Hydrodynamic study of Middle Devonian strata, southeastern Great Slave Plain, Northwest Territories

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Janicki, E.P., 2006: Hydrodynamic study of Middle Devonian strata, southeastern Great Slave Plain, Northwest Territories; *in* Potential for Carbonate-hosted Lead-zinc Mississippi Valley-type Mineralization in Northern Alberta and Southern Northwest Territories: Geoscience Contributions, Targeted Geoscience Initiative, (ed.) P.K. Hannigan; Geological Survey of Canada, Bulletin 591, p. 165–177.

Abstract: A study was undertaken in the southeastern portion of the Great Slave Plain of the Northwest Territories to discover current hydrodynamic conditions in Middle Devonian formations. A pressure elevation chart, constructed from drill-stem test data, demonstrates one aquifer system because almost all points line up along an average water gradient of 0.47 psi/foot.

A potentiometric surface map indicates that flow is primarily to the northeast in the direction of Precambrian outcrop. A small area of apparently low hydrodynamic potential exists near Cameron Hills. Widely spaced potential contours over most of the area indicate near-uniform flow conditions. Excellent water recovery on drill-stem tests and core evidence indicate good permeability for the overall Middle Devonian section.

Formation water salinity generally freshens to the northeast in the direction of Great Slave Lake and middle Devonian outcrops. Salinity varies widely near Cameron Hills.

Résumé : Nous avons mené une étude dans la partie sud-est de la plaine du Grand lac des Esclaves, dans les Territoires du Nord-Ouest, afin de connaître les conditions hydrodynamiques actuelles dans les formations du Dévonien moyen. Une carte de l'augmentation de la pression, établie à partir de données tirés d'essais aux tiges, révèle l'existence d'une seule formation aquifère, puisque presque tous les points s'alignent le long d'un gradient hydraulique moyen de 0,47 lb/po^2/pied.

Une carte de la surface piézométrique indique que l'écoulement s'effectue principalement vers le nord-est en direction d'affleurements précambriens. Une petite zone, apparemment de faible potentiel hydrodynamique, est située près des collines Cameron. Les courbes du potentiel, qui sont très espacées dans la plus grande partie de la région, indiquent des conditions d'écoulement presque uniformes. Une excellente récupération de l'eau lors des essais aux tiges et des données tirées de carottes indiquent une bonne perméabilité pour les strates datant dans l'ensemble du Dévonien moyen.

En général, la salinité de l'eau de formation diminue vers le nord-est, en direction du Grand lac des Esclaves et des affleurements rocheux du Dévonien moyen. La salinité varie considérablement près des collines Cameron.

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INTRODUCTION

This study is part of a project undertaken by the Geological Survey of Canada, the C.S. Lord Northern Geoscience Centre and the Alberta Geological Survey to investigate the potential for carbonate-hosted (Mississippi Valley Type – MVT) base metal deposits in the southern Northwest Territories (NWT) and northern Alberta. The Pine Point deposit near Hay River, NWT, which until recently produced lead and zinc from Middle Devonian Presqu'ile dolomite (Rhodes et al., 1984), is a local example of carbonate-hosted mineralization. Much farther west, in the mountain and foothills, mineralized MVT occurrences are hosted in Manetoe dolomite (Morrow et al., 1990) of Middle Devonian age.

Inherent in theories of MVT formation is the fundamental role that fluids play in carrying the dissolved mineral ions that cause secondary dolomitization and eventual mineralization. This study was done to discover current hydrodynamic conditions – possibly comparable to those that existed at the time of MVT mineralization – in the economically important Middle Devonian section. Proprietary hydrodynamic studies have been done in this area for petroleum exploration companies, but their reports are not publicly available.

The study area is shown in Figure 1, in relation to exploration regions of the NWT. Figure 2 illustrates the topography (elevation at wellsite), underlying structures, and stratigraphic features that likely influence the regional hydrodynamics. Imperial measurements are used in most of the figures because the majority of the wells were drilled before the introduction of the metric system in Canada. The reader will find it more convenient when checking against original information.

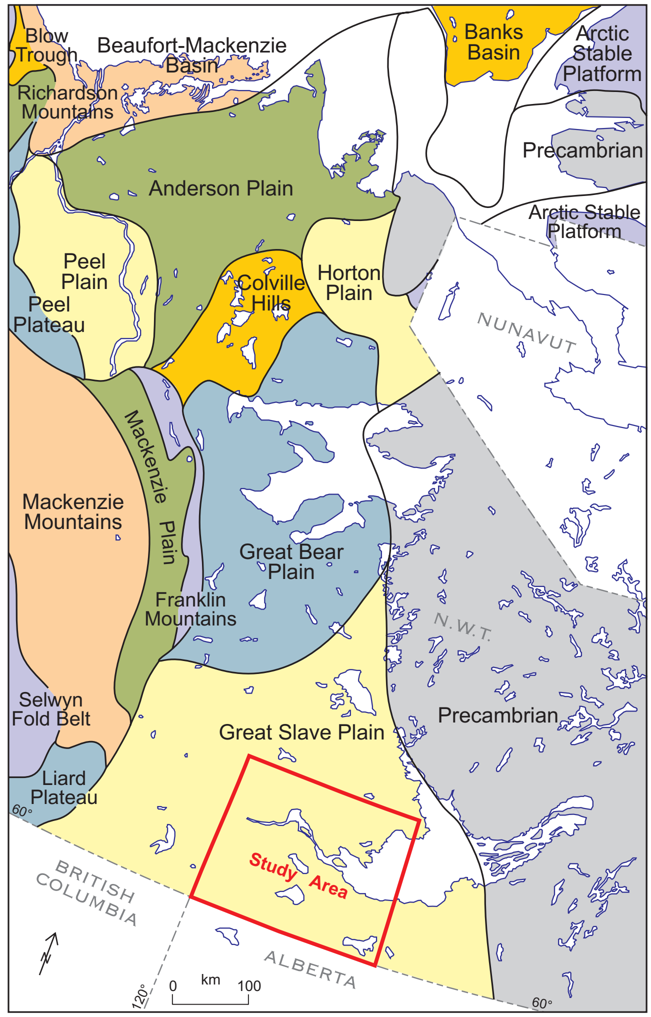

Figure 1. Hydrocarbon exploration regions of the Northwest Territories and hydrodynamic study area (exploration regions courtesy of P. H. Davenport, GSC-Calgary, 2001).

