GS2018-9

Summary of helium occurrences in southwestern Manitoba

by M.P.B. Nicolas

In Brief:

- 80% of the oil and gas wells tested in Manitoba have helium gas
- Six wells have economic helium concentration between 0.30 to 2.00 mol %
- Deadwood, Winnipeg, Bakken and Torquay formations have good potential as helium reservoirs

Citation:
Nicolas, M.P.B. 2018: Summary of helium occurrences in southwestern Manitoba; *in* Report of Activities 2016, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 110–118.

Summary

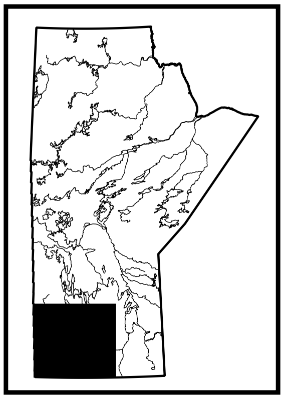
Southwestern Manitoba is geologically well positioned for economic helium deposits within its sedimentary strata. A search of oil and gas technical well files identified 69 wells with recorded helium occurrences. Of those occurrences, six wells had helium values above the economic cut-off of 0.30 mol % He with ranges from 0.30 to 2.00 mol % He. The best helium values came from the sandstone of the lower Winnipeg Formation to the weathered Precambrian regolith interval, the Middle Bakken Member to Torquay Formation interval and the Mission Canyon Formation. The source of this helium is thought to be the basement Precambrian rocks and radioactive (high gamma ray or 'hot') shales of the Upper Bakken Member. The best prospects for economic helium deposits are within the Deadwood to Winnipeg formations interval overlying Precambrian rocks where basement structural features may have created trapping conditions; and within the Middle Bakken Member to Torquay Formation interval where the Middle Bakken Member sandstone is thick and the Upper Bakken Member shale has a strong gamma-ray ('hot') signature.

Introduction

The second element on the periodic table after hydrogen, helium is a nontoxic, chemically inert, light element with a low density, low boiling point and high thermal conductivity. These properties make it the ideal element for a multitude of uses, including in cryogenic applications, as a coolant for superconductors such as the magnets used in magnetic resonance imaging (MRI) machines and particle colliders (e.g., the Large Hadron Collider), in fibre optics and silicon wafer manufacturing, in the space industry, in air tanks for scuba diving, as a shielding gas in arc welding, as a tracer gas for detecting leaks in an industrial high vacuum, in high pressure systems and in balloons, the most commonly known use.

The United States is the world's largest producer of helium (accounting for 80% of the worldwide helium production), followed by Algeria, Qatar, Russia and Canada (United States Geological Survey, 2018). Increased demand and a decreased US supply have resulted in an increase in the price of helium, sparking a renewed interest to explore for helium in politically stable countries like Canada, and specifically in provinces such as Saskatchewan (Yurkowski, 2016).

Helium is formed primarily by the radioactive decay of uranium- and thorium-bearing minerals in crystalline Precambrian basement rocks and in detrital sedimentary rocks such as shale. In the subsurface, this element can diffuse through solid rock into porewater, where its transmissivity is strongly controlled by the chemistry of the migrating fluids in which it resides. Unless trapped underground, this small and light element will reach the Earth's surface, where it easily escapes the atmosphere into space. Less than 5 ppm He resides in the Earth's atmosphere.



Helium can occur in the subsurface in concentrations of up to 8% (National Academy of Sciences, 2000), in association with natural gases such as nitrogen, carbon dioxide, methane and minute amounts of other noble gases. Economic concentrations of helium can be produced as a byproduct of oil and gas production operations and is referred to as crude helium. It is estimated that at concentrations greater than 0.3% by volume (or 0.3 mol % assuming ideal gas conditions), helium can be economically separated from natural gas during the removal of nitrogen, a process used to improve the heating value of natural gas (National Academy of Sciences, 2000).

In Manitoba, exploration for helium was conducted near the community of Lundar, on the east side of Lake Manitoba. In 1962, Hemisphere Helium Corporation drilled two wells at L.S. 14, Sec. 17, Twp. 20, Rge. 5, W 1st Mer. (abbreviated 14-17-20-05W1) and 16-15-20-06W1, where they collected four fluid samples that returned helium concentrations of 0.2–2.0 mol % from the lower sandstone member of the Winnipeg Formation (Hemisphere Helium Corporation Ltd., 1962a, b). Both wells had drill stem tests (DSTs) run, testing the Red River Formation and the lowermost sandstone beds of the Winnipeg Formation to the uppermost interval of the weathered Precambrian rocks. All DST results show strong initial gas flows, followed by a decrease in gas and increase in water flows over the course of the tests (Hemisphere Helium Corporation Ltd., 1962a, b).

Before 1950, documented helium occurrences were identified in 2-22-2-9W1, 8-26-2-9W1, 3-9-12-7W1, 8-23-20-6W1 and NE-35-12-7W1. Concentrations measured were between 0.08 and 5.44% helium by volume. Sparse information is available on these occurrences and the stratigraphic intervals from which these gas analyses were collected is uncertain. These occurrences are shown in Figure GS2018-9-1 and listed Table GS2018-9-1; however, although these occurrences are worth mentioning, they will not be discussed further herein due to the uncertainty of the information available.

No known active helium exploration has occurred in the province since 1962, but recent increases in demand has resulted in more inquiries on occurrences in Manitoba. The purpose of this paper is to summarize the known helium occurrences in southwestern Manitoba and provide some geological context to those occurrences.

