadomin cores in the central and northern Plains Study Area, where logs indicate better porosities.

Enclosure P-45 shows net porous sandstone thickness for the Cadomin, using a 10% porosity cutoff. The porosity-permeability crossplot (Appendix P-2) shows a wide scatter, making it difficult to assign a permeability equivalent. Thick porous sands are found in the north, in the alluvial plain and channel deposits associated with the Peace River depocentre. Thicknesses generally decrease southward with increased burial depth and diagenesis, and little effective porosity occurs south of the limit line on Enclosure
P-45. Average porosity values are highest in the far northeast, where the Cadomin has experienced the least burial diagenesis (Enclosure P-46).

# Gething Formation

## Definition and Distribution

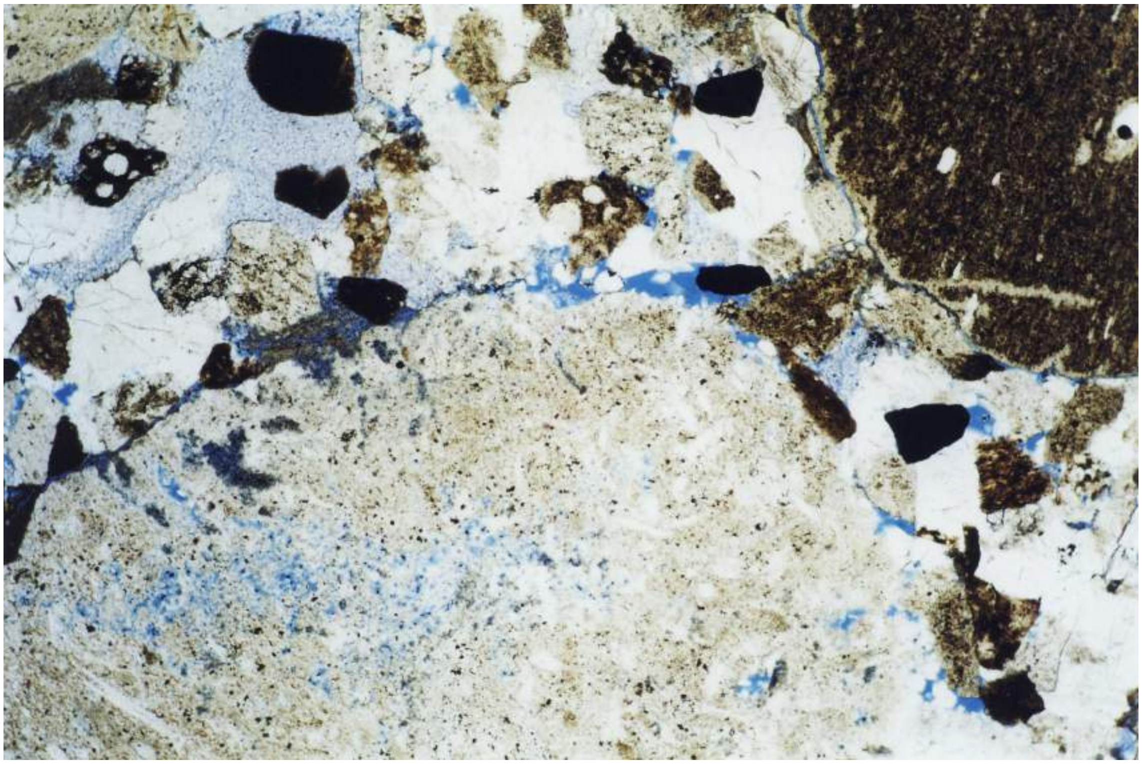
Gething strata were deposited during Aptian-Albian (Early Cretaceous) time, as a northeasterly-thinning clastic wedge, in response to eustatically-rising sea level and continued strong sediment supply from the westerly Columbian Orogen. Thick continuous sandstones were deposited in major valleys to the north, but outside these valleys, alluvial plain and coal-swamp settings replaced the widespread fluvial/alluvial fan environments of the Cadomin. Gething deposition was terminated with the first major Cretaceous transgression of the Boreal (northerly) sea. The Gething has been described in outcrop by Stott (1973) and Gibson (1992a), in the B.C. Deep Basin subsurface by Smith et al. (1984), and in the Plains area north of the current Plains Study Area by PRCL (1997, 2004).

White (kaolinitic) clays fill isopated patches of interpebble porosity i a better-sorted interval. b-28-I/93-I-16; 2923 m.

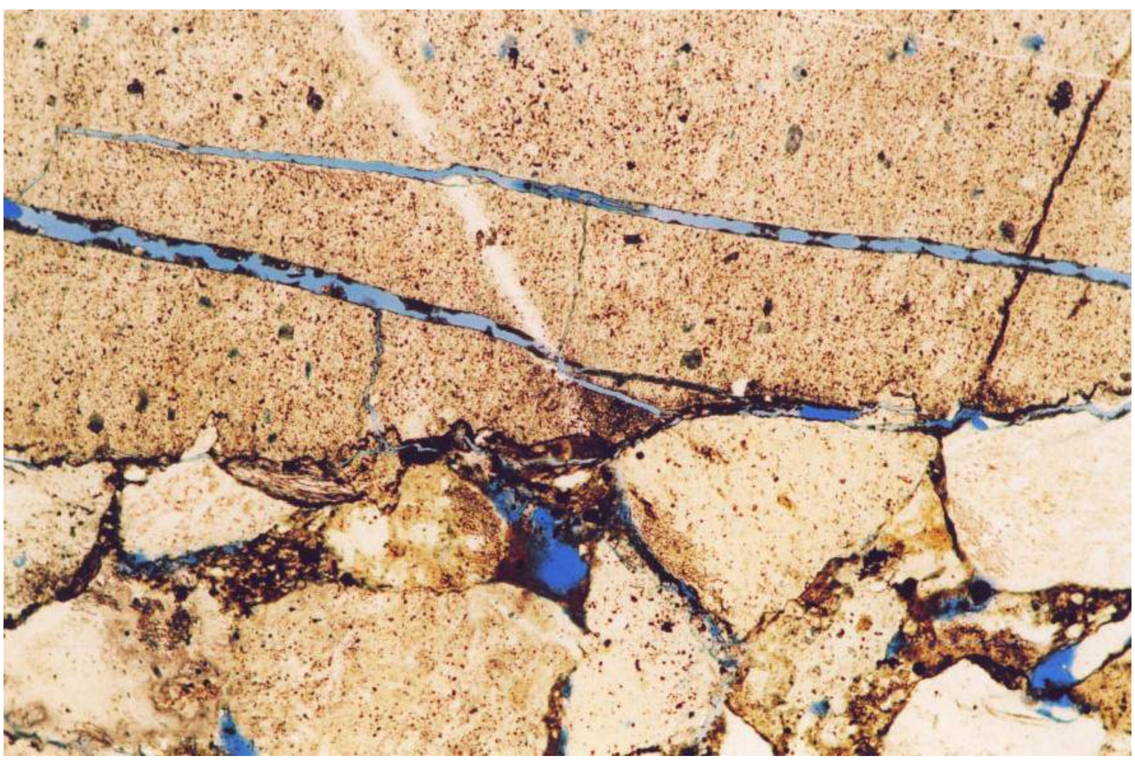

Typical poorly-sorted, brittle Cadomin conglomerate exhibiting extensive subvertical fracturing. b-28-I/93-I-16; 2919.5-2920.7 m.

Close-up of fractured Cadomin conglomerate, illustrating pervasive sand filling interpebble porosity, with numerous short fractures breaking up several pebbles. b-28-I/93-I-16; 2919.6 m.

**Figure P-13.** Core photo montage, Cadomin Formation.



Thin section illustrating clay fill of interpebble porosity (upper left. d-68-K/93-P-1; 2604.3 m.



Thin section illustrating small-scall fracturing across pebbles and along grain boundaries. c-49-I/93-P-7; 2360.5 m.

**Figure P-14.** Thin section photo montage, Cadomin Formation.

Enclosure P-47 is a gross isopach map of the Gething Formation in the Foothills Study Area. It ranges from less than 60 metres thick in eastern areas, to more than 300 metres southwestward. In the far southwest, Gething strata are deformed and, in places, thrust-repeated in wells close to outcrop. Regional mapping shows that the west-east thick in 94-G-1 and 94-H-4 reflects filling of the Edmonton Valley system, and southwestward thickening is partly a product of filling of the northwestward-trending Spirit River Valley (Fig. P-12; Hayes, 2005). Thick continuous sandstones characterize the lower part of the Gething in the major valleys, while upper Gething strata in the valleys and over interfluves consists of fine-grained alluvial plain to deltaic strata (PRCL 1997, 2004) (e.g., Cross-section G-G'). Sandstones correlative to the Cadomin are included in the Gething in the southern part of the Foothills map sheet, as we noted in the discussion of the Cadomin Formation. Burial depths range up to 1400 metres, but are less than 500 metres where the Gething is structurally deformed in wells close to Foothills outcrop (Enclosure P-48).

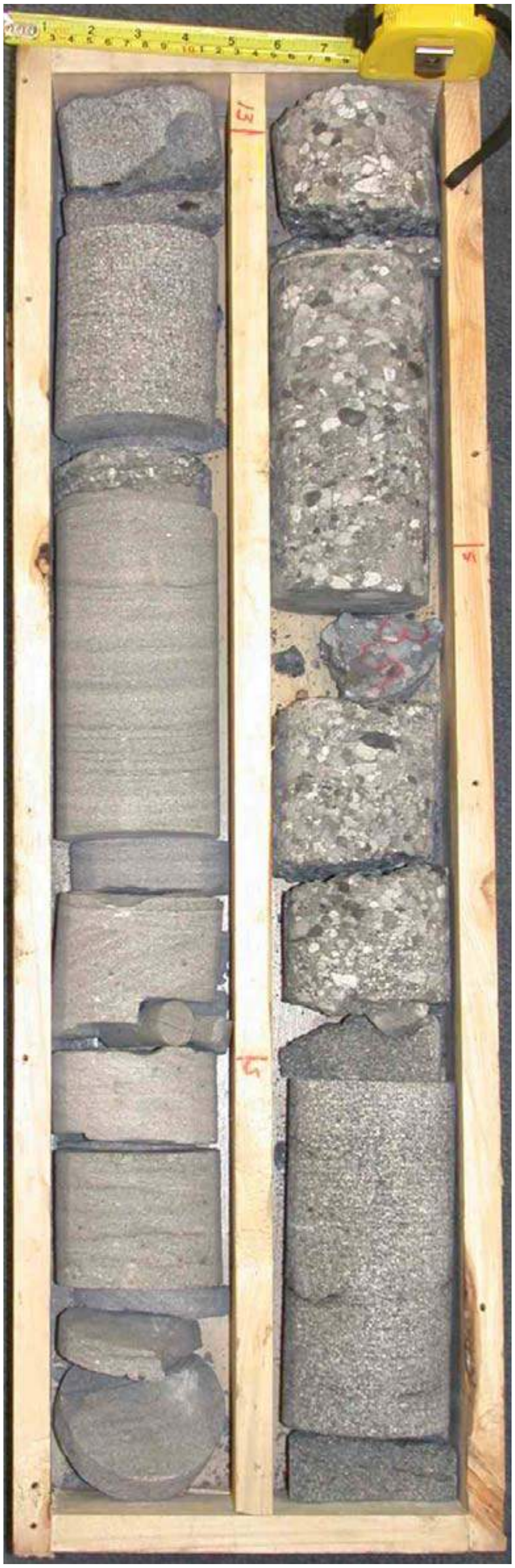
Enclosure P-49 is a gross isopach map of the Gething Formation in the Plains Study Area. General westward thickening reflects increased accommodation space toward the western foredeep. While thick sandstone channels are present locally, fine-grained alluvial plain strata dominate. Local irregular thickness patterns reflect the presence of discontinuous channel sandstones, and also relief and differential compaction over thick underlying Cadomin sandstones.

## Aquifer Lithologies and Reservoir Quality Assessment

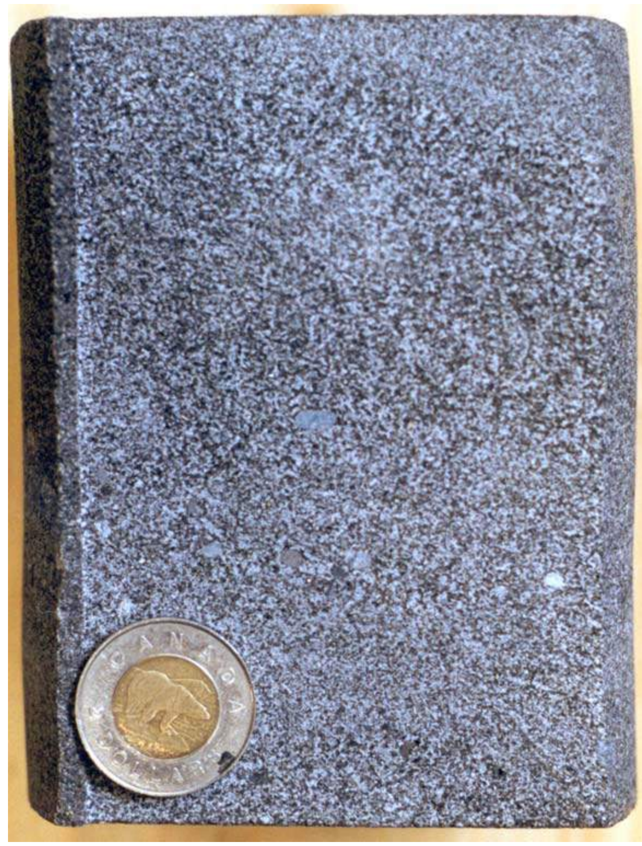
Lower Gething sections filling the basal part of major valleys typically consist of thick, blocky basal sandstones, broken by thin argillaceous and coaly beds, overlain by an overall fining-upward succession, culminating in sandy or silty mudstones with thin coal beds (e.g. core logs 10-27-87-18W6, 6-6-87-20W6, and b-17-K/94-G-1, Appendix P-3; Fig. P-15). Wells 7-19-84-24W6 and b-7-L/94-A-12 on Cross-section G-G' are good log examples. Large-scale, low-angle cross-bedding and trough cross-bedding are dominant bedforms, although current ripples and flaser bedding are present in finer intervals.

Sandstones are composed predominantly of quartz, chert, and lithic fragments (Fig. P-16). Grain size varies from predominantly medium- to coarse-grained with pebbly intervals to the base, up to fine- to medium-grained toward the top. Quartz overgrowths are the primary cement, while kaolinite, ferroan dolomite and bitumen are locally important. Mud clasts, wood fragments, carbonaceous debris, and disseminated pyrite are common accessories.

Upper Gething strata, filling the upper parts of valleys and deposited across interfluves, are more heterogeneous. Volumetrically, they are dominated by heterolithic, interbedded fine-grained sandstone, siltstone and shale (e.g., Core logs 10-27-87-18W6 and d-39-J/94-A-10, Appendix P-3; Fig. P-17). Individual beds are typically thin (less than a metre), bedding features are small-scale, and lithologies may grade into one another. On logs, these successions appear as stacked thin coarsening-upward cycles, although this cyclicity is generally less apparent in core.



Lower Gething Formation. Interbedded poorly-sorted pebbly sandstone and better-sorted medium-grained lithic sandstone, exhibiting poorly-developed trough cross-stratification. (Top of core is to the upper right in the box) Numac North Red 15-1-86-22W6; 1212.2-1213.7 m.

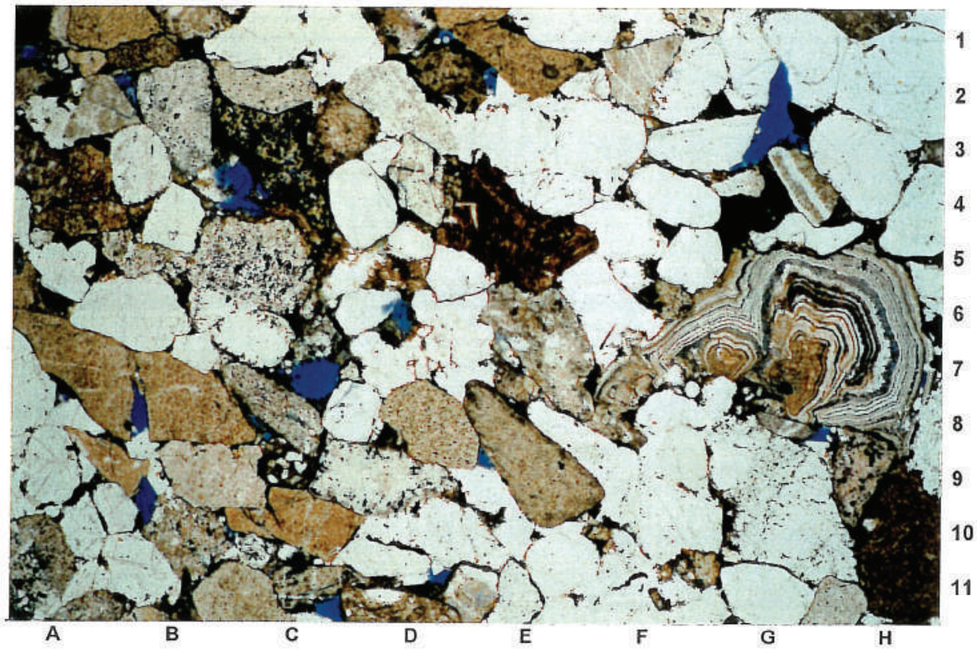


Lower Gething Formation. Massive, relatively well-sorted, medium- to coarse-grained lithic sandstone with good apparent porosity. Total Squirrel 10-4-88-19W6; 1194 m.

**Figure P-15.** Core photo montage, lower Gething Formation.

| Well: | b-17-K/94-G-1 | Depth: | 4374.0 ft. | Magnification: | 31.25 | Polarization: |
|---|---|---|---|---|---|---|

A




| Well: | b-66-G/94-H-3 | Depth: | 1091.30m | Magnification: | 25 | Polarization: |
|---|---|---|---|---|---|---|

B

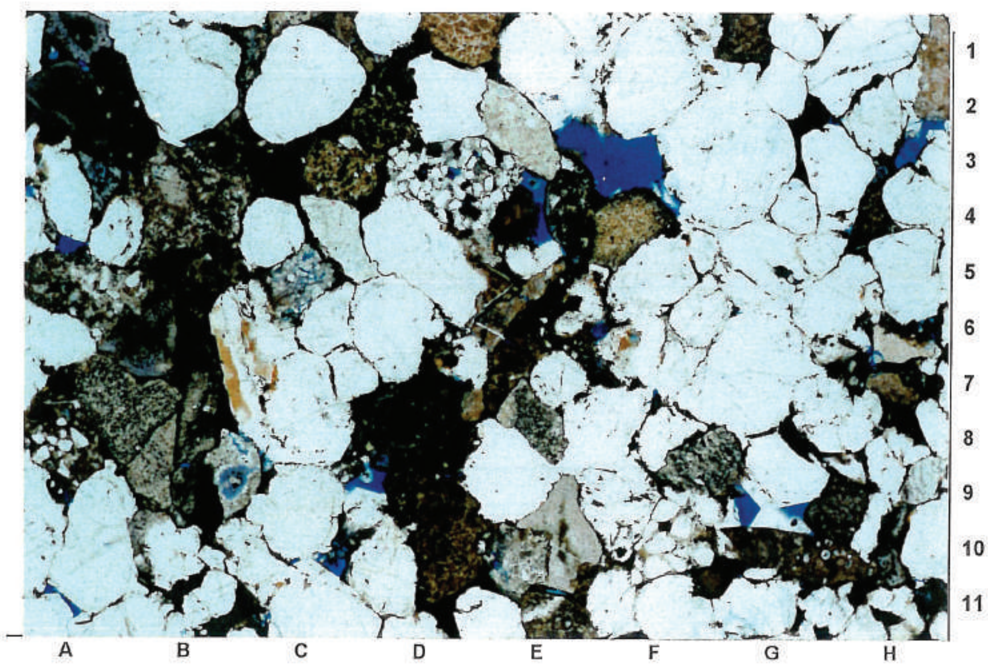



**Figure P-16.** Lower Gething Formation.

**A.** Medium-grained chert litharenite, sorting fair in this view but poorer elsewhere. Primary porosity is reduced by compaction and deformation of softer grains (D7), quartz overgrowths, and chalcedony cement (A5, 6). Secondary porosity is poorly developed, with only partial leaching of lithic grains (F9). Core analysis: Ø 7.5%, K 0.13 mD, PEX et al Beg B-17-K/94-G-1.

**B.** Medium- to coarse-grained chert litharenite, much as above. Bitumen and pyrite (black materials) are significant cements here. Pyrite has replaced a foraminiferal test (D8) originally contained in a rock fragement. Core analysis: Ø 8.8%, K 1.8 mD. Home et al Birley b-66-G/94-H-3.


Upper Gething / Lower Gething Contact. Top of lower Gething lies within the rooted paleosol and coaly interval in box to the left, and is overlain by more competent silty mudstones grading up to heterolithic sandstone/shale and massive sandstone of the upper Gething toward the top of the core box to the right.
Pacific Imperial Boundary Lake #1, 11-10-85-14W6, 3623-3633 ft.


Upper Gething Formation. Channel sandstone in Upper Gething. Dark/light laminae highlight large-scale bedding and smaller-scale ripples. Note convolute bedding on decimetre scale.
Trilogy Hunter d-57-I/94-H-2, 942.75-944.15 m.

**Figure P-17.** Core photo montage, upper Gething Formation.

Upper Gething sandstones are compositionally similar to those of the lower Gething, but are typically finer-grained and more quartzose. Highly quartzose, coarser-grained sandstones occur locally in the Foothills Study Area, and likely represent reworking of sediment from adjacent highlands floored by the Buick Creek (Nikanassin) sandstone. As for the lower Gething, reservoir quality degrades westward with increasing burial compaction.

Enclosure P-50 shows the thickness of net clean sandstone (applying a 60 API gamma log cutoff) for the Gething in the Foothills Study Area; it is dominated by lower Gething sandstones filling the Edmonton Valley to the north and the Spirit River Valley to the south. Applying a 10% sandstone density porosity cutoff, we see that only thick basal Gething sandstones in the Spirit River Valley in the southeast provide substantial continuous volumes of potential aquifer rock (Enclosure P-51). Average porosities of these sandstones are generally in the 11 to 12% range (Enclosure P-52). The porosity-permeability crossplot in Appendix P-2 shows a wide scatter of values, but it is notable that most cluster below 10% porosity and 1 mD permeability.

We did not map Gething aquifer quality in the Plains Study Area, as sandstone bodies could not be correlated with confidence from well to well, on either local or regional scales.

## Bluesky Formation

### Definition and Distribution

The term Bluesky has been applied to a variety of shallow marine to estuarine (and even fluvial) sandstone bodies throughout west-central to northern Alberta and northeastern British Columbia (Hayes et al., 1994; Smith, 1994; O'Connell, 1998). It generally marks a transgressive interval between dominantly continental Gething strata below and marine Wilrich shales above.

Bluesky strata overlie upper Gething strata transgressively, separated by a scoured or loaded contact, and in places by a burrowed *Glossifungites* surface. The Bluesky consists predominantly of coarsening- and/or sandier-upward successions, grading up from heterolithic sandstone/shale to well-sorted, very fine- to medium-grained sandstones, and to granule conglomerates in some places (Core logs d-39-J/94-A-10 and 11-32-88-19W6, Appendix P-3; Fig. P-18). Many sandstones are massive, although low- to moderate-angle large scale cross-bedding characterizes some sections.

Bioturbation commonly obscures bedforms, although individual ichnotaxa may be difficult to identify because of extensive biogenic reworking or lack of lithic contrast . Robust forms with distinct muddy linings, such as *Skolithos*, *Diplocraterion*, and *Ophiomorpha*, are common in coarser sandstone sections (Fig. P-18). More diverse

BLUESKY / UPPER GETHING CONTACT
Well-developed Glossifungites surface at base of Bluesky. Note coarse, glauconitic Bluesky sands being "piped" down burrows excavated in semi-lithified Gething heterolithic mudstones, indicative of burial, partial compaction and re-excavation of the Gething prior to Bluesky deposition.
Saskoil et al Osborne 3-22-90-8W6, 1176.7 m

BLUESKY FORMATION
Massive very coarse-grained sandstone to granule chert conglomerate. Moderately- to well-sorted, bed-by-bed, with little fine sand to occlude large pores; reservoir quality is consequently excellent.
CNRL Beaverhill c-92-C/94-A-15, 3286 ft.

BLUESKY FORMATION
Discrete vertical burrows (Skolithos, Diplocraterion), up to tens of centimetres long, in fine- to medium-grained shoreface sandstone, overprinted by smaller-scale burrows with various orientations.
Talisman et al Buick 11-32-88-19W6, 1066.6 m.

**Figure P-18.** Core photo montage. Bluesky Formation valley fill.

assemblages occur in finer sandstones and heterolithic sections, including *Rosselia*, *Thalassinoides*, *Planolites*, *Asterosoma*, *Conichnus*, and *Chondrites*. Bluesky sedimentology and ichnology are consistent with deposition in marine deltaic to shoreface settings in most areas.

In the Plains Study Area, two west-east Bluesky thicks are evident – one in the far south and one in the north (Enclosure P-53). The southern thick is associated with the Chamberlain Delta complex in the southern Foothills of N.E.B.C. (Gibson, 1992a), whereas stacked shoreface successions make up the northern thick. Burial depths range from less than 600 metres in the northwest to greater than 2400 metres in the south (Enclosure P-54). In the Foothills Study Area, a southwest-northeast thick is dominated by blocky massive sandstone sections, and was interpreted as a estuarine valley fill complex by PRCL (1997) (Core log c-89-G/94-B-16, Appendix P-3; Fig. P-19; Well 02/c-76-D/94-B-16, Cross-section E-E') (Enclosure P-55). In the far southeast, stacked sandier-upward shoreface successions characterize another significant thick trend. Burial depths range from about 400 metres adjacent to outcrop in the southwest, and up to 1400 metres in the central part of the Foothills Study Area (Enclosure P-56).

## Aquifer Lithologies and Reservoir Quality Assessment

Petrographically, the Bluesky consists of chert-quartz litharenites to sublitharenites; polycrystalline quartz, feldspar, and argillaceous and metamorphic rock fragments are minor sand components (Fig. P-20). Matrix clays may range up to 6% in clean sandstones, and up to 16% in burrowed/heterolithic sandstones. Glauconite and phosphate peloids or ooids are common accessories, and help to distinguish the Bluesky from the upper Gething. Quartz overgrowths are the primary cement, but ferroan dolomite also occurs, with lesser amounts of kaolinite, calcite, siderite, and pyrite. Bitumen is an important pore-occluding cement in many places. In core, bitumen ranges from scattered dark flecks to occurrences where it makes the entire core a dark grey, and occludes most or all porosity.

Enclosure P-57 illustrates distribution of Bluesky net clean sandstones (applying a 60 API gamma log cutoff) in the Plains Study Area. Thick clean sandstones are characteristics of the northerly stacked shoreface complex, while most of the Chamberlain Delta complex in the south fails to make the cutoff. In the Foothills Study Area, both the northwestern estuarine trend and the southeastern shoreface trend exhibit high proportions of clean sandstone (Enclosure P-58).

Bluesky reservoir quality ranges from poor to excellent, but is good to excellent in most sections. Porosities range up to 27%, particularly in less-compacted strata in the eastern part of the Plains Study Area. Porosity-permeability crossplots indicate that 12% porosity is equivalent to about 10 mD permeability in the Plains. In the Foothills, we see two relationships – a steeply-dipping trend where 12% porosity indicates permeabilities of more than 1000 mD (mostly well-sorted conglomerates), and a much


a

A. Small, thin flat mud clasts highlight large-scale, ow-angle cross-bedding in Bluesky valley fill sandstone. Bedding would not otherwise be apparent in sections such as this, where there are few other elements of lithological contrast. No core analysis in this interval. PCI et al Martin d-12-I/94-H-5, 1249.3 m.

b

B. Somewhat argillaceous, fine- to medium-grained sandstone displaying pervasive low-angle cross-lamination, highlighted by clay-rich darker laminae. Clays and silica and calcite cement reduce reservoir quality significantly. No core analysis available. CanHunter Town c-89-G/94-B-16, 1329.22 m.


c

C. Massive, homogeneous upper fine sandstone, typical of good reservoir rock in Bluesky valley fill sections. Alignment of two thin flat mud clasts suggest low- to moderate-angle cross-bedding. Cryptobioturbation in an estuarine setting may have obscured any bedding originally present. Core analysis: ø 22.8%, K 205 mD. UPRI Tarragon Laprise a-65-A/94-G-8, 1306.0 m.


d

D. Heterolithic, wavy-bedding very fine-grained sandstone and sideritized mudstone. Original bedding is extensively modified by soft-sediment deformation, likely as the result of slumping by localized sediment loading in an estuarine setting. Rigel Daiber c-25-D/94-B-16, 881.0 m.

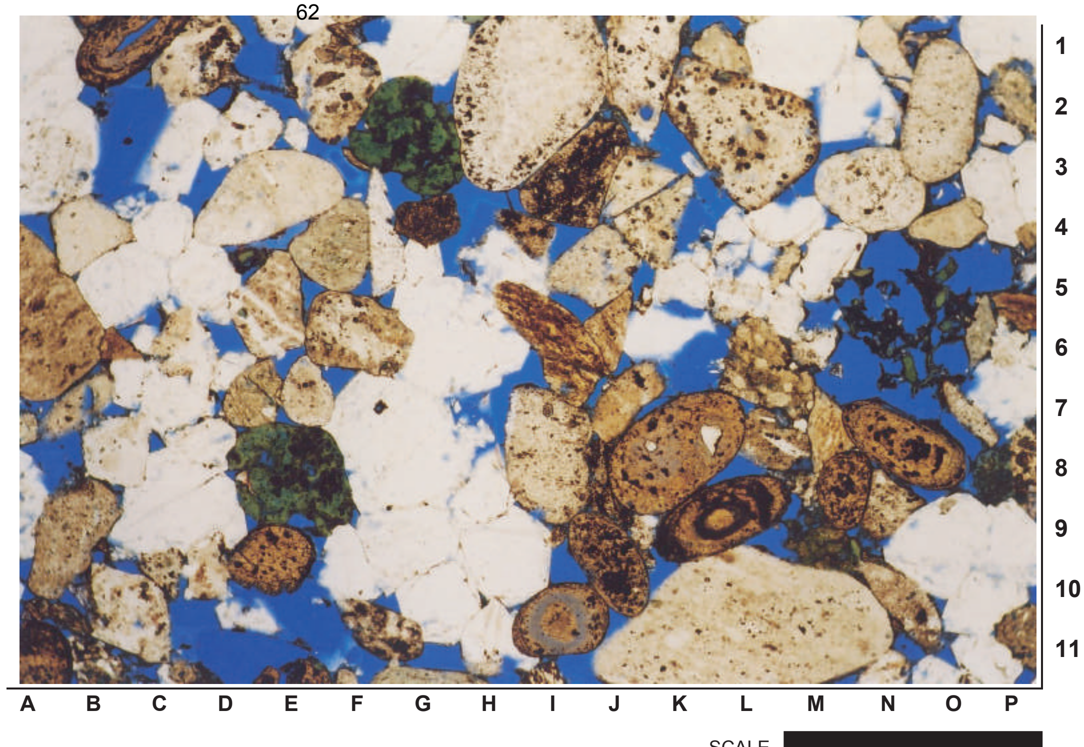
**Figure P-19.** Core photo montage, Bluesky Formation valley fill.

a.

LOCATION: b-21-J/94-A-9
DEPTH: 1079 m

FRM: BLUESKY

MAGNIFICATION: 35X
POLARIZATION: PL



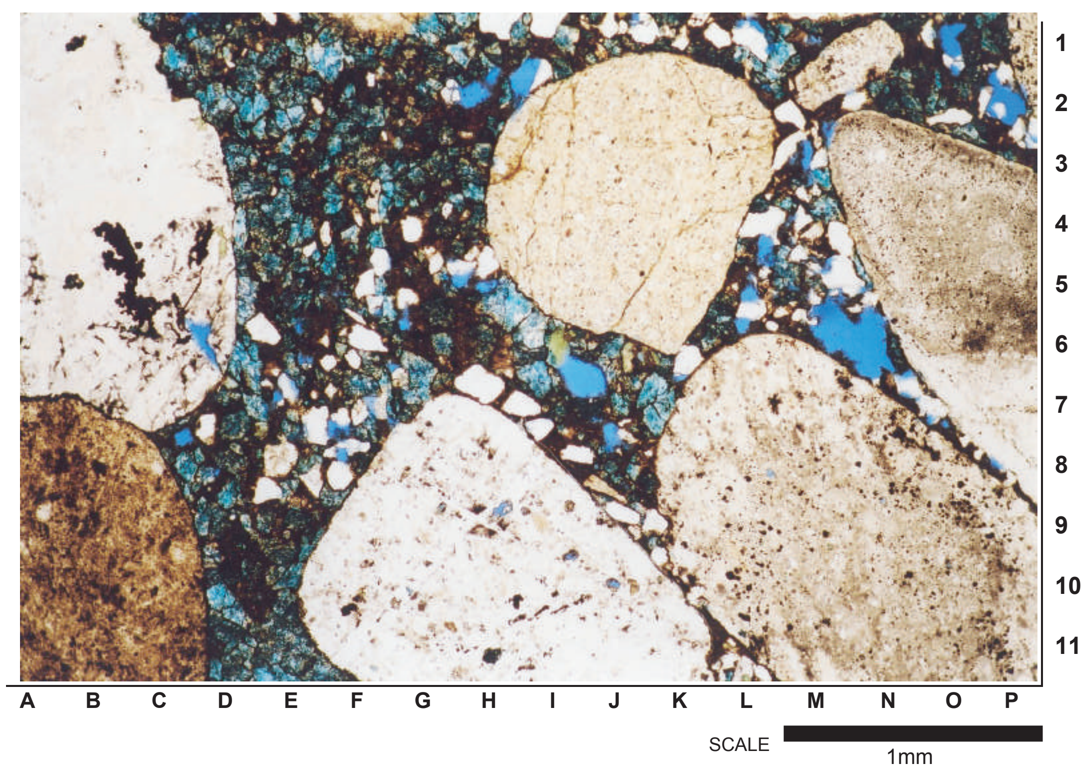

a. Poorly-sorted, coarse-grained chert litharenite. Note green glauconite peloids and brown phosphatic ooids. Quartz overgrowths cement clusters of quartz grains tightly.
Texaco et al Osborne b-21-J/94-A-9, 1079 m.

b.

LOCATION: b-2-E/94-A-15
DEPTH: 3493 ft.

FRM: BLUESKY

MAGNIFICATION: 35X
POLARIZATION: PL




b. Chert granule conglomerate with very fine sand and clay matrix. Ferroan dolomite cement (blue-green) and matrix clays occlude most porosity - reservoir quality is poor.
Ashland Cdn-Sup Junction b-2-E/94-A-15, 3493 ft.

**Figure P-20.** Thin section photo montage, Bluesky Formation.

shallower trend, where 12% porosity is equivalent to permeabilities of less than 1 mD (mostly fine sandstones). Pore systems range from predominantly modified primary intergranular pores, to those with both modified primary and significant amounts of grain dissolution porosity. Cements and degree of compaction are the primary controllers of reservoir quality, although porosity occlusion by matrix clays (including burrow linings) and bitumen are important locally.

Enclosure P-59 shows substantial thicknesses and good continuity of net porous Bluesky sand (using a 12% sandstone density cutoff) in the northern shoreface trend of the Plains Study Area, particularly near the eastern updip limit. Average porosities in the net porous sand section range in excess of 20% (Enclosure P-60). There is essentially no net porous sand in the southern Chamberlain Delta. In the Foothills Study Area, Bluesky sands make the porosity cutoff in only a few scattered wells (Enclosure P-61), and exhibit average porosities of 13 to 14% (Enclosure P-62).

## Spirit River Formation

### Definition and Distribution

The Spirit River Formation is a thick clastic succession, composed of stacked transgressive-regressive cycles deposited at the front of the southerly-advancing Boreal Sea during Albian (Early Cretaceous) time (Fig. P-21). In the southern part of the Plains Study Area, fully-developed T-R cycles are assigned to various submembers of the Falher Member and to the overlying Notikewin Member. Coarse sandstones and conglomerates deposited in shoreface to foreshore settings are significant Deep Basin gas reservoirs (Smith et al., 1984; Hayes et al., 1994; PRCL, 2005).

Northward, individual cycles lose their identity as the section becomes more marine, and regressive components pinch out or cannot be identified. In the northern part of the Plains Study Area, the Spirit River is a succession of distal marine, fine-grained sandstones that cannot be correlated individually on a regional basis (e.g., see Cross-section BB-BB'). The entire member thins northward from Twp. 77; abrupt northwestward thinning in Twp. 82 and 83, west of 20W6 occurs where marine shales become dominant (Enclosure P-63).

In the Foothills Study Area, the Spirit River becomes progressively shalier, and passes northward to the equivalent Buckinghorse Shale. We therefore have not correlated or mapped it in the Foothills Study Area.

### Reservoir Quality Assessment and Fluids

In the southern part of the Plains Study Area, there are high-quality reservoirs in the Spirit River, but they lie in the gas-saturated Deep Basin (Smith et al., 1984; PRCL,

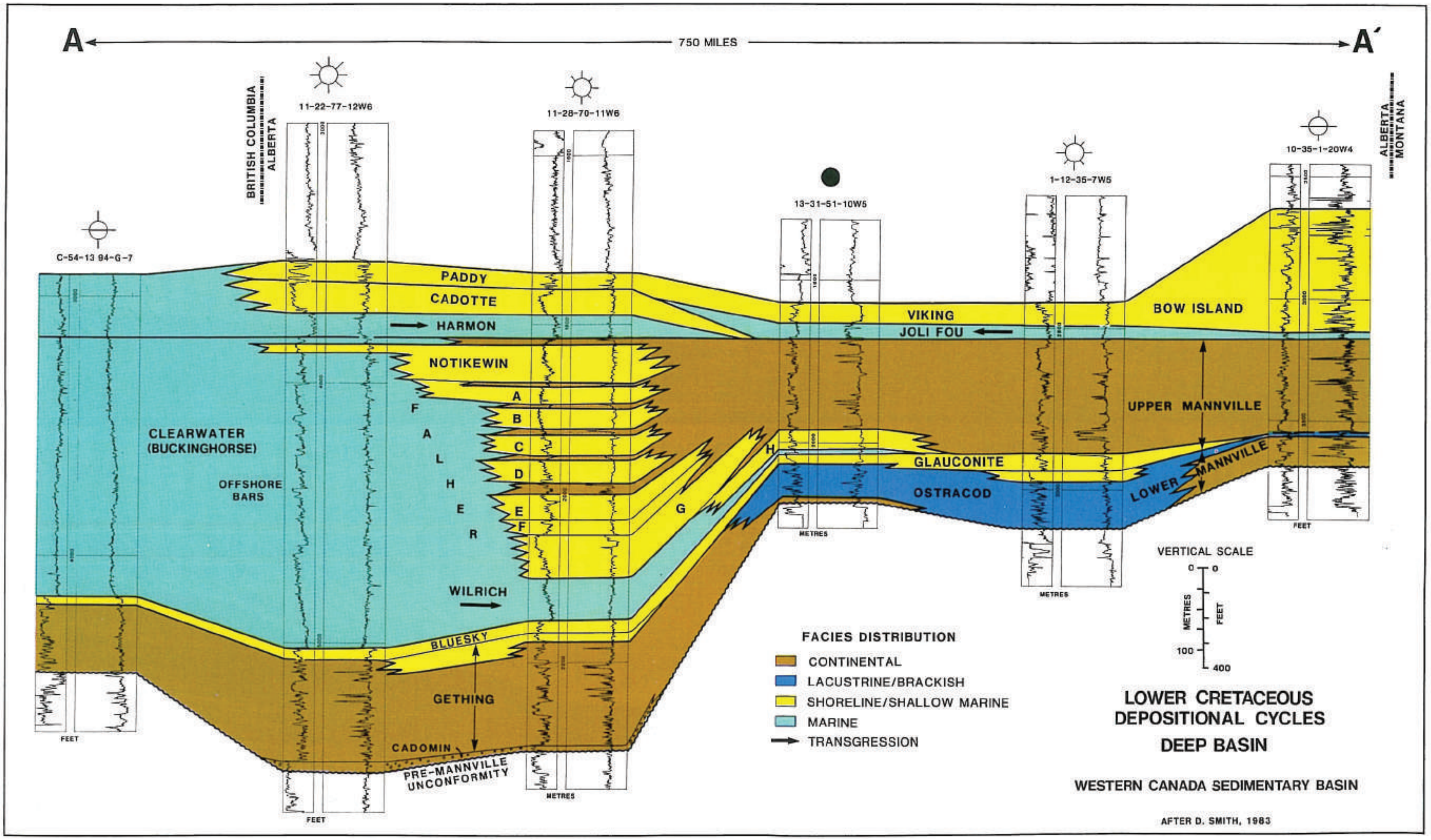



**Figure P-21.** Schematic cross-section illustrating Spirit River Formation deposition.

2005). Thus, there is no substantial aquifer potential in this area. North of the Falher and Notikewin shoreline complexes, fine-grained sandstones exhibit poor reservoir quality, and generally test tight (note poor permeabilities on core log 02/14-16-85-20W6 (cores #1 and 2), Appendix P-3; Fig. P-22).

As substantial aquifer and disposal potential appear to be lacking in the Spirit River section, we have undertaken no further analysis.

## Peace River Formation

### Definition and Distribution

The Harmon, Cadotte, and Paddy Members of the Peace River Formation represent a final transgressive/regressive cycle during Early Cretaceous time, prior to inundation of the entire basin by the Shaftesbury/Colorado sea. Harmon marine shales were deposited as the Boreal sea re-advanced from the north. Cadotte shoreface strata record northerly progradation with renewed sediment supply from the south and west (Fig. P-23). Paddy strata were deposited in widespread bay/lagoonal environments behind a west-east barrier shoreface, prior to the final transgression (Fig. P-24).

Smith et al. (1984), Rahmani and Smith (1988), and Hayes (1988) have described the Cadotte in the subsurface, while Gibson (1992b) described the equivalent Boulder Creek Formation in outcrop.

In the southern Plains Study Area, Peace River strata are 70-80 metres thick, thickening westward (towards the sediment source area) to more than 100 metres (Enclosure P-64). The formation thins north of Twp. 78, to 60 metres or less in Twp. 79 and northward. North-south regional cross-sections BB-BB' and CC-CC' show that this abrupt thinning is the product of a facies change from sand-dominated shoreface successions in both the Cadotte and Paddy in the south, to offshore marine silts and shales to the north. We have not interpreted thickness contours north of this facies transition (Enclosure P-64). Depth of burial ranges from about 700 metres at the northern sand limit to greater than 1700 metres at the southern limit of the Plains Study Area (Enclosure P-65).

There are no reservoir-quality sandstones in the Peace River equivalents in the Foothills Study Area.

### Aquifer Lithologies and Reservoir Quality Assessment

Cadotte reservoirs south of Twp. 78 consist of moderately- to well-sorted granule to small pebble conglomerates, deposited in upper shoreface to foreshore environments, similar to the Falhers. Reservoir quality is very good, with the best conglomerates exhibiting porosities up to 12%, and permeabilities ranging up to hundreds of millidarcies or darcies (Core log b-24-A/93-P-7; Appendix P-3; Figs. P-25, P-26).


FALHER MEMBER

Upper to middle shoreface. Massive sands with low-angle laminae, highlighted by carbonaceous partings and thin mud beds, with a few large *Teichichnus* burrows. Becomes finer-grained with depth.
Scurry West Stoddart 102/14-16-85-20W6, 877.1-878.55 m.


NOTIKEWIN MEMBER

Top of Notikewin Member - heterolithic light-grey sands and dark-grey muds with pervasive burrowed texture, overprinted with long vertical traces. Gradational contact with underlying sands, becoming massive towards base.
Scurry West Stoddart 102/14-16-85-20W6, 768.5-769.9 m.

