

Preliminary Investigation of Potash Potential in Alberta



Energy Resources Conservation Board

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Abstract

From the late 1800s onward, salt has been an essential ingredient in the development of Alberta's mineral resource industry. The same cannot be said for potash, a potassium chloride–bearing impurity of salt for which the neighbouring province of Saskatchewan is the worldwide leader in production. Interest in potash exploration has recently spilled over the border into eastern Alberta. This is largely due to global potash markets that continue to experience favourable growth due to the steady growth in the world's population and subsequent demand for food-crop fertilizers. Renewed interest in Alberta's potash potential is encouraged by the results of historical 1940s drilling, mid-1960s exploration and mid-1970s government work. Thus, one objective of this report is to provide an historical overview of potash exploration and research in Alberta.

The Alberta portion of the Western Canada Sedimentary Basin contains an enormous volume of pure or nearly pure halite in the Lower to Middle Devonian Elk Point Group. When present, salt impurities occur mainly within the Prairie Evaporite Formation of the Upper Elk Point Group. In Alberta, according to Energy Resource Conservation Board well records, at least 470 oil and gas wells have penetrated into or through the Prairie Evaporite Formation, of which fewer than 70 wells have been cored. Mid-1990s government studies of Alberta formation waters reported that waters of the Beaverhill Lake Group, which overlies the Prairie Evaporite Formation, had potassium concentrations of up to 19 000 mg/L. A primary objective of this report, therefore, is to test historical core and water data for their potash potential. We interpreted more than 300 new semiquantitative geochemical analyses on selected Prairie Evaporite Formation-water datasets. The geochemical core analyses were obtained using a portable x-ray fluorescence (XRF) analyzer, which is a modern, nondestructive means of testing these historic cores, some of which date back to 1944.

Calcium sulphate (CaSO₄) and carnallite (KCl·MgCl₂·6H₂O) are the two main impurities recorded in the XRF analyses. Carnallite is particularly prevalent (up to 48%) in core from the well Pectal Dina 10-32-45-1W4, drilled in the Paradise Valley area south of the community of McLaughlin. The Pectal Dina core also contains the thickest zone of carnallite: a 35 m intersection (1049–1084 m) of greater than 20% carnallite with 1%–8% K₂O. Five of the six wells investigated in this report yielded spot analyses with greater than 10% sylvite (KCl). Two analyses from Vermilion Consolidated Oils #15 (VCO#15) 6-12-49-6W4, collared south of the town of Vermilion, yielded 19 wt. % and 13 wt. % K₂O, values, which are greater than the suggested potash exploration cut-off grade of 12 wt. % K₂O. Vermilion Consolidated Oils #15 also has the thickest zone of potash, with seven samples representing more than 9 m of continuous core yielding an average grade of 11 wt. % K₂O. Distinct chemical differences within the salt cores selected for this report suggest that there is presently inadequate knowledge of the chemical and physical (e.g., variability in evaporation trends) properties of these strata in Alberta. Therefore, a local-scale potash deposit may exist in the Prairie Evaporite Formation of southeastern Alberta.

Previous studies have shown that formation waters associated with Middle Devonian strata in southeastern Alberta, particularly those of the Beaverhill Lake Group, have elevated levels of potassium; investigators thought the anomaly corresponded to potash mineralization in the underlying Prairie Evaporite salt. The present report illustrates that formation waters containing greater than 10 000 mg/L K are prevalent throughout western Alberta in areas that are not underlain by the Prairie Evaporite Formation. The most significant concentration of high-potassium waters occurs in the Swan Hills Member of the Beaverhill Lake Group, which represent early Beaverhill Lake reef growth in the Swan Hills area of west-central Alberta. Thus, rather than heavy evaporative brines propagating directly upwards from the Prairie Evaporite to the overlying Beaverhill Lake Group, the dissolution and migration of potassium-enriched fluids might favour Beaverhill Lake and equivalent strata west of the Prairie Evaporite Formation because these units are now structurally at a lower elevation. Regardless, K-rich

formation waters should be further evaluated by hydrodynamic modelling to explain the origin of the potassium, and as an economic prospect for potassium extraction.

1 Introduction

Potash refers to potassium-bearing compounds and minerals, the most common being potassium chloride (KCl) or potash. It is derived from deposits of salt that contain the element potassium (K) in water-soluble form. Potash is essential for modern agriculture because it improves water retention, yield, nutrient value, taste, colour, texture and disease resistance of food crops. Therefore, approximately 95% of world potash consumption is in the form of fertilizer.

The world potash market is characterized by a limited number of producers, with four countries—Canada, Russia, Germany and Belarus—accounting for three-quarters of global output. Canada is the world's largest producer of potash with almost a third of the total. Saskatchewan has the most significant potash reserves in Canada (7–23 Bt KCl conventional and 69–103 Bt KCl solution; Berenyi et al., 2008), in the Middle Devonian strata of the Elk Point Group. The Elk Point Group salt deposits formed within a broad intracratonic basin that extended from North Dakota and northeastern Montana at its southern extent, northwards to southwestern Manitoba, southern and central Saskatchewan, eastern and northern Alberta, and parts of northeastern British Columbia and the Northwest Territories.

During the mid-1910s, the discovery of salt by deep drilling in Saskatchewan and Alberta was shown, in subsequent studies, to be the same contiguous distribution of salt, known as the Prairie Evaporite Formation (Hamilton, 1971). One significant cross-border difference was that salt within the Prairie Evaporite Formation in Saskatchewan contained 'impurities' formed when seawater became so concentrated that potash salt precipitated. In contrast, the Alberta basin portion of the Prairie Evaporite Formation was thought to have been continually replenished by normal marine water from the northwest, which kept the concentration of the seawater below the level required for large-scale precipitation of potash minerals (Hamilton, 1971).