Helium occurrences

Helium occurrences have been documented during oil and gas operations in Manitoba because gas analyses

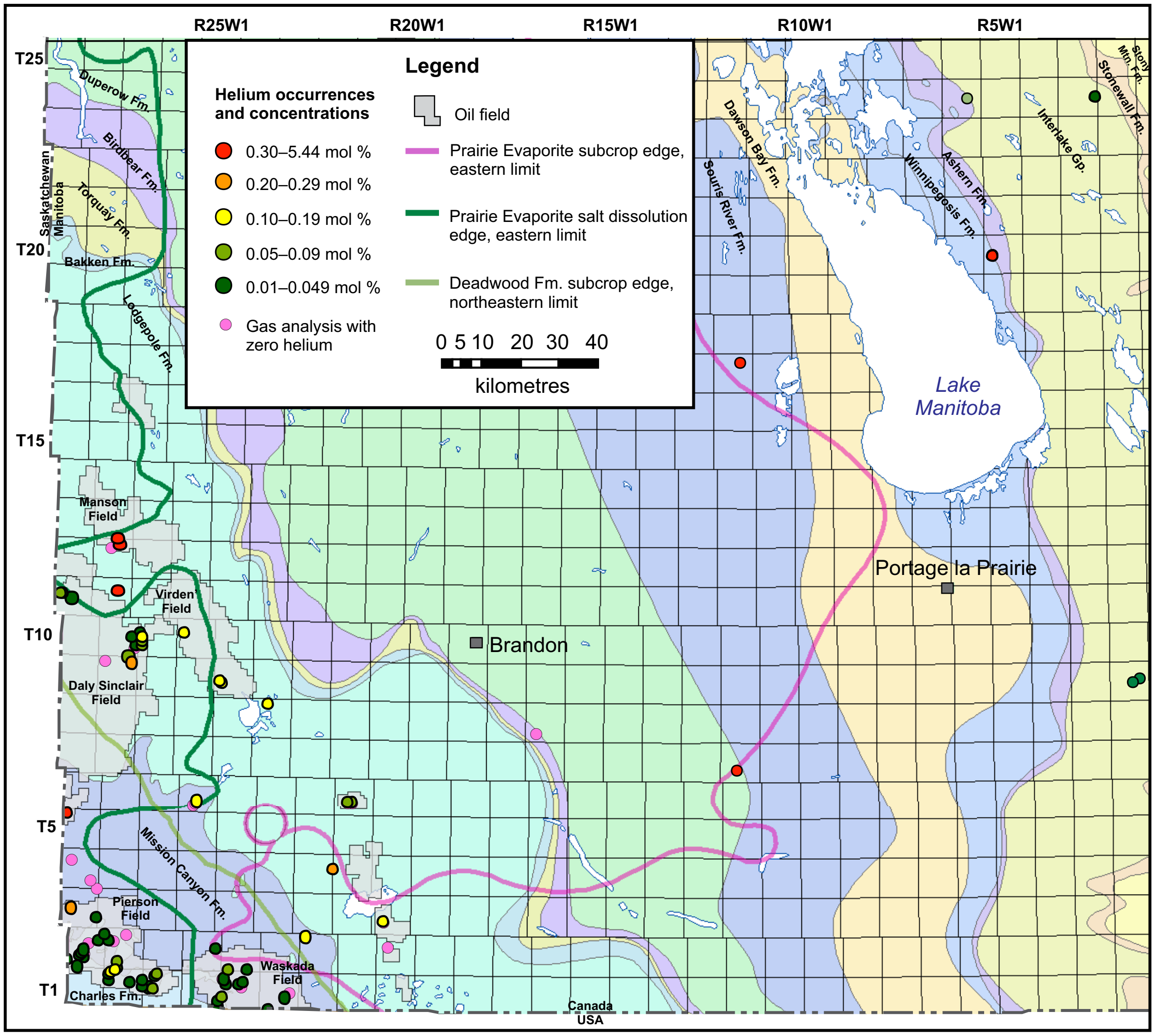


Figure GS2018-9-1: *Paleozoic stratigraphic map showing the distribution of gas analyses and helium occurrences in southwestern Manitoba. Select oil fields are labelled. Abbreviations: Fm., Formation; Gp., Group; Mtn., Mountain.*

Table GS2018-9-1: Helium concentrations reported in gas analyses for southwestern Manitoba. He air free is the concentration of the gas with the air removed and directly measured, and He acid free is the concentration of the gas with the acidic components (H_2S and CO_2) removed. Abbreviations: Fm., Formation; Mb., Member; TVD, true vertical depth.