**Figure P-22.** Core photo montage. Spirit River Formation

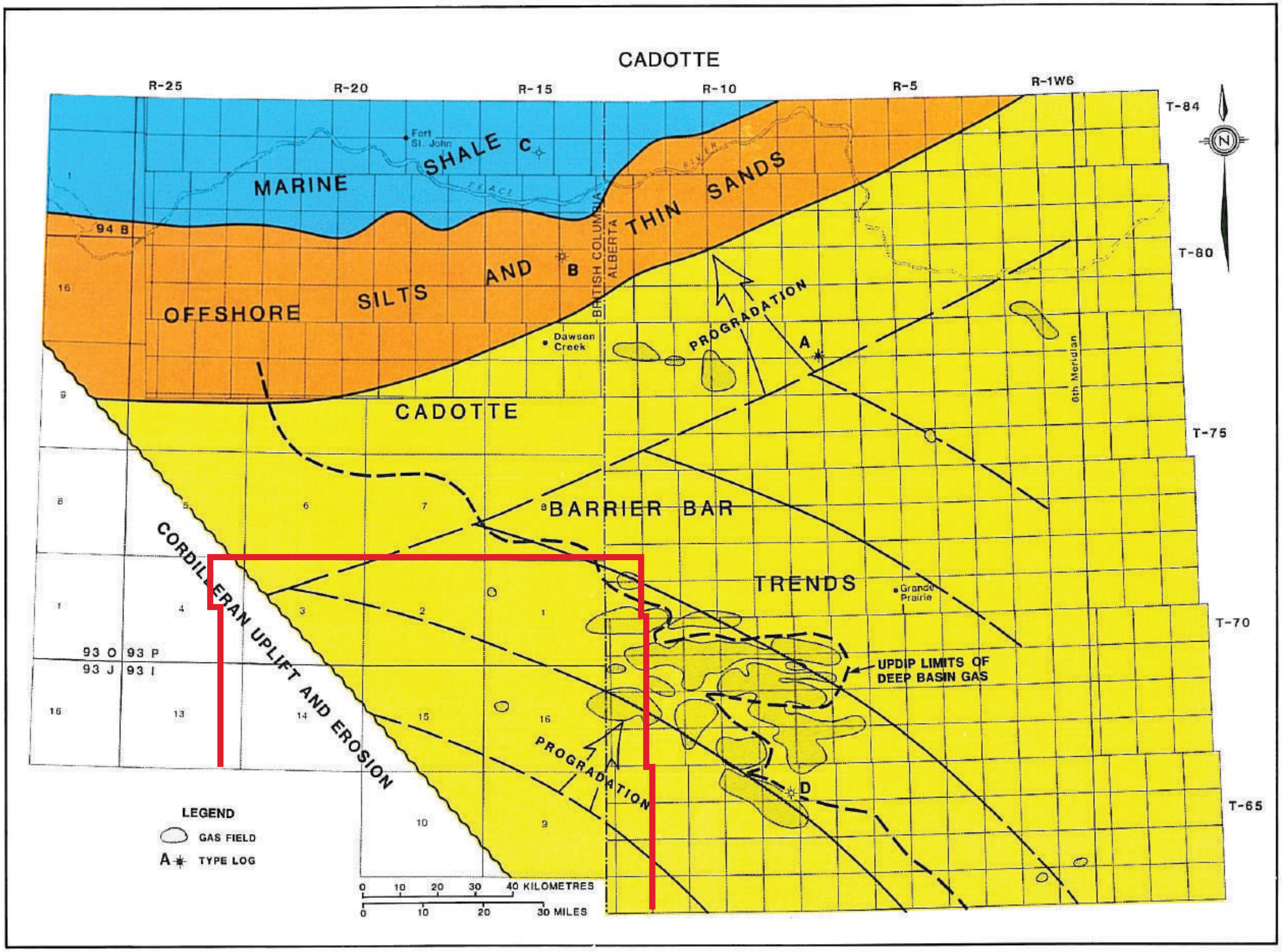



**Figure P-23.** Schematic paleogeography, Cadotte Member. Plains Study Area is outlined in red (after Smith et al.).

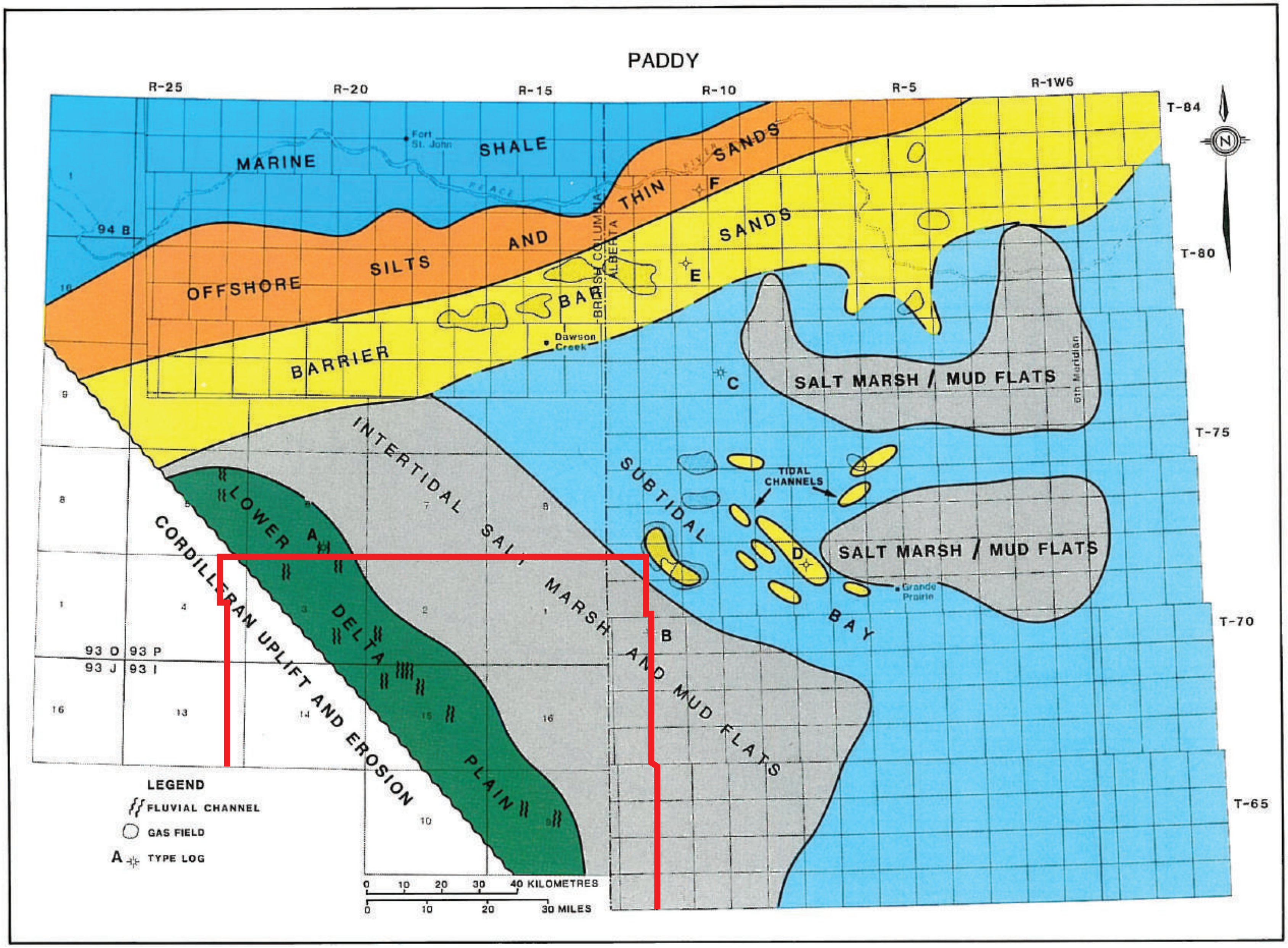
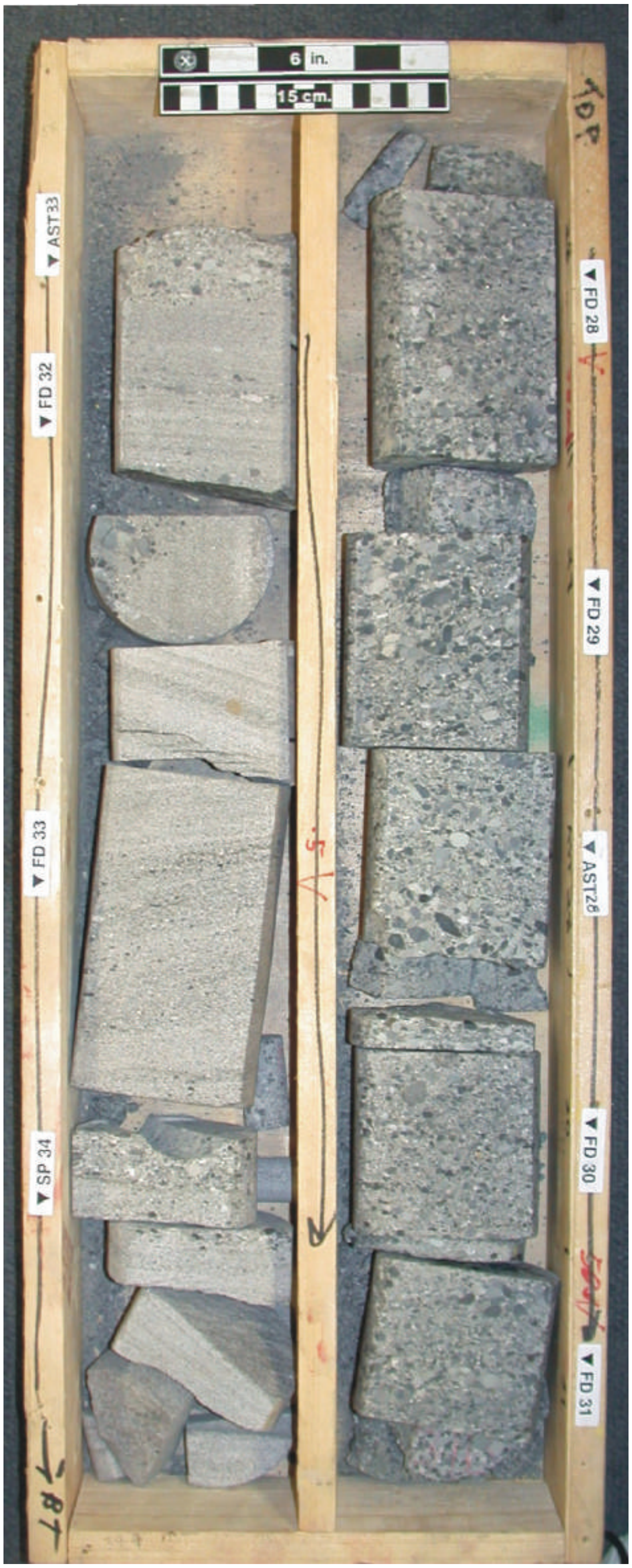



**Figure P-24**. Schematic paleogeography, Paddy Member (after Smith et al.). Plains Study Area outlined in red.




Cadotte upper shoreface, grading from cross-bedded pebbly sandstone up to sandy conglomerate. Sharp contact with finer-grained lower shoreface sandstones is near base of this interval, just below SP34 label. b-24-A/93-P-7, 2057.8 m.

Well-sorted very coarse-grained sandstones to granule conglomerate of Cadotte foreshore, exhibiting good intergranular porosity. b-24-A/93-P-7, 2054.5 m.

**Figure P-25.** Core photo montage, Cadotte Member.

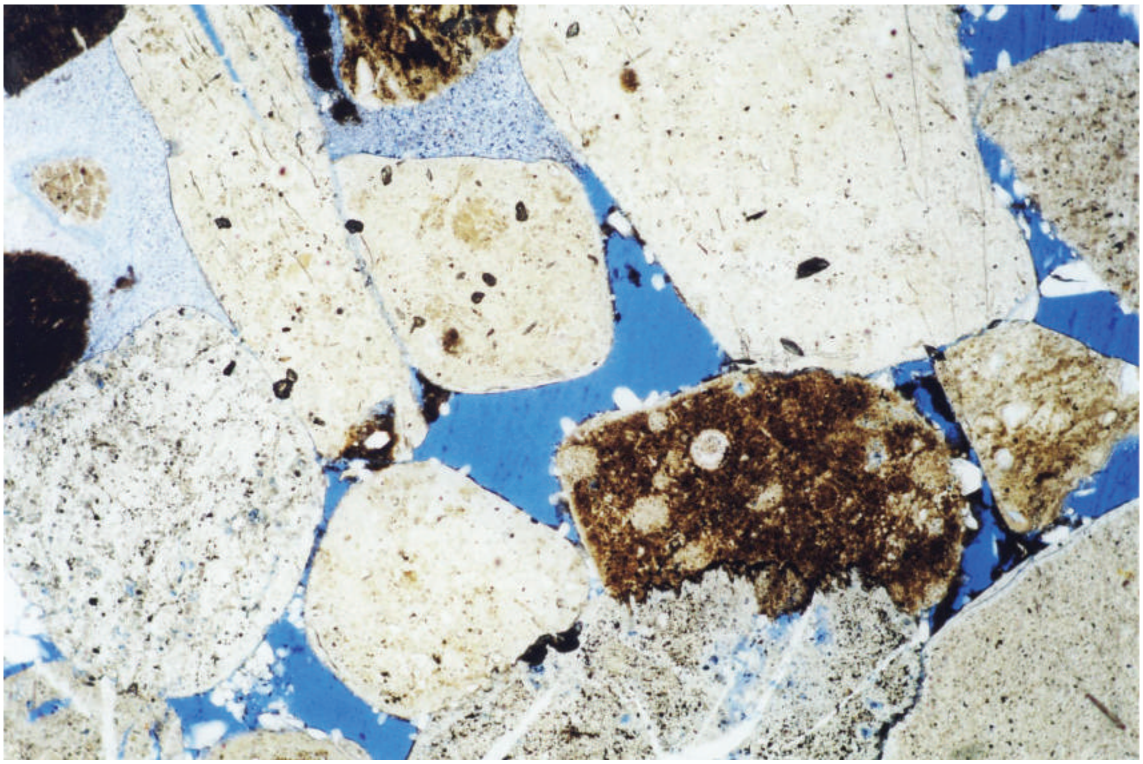


**Figure P-26.** Thin section photo, Cadotte Member. Good interpebble porosity in well-sorted Cadotte upper shoreface to foreshore interval. Note stylolitic contacts, indicative of pressure solution between some chert pebbles. Clay martix occludes some porosity. b-24-A/93-P-7, 2054.3 m.

Reservoir quality is poorer in less-sorted sandy conglomerates (Core log c-14-F/93-P-7; Appendix P-3). Productive reservoir facies range up to 7-10 metres thick, and overlie finer-grained, low-permeability shoreface sandstones with a sharp to gradational contact. Individual Cadotte reservoir bodies exhibit strong east-west continuity, reflecting preservation of continuous upper shoreface to foreshore deposits (Smith et al., 1984; PRCL, 2005).

Paddy strata south of Twp. 78 are dominated by fine-grained clastics and coals, and lack regional stratigraphic markers. Good reservoir rock is found only in isolated north-south trending estuarine valley fills, and in the northern barrier complex in Twp. 78 and 79. Where the terminal Paddy and Cadotte barrier shoreface complexes stack atop one another, they are difficult to distinguish (e.g., well 10-14-78-19W6, Cross-section BB-BB').

Enclosure P-66 illustrates the distribution of net clean sandstones (applying a 60 API gamma log cutoff) in the Peace River Formation. The west-east thick in Twp. 77 and 78 reflects the stacking of high net-to-gross sandy shoreface barriers in the Paddy and Cadotte members. Southward, clean sands are found primarily in the Cadotte. To the north, there is little clean sand seaward of the Paddy / Cadotte barriers.

Applying a 12% sandstone density porosity cutoff, thick porous sandstones occur only in the eastern part of the stacked barrier trend (Enclosure P-67). As we have seen in other units, increased burial diagenesis occurs to the west, degrading reservoir quality. Average porosities in the net porous sandstones range from 14 to 19% (Enclosure P-68). In the south (93-P-7 to 93-P-10), narrow west-east Cadotte conglomerate bodies may exhibit excellent permeabilities, but with porosities less than 12%, and host either water or gas (PRCL, 2005). Wet conglomerates may provide attractive local aquifer targets.

## Dunvegan Formation

### Definition and Distribution

Dunvegan strata form a large, southeasterly-prograding wedge of deltaic and shoreface sediments, which originated in far northern B.C. and the Territories, and reached a distal edge in west-central Alberta (Fig. P-27). It lies between marine shales of the Shaftesbury Formation below and the Kaskapau Formation above. Thin sandstones in the lower Kaskapau transgressive package, termed the Doe Creek Member, are also addressed in this review.

The Dunvegan has been mapped in outcrop by Stott (1982), and in the subsurface by several workers. Dunvegan sandstones were deposited in deltaic to shoreface settings at the seaward limit of several regressive subunits (allomembers of Plint (2000)), and in associated distributary channels and valley fills. Plint (2000) and Plint et al. (2001) mapped regional paleogeography and generalized sand distribution for each allomember, but detailed reservoir maps have not been published.

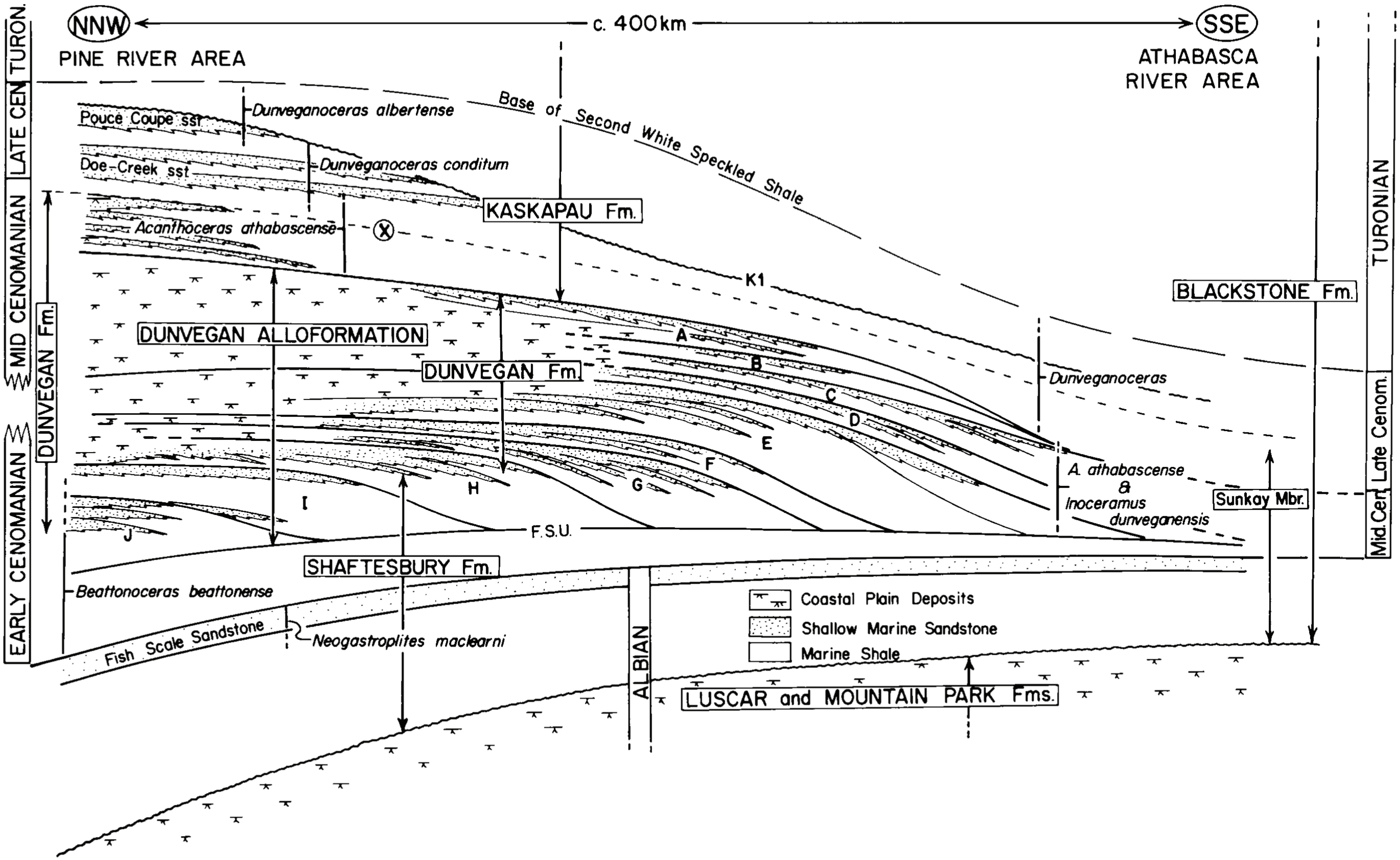



**Figure P-27.** Schematic NNW-SSE cross-section, Dunvegan Formation. Summary of the lithostratigraphic relationships between the Dunvegan and the overlying Shaftesbury and Kaskapau formations. The diachronous nature of the Dunvegan Formation is well seen where updip sandy Dunvegan strata of allomembers J-D pass downdip into prodelta Shaftesbury mudstones, and Dunvegan allomembers C-A pass downdip into laterally equivalent mudstones of the Kaskapau Formation. The base of the Dunvegan alloformation is defined by the FSU (fish scales upper) marker, and the top is taken at the flooding surface that defines the top of allomember A. Because the Dunvegan strata were deposited in marginal marine environments, marine molluskan fossils are sparse; however, ammonite and benthic foraminifera have been collected from more offshore facies, and these permit broad subdivision of the Cenomanian. Surface X is a regional flooding surface used as a stratigraphic marker, and K1 is a regional unconformity (after Plint, 2000).

In the Plains Study Area, the Dunvegan crops out in a broad band across the map sheet, and measured sections have been published for several outcrop locations (e.g., McCarthy, 2002) (Enclosure P-69; Fig. P-28). Part or all of the Dunvegan lies behind surface casing in petroleum boreholes over most of the remaining area; it is fully preserved in the subsurface, below surface casing, only in the southeast. Stratigraphic top and base picks in adjacent Alberta show it to be about 160-170 metres thick, but we decided not to extend isopach mapping into B.C., as the gross isopach has little relationship to thickness of available reservoir.

The Dunvegan crops out or is eroded over almost the entire Foothills Study Area, and thus was not considered in this study (Enclosure P-4).

### Aquifer Lithologies and Reservoir Quality Assessment

The Dunvegan is conglomeratic in outcrop in far northern B.C., but is dominated by fine- to medium-grained sandstones in the Plains study area (Stott, 1982; Plint and Hart, 1988). Bhattacharya and Walker (1992) described very fine- to medium-grained reservoir sandstones in adjacent west-central Alberta, deposited in a variety of fluvial, estuarine, deltaic, and shoreface settings.

Regional correlation of individual allomembers is difficult, but detailed mapping (by allomember) would be required to reasonably assess potential reservoir trends. We judged such mapping to be beyond the scope of this study, and unlikely to produce meaningful results given the limited distribution of fully preserved (and logged) subsurface sections. Plint et al. (2001) mapped edges of individual allomembers and showed, for example, a trend of delta front sandstones at the depositional limit of Allomember H (Enclosure P-69)

Reservoir quality information is scanty, as few cores have been cut in the study area. Logs, sample cuttings, and test results suggest that most Dunvegan sandstones have low to moderate reservoir quality in the subsurface of the southern Plains Study Area. Better reservoir quality is expected to occur at shallower depths near outcrop – we have noted in past studies, for example, excellent reservoir quality (porosities > 30%, permeabilities > 1000 mD) in Dunvegan sandstones at Ladyfern d-29-H/94-H-1.

## Cardium Formation

### Definition and Distribution

The Cardium is a northeasterly-prograding shoreface/alluvial plain complex, derived from westerly highlands. It is overlain by a thinner progradational complex (Muskiki/Marshybank/Badheart Formations); both successions are encased within thick marine shales of the Smoky Group (Fig. P-29). Although most regional stratigraphic

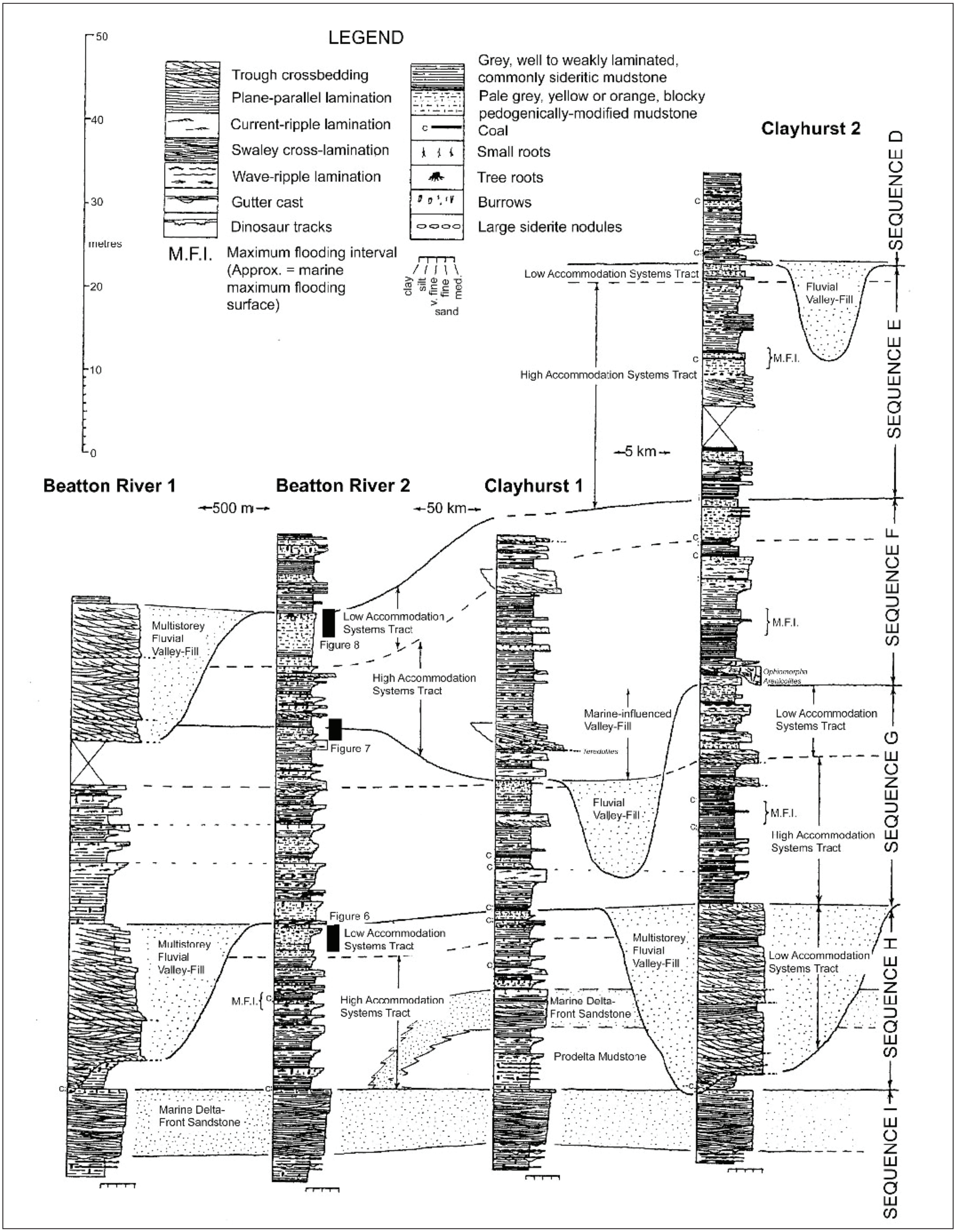



**Figure P-28.** Sequence stratigraphic corelation of Dunvegan Formation outcrop sections (from McCarthy, 2002).

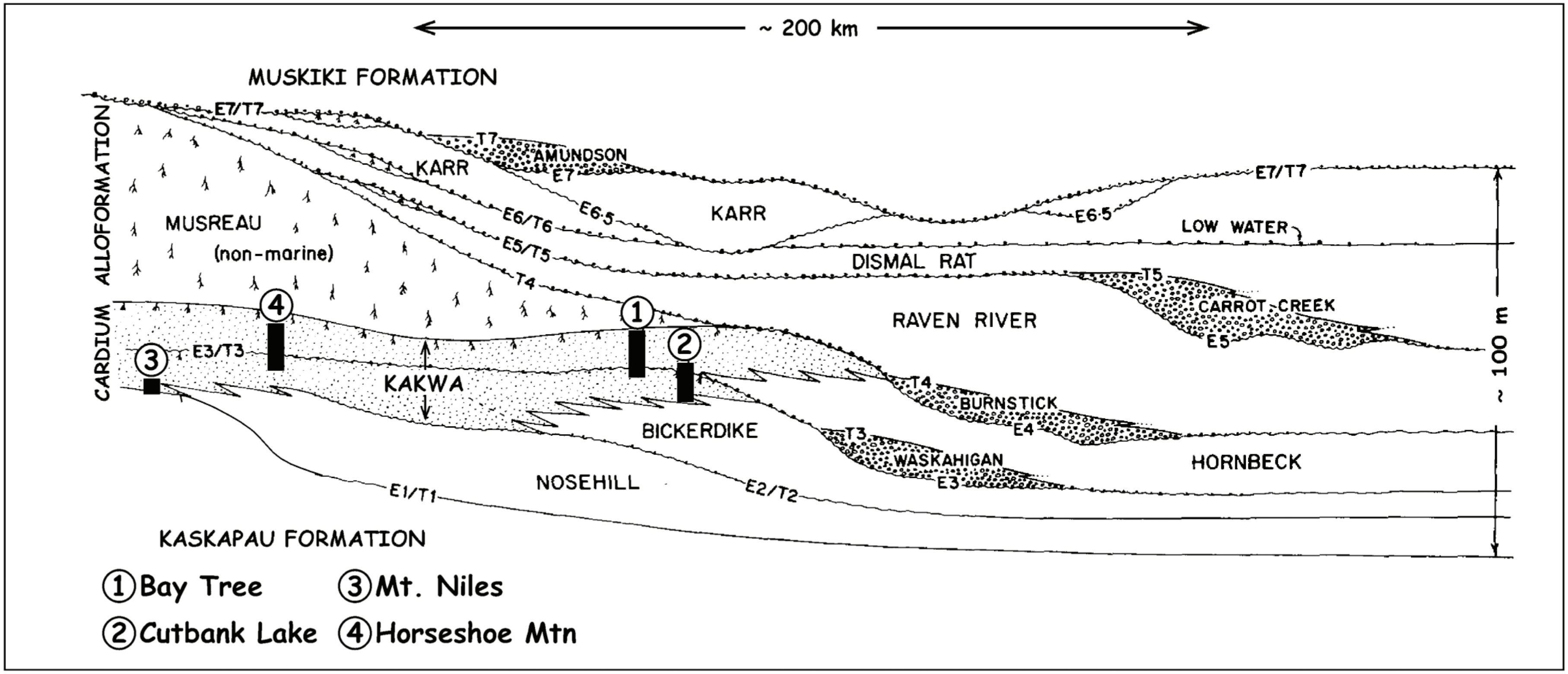



**Figure P-29.** Schematic cross-section, Cardium Formation (from Hart and Plint, 2003). The Cardium addressed in the Plains Study Area is primarily the Kawka Member.

work has been done in Alberta, northeastern B.C. has been tied into the regional framework by Plint and Hart (1988), and Hart and Plint (2003).

Cardium shoreface sandstones (Kakwa Member) occur as sandier- and coarsening-upward successions, grading up from Kaskapau marine shales, and capped by backshore to continental fine-grained clastics of the Musreau Member (Core log a-3-B/93-P-1, Appendix P-3; Fig. P-30). Channelized deposits have been described locally by Hart and Plint (2003). Relatively thin, reservoir-quality sandstones occur in transgressive units capping the Musreau; these are productive at Kakwa (Twp. 62-64, Rge. 3-5W6, Alberta), but are not volumetrically significant in B.C.

Cardium strata crop out in the southern part of the Plains Study Area (Enclosure P-70; note locations of published outcrop sections). To the north (and in the Foothills Study Area), they are completely eroded. To the south, the Cardium is behind surface casing in most wellbores except in the far southeastern corner of the area. Kakwa Member shoreface sandstones are 25 to 30 metres thick over this area; note that cased hole logs were used in several wells to pick the Cardium top and base.

## Aquifer Lithologies and Reservoir Quality Assessment

Cardium sandstones range from silty to very fine-grained in the lower to middle shoreface, and grade or pass abruptly up to fine- to medium-grained sandstone in the upper shoreface to foreshore (Core log a-3-B/93-P-1; Appendix P-3; Fig. P-30). Cardium sandstones are typically quartz-chert litharenites, with minor sedimentary and metamorphic rock fragments, and traces of feldspar. Conventional reservoir quality is generally preserved only in the capping upper shoreface to foreshore deposits; porosity values in middle shoreface sandstones are generally less than 10%, and permeabilities rarely exceed 0.1 mD. Conventional reservoir quality may be found in conglomerates if they are sufficiently sorted, but no examples have been documented in the Plains Study Area subsurface.

Enclosure P-71 shows net porous sandstone isopach values, using a 12% sandstone density log cutoff, and Enclosure P-72 shows that average porosities in the net porous sandstone sections range generally between 13 and 17%.

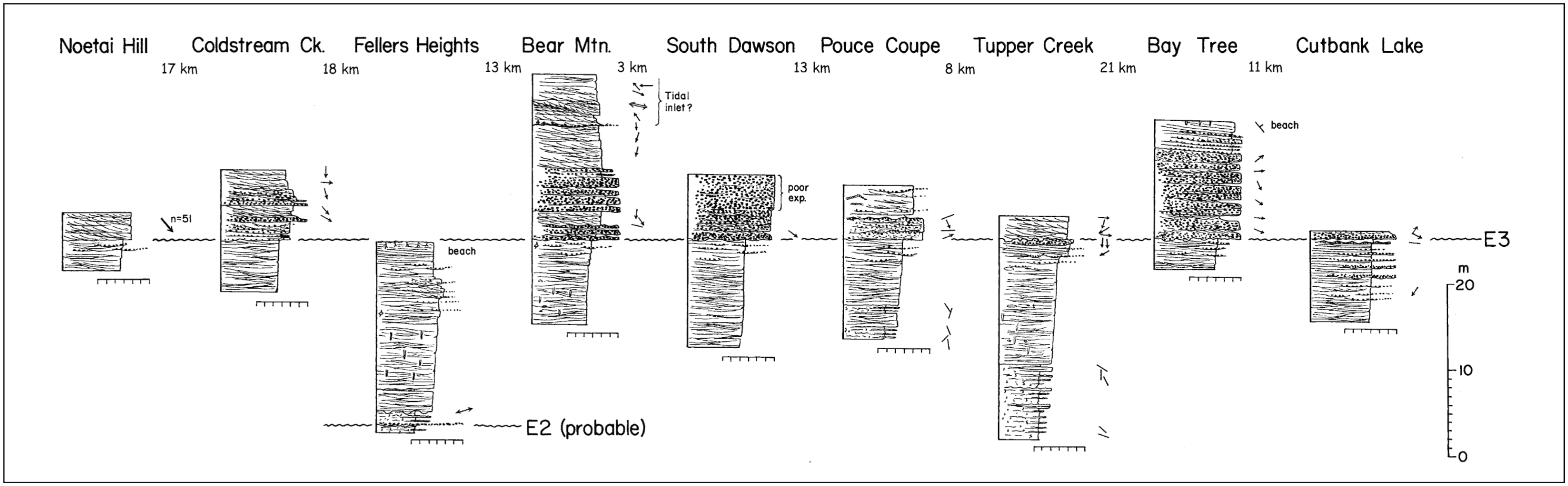



**Figure P-30.** Correlation of Cardium outcrop sections in Plains Study Area, showing consistency of coarsening-upward shoreface successions (from Hart and Plint, 2003).

## Results and Discussion Plains Area

### Halfway Formation

#### *Water and Gas Chemistry*

Halfway Formation waters range from approximately 112,723 mg/L to 193,000 mg/L TDS and comprise mainly Na and Cl ions. TDS values are highest around the city of Fort St. John in the north-central portion of the Plains Study Area, as well as in the southeastern corner along the Alberta-BC provincial border. Data control points suggest an average TDS value of approximately 153,076 mg/L. The Halfway Formation salinity map is illustrated in Enclosure C-1.

Hydrogen sulphide gas ($H_2S$) values plotted on Enclosure C-1 for the Halfway Formation range from a minimum value of 0% to a maximum value of 38.7% across the Plains Study Area, with an average value of approximately 2.6%.

#### *Hydrogeology*

The Halfway Formation has a range in hydraulic head from approximately 1,000 metres in the central and southeastern areas decreasing to approximately 550 metres to the north. Generally, groundwater flow within the Halfway Formation trends from the south to the north-northeast across the Plains Study Area. The hydraulic head map for the Halfway Formation is Enclosure C-2.

The Halfway Formation total available head map shows available head values to be highest in the central portion of the study area at approximately 3,000 metres. Available head decreases to approximately 1,400 metres toward the north-northeast. The total available head map for the Halfway Formation is Enclosure C-3.

#### *Water Volume and Deliverability*

Due to the poor aquifer characteristics of the Halfway Formation and the discontinuous nature of the deposit, especially at the 12% porosity cutoff, DST analyses were not conducted for the Plains Study Area.

The Halfway Formation storativity map shows storativity values to be highest in the northwestern corner of the mapped aquifer area, as well as in township 77, ranges 13-15W6 with values ranging from 0.221 to 0.260 $m^3/m^2$. Storativity values were calculated based on the Halfway Formation net-porous reservoir map provided by PRCL using a 6% porosity cutoff. The storativity map for the Halfway Formation is Enclosure C-4.

Total water volume calculated to be available from storage for the Halfway Formation is estimated at 621 million $m^3$ based on 6% porosity areal aquifer coverage as mapped by PRCL.

Table C-6 provides a summary of estimated permeability, deliverability and total water volume for the Plains Study Area. Figure C-1 is a graph of the total water volume available from storage per formation for the Plains Study Area.

### *Production Summary*

A production map (Figure C-2) showing hydrocarbon and water production from the Halfway Formation was made using publically available data. Gas is produced from the giant Monias Field in the northwest, and from a number of smaller pools controlled at least in part by structures associated with the Fort St. John Graben. Note that almost all production occurs in the north, where the best reservoir quality has been mapped.

Table P-1 shows three Halfway water disposal wells in the Plains Study Area, which have taken between 64 $e^3m^3$ and 278 $e^3m^3$ each.

## Baldonnel Formation

### *Water and Gas Chemistry*

Baldonnel Formation waters range from approximately 20,997 mg/L to 64,313 mg/L TDS and comprise mainly Na and Cl ions. Baldonnel Formation waters indicate a transition in ion concentrations from $HCO_3$ to $SO_4$ as the second most abundant anion after Cl, compared to the formation waters from the overlying stratigraphic units. Data control points suggest an average TDS value of approximately 36,532 mg/L. The Baldonnel Formation salinity map is Enclosure C-5.

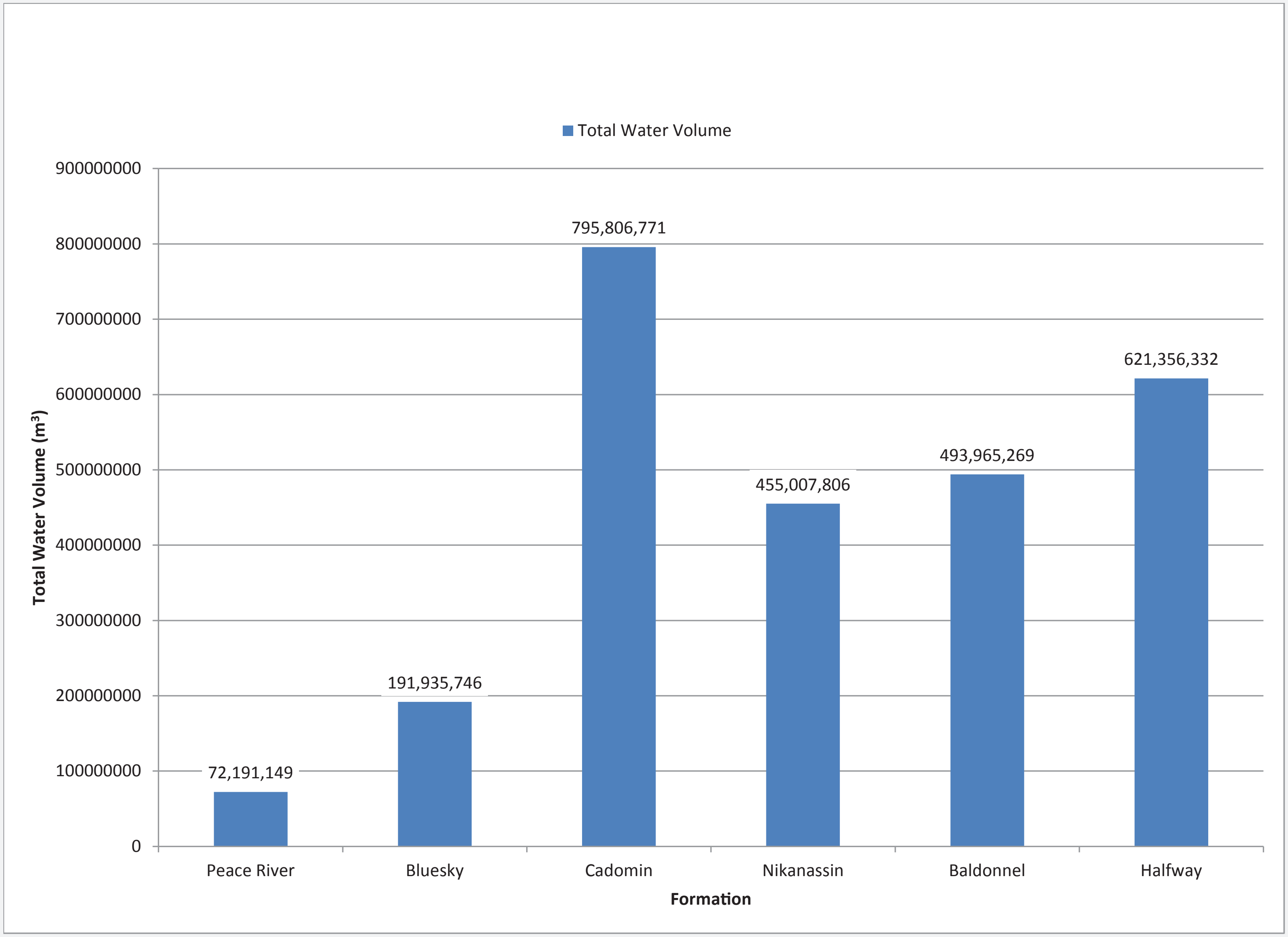
Hydrogen sulphide gas ($H_2S$) values plotted on Enclosure C-5 for the Baldonnel Formation range from a minimum value of 0% to a maximum value of 24.3% across the Plains Study Area, with an average value of approximately 4.0%.

### *Hydrogeology*

The Baldonnel Formation has a range in hydraulic head from approximately 750 metres in the southwest decreasing to approximately 575 metres in the northeast. Generally, groundwater flow within the Baldonnel Formation trends from the southwest to the northeast across the Plains Study Area. The hydraulic head map for the Baldonnel Formation is illustrated in Enclosure C-6.