This last point, however, is subject to some debate, particularly because

- 1) the extent of potash mineralization along the Saskatchewan-Alberta border and extending into Alberta is not clearly defined;
- 2) the depositional complexity of the Prairie Evaporite Formation makes it difficult to establish salt distribution and thickness on a regional scale;
- 3) only a small number of exploration wells have penetrated and cored the Prairie Evaporite Formation in eastern Alberta, limiting our knowledge of the potash potential; and
- 4) few geochemical data for Alberta salt are known to the authors.

The purpose of this report, therefore, is to conduct an historical examination of potash exploration in Alberta, together with a reconnaissance investigation that includes geological modelling of Alberta's groundwater and formation water datasets, and a preliminary geochemical evaluation of selected Prairie Evaporite cores.

2 General Geology of Salt and the Prairie Evaporite Formation

The major salt deposits of the Western Canada Sedimentary Basin (WCSB) occur within the Lower to Middle Devonian Elk Point Group (Figure 1), which comprises limestone, dolomite, anhydrite, rock salt, redbed and fine- to coarse-grained siliciclastic rocks. It unconformably overlies Precambrian or lower Paleozoic rocks that have up to 1400 m of relief, and is overlain by a thin, flat layer of green or reddish brown shale of the Watt Mountain Formation (Meijer Drees, 1994; Grobe, 2000). It has been mapped in Alberta by Hamilton (1971), Meijer Drees (1986, 1994) and Grobe (2000); in Saskatchewan by Holter (1969) and Yang et al. (2009a–c); and in Manitoba by Bezys et al. (2008a, b).



Figure 1. Formations of the Devonian Elk Point Group (from Grobe, 2000).

Salts of the Elk Point Group can be divided into four main groups (Figure 1). The lower and upper Lotsberg Formation salts occur in the Lower Elk Point Group and are separated by unnamed red shale that ranges in thickness from 28 to 67 m. The Cold Lake Formation salt represents the middle to upper part of the Lower Elk Point Group. Lastly, the Prairie Evaporite Formation, which is the focus of this report, consists of a thick sequence of evaporite that occurs in the Upper Elk Point Group. The Upper Elk Point Group is much more widespread in distribution relative to the lower Elk Point Group. The Prairie Evaporite Formation underlies most of southern Saskatchewan and parts of southwestern Manitoba and eastern Alberta (Figure 2).

All major salt deposits form when a body of seawater is partly or wholly cut off from the ocean by, for example, differential downwarping within an embayment and formation of a sill or reef barrier. The reefal barrier that separates the Upper Elk Point Evaporite basin from the open ocean is the Presqu'ile barrier complex (Figure 2; Kyle, 1981; Rhodes et al., 1984). This constricted linear buildup of Devonian carbonates up to 200 m thick separates two depositional sub-basins: the Mackenzie sub-basin to the north, where shale and argillaceous limestone were deposited; and the Elk Point sub-basin to the south, where evaporites and lesser carbonates formed. In a restricted basin, the seawater evaporites and salt begins to precipitate in an evaporation cycle that depends on the saturation state with respect to its solutes. Calcium carbonate and calcium sulphate precipitate first, followed by sodium chloride and, lastly, by polyhalite (including magnesium- and potassium-enriched salt).



Figure 2. Distribution and thickness of salt within the Devonian Elk Point Group in the Alberta and Saskatchewan portions of the Western Canadian Sedimentary Basin (from Grobe, 2000). Location of the Presqu'ile barrier complex from Hannigan (2007). Location of the Meadow Lake Escarpment and the Central Alberta and Saskatchewan sub-basins from Holter (1969).

Several authors, including Holter (1969), Hamilton (1971) and Meijer Drees (1994), have suggested that another major restriction of the seawater was caused by a reefal barrier associated with the Meadow Lake Escarpment, which then limited the flow of seawater southeastward and divided the Central Alberta subbasin from the Saskatchewan sub-basin (Figure 2). The Meadow Lake Escarpment is a pre-Devonian erosional feature that affected much of the Middle Devonian sedimentation. For example, depositional facies changes in several Upper Devonian strata occur across the escarpment (Switzer et al., 1994). Some authors have attributed the origin of the Meadow Lake Escarpment to transcurrent basement faulting (e.g., Haites, 1960; Douglas et al., 1970). The Prairie Evaporite Formation isopach map of Grobe (2000), however, does not show evidence of a 'reef barrier' comparable to the Presqu'ile barrier overlying the Meadow Lake Escarpment. Rather, the division of these basins corresponds to the inflection point between the Alberta and Williston basins, which is southeast of the Meadow Lake Escarpment and may be dependent on tectonic events associated with the Sweetgrass Arch. The Sweetgrass Arch encompasses an area of approximately 32 000 km² in northwestern Montana, southeastern Alberta and southwestern Saskatchewan, and was active during several stages of geological time, predominantly pre-Devonian and pre-Jurassic (Herbaly, 1974; Kent and Christopher, 1994).

Salt of the lower and upper Lotsberg and Cold Lake formations formed normal first-cycle marine evaporite deposits by encroachment of the ocean from the north, followed by restricted circulation between the ocean and the lower Elk Point sea (Hamilton, 1971). The Lower Elk Point salts are closely associated with clastic sediments suggestive of shallow water and an oxidizing environment during their formation (Schmalz, 1969). In addition, the low bromine content of the lower Elk Point salt (Wardlaw and Watson, 1966) indicates that these salts were dissolved and redeposited by meteoric water. Under these conditions, the Lotsberg and Cold Lake salt brine was refined and purified to form the 'pure salt' that is heavily favoured by ongoing sodium chlorate and chlor-alkali production in Alberta. The Central Alberta sub-basin was filled during deposition of the Lower Elk Point Lotsberg and Cold Lake salts.

In contrast, the younger Prairie Evaporite Formation formed in deepwater, with brine depths decreasing until the desiccation of the evaporite cycle was completed. In isolation, elevated salinities at the centre of the Saskatchewan sub-basin advanced the progressive evaporation cycle of the Prairie Evaporite Formation to polyhalite accumulation by the process of "evaporative drawdown" (Maiklem, 1971). Several major cycles of flooding and desiccation then led to partial dissolution of the evaporites and the accumulation of potash salts (Meijer Drees, 1994). After the evaporate deposition was completed, shallow-marine waters deposited the Second Red Beds and carbonate sediments of the Dawson Bay Formation, after which there was a brief emergence and deposition of the brackish clastic sediments (First Red Beds) of the Watt Mountain Formation to mark the end of Elk Point deposition.

