



Open File Report 2016-1

Helium in Southwestern Saskatchewan: Accumulation and Geological Setting

Melinda M. Yurkowski

2016

(Revised 14 December 2016)

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Helium in Southwestern Saskatchewan: Accumulation and Geological Setting

by Melinda M. Yurkowski¹

Introduction and Study Area

Saskatchewan is experiencing renewed interest in the helium potential of southwestern Saskatchewan. Interest in the past, which began in the 1950s, resulted in helium production in the early 1970s from four wells in the Swift Current area. Recently, two wells began producing helium in southwest Saskatchewan: one northwest of Swift Current and one to the southeast, near the town of Mankota.

This Open File Report has been compiled to help in the exploration for and development of helium resources in southwestern Saskatchewan. It reports the results of 1873 gas analyses, from 1412 wells, that have been tested for helium. The report also discusses potential helium sources and traps.

In the study area, the lower Paleozoic formations—in particular, the Deadwood Formation—have the highest concentrations of helium. The helium accumulations in the Deadwood Formation are assumed to be derived from the decay of uranium and thorium from a granitic source rock in the Precambrian basement, or from the shales within the Deadwood Formation itself. Exploration targets include lower Paleozoic structural highs, such as those draped over Precambrian structures, that have an effective seal to trap the small helium molecule.

The study area covers Townships 1 to 25, extending from Range 14 west of the Second Meridian (W2M) to the Alberta border (Figure 1).

Keywords: *helium, Deadwood Formation, Precambrian, Cambrian, southwest Saskatchewan, nitrogen, Wilhelm, Battle Creek, Mankota*

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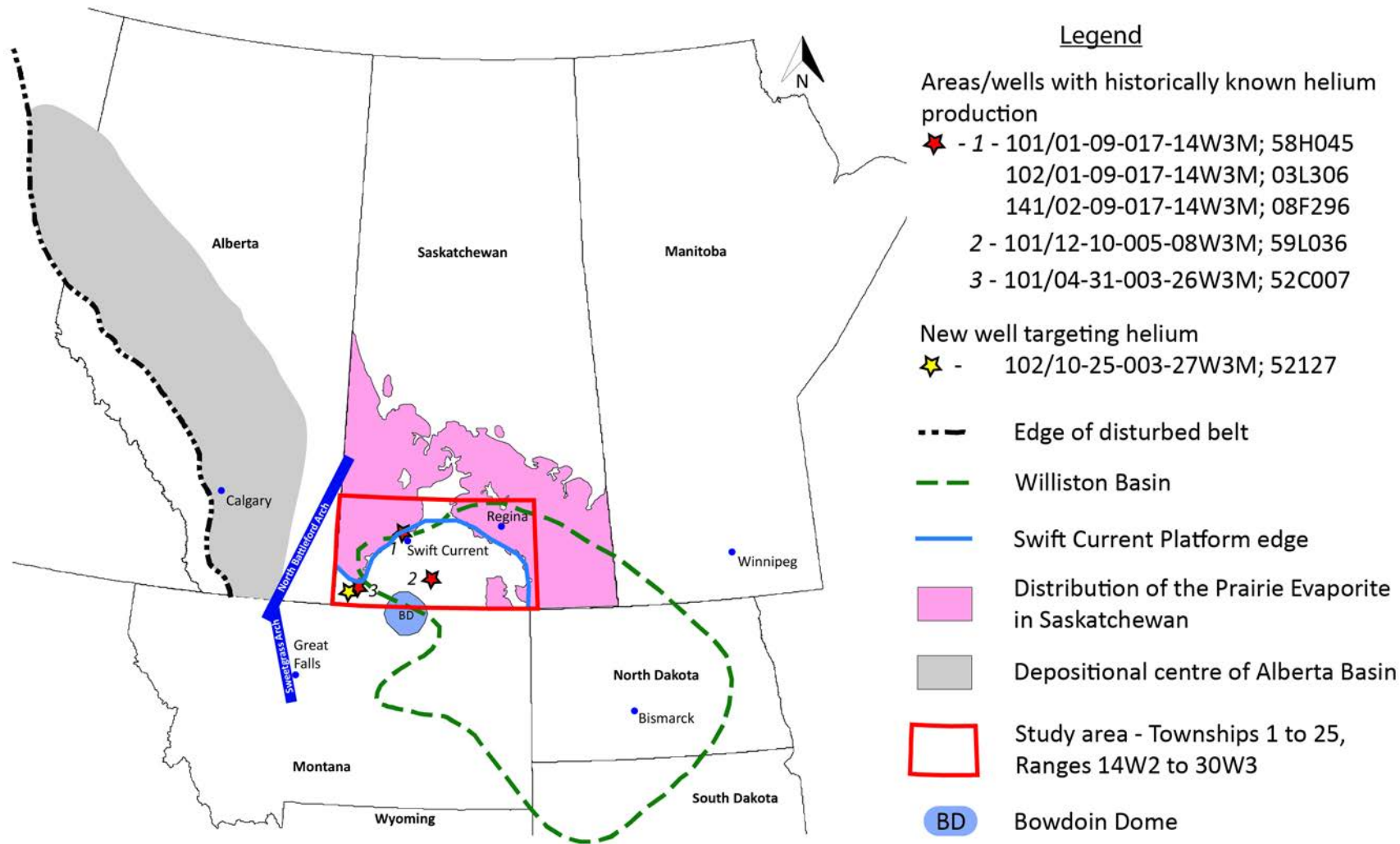


Figure 1 – Map showing the study area, the location of the present-day structural Williston Basin, the approximate centre of the Alberta Basin (Wright et al., 1994), and the location of wells that have produced or are producing helium (past-producing wells 02-09-017-14W3M and 12-10-005-08W3M were reporting helium production in August 2016). Also included are the structural elements within the Williston Basin and surrounding area. Modified from Kent and Haidl (1993), Kent and Christopher (1994) and Wright et al. (1994).