STUDY PARAMETERS

This study focuses on the aquifer(s) that exists within the Middle Devonian (Eifelian–Givetian age) formations. It makes use of drill-stem test (DST) data gathered from several hundred oil and gas wells in the study area during the past fifty years of exploration activity.

In several respects, the Middle Devonian formations of this area are well suited to a hydrodynamic study. A large proportion of the wells were drill-stem tested for their hydrocarbon potential in the Keg River (sometimes called Pine Point), Slave Point and other Givetian–Eifelian age formations (Fig. 3). Much good quality DST data are available. Shut-in pressures stabilized quickly, so Horner plots are not necessary to obtain the reservoir pressure. Few tests recovered either gas or oil, so those few could be omitted without seriously compromising data density; only tests that recovered abundant amounts of water were selected. Most importantly, oil or gas production within the study area is very recent (commencing March 2002 in Cameron Hills), so pressures can generally be assumed to be virgin.

Pressures may have been reduced slightly in the southeasternmost portion of the map area by de-watering of the Pine Point mine pits. However, many of the wells closest to Pine Point were drilled (and pressures recorded) before the Pine Point mine was established in 1964. A few wells in the vicinity (more than 50 km distant) were drilled as recently as 1970, after a few years of Pine Point de-watering.

METHODOLOGY

Dahlberg (1995) presented a good overview of the theory and application of petroleum hydrodynamics for those readers not familiar with this topic.

An area was selected for study that would be large enough to illustrate regional patterns in formational water flow. East

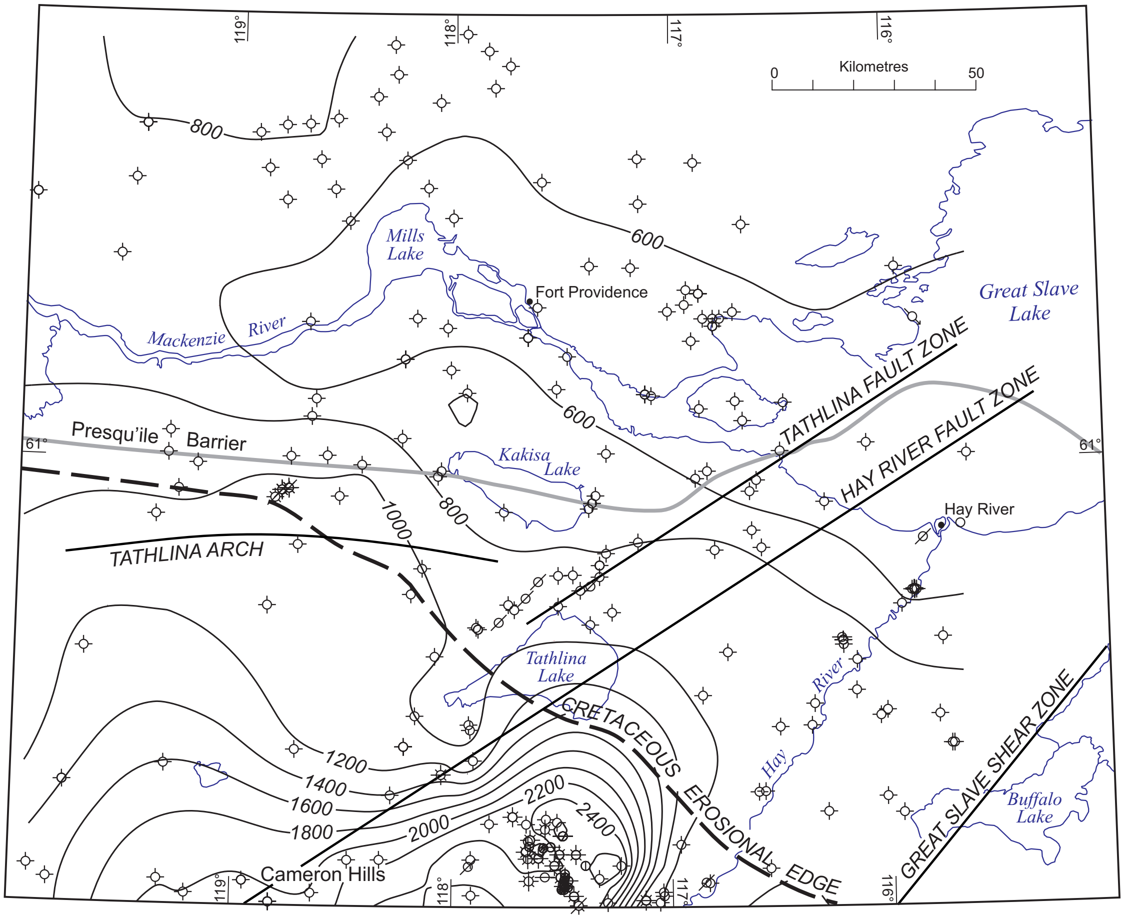

Figure 2. Topography of study area (feet with respect to mean sea level) with major tectonic features. Cretaceous erosional edge *after* Douglas and Norris (1973), Presqu'ile Barrier edge *after* Morrell (1995), Hay River Fault Zone *after* Williams (1981), and Tathlina Arch and Great Slave Shear Zone *after* Burwash, et al. (1994).

of the eastern boundary of 115° longitude very few wells have been drilled and none of those ran DSTs. North of 62°, Middle Devonian rock is mostly shale.

Publicly available DST data were obtained from the National Energy Board in Calgary. Pressure and water salinity data were, for the most part, extracted directly from original DST reports. Pressures and salinities for some locations, generally in the northern part of the map area, were taken from a proprietary database. These locations are noted in the remarks section of the spreadsheet in Appendix A. Original well file reports were used to verify the accuracy of a few of these proprietary points.

DSTs from Township 126 (Alberta Energy and Utilities Board) of neighbouring Alberta were also used to confirm that general trends in potentiometric surface continue across the boundary.

Constituent charts ("Stiff diagrams") in the formal analytical water analyses were commonly available to provide qualitative confirmation that the water samples originated from the formation. High water recoveries on DST also increased confidence that formation water was sampled rather than drilling mud or some other fluid.