Hamilton (1971) and Meijer Drees (1986) mapped the salt deposits in the subsurface of the Interior Plains. The depositional complexity of the Prairie Evaporite Formation makes it difficult to establish salt distribution and thickness on a regional scale. Grobe (2000) completed an isopach map of the Prairie Evaporite Formation using a cut-off of >40% halite and showed that the Prairie Evaporite ranges in thickness from <25 m in southern Alberta to >300 m in northeastern Alberta (Figure 2). Centres of maximum deposition occur in northeastern Alberta and central Saskatchewan (thickness of about 200 m near Saskatoon); the latter correlates with the recent Saskatchewan basin isopach thickness work of Yang et al. (2009a–c).

In general, the Prairie Evaporite Formation grades upward from layered halite and anhydrite into massive halite with several colour variations: colourless, white, light and dark grey, light and dark brown, light and dark pinkish to red. In Saskatchewan, the upper 60 m of the Prairie Evaporite Formation includes three potash-bearing members: the Esterhazy, Belle Plaine and Patience Lake members (e.g., Holter, 1969; Fuzesy, 1982; Yang et al., 2009a–c). The potash zones are generally between 6 and 15 m thick, and contain one or more beds of potash with intervening beds of lesser amounts of potash or barren salt. All three members contain sylvite (KCl) and are mined for potash in Saskatchewan, where there are currently

nine underground and/or solution mines in operation. Carnallite (KCl·MgCl₂·6H₂O) increases towards the margins of each member (Holter, 1969), except along the southern boundary of the Prairie Evaporite Formation. The potash beds of the Esterhazy Member are thinner and of lower grade (2%–20% sylvite; Holter, 1969) relative to the other members but are mined at the Esterhazy, Rocanville and Mosaic Belle Plaine potash mines. The Belle Plaine Member is a distinctive potash-rich sequence (0%–33% sylvite; Holter, 1969) that is separated from the Esterhazy Member by a fourth potash marker layer known as the White Bear potash-bearing marker bed. The Belle Plaine Member is mined at the Mosaic Belle Plaine potash mine. The uppermost member of the Prairie Evaporite Formation, the Patience Lake Member, ranges in thickness from 0 to 27 m (Holter, 1969) and contains sylvite-rich beds (10% to >30% sylvite; Holter, 1969) with halite and clay bands. The Patience Lake Member is mined in the Saskatoon, Lanigan and Mosaic Belle Plaine potash mines.

Based on the isopach work of Yang et al. (2009a), the Patience Lake Member is the most probable unit within the Prairie Evaporite Formation to extend into southeastern Alberta between latitudes 51.5° and 53°N. Grobe (2000) showed that the Prairie Evaporite Formation in this part of southeastern Alberta is between 100 and 130 m thick.

3 Historical Evaluation: Summary of Potash Exploration in Alberta

According to Hamilton and Olson (1994), the oldest record of mineral production in the Western Canada Sedimentary Basin dates back to 1820, when about 4 tons of salt were collected annually from saline springs in northeastern Alberta for use by the trading posts and missions of the Mackenzie River district (Allan, 1920).

Prominent papers by Allan (1943) and Cole (1915, 1948) represent some of the first published accounts of salt and potash exploration in Western Canada. Between 1910 and 1914, an early exploratory well near Neepewa, Manitoba encountered salt brine that was about 70% salt saturated. Between 1907 and 1912, drillholes by the Northern Alberta Exploration Company penetrated thick beds of rock salt near Fort McMurray, Alberta. During this period, other wells drilled in the Fort McMurray area, notably the Cottee well (10-89-9W4), penetrated and cored nearly 60 m of salt near Waterways, Alberta (Allan, 1943). Between 1927 and 1929, rock salt was encountered near Unity, Saskatchewan; the first attempt to mine potash in Canada occurred during the early 1950s at this locale. Advances in drilling techniques in the early to mid-1940s led to several southeastern Alberta discoveries, including salt in the following wells: Princess CPR No. 1 (13-22-20-12W4), Vermilion Consolidated Oils #15 (6-12-49-6W4), Anglo Canadian Beaverhill Lake No. 2 (11-11-50-17W4), Provost No. 2 (1-33-37-3W4), Imperial Looma No. 1 (10-50-23W4) and Elk Point No. 1 (7-26-56-5W4).

Salt discoveries throughout Western Canada led Cole (1948) to suggest that "underlying the western plains of Canada there is a large deposit or deposits of sodium chloride...associated with the sodium chloride are certain potash-bearing salts...and...potash salts have been encountered in at least eight drill holes widely scattered over the western provinces." In support of these statements and from an Alberta perspective, Cole (1948) reported 4.05% and 3.32% K₂O over 2.7 m and 1.5 m from two wells in southeastern Alberta: Vermilion Consolidated Oils #15 and Provost No. 2, respectively (Table 1).

In 1958, the Potash Company of America became Canada's first potash producer with the opening of an underground potash mine at Patience Lake, Saskatchewan; due to water seepage, however, production stopped in 1959 (resuming in 1965). In 1964, Kalium Chemicals Ltd. opened the world's first potash solution mine near Regina, at a depth of 1585 m.