*Continued from previous page*

| PLAINS STUDY AREA | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UWI | DST # | DST ID | TOP (m) | BOTTOM (m) | LATITUDE | LONGITUDE | FORMATION | PERMEABILITY, k (mD) | PRODUCTIVE THICKNESS, h (m) | PORSOSITY, ϕ (%) | CURVE # | SKIN VALUE | ONE WELL PER SECTION 6 MONTH DELIVERABILITY RATE ($m^3$/DAY) | ONE WELL PER TOWNSHIP 6 MONTH DELIVERABILITY RATE ($m^3$/DAY) | TOTAL VOLUME OF WATER AVAILABLE IN STORAGE USING 100% AVAILABLE HEAD ($m^3$) |
| 100/16-10-082-18W6/00 | 4 | 3392 | 1,125 | 1,137 | 56.099 | -120.715 | Nikanassin | 11.76 | 25.00 | 15.00 | 1 | 2.13 | 128.2 | 178.0 | 455,007,806 |
| | | | | | | | | | | | 2 | 0.00 | 143.1 | 215.3 | |
| | | | | | | | | | | | 3 | -4.00 | 166.0 | 354.6 | |
| 100/13-34-081-21W6/00 | 8 | 3106 | 1,005 | 1,020 | 56.070 | -121.203 | Nikanassin | 0.65 | 12.00 | 11.00 | 1 | 0.00 | 1.2 | 1.2 | |
| | | | | | | | | | | | 2 | -4.00 | 10.0 | 10.0 | |
| 100/08-07-080-18W6/00 | 1 | 2509 | 1,426 | 1,457 | 55.918 | -120.797 | Nikanassin | 9.03 | 14.00 | 14.00 | 1 | 1.88 | 71.8 | 92.5 | |
| | | | | | | | | | | | 2 | 0.00 | 80.6 | 109.8 | |
| | | | | | | | | | | | 3 | -4.00 | 102.0 | 182.2 | |
| 100/07-36-079-15W6/00 | 1 | 2062 | 1,385 | 1,400 | 55.889 | -120.200 | Nikanassin | 21.61 | 15.00 | 14.00 | 1 | 0.13 | 119.9 | 292.2 | |
| | | | | | | | | | | | 2 | -4.00 | 94.4 | 477.2 | |
| 100/08-19-084-18W6/00 | 1 | 6225 | 1,054 | 1,074 | 56.296 | -120.824 | Nikanassin | 4.64 | 18.00 | 8.00 | 1 | -0.42 | 49.3 | 62.3 | |
| | | | | | | | | | | | 2 | -4.00 | 65.4 | 99.4 | |
| 100/06-05-083-15W6/00 | 2 | 3831 | 1,134 | 1,170 | 56.165 | -120.334 | Nikanassin | 154.67 | 30.00 | 18.00 | 1 | 15.58 | 174.6 | 1313.0 | |
| | | | | | | | | | | | 2 | 0.00 | 27.1 | 2999.0 | |
| | | | | | | | | | | | 3 | -4.00 | 2.6 | 4433.3 | |
| 100/16-30-081-18W6/00 | 2 | 3026 | 1,167 | 1,192 | 56.055 | -120.796 | Nikanassin | 1.49 | 36.00 | 20.00 | 1 | 0.04 | 47.2 | 47.5 | |
| | | | | | | | | | | | 2 | -4.00 | 84.4 | 85.3 | |
| 200/a-082-I 093-P-08/00 | 3 | 14044 | 2,145 | 2,174 | 55.485 | -120.016 | Baldonnel | 56.11 | 5.00 | 6.00 | 1 | 6.20 | 21.9 | 538.4 | 493,965,269 |
| | | | | | | | | | | | 2 | 0.00 | 8.8 | 355.1 | |
| | | | | | | | | | | | 3 | -4.00 | 1.4 | 231.7 | |
| 102/06-21-081-21W6/00 | 2 | 3099 | 1,277 | 1,297 | 56.034 | -121.225 | Baldonnel | 5.39 | 4.00 | 16.00 | 1 | 3.26 | 15.4 | 17.2 | |
| | | | | | | | | | | | 2 | 0.00 | 19.7 | 23.0 | |
| | | | | | | | | | | | 3 | -4.00 | 28.8 | 38.7 | |
| 100/06-10-083-21W6/00 | 1 | 5249 | 1,073 | 1,084 | 56.179 | -121.231 | Baldonnel | 41.66 | 3.00 | 9.00 | 1 | 32.10 | 12.4 | 21.2 | |
| | | | | | | | | | | | 2 | 0.00 | 8.6 | 83.2 | |
| | | | | | | | | | | | 3 | -4.00 | 2.9 | 130.1 | |
| 100/16-21-084-18-W6/00 | 3 | 6248 | 1,146 | 1,158 | 56.303 | -120.770 | Baldonnel | 2.15 | 7.00 | 14.00 | 1 | -2.99 | 18.2 | 18.9 | |
| | | | | | | | | | | | 2 | -4.00 | 21.3 | 22.5 | |



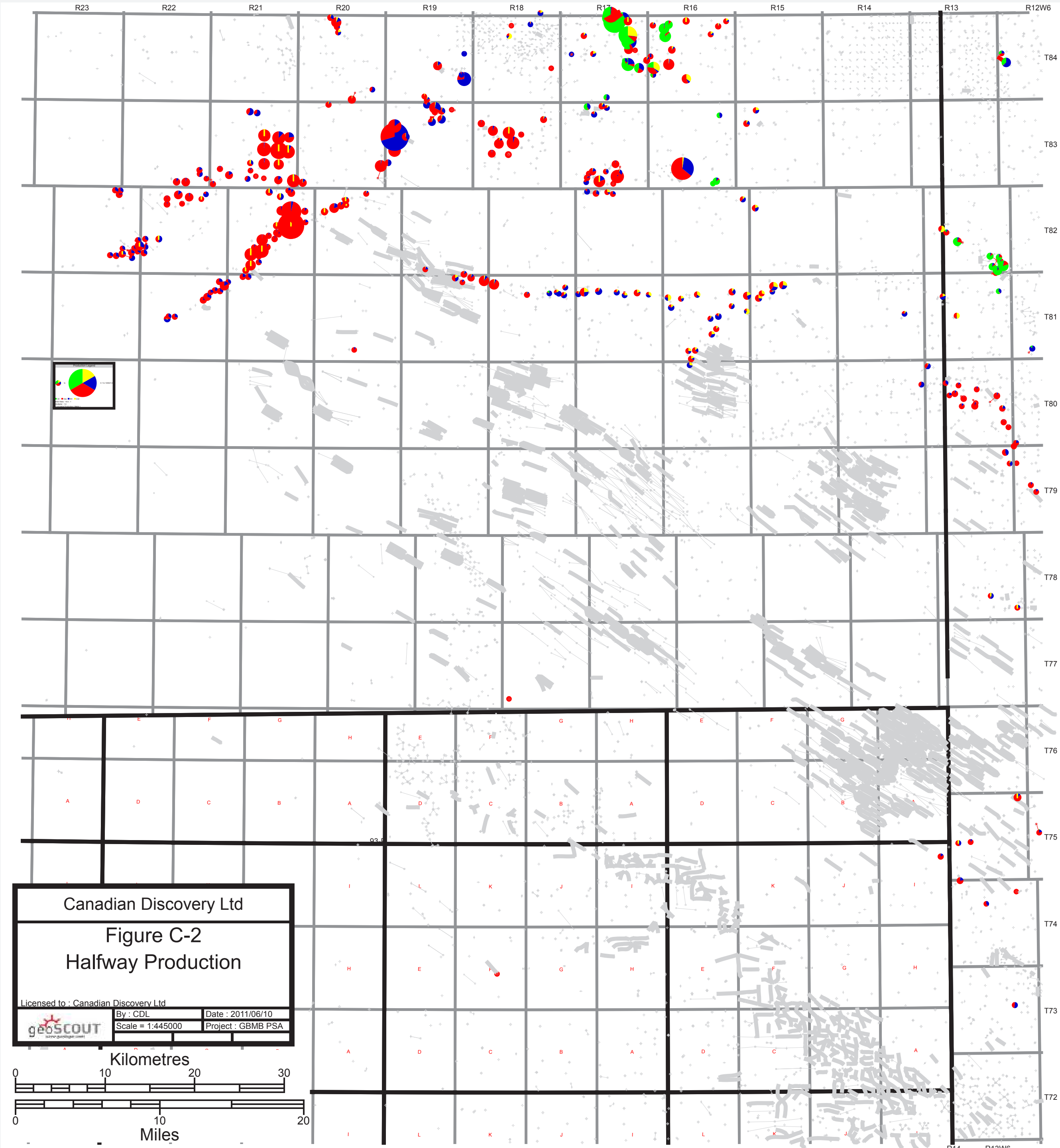

**GEOSCIENCE B.C MONTNEY BASIN**

| | | | |
|---|---|---|---|
| Project | GBMB | Author | Sheldon Thistle |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Total Water Volume Available in Storage by Formation (Declining 100% of the Total Available Head) Plains Study Area**

Canadian Discovery Ltd.

Figure C-1




## GEOSCIENCE B.C MONTNEY BASIN

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|---|---|---|---|
| Project | GBMB | Author | Jordan Brinsky |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Production Map**
**Halfway Formation**

Canadian Discovery Ltd.

Figure
**C-2**

The Baldonnel Formation total available head map (Enclosure C-7) shows available head values to be highest in the southeast corner of the Plains Study Area at approximately 2,300 metres. Available head decreases to approximately 1,100 metres toward the north-northeast.

### *Water Volume and Deliverability*

Baldonnel Formation permeabilities were estimated from DSTs conducted at four different well locations. Porosity (Φ) and productive thickness (h) were determined from borehole logs, and ranged from 6% to 16% and 3.0 to 7.0 metres, respectively. DST analyses in Fekete F.A.S.T. WellTest software resulted in permeability values between 2.15 and 56.11 mD.

Deliverability forecasts estimated over a twelve-month period for one well per section and one well per township produced a number of skin due to damage ($s_d$) scenarios. After six months of production, the skin scenarios resulted in a range of flow rates from 1.4 $m^3$/day to 28.8 $m^3$/day based on one well per section, and 17.2 $m^3$/day to 538.4 $m^3$/day based on one well per township.

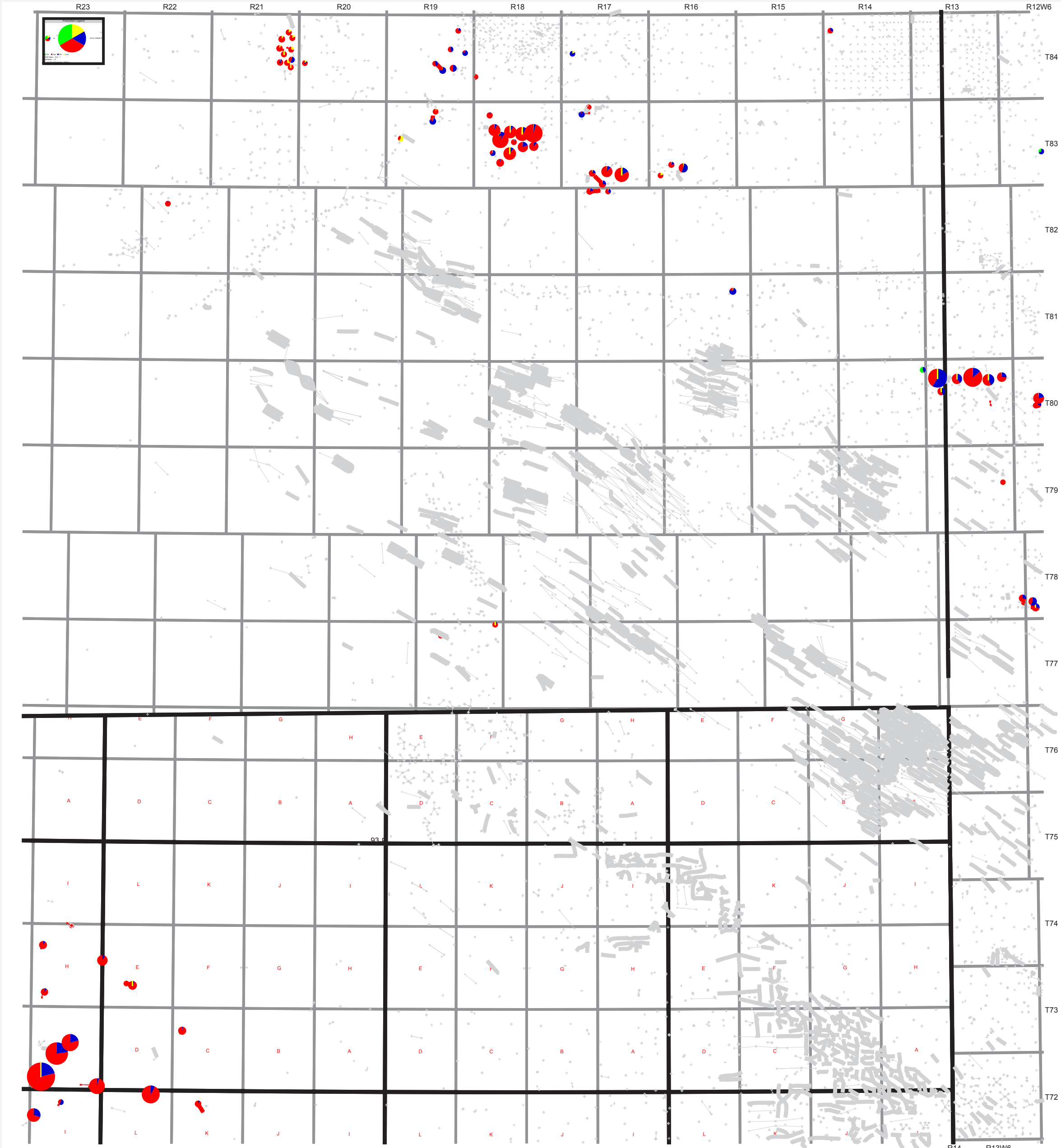
The Baldonnel Formation storativity map (Enclosure C-8) shows storativity values to be highest trending south toward the southern extent of the mapped aquifer, with values ranging from 0.221 to 0.260 $m^3/m^2$. A Baldonnel Formation net-porous reservoir map was not provided by PRCL; as a result, storativity values were calculated using an average aquifer thickness of 11 metres, based on borehole logs, using a 4% porosity cutoff.

Total water volume calculated to be available from storage for the Baldonnel Formation is estimated at 494 million $m^3$ based on 4% porosity areal aquifer coverage as mapped by PRCL.

Table C-6 provides a summary of estimated permeability, deliverability, and total water volume for the Plains Study Area. Figure C-1 is a graph of the total water volume available from storage per formation for the Plains Study Area.

### *Production Summary*

A production map (Figure C-3) showing hydrocarbon and water production from the Baldonnel Formation was made using publically available data. Gas production in the north is primarily from discrete structural traps with defined gas/water contacts; many of these were discovered in the early days of N.E.B.C. exploration (1950’s and 1960’s), and so many of the producing wells have old, incomplete log suites. Baldonnel production in the southwestern corner of the map sheet is from structural accumulations in the Foothills (Gwillim and Sukunka Fields).




Canadian Discovery Ltd

Baldonnel Production

Licensed to : Canadian Discovery Ltd

| By : CDL | Date : 2011/06/10 |
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| Scale = 1:445000 | Project : GBMB PSA |

geoSCOUT

Kilometres
0 10 20 30

0 10 20
Miles

## GEOSCIENCE B.C MONTNEY BASIN

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| Project | GBMB | Author | Jordan Brinsky |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Production Map**
**Baldonnel Formation**

Canadian Discovery Ltd.

Figure
**C-3**

Table P-1 shows two Baldonnel water disposal wells in the Plains Study Area, which have taken between 56 $e^3m^3$ and 141 $e^3m^3$ each.

## Nikanassin Formation

### *Water and Gas Chemistry*

Nikanassin Formation waters, which range widely from approximately 5,209 mg/L to 99,900 mg/L TDS, comprise mainly Na and Cl ions. Water analyses indicate an increase in all cation concentrations, as well as an increase in $SO_4$ and a decrease in $HCO_3$, compared to formation waters of the overlying Cadomin Formation. TDS values greater than 90,000 mg/L are isolated in the southeastern corner of the study area and were not contoured due to lack of sufficient data. The remaining TDS values show a decreasing trend radially from the city of Fort St. John. Data control points suggest an average TDS value of approximately 25,062 mg/L. The Nikanassin Formation salinity map is illustrated on Enclosure C-9.

No hydrogen sulphide gas ($H_2S$) greater than 0% was reported on Enclosure C-9 for the Nikanassin Formation, based on the publically available data observed for the Plains Study Area.

### *Hydrogeology*

The Nikanassin Formation has a range in hydraulic head from approximately 700 metres in the west decreasing to approximately 600 metres in the east. Generally, groundwater flow within the Nikanassin Formation trends from west to east across the Plains Study Area. The pressure versus elevation graph defines the approximate limit of the gas-saturated zone of the Deep Basin as trending east-southeast from Townships 78-79 to Township 74. The area in the southeast producing both gas and water is indicative of a possible transition zone into the Deep Basin setting, where the fluid saturation is moving from dominantly water to dominantly gas. The hydraulic head map for the Nikanassin Formation is Enclosure C-10.

The Nikanassin Formation total available head map (Enclosure C-11) shows available head values to be highest in the east and centrally in township 79 at approximately 1,300 metres. Available head decreases to approximately 800 metres toward the north-northwest.

### *Water Volume and Deliverability*

Nikanassin Formation permeabilities were estimated from DSTs conducted at seven different well locations. Porosity (Φ) and productive thickness (h) were determined from borehole logs, and ranged from 8% to 20% and 12.0 to 36.0 metres. DST analyses in Fekete F.A.S.T. WellTest software resulted in permeability values between 0.65 and 154.67 mD.

Deliverability forecasts estimated over a twelve-month period for one well per section and one well per township produced a number of skin due to damage ($s_d$) scenarios. After six months of production, the skin scenarios resulted in a range of flow rates from 1.2 $m^3$/day to 174.6 $m^3$/day based on one well per section, and 1.2 $m^3$/day to 4,433 $m^3$/day based on one well per township.

The Nikanassin Formation storativity map (Enclosure C-12) shows storativity values to be highest along Townships 80 and 81, Ranges 14-17W6, with values ranging from 0.241 to 0.260 $m^3/m^2$. Areas of high storativity are also present to the northwest and southeast of the main area. Storativity values were calculated based on the Nikanassin Formation net-porous reservoir map provided by PRCL, using a 12% porosity cutoff. Total water volume calculated to be available from storage for the Nikanassin Formation is estimated at 455 million $m^3$ based on 12% porosity areal aquifer coverage as mapped by PRCL.

Table C-6 provides a summary of estimated permeability, deliverability, and total water volume for the Plains Study Area. Figure C-1 is a graph of the total water volume available from storage per formation for the Plains Study Area.

### *Production Summary*

A production map (Figure C-4) showing hydrocarbon and water production from the Nikanassin Formation was made using publically available data. There are relatively few producers, and most in the southern Deep Basin area are little better than shows. In the far southeastern corner of the map, Nikanassin zones are commingled in vertical wellbores with other low-permeability Deep Basin sandstones. An immense tight gas resource has been recognized in the Nikanassin in west-central Alberta, and several companies are now systematically exploiting this, with both vertical (commingled) and horizontal (single-zone) wellbores. These strategies are spreading northwestward into British Columbia.

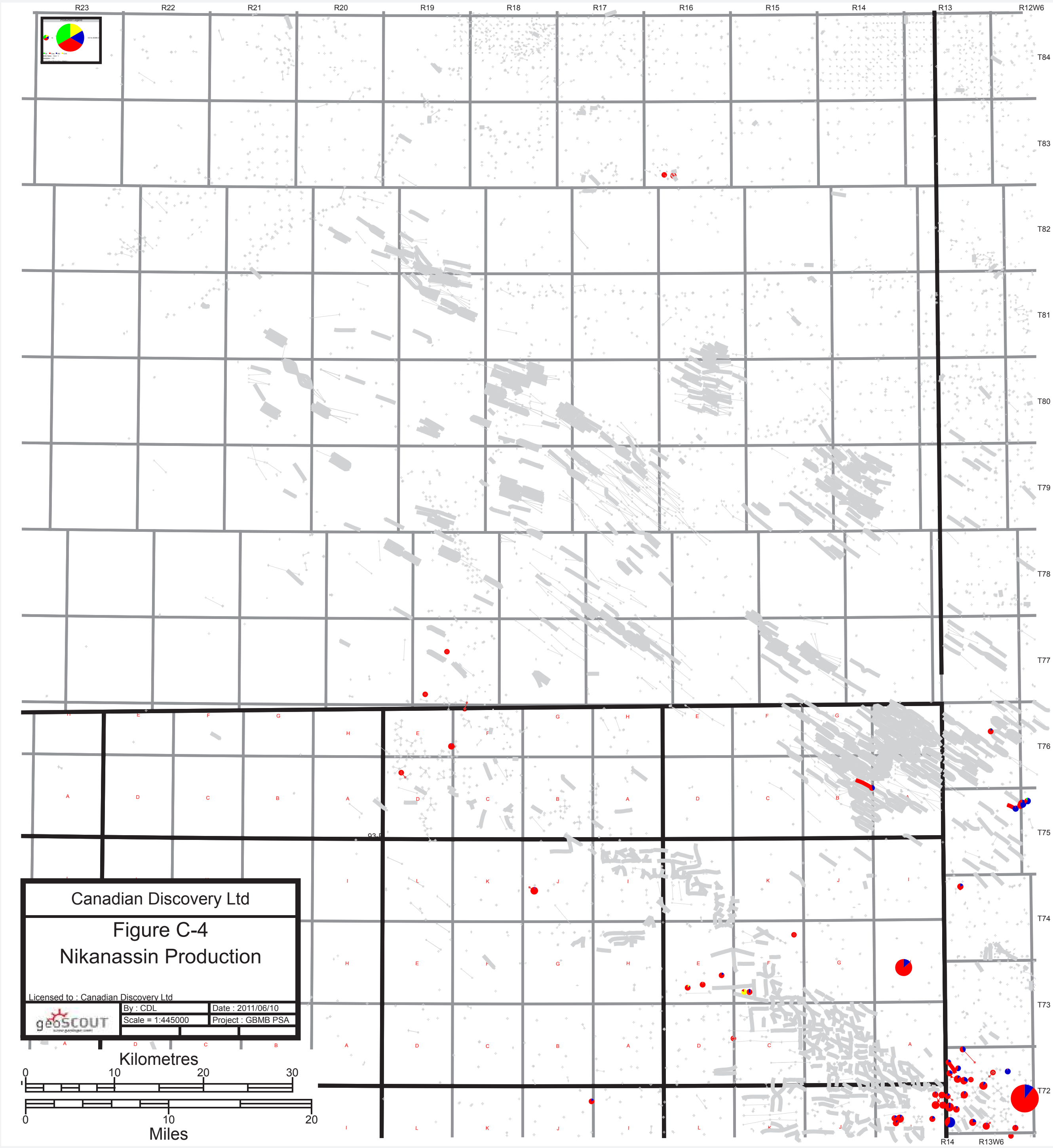
Table P-1 shows one Nikanassin water disposal well in the Plains Study Area, which has taken 111 $e^3m^3$ water.

Note that where the best-quality Nikanassin reservoirs have been mapped in the north, we see little or no gas production. We speculate that there is a lack of suitable traps within the continuous, good-quality sandstones.

## Cadomin Formation

### *Water and Gas Chemistry*

Cadomin Formation waters range from approximately 3,668 mg/L to 95,415 mg/L TDS and comprise mainly Na and Cl ions. Cadomin Formation waters show an increase in




GEOSCIENCE B.C MONTNEY BASIN

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|---|---|---|---|
| Project | GBMB | Author | Jordan Brinsky |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Production Map**
**Nikanassin Formation**

Canadian Discovery Ltd.

Figure
**C-4**

both Na and Cl ions compared to overlying units. TDS values show a decreasing trend north toward the Peace River, with higher values returning on the north side of the river. Data control points suggest an average TDS value of approximately 22,901 mg/L. The Cadomin Formation salinity map is Enclosure C-13.

Hydrogen sulphide gas ($H_2S$) values plotted on Enclosure C-13 for the Cadomin Formation range from a minimum value of 0% to a maximum value of 8.5% across the Plains Study Area, with an average value of approximately 0.10%.

### *Hydrogeology*

The Cadomin Formation has a range in hydraulic head from 700 metres in the west decreasing to approximately 600 metres in the east. Generally, groundwater flow within the Cadomin Formation trends from west to east across the Plains Study Area. The pressure versus elevation graph defines the approximate limit of the gas-saturated zone of the Deep Basin as trending southeast from Township 79 to Township 72. The area in the southeast producing both gas and water is indicative of a possible transition zone between a dominantly water-saturated setting to a gas-saturated setting. The hydraulic head map for the Cadomin Formation is Enclosure C-14.

The Cadomin Formation total available head map (Enclosure C-15) shows available head values to be highest in the east and centrally in township 76 at approximately 1,600 metres. Available head decreases to approximately 700 metres toward the north-northwest.

### *Water Volume and Deliverability*

Cadomin Formation permeabilities were estimated from DSTs conducted at nine different well locations. Porosity (Φ) and productive thickness (h) were determined from borehole logs, and ranged from 10% to 20.5% and 3.0 to 32.0 metres. DST analyses in Fekete F.A.S.T. WellTest software resulted in permeability values between 2.00 and 487.13 mD.

Deliverability forecasts estimated over a twelve-month period for one well per section and one well per township produced a number of skin due to damage ($s_d$) scenarios. After six months of production, the skin scenarios resulted in a range of flow rates from 10.3 $m^3$/day to 204.9 $m^3$/day based on one well per section, and 11.8 $m^3$/day to 1,996 $m^3$/day based on one well per township.

The Cadomin Formation storativity map (Enclosure C-16) shows storativity values to be highest along Townships 80 and 81, Ranges 13-19, with values ranging from 0.221 to 0.260 $m^3/m^2$. Storativity values were calculated based on the Cadomin Formation net porous reservoir map provided by PRCL, using a 10% porosity cutoff.

Total water volume calculated to be available from storage for the Cadomin Formation is estimated at 796 million $m^3$ based on 10% porosity areal aquifer coverage as mapped by PRCL.

Table C-6 provides a summary of estimated permeability, deliverability, and total water volume for the Plains Study Area. Figure C-1 is a graph of the total water volume available from storage per formation for the Plains Study Area.

### *Production Summary*

A production map (Figure C-5) showing hydrocarbon and water production from the Cadomin Formation was made using publically available data. Highly-mappable Cadomin reservoirs have been exploited systematically using horizontal and vertical wellbores along the updip edge of the Deep Basin, where reservoir quality is best in the gas-saturated regime. To the north, there are isolated small pools, characterized by high water cuts. As for the Nikanassin, we speculate that good trap configurations are lacking in the relatively continuous, good-quality reservoir rock.

Table P-1 shows four Cadomin water disposal wells in the Plains Study Area, which have taken between 2.6 $e^3m^3$ and 731 $e^3m^3$ each.

## Gething Formation

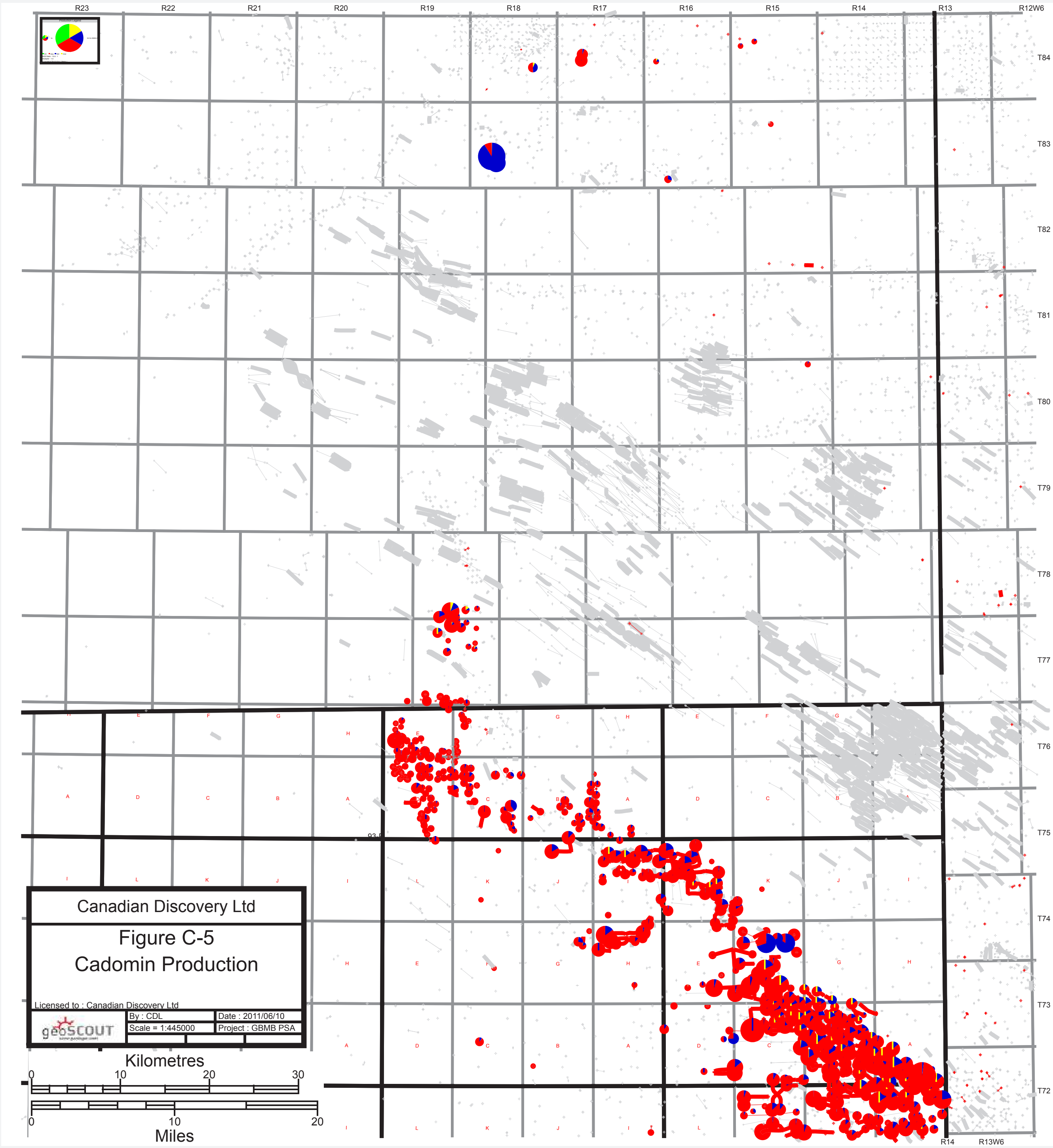
### *Water and Gas Chemistry*

Gething Formation waters range from approximately 6,612 mg/L to 43,682 mg/L TDS and comprise mainly Na and Cl ions. Gething Formation waters show a slight increase in $HCO_3$ ions compared to the Bluesky Formation. TDS values show a decreasing trend southeast from the city of Fort St. John, with possibly higher values returning south of Township 78. Data control points suggest an average TDS value of approximately 15,854 mg/L. The Gething Formation salinity map is Enclosure C-17.

Hydrogen sulphide gas ($H_2S$) values plotted on Enclosure C-17 for the Gething Formation range from a minimum value of 0% to a maximum value of 1.7% across the Plains Study Area, with an average value of approximately 0.03%.

### *Hydrogeology*

The Gething Formation has a range in hydraulic head from 640 metres in the west decreasing to approximately 560 metres in the east. Data are limited mostly to the northeastern section of the map; however, general groundwater flow within the Gething Formation trends from west to east. The pressure versus elevation graph defines the limit of the gas-saturated zone of the Deep Basin trending to the east-northeast from Township 77 to Township 78. The hydraulic head map for the Gething Formation is Enclosure C-18.




## GEOSCIENCE B.C MONTNEY BASIN

| | | | |
|---|---|---|---|
| Project | GBMB | Author | Jordan Brinsky |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Production Map**
**Cadomin Formation**

Canadian Discovery Ltd.

Figure
C-5

As PRCL noted in the geology section, the Gething Formation could not be be correlated with confidence from well to well, on either local or regional scales. As such, a Gething total available head map was not produced for this study.

### *Water Volume and Deliverability*

Estimates of water volume and deliverability were not calculated for the Gething Formation due to its discontinuous nature and lack of well control.

### *Production Summary*

A production map (Figure C-6) showing hydrocarbon and water production from the Gething Formation was made using publically available data. Many pools contain only a single well, reflecting stratigraphic trapping in a local channel sandstone that cannot be mapped to adjacent wells. No Gething water disposal wells were found in the Plains Study Area.

## Bluesky Formation

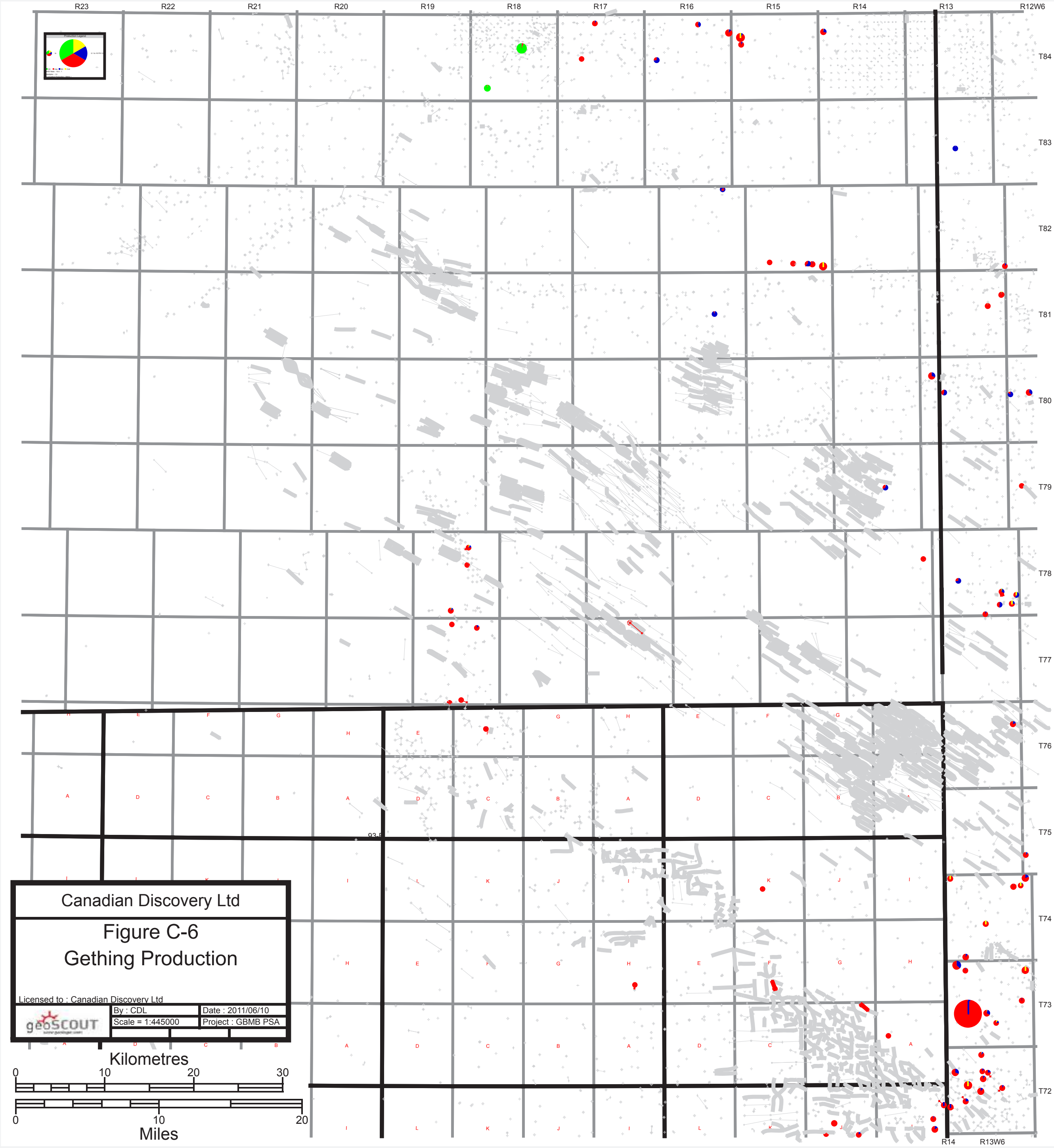
### *Water and Gas Chemistry*

Bluesky Formation waters range from approximately 10,709 mg/L to 25,402 mg/L TDS and comprise mainly Na and Cl ions. Compared to the overlying Peace River and Spirit River formations, the Bluesky Formation shows a slight increase in $HCO_3$ and $SO_4$ concentration. The TDS control points are located in the northern half of the study area with the highest values occurring just east of the city of Fort St. John. Data control points suggest an average TDS value of approximately 18,410 mg/L. The Bluesky Formation salinity map is Enclosure C-19.

Hydrogen sulphide gas ($H_2S$) was reported in one well (7-30-80-13W6) on Enclosure C-19 for the Bluesky Formation at a maximum value of 0.64% for the Plains Study Area.

### *Hydrogeology*

The Bluesky Formation has a range in hydraulic head from 675 metres in the west decreasing to approximately 500 metres in the east. Generally, groundwater flow within the Bluesky Formation trends from west to east across the Plains Study Area. Due to scarcity of data, the limit of the gas-saturated zone of the Deep Basin was defined using both the pressure versus elevation graph and the zero edge of the Bluesky net clean-sand map provided by PRCL. The approximate location of the Deep Basin line trends to the southeast from Township 80 to Township 78. The hydraulic head map for the Bluesky Formation is Enclosure C-20.




## GEOSCIENCE B.C MONTNEY BASIN

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| Project | GBMB | Author | Jordan Brinsky |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Production Map**
**Gething Formation**

Canadian Discovery Ltd.

Figure
**C-6**

The Bluesky Formation total available head map (Enclosure C-21) shows available head values to be highest centrally along Township 79 at approximately 1,000 metres. Available head decreases to approximately 700 metres towards the north.

### *Water Volume and Deliverability*

Bluesky Formation permeabilities were estimated from DSTs conducted at two different well locations. Porosity (Φ) and productive thickness (h) were determined from borehole logs, and ranged from 11% to 20% and 9.0 to 12.0 metres. DST analyses in Fekete F.A.S.T. WellTest software resulted in permeability values between 1.28 and 138.40 mD.

Deliverability forecasts estimated over a twelve-month period for one well per section and one well per township produced a number of skin due to damage ($s_d$) scenarios. After six months of production, the skin scenarios resulted in a range of flow rates from 2.4 $m^3$/day to 17.5 $m^3$/day based on one well per section, and 8.0 $m^3$/day to 1,348 $m^3$/day based on one well per township.

The Bluesky Formation storativity map (Enclosure C-22) shows storativity values to be highest along Townships 80 and 81, Ranges 13-14W6, with values ranging from 0.201 to 0.260 $m^3/m^2$. Storativity values were calculated based on the Bluesky Formation net porous reservoir map provided by PRCL, using a 12% porosity cutoff.

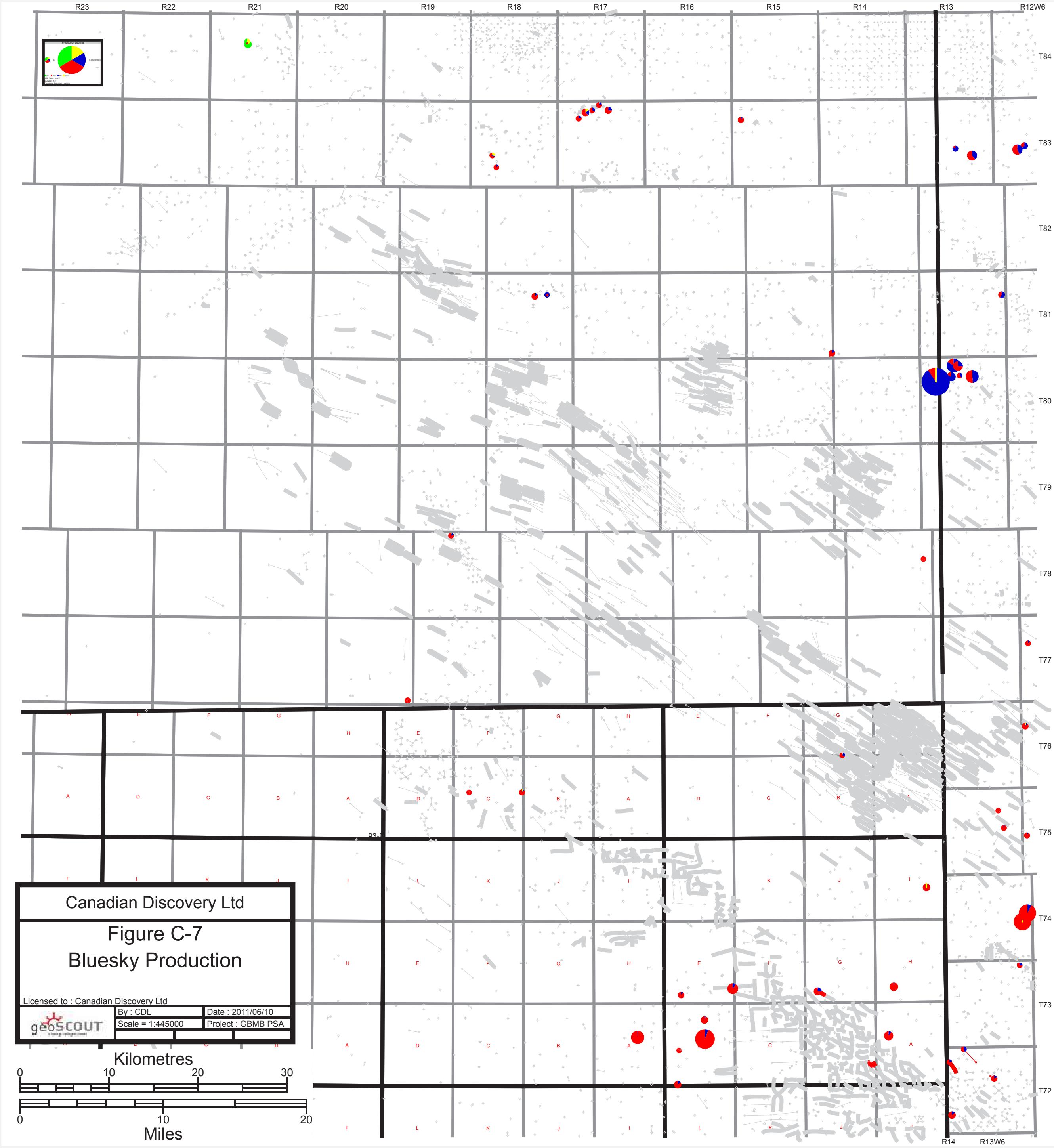
Total water volume calculated to be available from storage for the Bluesky Formation is estimated at 192 million $m^3$ based on 12% porosity areal aquifer coverage as mapped by PRCL.

Table C-6 provides a summary of estimated permeability, deliverability, and total water volume for the Plains Study Area. Figure C-1 is a graph of the total water volume available from storage per formation for the Plains Study Area.

### *Production Summary*

A production map (Figure C-7) showing hydrocarbon and water production from the Bluesky Formation was made using publically available data. Most good gas producers in the south are high-quality reservoirs with limited lateral continuity, deposited in estuarine or shoreline settings. As noted for the Nikanassin and Cadomin formations, there appear to be few effective trapping configurations in the continuous good-quality sandstones in the northeast. Thus, there are only isolated small gas pools, many showing relatively high water cuts.

Table P-1 shows one Bluesky water disposal wells in the Plains Study Area, which has taken 56 $e^3m^3$ water.




## GEOSCIENCE B.C MONTNEY BASIN

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| Project | GBMB | Author | Jordan Brinsky |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Production Map**
**Bluesky Formation**

Canadian Discovery Ltd.

Figure C-7

## Peace River Formation

### *Water and Gas Chemistry*

Peace River Formation waters, from the Paddy and Cadotte members, range widely from approximately 5,276 mg/L to 50,205 mg/L TDS and comprise mainly Na and Cl ions, with lesser amounts of Ca and $HCO_3$. TDS concentrations are highest in the southeastern corner of the study area as well as northwest of the town of Dawson Creek. Data control points suggest an average TDS value of approximately 19,206 mg/L. The Peace River Formation salinity map is Enclosure C-23.