UWI/location	Licence	Easting	Northing	Depth interval tested (m)	He air free (mol %)	He acid free (mol %)	N_2 air free (mol %)	N_2 acid free (mol %)	CO_2 air free (mol %)	H_2S air free (mol %)	CH_4 air free (mol %)	CH_4 acid free (mol %)	Stratigraphic unit
100/03-05-001-24W1/00	2755	378536.60	5428839.40	913.0–917.0	0.02	0.02	16.67	16.82	0.89	0.00	47.01	47.43	MC-2 Mb.
1C0/16-10-001-24W1/00	5273	382615.89	5431864.69	915.8–918.8	0.02	0.02	5.55	5.57	0.35	0.07	45.83	46.02	Lower Amaranth Mb.
100/13-07-001-25W1/00	2758	366852.68	5432076.42	930.0–948.0	0.06	0.06	19.38	19.38	0.02	0.00	67.24	67.25	MC-3b Mb.
100/16-19-001-25W1/00	7780	368212.17	5435406.94	906.8–908.5 (TVD)**	0.01	0.01	3.61	3.66	1.12	0.19	24.66	24.99	Lower Amaranth Mb.
100/15-21-001-25W1/00	4245	370991.07	5435255.84	898.0–908.0	0.02	0.02	7.84	7.88	0.36	0.09	49.31	49.53	Lower Amaranth Mb.
100/03-27-001-25W1/00	5127	372244.36	5435672.60	897.0–900.0	0.03	0.04	6.84	8.30	17.56	0.00	74.80	90.73	Lower Amaranth Mb.
100/11-30-001-25W1/00	2194	367359.30	5436589.05	920.5–930.2	0.03	0.03	11.04	11.12	0.60	0.13	49.56	49.92	MC-3b Mb.
102/11-30-001-25W1/00	3647	367414.70	5436642.28	924.0–926.0	0.03	0.03	9.07	9.12	0.45	0.06	47.57	47.81	MC-3b Mb.
100/10-01-001-26W1/00	2869	365969.08	5430064.82	912.0–928.0	0.02	0.02	12.14	12.18	0.30	0.00	62.14	62.33	Lower Amaranth Mb.
100/02-12-001-26W1/00	3094	365940.66	5430847.89	935.5–937.5	0.01	0.01	0.00	0.00	0.17	0.00	43.81	43.88	MC-3a Mb.
102/02-12-001-26W1/00	3914	365965.51	5430850.80	933.0–936.3	0.01	0.01	0.00	0.00	0.17	0.00	73.81	56.85	MC-3a Mb.
100/14-17-001-27W1/00	7420	349338.57	5434285.60	963.1–965.2 (TVD)	0.09	0.09	13.93	13.94	0.04	0.00	69.10	69.13	Lower Amaranth Mb.
100/01-19-001-27W1/00	8193	348535.87	5434529.74	959.8–964.2 (TVD)	0.04	0.04	14.34	14.47	0.82	0.10	67.08	67.70	Lower Amaranth Mb.
100/01-20-001-27W1/00	7473	350157.50	5434573.80	963.0–966.0	0.01	0.01	3.23	3.23	0.08	0.00	41.31	41.34	Lower Amaranth Mb.
100/16-29-001-27W1/00	7490	350251.12	5437515.49	949.9–950.0 (TVD)	0.02	0.02	12.28	12.29	0.07	0.00	63.84	63.88	Lower Amaranth Mb.
100/04-33-001-27W1/00	7505	350485.05	5437811.97	940.7–943.6 (TVD)	0.08	0.08	16.37	16.38	0.07	0.00	51.12	51.16	Lower Amaranth Mb.
100/16-22-001-28W1/00	7489	343680.96	5436063.48	986.2–990.8 (TVD)	0.01	0.01	5.39	5.40	0.11	0.00	68.27	68.35	Lower Amaranth Mb.
100/01-24-001-28W1/00	7434	346914.75	5434578.76	968.2–971.3 (TVD)	0.02	0.02	8.38	8.39	0.13	0.00	62.61	62.69	Lower Amaranth Mb.
100/01-25-001-28W1/00	8086	346976.17	5436222.99	967.7–973.1 (TVD)	0.05	0.05	17.57	17.70	0.74	0.00	63.32	63.79	Lower Amaranth Mb.
100/02-30-001-28W1/00	7485	338189.61	5436474.64	1006.0–1007.9 (TVD)	0.03	0.03	12.18	12.18	0.03	0.00	52.53	52.55	Lower Amaranth Mb.
100/15-30-001-28W1/00	7486	338217.13	5437846.77	1002.6–1006.6 (TVD)	0.01	0.01	7.62	7.63	0.11	0.00	44.13	44.18	Lower Amaranth Mb.
100/05-32-001-28W1/00	7487	339060.77	5438654.69	1001.3–1005.1 (TVD)	0.11	0.11	42.77	42.78	0.03	0.00	48.86	48.87	Lower Amaranth Mb.
100/10-32-001-28W1/00	7579	339888.82	5438874.10	979.6–985.6 (TVD)	0.14	0.14	54.54	54.64	0.18	0.00	27.73	27.78	Lower Amaranth Mb.
100/15-32-001-29W1/02	7447	330283.70	5439771.87	1031.2–1033.0 (TVD)	0.01	0.01	2.68	2.68	0.12	0.00	57.32	57.39	Lower Amaranth Mb.
02-22-002-09W1*					0.04		12.23		0.20		87.53		cannot be determined
08-26-002-09W1*					~0.04?								cannot be determined
100/08-31-002-23W1/00	2706	388023.33	5447265.80	812.0–932.0	0.17	0.18	62.59	64.94	2.49	1.13	11.71	12.15	MC-1 Mb.
100/01-03-002-25W1/00	5056	373093.00	5438927.00	877.0–880.0	0.03	0.03	6.58	7.57	13.11	0.00	79.76	91.79	Lower Amaranth Mb.
102/04-05-002-25W1/00	8078	368644.51	5439134.72	898.5–899.8	0.06	0.06	8.97	8.97	0.02	0.00	90.69	90.71	Lower Amaranth Mb.
100/05-24-002-26W1/00	2766	365454.00	5444482.91	893.0–909.0	0.03	0.03	79.02	79.04	0.02	0.00	7.74	7.74	MC-2 and MC-1 Mb.
100/04-04-002-28W1/00	7581	340722.27	5439683.12	878.0–982.0 (TVD)	0.06	0.06	21.83	21.85	0.08	0.00	39.22	39.25	Lower Amaranth Mb.
100/01-08-002-28W1/00	7225	340335.87	5441339.85	988.0–988.8 (TVD)	0.07	0.07	26.58	26.92	1.21	0.07	53.81	54.51	Lower Amaranth Mb.