In 1965, Vermilion Consolidated Oils #15 was revisited by Golden (1965), who reported that 3.7 m of carnallite overlies a 122 m section of common salt, and that a pinkish and greyish potash mineral (potentially sylvite) occurs throughout the first 15 m of the Prairie Evaporite Formation. Furthermore,

	Table 1. Summar	y of known	chemical a	analyses	of the	Prairie	Evaporite	salt.
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Well Name Well ID Sample		Sample Depth (m)	NaCI (wt. %)	MgCl₂ (wt. %)	Carnallite (%)	KCI _{carnallite} (%)	Kcltotal (%)	Kclsylvite (%)	CaSO ₄ (wt. %)	Reference
Imperial Irma No.1	6-14-46-9W4	1321.31–1325.88	93.7	0.20	0.58	0.16	0.35	0.20	1.04	Hamilton (1971)
Vermilion Consolidate Oils #15	6-12-49-6W4	1061.01–1079.30	95.8	0.14	0.41	0.11	0.32	0.21	1.08	Hamilton (1971)
Vermilion Consolidate Oils #15	6-12-49-6W4	667.51–670.26	n/a	n/a	n/a	n/a	6.41	n/a	n/a	Cole (1948)
Blackfoot Devonian Test Syndicate No.1	12-15-50-2W4	1026.26–1033.88	98.4	0.15	0.45	0.12	0.18	0.06	0.60	Hamilton (1971)
Anglo Canadian Beaverhill Lake No.2	11-11-50-17W4	1554.48–1556.92	98.0	0.05	0.15	0.04	0.39	0.35	0.92	Hamilton (1971)
Anglo Canadian Beaverhill Lake No.2	11-11-50-17W4	1570.33–1572.16	99.0	0.03	0.09	0.02	0.16	0.14	0.70	Hamilton (1971)
Anglo Canadian Beaverhill Lake No.2	11-11-50-17W4	1595.32–1597.15	99.0	0.04	0.10	0.03	0.05	0.02	0.58	Hamilton (1971)
Anglo Canadian Beaverhill Lake No.2	11-11-50-17W4	1613.31–1616.35	99.3	0.06	0.17	0.05	0.03	0.00	0.27	Hamilton (1971)
Anglo Canadian Beaverhill Lake No.2	11-11-50-17W4	1629.16–1630.99	98.1	0.08	0.23	0.06	0.03	0.00	0.63	Hamilton (1971)
Anglo Canadian Beaverhill Lake No.2	11-11-50-17W4	1647.75–1650.80	98.3	0.02	0.06	0.02	0.02	0.01	0.86	Hamilton (1971)
Imperial Ardrossan No.1	8-17-53-21W4	1764.79–1767.84	97.2	0.05	0.15	0.04	0.62	0.58	0.65	Hamilton (1971)
Chemcell Clover NACL	10-17-53-23W4	1824.53–1824.84	94.2	0.06	0.16	0.04	0.03	0.00	2.57	Hamilton (1971)
Chemcell Clover NACL	10-17-53-23W4	1824.84–1826.06	94.0	0.04	0.10	0.03	0.03	0.00	3.47	Hamilton (1971)
Chemcell Clover NACL	10-17-53-23W4	1826.36–1826.67	93.2	0.04	0.13	0.03	0.03	0.00	0.66	Hamilton (1971)
Chemcell Clover NACL	10-17-53-23W4	1831.54–1832.76	98.7	0.04	0.10	0.03	0.05	0.02	0.54	Hamilton (1971)
Imperial Pinedale No.1	7-28-54-16W4	1393.24–1399.34	94.7	0.13	0.39	0.10	0.17	0.07	1.06	Hamilton (1971)
Imperial Willingdon No. 1	14-14-55-15W4	1280.16–1285.95	95.7	0.17	0.49	0.13	0.42	0.29	0.81	Hamilton (1971)
Anglo Home C&E Elk Point No.2	3-14-57-6-W4	855.27-858.01	92.0	0.08	0.23	0.06	0.23	0.17	2.33	Hamilton (1971)
Anglo Home C&E Elk Point No.2	3-14-57-6-W4	868.07-869.59	98.0	0.09	0.27	0.07	0.07	0.00	0.94	Hamilton (1971)
Anglo Home C&E Elk Point No.2	3-14-57-6-W4	880.26-883.31	96.6	0.12	0.34	0.09	0.32	0.23	1.00	Hamilton (1971)
Anglo Home C&E Elk Point No.2	3-14-57-6-W4	895.50-898.55	97.6	0.09	0.27	0.07	0.13	0.05	1.09	Hamilton (1971)
Anglo Home C&E Elk Point No.2	3-14-57-6-W4	916.23–919.28	97.9	0.04	0.13	0.03	0.04	0.00	1.67	Hamilton (1971)
Anglo Home C&E Elk Point No.2	3-14-57-6-W4	929.94-931.47	94.7	0.15	0.45	0.12	0.06	0.00	0.68	Hamilton (1971)
Anglo Home C&E Elk Point No.2	3-14-57-6-W4	944.27–945.18	99.0	0.06	0.18	0.05	0.03	0.00	0.57	Hamilton (1971)
Anglo Home C&E Elk Point No.2	3-14-57-6-774	957.07-958.29	97.6	0.04	0.10	0.03	0.02	0.00	1.66	Hamilton (1971)
Anglo Home C&E Elk Point No.2	3-14-57-6-774	980.24-981.46	97.8	0.02	0.07	0.02	0.02	0.00	1.66	Hamilton (1971)
Anglo Home C&E Elk Point No.2	3-14-57-6-VV4	991.51-992.43	98.9	0.03	0.08	0.02	0.02	0.00	0.71	Hamilton (1971)
Imperial Fedoran No. 1	13-22-57-23004	1708.40-1711.15	97.1	0.02	0.07	0.02	0.02	0.00	1.01	Hamilton (1971)
Imperial Ciyde No. I	9-29-39-24004	1/00.2/-1/00./1	97.2	0.40	0.00	0.00	0.02	0.02	0.73	Hamilton (1971)
Angelus Ashmont No. I	13-3-60-11004	1050.74-1059.18	98.0	0.18	0.53	0.14	0.05	0.00	0.62	Hamilton (1971)
Imperial Daning No. I	0.05.77.004	1410.23-1421.20	97.9	0.04	0.11	0.05	0.04	0.01	0.75	Hamilton (1971)
Christina River Hardy No. I	2-25-77-9004	580.64-601.98	97.2	0.07	0.20	0.05	0.05	0.00	2.10	Hamilton (1971)
Christina River Hardy No.1	2-23-77-9004		90.0	0.59	0.11	0.40	0.03	0.00	0.99	Hamilton (1971)
	2-23-77-9004	130.09-130.40	90.4 07.6	0.04	0.11	0.05	0.23	0.20	2.01	Hamilton (1971)
Bear Vampire No. 1	7-20-07-12004	417.27-417.00	97.0	0.06	0.10	0.05	0.42	0.37	1.79	Hamilton (1971)
Bear Vampire No. 1	7-20-07-12004	453.12-434.04	95.0	0.05	0.14	0.04	0.03	0.00	0.52	Hamilton (1971)
Bear Vampire No.1	7 28 87 12/04	433.05-433.90	00 1	0.02	0.03	0.01	0.04	0.05	0.55	Hamilton (1971)
Dear Vampire No. 1	7-20-07-12004	479.70-400.00 501.70, 502.01	99.1	0.14	0.40	0.11	0.00	0.00	0.43	Hamilton (1971)
Bear Vampire No. 1	7 28 87 12///4	501.70-502.01	90.0	0.15	0.30	0.10	0.04	0.00	0.07	Hamilton (1971)
Bear Vampire No. 1	7-20-07-12004	519.07	99.4 07.0	0.05	0.14	0.04	0.03	0.00	0.34	Hamilton (1971)
Bear Vampire No.1	7-28-87-12///	540 72_541 02	97.9 07.7	0.03	0.20	0.07	0.03	0.00	1 37	Hamilton (1971)
Bear Vampire No.1	7-28-87-12///	555 01-555 35	97.7	0.03	0.09	0.02	0.03	0.01	5.78	Hamilton (1971)
Bear Vampire No.1	7-28-87-12///	572 11_573 02	92.0 03.0	0.02	0.07	0.02	0.03	0.01	5.70	Hamilton (1971)
Bear Biltmore No 1	7-11-87-17W/4	553 82-556 26	97.4	0.02	0.00	0.01	0.03	0.02	1 78	Hamilton (1971)
Bear Rodeo No 1	8-20-89-9W4	192 63-199 03	92.5	0.00	0.06	0.07	0.01	0.00	6 4 3	Hamilton (1971)
Bear Rodeo No 1	8-20-89-9W4	231 95-253 90	97.2	0.06	0.00	0.05	0.02	0.00	2 00	Hamilton (1971)
Provost No. 2	1-33-37-3W4	697 69-699 21	n/a	n/a	n/a	n/a	5.26	n/a	o	Cole (1948)
Federated LPGS3 Hardisty	10-30-42-9W4	1360.99	98.6	0.14	0.41	0.11	0.25	0.14	0.39	This report
Federated L PGS3 Hardisty	10-30-42-9W4	1363.23	96.0	0.09	0.28	0.07	2.44	2.36	0.68	This report
Petcal Dina	10-32-45-1W4	1055.68	73.9	8.44	24.65	6.62	6.49	0.00	0.46	This report
Petcal Dina	10-32-45-1W4	1058.64	89.2	2.62	7.64	2.05	2.07	0.02	0.92	This report
Petcal Dina	10-32-45-1W4	1060.92	93.4	1.25	3.65	0.98	1.04	0.07	0.49	This report
Newalta Hughenden	10-33-40-7W4	1381.11	93.9	0.14	0.41	0.11	5.02	4.91	0.46	This report
Newalta Hughenden	10-33-40-7W4	1383.13	96.8	0.09	0.28	0.07	1.39	1.32	1.46	This report
Newalta Hughenden	10-33-40-7W4	1383.13	96.0	0.09	0.28	0.07	1.41	1.33	1.41	This report
		Minimum	73.9	0.0	0.0	0.0	0.0	0.0	0.3	
		Maximum Average	99.4 06 2	8.4 0.2	24.7	6.6 0.2	6.5 0.7	4.9 0.2	6.4	
		Median	97.3	0.1	0.2	0.0	0.1	0.0	0.9	