No hydrogen sulphide gas ($H_2S$) greater than 0% was reported on Enclosure C-23 for the Peace River Formation, based on the publically available data observed in this study area.

### *Hydrogeology*

The Cadotte Member of the Peace River Formation ranges in hydraulic head from 600 metres decreasing to approximately 300 metres in the east. On a regional scale across the Plains Study Area, groundwater flow within the Cadotte Member trends in an east-northeast direction. The pressure versus elevation graph defines the limit of the gas-saturated zone of the Deep Basin trending southeast from A/93-P-12 to the southeastern corner of the map sheet. The area in the southeast recovering both gas and water is indicative of a possible transition zone between a dominantly water-saturated setting to a gas-saturated setting.

Similarly, the Paddy Member ranges in hydraulic head from 600 metres to approximately 300 metres, with groundwater flow generally to the east. The pressure versus elevation graph defines the limit of the gas-saturated zone of the Deep Basin for the Paddy Member from approximately H/93-P-12 trending to the southeast. Hydraulic head maps for the Cadotte and Paddy are Enclosures C-24 and C-25, respectively.

The Peace River Formation total available head map (Enclosure C-26) shows available head values to be highest in the southeast within Township 74, at approximately 1,200 metres. Available head decreases to approximately 400 metres toward the north at Township 80.

### *Water Volume and Deliverability*

Peace River Formation permeabilities were estimated from DSTs conducted at five different well locations. Porosity ($\Phi$) and productive thickness (h) were determined from borehole logs, and range from 12% to 20% and 4.0 to 22.0 metres. DST analyses in Fekete F.A.S.T. WellTest software resulted in permeability values between 3.00 and 369.62 mD.

Deliverability forecasts estimated over a twelve-month period for one well per section and one well per township produced a number of skin due to damage ($s_d$) scenarios. After six months of production, the skin scenarios resulted in a range of flow rates from 2.9 $m^3$/day to 67.1 $m^3$/day based on one well per section, and 17.2 $m^3$/day to 782.4 $m^3$/day based on one well per township.

The Peace River Formation storativity map (Enclosure C-27) shows storativity values to be highest in Township 79, Range 13W6, with values ranging from 0.121 to 0.200 $m^3/m^2$. Storativity values were calculated based on the Peace River Formation net porous reservoir map provided by PRCL, using a 12% porosity cutoff.

Total water volume calculated to be available from storage for the Peace River Formation is estimated at 72 million $m^3$ based on 12% porosity areal aquifer coverage as mapped by PRCL.

Table C-6 provides a summary of estimated permeability, deliverability, and total water volume for the Plains Study Area. Figure C-1 is a graph of the total water volume available from storage per formation for the Plains Study Area.

### *Production Summary*

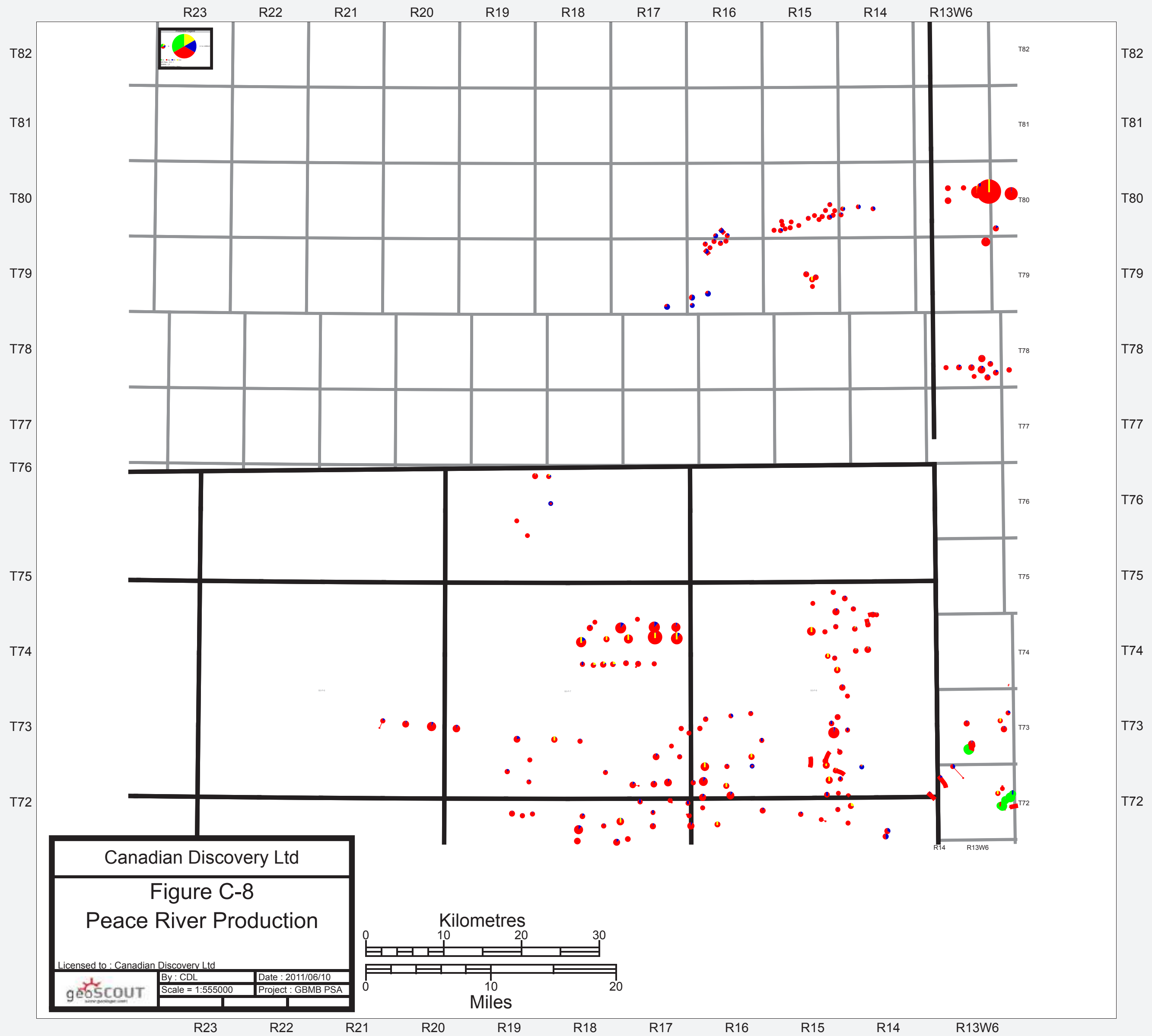
A production map (Figure C-8) showing hydrocarbon and water production from members of the Peace River Formation was made using publically available data. Much of the production in the south is from Cadotte shoreface sandstones and conglomerates in the Deep Basin. West-east productive trends in northeastern 93-P-7 (Sundown area) are discrete high-quality Cadotte shoreface conglomerates; some of these are gas-filled, while adjacent trends are wet. The south-north trend in 93-P-10 produces primarily from estuarine sandstones of the upper Paddy Member. To the north in Townships 79 and 80, gas is produced from stacked Peace River shoreline sandstones in broad structural traps, and from more isolated stratigraphic traps behind (south of) the main barrier.

Table P-1 shows two Peace River water disposal wells in the Plains Study Area, one from the Cadotte which has taken 354 $e^3m^3$, and one from the Paddy which has take 15 $e^3m^3$.

## Other Zones Water Chemistry

In addition to the formations discussed above, some chemistry data was examined for other formations in the study area. These results are summarized as follows:

Spirit River Formation waters from the Notikewin and Falher members range from approximately 11,874 mg/L to 33,570 mg/L TDS, and comprise mainly Na and Cl ions, with slightly lower amounts of Ca and $HCO_3$ compared to the Peace River Formation waters. Formation water samples were scarce in the Spirit River, with the majority of




GEOSCIENCE B.C MONTNEY BASIN

| | | | | | |
|---|---|---|---|---|---|
| Project | GBMB | Author | Jordan Brinsky | Production Map<br>Peace River Formation | Figure C-8 |
| Created | 15/06/11 | Graphics | Ally Masoud | | |
| File | *.idd | Reviewer | David Hume | | |

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the TDS control points occurring in the southeastern corner of the study area. PRCL concluded that the Spirit River contains insufficient aquifer-quality rock to justify detailed mapping or analysis for this study.

Triassic Charlie Lake Formation waters show relatively large TDS values, ranging from 90,289 mg/L to 162,838 mg/L. The main ion constituents remain Na and Cl, although at higher concentrations. Anion concentrations of $SO_4$ are also higher when compared to Nikanassin waters and other overlying formation waters. Charlie Lake TDS data are mostly in the northern half of the study area and demonstrate an increasing trend to the north. The Charlie Lake Formation was not mapped as part of this study.

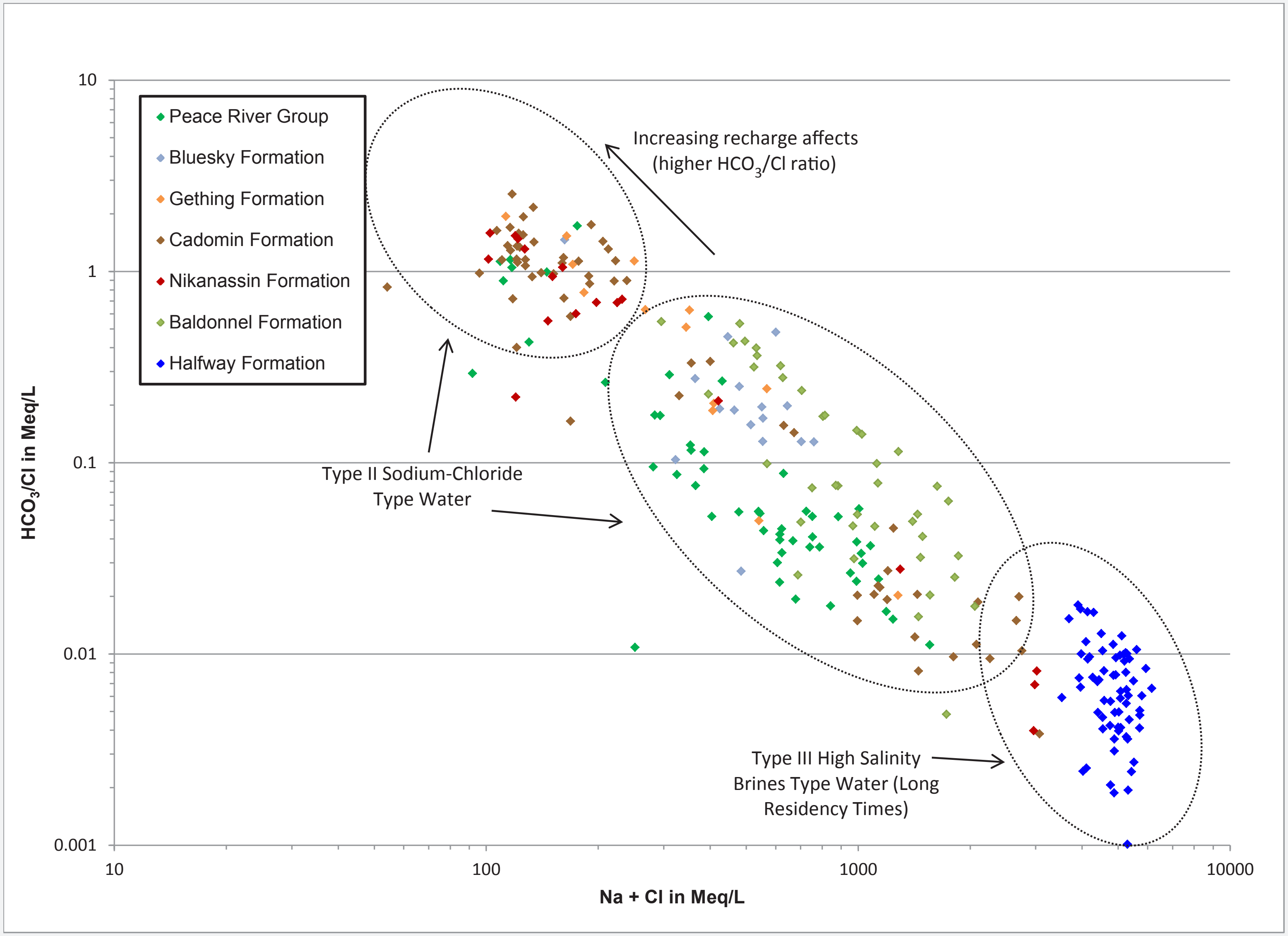
## Formation Water Characterization and Trends

### *Piper Diagrams*

Piper diagrams constructed for the Peace River Formation down to the Nikanassin plot in very similar space. The plots suggest the main hydrochemical facies for these formations is indicative of sodium-chloride-bicarbonate type formation water. The Peace River, Cadomin, and Nikanassin show the largest scatter, mainly due to the fluctuation in anion percentage of $HCO_3$, and $SO_4$. The Triassic Baldonnel Formation has similar sodium and chloride ion percentages; however, the Piper diagram shows an increase in $SO_4$ relative to $HCO_3$. This suggests a transition to sodium-chloride-sulphate type formation water, as the water is becoming increasingly sulphate-rich. The decreasing bicarbonate trend is also illustrated in the Piper diagram for the Halfway Formation. Formation waters in this formation have virtually no bicarbonate component and have varying amounts of sulphate. Sodium and chloride remain the dominate ions present. Piper plots are presented on their corresponding formation salinity maps.

### *Formation Water and Trend Mixing*

Figure C-9 presents a plot of formation waters from the Peace River Formation down to the Halfway Formation. Formation waters that appear more affected by meteoric recharge or indicate a mixing relationship between meteoric and sodium-chloride type waters are from the Peace River, Gething, Cadomin and Nikanassin formations. The Baldonnel Formation mainly plots within the Type II high salinity water; however, some data points indicate possible mixing between Type II and Type III water.




**GEOSCIENCE B.C MONTNEY BASIN**

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|---|---|---|---|
| Project | GBMB | Author | Sheldon Thistle |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Formation Water Grouping and Mixing Trend**
**Plains Study Area**

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Figure
**C-9**

# Results and Discussion Foothills Area

## Debolt Formation

### *Water and Gas Chemistry*

Debolt Formation waters range widely from 19,191 mg/L to 156,737 mg/L TDS and comprise mainly Na and Cl ions. TDS values appear to increase across the study area to the east. Data control points suggest an average TDS value of approximately 61,496 mg/L. The Debolt Formation salinity map is Enclosure C-28.

Hydrogen sulphide gas ($H_2S$) values plotted on Enclosure C-28 for the Debolt Formation range from a minimum value of 0% to a maximum value of 0.3% in three wells across the Foothills Study Area.

### *Hydrogeology*

The Debolt Formation ranges in hydraulic head from 1,000 metres decreasing to approximately 600 metres to the east. On a regional scale across the Foothills Study Area, groundwater flow within the Debolt Formation trends in an east-northeast direction. The pressure versus elevation graph identifies an overpressure zone in the southeastern corner of the study area. The hydraulic head map for the Debolt Formation is in Enclosure C-29.

The Debolt Formation total available head map (Enclosure C-30) shows available head values to be highest in the southwest at approximately 2,900 metres. Available head decreases to approximately 1,900 metres towards the northeast.

### *Water Volume and Deliverability*

Debolt Formation permeability was estimated from a DST conducted on a well located at 5-23-87-25W6. Porosity ($\Phi$) and productive thickness (h) were determined from borehole logs recorded in the well. Analysis of the DST in Fekete F.A.S.T. WellTest software resulted in a low permeability value of 0.85 mD.

Deliverability forecasts estimated over a twelve-month period for one well per section and one well per township produced two scenarios. The first scenario used a calculated skin due to damage ($s_d$) value of 0.55, while the second stimulated well scenario used a skin value of -4.00. After six months of production, the two scenarios ranged from approximate flow rates of 18.5 $m^3$/day to 33.0 $m^3$/day based on one well per section, and 19.0 $m^3$/day to 35.0 $m^3$/day based on one well per township.

The Debolt Formation storativity map (Enclosure C-31) shows storativity values to be highest in the west-central portion of the study area with values ranging from 0.320 to 0.400 $m^3/m^2$. A Debolt Formation net porous reservoir map was not provided by PRCL;

as a result, storativity values were calculated using an average aquifer thickness of 8 metres, based on borehole logs, using a 4% porosity cutoff.

Total water volume calculated to be available from storage for the Debolt Formation is estimated at 260 million $m^3$ based on 4% porosity areal aquifer coverage as mapped by PRCL.

Table C-7 provides a summary of estimated permeability, deliverability, and total water volume for the Foothills Study Area. Figure C-10 is a graph of the total water volume available from storage per formation for the Foothills Study Area.

### *Production Summary*

A production map (Figure C-11) showing hydrocarbon and water production from the Debolt Formation was made using publically available data. Almost all production is strongly tied to structural closures associated with the northwest-southeast anticlinal trends that characterize the Foothills Study Area. At Blueberry (94-A-12 and 13), the Debolt hosts oil, whereas most pools to the north and west host gas.

Table P-2 shows nine Debolt water disposal wells in the Foothills Study Area, which have taken between 156 $e^3m^3$ and 913 $e^3m^3$ each.

## Halfway Formation

### *Water and Gas Chemistry*

Halfway Formation waters range from approximately 80,503 mg/L to 164,000 mg/L TDS and comprise mainly Na and Cl ions. TDS values seem to increase to the north and south from the center of the study area. Data control points suggest an average TDS value of approximately 116,665 mg/L. The Halfway Formation salinity map is Enclosure C-32.

Hydrogen sulphide gas ($H_2S$) values plotted on Enclosure C-32 for the Halfway Formation range from a minimum value of 0.4% to a maximum value of 11.5% across the Foothills Study Area.

### *Hydrogeology*

The Halfway Formation ranges in hydraulic head from approximately 900 metres decreasing to approximately 600 metres to the east. Across the Foothills Study Area, groundwater flow within the Halfway Formation trends in an east-northeast direction. The pressure versus elevation graph identifies an overpressure zone within the west-central portion of the study area. The hydraulic head map for the Halfway Formation is Enclosure C-33.

| FOOTHILLS STUDY AREA | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UWI | DST # | DST ID | TOP (m) | BOTTOM (m) | LATITUDE | LONGITUDE | FORMATION | PERMEABILITY, k (mD) | PRODUCTIVE THICKNESS, H (m) | POROSITY, ϕ (%) | CURVE # | SKIN VALUE | ONE WELL PER SECTION 6 MONTH DELIVERABILITY RATE ($m^3$/DAY) | ONE WELL PER TOWNSHIP 6 MONTH DELIVERABILITY RATE ($m^3$/DAY) | TOTAL VOLUME OF WATER AVAILABLE IN STORAGE USING 100% AVAILABLE HEAD ($m^3$) |
| 100/10-07-085-25-W6/00 | 2 | 4905 | 880.0 | 890.0 | 56.356 | -121.936 | Bluesky | 10.00 | 9.50 | 6.00 | 1 | 4.23 | 20.0 | 29.0 | 6,669,103 |
| | | | | | | | | | | | 2 | 0.00 | 24.0 | 41.0 | |
| | | | | | | | | | | | 3 | -4.00 | 25.0 | 67.0 | |
| 100/07-05-086-24-W6/00 | 5 | 5037 | 1072.9 | 1097.3 | 56.426 | -121.752 | Gething | 9.41 | 7.20 | 10.00 | 1 | 0.08 | 33.0 | 49.5 | 77,077,353 |
| | | | | | | | | | | | 2 | -4.00 | 36.5 | 82.5 | |
| 200/C-074-B/094-B-09/00 | 1 | 1941 | 1257.0 | 1274.1 | 56.564 | -122.173 | Nikanassin | 14.00 | 16.00 | 9.00 | 1 | 18.92 | 65.0 | 92.0 | 86,420,154 |
| | | | | | | | | | | | 2 | 0.00 | 90.0 | 256.0 | |
| | | | | | | | | | | | 3 | -4.00 | 65.0 | 411.0 | |
| 100/10-11-086-24-W6/00 | 2 | 5047 | 1499.6 | 1539.2 | 56.444 | -121.672 | Baldonnel | 28.58 | 3.00 | 22.00 | 1 | 2.24 | 39.0 | 48.0 | 483,287,621 |
| | | | | | | | | | | | 2 | 0.00 | 46.0 | 59.0 | |
| | | | | | | | | | | | 3 | -4.00 | 62.0 | 98.0 | |
| 200/B-006-K/094-H-04/00 | 2 | 4561 | 1452.0 | 1469.0 | 57.170 | -121.823 | Halfway | 1.30 | 9.00 | 7.00 | 1 | -0.38 | 11.0 | 11.5 | 355,375,948 |
| | | | | | | | | | | | 2 | -4.00 | 17.5 | 19.0 | |
| 100/05-23-087-25-W6/00 | 1 | 5453 | 2042.0 | 2060.0 | 56.556 | -121.879 | Debolt | 0.85 | 13.00 | 5.00 | 1 | 0.55 | 18.5 | 19.0 | 259,892,322 |
| | | | | | | | | | | | 2 | -4.00 | 33.0 | 35.0 | |

**GEOSCIENCE B.C MONTNEY BASIN**

| | | | |
|---|---|---|---|
| Project | GBMB | Author | Sheldon Thistle |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Summary of Permeability, Deliverability, and Total Water Volume**
**Foothills Study Area**

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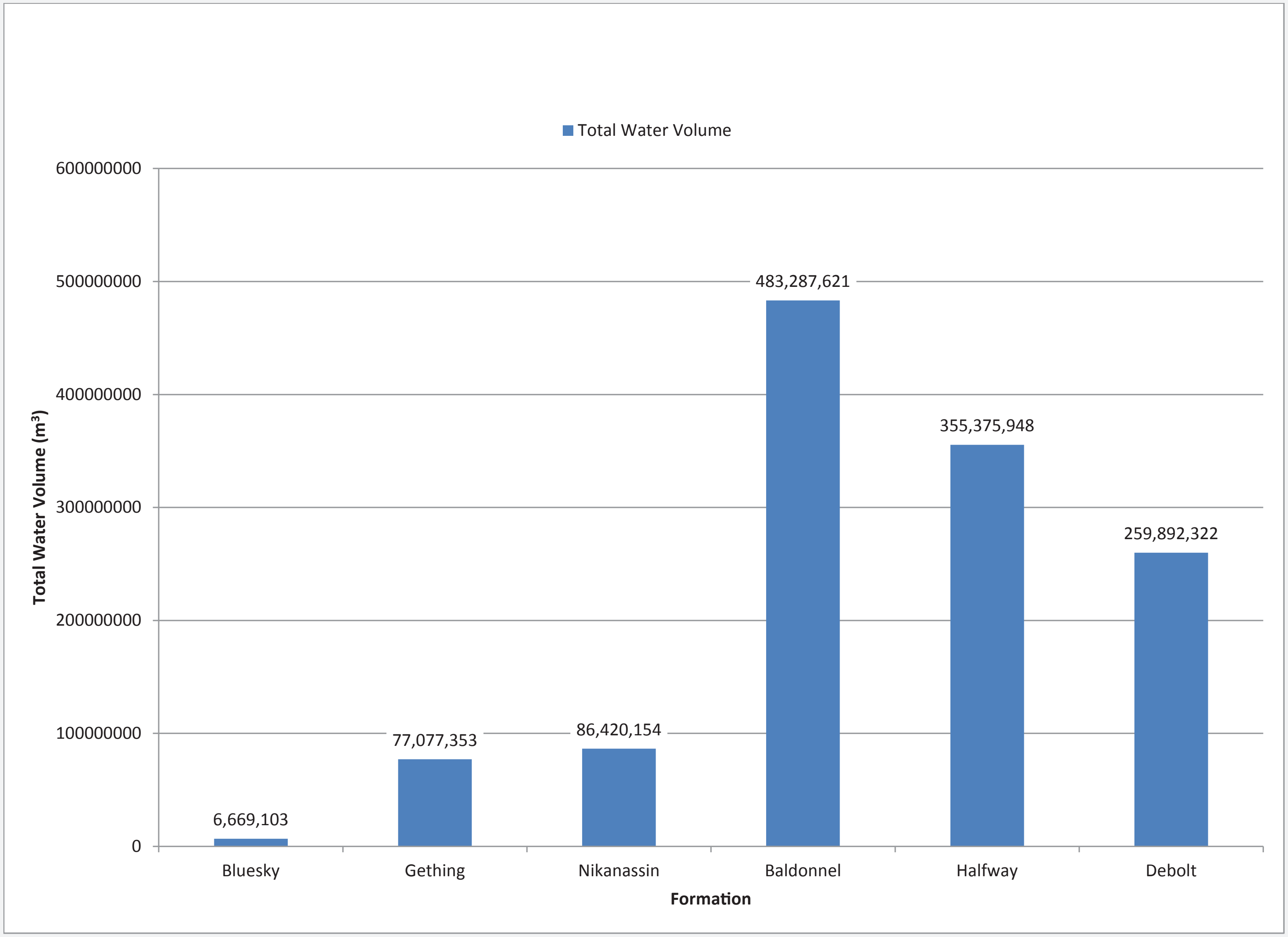
Table C-7




**GEOSCIENCE B.C MONTNEY BASIN**

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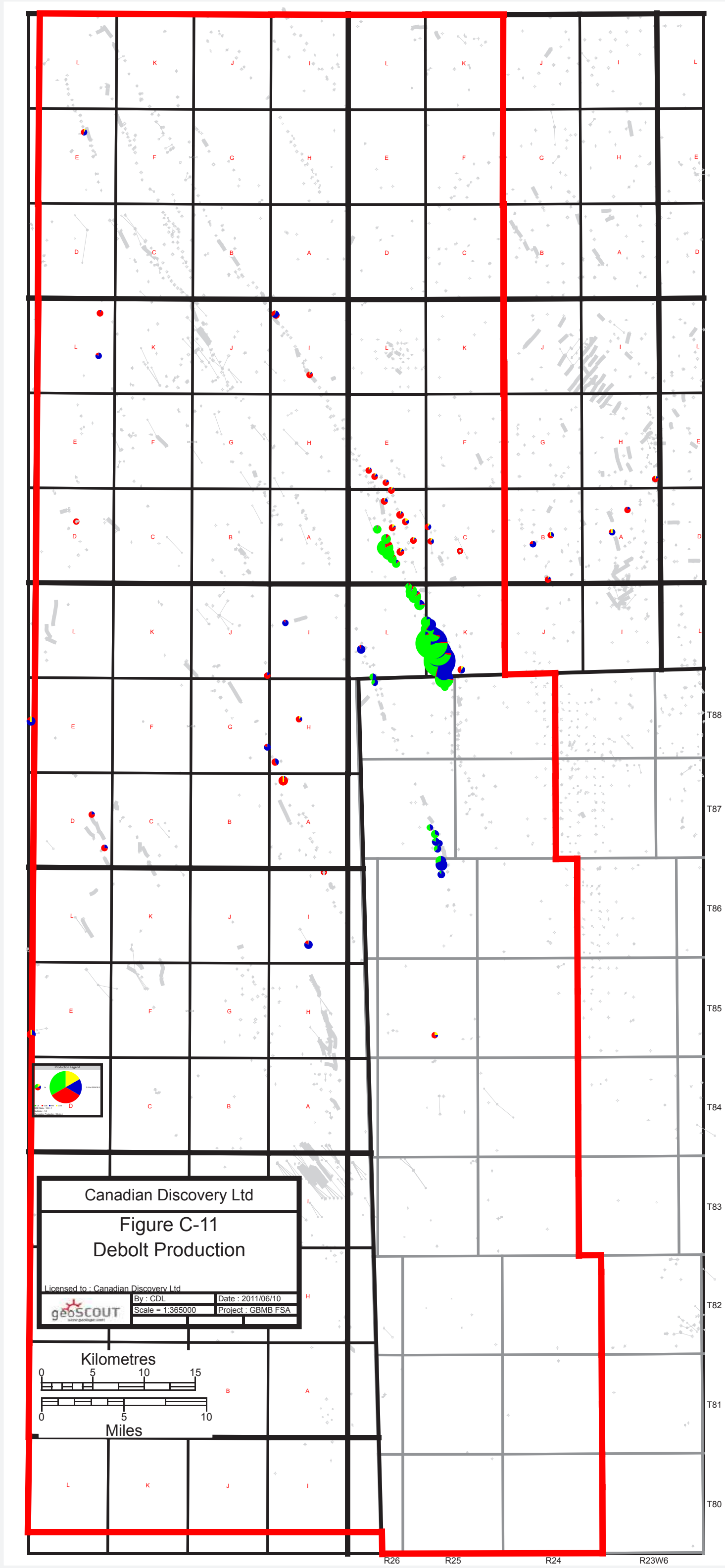
|---|---|---|---|
| Project | GBMB | Author | Sheldon Thistle |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Total Water Volume Available in Storage by Formation**
**(Declining 100% of the Total Available Head)**
**Foothills Study Area**

Canadian Discovery Ltd.

Figure **C-10**




## GEOSCIENCE B.C MONTNEY BASIN

| | | | | | |
|---|---|---|---|---|---|
| Project | GBMB | Author | Jordan Brinsky | **Production Map Debolt Formation** | Figure C-11 |
| Created | 15/06/11 | Graphics | Ally Masoud | | |
| File | *.idd | Reviewer | David Hume | | |

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The Halfway Formation total available head map (Enclosure C-34) shows available head values to be highest in the southwest at approximately 1,600 metres. Available head decreases to approximately 1,200 metres towards the northeast.

### *Water Volume and Deliverability*

Halfway Formation permeability was estimated from a DST conducted on a well located at b-6-K/94-H-4. Porosity (Φ) and productive thickness (h) were determined from borehole logs recorded in the well. Analysis of the DST in Fekete F.A.S.T. WellTest software resulted in a permeability value of 1.30 mD.

Deliverability forecasts estimated over a twelve-month period for one well per section and one well per township produced two scenarios. The first scenario used a calculated skin due to damage ($s_d$) value of -0.38, while the second stimulated well scenario used a skin value of -4.00. After six months of production, the two scenarios ranged from approximate flow rates of 11.0 $m^3$/day to 11.5 $m^3$/day based on one well per section, and 17.5 $m^3$/day to 19.0 $m^3$/day based on one well per township.

The Halfway Formation storativity map (Enclosure C-35) shows storativity values to be highest over the majority of the mapped aquifer area with values ranging from 0.121 to 0.140 $m^3/m^2$. Storativity values were calculated based on the Halfway Formation net-porous reservoir map provided by PRCL using a 6% porosity cutoff.

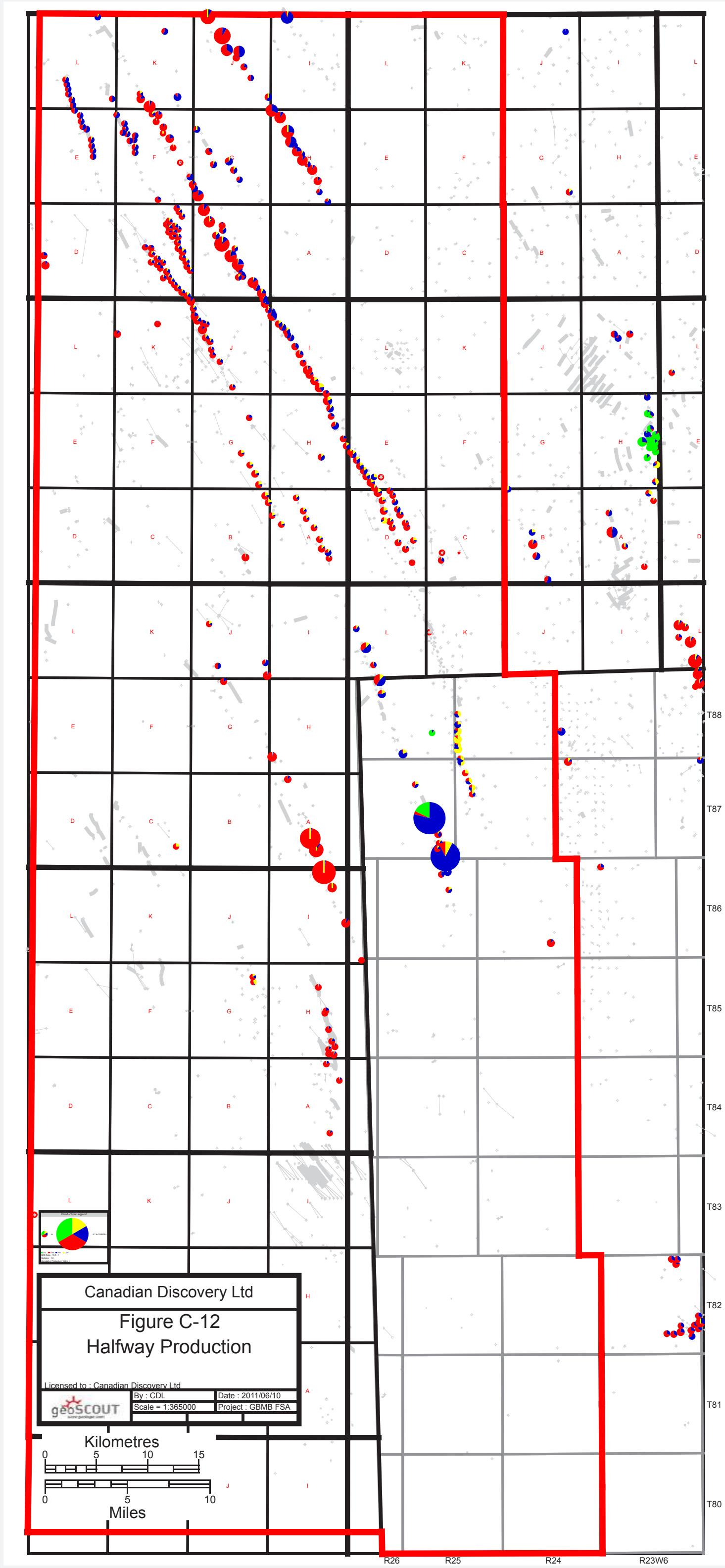
Total water volume calculated to be available from storage for the Halfway Formation is estimated at 355 million $m^3$ based on 6% porosity areal aquifer coverage as mapped by PRCL.

Table C-7 provides a summary of estimated permeability, deliverability, and total water volume for the Foothills Study Area. Figure C-10 is a graph of the total water volume available from storage per formation for the Foothills Study Area.

### *Production Summary*

A production map (Figure C-12) showing hydrocarbon and water production from the Halfway Formation was made using publically available data. Halfway gas is produced almost exclusively from the crests of northwest-southeast trending anticlines in the outer Foothills, and there are relatively few tests off-trend. Significant water is produced throughout, particularly in the Blueberry West / Halfway area, where some oil is also produced.

Table P-2 shows one Halfway water disposal wells in the Foothills Study Area, which has taken 20 $e^3m^3$ water.




## GEOSCIENCE B.C MONTNEY BASIN

| | | | | | |
|---|---|---|---|---|---|
| Project | GBMB | Author | Jordan Brinsky | **Production Map Halfway Formation** | Figure C-12 |
| Created | 15/06/11 | Graphics | Ally Masoud | | |
| File | *.idd | Reviewer | David Hume | | |

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## Baldonnel

### *Water and Gas Chemistry*

Baldonnel Formation waters range from 8,032 mg/L to 51,797 mg/L TDS and comprise mainly Na and Cl ions. Baldonnel Formation waters indicate a greater range of $HCO_3$ and $SO_4$ alternating as the second dominant anion after Cl, compared to formation waters from the overlying stratigraphic units. TDS values seem to increase to the north and south from the centre of the study area. Data control points suggest an average TDS value of approximately 20,367 mg/L. The Baldonnel Formation salinity map is Enclosure C-36.

Hydrogen sulphide gas ($H_2S$) values plotted on Enclosure C-36 for the Baldonnel Formation range from a minimum value of 0.01% to a maximum value of 6.3% across the Foothills Study Area, with an average value of approximately 0.10%.

### *Hydrogeology*

The Baldonnel Formation ranges in hydraulic head from approximately 900 metres decreasing to approximately 600 metres to the east and in the south. Across the Foothills Study Area, groundwater flow within the Baldonnel Formation trends in an east-northeast direction, with an indication of localized flow to the south along the southern boundary of the study area. The hydraulic head map for the Baldonnel Formation is Enclosure C-37.

The Baldonnel Formation total available head map (Enclosure C-38) shows available head values to be highest in the west, at approximately 1,600 metres. Across the study area, available head decreases to approximately 1,200 metres towards the east. To the south, total available head decreases to 900 metres.

### *Water Volume and Deliverability*

Baldonnel Formation permeability was estimated from a DST conducted on a well located at 10-11-86-24W6. Porosity (Φ) and productive thickness (h) were determined from borehole logs recorded in the well. Analysis of the DST in Fekete F.A.S.T. WellTest software resulted in a permeability value of 28.6 mD.

Deliverability forecasts estimated over a twelve-month period for one well per section and one well per township produced three scenarios. The first scenario used a calculated skin due to damage ($s_d$) value of -0.38, the second scenario used a skin value of 0.00, and the third stimulated well scenario used a skin value of -4.00. After six months of production, the three scenarios ranged from approximate flow rates of 39.0 $m^3$/day to 62.0 $m^3$/day based on one well per section, and 48.0 $m^3$/day to 98.0 $m^3$/day based on one well per township.

The Baldonnel Formation storativity map (Enclosure C-39) shows storativity values to be highest along the west-central boundary and in the southwestern corner trending northeastward to Township 87, Range 24W6. Values in these areas range from 0.081 to 0.100 $m^3/m^2$. A Baldonnel Formation net porous reservoir map was not provided by PRCL; storativity values were therefore calculated using an average aquifer thickness of 6 metres, based on borehole logs, using a 4% porosity cutoff.

Total water volume calculated to be available from storage for the Baldonnel Formation is estimated at 483 million $m^3$ based on 4% porosity areal aquifer coverage as mapped by PRCL.

Table C-7 provides a summary of estimated permeability, deliverability, and total water volume for the Foothills Study Area. Figure C-10 is a graph of the total water volume available from storage per formation for the Foothills Study Area.

### *Production Summary*

A production map (Figure C-13) showing hydrocarbon and water production from the Baldonnel Formation was made using publically available data. As for the Halfway and Debolt, most Baldonnel gas production in the Foothills Study Area is from structural traps on regional northwest-southeast anticlinal trends. To the east, oil production at Birch and gas production at Laprise Creek is controlled more by stratigraphic trapping associated with relief on the pre-Cretaceous unconformity, which caps the Baldonnel in these areas.

Table P-2 shows nine Baldonnel water disposal wells in the Foothills Study Area, which have taken between 4 $e^3m^3$ and 689 $e^3m^3$ each.

## Nikanassin Formation

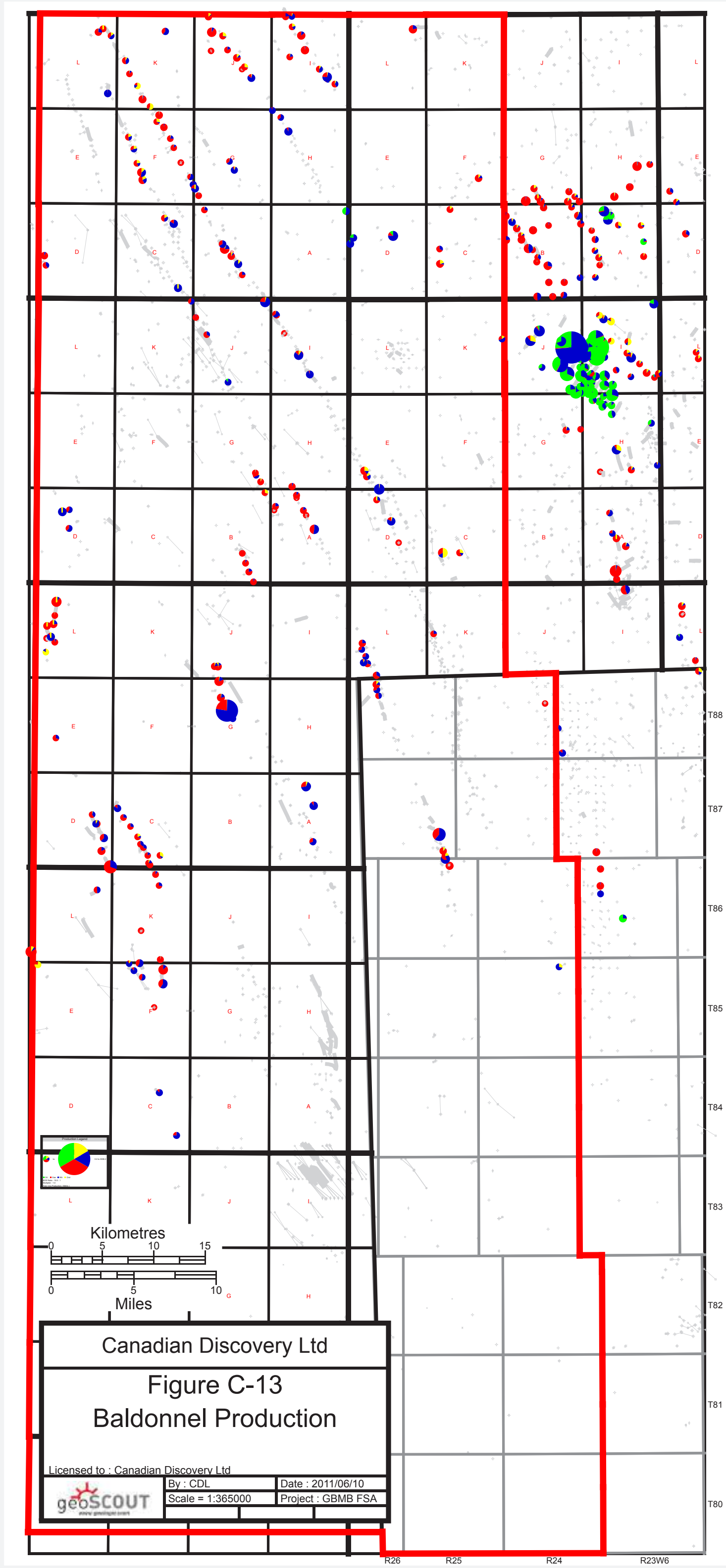
### *Water and Gas Chemistry*

Nikanassin Formation waters range from 15,865 mg/L to 44,053 mg/L TDS and comprise mainly Na and Cl ions. TDS values indicate an increasing trend from west to east. Data control points suggest an average TDS value of approximately 24,651 mg/L. The Nikanassin Formation salinity map is Enclosure C-40.

Hydrogen sulphide gas ($H_2S$) values plotted on Enclosure C-40 for the Nikanassin Formation range from a minimum value of 0.0% to a maximum value of 0.69% in three wells across the Foothills Study Area.

### *Hydrogeology*

The Nikanassin Formation ranges in hydraulic head from approximately 1,000 metres decreasing to approximately 550 metres to the east and in the south. Across the




## GEOSCIENCE B.C MONTNEY BASIN

| | | | |
|---|---|---|---|
| Project | GBMB | Author | Jordan Brinsky |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Production Map**
**Baldonnel Formation**

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Figure
C-13

Foothills Study Area, groundwater flow within the Nikanassin Formation trends in an east-northeast direction. The hydraulic head map for the Nikanassin Formation is Enclosures C-41.

The Nikanassin Formation total available head map shows values to be highest in the west-central portion of the study area at approximately 1,400 metres. Across the study area, available head decreases to approximately 1,000 metres toward the east. In the southeastern region of the study area, the total available head continues to decrease to approximately 800 metres. The total available head map for the Nikanassin Formation is Enclosure C-42.

### *Water Volume and Deliverability*

Nikanassin Formation permeability was estimated from a DST conducted on a well located at c-74-B/94-B-9. Porosity (Φ) and productive thickness (h) were determined from borehole logs recorded in the well. Analysis of the DST in Fekete F.A.S.T. WellTest software resulted in a permeability value of 14.0 mD.