Appendix A is a spreadsheet compilation of data used to calculate the potentiometric surface values for locations with useable DST results. Pressure charts from DST reports were qualitatively consulted to confirm whether or not shut-in pressures had stabilized. In most tests the charts clearly showed stabilization of shut-in pressures. Those that had not stabilized were not used in this study; Horner plots (graphs that extrapolate pressure build-ups to reservoir condition) were therefore not required. Some DST reports included extrapolated Horner pressures done by the DST service company. These extrapolations were all close in value to the reported shut-in pressures, thereby confirming that pressures had nearly stabilized.

In the 'Remarks' column of Appendix A, a usability ranking for DSTs is provided. Under this commonly used system of ranking, "code a" refers to the best quality of DST (stabilization and recovery of abundant formation water). Codes b

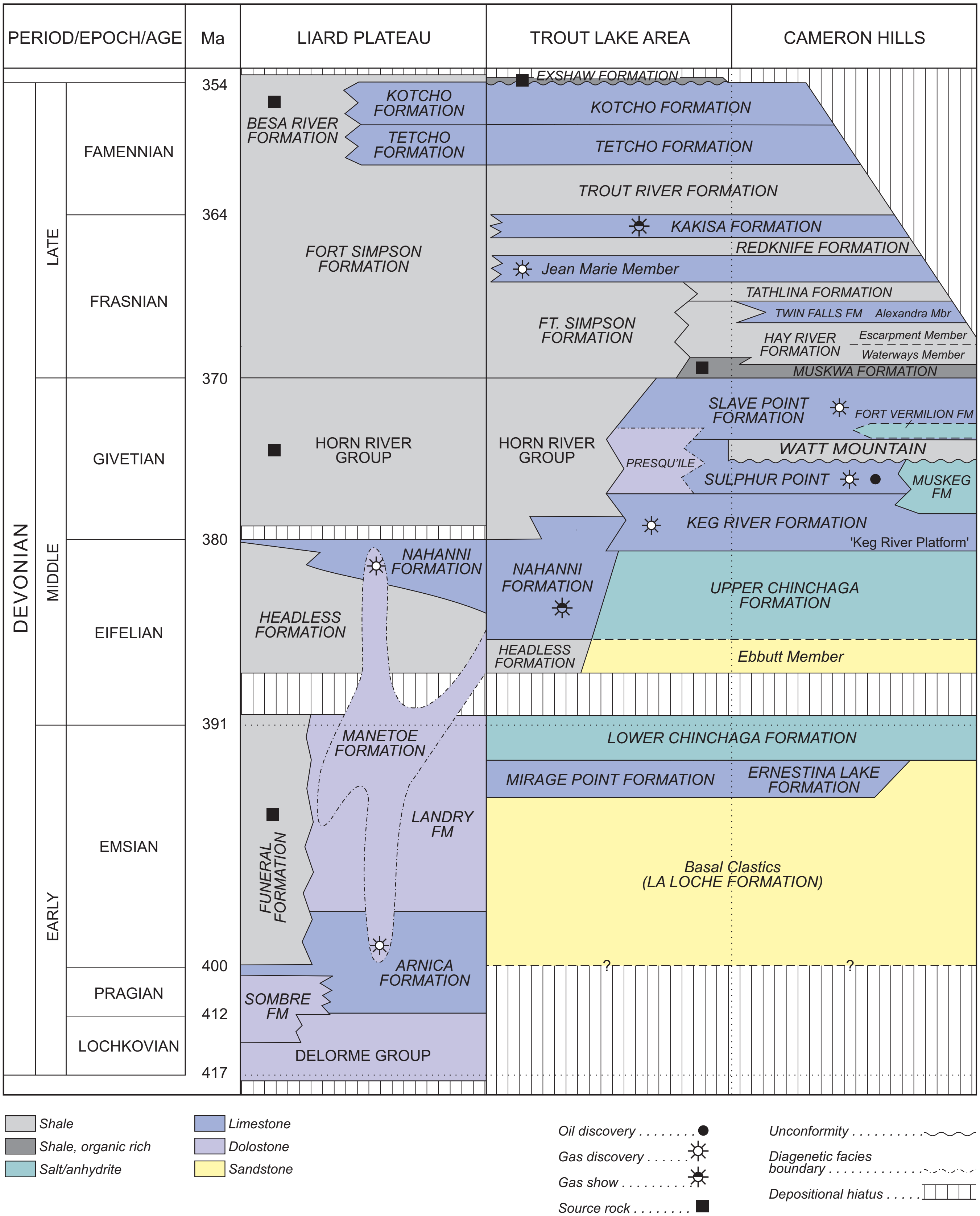

Figure 3. Table of Devonian formations in southern Northwest Territories.

and c suggest DSTs that are useable, but with constraints such as the need for Horner extrapolations, or the uncertainty of whether or not the produced water originated from the formation. Code "d" represents poor quality, unusable data. Only data points with DSTs coded "a" or "b" were used to calculate the potentiometric surface.

The potentiometric surface value (the height to which the formation water would rise if allowed to come to atmospheric pressure) for each location was calculated by the following formula:

Potentiometric Surface (feet or metres above sea level) = (Static Reservoir Pressure (psi or kpa)/ Gradient (psi/ft. or kpa/m)) + Pressure Gauge Elevation (feet or metres above sea level)

The static reservoir pressure inserted into the above equation is either the stabilized shut-in pressure or extrapolated pressure (if provided). The higher of initial or final shut-in pressure was used under the assumption that this would be closest to virgin pressure. As previously stated, final, initial and extrapolated shut-in values were usually very similar, so whichever value was used would not make a significant difference to the potentiometric surface map.

The water gradient value of 0.47 psi/ft., which was used to calculate potentiometric surface, was taken from the "best-fit" slope of the pressure-elevation graph (Fig. 4). Measured salinity water gradient values were not used to calculate the mapped potentiometric surface, but calculations using those values are provided in Appendix A for comparison. Appendix B provides a tabular comparison of weights, gravities, salinities and pressure gradients of fluids so that the reader can relate one unit to another and make conversions if necessary.

Water density in g/cm^3, or parts per million (ppm) salinity, were taken directly from the formal water analyses provided for most locations. Values were plotted and contoured in Figure 5 to show distribution of salinity.