Golden (1965) suggested that the geological strata in the Vermilion area are closely related to the Saskatchewan potash-rich mine areas at Esterhazy, Saskatoon and Unity.

A flurry of Alberta potash activity occurred in the mid-1960s (e.g., Golden, 1965, 1966; Bayfield Oil & Gas Ltd., 1966; Brownless, 1966; Irwin, 1966; MacDonald, 1967). Information from these reports included isopach and structure/tectonic maps, and correlation of gamma-ray logs with cross-sections of Middle Devonian formations, mostly in the area of the original Vermilion Consolidated Oils #15 well (6-12-49-6W4) but also extending northwards to Bonnyville and Cold Lake (Ernestina Lake). Coincidently, oil, gas and potash exploratory drilling in Saskatchewan generated a vast amount of information for Saskatchewan's emerging potash industry. A keystone report on Saskatchewan potash by Holter (1969) showed that the areal extent of Prairie Evaporite Formation potash mineralization extends into Alberta over a small tract of about 12 townships along the Alberta-Saskatchewan border. Holter (1969) noted that the Alberta mineralization is about 3 m thick and almost certainly carnallitic.

Increasing development of rock salt (NaCl) deposits due to commercial thickness and purity in eastcentral and northeastern Alberta led to the publication of a government bulletin by Hamilton (1971). Hamilton presented 46 analyses from 17 wells that penetrated the Prairie Evaporite Formation. Table 1 presents a summary of these data. Hamilton observed no potash except for traces of carnallite in the upper part of the Prairie Evaporite salt. This led him to suggest that "future potential for potash mining in Alberta perhaps lies mainly in magnesium extraction inasmuch as carnallite (the suspected potash mineral) contains 30% MgCl₂."