Deliverability forecasts estimated over a twelve-month period for one well per section and one well per township produced three scenarios. The first scenario used a calculated skin due to damage ($s_d$) value of 18.92, the second scenario used a skin value of 0.00, and the third stimulated well scenario used a skin value of -4.00. After six months of production, the three scenarios ranged from approximate flow rates of 65.0 $m^3$/day to 90.0 $m^3$/day based on one well per section, and 90.0 $m^3$/day to 410.0 $m^3$/day based on one well per township.

The Nikanassin Formation storativity map (Enclosure C-43) shows storativity values to be highest to the east around Townships 84-85, Ranges 24-25W6, and just west of the Alberta provincial border in blocks A and H of Map Sheet 93-P-9, with values ranging from 0.121 to 0.140 $m^3/m^2$. Storativity values were calculated based on the Nikanassin Formation net porous reservoir map provided by PRCL using a 12% porosity cutoff.

Total water volume calculated to be available from storage for the Nikanassin Formation is estimated at 86 million $m^3$ based on 12% porosity areal aquifer coverage as mapped by PRCL.

Table C-7 provides a summary of estimated permeability, deliverability, and total water volume for the Foothills Study Area. Figure C-10 is a graph of the total water volume available from storage per formation for the Foothills Study Area.

### *Production Summary*

No production from the Nikanassin Formation was reported within the Foothills Study Area from a review of publically available data, as stratigraphic tops from public databases do not accurately distinguish Nikanassin-equivalent sandstones of the Buick Creek from overlying Gething strata. PRCL (1997) demonstrated that the Buick Creek is a major gas reservoir through the northwestern part of 94-A and southwestern part of 94-H, on the eastern margin of the Foothills Study Area.

Table P-2 shows one Nikanassin water disposal well in the Foothills Study Area, which has taken 189 $e^3m^3$ water.

## Bullhead Group

### *Water and Gas Chemistry*

Bullhead Group waters, mainly from the Bluesky and Gething formations, range from 4,632 mg/L to 62,861 mg/L TDS and comprise mainly Na and Cl ions. Although control points for the Bullhead Group are scarce, TDS values indicate an increasing trend from west to east. Data control points suggest an average TDS value of approximately 21,784 mg/L. The Bullhead Group salinity map is Enclosure C-44.

### *Hydrogeology*

The Gething Formation of the Bullhead Group ranges in hydraulic head from 1,000 metres in the west- central area of the study area decreasing to approximately 700 metres toward the east and northeast. On a regional scale across the Foothills Study Area, groundwater flow within the Gething Formation trends in an east-northeast direction. The pressure versus elevation graph also indicates a west to east flow direction within the Gething Formation. The hydraulic head map for the Gething Formation of the Bullhead Group is Enclosure C-45.

The Gething Formation total available head map (Enclosure C-46) shows available head values to be highest in the west- central and northwestern portion of the study area with values of approximately 1,100 metres. Available head decreases to approximately 800 metres toward the east and to approximately 600 metres to the southeast.

Similarly, the Bluesky Formation ranges in hydraulic head from 1,000 metres in the west to approximately 700 metres in the east, with groundwater flow generally to the east. There is evidence of localized flow in the southern portion of the map centring on an area of lower hydraulic head. The pressure versus elevation graph also indicates a west to east flow direction within the Bluesky Formation. The hydraulic head map for the Bluesky Formation of the Bullhead Group is Enclosure C-47.

The Bluesky Formation total available head map (Enclosure C-48) shows available head values to be highest in the northern portion of the study area at approximately 1,100 metres. Available head decreases toward the south to approximately 600 metres.

*Water Volume and Deliverability*

Gething Formation permeability was estimated from a DST conducted on a well located at 7-5-86-24W6. Porosity (Φ) and productive thickness (h) were determined from borehole logs recorded in the well. Analysis of the DST in Fekete F.A.S.T. WellTest software resulted in a permeability value of 9.41 mD.

Deliverability forecasts estimated over a twelve-month period for one well per section and one well per township produced two scenarios. The first scenario used a calculated skin due to damage ($s_d$) value of 0.08, while the second stimulated well scenario used a skin value of -4.00. After six months of production, the two scenarios ranged from approximate flow rates of 33.0 $m^3$/day to 36.5 $m^3$/day based on one well per section, and 49.5 $m^3$/day to 82.5 $m^3$/day based on one well per township.

The Gething Formation storativity map (Enclosure C-49) shows storativity values to be highest in the eastern portion of the study area with values ranging from 0.141 to 0.200 $m^3/m^2$. Storativity values were calculated based on the Gething Formation net porous reservoir map provided by PRCL using a 10% porosity cutoff.

Total water volume calculated to be available from storage for the Gething Formation is estimated at 77 million $m^3$ based on 10% porosity areal aquifer coverage as mapped by PRCL.

Bluesky Formation permeability was estimated from a DST conducted on a well located at 10-7-85-25W6. Porosity (Φ) and productive thickness (h) were determined from borehole logs recorded in the well. Analysis of the DST in Fekete F.A.S.T. WellTest software resulted in a permeability value of 10.0 mD.

Deliverability forecasts estimated over a twelve-month period for one well per section and one well per township scale produced three scenarios. The first scenario used a calculated skin due to damage ($s_d$) value of 4.23, the second scenario used a skin value of 0.00, and the third stimulated well scenario used a skin value of -4.00. After six months of production, the three scenarios ranged from approximate flow rates of 20.0 $m^3$/day to 25.0 $m^3$/day based on one well per section, and 28.0 $m^3$/day to 67.0 $m^3$/day based on one well per township.

The Bluesky Formation storativity map (Enclosure C-50) shows storativity values to be highest in the northern portion of the study area in small pockets with values ranging from 0.081 to 0.100 $m^3/m^2$. Storativity values were calculated based on the Bluesky Formation net-porous reservoir map provided by PRCL using a 12% porosity cutoff.

Total water volume calculated to be available from storage for the Bluesky Formation is estimated at 6.7 million $m^3$ based on 12% porosity areal aquifer coverage as mapped by PRCL.

Table C-7 provides a summary of estimated permeability, deliverability, and total water volume for the Foothills Study Area. Figure C-10 is a graph of the total water volume available from storage per formation for the Foothills Study Area.

### *Production Summary*

Production maps for the Gething (Figure C-14) and Bluesky (Figure C-15) were prepared using publically-available data. Public database stratigraphic tops are not totally reliable, resulting in erroneous assignment of some production. For, the Aitken Creek oil and gas pool in L/94-A-13 produces from a Bluesky estuarine valley fill, but is posted on the Gething map. Viewing both maps, however, it is apparent that there is little production from basal Gething sandstones, and that most gas is produced from stratigraphic traps (estuarine valley fills and thin regional shoreface deposits) of the Bluesky.

Table P-2 shows one Bluesky water disposal well in the Foothills Study Area, which has taken 7.1 $e^3m^3$ water. There are no Gething disposal wells.

## Other Zones Water Chemistry

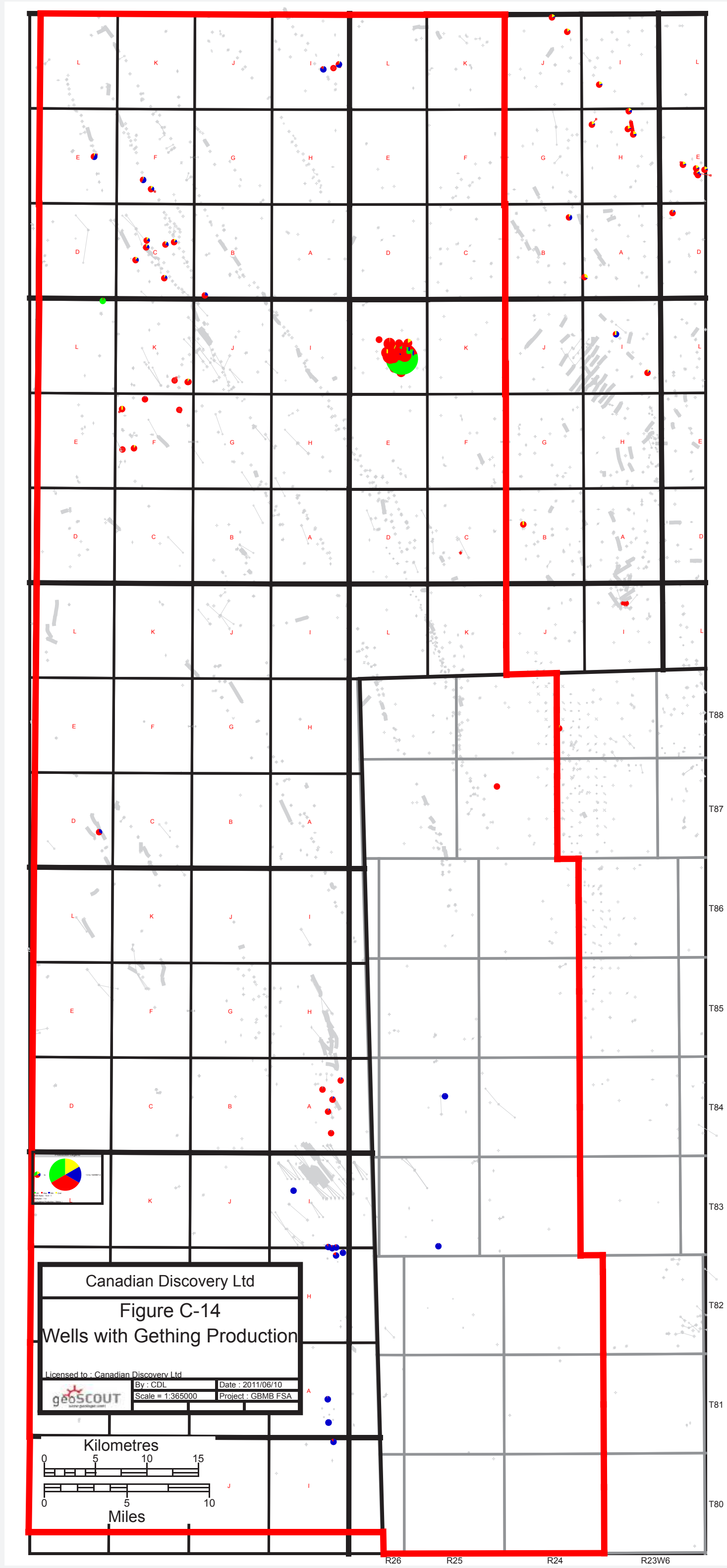
In addition to the formations analyzed, some chemistry data was examined for one other formation in the study area. These results are summarized as follows:

Charlie Lake Formation waters show TDS ranging from 122,479 mg/L to 132,968 mg/L. The main ion constituents remain Na and Cl. Anion concentrations of $SO_4$ are also higher when compared to Nikanassin waters and other overlying formation waters. TDS data is scarce in this formation; however, TDS values appear to be decreasing to the northeast. The Charlie Lake Formation was not mapped as part of this study.

## Formation Water Characterization and Trends

### *Piper Diagrams*

A Piper diagram constructed for the Bullhead Group indicates varying amounts of bicarbonate and sulphate suggesting the main hydrochemical facies is a sodium-chloride-bicarbonate-sulphate type formation water. The Nikanassin Formation plots in a similar space compared to the overlying Bullhead Group. The Baldonnel Formation shows a much larger range in ion percentages in relation to the Bullhead Group and Nikanassin Formation. Baldonnel waters may be categorized as a mixture of sodium-chloride-sulphate-bicarbonate type water. Less variety in ion percentages are illustrated in the piper diagram for the Charlie Lake Formation, with Na and Cl being the major ions. The Halfway Formation and the Mississippian-aged Debolt Formation plot in similar space, as indicated on their Piper diagrams, showing a slightly higher variance in




## GEOSCIENCE B.C MONTNEY BASIN

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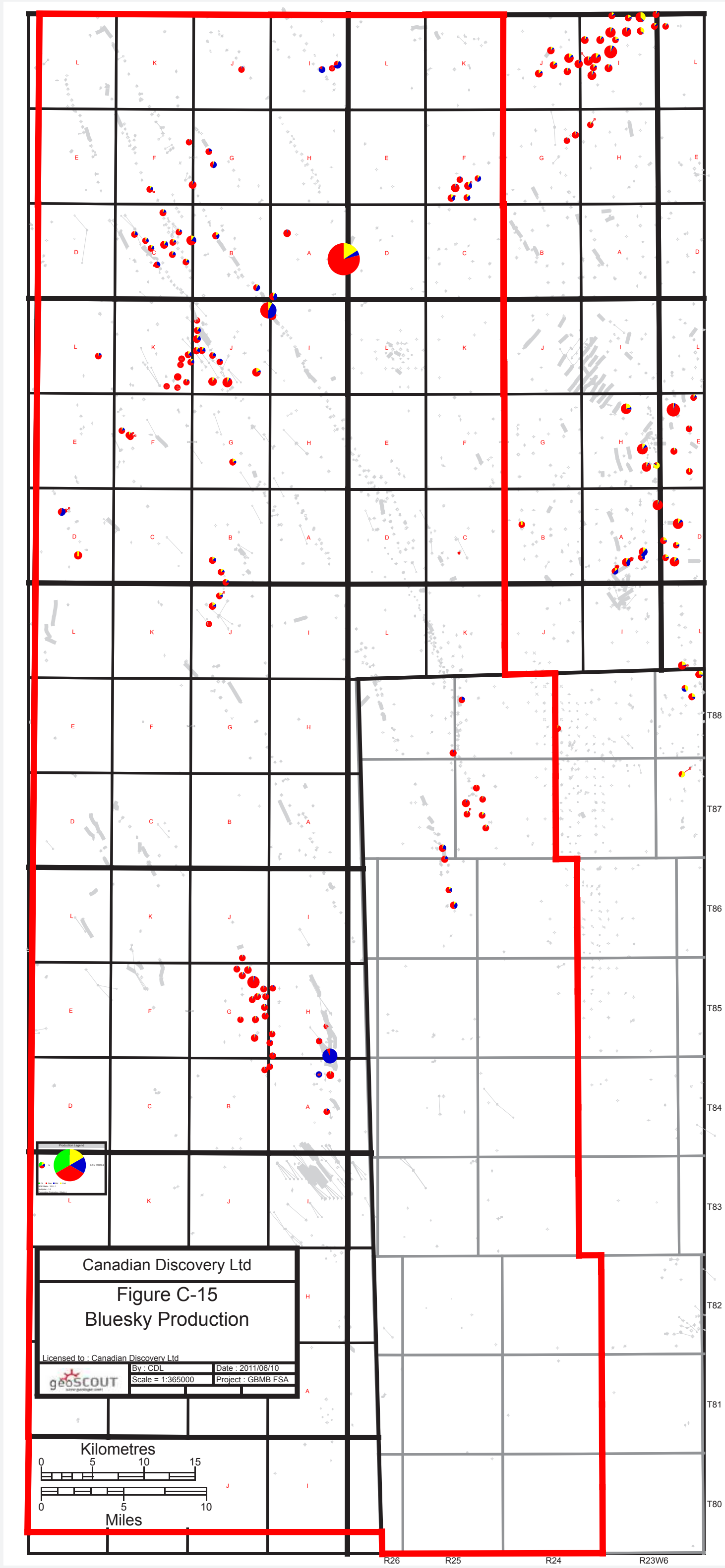
| Project | GBMB | Author | Jordan Brinsky |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Production Map**
**Gething Production**

Canadian Discovery Ltd.

Figure
**C-14**




## GEOSCIENCE B.C MONTNEY BASIN

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| Project | GBMB | Author | Jordan Brinsky |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Production Map**
**Bluesky Formation**

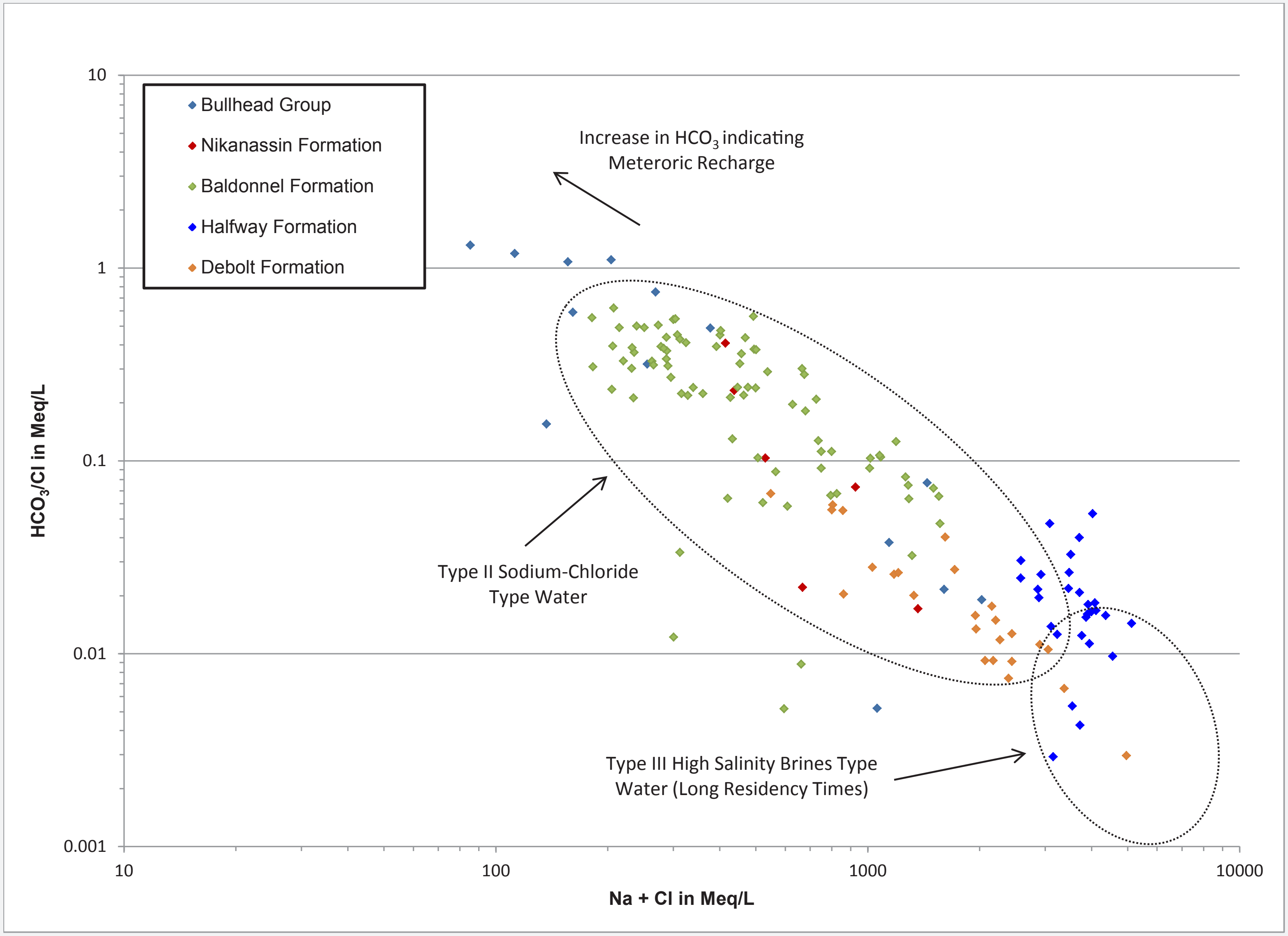
Canadian Discovery Ltd.

Figure
**C-15**

ion percentages of Cl and $SO_4$ compared to the Charlie Lake Formation. Piper plots are presented on their corresponding formation salinity maps.

### *Formation Water Trend and Mixing*

Figure C-16 presents a plot of formation waters from the Bullhead Group down to the Debolt Formation. Formation waters from the Bullhead Group appear to be affected by meteoric recharge as the ratio of $HCO_3$/Cl increases within those stratigraphic sequences. The Nikanassin and Baldonnel formations indicate Type II sodium-chloride type waters. The high TDS Charlie Lake Formation appears to plot within the Type III sodium-chloride high salinity type waters. Additionally, data from the Halfway and Debolt formations suggest a mixing relationship between Type II sodium-chloride and Type III high salinity waters, with the Debolt Formation showing greater $HCO_3$/Cl ratios indicating freshwater mixing.




## GEOSCIENCE B.C MONTNEY BASIN

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| Project | GBMB | Author | Sheldon Thistle |
| Created | 15/06/11 | Graphics | Ally Masoud |
| File | *.idd | Reviewer | David Hume |

**Formation Water Grouping and Mixing Trend**
**Foothills Study Area**

Canadian Discovery Ltd.

Figure
**C-16**

# SUMMARY AND RECOMMENDATIONS

Regional stratigraphic and hydrogeological mapping demonstrate that deep saline aquifer potential is present in a number of formations throughout the Montney play fairway, as noted in the following summary.

## Plains Study Area Aquifers

### Halfway Formation

- *Geology*: Massive shoreface sandstones, but fine-grained and generally low-permeability. Little net porous sand is mapped, although reservoir quality improves overall to the north and northeast.
- *Burial depths*: <1400 to >3200 m
- *Hydrogeology*: Low storativity, low deliverability. Waters have high salinity, and $H_2S$ is present.
- *Aquifer Quality*: Poor; note that water has been successfully injected into the Halfway in three wells.
- *Recommendation*: No further regional work recommended, although may be considered locally for fluid disposal.

### Baldonnel Formation

- *Geology*: Stacked, shallow marine carbonate/clastic cycles. Variable lithologies make log-based reservoir assessment difficult. Some good reservoir quality exists in producing fields.
- *Burial Depths*: <1000 to >3000 m
- *Hydrogeology*: Low storativity, overall low deliverability. Waters have low to moderate salinity, and $H_2S$ is present.
- *Aquifer Quality*: Variable, may be good locally. Locally, deliverability forecasts show potential for six-month rates of several hundred $m^3$/day. Note that water has been successfully injected into the Baldonnel in two wells.

- *Recommendation*: Requires local assessment. Sample cuttings review may provide useful calibration for well logs by detailing lithologies and porosity/permeability relationships.

## Nikanassin Formation

- *Geology*: Basal massive sandstone, overlain by westward-thickening channelized succession. Substantial net porous sandstone can be mapped in updip areas, but becomes more silica-cemented with depth.
- *Burial Depths*: <900 to >2500 m
- *Hydrogeology*: Deep Basin (gas-saturated) regime mapped over southern half of PSA. Good storativity, moderate deliverability in northeastern porous sand trend. Waters have low salinity, and only one $H_2S$ value was noted.
- *Aquifer Quality*: Moderate to good aquifer in northeastern PSA. Deliverability forecasts show potential for six-month rates of several thousand $m^3$/day. Note that water has been successfully injected into the Nikanassin in one well.
- *Recommendation*: Consider as primary candidate for water source and disposal in northeast.

## Cadomin Formation

- *Geology*: Thick alluvial fan / braidplain deposits, thinning eastward. Substantial net porous sandstone thickness in northeast, but becomes more silica-cemented with depth.
- *Burial Depths*: 750 to >2500 m
- *Hydrogeology*: Deep Basin (gas-saturated) regime mapped over southwestern part of PSA. Excellent storativity, highest deliverability in northern porous sand trends. Waters have low salinity, and no $H_2S$ values were noted.
- *Aquifer Quality*: Good to excellent aquifer in northern PSA. Deliverability forecasts show potential for six-month rates of hundreds to thousands of $m^3$/day. Note that water has been successfully injected into the Cadomin in four wells; the best well has taken 731 $e^3m^3$ water and is still on injection.
- *Recommendation*: Consider as primary candidate for water source and disposal in north.

## Bluesky Formation

- *Geology*: Stacked shallow marine shorefaces in broad east-west trend across northern part of PSA, with good secondary solution porosity in cleanest intervals. Thick deltaic succession in the south is fine-grained and generally tight.

- *Burial Depths*: <600 to >2400 m

- *Hydrogeology*: Deep Basin (gas-saturated) regime mapped over southern half of PSA. Moderate storativity, good deliverability, with best quality in far northeast. Waters have low salinity, and only one $H_2S$ value was noted.

- *Aquifer Quality*: Moderate to good aquifer in northeastern PSA. Deliverability forecasts show potential for six-month rates to exceed 1000 $m^3$/day. Note that water has been successfully injected into the Bluesky in one well.

- *Recommendation*: Consider as candidate for water source and disposal in north, probably behind Cadomin and Nikanassin in most areas.

## Peace River Formation

- *Geology*: Thick west-east barrier complex where Paddy and Cadotte members stack in Twp. 78-79. Good continuous porous sandstone is mapped in the east, but degrades westward with burial depth. Isolated high-quality Cadotte shoreface trends are water-bearing to the south, but required detailed local mapping to define.

- *Burial Depths*: 700 to >1700 m

- *Hydrogeology*: Deep Basin (gas-saturated) regime mapped over southwestern part of PSA. Low to locally moderate storativity, low deliverability, with best quality in far east. Waters have low salinity, and no $H_2S$ was noted.

- *Aquifer Quality*: Moderate aquifer in Twp. 77-79, Rge 14-17W6. Deliverability forecasts show potential for six-month rates up to hundreds of $m^3$/day. Note that water has been successfully injected into the Cadotte in one well and the Paddy in one well.

- *Recommendation*: Consider as candidate for water source and disposal in best area, as noted above.

## Dunvegan Formation

- *Geology*: Southeasterly-prograding wedge of deltaic and shoreface strata, dominated by fine clastics, and fine- to medium-grained sandstone.

- *Burial Depths*: Outcrop to several hundred metres. Can be mapped in the subsurface only in the southeastern part of the PSA, as it is too shallow elsewhere.

- *Hydrogeology*: Very few tests; may be in Deep Basin regime near the southern boundary of the PSA.

- *Aquifer Quality*: Cannot be assessed systematically in the deep subsurface, but there are no positive indications of good reservoir quality. May demonstrate better quality at very shallow depths.

- *Recommendation*: Study in shallow subsurface using water well and outcrop data, tied to limited deep subsurface control. Not a high priority regionally at this time.

### Cardium Formation

- *Geology*: Northeasterly-prograding shoreface/alluvial plain complex. Sandier- and coarsening-upward shoreface sands (Kakwa Member) are generally fine-grained, with limited porosity and poor permeability. Some net porous sandstone has been mapped in the southeastern corner of the PSA.

- *Burial Depths*: Outcrop to several hundred metres. Can be mapped in the subsurface only in the southeastern part of the PSA, as it is too shallow elsewhere.

- *Hydrogeology*: Very few tests; may be in Deep Basin regime near the southern boundary of the PSA.

- *Aquifer Quality*: Cannot be assessed systematically in the deep subsurface, but there are no positive indications of good reservoir quality. May demonstrate better quality at very shallow depths.

- *Recommendation*: Study in shallow subsurface using water well and outcrop data, tied to limited deep subsurface control. Probably has less shallow control than Dunvegan, as shallow burial area is remote from human development and abundant water wells. Not a high priority regionally at this time.

## Foothills Study Area Aquifers

### Debolt Formation

- *Geology*: Stacked shoaling-upward carbonate platform cycles; most reservoir quality appears to be associated with dolomitization, solution, and fracturing.

Production indicates good reservoir quality on anticlinal trends; relatively little information off-trend.

- *Burial Depths*: 1950 to >3000 m
- *Hydrogeology*: Low storativity, variable deliverability. Waters have moderate salinity, and $H_2S$ is present.
- *Aquifer Quality*: Variable, may be good very locally. Deliverability forecasts indicate relatively low rates, but potential performance of fractured reservoir is difficult to estimate. Note that water has been successfully injected into the Debolt in nine well; the best well has taken 913 $e^3m^3$ water and is still on injection.
- *Recommendation*: Requires local assessment; sample cuttings review may provide useful calibration for well logs by detailing lithologies and porosity/permeability relationships

## Halfway Formation

- *Geology*: Massive shoreface sandstones, but fine-grained and generally low-permeability. Little net porous sand is mapped.
- *Burial Depth*: <1400 to >2100 m
- *Hydrogeology*: Low storativity, low deliverability. Waters have moderate to high salinity, and $H_2S$ is present.
- *Aquifer Quality*: Poor. Note that modest amounts of water have been injected into the Halfway in one well.
- *Recommendation*: No further work recommended, although may be considered locally for fluid disposal.

## Baldonnel Formation

- *Geology*: Stacked, shallow marine carbonate/clastic cycles. Variable lithologies make log-based reservoir assessment difficult. Some demonstrated reservoir quality in producing fields on anticlinal trends.
- *Burial Depth*: <1200 to >1800 m
- *Hydrogeology*: Moderate storativity, moderate deliverability. Waters have low to moderate salinity, and $H_2S$ is present only locally.

- *Aquifer Quality*: Variable, may be good very locally. Note that water has been successfully injected into the Baldonnel in nine wells; the best well has taken 689 $e^3m^3$ water, and is still on injection.

- *Recommendation*: Requires local assessment; sample cuttings review may provide useful calibration for well logs by detailing lithologies and porosity/permeability relationships.

## Nikanassin Formation

- *Geology*: Basal massive sandstone (Buick Creek sandstone), thickens markedly southwestward. Silica cementation has reduced reservoir quality substantially throughout the FSA, although some net porous sandstones can be mapped in the southeast.

- *Burial Depth*: <900 to >1500 m

- *Hydrogeology*: Good storativity, good deliverability in eastern porous sand trend. Waters have low salinity, and no $H_2S$ was noted.

- *Aquifer Quality*: Moderate to good aquifer in southeastern FSA. Note that water has been successfully injected into the Nikanassin in one well.

- *Recommendation*: Consider as primary candidate for water source and disposal in southeast, although limited reservoir quality may restrict lifespan of wells.

## Gething Formation

- *Geology*: Lower Gething sandstones are relatively massive and continuous, filling lower portions of major valley trends. Upper Gething sandstones are more isolated within a dominantly fine-grained succession. Silica cementation has degraded reservoir quality substantially through the FSA.

- *Burial Depth*: <500 to 1400 m

- *Hydrogeology*: Moderate storativity, moderate deliverability in eastern porous sand trends. Waters have low salinity, and no $H_2S$ was noted.

- *Aquifer Quality*: Moderate aquifer in southeastern FSA, although deliverability forecasts indicate low (<100 $m^3$/day) six-month rates. There are no Gething water injectors in the Foothills Study Area.

- *Recommendation*: Consider as possible candidate for water source and disposal in southeast.

## Bluesky Formation

- *Geology*: Estuarine valley fill trend in northwest is sand-dominated, but exhibits good reservoir quality only in isolated conglomeratic intervals. Stacked west-east shorefaces in south are like those on Plains, although generally thinner and tighter.

- *Burial Depth*: 400 to 1400 m

- *Hydrogeology*: Low storativity, moderate(?) deliverability. Waters have low salinity, and only one $H_2S$ value was noted.

- *Aquifer Quality*: Isolated very good reservoir quality in estuarine valley fill and shoreface settings. Overall poor to moderate quality, with deliverability forecasts indicating low (<100 $m^3$/day) six-month rates. Note that modest amounts of water have been injected into the Bluesky in one well.

- *Recommendation*: Consider locally as aquifer candidate in southern FSA, where there is little alternative.

Maps 73 and 74 overlay primary areas of net porous reservoir development for all target aquifer units in the Plains and Foothills Study Areas, respectively. Some general observations can be made:

- Deep subsurface aquifers with potential to produce saline water to support drilling and completions operations, and to act as sinks for waste water, are distributed quite unevenly across the Montney development fairway.

- The northern Plains study area contains substantial stacked aquifer potential in the Nikanassin, Cadomin, and Bluesky formations. Baldonnel aquifers may occur locally as well.

- The southernmost Plains region has sparse deep aquifer potential, as many units are in a Deep Basin (gas-saturated) regime. Further work may reveal relatively shallow source potential in the Cardium and Dunvegan, and more detailed mapping should highlight narrow west-east Cadotte shoreface trends with good reservoir quality but likely limited storativity.

- Good aquifer potential is sparse in the Foothills Study Area. Many units have been subjected to deeper burial depths in the past, and burial diagenesis has significantly reduced reservoir quality.

- In the Foothills Study Area, more detailed work and additional data collection are required to determine whether gas production along anticlinal trends (particularly Debolt, Baldonnel, Halfway, and Nikanassin) can be linked to fracturing, and whether such fractured reservoirs are capable of water production outside of established pool areas.

# DATA GAPS AND FUTURE STUDY

Much more detailed work can be done in local areas throughout the Montney play fairway, following up on the regional mapping and hydrogeological analysis completed in this report. Some more general areas where additional data collection and study would improve upon our knowledge of aquifer potential include:

1. More detailed analysis of Debolt and Baldonnel carbonate reservoirs – Detailed logging of sample cuttings from selected wells would provide a much better regional assessment of lithologies and reservoir quality. Analysis of all existing hydrocarbon production and source / injection well histories would provide more detailed reservoir performance assessment.

2. Aquifer performance modeling – For reservoirs that can be reasonably characterized by well logs, construction of detailed geocellular models, followed by fluid flow modeling based on detailed analysis of test and production/injection data, would provide additional insights on short- and long-term aquifer performance potential.

3. Tying deep subsurface to shallow subsurface mapping – A data gap exists in the subsurface below the depths to which most domestic water wells are drilled, and above surface casing in petroleum boreholes. Additional data can be mined with considerable effort to address this interval (particularly in detailed review of shallow well drillers' reports, and deep well tour sheets), and better links built between deep subsurface and shallow subsurface mapping. This is particularly important for the Dunvegan and Cardium formations in the southern PSA, where deeper aquifers hold little promise. Published outcrop studies should also be used for additional control.

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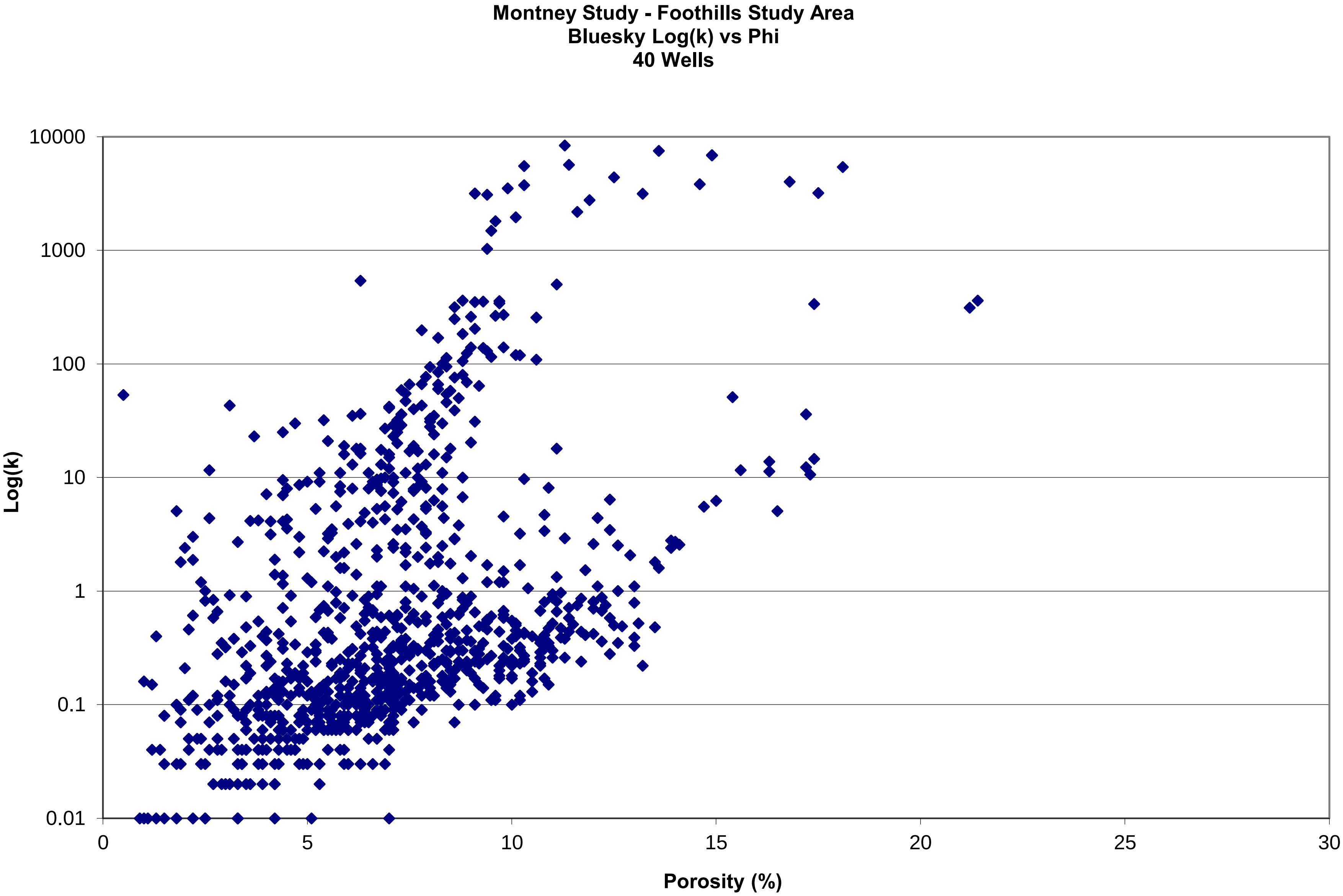
# APPENDIX P-1

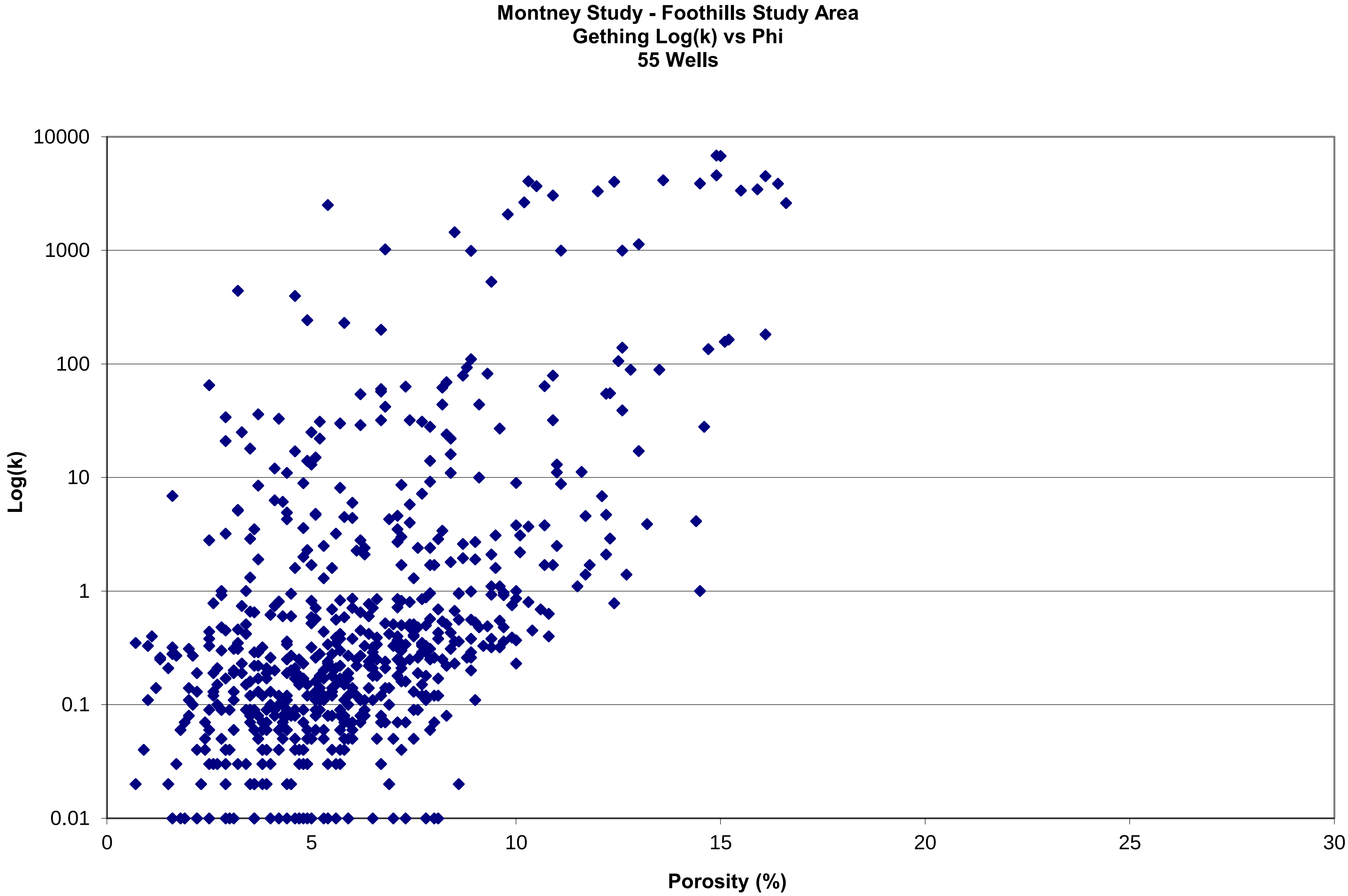
## Stratigraphic Tops Database

## Available Digitally Only

# APPENDIX P-2

## Core Analysis Data


Montney Study - Foothills Study Area
Bluesky Log(k) vs Phi
40 Wells
Log(k)
10000
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)