History of Helium Exploration and Development in Saskatchewan

In 1952, the first indication of helium potential in Saskatchewan came from tests in the United Canso-Consumers Co-op Battle Creek No.4-3 well (101/04-31-003-26W3M; 52C007; well 3 on Figure 1), which showed non-flammable gas from the Devonian Duperow Formation (81.7% CO₂, 13.5% N₂, 0.14% He and 5.66% other gases) and the Dawson Bay Formation (95.16% N₂, 0.47% He and 4.47% other gases) (Sawatzky *et al.*, 1960). However, exploration for helium was not pursued in Saskatchewan until 1958, when gas containing anomalous helium content was recorded in well B.A. Wilhelm 101/01-09-017-14W3M; 58H045 (area 1 on Figure 1). The gas was found in sedimentary rocks of the Upper Cambrian Deadwood Formation (Figure 2), 2000 m below ground level. The host rocks were silicified siltstones and mudstones draping a basement (Precambrian) topographic high about 14.5 km north of Swift Current (Sawatzky *et al.*, 1960). Tests indicated an inert gas that flowed at a rate of 0.02 to 0.14 million cubic metres (m³; 1 to 5 million cubic feet (mcf)) per day and was composed of 97% N₂, 2% He and 1% CO₂.

In 1960, helium was discovered in a second well at Texaco Wood Mountain 101/12-10-005-08W3M; 59L036 (now CVE Mankota; well 2 on Figure 1), southeast of Swift Current (Sawatzky *et al.*, 1960; Lane, 1987). A drill stem test (DST) over a 6 metre (20 foot) sandstone interval gave flow rates of 0.46 to 0.57 million m³ (16.3 to 20.0 mcf) of inert gas per day, which was composed of 96.35% N₂, 1.08% He and 2.5% other gases (exact composition unknown).

Helium production began in 1963 and continued until 1977 from four wells in Ranges 14 to 17W3M, producing a combined total of 57.2 x 10⁶ m³ of gas (2 billion cubic feet (bcf)). It is estimated that 1.4% of this production was helium.

In 2004, Industrial Air Corporation re-entered the B.A. Wilhelm 102/01-09-017-14W3M; 61E006 well (IAC Wilhelm 102/01-09-017-14W3M; 03L306), and in 2008 drilled a second well at IAC Wilhelm 141/02-09-017-14W3M; 08F296. In June of 2014, Canadian Helium Inc. began to produce from the 141/02-09-017-14W3M; 08F296 well and as of the end of September 2015, 8.8 x 10⁶ m³ of gas (310,600 mcf; helium is not broken out) has been produced. The well, B.A. Wilhelm 102/01-09-017-14W3M; 61E006 has since been abandoned.

In January 2016, North American Helium Inc. began drilling for helium at NA Helium 102/10-25-003-27W3M; 52127 (yellow star on Figure 1) and in August 2016, Weil Group Resources, LLC opened a helium processing plant near Mankota, approximately 150 km southeast of Swift Current. At the end of August 2016, there were two wells reporting helium production in southwest Saskatchewan: well 12-10-005-08W3M and well 02-09-017-14W3M (identified on Figure 1 respectively as past-producing wells 2 and the third well listed under area 1).

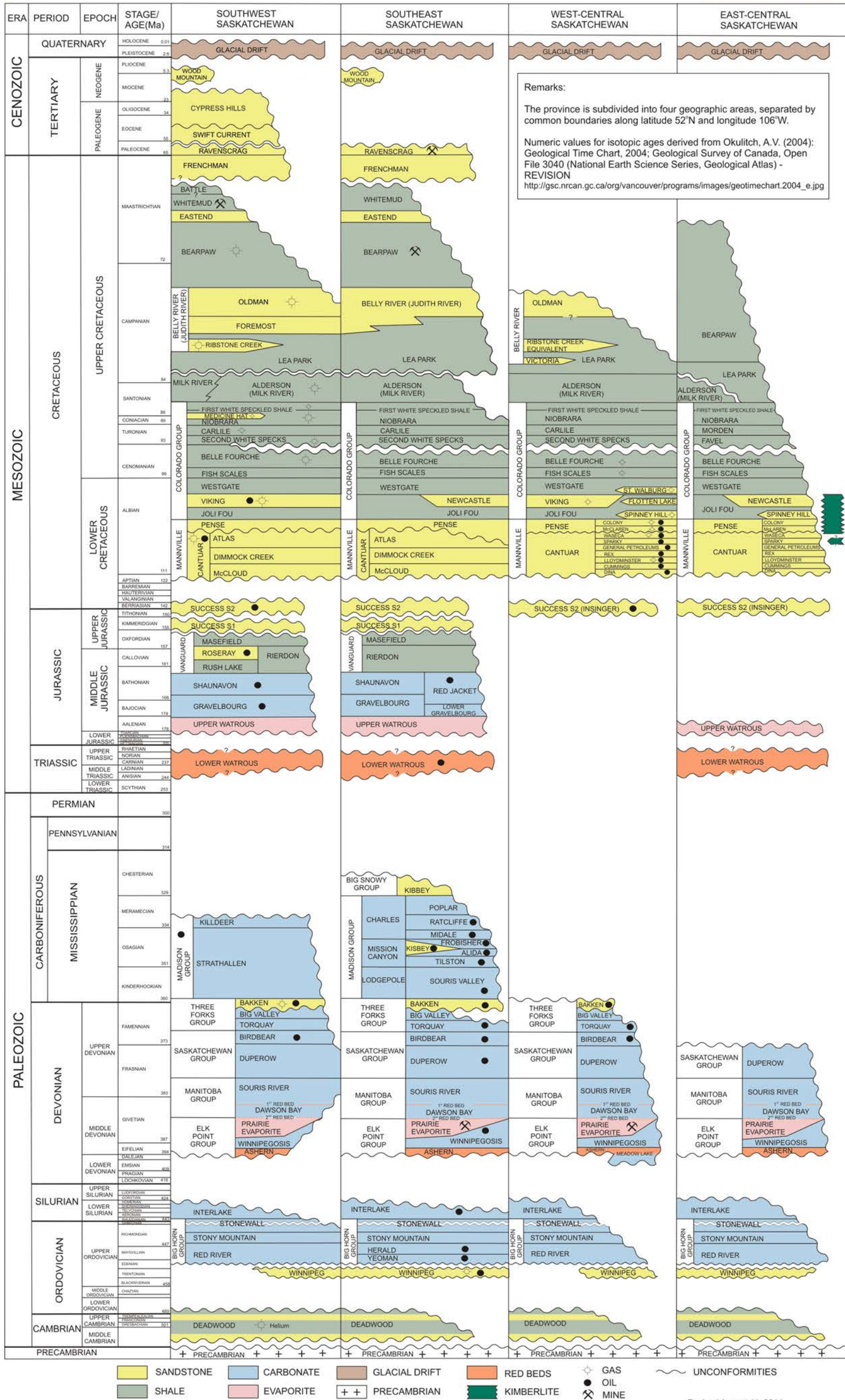


Figure 2 – Saskatchewan's stratigraphic correlation chart (from Saskatchewan Ministry of the Economy, 2014). Helium has been reported in gas analyses from stratigraphic intervals spanning the Cambrian to Cretaceous in southwestern Saskatchewan.