From 1970 until recently (see following text), potash exploration in Alberta was simply nonexistent. Salt production in Alberta is mainly by extraction from salt brine from the extensive, pure Upper Lotsberg salts. The salt is used in the manufacture of sodium chlorate and chlor-alkali products (e.g., chlorine, hydrochloric acid, potassium hydroxide, sodium hydroxide, sodium hypochlorite, and co-products hydrogen, sodium chloride and dilute sulphuric acid). The largest producer of sodium chlorate in North America, ERCO Worldwide, produces an average of 100 t/day of brine from the Bruderheim facilities to synthesize sodium chlorate. The Canadian Salt Company Ltd. produces 400 t/day of brine from the Lindbergh facilities for coarse and fine salt (evaporated salt). Dow Chemical Canada Inc. produces 2500 t/day of brine from the Fort Saskatchewan facility to produce chlor-alkali products.

Of interest to potash exploration, formation waters of the Beaverhill Lake Group, which overlies the Elk Point Group, contain up to 19 000 mg/L K and up to 2786 mg/L Br (Figure 3; Hitchon et al., 1993; Underschultz et al., 1994; Bachu et al., 1995). The high bromine compositions suggest that not all of the salt was dissolved and redeposited by freshwater (Braitsch, 1962; Wardlaw, 1968). Hitchon et al. (1993) first suggested that the potassium-bromine anomaly in the waters of the Beaverhill Lake Group might correspond to potash mineralization in the underlying Prairie Evaporite salt.

Lastly, with the global potash market having experienced rapid growth during the past decade, several companies have recently staked metallic and industrial mineral permits on the Alberta side of the Alberta-Saskatchewan border south of latitude 55°N. The play is developing, in large part, because of the historical mid-1960s exploratory and government work presented above.

4 Water Geochemical Evaluation: Potassium in Ground and Formation Water

We have reassessed potassium in ground and formation water in Alberta. The search for data on potassium concentrations covered several databases, including those from Alberta Environment, Alberta Geological Survey (Alberta Energy Research Institute, Beaver River Basin and Western Economic Partnership Agreement projects), Alberta Health and Wellness, Alberta Research Council and the ERCB oil and gas well data. There are 214 405 records with potassium values, of which 128 568 records (60%) have been verified based on quality assessment using various culling criteria (e.g., Hitchon and Brulotte,





Figure 3. a) Distribution of potassium and bromine (>1000 mg/L; combines Figures 11 and 12 from Hitchon et al., 1993) in formation waters of the Beaverhill Lake Group in southeastern Alberta. b) Potassium resource estimates in formation waters, with contours in kg/m² or 1000 t/km² (Figure 15 from Bachu et al., 1995).

a)

1994). Of the culled data, 1932 records represent individual wells with formation water containing >10 000 mg/L K. Figure 4 is a contour map of the potassium concentrations >10 000 mg/L that illustrates, in two dimensions, the distribution of potassium in formation waters throughout Alberta. With the exception of the anomalous area pointed out by Hitchon et al. (1993) in southeastern Alberta and another area of potassium enrichment in the Fort McMurray area of northeastern Alberta, potassium does not consistently correlate with the area of the Prairie Evaporite Formation (Figure 4). Rather, water in other parts of Alberta, most notably along the foothills and in west-central to northwestern Alberta, has significant concentrations of potassium.

Table 2 summarizes the subsurface distribution of formation water with >10 000 mg/L K in selected stratigraphic units (note that the formation unit names are the same as those provided in the source databases). The highest potassium value recorded is 118 480 mg/L in well Adamant Tangent 11-14-81-25W5, located in northwestern Alberta. Although this record does not have an assigned formation name, it likely comes from strata of the Wabamun Group given its depth of 587.3–588.6 m. In terms of stratigraphic horizons, the Devonian Swan Hills Member has the highest average potassium value (38 000 mg/L, n = 11) followed by the Granite Wash (35 700 mg/L, n = 2), Jurassic Rock Creek Member (28 800 mg/L, n = 19) and Devonian Beaverhill Lake Group (26 800 mg/L, n = 11). Potassium is ubiquitously present in the Cretaceous clastic units (e.g., Viking, Dunvegan, Cardium and Belly River), albeit at lower concentrations than in the aforementioned units.

Table 3 presents potassium concentrations in formation waters of the Swan Hills Member and the Beaverhill Lake Group. The Swan Hills Member represents early Beaverhill Lake reef growth in west-central Alberta and, in places, occupies the entire Beaverhill Lake interval (e.g., Fong, 1960; Jenik and Lerbekmo, 1968). Five of the top seven potassium concentrations (average values of between 53 700 and 107 650 mg/L) are derived from well PC Erith 6-31-47-17W5, southeast of the abandoned coal-mining town of Coalspur. A water sample from nearby well PC Hanlan 11-8-47-17W5 yielded 62 000 mg/L and, farther to the southeast, a sample from well Shell Canterra Ram 5-13-37-12W5 yielded 81 900 mg/L. The location of these anomalous potassium values is well beyond the limits of known Prairie Evaporite strata (Figures 2 and 4). Thus, the high potassium in the Swan Hills Member is related to other unknown influences, theories on which range from leaching of potassium from the basement or the Granite Wash to contamination by drilling fluids.

In areas where the Prairie Evaporite Formation exists, the value of 19 160 mg/L K, documented by Hitchon et al. (1993), at a depth of 1595–1605 m in Husky CS Kirkwall 8-3-27-5W4 remains the highest value for ground and formation water in southeastern Alberta. In the Fort McMurray region of northeastern Alberta, where there is partial to complete dissolution of the Prairie Evaporite Formation, waters with 18 000–44 400 mg/L K occur in sandstone units of the Middle to Late Cretaceous Mannville Group, Colony Member, and Viking and Grand Rapids formations.