Montney Study - Foothills Study Area
Gething Log(k) vs Phi
55 Wells
Log(k)
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1000
100
10
1
0.1
0.01
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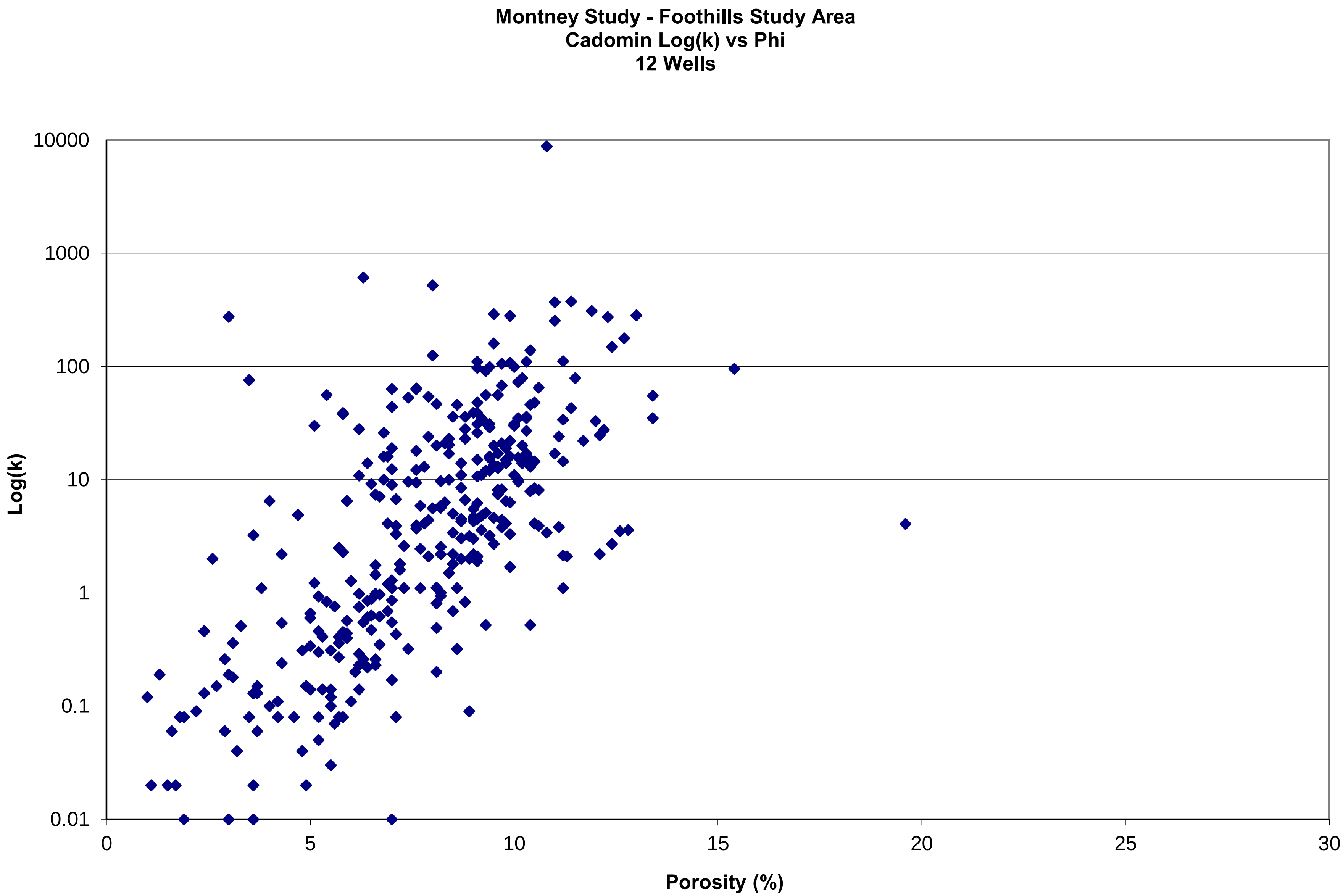
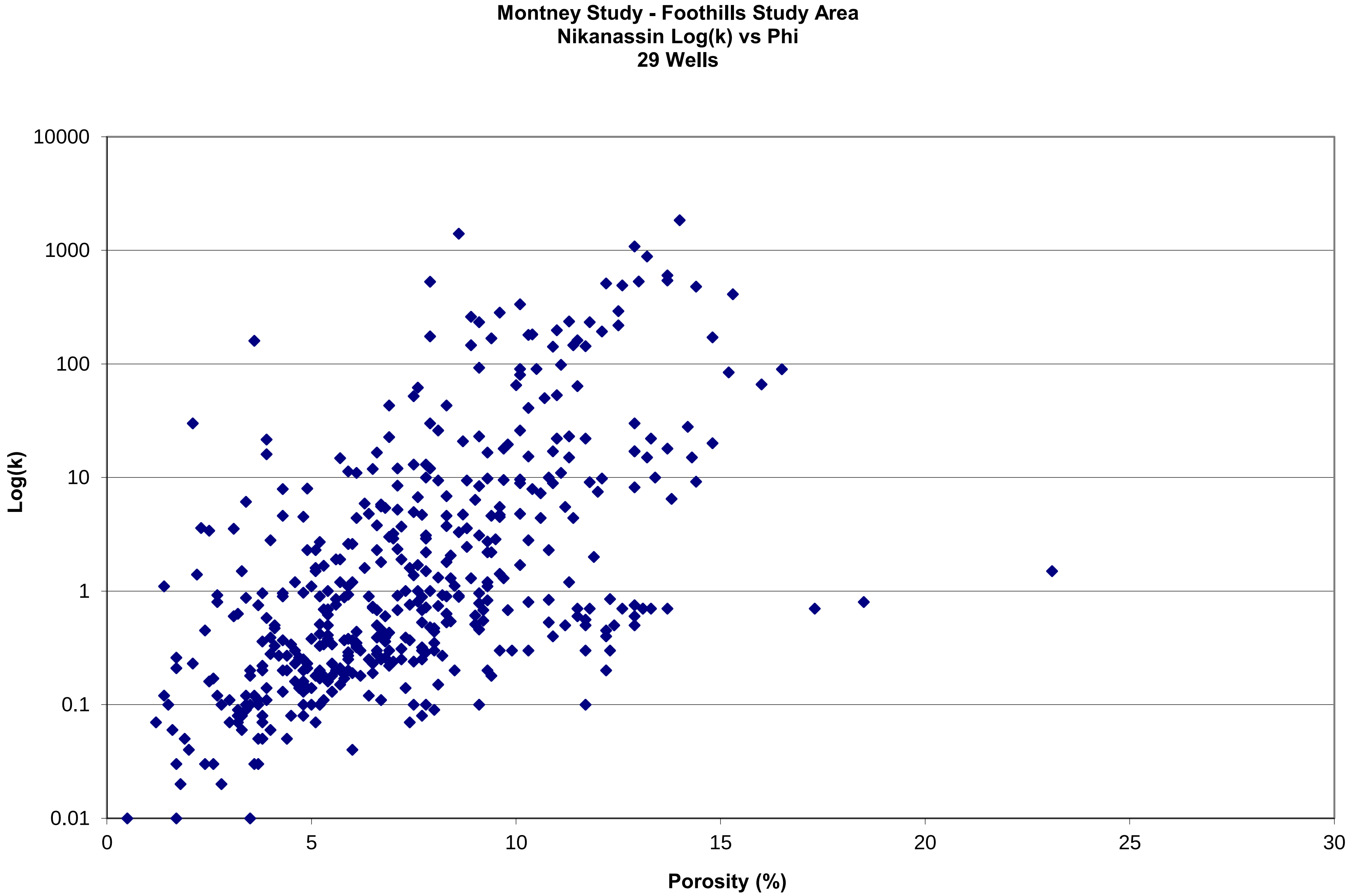
10
15
20
25
30
Porosity (%)



Montney Study - Foothills Study Area
Cadomin Log(k) vs Phi
12 Wells
10000
1000
100
10
1
0.1
0.01
Log(k)
0
5
10
15
20
25
30
Porosity (%)


Montney Study - Foothills Study Area
Nikanassin Log(k) vs Phi
29 Wells
10000
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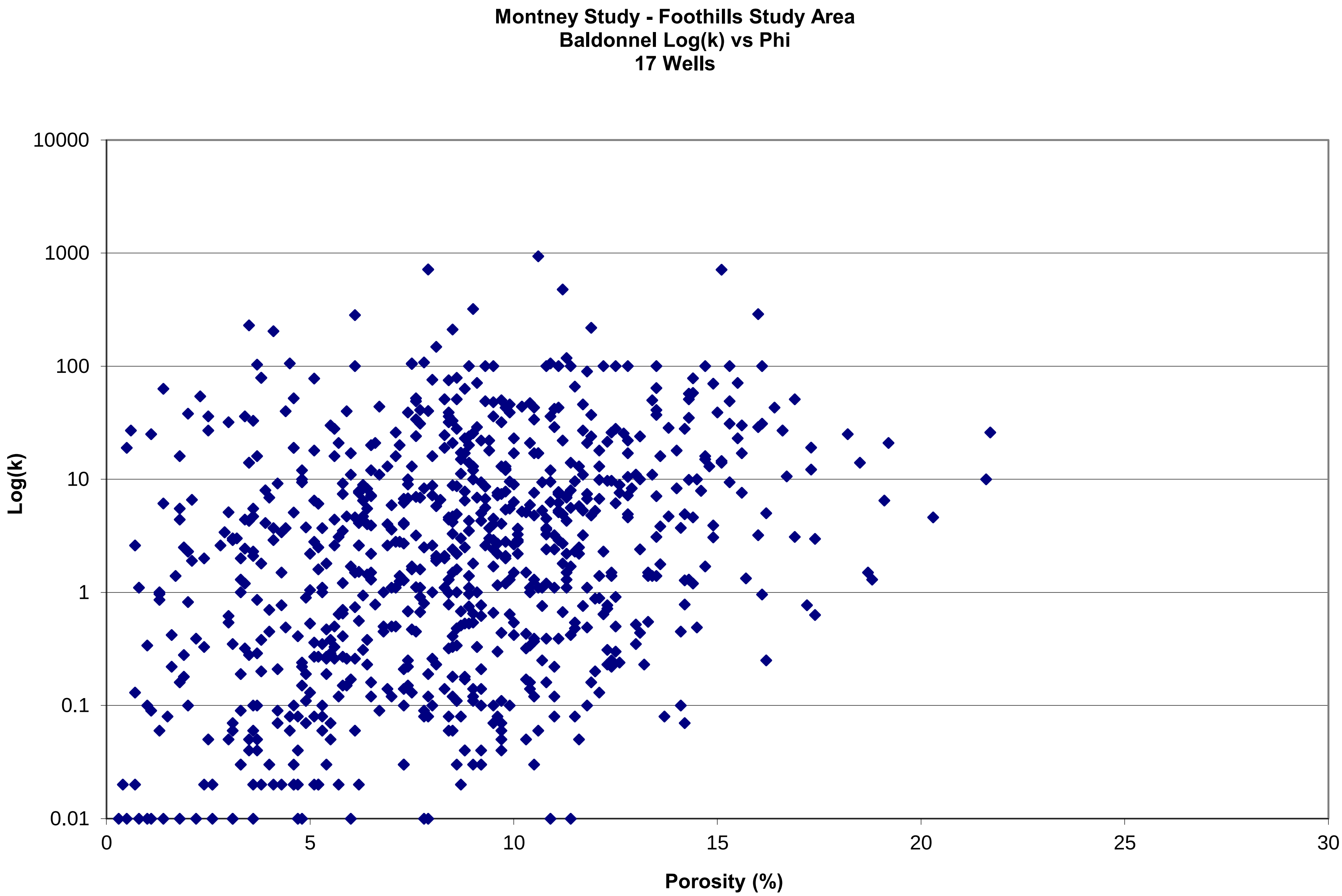
10
1
0.1
0.01
Log(k)
0
5
10
15
20
25
30
Porosity (%)


Montney Study - Foothills Study Area
Baldonnel Log(k) vs Phi
17 Wells
10000
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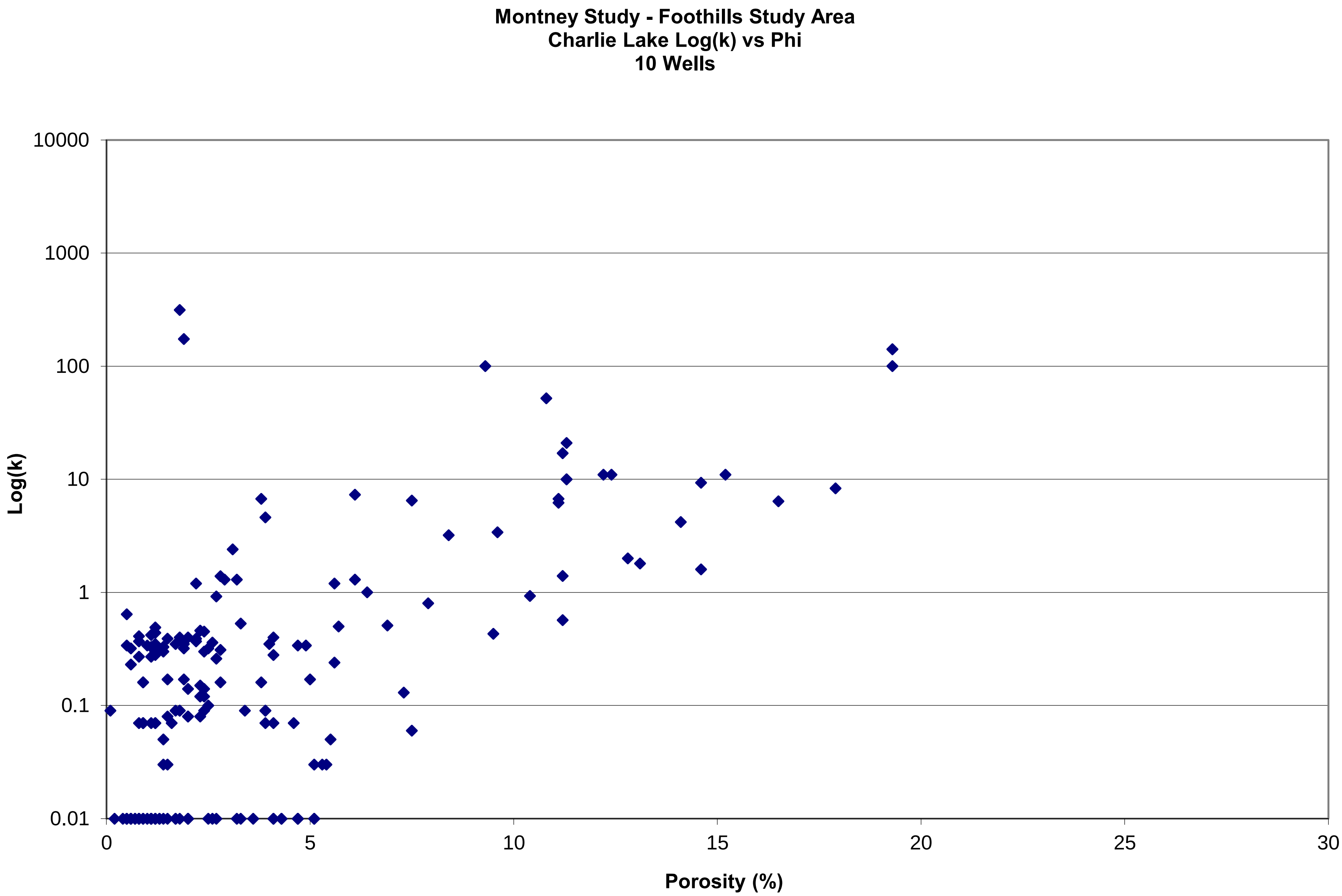
100
10
1
0.1
0.01
Log(k)
0
5
10
15
20
25
30
Porosity (%)


Montney Study - Foothills Study Area
Charlie Lake Log(k) vs Phi
10 Wells
10000
1000
100
10
1
0.1
0.01
Log(k)
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5
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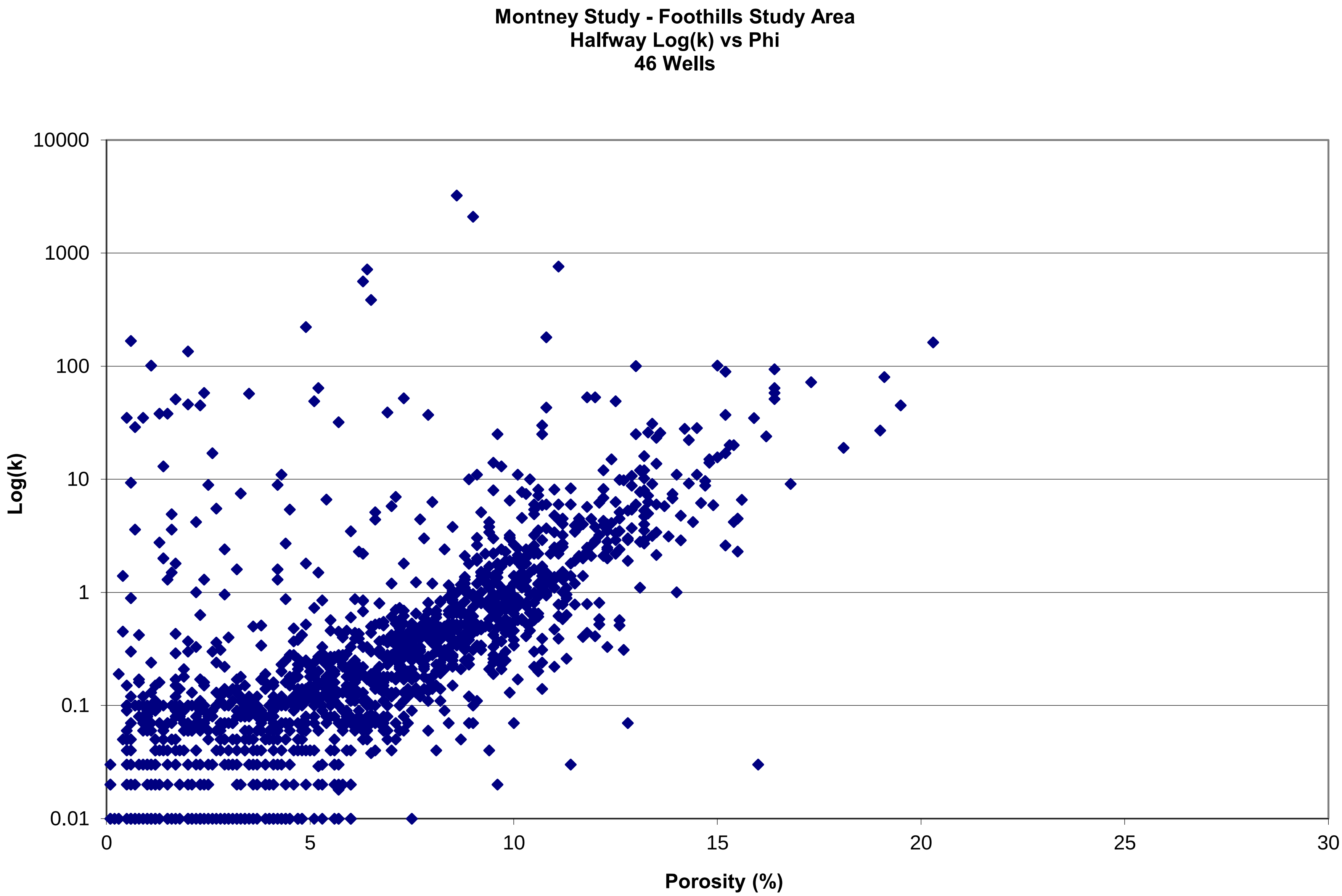
15
20
25
30
Porosity (%)


Montney Study - Foothills Study Area
Halfway Log(k) vs Phi
46 Wells
Log(k)
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1000
100
10
1
0.1
0.01
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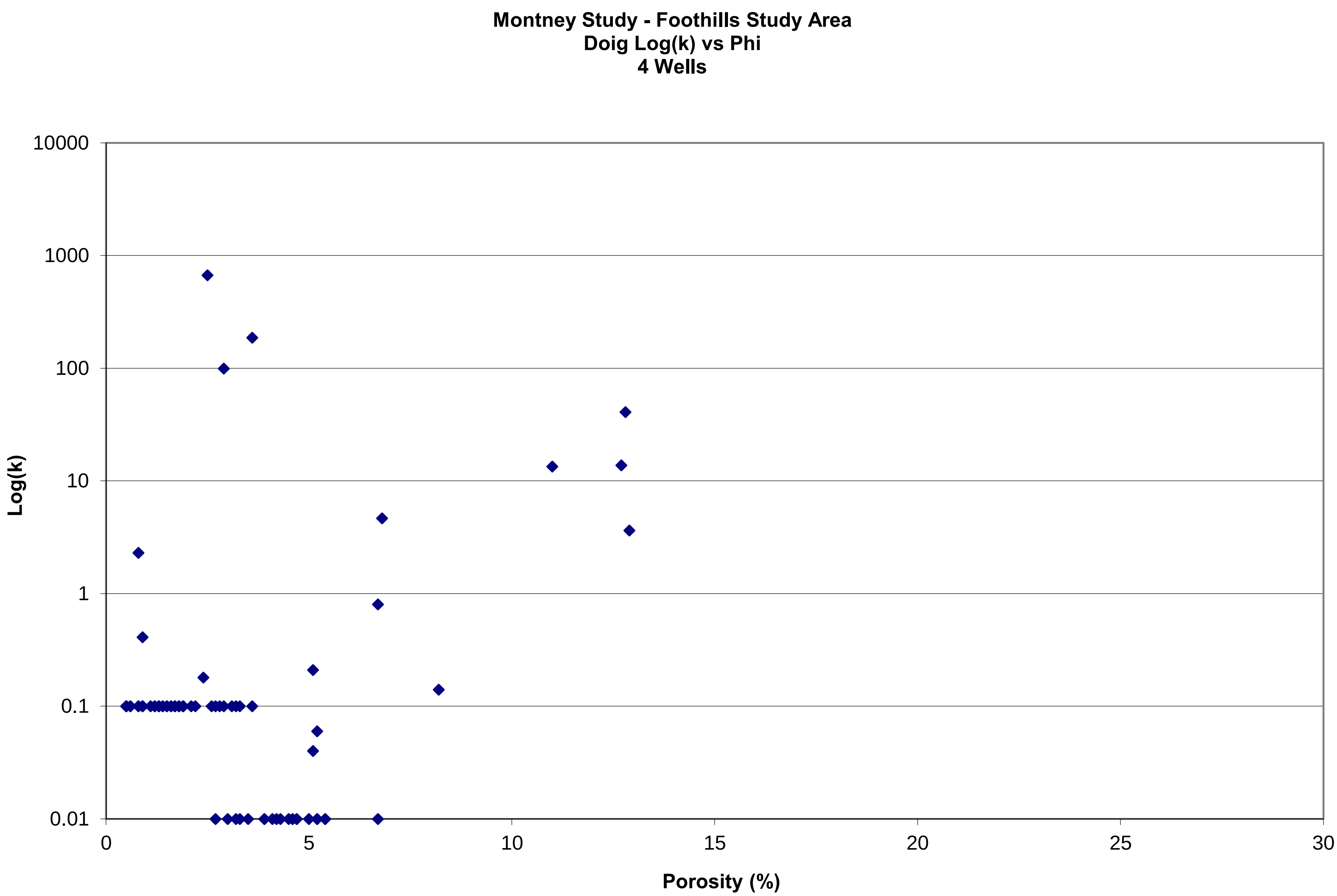
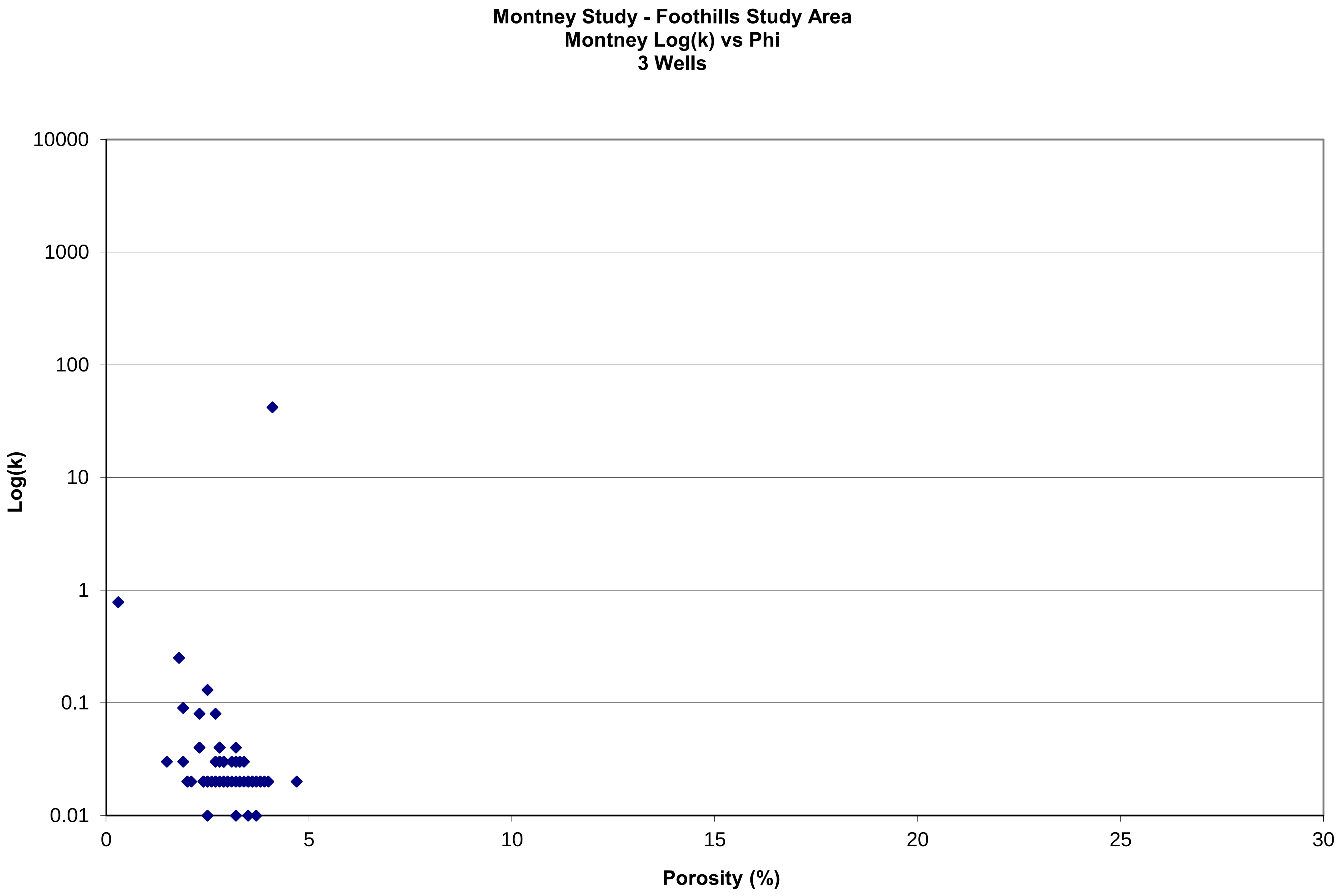
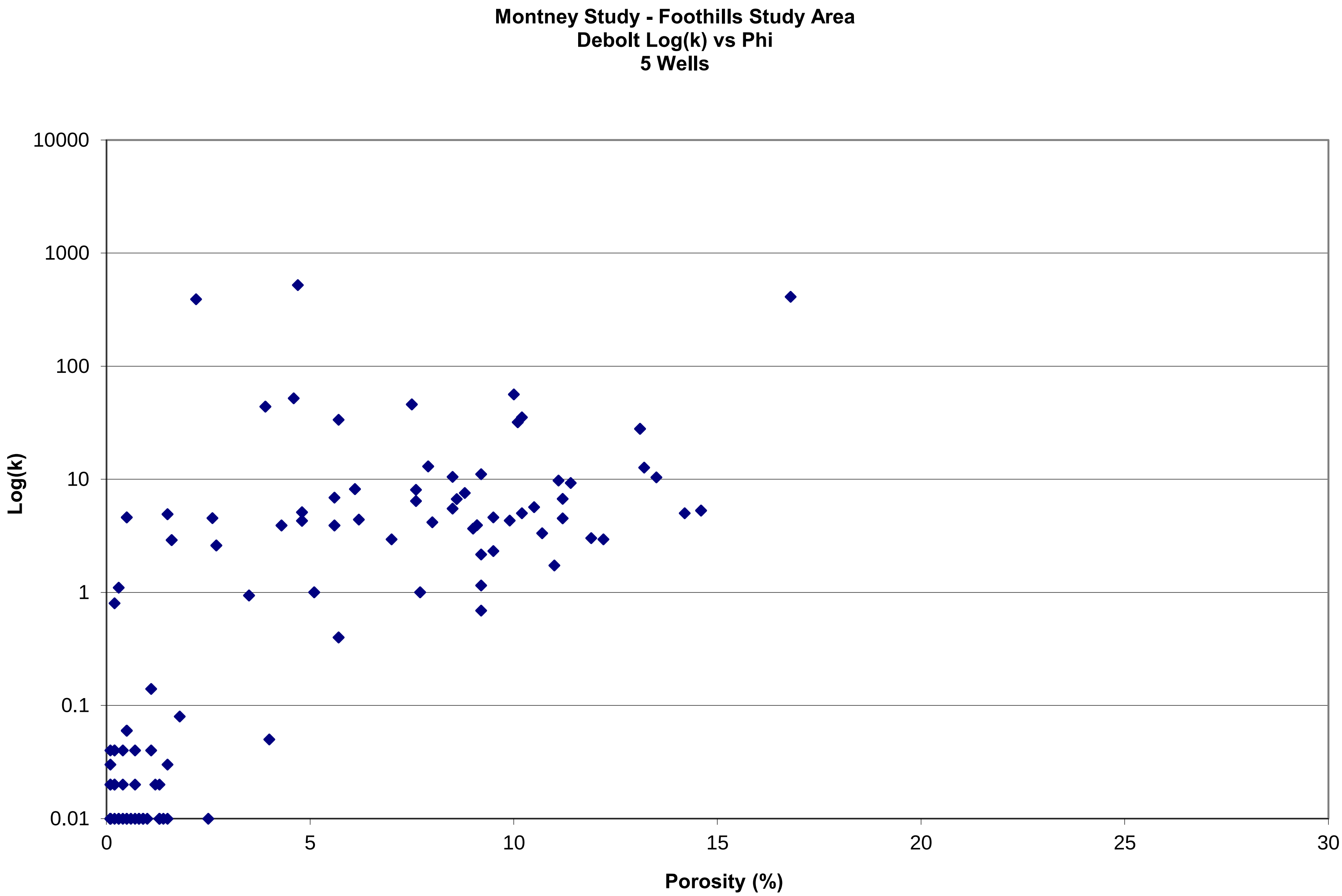
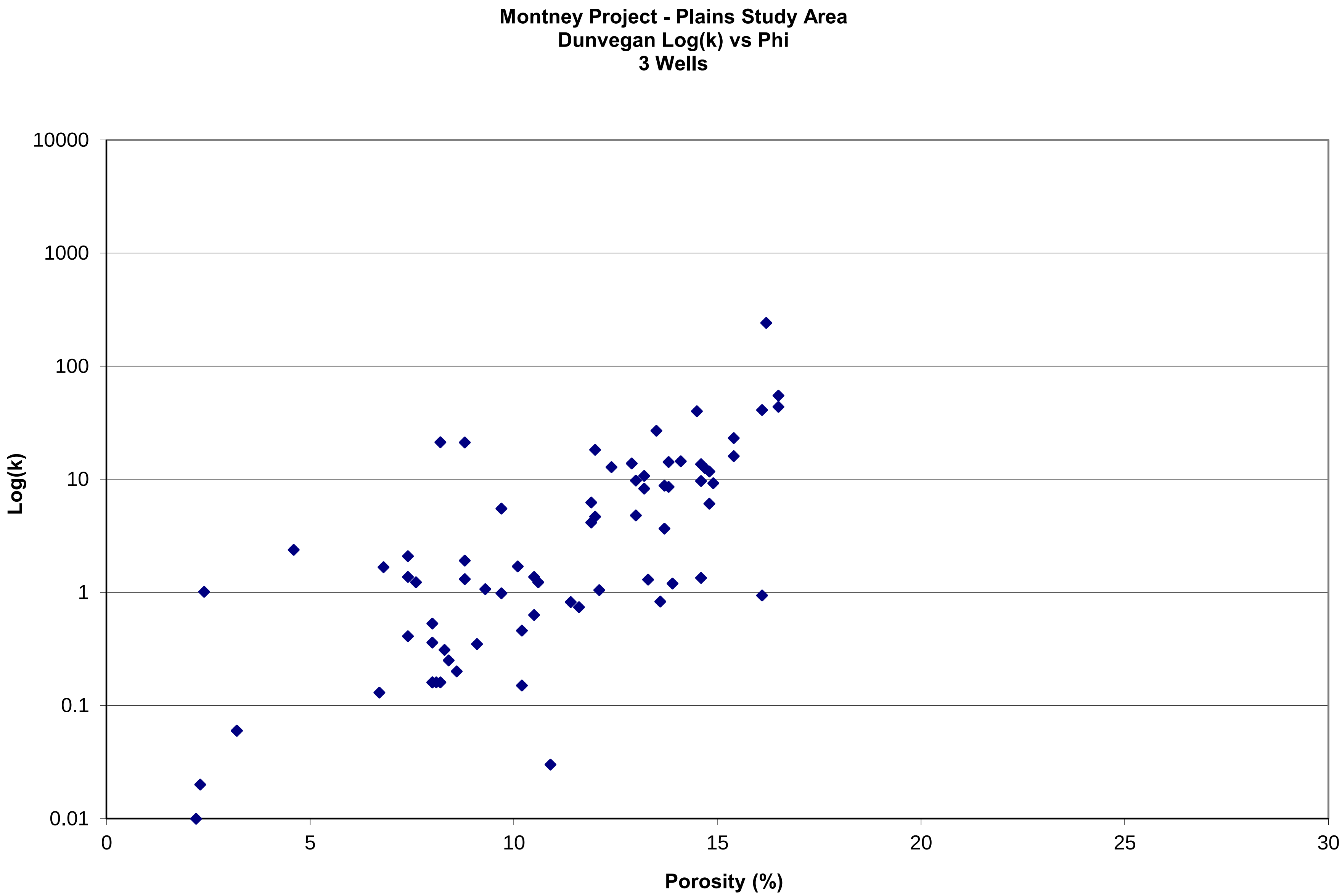
5
10
15
20
25
30
Porosity (%)

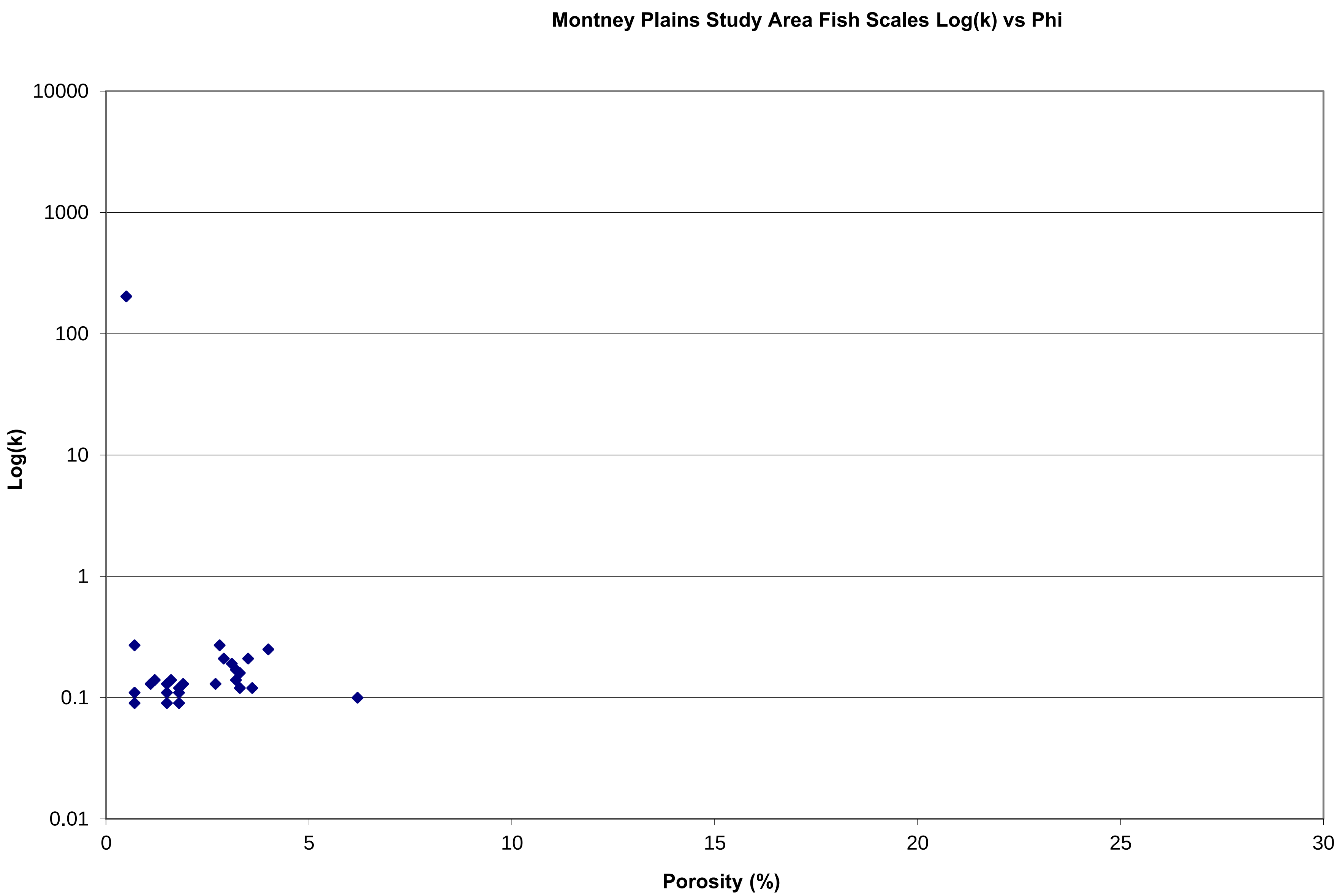

Montney Study - Foothills Study Area
Doig Log(k) vs Phi
4 Wells
Log(k)
10000
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)



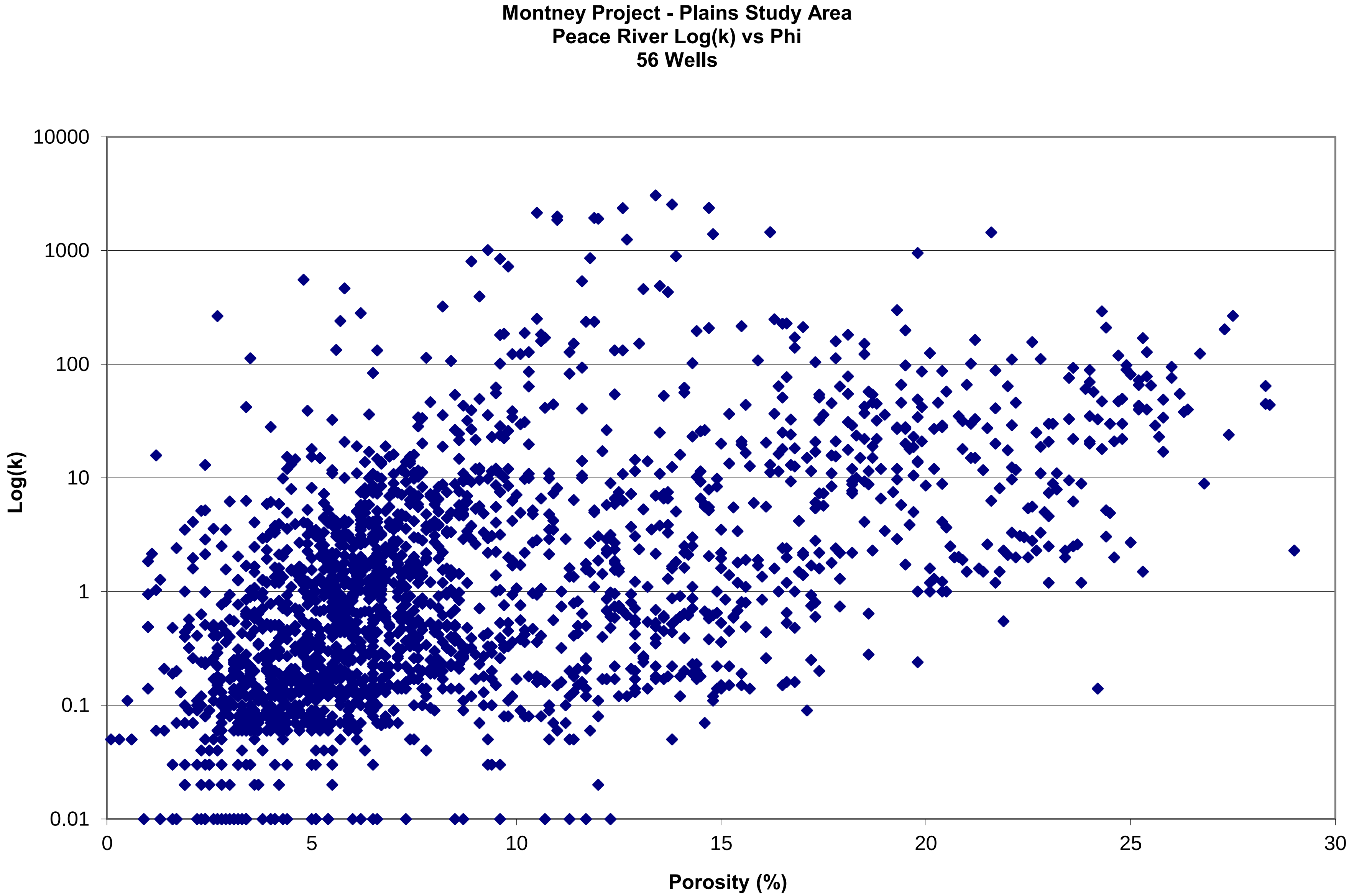
Montney Study - Foothills Study Area
Montney Log(k) vs Phi
3 Wells
Log(k)
10000
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)


Montney Study - Foothills Study Area
Debolt Log(k) vs Phi
5 Wells
10000
1000
100
10
1
0.1
0.01
Log(k)
0
5
10
15
20
25
30
Porosity (%)


Montney Project - Plains Study Area
Dunvegan Log(k) vs Phi
3 Wells
10000
1000
100
10
1
0.1
0.01
Log(k)
0
5
10
15
20
25
30
Porosity (%)



Montney Plains Study Area Fish Scales Log(k) vs Phi
Log(k)
10000
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)


Montney Project - Plains Study Area
Peace River Log(k) vs Phi
56 Wells
10000
1000
100
10
1
0.1
0.01
Log(k)
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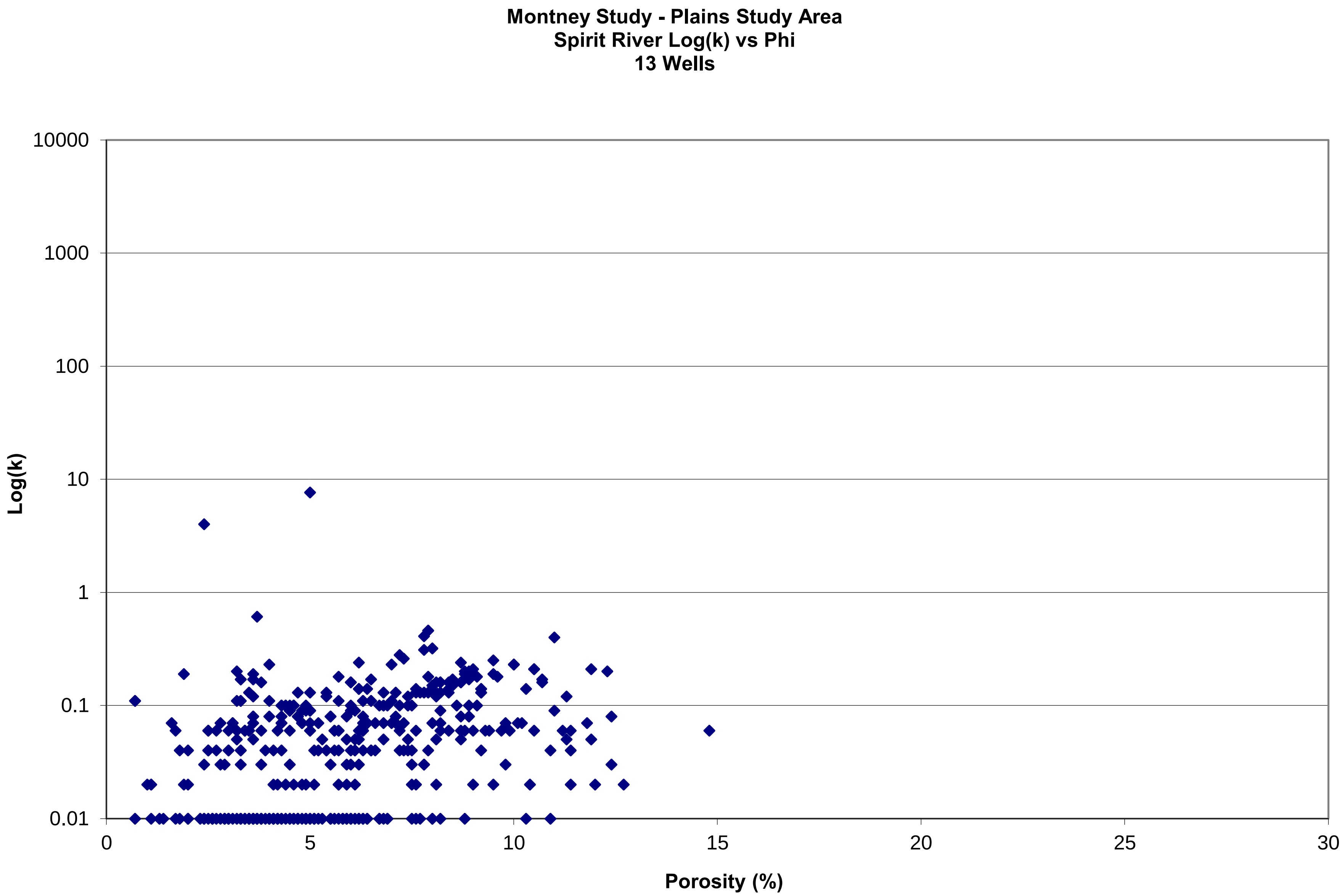
5
10
15
20
25
30
Porosity (%)