Understanding Helium Accumulation in the Subsurface

Although the physical processes required to trap economic amounts of helium (source, migration, carrier beds and trap with seal) are similar to hydrocarbon natural gas traps, helium differs from hydrocarbon gases in two ways: it has a non-organic source, and it occurs as a very small molecule. This means it requires a more robust seal for its reservoir than most hydrocarbons, as a helium molecule is roughly half the size of a methane molecule (Hunt, 1996).

Helium occurs in two isotopes, ^3He and ^4He (Broadhead, 2005). ^3He is rare and is derived from mantle gases or from neutron capture by hydrogen with lithium. Lithium occurs in continental brines or with lithium-bearing minerals such as spodumene, or in igneous rocks such as devitrified rhyolite or ash-flow tuff, and occurs naturally in low concentrations. Most helium found in the subsurface is ^4He , which is derived from radioactive decay of uranium and thorium.

Regardless of composition, helium is present in most hydrocarbon gases (natural gas) found in the subsurface, but generally only in trace amounts that are rarely of economic value. Helium is also sometimes produced as a secondary byproduct in association with natural gas production where natural gas is liquefied for transport, as helium can be effectively separated and concentrated in this process.

Helium also occurs as a primary commodity, often in association with nitrogen (Johnson, 2012). Where it does occur as a primary commodity, such as in Saskatchewan, scientists have proposed several geological models to explain helium generation and trapping. Some models suggest a granitic basement source, and include generation and migration methods such as diffusive migration out of basement granitic rocks or thermal release of helium from the crustal rocks (Broadhead, 2005). These models require the presence of fracture and/or fault systems that help serve as migration pathways for the helium from the impermeable granite.

Helium can also be generated by radioactive decay of uranium and thorium in orebodies within sedimentary sequences (Broadhead, 2005). It can also be produced from rocks with uranium and thorium concentrations similar to that of an average shale (3.7 ppm U, 12 ppm Th; Brown, 2010), whereby helium migrates from the uranium- and thorium-hosted minerals into stagnant pore water. Upon contact with the stagnant pore water, the helium then partitions into a gas phase. In this case, it requires a significant amount of time (hundreds of millions of years) to generate economic amounts of helium. Brown (2010) also noted that helium partitions more readily from water into gas at lower pressures, higher salinity and cooler temperatures.

Data Collection and Methods

As of January 2016, close to 38 000 oil, gas and potash wells have been drilled in the study area (Figure 3). Of these wells, 1412 were identified in Government of Saskatchewan data files as having gas analyses. Some of these wells have multiple gas analyses from various stratigraphic intervals, resulting in 1873 gas analyses for the 1412 wells.

The data for this report were gathered by manually inspecting each well file at the Ministry of the Economy that had been identified as containing a gas analysis, then tabulating all the analyses (Appendix 1). The data collected from the well files include concentrations of helium (He), nitrogen (N₂), carbon dioxide (CO₂) and hydrogen (H₂), all expressed as a mole fraction. Concentrations of other gases were reported (*e.g.*, methane, ethane and propane), but these were not compiled. The stratigraphic unit for each tested interval was defined from either stratigraphic data sourced from the Ministry of the Economy (where available and as per Figure 2), or by examination of geophysical well logs.