Lastly, the predominance of potassium-enriched formation waters in Middle Devonian strata of western Alberta does little to support the Hitchon et al. (1993) theory that high potassium values in strata of the Beaverhill Lake Group strata in southeastern Alberta are related to underlying potash mineralization from the Prairie Evaporite Formation. Not only is there a general lack of potassium in ground and formation waters in the vicinity of the Prairie Evaporite Formation, but there is also difficulty in explaining how heavier evaporative brines could propagate directly upwards into the Beaverhill Lake Group. Rather, elevated potassium in southeastern Alberta formation water might be related to a geochemical signature from other evaporite horizons within, for example, the Swan Hills/Slave Point and Souris River formations. Furthermore, the dissolution of potash minerals and migration of potassium-enriched brine from the Prairie Evaporite Formation might favour Beaverhill Lake and equivalent strata west of the Prairie Evaporite because these units are now structurally at a lower elevation. This theory would imply that heavier potassium-enriched brines would have moved after the Alberta syncline formed due to the formation of the Rocky Mountains.



Figure 4. Shaded contour map of culled formation water samples in Alberta containing >10 000 mg/L K. Dashed polygon represents the Prairie Evaporite isopach with halite >40% from Grobe (2000). Inset histogram shows the depth distribution of the potassium data.

٨٥٥	Group/Formation	No. of	Pot	tassium (mg/L))
Age	Group/Formation	Analyses	Minimum	Maximum	Average
	No formation name provided	156	10180	118480	21415
	Belly River Group	176	10010	65800	21684
	Lea Park Formation	18	13650	45133	26081
	Cardium Formation	93	10690	41900	21444
	Second White Specks	38	10100	99310	21237
	Dunvegan Formation	26	10100	46880	19575
	Base of Fish Scales	15	10500	27370	17302
	Viking Formation	130	10140	106000	18396
	Bow Island Formation	27	10480	47300	18287
sno	Colony Member	17	10090	82000	23213
ace	Grand Rapids Formation	13	10200	40000	17601
Cret	Fahler Member	26	10195	65000	23875
	Blairmore Group	20	12000	30500	17531
	Mannville Group	126	10050	44000	17322
	Lower Mannville Formation	15	10570	26040	16919
	Spirit River Group	18	10230	59000	21458
	Bluesky Formation	32	10600	75750	18360
	Gething Formation	61	10160	71400	19355
	Ellerslie Member	43	10700	40800	18152
	McMurray Formation	14	10900	93845	22076
	Cadomin Formation	28	12640	83250	25171
с	Nikanassin Formation	21	10645	48800	19010
assi	Rock Creek Member	19	13900	69280	28763
Inf	Fernie Group	12	12550	34500	19535
U	Nordegg Member	30	10370	36000	18368
assi	Charlie Lake Formation	29	10420	93900	20636
Ë	Halfway Formation	38	10100	56000	19091
۲ E	Doig Formation	17	10950	49500	22902
mi mi	Belloy Formation	14	10080	50080	18324
	Kiskatinaw Formation	16	11200	34000	18469
u	Debolt Formation	15	12200	65000	23292
ippis	Elkton Member	18	10540	32000	16618
siss	Shunda Formation	24	10500	30500	18139
Mis	Pekisko Formation	27	10165	43000	16330
	Banff Formation	30	10100	46000	17196
	Wabamun Group	34	10910	76500	22677
	Winterburn Group	13	10320	23400	13492
	Nisku Formation	16	10170	16600	12743
Jian	Leduc Formation	16	10010	32460	17628
evoi	Swan Hills Member	11	10140	107650	37999
Δ	Beaverhill Lake Group	11	10720	81900	26809
	Pra	airie Evaporite	Formation		
	Granite Wash	2	17200	54267	35733

Table 2. Summary of culled formation water samples from selected formations containing >10 000 mg/L K. Formation unit names are the same as those provided in the source databases.

Samula ID		ا مغافيها م	ا مەمىلەر م	Pot	tassium (mg/L)	Kelly Bushing	Sample Depth (m)			
Sample ID	Unique weil ID	Latitude	Longitude	Minimum	Maximum	Average	Elevation (m) ¹	Тор	Bottom		
Beaverhill Lake	Formation										
135042	00/05-13-037-12W5	52.177315	-115.592895	81900	81900	81900	1496	5275	5280		
67782	00/06-31-047-17W5	53.096565	-116.478233	79900	79900	79900	1199	4522	4550		
35505 00/08-03-027-05W4 51.277435		-110.619207	19160	19160	19160	809	1595	1605			
18485	00/10-01-017-08W4	50.407126	-110.975997	18460	18460	18460	754	1483	1491		
83774	00/11-34-053-14W5	53.624127	-115.984784	14200	18000	16567	876	3200	3261		
87451	00/10-33-055-18W5	53.796124	-116.613296	16250	16250	16250	1094	3412	3428		
149390	00/09-19-036-07W5	52.109465	-114.982731	14800	14800	14800	1175	4118	n/a		
36729	00/11-14-028-19W4	51.394882	-112.57418	13550	13750	13650	692	1908	1940		
132986	132986 02/08-24-025-15W4 51.146101 -		-111.963776	10560	14080	11863	769	1815	1855		
87358	00/06-05-055-14W5	53.722377	-116.046239	11625	11625	11625	813	3124	3168		
85116	00/10-14-054-16W5	53.664832	-116.243869	10720	10720	10720	842	3297	3354		
Swan Hills Mem	ber										
67782	00/06-31-047-17W5	53.096565	-116.478233	105000	110000	107650	1199	4560	4566		
67782	00/06-31-047-17W5	53.096565	-116.478233	34000	97500	75771	1199	4522	4550		
67782	00/06-31-047-17W5	53.096565	-116.478233	57700	66700	62200	1199	3542	3554		
67782	00/06-31-047-17W5	53.096565	-116.478233	47200	57600	53700	1199	3523	3538		
67774	00/11-08-047-17W5	53.041369	-116.455953	26000	62000	46400	1238	n/a	n/a		
149390	00/09-19-036-07W5	52.109465	-114.982731	14800	14800	14800	1175	4138	n/a		
149390	00/09-19-036-07W5	52.109465	-114.982731	11400	15500	12850	1175	4118	n/a		
149390	00/09-19-036-07W5	52.109465	-114.982731	10300	16200	12220	1175	4132	4132		
87382	00/06-18-055-15W5	53.751391	-116.224359	11940	11940	11940	881	3153	3166		
162548	00/13-11-060-14W5	54.184282	-116.004938	10320	10320	10320	764	2883	2892		
83788	00/11-26-053-15W5	53.609677	-116.102359	10140	10140	10140	916	3315	3335		

Table 3. Culled formation water samples from the Beaverhill Lake Group and Swan Hills Member containing >10 000 mg/L K.