INTERPRETATION

Reservoir continuity

Figure 4 demonstrates that the formations of Givetian–Eifelian age comprise essentially one reservoir or aquifer system. Most points fall along or close to the pressure gradient of 0.47 psi/ft., which is within the range of a normally pressured system (Dahlberg, 1995) of moderately saline formation water where the rock framework supports itself and pressure is largely due to the weight of the water.

Only one well with a code "a" ranking (B52-6100-11530) on the southern shore of Great Slave Lake indicates a significantly lower pressure. It is one of the shallowest wells in this survey. Of all the wells used in this study, it is the one most likely to have been affected by the Pine Point de-watering. It also has the lowest salinity value (9620 ppm), indicating the likelihood of mixing with meteoric water. Other shallow wells, such as B07-6040-11545 and H28-6130-11930, also plot very slightly to the left of the gradient. Location D06-6100-11830 plots lower, but it might not be valid because no gauge depth was available (Appendix A).

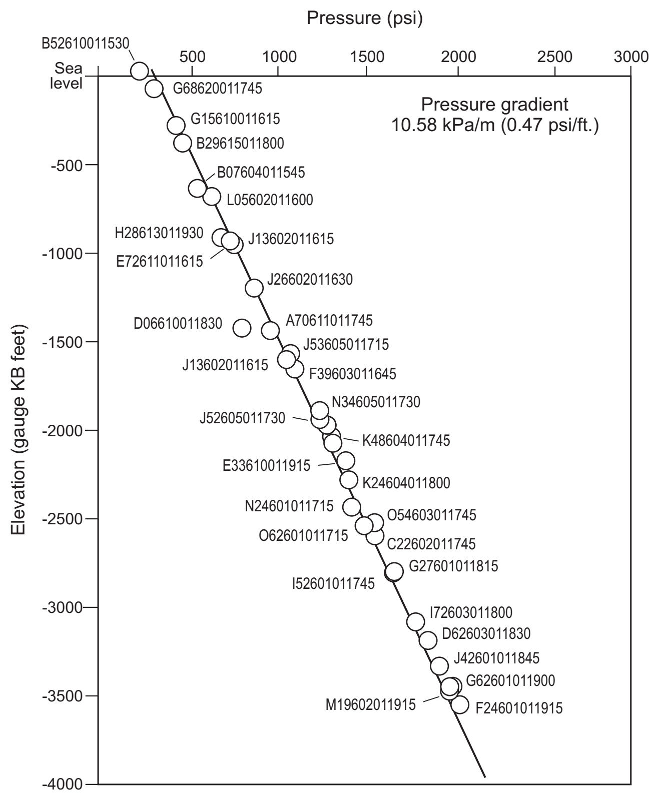

Figure 4. Pressure-elevation chart for Devonian formations of Givetian–Eifelian age. Numbers within graph are Northwest Territories well designation numbers.

Cross-sections constructed from wireline logs, core, and sample evidence strongly suggests that the low-pressured locations are part of the same aquifer. Their slightly low pressures are therefore likely due to local discharge or leakage of the aquifer.

High permeabilities characterize the Middle Devonian formations of the study area, as demonstrated by the large volumes of water produced on the DSTs and the rapid stabilization of shut-in area pressures. The networks of vuggy and fracture porosity observed in cores by this author are an indication that good permeability is extensive and commonly cross-formational.

Potentiometric surface

Figure 6 represents the potentiometric surface (using a common water gradient of 0.47 psi/ft.) for the Eifelian–Givetian formations (other than Slave Point). Consistent with the topography and the eastward shallowing

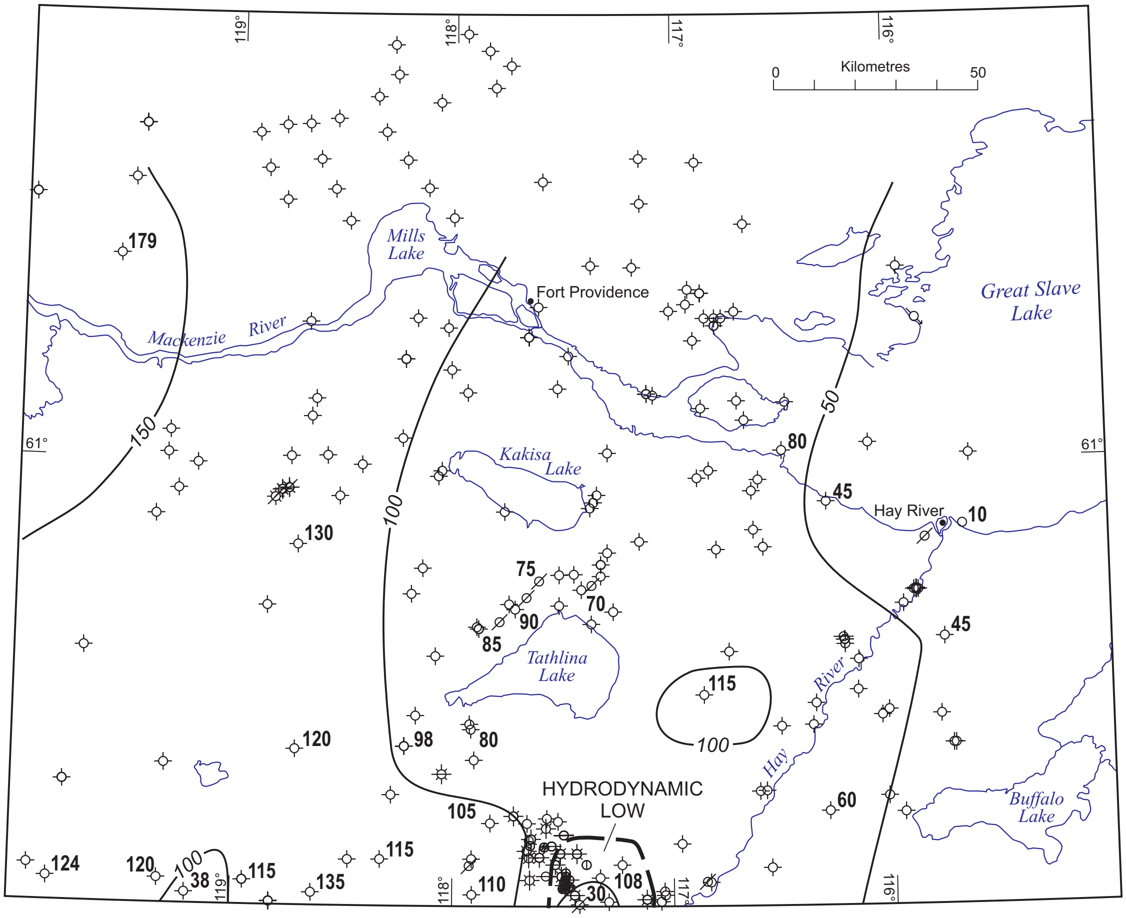

Figure 5. Formation water salinities of Devonian formations of Givetian–Eifelian age.

of the Phanerozoic section, flow is primarily from the southwest to northeast: from areas of deep burial (high pressure) to near surface (low pressure). Contours are for the most part widely spaced, indicating slow hydrodynamic flow conditions and an even distribution of permeability.