Montney Study - Plains Study Area
Spirit River Log(k) vs Phi
13 Wells
10000
1000
100
10
1
0.1
0.01
Log(k)
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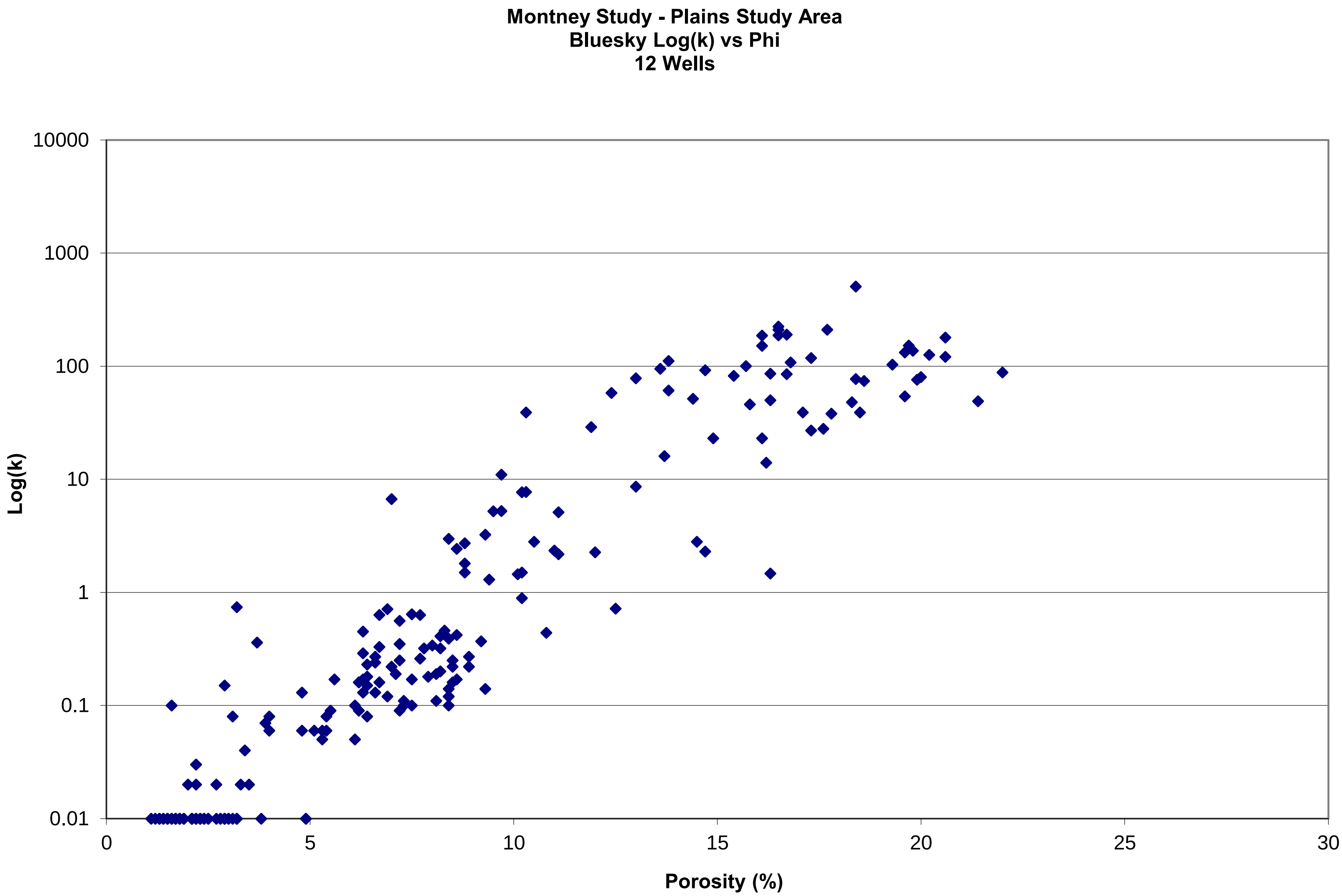
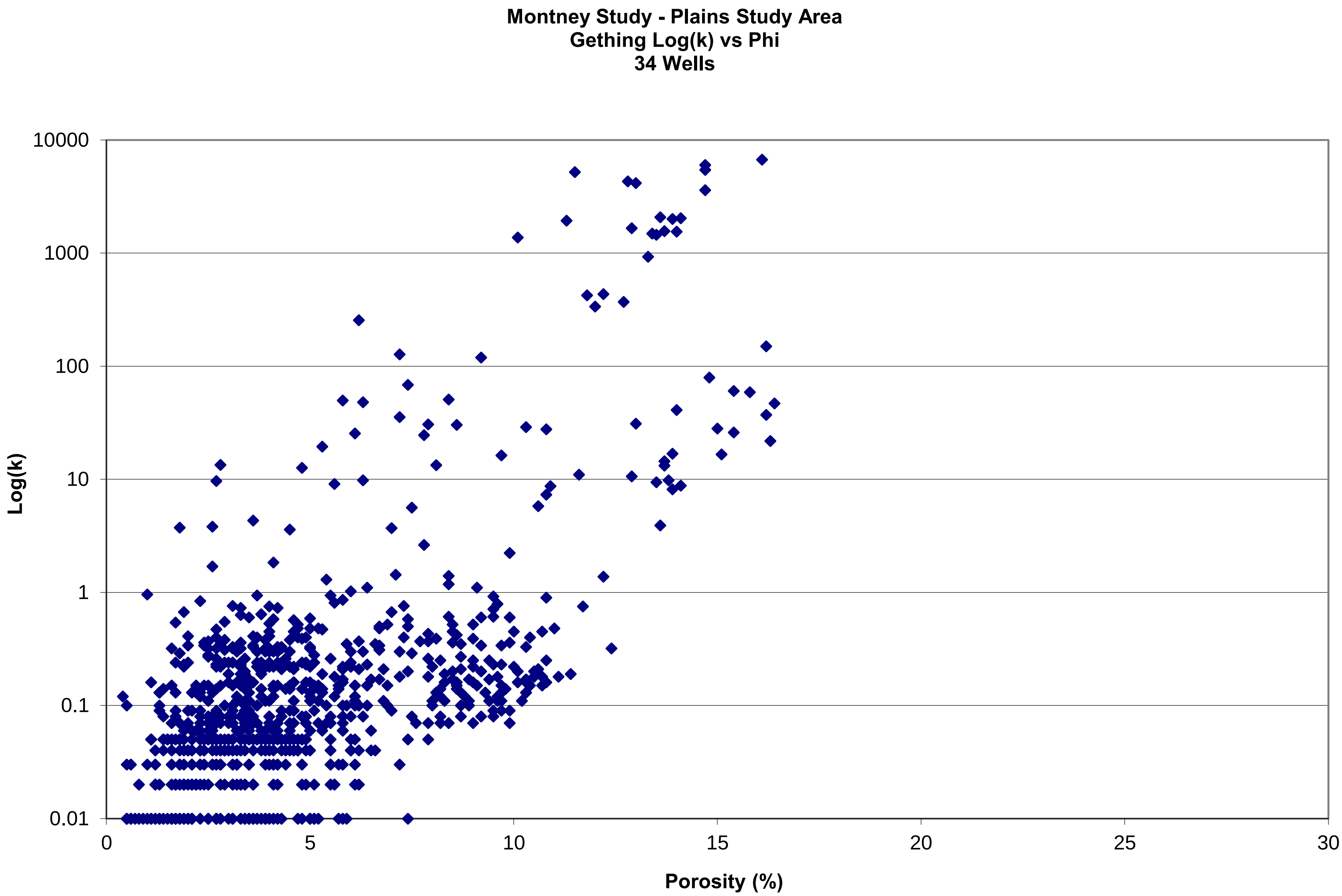
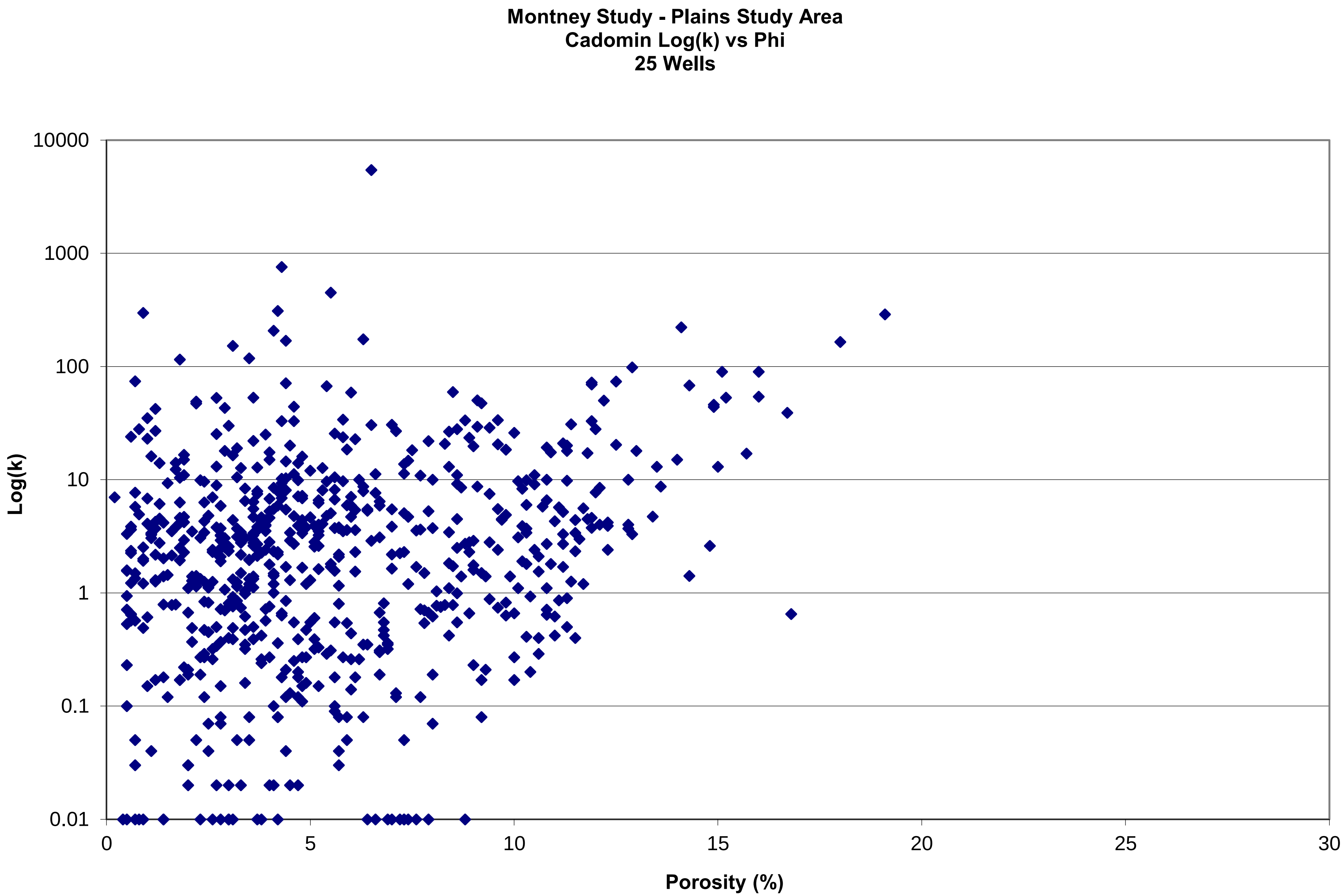
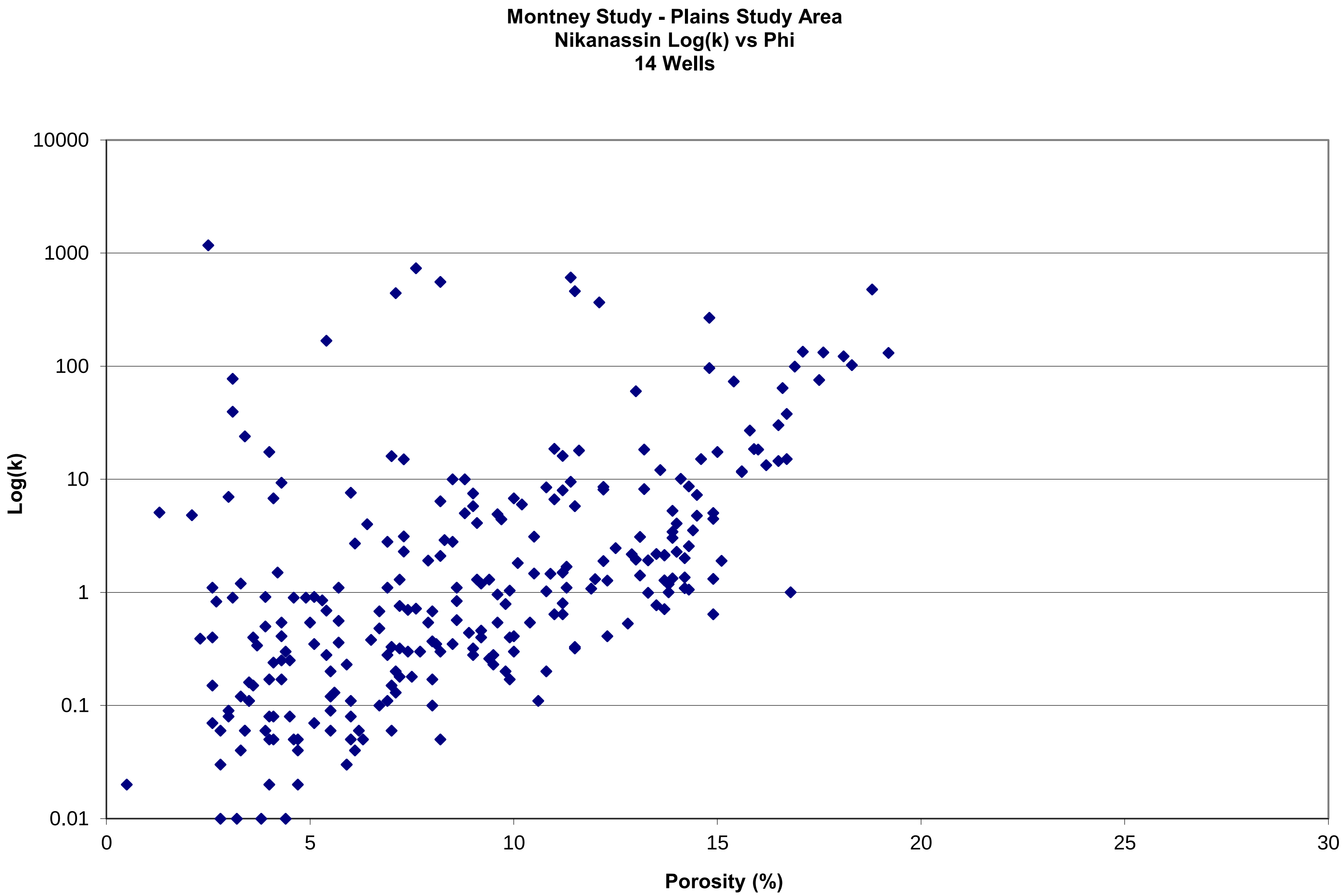
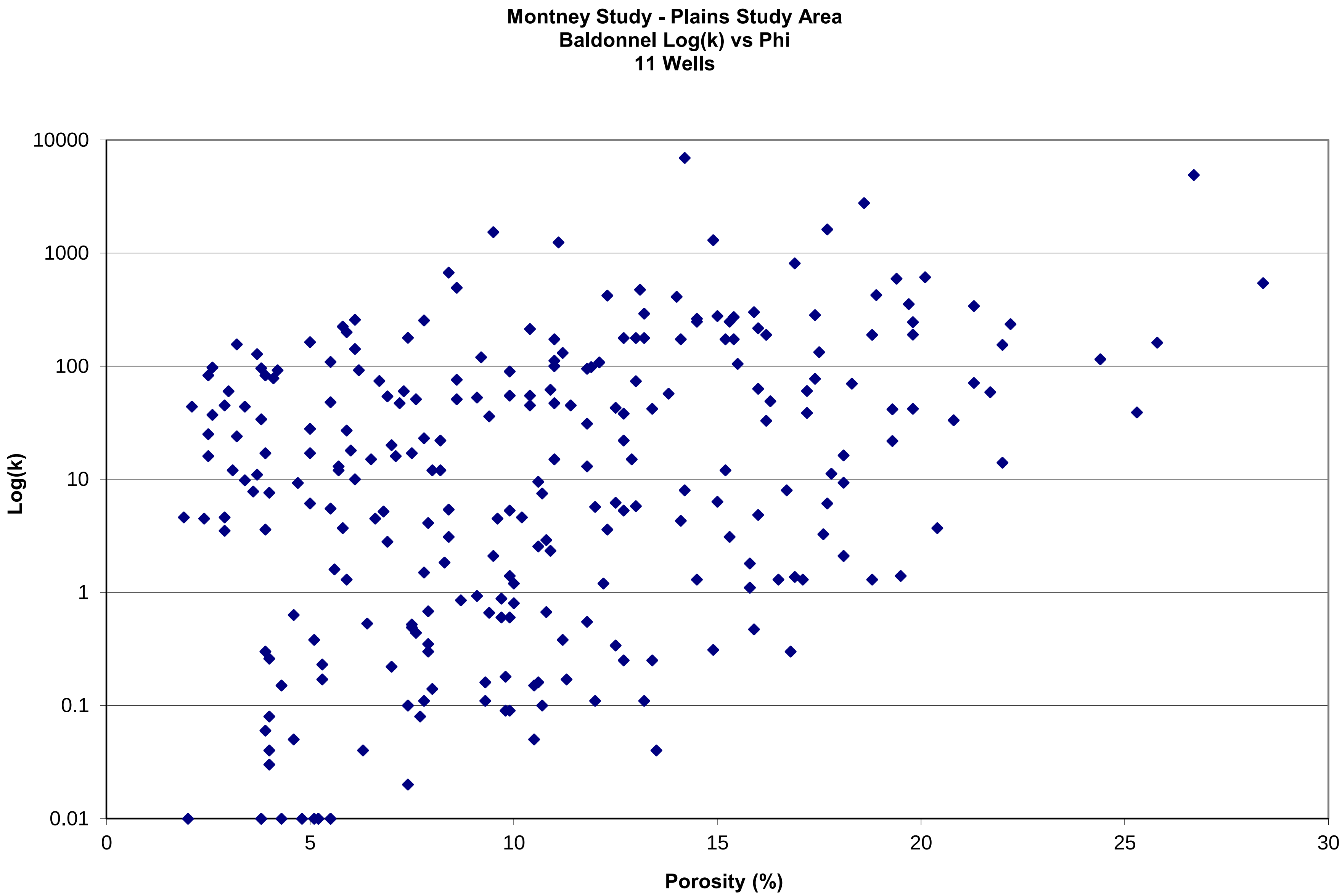
5
10
15
20
25
30
Porosity (%)

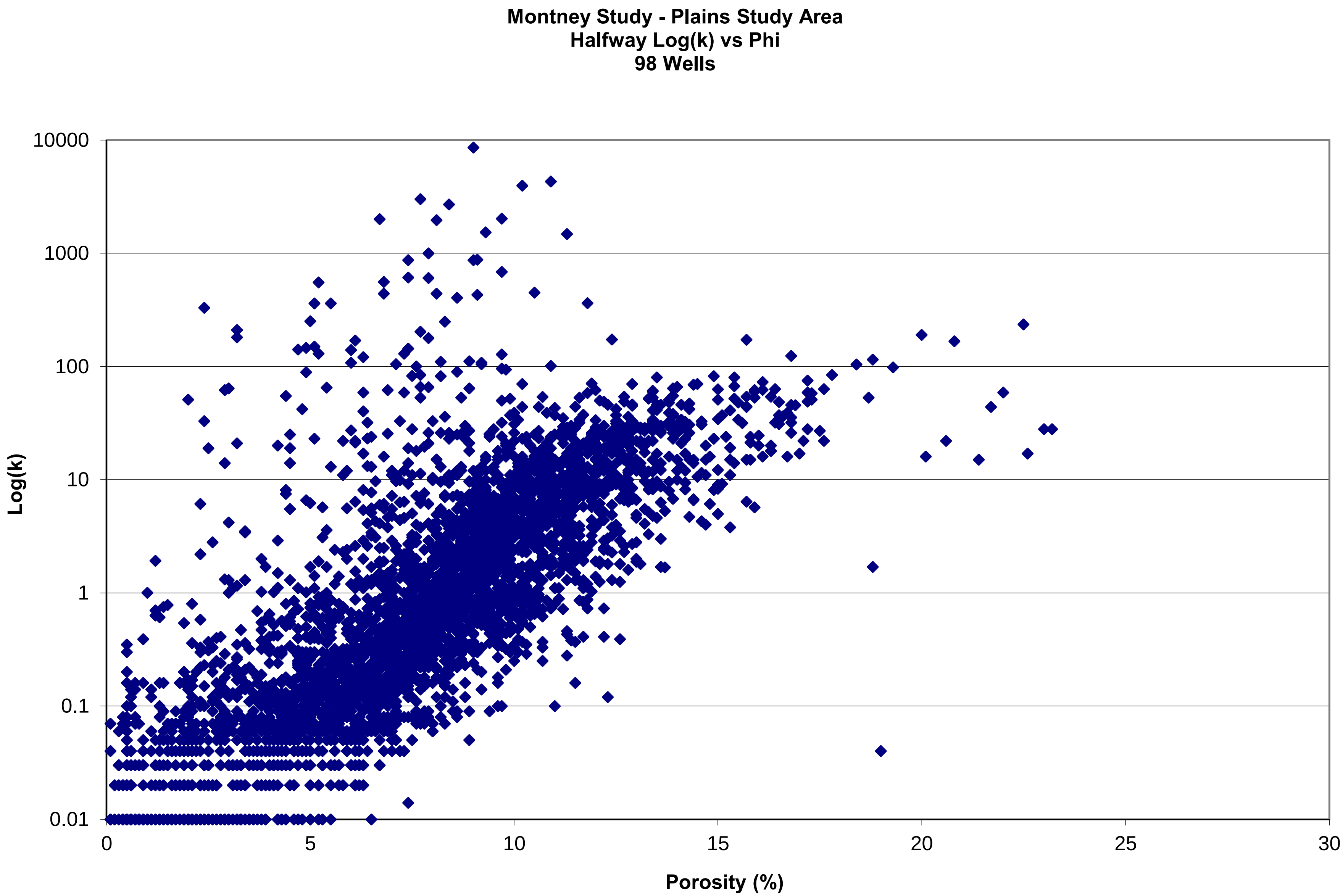

Montney Study - Plains Study Area
Bluesky Log(k) vs Phi
12 Wells
10000
1000
100
10
1
0.1
0.01
Log(k)
0
5
10
15
20
25
30
Porosity (%)

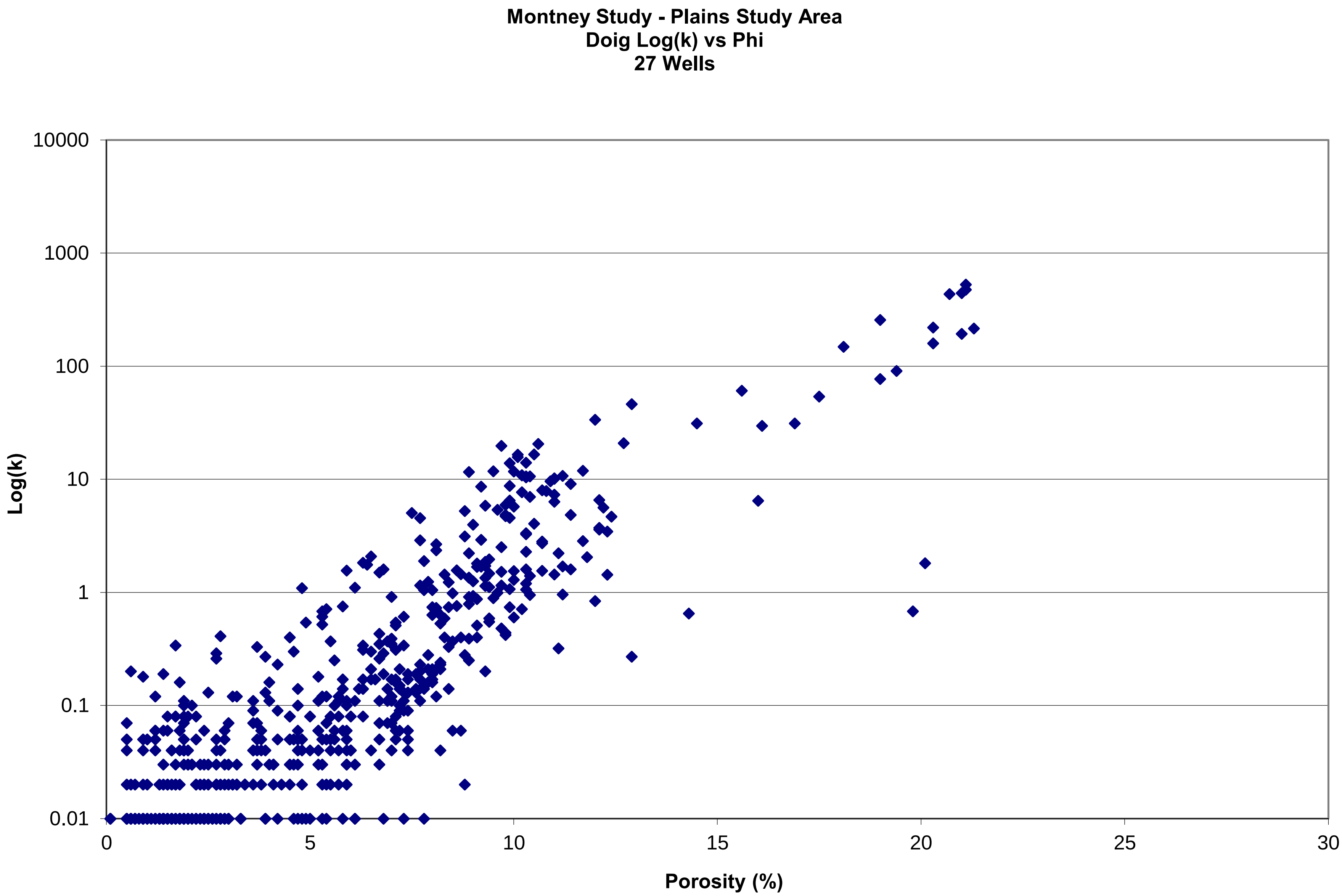

Montney Study - Plains Study Area
Gething Log(k) vs Phi
34 Wells
Log(k)
10000
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)


Montney Study - Plains Study Area
Cadomin Log(k) vs Phi
25 Wells
Log(k)
10000
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)


Montney Study - Plains Study Area
Nikanassin Log(k) vs Phi
14 Wells
Log(k)
10000
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)


Montney Study - Plains Study Area
Baldonnel Log(k) vs Phi
11 Wells
Log(k)
10000
1000
100
10
1
0.1
0.01
0
5
10
15
20
25
30
Porosity (%)


Montney Study - Plains Study Area
Halfway Log(k) vs Phi
98 Wells
10000
1000
100
10
1
0.1
0.01
Log(k)
0
5
10
15
20
25
30
Porosity (%)


Montney Study - Plains Study Area
Doig Log(k) vs Phi
27 Wells
10000
1000
100
10
1
0.1
0.01
Log(k)
0
5
10
15
20
25
30
Porosity (%)

# APPENDIX P-**3**

## Core Descriptions

# ARC Resources Doe
# 9-30-80-13W6
(Nordegg / Baldonnel)

Core to logs correction (-0.25 m).

**Core 1 1404-1419 m Rec. 14.60 m 11 boxes**

| Depth (m) | Description |
|---|---|
| 1404-1408 | Nordegg – black shale with sandy interbeds. Lowermost 8 cm – grey claystone. |
| 1408-1410.84 | Baldonnel – interbedded: 1) grey argillaceous mudstone, 2) black, bituminous mudstone, 3) grey packstone. Lithology ranges from limestone to dolomitic limestone. No visible porosity. |
| 1410.84-1413 | Dark grey, dolomitic packstone, locally nodular. Abundant pinpoint/moldic porosity. |
| 1413-1415.6 | Pervasive diagenesis, original texture largely obscured. Nodular, tan/grey/black, dolomitic packstone and intraclast floatstone with dolomitic packstone matrix. Large white and grey nodules. Abundant pinpoint/moldic and common vuggy (up to >5 cm) porosity. |
| 1415.6-1418.57 | Thin to medium bedded, tan/grey, dolomitic packstone with interbeds of intraclast dolomitic floatstone with packstone matrix. Original texture largely obscured. Abundant pinpoint/moldic porosity. Core highly fractured in lower 1.2 m. |

**Core 2 1419-1421 m Rec. 1.7 m 2 boxes**

| Depth (m) | Description |
|---|---|
| 1419-1420.7 | Core mostly rubble. Grey/tan, dolomitic packstone, locally nodular. Scattered pinpoint porosity. |

**Core 3 1421.60-1426.6 m Rec. 1 m 1 box**

| Depth (m) | Description |
|---|---|
| 1421.6-1422.6 | Core mostly rubble, appears to be nodular dolomitic packstone. Texture preserved within white nodules is skeletal dolopackstone (crinoids and thin bivalves). Some fractures occluded with coarse white calcite cement. Some pinpoint porosity visible, likely some intercrystalline. |


| 09-30-080-13W6 WA#11541 | Core 1 Box 3 | 1406.85-1408.35 m |
| --- | --- | --- |


| 09-30-080-13W6 WA#11541 | Core 1 Box 5 | 1409.77-1411.27 m |
|---|---|---|


| 09-30-080-13W6 WA#11541 | Core 1 Box 7 | 1412.61-1413.95 m |
| --- | --- | --- |


| 09-30-080-13W6 WA#11541 | Core 1 Box 8 | 1413.92-1415.32 m |
| --- | --- | --- |

# CNRL et al Mica
# 6-16-81-14W6
(Nordegg / Baldonnel)

**Core 4** **4895-4915 ft.** **Rec. 19.6 ft.**

| Depth (ft.) | Description |
|---|---|
| **4895-4889.2** | Nordegg - black, bituminous mudstone. |
| **4898.2-4898.7** | Dolofloatstone consisting of brecciated dolomudstone clasts in an argillaceous dolomudstone matrix. |
| **4898.7-4913.6** | Tan to brown, nodular, slightly calcareous dolomudstone. Some nodules are bluish – phosphatic? Skeletal dolofloatstone interbeds, bioclasts – crinoids and stick bryozoans? Rare dolopackstone and rare intraclast dolofloatstone interbeds. Oil staining is scattered thoughout but most common in upper 7' of interval. Good pinpoint porosity in dolopackstone beds. Intraskeletal porosity in stick bryozoans. Intercrystalline porosity where solid oil staining. Overall porosity decreases downwards in the interval. |


| 06-16-081-16W6 WA#230 | Core 4 Box 1 | 4895-4899.7 ft. |
| --- | --- | --- |


| 06-16-081-16W6 WA#230 | Core 4 Box 2 | 4899.7-4904.5 ft. |
| --- | --- | --- |


| | | |
|---|---|---|
| 06-16-081-16W6 WA#230 | Core 4 Box 3 | 4904.5-4909.3 ft. |


| 06-16-081-16W6 WA#230 | Core 4 Box 4 | 4909.3-4913.6 ft. |
| --- | --- | --- |

# Suncor PC et al Parkland
# 6-33-81-15W6
(Nordegg / Baldonnel)

**Core 1** **1390-1399.4 m** **9 boxes**

| Depth (m) | Description |
|---|---|
| 1390-1392.68 m | Nordegg – black, calcareous mudstone. |
| 1392.68-1394.56 | Tan and light grey, bedded, dolomitic mudstone, locally brecciated in situ > dolomitic rudstone/floatstone. Core very fragmented – horizontal fractures. Intercrytalline porosity. |
| 1394.56-1396 | Dark grey, skeletal, dolomitic wackestone with thin, light grey packstone interbeds. Locally nodular with white calcite/dolomite nodules. Bioclasts – crinoids. |
| 1396-1397.36 | Interbedded: 1) dark grey dolomitic packstone, and 2) intraclast dolomitic rudstone-floatstone with dolomitic packstone matrix. Bituminous laminite at base of interval 1 cm thick. Rare pinpoint, interparticle, and vuggy porosity. |
| 1397.36-1399.4 | Dark grey, dolomitic mudstone with scattered white nodules, rare thin buff dolomitic packstone interbeds. Core highly fragmented – horizontal fractures. |

**Core 2** **1399.4-1409.6 m** **Rec. 9.9 m**

| Depth (m) | Description |
|---|---|
| **1399.4-1402.74** | Thinly bedded to massive, nodular, dolomitic mudstone, light brown to dark grey with rare tan beds. White nodules locally very abundant. Rare thin skeletal dolomitic packstone interbeds. Rare pinpoint porosity in nodules and packstone beds. |
| **1402.74-1403.75** | Thinly bedded, grey, dolomitic packstone. Pinpoint porosity locally very abundant. Core very fragmented – horizontal fractures. |
| **1403.75-1408.85** | Medium to dark grey dolomitic mudstone. No visible porosity. |

**Core 3 1409.6-1427.6 m Rec. 18 m**

| Depth (m) | Description |
|---|---|
| **1409.6-1411.35** | Dark grey, dolomitic mudstone with skeletal packstone interbeds (as above). No visible porosity. |
| **1411.35-1419.24** | Grey dolomitic packstone to dolopackstone. Pinpoint/biomoldic porosity throughout, locally abundant. Rare scattered vugs (up to 3 cm). Many horizontal fractures. |
| **1419.24-1420.34** | Grey, skeletal dolowackestone, slightly calcareous. Bioclasts – mostly bivalves, mostly dissolved > molds. Good moldic porosity, many horizontal fractures. |
| **1420.34-1422.57** | Dolopackstone (as above). Good pinpoint/biomoldic porosity. |
| **1422.57-1424.25** | Light to dark grey, dolomitic mudstone. No visible porosity. |
| **1424.25-1427.6** | Dolomitic packstone to dolopackstone (as above), locally very good pinpoint/biomoldic porosity. |


| 06-33-081-15W6 WA#16057 | Core 1 Box 1 | |
|---|---|---|

| 06-33-081-15W6 WA#16057 | Core 1 Box 2 | |
|---|---|---|

| | | |
|---|---|---|
| **06-33-081-15W6   WA#16057** | **Core 1 Box 3** | |

| 06-33-081-15W6 WA#16057 | Core 1 Box 4 | |
| --- | --- | --- |

| 06-33-081-15W6 WA#16057 | Core 1 Box 5 | |
|---|---|---|

| 06-33-081-15W6 WA#16057 | Core 1 Box 6 | |
|---|---|---|

| 06-33-081-15W6 WA#16057 | Core 1 Box 7 | |
|---|---|---|

| 06-33-081-15W6   WA#16057 | Core 1 Box 8 | |
| --- | --- | --- |


| | | |
|---|---|---|
| 06-33-081-15W6 WA#16057 | Core 1 Box 9 | |

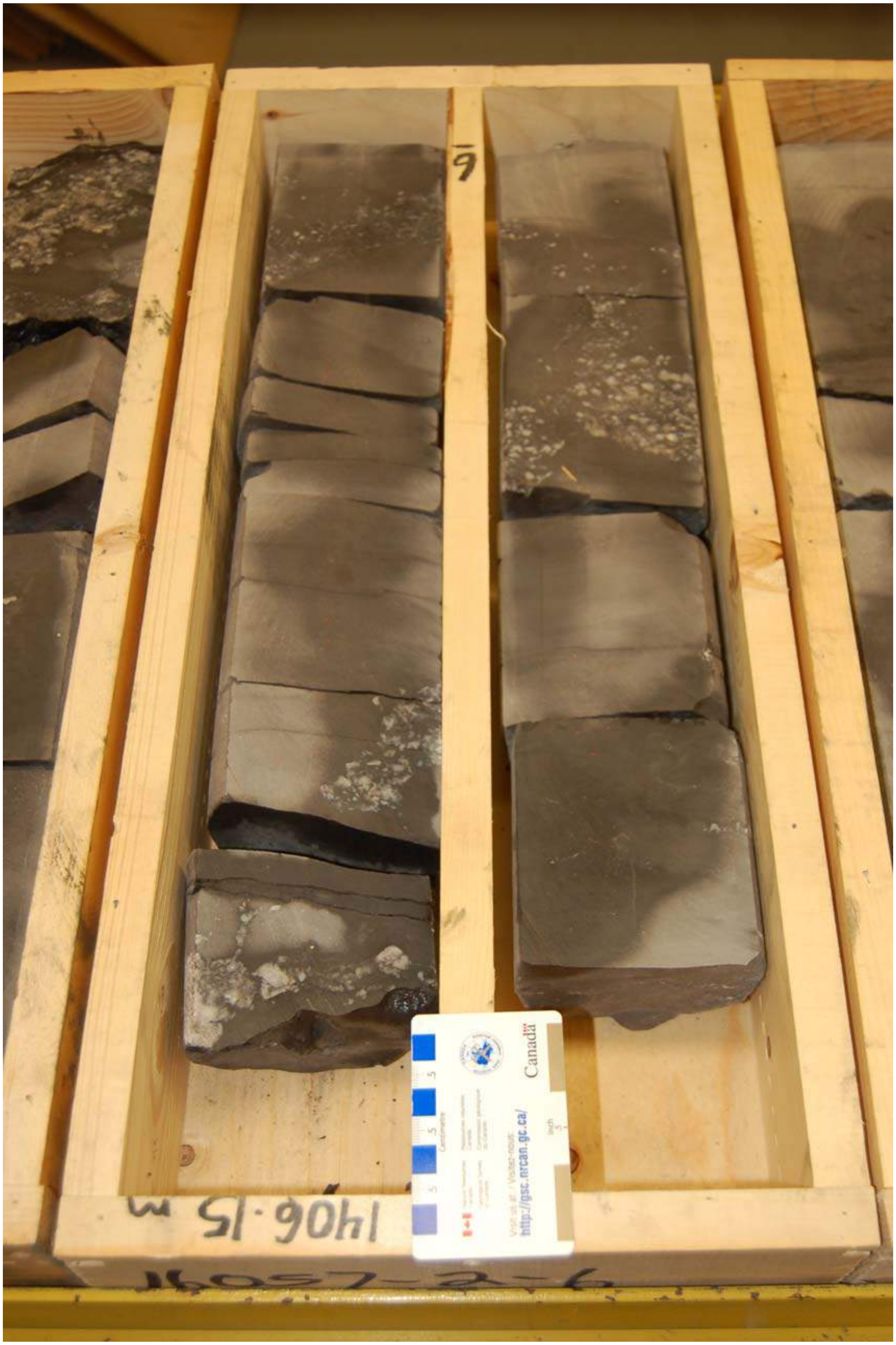

| 06-33-081-15W6 WA#16057 | Core 2 Box 1 | |
|---|---|---|

| 06-33-081-15W6 WA#16057 | Core 2 Box 2 | |
| --- | --- | --- |

| 06-33-081-15W6 WA#16057 | Core 2 Box 3 | |
|---|---|---|

| 06-33-081-15W6 WA#16057 | Core 2 Box 4 | |
|---|---|---|

| 06-33-081-15W6 WA#16057 | Core 2 Box 5 | |
|---|---|---|



| 06-33-081-15W6 WA#16057 | Core 2 Box 6 | |
|---|---|---|

| 06-33-081-15W6 WA#16057 | Core 2 Box 7 | |
|---|---|---|


| | | |
|---|---|---|
| 06-33-081-15W6 WA#16057 | Core 2 Box 8 | |


| | | |
|---|---|---|
| **06-33-081-15W6 WA#16057** | **Core 2 Box 9** | |


| 06-33-081-15W6 WA#16057 | Core 3 Box 1 | |
|---|---|---|

| | | |
|---|---|---|
| **06-33-081-15W6 WA#16057** | **Core 3 Box 2** | |

| | | |
|---|---|---|
| **06-33-081-15W6 WA#16057** | **Core 3 Box 3** | |


| 06-33-081-15W6 WA#16057 | Core 3 Box 4 | |
|---|---|---|


| | | |
|---|---|---|
| **06-33-081-15W6   WA#16057** | **Core 3 Box 5** | |

| | | |
|---|---|---|
| **06-33-081-15W6 WA#16057** | **Core 3 Box 6** | |


| 06-33-081-15W6 WA#16057 | Core 3 Box 7 | |
|---|---|---|

| | | |
|---|---|---|
| 06-33-081-15W6 WA#16057 | Core 3 Box 8 | |


| 06-33-081-15W6 WA#16057 | Core 3 Box 9 | |
| --- | --- | --- |

| 06-33-081-15W6 WA#16057 | Core 3 Box 10 | |
|---|---|---|


| 06-33-081-15W6 WA#16057 | Core 3 Box 11 | |
|---|---|---|

| 06-33-081-15W6 WA#16057 | Core 3 Box 12 | |
|---|---|---|


| | | |
|---|---|---|
| **06-33-081-15W6 WA#16057** | **Core 3 Box 13** | |


| 06-33-081-15W6 WA#16057 | Core 3 Box 14 | |
|---|---|---|


| 06-33-081-15W6 WA#16057 | Core 3 Box 15 | |
|---|---|---|


| | | |
|---|---|---|
| **06-33-081-15W6 WA#16057** | **Core 3 Box 16** | |

# ARC Resources Parkland
# 4-20-81-16W6
(Baldonnel)

**Core 1** **1456-1464.8 m** **Rec. 8.8 m** **4 boxes**

| Depth (m) | Description |
|---|---|
| 1456-1456.3 | Black, bituminous dolomudstone. |
| 1456.3-1464.4 | Interbedded: 1) light to dark grey, locally nodular dolomudstone, and 2) intraclast dolorudstone/floatstone (brecciated mudstone). No visible porosity. |
| 1464.4-1464.8 | Grey dolopackstone and dolomustone, rubble in box. No visible porosity. |


| 04-20-081-16W6 WA#166 | Core 1 Box 1 | 1456-1460.7 m |
| --- | --- | --- |


| 04-20-081-16W6 WA#166 | Core 1 Box 2 | 1460.7-1464.9 m |
| --- | --- | --- |

# Suncor Atlantic Pingel Creek
# 3-33-81-18W6
(Nordegg / Baldonnel)

**Core 2 4690-4710 ft. Rec. 20 ft. 4 boxes**

| Depth (ft.) | Description |
|---|---|
| 4690-4691.9 | Nordegg - Black, bituminous dolomudstone, slightly calcareous. Sharp irregular lower contact with intraclasts at base. |
| 4691.9-4697.1 | Grey, bedded, locally nodular dolpackstone, slightly calcareous, feels sandy. No visible porosity. |
| 4697.1-4700.7 | Dark grey, locally mottled, dolomudstone with intraclast floatstone interbeds. Lowermost 0.5' – black bituminous dolomudstone/shale. No visible porosity. |
| 4700.7-4710 | Grey, slightly calcareous dolopackstone, possibly some wackestone, skeletal in part. Bioclasts – crinoids and rare stick bryozoans. Rare bituminous dolomudstone and light grey argillaceous interbeds. Scattered pinpoint porosity, abundant in some beds. |

**Core 3 4710-4725 ft. Rec. 15 ft. 2 boxes**

| Depth (ft.) | Description |
|---|---|
| 4710-4718.3 | Interbedded: 1) grey dolopackstone, some beds have good pinpoint/biomoldic porosity, possible local oil staining. 2) Grey/black dolmudstone, some beds brecciated in part (in situ). Localized fractures occluded with white calcite. |
| 4718.3-4725 | Light to dark grey dolomudstone, mostly brecciated (in situ) > dolorudstone/dolofloatstone with argillaceous matrix. No visible porosity. |

**Core 4 4725-4734 ft. Rec. 8 ft. 2 boxes**

| Depth (ft.) | Description |
|---|---|

| | |
|---|---|
| 4725-4727.5 | Brecciated grey dolomudstone (as above). |
| 4727.5-4730.6 | Laminated-bedded, light grey/dark grey/off white colored dolomudstone with rare dolowackestone-dolopackstone interbeds. No visible porosity. |
| 4730.6-4732.3' | Grey, bedded dolopackstone, skeletal in part, bioclasts – crinoids. Good pinpoint/biomoldic porosity. |