Table GS2018-9-1 (continued): Helium concentrations reported in gas analyses for southwestern Manitoba. He air free is the concentration of the gas with the air removed and directly measured, and He acid free is the concentration of the gas with the acidic components (H_2S and CO_2) removed. Abbreviations: Fm., Formation; Mb., Member; TVD, true vertical depth.

UWI/location	Licence	Easting	Northing	Depth interval tested (m)	He air free (mol %)	He acid free (mol %)	N_2 air free (mol %)	N_2 acid free (mol %)	CO_2 air free (mol %)	H_2S air free (mol %)	CH_4 air free (mol %)	CH_4 acid free (mol %)	Stratigraphic unit
102/02-30-002-28W1/00	7503	338448.71	5446288.16	971.4–976.8 (TVD)	0.02	0.02	16.15	16.30	0.74	0.18	52.44	52.93	Lower Amaranth Mb.
100/13-06-002-29W1/00	7521	327721.58	5441502.68	1032.3–1032.8 (TVD)	0.04	0.04	9.93	9.99	0.54	0.08	50.60	50.92	Lower Amaranth Mb.
100/08-09-002-29W1/00	3906	332250.20	5442137.57	1020.5–1035.0	0.02	0.02	8.65	8.79	1.10	0.50	40.01	40.66	Lower Amaranth and MC-3b mb.
100/12-09-002-29W1/00	4045	331086.47	5442547.08	1022.5–1025.5	0.05	0.05	8.23	8.23	0.01	0.00	64.34	64.35	Lower Amaranth Mb.
100/03-16-002-29W1/00	4373	331577.71	5443346.81	1033.5–1036.5	0.02	0.02	13.36	13.39	0.22	0.00	61.61	61.75	MC-3b mb.
100/10-16-002-29W1/00	4303	331865.89	5444078.98	1007–1026.5	0.01	0.01	8.86	8.88	0.23	0.00	47.64	47.75	Lower Amaranth Mb.
100/01-26-002-29W1/00	7541	335779.51	5446388.02	981.3–985.2	0.05	0.05	21.94	22.01	0.33	0.00	56.43	56.62	Lower Amaranth Mb.
100/01-36-002-29W1/00	6625	337427.23	5448004.93	1002.5–1004.0	0.01	0.01	0.24	0.24	0.71	0.00	82.94	83.53	MC-3b mb.
100/16-08-003-21W1/00	4869	407907.32	5451204.80	783–787	0.15	0.16	46.21	50.51	8.52	0.00	12.03	13.15	upper Whitewater Lake Mb.
100/10-12-003-29W1/00	3277	335003.63	5452388.94	991.5–995.5	0.02	0.02	12.19	12.19	0.04	0.00	22.57	22.58	MC-3 Mb.
100/16-17-003-29W1/00	3446	328909.49	5454650.89	1003–1014	0.30	0.30	20.90	20.90	0.00	0.00	47.31	47.31	MC-3 Mb.
102/13-19-004-22W1/00	5063	395261.00	5464534.00	772.5–777.5	0.22	0.22	79.23	80.06	1.04	0.00	1.08	1.09	upper Whitewater Lake Mb.
102/09-31-005-29W1/00	2647	327906.14	5478887.96	946.5–948.5	0.68	0.83	42.98	52.73	13.43	5.06	8.01	9.83	MC-1 Mb.
100/02-16-006-22W1/00	1883	399704.84	5481225.54	650.0–655.0	0.10	0.12	55.13	65.95	16.41	0.00	1.36	1.63	upper Virden Mb.
100/04-16-006-22W1/00	1884	398892.74	5481241.88	662.9–662.9	0.07	0.08	39.22	44.42	11.70	0.01	1.22	1.38	lower Virden Mb.
100/15-09-006-26W1/00	4669	360508.55	5481644.00	759–764.5	0.17	0.18	29.38	30.53	3.11	0.65	8.32	8.65	MC-1 Mb.
100/03-33-008-24W1/00	5193	378575.73	5506293.78	579.1–582.0	0.19	0.21	69.68	78.42	11.15	0.00	1.03	1.16	Lower Amaranth Mb.–Lodgepole Fm.
100/04-17-009-25W1/00	4137	366952.98	5511582.09	645.0–652.0	0.17	0.17	9.70	9.78	0.85	0.00	4.42	4.46	lower Virden Mb.
100/09-18-009-25W1/00	4122	366603.64	5512238.15	639.0–647.0	0.20	0.22	13.51	14.75	8.39	0.00	7.66	8.36	Whitewater Lake Mb.
100/13-25-009-28W1/00	3281	344171.50	5516582.56	715.5–746.0	0.21	0.21	66.35	66.35	0.00	0.00	17.11	17.11	Lodgepole Fm.
100/15-35-009-28W1/00	3293	343425.14	5518211.66	730.0–738.5	0.09	0.09	49.80	49.92	0.25	0.00	27.06	27.13	Lodgepole Fm.
100/13-20-010-26W1/00	3820	357458.49	5524431.71	649.0–655.5	0.16	0.19	14.80	17.32	9.07	5.48	5.86	6.86	Virden Mb.
100/10-07-010-27W1/00	2572	346720.95	5521068.75	705.3–718.7	0.08	0.08	99.57	99.57	0.00	0.00	0.34	0.34	Lodgepole Fm.
100/07-18-010-27W1/00	2562	346749.20	5522286.52	1071.4–1079.0	0.04	0.04	99.29	99.38	0.09	0.00	0.56	0.56	Souris River Fm.
100/07-18-010-27W1/03	4385	346749.69	5522243.31	1071.1–1079.0	0.07	0.07	98.48	98.48	0.00	0.00	0.61	0.61	Lodgepole Fm.
100/15-18-010-27W1/00	15	346766.10	5523092.01	915.9–919.9	0.20	0.20	94.30	92.42	0.00	0.00	6.10	6.00	Duperow Fm.
100/15-18-010-27W1/00	15	346766.10	5523092.01	1066.5–1070.2	0.10	0.10	96.69	96.60	0.00	0.00	0.55	0.00	Souris River Fm.
102/15-18-010-27W1/00	2294	346763.88	5523076.46	870–1071.4	0.16	0.16	97.24	97.25	0.01	0.00	2.45	2.45	Duperow or Souris River Fm.
100/11-19-010-27W1/00	2564	346491.10	5524366.90	1080.5–1082	0.04	0.04	99.60	99.60	0.00	0.00	0.35	0.35	Souris River Fm.