Because water flows from high potential (usually topographically higher elevations) to low (usually topographically lower elevations), discharge likely takes place along the subcrop edge and middle Devonian outcrop near the eastern edge of the map area (Bachu, 1997; Douglas and Norris, 1973). Salt springs are known to exist south of Great Slave Lake (Meijer Drees, 1993) where lakes and rivers drain into underground cavities in the carbonate sediments and formation brine is introduced to the surface. Great Slave Lake (representing high fresh-water level) is present at the contact between Precambrian and Devonian rock at the eastern edge. Some mixing with meteoric water likely takes place where outcrop or subcrop is in contact with the surface water table.

Contours tighten somewhat, in combination with an abrupt drop to lower potential, in the south-central portion of the study area near the Cameron Hills. This finding is based upon only a few data points, but they all have high-quality DSTs.

In the western part of the study area the potentiometric elevation is everywhere lower than the ground surface, so flow to surface of formation water (artesian flow) would not occur.

Salinity

A general eastward freshening (lower salinity) is apparent on Figure 5 in the direction of thin sedimentary cover and contact with meteoric water. Salinity increases steadily to the west as the middle Devonian strata deepen. Similar to the potentiometric surface, the contours for salinity are widely spaced, except within the Cameron Hills area where variations in salinity occur.

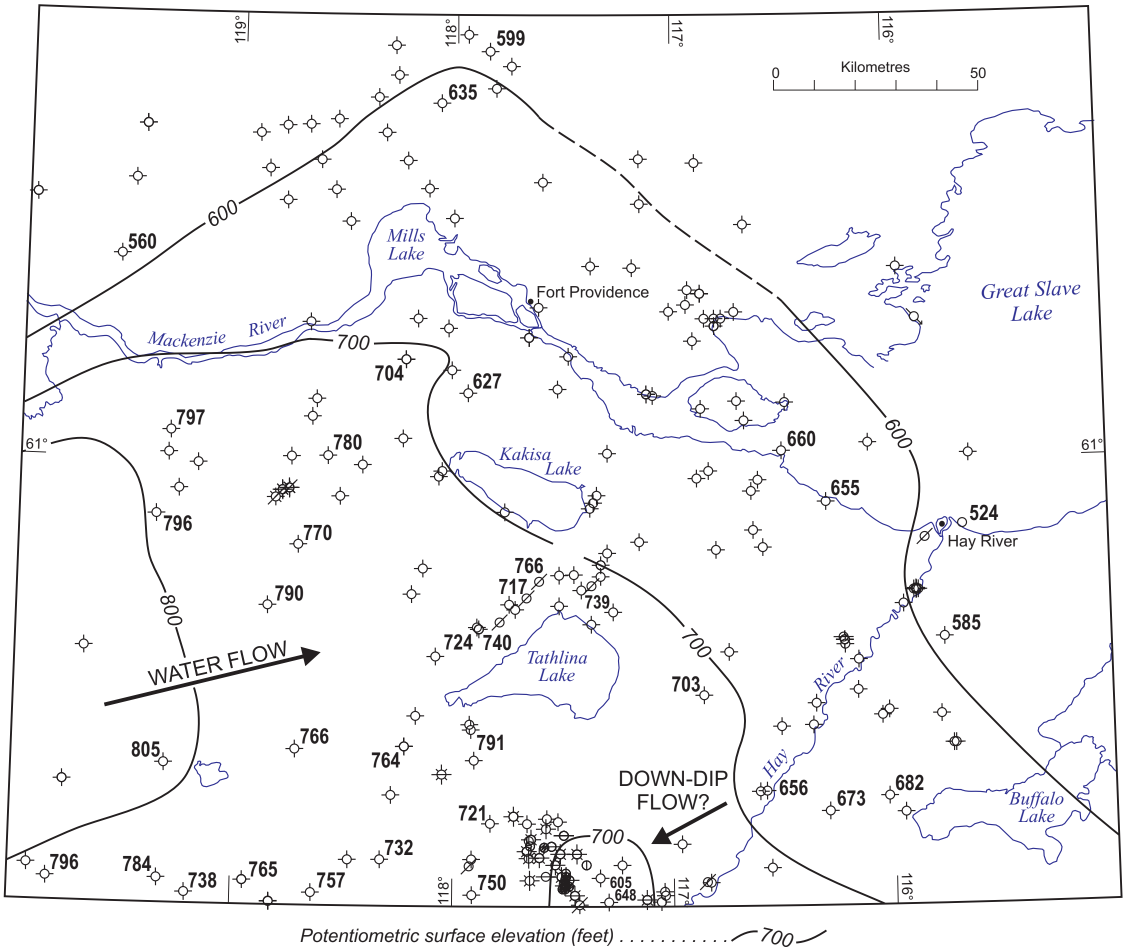

Figure 6. Potentiometric surface elevations (feet with respect to mean sea level) of Devonian formations of Givetian–Eifelian age.

CONCLUSIONS

- Middle Devonian formations in the region south and west of Great Slave Lake appear to be part of one aquifer/reservoir system. Pressure and elevation points for most wells fall on a gradient of 0.47 psi/ft.
- Good permeability in the Middle Devonian section is indicated by rapid stabilization of shut-in pressures and abundant salt water recovered on DSTs.
- Formation water flow direction is primarily from southwest to northeast. Local variations to the regional trend occur in the Cameron Hills area, where anomalously low potential is found.
- Formation water salinity freshens to the east near Great Slave Lake; it is variable in the Cameron Hills area.