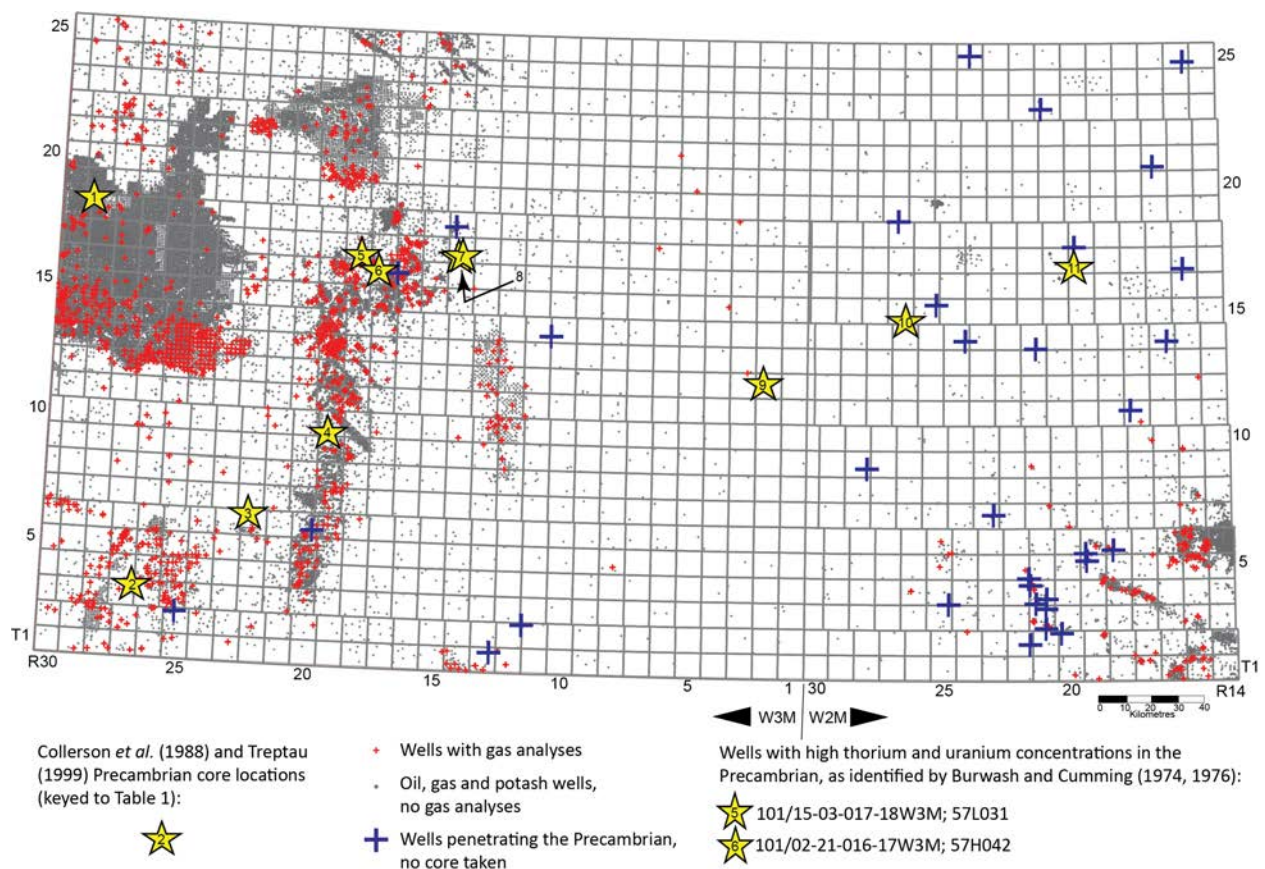


Figure 3 – Map outlining the distribution of oil, gas and potash wells (small grey crosses) in the study area and the wells with gas analyses (small red crosses). Also included is the distribution of Precambrian well penetrations, Precambrian drill cores and rock types identified by Collerson *et al.* (1988) and Treptau (1999) that are shown as numbered yellow stars and correspond to the well locations in Table 1. Wells that were drilled into the Precambrian that do not have cores are identified by the larger blue crosses. The wells identified by Burwash and Cumming (1974, 1976) as having high thorium and uranium concentrations contained >46 ppm Th and >15 ppm U. Abbreviations: T - Township, R - Range, W2M - west of the Second Meridian, W3M - west of the Third Meridian.

Table 1 – Compilation of rock types in cores that penetrated the Precambrian, as identified by Collerson et al. (1988) and Treptau (1999).

Well Number on Figure 3	Well Location	Licence Number	Rock Type (from Collerson et al., 1988)	Rock Type (from Treptau, 1999)
1	101/01-31-018-28W3/00	56G058	Dioritic gneiss	Volcaniclastic tuff overlying tonalitic gneiss
2	101/04-31-003-26W3/00	52C007	Diopside-bearing quartzite	Quartzite
3	101/09-32-006-22W3/00	55K012	Albite granite	Alkali-feldspar granite
4	101/02-04-010-19W3/02	53H018	Granite	Pegmatitic granite
5	101/15-03-017-18W3/00	57L031	Hastingsite-bearing granite	Porphyritic granite
6	101/02-21-016-17W3/00	57H042	Biotite-bearing microcline granite	Porphyritic granite
7	101/03-10-017-14W3/00	62H013	Porphyritic microgranite rhyolite	Crystal lithic tuff
8	101/01-09-017-14W3/00	58H045	Hastingsite-biotite-bearing microgranite	Feldspar-rich rhyolitic porphyry
9	101/09-20-012-02W3/00	51I030	Volcaniclastic tuff	Not analyzed
10	101/02-11-015-26W2/00	58I075	Mesoperthite-biotite-bearing granite	Not analyzed
11	131/03-08-017-19W2/02	78L010	Megacrystic garnet-bearing granitic gneiss	Not analyzed

The helium concentrations reported in the well files are from stratigraphic intervals spanning the Cambrian to Cretaceous (Appendix 1). Of the 1873 gas analyses compiled, 890 came from the Upper Cretaceous (Eastend Formation to base of Fish Scales), 197 from the Lower Cretaceous (Viking Formation to base of Mannville Group), 399 from the Jurassic (Success Formation to base of Gravelbourg Formation), 91 from the Mississippian–Devonian (Poplar Beds to base of Bakken Formation), 29 from the Devonian (Birdbear Formation to base of Winnipegosis Formation), 18 from the Ordovician (Red River and Stony Mountain formations), and 33 from the Ordovician–Cambrian (Winnipeg and Deadwood formations). There were also 216 analyses for which the stratigraphic interval could not be determined. Given that hydrocarbon production is predominantly from the Cretaceous, it stands to reason that the number of wells analyzed is skewed toward the shallower zones.

Where available, the sampling point was recorded (e.g., drill stem test, flareline valve, wellhead), though some tests were not directly from an individual well but from part of a gas gathering system (e.g., battery tests, sales line). These latter results were included in the dataset even though a single helium source was not identified, as these values may still aid in understanding the regional context of helium occurrence. Some gas analyses did not indicate a sampling point from either the well or gathering system, but rather from the container in which it was received at the lab (identified as tedlar bag, can or vial). The type of container used may be more sensitive to helium leakage and may give an indication of the quality of the sample received by the lab, and so these were not excluded. Sample numbers assigned by the lab for each test were also noted, in order to identify and differentiate multiple analyses for individual wells. Remarks on the gas analyses were also recorded, where available, but were confined primarily to factors that might affect helium, nitrogen or carbon dioxide values. No gas values were culled or corrected, to avoid any bias in reporting.

The wells from which the gas analyses in Appendix 1 were compiled were drilled and tested over a span of nearly 80 years, by many different companies, and under many different circumstances; drilling and sampling technology, along with type and precision of analytical methods have changed significantly over this time period. As well, the author is unaware of any circumstances where helium concentrations can be increased during gathering and testing, but it is very easy to deplete helium concentrations during this process (e.g., inadequate container selection can allow the small helium molecule to easily escape to the atmosphere). Therefore, caution is advised when using the data to plan exploration or drilling programs, since values may not be truly representative of actual reservoir conditions.

Geological Setting of the Helium Reservoirs in Saskatchewan

The western part of the modern-day Williston Basin is in southwestern Saskatchewan. It is separated from the Alberta Basin by the Sweetgrass and North Battleford arches (Figure 1). All of these elements were periodically active throughout the Phanerozoic (Kent and Christopher, 1994). In Saskatchewan, the Phanerozoic can be broadly divided into three informal lithological packages: a lower Phanerozoic clastic succession (Cambrian and Ordovician); a middle Phanerozoic carbonate and evaporitic succession (Upper Ordovician to Middle Jurassic); and an upper Phanerozoic clastic succession (Middle Jurassic to Tertiary; Figure 2). A thorough examination of the Phanerozoic in southwestern Saskatchewan is beyond the scope of this paper, and the reader is referred to Marsh and Heinemann (2006) and Christopher *et al.* (1971) for a more complete description of the stratigraphy of this area, and to Marsh and Love (2014) for the most recent isopach and structural maps of the province.

Although there are numerous reported occurrences of helium throughout Paleozoic and Mesozoic strata in the study area (see Appendix 1), in order to identify potential plays for exploration and development, an arbitrary cutoff value of 0.3% He was chosen because it has been quoted in literature as roughly the limit at which helium can economically be produced as a primary product (Beebe *et al.*, 2000; Johnson, 2012). Strata in the lower Paleozoic have the predominance of occurrences greater than 0.3% He (Figure 4) and, in particular, the Deadwood Formation had anomalously high concentrations of helium in all its tests in the study area (Figure 5).