Table GS2018-9-1 (continued): Helium concentrations reported in gas analyses for southwestern Manitoba. He air free is the concentration of the gas with the air removed and directly measured, and He acid free is the concentration of the gas with the acidic components (H_2S and CO_2) removed. Abbreviations: Fm., Formation; Mb., Member; TVD, true vertical depth.

UWI/location	Licence	Easting	Northing	Depth interval tested (m)	He air free (mol %)	He acid free (mol %)	N_2 air free (mol %)	N_2 acid free (mol %)	CO_2 air free (mol %)	H_2S air free (mol %)	CH_4 air free (mol %)	CH_4 acid free (mol %)	Stratigraphic unit
100/10-12-010-28W1/00	167	345084.10	5521073.82	699.5–721.5	0.01	0.01	99.10	99.10	0.00	0.00	0.69	0.69	Lodgepole Fm.
102/10-12-010-28W1/00	2571	345180.01	5521129.08	1076.6–1078.1	0.01	0.01	99.10	99.10	0.00	0.00	0.69	0.69	Souris River Fm.
100/13-13-010-28W1/00	635	344359.31	5523135.73	733.0–736.4	0.05	0.05	38.55	39.94	3.37	0.00	10.59	10.97	Lodgepole Fm.
100/16-22-011-28W1/00	9009	340748.16	5534927.33	822.7–830.9 (TVD)	1.28	1.30	78.05	79.37	1.66	0.00	11.61	11.81	Middle Bakken Mb.–Torquay Fm.
100/09-16-011-29W1/00	6997	329117.10	5532976.60	844.5–845.5	0.02	0.02	0.30	0.31	2.99	0.05	89.53	92.34	Middle Bakken Mb.–Torquay Fm.
100/05-20-011-29W1/00	10496	326360.71	5534451.02	853.4–863.0 (TVD)	0.08	0.08	22.97	22.97	0.01	0.00	7.42	7.42	Middle Bakken Mb.
102/06-20-011-29W1/00	10497	326563.95	5534446.16	849.9–862.3 (TVD)	0.01	0.01	39.76	39.79	0.07	0.00	2.82	2.82	Middle Bakken Mb.
03-09-012-07W1*					3.38—5.44		93.17						cannot be determined
NE-35-12-17W1*					1.19		97.37		0.20				cannot be determined
100/13-26-012-28W1/00	9575	341320.26	5546302.11	688.7–692.1 (TVD)	0.53	0.56	81.89	86.98	5.85	0.00	1.12	1.19	Middle Bakken Mb.
100/02-03-013-28W1/00	9197	340742.71	5548222.23	668.3–680.4 (TVD)	0.43	0.45	75.80	79.35	4.47	0.00	6.79	7.11	Middle Bakken Mb.
100/14-17-020-05W1/00	1846	561704.00	5619715.80	304.8–326.7	2.00	2.00	89.49	91.51	2.21	0.00	8.09	8.27	lower Winnipeg mb.
08-23-020-06W1*					0.08		99.92		0.00				cannot be determined
100/01-24-024-03W1/00	2171	587719.61	5659942.96	187.1–194.8	0.04	0.05	79.42	95.20	0.00	0.00	0.00	0.00	Red River Fm.

* Historical gas analysis on wells drilled prior to 1950. Results may be questionable.

** (TVD) denotes horizontal wells with measured depths converted to true vertical depths (TVD).

are required to be submitted under Manitoba's *Oil and Gas Act*. This has resulted in a concentration of documented helium occurrences in oil-producing areas that may be representative of the larger helium potential in the Williston Basin in Manitoba.