**Core 5 4725-4734 ft. Rec. 12 ft. 3 boxes**

| Depth (ft.) | Description |
|---|---|
| 4734-4746 | Thin to medium interbedded: 1) grey dolopackstone with good pinpoint porosity; 2) grey-black dolomudstone, laminated in part, no visible porosity; 3) skeletal dolograinstone. Lithologies locally inter-burrowed/mottled. Minor vugs in dolopackstone/dolograinstone. |

**Core 6 4750-4764 ft. Rec. 14.2 ft.**

| Depth (ft.) | Description |
|---|---|
| 4750-4753.5 | Dark grey, argillaceous/bituminous, skeletal dolowackestone. |
| 4753.5-4764 | Grey, locally nodular dolopackstone with minor interbeds of skeletal dolograinstone and dolomudstone. Good pinpoint/biomoldic porosity in dolopackstone, scattered vugs in packstone/grainstone up to 1 cm. |

**Core 7 4764-4784 ft. Rec. 20 ft. 4 boxes**

| Depth (ft.) | Description |
|---|---|
| 4764-4768.8 | Grey, dolomudstone to skeletal dolowackestone, locally nodular. Rare possible oncoids. Rare skeletal dolograinstone interbeds. Minor vuggy porosity in calcareous nodules. |
| 4768.8-4784 | Dark grey, argillaceous, locally nodular dolomudstone. Nodules – white, calcareous, some have vuggy up to >2 cm. |

**Core 8 4784-4800 ft. Rec. 16 ft. 4 boxes**

| Depth (ft.) | Description |
|---|---|
| 4784-4795.7 | Dark grey dolomudstone (as above). |
| 4795.7-4800 | Dolomitic skeletal packstone (mostly crinoidal), locally nodular, no visible porosity. |

**Core 9 4800-4810 ft. Rec. 9 ft. 1 box**

| Depth (ft.) | Description |
|---|---|
| 4800-4809’ | Brown dolomitic packstone to dolopackstone. Scattered pinpoint porosity, locally fractured, core is highly fragmented. |

**Core 10 4810-4825 ft. Rec. 14 ft. 3 boxes**

| Depth (ft.) | Description |
|---|---|
| 4810-4824 | Grey dolomitic packstone to dolopackstone. Good pinpoint/biomoldic porosity. |

**Core 11 4825-4840 ft. Rec. 10 ft. 3 boxes**

| Depth (ft.) | Description |
|---|---|
| 4825-4826.7 | Dolomitic packstone (as above). |
| 4826.7-4835 | Grey dolomitic mudstone with dolomitic packstone interbeds, locally nodular. Scattered pinpoint porosity in packstone. |

**Core 12 4840-4850 ft. Rec. 10 ft.**

| Depth (ft.) | Description |
|---|---|
| 4840-4849 | Grey, skeletal, dolomitic packstone. Scattered pinpoint porosity. |
| 4849-4849.5 | Light grey dolomudstone. |
| 4849.5-4850 | Packstone as above. |

**Core 13 4850-4860 ft. Rec. 10 ft.**

| Depth (ft.) | Description |
|---|---|
| 4850-4860 | Light grey to dark grey, laminated to thinly bedded dolomitic mudstone. No visible porosity. |


| | | |
|---|---|---|
| 03-33-081-18W6 WA#148 | Core 2 Box 1 | 4690-4694.7 ft. |


| 03-33-081-18W6 WA#148 | Core 3 Box 1 | 4710-4714.6 ft. |
|---|---|---|


| 03-33-081-18W6 WA#148 | Core 3 Box 2 | 4714.6-4719.1 ft. |
|---|---|---|


| | | |
|---|---|---|
| **03-33-081-18W6 WA#148** | **Core 3 Box 3** | **4719.1-4723.4 ft.** |


| 03-33-081-18W6 WA#148 | Core 5 Box 1 | 4734-4739 ft. |
|---|---|---|


| 03-33-081-18W6 WA#148 | Core 6 Box 2 | 4752.5-4757.5 ft. |
|---|---|---|


| | | |
|---|---|---|
| 03-33-081-18W6 WA#148 | Core 7 Box 4 | 4690-4694.7 ft. |


| | | |
|---|---|---|
| **03-33-081-18W6 WA#148** | **Core 8 Box 1** | **4784-4788.8 ft.** |


| | | |
|---|---|---|
| 03-33-081-18W6 WA#148 | Core 10 Box 1 | 4810-4815 ft. |


| 03-33-081-18W6 WA#148 | Core 12 Box 1 | 4842.5-4847.5 ft. |
| --- | --- | --- |


| | | |
|---|---|---|
| **03-33-081-18W6 WA#148** | **Core 13 Box 1** | **4856.2-4860 ft.** |

# Sinclair Canadian Atlantic
# 3-20-82-20W6
## (Pardonet / Baldonnel)

**Core 1** **3690-3712.4 ft.** **Rec. 22.4 ft.** **5 boxes**

| Depth (ft.) | Description |
|---|---|
| 3690-3712.4 | Pardonet Formation – mostly black, bituminous dolomudstone, grading locally to dolomitic mudstone. Rare intraclastic/skeletal dolopackstone-dolorudstone beds (2-28 cm thick), sharp basal contacts, gradational upper contacts. Bioclasts – mostly crinoids, some bivalves/brachs. Rare vertical fractures occluded with white calcite. No visible porosity. |

**Core 2** **3715-3732 ft.** **Rec. 7.5 ft. (~3' in box)** **1 box**

| Depth (ft.) | Description |
|---|---|
| 3715-3715.25 | Black, bituminous, skeletal dolomudstone; bioclasts – crinoids; nodules at base of interval; sharp, steeply dipping lower contact. No visible porosity. |
| 3715.25-3718 | Dark grey dolopackstone; skeletal in part, bioclasts appear to be crinoids; sub-vertical to vertical fractures, most occluded with white calcite. |

**Core 3** **3732-3752 ft.** **Rec. 19.4 ft.** **4 boxes**

| Depth (ft.) | Description |
|---|---|
| 3732-3738.5 | Medium to dark grey, thin to medium bedded dolopackstone (slightly calcareous locally). Skeletal in part, bioclasts appear to be crinoids. May be some thin dolomudstone interbeds. Sharp basal contact with nodules at base. Rare pinpoint/moldic porosity, possibly some intercrystalline porosity. |
| 3738.5-3742.4 | Interbedded (~10-20 cm): 1) laminated, argillaceous/bituminous, dark grey to black, dolomitic mudstone to mudstone, locally interlaminated black and tan laminae with varved appearance. 2) dark-grey to black, |

| | |
|---|---|
| | skeletal wackestone, bioclasts appear to be mostly crinoids. 3) grey dolomudstone. Numbers 2 and 3 are locally inter-mottled/bioturbated. No visible porosity. |
| 3748.4-3750.9 | Grey dolopackstone, rare pinpoint porosity. |

**Core 4 3752-3772 ft. Rec. 20 ft. 4 boxes**

| Depth (ft.) | Description |
|---|---|
| 3752-3765 | Dark grey dolopackstone, locally nodular (tan/white irregular nodules). Bioclasts appear to be mostly crinoids. Rare, thin, tan, coquina-like dolopackstone interbeds with sharp contacts. Localized pinpoint/moldic and small vuggy (<3 mm) porosity. |
| 3765-3770.2 | Thin to medium interbedded, grey to dark grey, dolomudstone and dolopackstone with mostly irregular bedding contacts, rare nodules. Rare pinpoint porosity in dolopackstone. |

**Core 5 3772-3782 ft. Rec. 6.8 ft. 2 boxes**

| Depth (ft.) | Description |
|---|---|
| 3772-3772.5 | Grey-black dolomudstone, tight. |
| 3772.5-3773.8 | Dark grey, intraclastic/skeletal, dolomitic packstone-rudstone to dolopackstone/ dolorudstone. Bioclasts – bivalves/brachs. White dolomite/calcite cement occludes interparticle and vuggy porosity near base of interval. |
| 3773.8-3778.6 | Grey to dark grey, interbedded/intermottled, dolomudstone and dolopackstone. Bioclasts – mostly crinoids, rare brachs. No visible porosity. |


| | | |
|---|---|---|
| **03-20-082-20W6 WA#148** | **Core 1 Box 1** | **3690-3694.6 ft.** |


| 03-20-082-20W6 WA#148 | Core 3 Box 2 | 3736.7-3741.4 ft. |
|---|---|---|


| 03-20-082-20W6 WA#148 | Core 3 Box 3 | 3741.4-3746.3 ft. |
|---|---|---|


| | | |
|---|---|---|
| **03-20-082-20W6 WA#148** | **Core 3 Box 4** | **3746.3-3751.2 ft.** |

# Penn West Fort St. John SE
# 4-9-83-17W6
(Nordegg / Baldonnel)

Note: Core to log correction (+1.3')

**Core 1 3829-3869 ft. Rec. 34.5 ft. 8 boxes**

| Depth (ft.) | Description |
|---|---|
| 3829-3833.7 | Nordegg – black shale. |
| 3833.7-3841 | Laminated to thinly bedded, light grey to dark brown dolomudstone, locally nodular. Rare pinpoint porosity. |
| 3841-3843.1 | Brown dolopackstone, slightly calcareous, locally nodular. Abundant pinpoint/biomoldic porosity. |
| 3843.1-3847.1 | Tan, brown, and bluish grey dolomudstone, bedded and locally mottled, rare bituminous laminites (0.5-2 cm thick). Rare pinpoint porosity and vugs (up to 1 cm). |
| 3847.1-3863.5 | Thin to medium interbedded, grey to dark brown, dolopackstone and dolomudstone, locally intermottled, locally nodular. Good pinpoint/small vuggy porosity in dolopackstone. |

**Core 2 3884-3890 ft. Rec. 5 ft.**

| Depth (ft.) | Description |
|---|---|
| 3884-3889 | Dark grey dolomudstone. No visible porosity. |

**Core 3 3890-3895 ft. Rec. 5 ft.**

| Depth (ft.) | Description |
|---|---|
| 3890-3894 | Dark brown dolomudstone, locally nodular with dolopackstone interbeds. No visible porosity. |

**Core 4 3895-3905 ft. Rec. 8 ft.**

| Depth (ft.) | Description |
|---|---|
| **3895-3903** | Thin to medium bedded dolopackstone, dark brown, rare tan nodules. Abundant pinpoint porosity, scattered vugs (up to 1.5 cm). |

**Core 5 3905-3915 ft. Rec. 9.6 ft.**

| Depth (ft.) | Description |
|---|---|
| **3905-3914.6** | Grey to brown bedded dolopackstone, skeletal in part, locally nodular. Good pinpoint/biomoldic porosity, scattered vugs (up to 2 cm). Locally fractured. |


| 04-09-083-17W6 WA#166 | Core 1 Box 1 | 3829-3833.6 ft. |
|---|---|---|


| | | |
|---|---|---|
| **04-09-083-17W6 WA#166** | **Core 1 Box 2** | **3833.6-3838.2 ft.** |


| 04-09-083-17W6 WA#166 | Core 1 Box 3 | 3838.2-3843 ft. |
|---|---|---|


| 04-09-083-17W6 WA#166 | Core 1 Box 4 | 3843-3847.3 ft. |
| --- | --- | --- |


| | | |
|---|---|---|
| **04-09-083-17W6 WA#166** | **Core 1 Box 5** | **3847.3852.1 ft.** |


| | | |
|---|---|---|
| **04-09-083-17W6 WA#166** | **Core 1 Box 6** | **3852.1-3856.9 ft.** |


| 04-09-083-17W6 WA#166 | Core 1 Box 7 | 3856.9-3861.7 ft. |
|---|---|---|


| 04-09-083-17W6 WA#166 | Core 1 Box 8 | 3861.7-3863.5 ft. |
| --- | --- | --- |


| 04-09-083-17W6 WA#166 | Core 2 | 3884-3889 ft. |
| --- | --- | --- |


| | | |
|---|---|---|
| **04-09-083-17W6 WA#166** | **Core 3** | **3890-3895 ft.** |


| | | |
|---|---|---|
| **04-09-083-17W6 WA#166** | **Core 4 Box 1** | **3895-3899.5 ft.** |


| 04-09-083-17W6 WA#166 | Core 5 Box 1 | 3905-3909.2 ft. |
| --- | --- | --- |

# Canetic ABC Airport
# 12-34-83-17W6
(Baldonnel)

**Core 9 4107-4117 ft. Rec. 7.5 ft. 2 boxes**

| Depth (ft.) | Description |
|---|---|
| 4107-4114.5 | Brown-grey, bedded, dolomitic mudstone to dolomudstone. Locally nodular, locally fractured. Interbeds of dolopackstone with pinpoint/biomoldic porosity. |

**Core 10 4117-4127 ft. Rec. 5.8 ft.**

| Depth (ft.) | Description |
|---|---|
| 4117-4122.8 | Brown, locally bioclastic dolopackstone with dolomudstone interbeds. Good pinpoint/biomoldic porosity. |

**Core 11 4127-4137 ft. Rec. 10 ft.**

| Depth (ft.) | Description |
|---|---|
| 4127-4137 | Dark grey, locally bioclastic argillaceous dolomudstone, locally nodular. Bioclasts – crinoids. Rare vuggy porosity in nodules (0.5-2.5 cm). |

**Core 12 4137-4150 ft. Rec. 12 ft.**

| Depth (ft.) | Description |
|---|---|
| 4137-4149 | Dark grey, locally bioclastic, locally nodular dolomudstone. Rare vuggy porosity in nodules (0.5-7 cm). |

**Core 13 4150-4166 ft. Rec. 15 ft.**

| Depth (ft.) | Description |
|---|---|

| | |
|---|---|
| 4150-4151.8 | Dark brown dolomudstone. No visible porosity. |
| 4151.8-4165 | Brown to dark brown dolopackstone with dolomudstone interbeds. Pinpoint/biomoldic porosity in dolopackstone. Vertical fractures in lower 2', partly occluded with very coarse white dolomite/calcite cement. |

**Core 14 4166-4176 ft. Rec. 8 ft.**

| Depth (ft.) | Description |
|---|---|
| 4166-4174 | Brown, thin to medium interbedded, dolomudstone and dolopackstone. Good pinpoint/biomoldic porosity in dolopackstone. |


| 12-34-083-17W6 WA#35 | Core 11 Box 1 | 4127-4132 ft. |
|---|---|---|


| 12-34-083-17W6 WA#35 | Core 13 Box 1 | 4150-4155 ft. |
| --- | --- | --- |


| | | |
|---|---|---|
| 12-34-083-17W6 WA#35 | Core 13 Box 3 | 4162.5-4165 ft. |


| 12-34-083-17W6 WA#35 | Core 14 Box 1 | 4166-4171 ft. |
|---|---|---|

# Penn West et al Fort St. John
# 14-22-83-18W6
(Baldonnel)

**Core 4 3781-3806 ft. Rec. 25 ft. 5 boxes**

| Depth (ft.) | Description |
|---|---|
| 3781-3794.6 | Grey/brown dolomudstone with rare dolopackstone interbeds/lenses, uppermost 1" is bituminous. Locally fractured, otherwise no visible porosity. Pardonnet? |
| 3794.6-3801.1 | Interbedded: 1) Mottled dark and light grey dolomudstone-dolopackstone. 2) Dark brown, bituminous dolomudstone. 3) Nodular, grey, argillaceous dolomudstone. 4) Grey dolopackstone. 5) Intraclast dolofloatstone with dolopackstone matrix. No visible porosity. |
| 3801.1-3804.1 | Dark grey dolopackstone. Abundant, pinpoint/moldic porosity, vuggy porosity common (up to 2 cm). Core very fragmented. |

**Core 5 3806-3821 ft. Rec. 15 ft. 3 boxes**

| Depth (ft.) | Description |
|---|---|
| 3806-3811.5 | Tan to dark brown dolopackstone, skeletal in part, bioclasts – crinoids. Pinpoint/moldic porosity locally very abundant, vugs up to 1 cm. |
| 3811.5-3815.5 | Dark brown dolomudstone with rare dolopackstone lenses and thin interbeds. Pinpoint porosity in dolopackstone, mudstone tight. |
| 3815.5-3816.9 | Brown dolopackstone, good pinpoint porosity. |

**Core 6 3821-3841 ft. Rec. 19.5 ft.**

| Depth (ft.) | Description |
|---|---|
| 3821-3821.9 | Brown dolopackstone, skeletal in part. Scattered pinpoint porosity and rare vugs up to 1 cm. |

| | |
|---|---|
| 3821.9-3839.1 | Dark brown dolomudstone with scattered crinoidal dolopackstone/ dolomitic packstone lenses and thin interbeds. Localized vertical fractures occluded with coarse white calcite cement. |

**Core 7** **3841-3866 ft.** **Rec. 25.5 ft.** **5 boxes**

| Depth (ft.) | Description |
|---|---|
| 3841-3852.4 | Dark brown dolomudstone with rare dolopackstone lenses/interbeds (as above). |
| 3852.4-3865.4 | Grey dolopackstone grading locally to intraclast dolofloatstone, locally nodular. Pinpoint/moldic porosity throughout, scattered vugs (up to 1 cm). |

**Core 8** **3868-3878 ft.** **Rec. 10 ft.**

| Depth (ft.) | Description |
|---|---|
| 3868-3878 | Grey dolopackstone with pinpoint/biomoldic/vuggy porosity (as above). |


| | | |
|---|---|---|
| **14-22-083-18W6 WA#76** | **Core 4 Box 1** | **3781-3785.5 ft.** |


| 14-22-083-18W6 WA#76 | Core 4 Box 4 | 3795.5-3800.3 ft. |
| --- | --- | --- |


| 14-22-083-18W6 WA#76 | Core 4 Box 5 | 3800.3-3804.1 ft. |
| --- | --- | --- |


| | | |
|---|---|---|
| **14-22-083-18W6 WA#76** | **Core 5 Box 1** | **3806-3810.9 ft.** |


| 14-22-083-18W6 WA#76 | Core 5 Box 2 | 3810.9-3815.9 ft. |
|---|---|---|


| 14-22-083-18W6 WA#76 | Core 6 Box 4 | 3834.2-3839.1 ft. |
| --- | --- | --- |


| | | |
|---|---|---|
| **14-22-083-18W6 WA#76** | **Core 8 Box 1** | **3868-3872.8 ft.** |

# Penn West et al Fort St. John
# 13-23-83-18W6
(Baldonnel)

**Core 2** **3837-3862 ft.** **Rec. 23 ft.** **5 boxes**

| Depth (ft.) | Description |
|---|---|
| 3837-3853 | Grey, dark brown, black, locally bioclastic, dolomudstone. Bioclasts – crinoids. Core locally fragmented. |
| 3853-3860 | Tan to brown dolopackstone. Pinpoint, biomoldic, and vuggy (up to 4 cm) porosity. Core is fragmented – fractured? Patchy oil staining? |

**Core 3** **3862-3866 ft.** **Rec. 2 ft.** **1 box**

| Depth (ft.) | Description |
|---|---|
| 3862-3864 | Grey/brown, interbedded dolopackstone and dolomudstone. No visible porosity but core fragmented – fractured? |

**Core 4** **3866-3887 ft.** **Rec. 19 ft.** **5 boxes**

| Depth (ft.) | Description |
|---|---|
| 3866-3885 | Dark grey, locally nodular dolomudstone. Locally fractured, rare vugs in nodules (typically <1 cm). |


| 13-23-083-18W6 WA#82 | Core 2 Box 1 | 3837-3842 ft. |
| --- | --- | --- |


| 13-23-083-18W6 WA#82 | Core 2 Box 2 | 3842-3847 ft. |
|---|---|---|


| 13-23-083-18W6 WA#82 | Core 2 Box 4 | 3852.5-3857.5 ft. |
|---|---|---|


| | | |
|---|---|---|
| 13-23-083-18W6 WA#82 | Core 2 Box 4 | 3880-3885 ft. |

# Devon W Fort St. John
# 10-32-83-19W6
(Baldonnel)

**Core 1** **3769-3793 ft.** **Rec. 19 ft.** **4 boxes**

| Depth (ft.) | Description |
|---|---|
| 3769-3771.4 | Intraclast dolofloat (brecciated mudstone) in argillaceous dolomudstone matrix. |
| 3771.4-3773 | Brown dolomudstone, no visible porosity. |
| 3773-3779.4 | Light to dark brown dolopackstone. Rare colonial coral fragments? Very good pinpoint porosity locally. |
| 3779.4-3780.7 | Dark brown interbedded dolomudstone and dolopackstone, locally nodular. Scattered pinpoint porosity. |
| 3780.7-3788 | Interbedded grey dolopackstone and tan skeletal dolograinstone (cocquina-like), bioclasts mostly thin bivalves. Good pinpoint/biomoldic and vuggy (up to 1 cm) porosity. |

**Core 2** **3793-3795 ft.** **Rec. .75 ft.** **1 box**

| Depth (ft.) | Description |
|---|---|
| 3793-3793.75 | Black dolomudstone. No visible porosity. |


| | | |
|---|---|---|
| **10-32-083-19W6 WA#2493** | **Core 1 Box 1** | **3769-3773.8 ft.** |


| | | |
|---|---|---|
| **10-32-083-19W6 WA#2493** | **Core 1 Box 4** | **3784-3788 ft.** |

# Cdn Sup Whitehall Inga
# 6-28-88-24W6M
(Baldonnel)

**Core 1** **4730-4780 ft.** **Rec. 50 ft.** **11 boxes**

| Depth (ft.) | Description |
|---|---|
| 4730-4737.2 | Tan to grey, slightly calcareous dolopackstone. Locally very good pinpoint, biomoldic, and vuggy (up to 2 cm) porosity. |
| 4737.2-4744.8 | Dark grey dolomudstone. No visible porosity. |
| 4744.8-4769.4 | Grey dolopackstone. Very good pinpoint/biomoldic porosity throughout. Scattered vugs (up to 2 cm). Oil stained. |
| 4769.4-4780 | Laminated to bedded, light to dark grey dolomudstone, locally brecciated (in situ), locally argillaceous. No visible porosity. |


| 06-28-088-02-W6M | Core 1, Box 1 | 4730-____ ft. |
| --- | --- | --- |

| 06-28-088-02-W6M | Core 1, Box 2 | ____-____ ft. |
| --- | --- | --- |

| 06-28-088-02-W6M | Core 1, Box 3 | ____-____ ft. |
| --- | --- | --- |

| 06-28-088-02-W6M | Core 1, Box 4 | ____-____ ft. |
| --- | --- | --- |

| 06-28-088-02-W6M | Core 1, Box 5 | ____-____ ft. |
|---|---|---|

| | | |
|---|---|---|
| **06-28-088-02-W6M** | **Core 1, Box 6** | **____-____ ft.** |

| | | |
|---|---|---|
| **06-28-088-02-W6M** | **Core 1, Box 7** | **____-____ ft.** |


| 06-28-088-02-W6M | Core 1, Box 8 | ____-____ ft. |
| --- | --- | --- |


| | | |
|---|---|---|
| 06-28-088-02-W6M | Core 1, Box 9 | ____-____ ft. |


| | | |
|---|---|---|
| **06-28-088-02-W6M** | **Core 1, Box 10** | **____-____ ft.** |


| | | |
|---|---|---|
| **06-28-088-02-W6M** | **Core 1, Box 11** | **____-____ ft.** |

# Progress COP Dogrib
# c-28-L / 94-G-1
(Baldonnel)

**Core 1** **1375-1380 m** **Rec. 4.9 m** **4 boxes**

| Depth (m) | Description |
|---|---|
| 1375-1377.79 | Thin to medium interbedded: 1) dark grey mudstone, 2) dark grey skeletal wackestone, 3) grey packstone. Pinpoint porosity in packstone. |
| 1377.78-1379.9 | Grey dolomitic packstone to dolopackstone, very good pinpoint/ biomoldic porosity, some vugs (up to 1 cm). |

**Core 2** **1380-1387 m** **Rec. 6.9 m** **5 boxes**

| Depth (m) | Description |
|---|---|
| 1380-1381.7 | Dark grey, dolomitic packstone to dolopackstone, skeletal in part. Very good pinpoint porosity, scattered vugs (up to 1.5 cm), locally fractured. |
| 1381.7-1382.9 | Tan to grey, skeletal dolopackstone/dolograinstone, coquina-like in places. Good pinpoint/biomoldic, scattered vugs (up to 0.5 cm). |
| 1382.9-1384.57 | Interbedded: 1) grey dolomitic packstone to dolopackstone, 2) black skeletal dolowackestone, 3) black dolomitic mudstone to dolomudstone. Rare pinpoints in dolomitic packstone/dolopackstone. |
| 1384.57-1386.9 | Grey/white dolomitic skeletal packstone. Some fractures occluded with white cement. Rare fracture porosity. |


| C-28-L 094-G-01 WA#7680 | Core 1, Box 1 | 1375-____ m |
|---|---|---|


| | | |
|---|---|---|
| **C-28-L 094-G-01 WA#7680** | **Core 2, Box 1** | **____-____ m** |


| C-28-L 094-G-01 WA#7680 | Core 2, Box 2 | ____-____ m |
| --- | --- | --- |


| C-28-L 094-G-01 WA#7680 | Core 2, Box 3 | ____-____ m |
|---|---|---|


| | | |
|---|---|---|
| **C-28-L 094-G-01 WA#7680** | **Core 2, Box 4** | **____-____ m** |


| C-28-L 094-G-01 WA#7680 | Core 2, Box 5 | ____-____ m |
|---|---|---|

# Devon et al Bubbles
# d-88-I / 94-G-1
(Baldonnel)

**Core 1 4579-4608 ft. Rec. 22 ft.**

| Depth (ft.) | Description |
|---|---|
| 4579-4601 | Core unslabbed and dark – appears to be very dark grey, locally nodular, dolomudstone to dolowackestone with rare skeletal packstone interbeds. No visible porosity. |

**Core 2 4608-4629 Rec. 21 ft.**

| Depth (ft.) | Description |
|---|---|
| 4608-4620.5 | Dark grey, slightly calcareous dolomudstone with dolopackstone interbeds. Minor pinpoint porosity and small vugs in dolopackstone. |
| 4620.5-4629 | Bedded, dark grey, slightly calcareous dolopackstone. Variable pinpoint and vuggy porosity (up to 0.5 cm). |

**Core 3 4629-4674 Rec. 44 ft.**

| Depth (ft.) | Description |
|---|---|
| 4629-4655 | Tan to dark grey, locally calcareous, dolopackstone with dolowackestone interbeds. Variable pinpoint – biomoldic porosity in dolopackstone. Vugs scattered thoughout (up to >6 cm). |
| 4655-4673 | Dark grey, locally nodular, dolomitic to dolomudstone with minor dolomitic packstone interbeds. Scattered vuggy porosity (up to >6 cm). |

**Core 4 4674-4704 Rec. 29.5 ft.**

| Depth (ft.) | Description |
|---|---|

| | |
|---|---|
| 4674-4682.7 | Dark grey dolomudstone with rare vugs (~1 cm). |
| 4682.7-4688 | Bioclastic dolopackstone, bioclasts – bivalves. Variable pinpoint, biomoldic, and vuggy porosity. |
| 4688-4703.5 | Dark grey, locally nodular dolomudstone with minor skeletal dolopackstone interbeds. Minor pinpoint and vuggy porosity in dolopackstone. |


| 200/d-88-I 94-G-01 WA#462 | Core 2 Box 1 | ____ - ____ ft. |
|---|---|---|


| | | |
|---|---|---|
| **200/d-88-I 94-G-01 WA#462** | **Core 2 Box 2** | **____ - ____ ft.** |


| | | |
|---|---|---|
| **200/d-88-I 94-G-01 WA#462** | **Core 2 Box 3** | **____ - ____ ft.** |


| | | |
|---|---|---|
| 200/d-88-I 94-G-01 WA#462 | Core 2 Box 4 | ____ - ____ ft. |

| 200/d-88-I 94-G-01 WA#462 | Core 2 Box 5 | ____ - ____ ft. |
|---|---|---|


| 200/d-88-I 94-G-01 WA#462 | Core 3 Box 1 | ____ - ____ ft. |
|---|---|---|

| 200/d-88-I 94-G-01 WA#462 | Core 3 Box 2 | ____ - ____ ft. |
|---|---|---|

| 200/d-88-I 94-G-01 WA#462 | Core 3 Box 3 | ____ - ____ ft. |
| --- | --- | --- |


| | | |
|---|---|---|
| **200/d-88-I 94-G-01 WA#462** | **Core 3 Box 4** | **____ - ____ ft.** |

| | | |
|---|---|---|
| **200/d-88-I 94-G-01 WA#462** | **Core 3 Box 5** | **____ - ____ ft.** |

| | | |
|---|---|---|
| 200/d-88-I 94-G-01 WA#462 | Core 3 Box 5 | ____ - ____ ft. |


| | | |
|---|---|---|
| 200/d-88-I 94-G-01   WA#462 | Core 3 Box 6 | ____ - ____ ft. |

| 200/d-88-I 94-G-01 WA#462 | Core 3 Box 7 | ____ - ____ ft. |
|---|---|---|


| | | |
|---|---|---|
| **200/d-88-I 94-G-01 WA#462** | **Core 3 Box 8** | **____ - ____ ft.** |


| 200/d-88-I 94-G-01 WA#462 | Core 3 Box 9 | ____ - ____ ft. |
|---|---|---|

# Progress et al Blueberry
# d-97-D / 94-A-13
(Baldonnel)

**Core 2** **4609-4659 ft.** **Rec. 50 ft.** **11 boxes**

| Depth (ft.) | Description |
|---|---|
| **4609-4612** | Brown dolopackstone. Very good pinpoint/biomoldic porosity, scattered vugs (up to 2 cm). |
| **4612-4619.2** | Dark grey, bedded, dolomudstone to dolowackestone, locally nodular. No visible porosity. |
| **4619.2-4645.32** | Grey, dolomitic packstone to dolopackstone. Good pinpoint/ biomoldic porosity throughout, scattered small vugs (up to 0.5 cm). |
| **4645.32-4659** | Dark grey dolomitic packstone to wackestone. No visible porosity, core locally fragmented – fractured? |

**Core 3** **4659-4709** **Rec. 50 ft.** **11 boxes**

| Depth (ft.) | Description |
|---|---|
| **4659-4667.3** | Dark brown, locally nodular dolomudstone to dolowackestone, uppermost 1’ is light grey dolomudstone. No visible porosity. |
| **4667.3-4674.7** | Dark grey dolomitic packstone. No visible porosity. |
| **4674.7-4686.4** | Dark brown, interbedded dolomitic mudstone to dolomudstone and intraclast dolofloatstone with dolomudstone matrix. No visible porosity. |
| **4686.4-4693.9** | Slightly calcareous dolopackstone. Good pinpoint/biomoldic porosity. |
| **4693.9-4697.6** | Dolomitic intraclast floatstone with mudstone matrix. No visible porosity. |
| **4697.6-4709** | Dark grey dolomitic mudstone to skeletal wackestone. No visible porosity. |


| | | |
|---|---|---|
| **d-097-D 094-A-13 WA#581** | **Core 2 Box 1** | **____ - ____ ft.** |


| d-097-D 094-A-13 WA#581 | Core 2 Box 2 | ____ - ____ ft. |
|---|---|---|


| d-097-D 094-A-13 WA#581 | Core 2 Box 3 | ____ - ____ ft. |
|---|---|---|


| d-097-D 094-A-13 WA#581 | Core 2 Box 4 | ____ - ____ ft. |
|---|---|---|


| | | |
|---|---|---|
| **d-097-D 094-A-13 WA#581** | **Core 2 Box 5** | **____ - ____ ft.** |


| | | |
|---|---|---|
| **d-097-D 094-A-13 WA#581** | **Core 2 Box 6** | **____ - ____ ft.** |


| d-097-D 094-A-13 WA#581 | Core 2 Box 7 | ____ - ____ ft. |
|---|---|---|


| | | |
|---|---|---|
| **d-097-D 094-A-13 WA#581** | **Core 2 Box 8** | **____ - ____ ft.** |

| | | |
|---|---|---|
| **d-097-D 094-A-13 WA#581** | **Core 2 Box 9** | **____ - ____ ft.** |


| | | |
|---|---|---|
| d-097-D 094-A-13 WA#581 | Core 2 Box 10 | ____ - ____ ft. |


| d-097-D 094-A-13 WA#581 | Core 2 Box 11 | ____ - ____ ft. |
|---|---|---|

# COPOL Petrorep Inga
# b-32-F / 94-A-13
(Debolt)

**Core 1** **2062-2064.6 m** **Rec. 1.6 m** **2 boxes**

| Depth (m) | Description |
|---|---|
| 2062-2064.6 m | Thin to medium bedded, dark grey, dolomitic packstone with thin to medium tan dolomudstone interbeds. Intraclast dolomitic rudstone-floatstone at top (in situ brecciated mudstone). Scattered pinpoint and small vuggy porosity (~2 mm). |

**Core 2** **2064.60-2075.8 m** **Rec. 9.3 m** **7 boxes**

| Depth (m) | Description |
|---|---|
| 2064.60-2066.55 | Tan to light grey, dolomitic mudstone to skeletal wackestone. No visible porosity, core locally very fragmented. |
| 2066.55-2068.65 | Tan packstone, locally slightly bituminous, whispy microstylolites. No visible porosity. |
| 2068.65-2073.9 m | Light brown, nodular-bedded packstone, variably bituminous – black microstylolites. |


| 200/b-032-F 094-A-13 WA#08365 | Core 1 Box 1 | 2062 - ____ m |
|---|---|---|


| 200/b-032-F 094-A-13 WA#08365 | Core 1 Box 2 | ____ - ____ m |
| --- | --- | --- |


| | | |
|---|---|---|
| **200/b-032-F 094-A-13 WA#08365** | **Core 2 Box 1** | **____ - ____ m** |

| 200/b-032-F 094-A-13 WA#08365 | Core 2 Box 2 | ____ - ____ m |
|---|---|---|


| | | |
|---|---|---|
| **200/b-032-F 094-A-13 WA#08365** | **Core 2 Box 3** | **____ - ____ m** |

| 200/b-032-F 094-A-13 WA#08365 | Core 2 Box 4 | ____ - ____ m |
|---|---|---|


| | | |
|---|---|---|
| 200/b-032-F 094-A-13 WA#08365 | Core 2 Box 5 | ____ - ____ m |

| 200/b-032-F 094-A-13 WA#08365 | Core 2 Box 6 | ____ - ____ m |
|---|---|---|


| 200/b-032-F 094-A-13 WA#08365 | Core 2 Box 7 | ____ - ____ m |
|---|---|---|

# UCEL Gundy
# b-33-A / 94-B-16
(Debolt)

**Core 4** **2092.5-2104 m** **Rec. 11.2 m**

| Depth (m) | Description |
|---|---|
| 2092.5-2095.3 | Grey skeletal wackestone, bioclasts – crinoids. No visible porosity. |
| 2095.3-2103.7 | Grey packstone grading downwards to skeletal wackestone. Minor syringoporids and digitate coral fragments. No visible porosity. |


| 200/b-033-A 094-B-16/00 WA#7650 | Core 4 Box 1 | |
|---|---|---|


| 200/b-033-A 094-B-16/00 WA#7650 | Core 4 Box 2 | |
| --- | --- | --- |


| | | |
|---|---|---|
| **200/b-033-A 094-B-16/00 WA#7650** | **Core 4 Box 3** | |


| 200/b-033-A 094-B-16/00 WA#7650 | Core 4 Box 4 | |
|---|---|---|


| | | |
|---|---|---|
| **200/b-033-A 094-B-16/00 WA#7650** | **Core 4 Box 5** | |


| 200/b-033-A 094-B-16/00 WA#7650 | Core 4 Box 6 | |
|---|---|---|

| | | |
|---|---|---|
| **200/b-033-A 094-B-16/00 WA#7650** | **Core 4 Box 7** | |

| 200/b-033-A 094-B-16/00 WA#7650 | Core 4 Box 8 | |
| --- | --- | --- |

# Progress et al Blueberry
# d-50-K / 94-A-12
(Debolt)

**Core 13** **6699-6729 ft.** **Rec. 29.9 ft.** **7 boxes**

| Depth (ft.) | Description |
|---|---|
| 6699-6729 | Tan to dark grey dolomitic packstone with dolomitic wackestone/mudstone interbeds. Locally abundant pinpoint/biomoldic porosity. Best porosity is at base of core. |

**Core 14** **6730-6760 ft.** **Rec. 30 ft.**

| Depth (ft.) | Description |
|---|---|
| 6730-6738 | Dolopackstone (as above). Excellent porosity. |
| 6738-6760’ | Locally dolomitic interbedded packstone and wackestone, rare nodules. No visible porosity. |

**Core 15** **6761-6786 ft.** **Rec. 24.6 ft.**

| Depth (ft.) | Description |
|---|---|
| 6761-6785.6 | Medium grey, locally dolomitic, bedded packstone with rare mudstone interbeds. Rare rugose corals. No visible porosity. |

**Core 16** **6787-6816 ft.** **Rec. 29 ft.**

| Depth (ft.) | Description |
|---|---|
| 6787-6811 | Dark grey, bedded dolomudstone. Brecciated beds and white dolomite locally. No visible porosity. |
| 6811-6816 | Dolopackstone, broken core surface shows abundant pinpoint porosity and solid oil staining, strong odor. |

**Core 17** **6817-6838 ft.** **Rec. 19 ft.**

| Depth (ft.) | Description |
|---|---|
| **6817-6836** | Dolostone, heavy oil staining at top of core in dolopackstone. Out of time. |

**Core 18** **6838-6860 ft.** **Rec. 19 ft.**

| Depth (ft.) | Description |
|---|---|
| **6838-6857** | Limestone at top grading down to dolostone at base. Out of time. |


| | | |
|---|---|---|
| d-50-K 94-A-12 WA#242 | Core 13 Box 1 | |


| d-50-K 94-A-12   WA#242 | Core 13 Box 2 | |
|---|---|---|


| d-50-K 94-A-12 WA#242 | Core 13 Box 3 | |
|---|---|---|


| d-50-K 94-A-12 WA#242 | Core 13 Box 4 | |
|---|---|---|


| | | |
|---|---|---|
| **d-50-K 94-A-12 WA#242** | **Core 13 Box 5** | **____ - ____ ft.** |


| d-50-K 94-A-12 WA#242 | Core 13 Box 6 | |
|---|---|---|


| d-50-K 94-A-12 WA#242 | Core 13 Box 7 | |
|---|---|---|


| | | |
|---|---|---|
| **d-50-K 94-A-12   WA#242** | **Core 14 Box 1** | |


| d-50-K 94-A-12 WA#242 | Core 14 Box 2 | |
|---|---|---|


| d-50-K 94-A-12 WA#242 | Core 14 Box 3 | |
| --- | --- | --- |


| d-50-K 94-A-12 WA#242 | Core 14 Box 4 | |
|---|---|---|


| d-50-K 94-A-12 WA#242 | Core 14 Box 5 | |
|---|---|---|


| d-50-K 94-A-12 WA#242 | Core 14 Box 6 | |
|---|---|---|


| | | |
|---|---|---|
| **d-50-K 94-A-12   WA#242** | **Core 15 Box 1** | |


| | | |
|---|---|---|
| d-50-K 94-A-12 WA#242 | Core 15 Box 2 | |


| d-50-K 94-A-12 WA#242 | Core 15 Box 3 | |
| --- | --- | --- |

| | | |
|---|---|---|
| d-50-K 94-A-12 WA#242 | Core 15 Box 4 | |


| | | |
|---|---|---|
| **d-50-K 94-A-12   WA#242** | **Core 15 Box 5** | |


| | | |
|---|---|---|
| d-50-K 94-A-12 WA#242 | Core 16 Box 1 | |


| d-50-K 94-A-12 WA#242 | Core 16 Box 2 | |
|---|---|---|


| d-50-K 94-A-12 WA#242 | Core 16 Box 3 | |
|---|---|---|


| d-50-K 94-A-12 WA#242 | Core 16 Box 4 | |
|---|---|---|


| | | |
|---|---|---|
| d-50-K 94-A-12 WA#242 | Core 16 Box 5 | |


| | | |
|---|---|---|
| d-50-K 94-A-12 WA#242 | Core 16 Box 6 | |


| | | |
|---|---|---|
| **d-50-K 94-A-12 WA#242** | **Core 17 Box 1** | |


| d-50-K 94-A-12 WA#242 | Core 17 Box 2 | |
|---|---|---|


| d-50-K 94-A-12 WA#242 | Core 17 Box 3 | |
|---|---|---|


| d-50-K 94-A-12 WA#242 | Core 17 Box 4 | |
|---|---|---|


| | | |
|---|---|---|
| **d-50-K 94-A-12 WA#242** | **Core 18 Box 1** | |


| | | |
|---|---|---|
| d-50-K 94-A-12 WA#242 | Core 18 Box 2 | |


| d-50-K 94-A-12 WA#242 | Core 18 Box 3 | |
|---|---|---|


| d-50-K 94-A-12 WA#242 | Core 18 Box 4 | |
|---|---|---|


| | | |
|---|---|---|
| **d-50-K 94-A-12 WA#242** | **Core 18 Box 5** | |

# Crew et al Townsend
# d-57-H / 94-B-9
(Debolt)

**Core 2** **2225-2243 m** **Rec. 15.2 m** **9 boxes**

Boxes 1-5 dolomite
Boxes 6-9 limestone

**Core 3** **2243-2257** **Rec. 13.9 m** **10 boxes**

| Depth (m) | Description |
|---|---|
| **2243-2256.9** | Mostly limestone, locally dolomitic. |


| d-57-H 94-B-09 WA#4922 | Core 2 Box 1 | |
|---|---|---|

| d-57-H 94-B-09 WA#4922 | Core 2 Box 2 | |
|---|---|---|

| d-57-H 94-B-09 WA#4922 | Core 2 Box 3 | |
| --- | --- | --- |

| d-57-H 94-B-09 WA#4922 | Core 2 Box 4 | |
|---|---|---|


| d-57-H 94-B-09 WA#4922 | Core 2 Box 5 | |
|---|---|---|

| d-57-H 94-B-09 WA#4922 | Core 2 Box 6 | |
|---|---|---|

| d-57-H 94-B-09 WA#4922 | Core 2 Box 7 | |
| --- | --- | --- |

| d-57-H 94-B-09 WA#4922 | Core 2 Box 8 | |
|---|---|---|


| | | |
|---|---|---|
| d-57-H 94-B-09 WA#4922 | Core 2 Box 9 | |

| | | |
|---|---|---|
| d-57-H 94-B-09 WA#4922 | Core 2 Box 10 | |


| d-57-H 94-B-09 WA#4922 | Core 3 Box 1 | |
|---|---|---|


| d-57-H 94-B-09 WA#4922 | Core 3 Box 2 | |
| --- | --- | --- |


| d-57-H 94-B-09 WA#4922 | Core 3 Box 3 | |
|---|---|---|


| d-57-H 94-B-09   WA#4922 | Core 3 Box 4 | |
|---|---|---|


| | | |
|---|---|---|
| **d-57-H 94-B-09   WA#4922** | **Core 3 Box 5** | |


| d-57-H 94-B-09 WA#4922 | Core 3 Box 6 | |
| --- | --- | --- |

| d-57-H 94-B-09 WA#4922 | Core 3 Box 7 | |
| --- | --- | --- |


| d-57-H 94-B-09 WA#4922 | Core 3 Box 8 | |
|---|---|---|


| d-57-H 94-B-09 WA#4922 | Core 3 Box 9 | |
|---|---|---|


| | | |
|---|---|---|
| **d-57-H 94-B-09 WA#4922** | **Core 3 Box 10** | |

# APPENDICES C-1 TO C5

Appendix C-1. Hydraulic Head Pressure Data: Plains Study Area: a) Plains Study Area; b) Foothills Study Area.

Appendix C-2. Water Chemistry: a) Plains Study Area; b) Foothills Study Area.

Appendix C-3. H2S Values: a) Plains Study Area; b) Foothills Study Area.

Appendix C-4. Total Available Head Pressure Data: a) Plains Study Area; b) Foothills Study Area.

Appendix C-5. Deliverability Estimates: a) Plains Study Area; b) Foothills Study Area.

**Available Digitally Only**