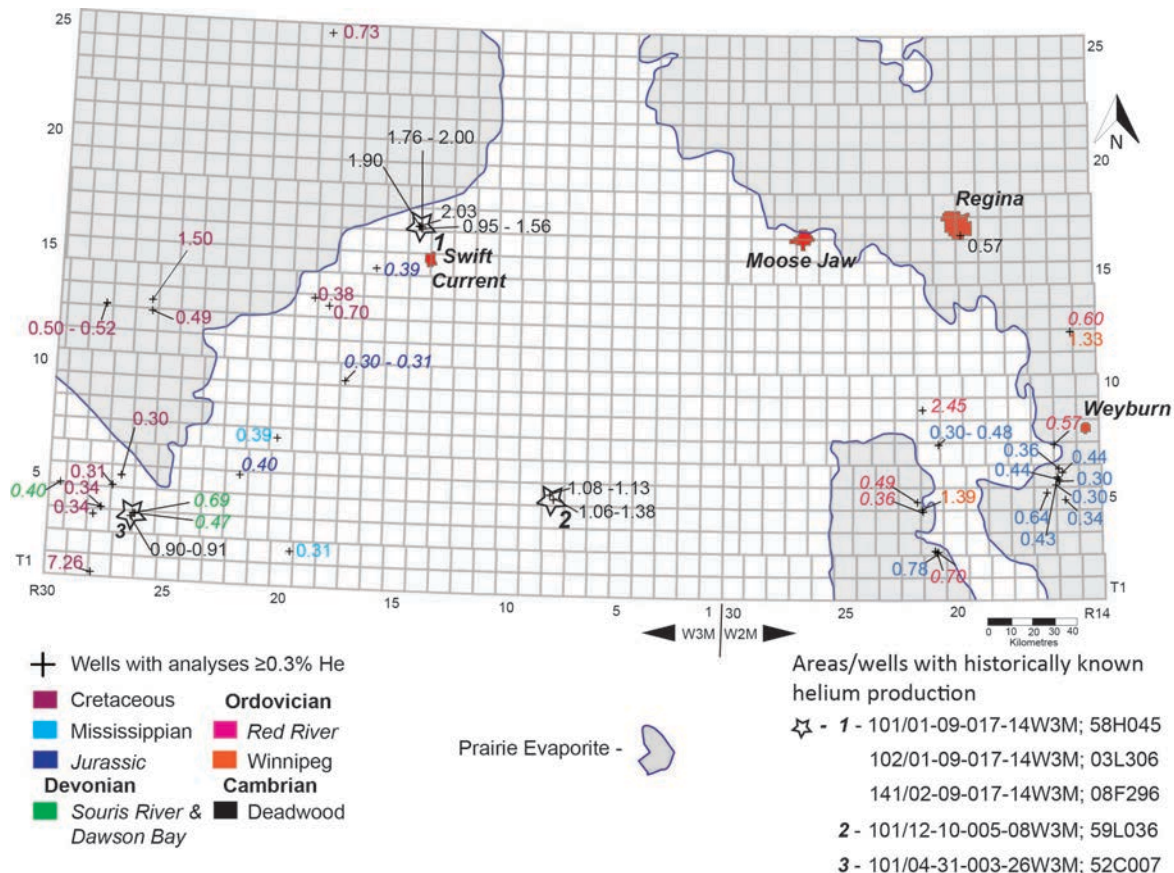


Figure 4 – Distribution throughout the geological column of helium occurrences with concentrations greater than the economic cutoff of 0.3% He, shown by formation and/or period. Also shown is the distribution of the Prairie Evaporite and areas of historically known helium production. Past-producing wells 02-09-017-14W3M and 12-10-005-08W3M were reporting helium production in August 2016. Abbreviations: T - Township, R - Range, W2M - west of the Second Meridian, W3M - west of the Third Meridian.