A search of the Manitoba Growth, Enterprise and Trade, Petroleum Technical Well files (https://www.gov.mb.ca/iem/petroleum/gis/technical.html) resulted in a total of 120 gas analyses from 86 wells. Of those wells, 69 (or 80%) of them reported helium concentrations. Table GS2018-9-1 lists those helium concentrations broken down as He air free and He acid free, where the former is the concentration of the gas with the air removed and the latter is the concentration of the gas with the acidic components (H_2S and CO_2) removed; concentrations of other selected gas components are listed in Table GS2018-9-1 for context. These helium occurrences are widely distributed, both geographically and stratigraphically, throughout Manitoba (Figures GS2018-9-1, -2). The youngest tested interval is the Triassic–Jurassic Amaranth Formation interval, and the oldest is the lower Winnipeg Formation sandstone to weathered Precambrian regolith interval. The most gas tests have occurred within those intervals with an affinity to produce natural gas, such as the Amaranth and Mission Canyon formations in the Pierson and Waskada oil fields (Figure GS2018-9-1). In the last five years, gas analyses have been conducted on the Middle Bakken Member to Torquay Formation interval in the Daly-Sinclair and Manson oil fields, where potentially economical helium concentrations of 0.45–1.3 mol % occur between townships 11 and 13, range 28W1.

This study identified six wells that have helium concentrations at or above the economic cut off for crude helium at 0.3 mol %. The highest results come from the Hemisphere Helium et al Lauder Prov. 14-17-20-05W1 well (one of the original Hemisphere Helium Corporation exploration wells) at 2.00 mol % from the lower Winnipeg Formation sandstone to the weathered Precambrian regolith interval, and from the Middle Bakken Member to Torquay Formation interval in the CPEC Elkhorn Hzntl 16-22-11-28W1 well with 1.30 mol %. High helium values have also been found within the MC-1 and MC-3 members of the Mission Canyon Formation. Figure GS2018-9-2 summarizes the helium occurrences based on their stratigraphic location.

Helium exploration

The exploration for helium requires the same approach (source, migration, trap) and data as conventional oil and gas exploration, but with some differences. Brown (2010) states that the best places to explore for helium include in old sediments with stagnant porewater (>100 Ma; Early Cretaceous or older); in areas with saline and cool shallow traps because helium degasses from fluids at low pressures (preferably between 0.5 to 2.5 km depth); at the end of long migration pathways, which maximize gas exposure to helium-bearing water; and away from supercharged and thermally mature hydrocarbon systems to avoid dilution in natural gas–rich reservoirs.

The best sources for these accumulations are old siliciclastic sediments, fractured shales, arkoses, granite wash and shallow fractured basement rocks (Brown, 2010). The best traps are capped by especially impervious rocks, such as halite, anhydrite and some very tight highly organic shales (Broadhead, 2005).

When considering all these factors, southwestern Manitoba is favourable for helium exploration because

- southwestern Manitoba is located on the northeastern rim of the Williston Basin, hundreds of kilometres away from the supercharged, thermally mature basin centre located in North Dakota.
- there is long-range migration of basinal fluid flow updip as the strata shallows toward the northeast.
- basinal fluid and gas are trapped by a multitude of northwest-trending subcrop and outcrop stratigraphic edges.
- Paleozoic–Jurassic groundwater in southwestern Manitoba is saline (Palombi and Rostron, 2013) and does not occur over any major heat anomalies.
- the maximum depth to the Precambrian surface in Manitoba is approximately 2.3 km (TGI Williston Working Group, 2008), placing all the Manitoba strata within the preferred depths to maximize helium degassing conditions.

Using these criteria, the oldest sedimentary rocks in Manitoba, the basal sandstones of the Deadwood and Winnipeg formations, may be the best candidates for helium exploration. These potential helium reservoir rocks directly overlie fractured Precambrian basement helium source rocks and together underlie a good portion of the Phanerozoic rocks in Manitoba, Saskatchewan, Alberta, Montana and North Dakota, resulting in a large catchment area and long-range migration opportunities for helium. The limited subsurface distribution of the Deadwood Formation in Manitoba is shown in Figure GS2018-9-1 but the Winnipeg Formation is present throughout southwestern Manitoba, underlying the entire map area.

In the extreme southwestern corner of Manitoba, these formations are excellent candidates to have old,