ACKNOWLEDGMENTS

Thanks are due to Adrianne Jones, Bernie MacLean and Allan Turner of the C.S. Lord Northern Geoscience Centre for their critical comments and suggestions to improve the text. Jennifer Adams of the Alberta Geological Survey contributed a very helpful technical review based upon her experience in this field of study. Peter Hannigan and Steve Grasby of the Geological Survey of Canada provided a thorough technical review and many suggestions to strengthen the text and figures. I appreciate the time provided by Hugh W. Reid of H.W. Reid & Associates Ltd. for valuable discussions on the methodology and results.

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Appendix A

Compilation of data used to calculate the potentiometric surface values for locations with usable DST results

Keg River (Pine Point), Sulphur Point,Presqu'ile (Eifelian–Givetian formations)										
Location	DST #	DST Interval feet	Formation	Recovery	ISIP-FSIP* psi	KB feet elevation	Gauge feet depth	Gauge KB feet subsea	Potentiometric surface feet** (metres) Potentiometric surface feet***(metres)	Remarks
H34-6010-11645	3	2990–3050	Keg River	105' m	1315-1298	974	3010	2036	1315/.439-2036=**959' (298.8)** 1315/.47-2036=**762' (237.4)**	code b-c, 1.015g/cm^3, not mapped
N24-6010-11715	2	4910–5040	Keg River	2400' sul sw	1428-1428	2592	5025	2433	1428/.465-2433=**638' (198.8)** 1428/.47-2433=**605' (188.5)**	108 880 mg/l, code a, high perm
J62-6010-11715	1	4967–5013	Keg River	3033 gc sul w	1498-1498	2475	?	2539?	1498/.443-2539=**842' (262.3)** 1498/.47-2539=**648' (201.9)**	30 400 ppm, commercial values, no DST report, code c
C50-6010-11730	1,2		Keg River/ Sul Pt.			2271				gas recoveries
I52-6010-11745	1	5180–5290	Keg River	3252' w	1653-1668	2397.5	5196	2798	1668/.465-2798=**789' (245.8)** 1668/.47-2798=**750' (233.6)**	109 600 ppm, code a
G27-6010-11815	3	4975–5100	Muskeg	2560' gsy sw	1662-1663	2186	4992	2806	1663/.46-2806=**809' (252.0)** 1663/.47-2806=**732' (228.0)**	87 108 mg/l, code a
G27-6010-11815	1	5102–5234	Muskeg	240' m, 4440' sw	1734-1732	2186	5115	2929	1734/.46-2929=**840' (261.7)** 1734/.47-2929=**760' (236.8)**	1.076 g/cm^3,code a 115 000 ppm
J42-6010-11830	5	5321–5357	Keg River	3925' sw	1917-1922	2031	5363	3332	1922/.467-3332=**783' (243.9)** 1922/.47-3332=**757' (235.8)**	135 000 mg/l, no charts, code b
H64-6010-11845	3	5407–5485	Keg River	443' m, 3000' sw	1980-1980	2043	5491	3448	1980/.465-3448=**810' (252.3)** 1980/.47-3448=**765' (238.3)**	115 000 mg/l, code b (plugging 1st flow)
G62-6010-11900	1	5475–5531	Keg River	1646' sul sw	1979-1967	2010	5483	3473	1979/.465-3473=**783' (243.9)** 1979/.47-3473=**738' (229.9)**	Horner extrapolation used; 37 500 g/m^3; code b
F24-6010-11915	2	5545–5570	Pine Point	2565' sul sw	2037-2034	2009	5559	3550	2037/.467-3550=**812' (253.0)** 2037/.47-3550=**784' (244.2)**	code a, 1.086 g/cm^3 120 000 ppm
B24-6010-11945	1	5190–5254	Sulphur Point	3518' sw	2087-2086	1571	5215	3644	2087/.467-3644=**824' (256.7)** 2087/.47-3644=**796' (248.0)**	123 662 mg/l, 1.085 specific gravity, code b
G63-6020-11545	1	1690–2471	Keg River	520' w	694-686	902	1712	810		needs Horner extrapolation

- *extrapolated values given if available (ISIP-FSIP- initial shut-in pressure, final shut-in pressure; psi - pounds per square inch)
- **shut-in pressure in DST interval (psi)/water gradient (psi/foot) minus pressure gauge depth with respect to Kelly Bushing (KB) (feet - subsea elevation) *(using water gradient for well)*
- ***shut-in pressure in DST interval (psi)/water gradient (psi/foot) minus pressure gauge depth with respect to Kelly Bushing (KB) (feet - subsea elevation) *(using average water gradient of 0.47 psi/ft.); this was used for potentiometric surface, in Figure 3*
- asl - above sea level
- ***commercial*** refers to values supplied by a vendor and not checked against the original source
- Codes a-b useable, codes c-d unuseable
- Salinity in ppm represents total solids calculated
- DST - Drill Stem Test, m - mud, s - salt, w - water, gsy - gassy, sul - sulphurous, gc - gas cut, blk - black, tr - trace, mdy - muddy, g/cm^3- grams per cubic centimetre, perm - permeability, ppm - parts per million, mg/l - milligrams/litre, rec - recorded, sl - slightly

Appendix A (cont.)