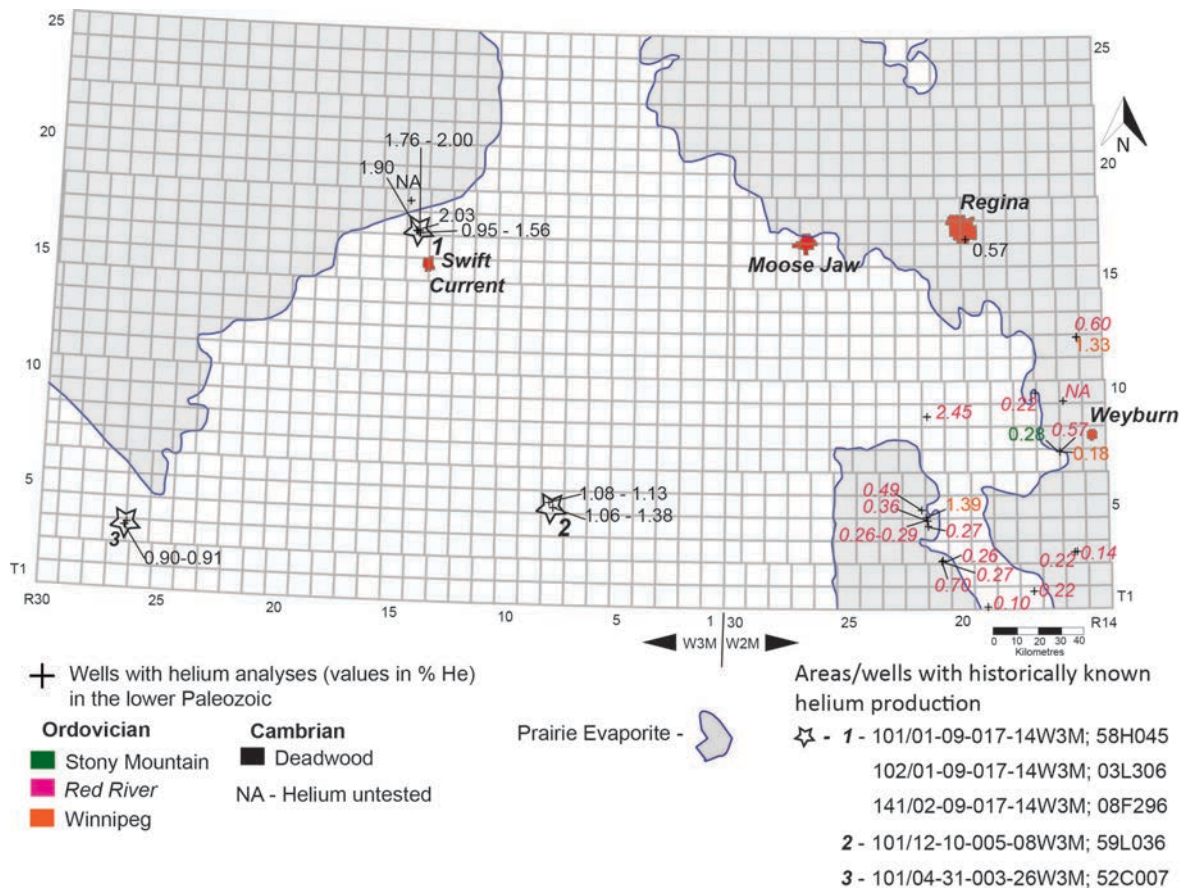


Figure 5 – Distribution of all known helium tests in the lower Paleozoic (Deadwood, Winnipeg, Red River and Stony Mountain formations). NA indicates that the well has a gas analysis, but was not tested for helium: these have been included to show the distribution of all wells that have had gas analyses. Past-producing wells 02-09-017-14W3M and 12-10-005-08W3M were reporting helium production in August 2016. Abbreviations: T - Township, R - Range, W2M - west of the Second Meridian, W3M - west of the Third Meridian.

The Deadwood Formation has been the primary focus of helium exploration and production in Saskatchewan. Understanding the potential for helium in the Deadwood Formation and its relationship with the underlying Precambrian rocks is the main focus of the remainder of this report.

Possible Source Rocks

The number of wells that penetrate the Deadwood Formation is quite low (117) compared to the overall number of oil, gas and potash wells in the study area (over 35 000), and the Precambrian has even fewer penetrations (46). As a result, developing a sound geological model for the origin of the helium deposits in southwest Saskatchewan is problematic, given the scant data available.

The isotopic composition of the helium in the study area is unknown, and the lithium concentrations in the pore waters have not been measured. Therefore, although it is unlikely the helium was generated from lithium/hydrogen sources, this cannot be completely dismissed, as Jensen (2015) found slightly elevated lithium values in the brines of the Duperow, Birdbear, Winnipegosis and Red River formations in several wells in southeastern Saskatchewan. Unfortunately, testing the deeper brines in the study area has proven challenging because of the limited number of actively producing wells in Paleozoic strata.

Another possible model for the geological source of helium in southwest Saskatchewan is the presence of a sedimentary ore deposit with a high concentration of uranium and thorium across the unconformity at the contact between the Precambrian and the Paleozoic. As there is no evidence from the available data to support this theory, further work is required to evaluate this possibility.

Given the geological conditions existing in southwestern Saskatchewan, two more likely models are 1) a granitic basement source (Precambrian) or 2) a shale with stagnant pore waters source (Deadwood Formation).

Granitic Basement (Precambrian)

In southwestern Saskatchewan, Burwash and Cumming (1974, 1976) identified high concentrations of uranium (15.25 to 23.99 ppm U) and thorium (46.4 to 82.3 ppm Th) in Precambrian rocks from the Saskoil Fosterton 101/15-03-017-18W3M; 57L031 well and the CPEC M.U.S. Cantuar Unit 101/02-21-016-17W3M; 57H042 well (wells 5 and 6, respectively, on Figure 3) and suggested that late in the Hudsonian orogeny, a uranium-thorium-rich epizonal pluton emplaced to the west of Swift Current was probably associated with acid volcanism. This theory was substantiated by Collerson *et al.* (1988) and Treptau (1999), who examined all 11 cores from the study area that intersected the Precambrian basement (Figure 3) and identified the rock types as a mixture of granitic and volcanic suites (Table 1).

A cursory look at the Precambrian structural provinces in the surrounding jurisdictions of Montana and southeastern Alberta in association with Saskatchewan's southwest corner reveals a complex geological setting (O'Neill and Lopez, 1985; Collerson *et al.*, 1988, 1989; Boerner *et al.*, 1998; Kreis *et al.*, 2004; Foster *et al.*, 2006). The study area is underlain by several blocks and tectonic provinces (Figure 6) that have influenced sedimentation and created structural elements that were active throughout the Phanerozoic (Kent and Christopher, 1994; Figure 1).

One of the long-lived structural elements of particular interest is the Great Falls Tectonic Zone, which has been interpreted as either an intercontinental shear zone or a suture zone between the Hearne and Wyoming cratons (Boerner *et al.*, 1998; Foster *et al.*, 2006). Lengyel (2013) mapped the heat generation at the top of the Precambrian and agreed with the earlier work of Burwash *et al.* (1994) who theorized that a heat-flow anomaly exists in southwest Saskatchewan near Swift Current. Lengyel suggests that one possible explanation for the heat-flow anomaly could be groundwater circulation in the basement, which would require open faults, allowing flow to occur in the area. It is proposed that faults and fractures produced by movement of structural elements, and in particular movement within the Great Falls Tectonic Zone, may have also allowed for the migration of helium from the basement.