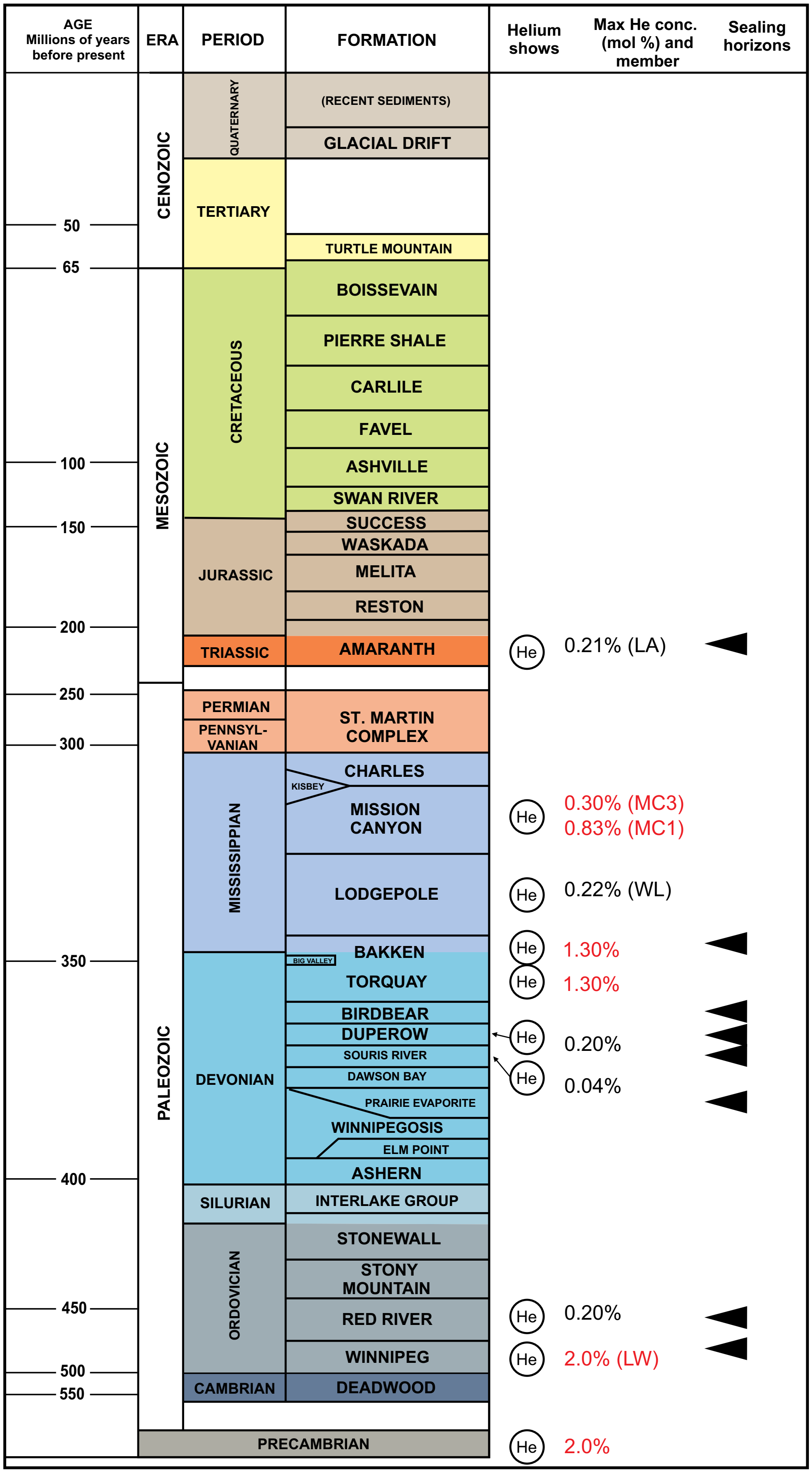


Figure GS2018-9-2: *Stratigraphic column of southwestern Manitoba showing helium occurrences: maximum helium concentrations reported for that interval; the abbreviation in parentheses indicates the member in which the occurrence was measured, if known; and known potential sealing horizons. Red text indicates values equal to or above 0.30 mol % He. Abbreviations: LA, lower Amaranth Formation; LW, lower Winnipeg Formation; MC1, MC-1 member; MC3, MC-3 member; WL, Whitewater Lake Member.*

saline, cool and locally stagnant porewater, creating the right conditions for the accumulation of helium for hundreds of millions of years if a proper cap is present. Halite and anhydrite are the only sedimentary rocks that can block the upward migration of helium; however, siliceous or kerogen-rich shales have also been known to serve as a cap (Broadhead, 2005). The upper shale member of the Winnipeg Formation has been known to be cemented (Yurkowski, 2016) and highly organic in places (Seibel and Bend, 2001), and the lower sandstone member is silicified in places (McCabe, 1978) and may therefore serve as a cap, but due to limited drillhole data in this region this is difficult to ascertain. Basement structural features can provide the right conditions for entrapment, such as that seen in the west. In Saskatchewan, at the site of the original producing wells, in township 17, range 14W3, the Deadwood Formation drapes a Precambrian structural high known as the Wilhelm structure, and is capped with a silicified siltstone. The Wilhelm structure has the some of the highest recorded helium concentrations (2%) in Saskatchewan (Yurkowski, 2016), and produced helium for 14 years in the late 1960s and early 1970s. In contrast, the high helium concentration in the Winnipeg Formation at 14-17-20-05W1 is 2.0 mol %, occurs at shallow depths between 256.0 and 326.8 m, and is associated with fresh groundwater, suggesting that there can be a wide range of conditions in which elevated levels of helium can potentially occur.

The Middle Bakken Member to Torquay Formation interval is capped with the regionally continuous, tight organic-rich shale of the Upper Bakken Member. This shale can have a very strong gamma-ray ('hot') signature and is a good candidate as a direct source for the high helium values measured in the Bakken–Torquay formations oil reservoir; however, the high helium occurrences in the Bakken–Torquay formations interval and the helium occurrences further south in township 10, range 27W1 in the Lodgepole, Duperow and Souris River formations all follow a north-south linear trend, suggesting a possible structural influence on the helium source and trapping mechanism. This region also falls within the boundaries of the Superior boundary zone (a deep crustal suture), the Birdtail-Waskada Zone (a post–Prairie Evaporite zone of structural disturbance) and within an embayment where the Prairie Evaporite salt is fully dissolved (Figure GS2018-9-1). All of these features can enhance localized fluid flow, result in localized thickening of potential reservoir units as is seen in the Middle Bakken Member sandstone (Nicolas, 2012) and may be related to basement faults. In the Daly-Sinclair region the horizons with helium occurrences all follow the eastern edge of a structural high that may also be related to a basement fault (Nicolas, 2012). These basement faults may serve as effective conduits to move helium-enriched fluids upward, permeating and trapping the fluids in several horizons. In addition, the Souris River and Duperow formations have multiple shale beds that may also serve locally as helium sources. Overall, the source of the helium is uncertain and may be a product of multiple combined sources but the helium appears to be preferentially trapped under shales with strong gamma-ray signatures where there are structurally controlled traps.