Keg River (Pine Point), Sulphur Point,Presqu'ile (Eifelian–Givetian formations)										
Location	**DST #**	**DST Interval feet**	**Formation**	**Recovery**	**ISIP-FSIP* psi**	**KB feet elevation**	**Gauge feet depth**	**Gauge KB feet subsea**	**Potentiometric surface feet** (metres)** **Potentiometric surface feet***(metres)**	**Remarks**
L05-6020-11600	2	1615–1715	Muskeg	1345' sw	640-641	945	1625	680	640/.467-680=**690' (215.0)** 640/.47-680=**682' (212.5)**	code a, 1.0295 specific gravity
J13-6020-11615	3	2150–2270	Muskeg/Keg River	1450' sw	877-879	978	2175	1197	879/.45-1197=**756' (235.5)**	1.0421 g/cm^3, code a
J13-6020-11615	4	1905–2145	Muskeg	700' sw,720' m	760-766	978	1930	952	766/.447-952=**761' (237.1)** 879/.47-952=**673' (210.7)**	1.0356 g/cm^3, code a 60 000 ppm
J26-6020-11630	2	2536–2654	Keg River	1594' sw	1061	964	2565	1601	1061/.45-1601=**756' (235.5)** 1061/.47-1601=**656' (204.4)**	code a-b, FSIP may not be stable
C22-6020-11745	2	4835–4995	Keg River	1230' sul gcsw	1557-1559	2263	4859	2596	1559/.465-2596=**756' (235.5)** 1559/.47-2596=**721' (224.6)**	1.073 g/cm^3,code a 105 000 ppm
M19-6020-11915	4	5046–5081	Presqu'ile	3700' gsy sul sw	1995-1998	1632	5078	3446	1998/.467-3446=**832' (259.2)** 1998/.47-3446=**805' (250.8)**	code a, no fluid analysis
F39-6030-11645	1	2608–2648	Muskeg	2280' sul w	1108-1108	986	2640	1654	1108/.467-1654=**719' (224.0)** 1108/.47-1654=**703' (219.0)**	1.08 g/cm^3,code a 115 000 ppm
O54-6030-11745	1	3500–3635	Keg River	2490' sw	1557-1557	982	3504	2522	1557/.447-2522=**961' (299.4)** 1557/.47-2522=**791' (246.4)**	46 400 ppm, code a-b, graphs too vague
I72-6030-11800	2	3910–3990	Keg River	3305' sw	1666-1674*	1125	3923	2798	1674/.463-2798=**818' (254.8)** 1674/.47-2798=**764' (238.0)**	98 200 ppm, code a
D62-6030-11830	1	4427–4447	Keg River	180' wc,180' m, 3600' sul gcsw	1855-1858	1257	4444	3187	1858/.435-3187=**1084' (337.7)** 1858/.47-3187=**766' (238.6)**	1.008 g/cm^3 (anomalously low), code b, also reported as 1.086 mg NaCl (120 000 ppm)
B07-6040-11545	4	1290–1377	Keg River	980' sw	573-559	739	1373	634	573/.45-634=**639' (199.1)** 573/.47-634=**585' (182.2)**	1.037 g/cm^3, code a, faint charts, 45 000 ppm
K48-6040-11745	1	3030–3311	Presqu'ile	2630' blk sul sw	1322-1322	963	3036	2073	1322/.459-2073=**807' (251.4)** 1322/.47-2073=**740' (230.5)**	1.061g/cm^3, code a, faint charts 85 000 ppm
K24-6040-11800	5	3230–3320	Presqu'ile	3060' sw	1411-1412	1035	3315	2280	1412/.459-2280=**796' (248.0)** 1412/.47-2280=**724' (225.5)**	1.072 g/cm^3, code b
J53-6050-11715	2	2501–2518	Presqu'ile	2300' sw	1084	920	2487	1567	1084/.452-1567=**831' (258.9)** 1084/.47-1567=**739' (230.2)**	1.046 g/cm^3, code a 70 000 ppm
N34-6050-11730	1	2755–2780	Presqu'ile	2500' sw, tr oil	1248-1244	885	2774	1889	1248/.455-1889=**853' (265.7)** 1248/.47-1889=**766' (238.6)**	1.054 g/cm^3, code a, commercial rec depth 75 000 ppm
J52-6050-11730	1	2830–2860	Pine Point	1600' sul sw	1249-1246	911	2850	1939	1249/.459-1939=**782' (243.6)**	1.061 g/cm^3, code a
J52-6050-11730	2	2960–2975	Pine Point	2650' sul sw	1305-1303	911	2971	2060	1305/.461-2060=**771' (240.2)** 1305/.47-2060=**717' (223.4)**	1.066 g/cm^3, code a 90 000 ppm

Appendix A (cont.)

Keg River (Pine Point), Sulphur Point,Presqu'ile (Eifelian–Givetian formations)										
Location	DST #	DST Interval feet	Formation	Recovery	ISIP-FSIP* psi	KB feet elevation	Gauge feet depth	Gauge KB feet subsea	Potentiometric surface feet** (metres) / Potentiometric surface feet***(metres)	Remarks
L69-6050-11830 L69-6050-11830	4 5	3124–3164 3091–3117	Pine Point Pine Point	1600' sw 1360' sw	1335-1289 1273-1237	1164 1164	3135 3108	1971 1944	1289/.471-1971=**766' (238.6)** 1273/.469-1944=**770' (239.9)** 1289/.47-1971=**772' (240.5)**	1.099 g/cm^3, code a, charts faint 1.084 g/cm^3, code a, charts faint 130 000 ppm
G31-6050-11845	5	3608–3710	Chinchaga	1370' sw	1530	1150	3615	2465	1530/.47-2465=**790' (246.1)** 1530/.47-2465=**790' (246.1)**	no fluid analysis, code a
B52-6100-11530	1	500–600	Presqu'ile	450' sul sw	233-233	540	512	28 asl	233/.435+28=**564' (175.7)** 233/.47+28=**524' (163.2)**	9620 ppm, code a
G15-6100-11615	1	819–879	Presqu'ile	870' sw	438-439	550	829	279	439/.447-279=**703' (219.0)** 439/.47-279=**655' (204.0)**	1.035 g/cm^3,code a 45 000 ppm
D06-6100-11830	1	2487–2509	Pine Point	720' sw	810	1086	2509?	1423	810/.47-1423=300' (93.5)	no gauge depth, commercial values, low p, code c
O25-6100-11845	5	2688–2708	Pine Point	1450' gcsw	1050	1083	2708?	1625?	1050/.47-1625=**609' (189.7)** 1050/.47-1625=**609' (189.7)**	no gauge depth, commercial values, code b
E33-6100-11915	3	3210–3240	Pine Point	2580' sul mdy w	1395-1387	1055	3227	2172	1395/.47-2172=**796' (248.0)** 1395/.47-2172=**796' (248.0)**	commercial values, code b
E72-6110-11615	2	1468–1528	Lonely Bay	1070' m, 290' w	744-748	527	1458	931	748/.458-931=**702' (218.7)** 748/.47-931=**660' (205.6)**	1.058 g/cm^3, gauge above interval, code a 80 000 ppm
A70-6110-11745	1	2230–2268	Chinchaga	615 sul sw	970-965	819	2256	1437	970/.47-1437=**627' (195.3)** 970/.47-1437=**627' (195.3)**	commercial values, code b
K21-6110-11830	2	2622–2644	Lonely Bay	900' sl gcsw	1169-1150	933	2640	1707	1169/.47-1707=**780' (243.0)** 1169/.47-1707=**780' (243.0)**	commercial values, code b
J74-6120-11800	1	2075–2152	Chinchaga	2122' sul sw	1048-1053	616	2152	1536	1053/.47-1536=**704' (219.3)** 1053/.47-1536=**704' (219.3)**	commercial values, code b
H28-6130-11930	2	1610–1720	Lonely Bay	930' mdy sw	692-692	706	1618	912	692/.487-912=**509' (158.6)** 692/.47-912=**560' (174.5)**	179 000 ppm, commercial values, code b