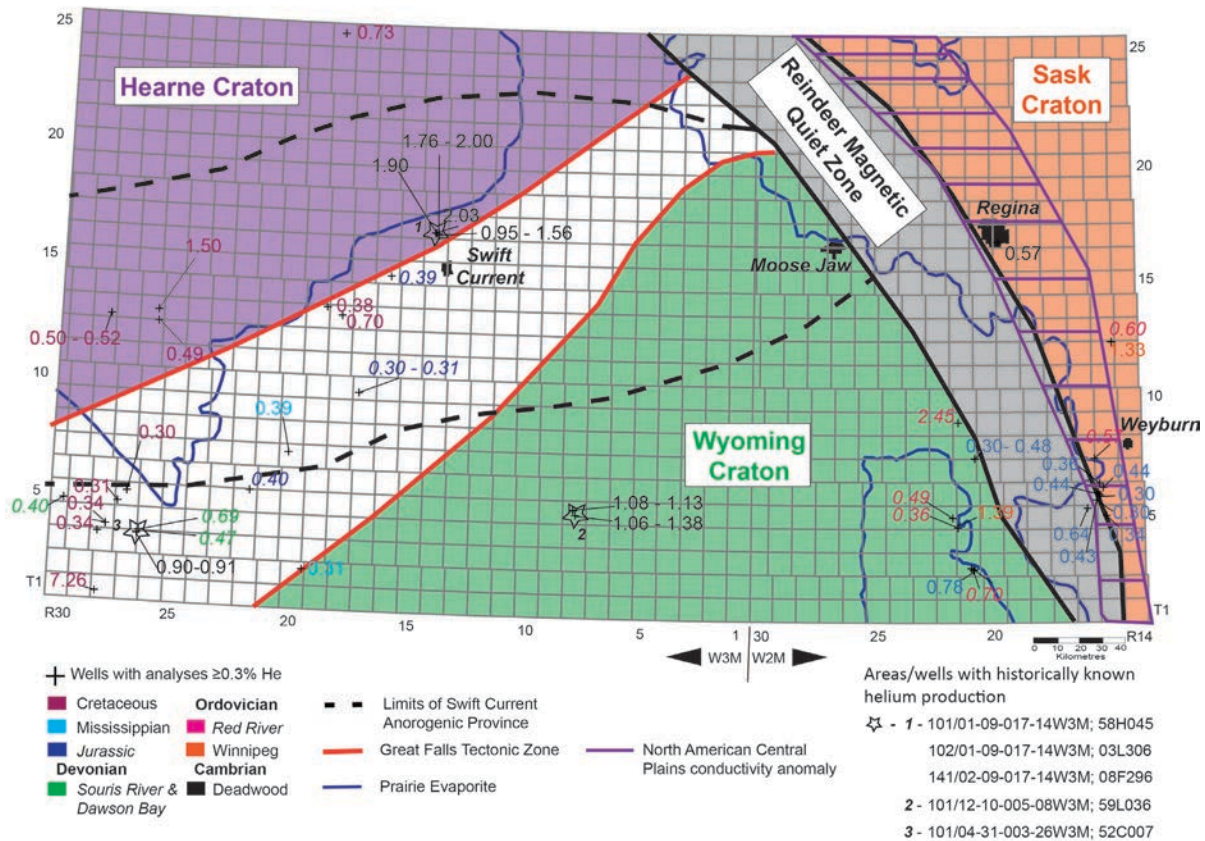


Figure 6 – Map of the study area with tectonic provinces of Kreis *et al.* (2004), subsurface extents of the Prairie Evaporite, and location of helium occurrences in the Deadwood and other formations (past-producing wells 02-09-017-14W3M and 12-10-005-08W3M were reporting helium production in August 2016). The North American Central Plains conductivity anomaly is a narrow region of high conductivity in the basement rocks that extends from northern Saskatchewan into southeastern Wyoming. The Swift Current Anorogenic Province has been defined by Collerson *et al.* (1989). Abbreviations: T - Township, R - Range, W2M - west of the Second Meridian, W3M - west of the Third Meridian.

Deadwood Formation Shale

In Saskatchewan, the Cambrian has been divided into three units (Paterson, 1971; Kreis *et al.*, 2004; Dixon, 2008): a basal sandstone (BSU); the Earlie Formation (glaucconitic siltstones interbedded with fine-grained sandstones and shales); and the Deadwood Formation (interbedded siltstones, fine-grained sandstones, and shales with minor interbeds of micritic limestone). Some authors have chosen to forgo the tripartite subdivision (Greggs, 2000) and refer to the entire section of sedimentary rocks as the Deadwood Formation.

In the southwest corner of the province, these rocks are dominated by shale, and it is difficult to distinguish the Earlie Formation from the Deadwood Formation (Greggs, 2000; Dixon, 2008). It also appears that the BSU is patchy in distribution, as it infills the irregular paleotopography of the underlying Precambrian basement (Kreis *et al.*, 2004). Dixon (2007) also noted that the Deadwood–Earlie unit is locally sandy.

Kreis *et al.*'s (2004) mapping of the Deadwood Formation (due to issues distinguishing each of the Cambrian units in either geophysical logs or seismic reflection surveys, these maps use 'Deadwood Formation' to mean all three units) suggests a considerable variability of thickness in the study area, from a regional maximum of over 400 m in the west, thinning eastward to 100 m. Locally the Deadwood Formation also thins dramatically over Precambrian highs (Kreis *et al.*, 2004; Marsh and Love, 2014), suggesting significant variation in Precambrian relief prior to its deposition.

Melnik (2012) mapped the 12 major aquifers in the Phanerozoic in southwest Saskatchewan and generated maps showing total dissolved solids (TDS), hydrochemical analyses, density and freshwater flow. Melnik (2012) also generated representative vertical hydraulic and TDS cross-sections with groundwater flow maps for each Phanerozoic aquifer system. He divided the Cambrian into a Basal Deadwood Aquifer (BSU of Kreis *et al.*, 2004) and an Upper Deadwood Aquitard (Earlie and Deadwood formations of Kreis *et al.*, 2004). The aquitard does contain minor sandstone tongues that are not in contact with the BSU in the study area, but merge together in eastern Saskatchewan, forming a major aquifer.

Melnik (2012) also noted that the fluid-flow gradients in southwestern Saskatchewan are low within the aquifers below the Birdbear aquifer, which may suggest low flow rates and longer residence time, and are interpreted as "slugs of heavy (high TDS) water" (Melnik, 2012, p.81) that are stagnant. In particular, Melnik (2012) identified that the Basal Deadwood Aquifer's TDS pattern is the result of a very long migration path and a very slow flow of the formation water. This would help support the theory of helium being derived from the upper Deadwood Formation shales.

Other shales in the lower Paleozoic include shales in the Winnipeg Formation (informally known as the Icebox Member), and the dolomitic shales of the Stonewall Formation, but these are generally limited in thickness and areal extent (Kreis *et al.*, 2004) and therefore would likely not make a large contribution to helium generation in the study area.

Helium Potential and Trapping in Southwestern Saskatchewan

In southwestern Saskatchewan the lower Paleozoic is deemed to be the most favourable target for helium, based on multiple helium concentrations in gas of greater than 0.3% He (Figures 4 and 5), proximity to a granitic source, and the presence of ancient stagnant pore waters within lower Paleozoic shales.

The helium occurrences with concentrations greater than 0.3% He are not limited to one particular craton or tectonic zone, and nor are they restricted to the Swift Current Anorogenic Zone (Collerson *et al.*, 1989). However, most of the high helium concentrations do appear to be geographically distributed close to the Prairie Evaporite edge (Figure 4). This edge closely mimics the edge of the Swift Current Platform (Figure 1), which has undergone numerous vertical fluctuations throughout the Phanerozoic (Kent and Haidl, 1993; Kent and Christopher, 1994). This relationship could be used to suggest that the distribution of helium in this area is related to either fracture and fault systems along the edge of the Swift Current Platform/Prairie Evaporite, or more simply due to the greater number of wells—and therefore a greater number of gas analyses—along this edge (Figure 3).