The sealing horizons on top of helium-charged reservoirs must be effective at preventing the small helium atom from escaping. A minimum of eight such seals exist in southwestern Manitoba and are identified in Figure GS2018-9-2. These include, from oldest to youngest, the upper Winnipeg Formation shales (when silicified or high in kerogen), the Lake Alma Member anhydrite in the Red River Formation, the Prairie Evaporite, the multiple anhydrite beds of the Souris River and Duperow formations, the upper member anhydrite beds of the Birdbear Formation, the Upper Bakken Member organic-rich shale and the Upper Amaranth Member of the Amaranth Formation. The Mississippian Charles Formation and the Dando Evaporite are not considered effective seals in Manitoba due to their irregular and limited distribution.

The most effective seal regionally is the Prairie Evaporite salt beds. This has been demonstrated in Saskatchewan where it serves as a good seal over the underlying Winnipegosis Formation, where high helium values have been identified from several wells in the southeastern corner of the province (M. Yurkowski, pers. comm., 2018). These helium occurrences occur dominantly where the Prairie Evaporite salt beds are not dissolved. Limited helium analyses in Manitoba make testing this theory difficult, but extrapolation from Saskatchewan studies suggests it may be worth investigating. Figure GS2018-9-1 shows the Prairie Evaporite salt dissolution edge relative to the documented helium occurrences.

Conclusions

Southwestern Manitoba has the right geological conditions for economic helium deposits. The best targets are the Bakken–Torquay formations interval, which benefits from the overlying 'hot' shales, and the Deadwood–lower Winnipeg formations interval, which sits directly over the Precambrian rocks. The areas with high solution gas may dilute the helium content too much for proper economic evaluation, suggesting the Amaranth, Mission Canyon and Lodgepole formations are the less likely targets, although that is not to say that they may not have local accumulations. Other Paleozoic formations are generally poorly explored and have too few analyses to suggest if and where there may be any helium deposits.

Economic considerations

A rise in helium demand globally has sparked a worldwide exploration rush for the commodity. Helium can be produced with oil and gas using infrastructure already in place and provided by the petroleum industry. The helium potential within the oil and gas produced may serve as a good economic opportunity for operators to improve profits from these wells and may help to extend the life of marginal oil wells.

Acknowledgments

The author thanks M. Yurkowski from the Saskatchewan Geological Survey for her motivation, good discussions and technical review of this paper. P. Fulton-Regula from the Manitoba Petroleum Branch is acknowledged for the critical review of this paper.

References

Broadhead, R. 2005: Helium in New Mexico—geologic distribution, resource demand, and exploration possibilities; New Mexico Geology, v. 27, p. 9.

Brown, A. 2010: Formation of high helium gases: a guide for explorationists; American Association of Petroleum Geologists, AAPG Convention, April 11–14, 2010, New Orleans, Louisiana, poster.

Hemisphere Helium Corporation Ltd. 1962a: Petroleum technical well file for licence 1845; Manitoba Growth, Enterprise and Trade, Petroleum Branch, p. 55, URL <http://content.gov.mb.ca/iem/petroleum/documents/technical/001845.pdf> [November 2018].

Hemisphere Helium Corporation Ltd. 1962b: Petroleum technical well file for licence 1846; Manitoba Growth, Enterprise and Trade, Petroleum Branch, p. 75, URL <http://content.gov.mb.ca/iem/petroleum/documents/technical/001846.pdf> [November 2018].

McCabe, H.R. 1978: Reservoir potential of the Deadwood and Winnipeg Formations, southwestern Manitoba; Manitoba Department of Mines, Resources and Environmental Management, Mineral Resources Division, 54 p.

National Academy of Sciences 2000: The impact of selling the federal helium reserve; National Academy Press, Washington, D.C., 99 p.

Nicolas, M.P.B. 2012: Stratigraphy and regional geology of the Late Devonian–Early Mississippian Three Forks Group, southwestern Manitoba (NTS 62F, part of 62G, K); Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Geoscientific Report GR2012-3, 92 p.

Palombi, D. and Rostron, B.J. 2013: Regional hydrogeological characterization of the northeastern margin of the Williston Basin; Manitoba Mineral Resources, Manitoba Geological Survey, Open File OF2011-3, set of 55 1:3 000 000 scale maps.

Seibel, C. and Bend, S. 2001: Organofacies and source potential of the Middle Ordovician Winnipeg Formation within southern Saskatchewan; *in* Canadian Society of Petroleum Geologists Annual Convention Program with Abstracts, June 18–22, 2001, Canadian Society of Petroleum Geologists, p. 4, URL <http://www.cspg.org/documents/Conventions/Archives/Annual/2001/14-082.pdf> [September 2018].

TGI Williston Working Group 2008: Precambrian erosional surface: structure contour; Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Stratigraphic Map SM2008-PC-S, digital web release, scale 1:1 000 000, URL <http://www.gov.mb.ca/iem/geo/willistontgi/mapfiles/pdfs/057_prec_precambrian_eros_surf_str.pdf>.

United States Geological Survey 2018: Helium; United States Geological Survey, Mineral Commodity Summaries, January 2018, URL <https://minerals.usgs.gov/minerals/pubs/commodity/helium/mcs-2018-heliu.pdf> [November 2018].

Yurkowski, M. 2016: Helium in southwestern Saskatchewan: accumulation and geological setting; Saskatchewan Ministry of the Economy, Saskatchewan Geological Survey, Open File Report 2016-1, 20 p.