- *extrapolated values given if available (ISIP-FSIP- initial shut-in pressure, final shut-in pressure; psi - pounds per square inch)
- **shut-in pressure in DST interval (psi)/water gradient (psi/foot) minus pressure gauge depth with respect to Kelly Bushing (KB) (feet - subsea elevation) *(using water gradient for well)*
- ***shut-in pressure in DST interval (psi)/water gradient (psi/foot) minus pressure gauge depth with respect to Kelly Bushing (KB) (feet - subsea elevation) *(using average water gradient of 0.47 psi/ft.); this was used for potentiometric surface, in Figure 3*
- asl - above sea level
- ***commercial*** refers to values supplied by a vendor and not checked against the original source
- Codes a-b useable, codes c-d unuseable
- Salinity in ppm represents total solids calculated

DST - Drill Stem Test, m - mud, s - salt, w - water, gsy - gassy, sul - sulphurous, gc - gas cut, blk - black, tr - trace, mdy - muddy, g/cm^3- grams per cubic centimetre, perm - permeability, ppm - parts per million, mg/l - milligrams/litre, rec - recorded, sl - slightly

Appendix A (cont.)

Location	DST #	DST Interval feet	Formation	Recovery	ISIP-FSIP* psi	KB feet elevation	Gauge feet depth	Gauge KB feet subsea	Potentiometric surface feet** (metres)	Remarks
Keg River (Pine Point), Sulphur Point,Presqu'ile (Eifelian–Givetian formations)										
B29-6150-11800	1	920–1000	Chinchaga	800' sw	476-474	622	1000?	378?	476/.47-378=**635' (197.8)** 476/.47-378=**635' (197.8)**	no gauge depth, commercial values, code b
G68-6200-11745	1	577–701	Chinchaga	615 mdy sw	315-313	630	701?	71?	315/.47-71=**599' (186.6)** 315/.47-71=**599' (186.6)**	no gauge value, commercial values, code b
Slave Point DSTs (not included in Figures 4 or 6)										
I16-6010-11730	1	4246–4328	Slave Point	300 mcf/d		2411				gas recovery
F51-6010-11715	1,6			TSTM		2410.5				gas recoveries
J62-6010-11715	3	4325–4420	Slave Pt./ Ft. Verm	328 mcsw	1192-1341	2475	4423?	1946?	1341/.441-1946= 1095?	gauge depth unknown, code c, 1.022 g/cm^3, 28 600 ppm
G21-6010-11845	1	4925–4970	Slave Point	164 mcf/d		2050				gas recovery
N18-6020-11800	4	3580–3610	Slave Point	1700 mcf/d		1313				gas recovery
F39-6030-11645	2	2099–2189	Slave Point	420' sul sw	877	986	2186	1190	877/.46-1190=**717'** 877/.47-1190=**676'**	1.065 g/cm^3, code b
O54-6030-11745	2	3170–3240	Slave Point	580' sw	1390-1390	982	3174	2192	1390/.458-2192=**843'** 1390/.47-2192=**765'**	80 400 ppm, code a
D66-6040-11600	4	1515–1532	Slave Point?	1287' sw	523	890	1530?	640	523/.45-640=522'	fm uncertain, recorder uncertain
K10-6040-11715	1	2306–2320	Slave Point	2158' sw	977-985	941	2315	1374	985/.456-1374=**786'** 985/.47-1374=**721'**	1.054 g/cm^3, code a 75 000 ppm
G31-6050-11845	6	3280–3336	Slave Point	2059' sw	1380	1150	3306	2156	1380/.46-2156=**844'** 1380/.47-2156=**780'**	no fluid analysis, code a
I44-6100-11715	1	1716–1752	Slave Point	1500' m	762-785	747	1766	1019	785/.456-1090=**702'** 785/.47-1019=**651'**	no fluid analysis, code a
H01-6110-11845	1	2640–2751	Slave Point	1680' sul sw	1177-1177	927	2751?	1824?	1177/.46-1824=735'	gauge depth unknown, commercial values
I24-6110-11915	1	2476–2624	Slave Point	2230' sul sw	1120-1120	899	2485	1586	1120/.46-1586=**848'** 1120/.47-1586=**797'**	commercial values, high perm, code a

Appendix B

Conversions and relationships between density, specific gravity, API gravity, total dissolved solids, and hydrostatic pressure gradients

Specific gravity	Hydrostatic Pressure Gradient kPa/m	Gravity API	Density kg/m³	Approximate Total Dissolved Solids in Water ppm	Hydrostatic Pressure Gradient psi/ft.
1.14	11.152	-7.5°	1140	200,000	.493
1.13	11.061	-6.3°	1129	187,000	.489
1.12	10.971	-5.2°	1120	175,000	.485
1.11	10.858	-3°	1110	160,000	.480
1.1	10.767	-2.7°	1100	145,000	.476
1.09	10.654	-1.7°	1090	130,000	.471
1.08	10.564	-0.5°	1080	115,000	.467
1.07	10.473	1°	1070	100,000	.463
1.06	10.383	2°	1060	85,000	.459
1.05	10.27	3°	1050	70,000	.454
1.04	10.179	4.5°	1040	55,000	.450
1.03	10.066	6°	1030	40,000	.445
1.02	9.976	7°	1020	30,000	.441
1.01	9.885	8.5°	1010	15,000	.437
1.0	9.795	10°	1000	0 (freshwater)	.433
0.993	9.727	11°	993		.430

*Specific gravity of water at 60°F in gm/ml.