The only >0.3% He occurrence that does not lie near the Prairie Evaporite edge is the Deadwood Formation occurrence at CVE Mankota 101/12-10-005-08W3M; 59L036 (well 2 on Figures 1, 4, 5 and 6). This well lies on the northern edge of the Bowdoin Dome (Figure 1) and as of August 2016 was reporting helium production. The Bowdoin Dome is a paleotopographic high that straddles the Canada–U.S. border, and which has been attributed to a domal uplift of Laramide origin that probably developed as a structural feature above a crustal block that was elevated by an isolated igneous body at the top of the Precambrian (Smith, 1970). Evidence for an igneous origin of the Bowdoin Dome was given by Schroth (1953), who noted several igneous dykes on the dome.

As a rule, the deeper in the Phanerozoic, the higher the average helium concentrations (Figure 4), with one notable exception in the Upper Cretaceous near the southwest corner of the study area. In a DST test in Pine Cliff Willow Creek 141/02-07-001-28W3M; 01G129, an anomalously high value of 7.26% He, with 8.28% N₂, 55.94% CO₂, 4.32% H₂ and 24% other gases, was recorded from a depth of 389.0 to 402.0 m. It was noted in the analysis that the received pressure differed significantly from the operating pressure, and this may be indicative of a non-representative sample. The test does not appear to have data entry errors (*i.e.*, the total value adds up to 100%), but because it is such an anomalously high concentration, it is unknown whether it is truly representative of the formation tested.

Due to the limited deep drillhole data, it is difficult to ascertain the source of the helium in the study area, and therefore also its geographic limits. As well, because of the limited data, the subtle nuances of the various facies needed to develop sound models for stratigraphic trapping are also unknown.

At this early stage of exploration and development of helium resources in Saskatchewan, the most obvious and easiest targets to suggest for exploration are structural traps characterized by sedimentary rocks that are draped over Precambrian monadnocks. These are easily identified in seismic surveys.

Composite seismic maps developed for the area by Sawatzky (1967a, 1967b, 1967c, 1967d) show several untested closed structures and noses, and although these maps are considerably outdated, they may be used as a starting point for further delineation of potential helium exploration targets.

Once structural targets are identified, perhaps more critical to identifying potential helium traps is locating an effective seal in sediments draping the structural highs, such as that found in the silicified siltstones trapping the helium in the Wilhelm pool.

Summary

Helium was reported in gas analyses from wells in southwestern Saskatchewan as early as the 1950s, most notably from the Battle Creek, Wilhelm and Mankota areas. Helium production began in the Wilhelm pool (Township 17, Range 14W3) in 1963 and continued until 1977. Saskatchewan production of helium ceased when market conditions deteriorated, but with current improved market conditions helium production is again being reported from two past-producing wells in the southwest part of the province, one just northwest of the city of Swift Current and the other near the town of Mankota.

With the mounting interest in helium due to supply concerns, the Saskatchewan Geological Survey embarked on a program to increase understanding of the generation, accumulation and geological setting of helium resources in the province.

As a first step, an exhaustive examination of gas analyses in Ministry of the Economy well files from southwestern Saskatchewan was undertaken (this study), which identified anomalous helium concentrations in stratigraphic intervals from the Cambrian to the Cretaceous.

The results of this examination can be summarized as follows:

- The lower Paleozoic formations—in particular, the Deadwood Formation—have the highest helium concentrations in the study area (with the exception of an Upper Cretaceous helium occurrence in the extreme southwest corner of the study area).
- The two most likely models for the development of helium occurrences in southwest Saskatchewan are
 - 1) generation of helium by radioactive decay of uranium and thorium in Precambrian granitic basement rocks, migration of the helium out of the impermeable granite along fracture and/or fault systems developed throughout the Phanerozoic by the numerous tectonic elements in this part of the province (in particular, the Great Falls Tectonic Zone), and entrapment of the helium in sediments draping structural highs, with effective seals such as silicified siltstone; and
 - 2) generation of helium by radioactive decay of uranium and thorium naturally occurring in the shales of the lower Paleozoic rocks (primarily Deadwood Formation shales), natural migration of the helium into stagnant pore water, partitioning of the helium from the water into gas, and trapping of the helium in a similar manner to the first model.
- Based on current understanding, the most viable model for exploration targets seems to be closed structures created by Cambrian to Cretaceous sediments draped over Precambrian monadnocks.

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Appendix 1 – Gas Analyses from Wells in Southwestern Saskatchewan (Townships 1 to 25, Ranges 14W2M to 30W3M) [see separate Microsoft® Excel® file]

The data in this appendix are from wells drilled within an area covered by Townships 1 to 25, Ranges 14 west of the Second Meridian (W2M) to 30 west of the Third Meridian (W3M). As of January 2016, close to 38 000 oil, gas and potash wells have been drilled in this area. Of these wells, 1412 were identified in Government of Saskatchewan data files as having gas analyses. Some of these wells have multiple gas analyses throughout the stratigraphic column, totalling 1873 gas analyses for the 1412 wells identified.

The wells presented in the spreadsheet were drilled and tested over a span of nearly 80 years, by many different companies, and under many different circumstances; drilling and sampling technology, along with type and precision of analytical methods have changed significantly over this time period. As well, the author is unaware of any circumstances where helium concentrations can be increased during gathering and testing, but it is very easy to deplete helium concentrations during this process (*e.g.*, inadequate container selection can allow the small helium molecule to easily escape to the atmosphere). Therefore, caution is advised when using the data to plan exploration or drilling programs, since values may not be truly representative of actual reservoir conditions.

Lane (1987) reported five gas analyses for well 101/16-11-006-20W3/00; 78I116 (CPEC 16-11-6-20), none of which could be found in the Ministry of the Economy's well file. As a result, the data were not included in Appendix 1, but are listed below, for convenience.

Formation	Sampling Point	Depth - Top (m)	Depth - Base (m)	He	N ₂	CO ₂	H ₂	Remarks
Duperow	Unknown	1844.0	1859.0	0.0026	0.7121	0.1519	NA	.0020 other as per Lane (1987)
Duperow	Unknown	1869.9	1886.0	0.0027	0.9000	0.0553	NA	
Duperow	Unknown	1930.0	1948.0	0.0019	0.9453	0.0006	NA	
Souris River	Unknown	2037.0	2041.5	0.0030	0.9590	0.0007	NA	
Souris River	Unknown	2028.0	2033.0	0.0040	0.9369	0.0006	NA	

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