¹The distance from the rotary kelly bushing of the drill rig to the mean sea level.

5 Salt Core Geochemical Evaluation: Analytical Methodology

5.1 Core Selection and General Description

Our frame of reference for core selection was largely dependent on historical potash literature, particularly from Cole (1948), Golden (1965) and Hamilton (1971). We therefore focused on well cores from between latitudes 52° and 54°N and longitudes 110° to 112°W, but also analyzed Prairie Evaporite Formation cores to the south and north of this area, creating a preliminary salt geochemical dataset that extends from Fort McMurray to Medicine Hat (Figure 5). Specific core intervals for analyses were selected using the wireline-log sylvite and carnallite estimate calculations of Alger and Crain (1965), Crain and Anderson (1966) and Costello and Norquay (1968).

A portable x-ray fluorescence (XRF) analyzer was used to produce quick and efficient semiquantitative geochemical results in a manner that was nondestructive to historical Prairie Evaporite cores. We examined nine wells and completed XRF measurements on eight of these (Table 4). Most of the cores included the upper contact between the Watt Mountain Formation mudstone and the underlying Prairie Evaporite Formation salt within the Elk Point Group. In general, the Watt Mountain Formation is composed of intercalated red and green-grey silty mudstone, and is in sharp contact with the underlying Prairie Evaporite Formation (Figure 6a). The Prairie Evaporite salts are typically coarsely crystalline and vary in colour from white to colourless to light and dark grey to light and dark brown to light and dark pinkish red (Figure 6b). Intercalated bands of mudstone, silty mudstone and anhydrite characterize the basal part of most of the core intervals viewed (Figure 6c).



Figure 5. Location of selected wells from which Prairie Evaporite Formation cores were available for analysis.

Well Name	Well ID	Core Viewing/ Measurement Interval (m)	No. of XRF Analyses ¹	General Description
Newalta Hughenden	10-33-40-7W4	1370.4–1382.2	45	Watt Mountain–Prairie Evaporite contact at 1373.5 m; pale white to dark grey to dark pinkish, coarsely crystalline salt; intercalated with mudstone and anhydrite near bottom of interval
Calstan Pacific Marwayne	14-29-52-2W4	94–108	6	Watt Mountain–Prairie Evaporite contact at 108 m; greenish mudstone intercalated with reddish silty mudstone
Husky DH Wildmere	10-3-49-6W4	110.69–1138.43	23	Watt Mountain-Prairie Evaporite contact at 1112.2 m; white, grey to pink, coarsely crystalline salt; cavities near bottom of interval
Suncor Clarke	2-32-89-12W4	399–424	24	Watt Mountain–Prairie Evaporite contact at 407.7 m; light grey to pale yellow, coarse-grained salt; bands of grey anhydrite at bottom of interval
CDN Land MedHat	14-36-20-1W4	1667–1697	41	Prairie Evaporite; white, dark grey and light to dark pink, coarsely crystalline salt
IMP Calstan Lake Newell	5-1-17-14W4	1749.25–1761.44	0	Elk Point Group; light to dark grey mudstone
Petcal Dina	10-32-45-1W4	1048.5–1097.3	113	Watt Mountain–Prairie Evaporite contact at 1049 m; white, dark grey and light pink, coarsely crystalline salt; intercalated with thin bands of grey silty mudstone near bottom of interval
Blackfoot Devonian Test Syndicate No. 1	12-15-50-2W4	1023–1032.8	23	Watt Mountain–Prairie Evaporite contact at 1028 m; intercalated red and green-grey silty mudstone; white to brown, coarsely crystalline salt
Vermilion Consolidate Oils #15	6-12-49-6W4	1057.96–1079.3 and 1100.63–1161.59	64	Watt Mountain–Prairie Evaporite contact at 1061 m; white to dark grey and pink, coarsely crystalline salt; intermittently intercalated with green-grey mudstone

Table 4. Summary of drillcores selected for geochemical analysis with portable x-ray fluorescence (XRF) analyzer.

¹ Includes 22 duplicate analyses.

5.2 Overview of the X-Ray Fluorescence Analyzer

Like conventional laboratory geochemical techniques, the field-portable XRF analyzer can be used for measuring metal concentrations in a variety of sample media, including soil, sediment and rock. Its versatility, coupled with time-efficient sample preparation and analysis to obtain semiquantitative results, provides a suitable technique for the quick evaluation of samples in the field and/or at core libraries.

In this report, we used a Niton XL3^t 900S portable XRF analyzer with geometrically optimized large-area drift detector (GOLDDTM) technology to obtain semiquantitative geochemical results on Prairie Evaporite Formation halite cores at the ERCB Core Research Centre in Calgary. This analyzer uses a miniature x-ray tube (50 kV with silver anode) for production of primary radiation and a silicon drift detector with approximately 150 electron volts (eV) resolution. It is equipped with a ¹⁰⁹Cd isotope source and uses NpL-shell emissions and 23.0 gamma-ray emission. The GOLDD technology collects 10 times the counts per second of previous analyzers, resulting in reduced measuring times and decreased error. The analyzer



Figure 6. Photographs of the Watt Mountain and Prairie Evaporite formations of the Elk Point Group: a) contact between Watt Mountain Formation and coarsely crystalline Prairie Evaporite salt, Husky DH Wildmere 10-3-49-6W4; b) halite-sylvite-bearing intervals from Vermilion Consolidated Oils #15 6-12-49-6W4; c) intercalated silty mudstone and anhydrite, CDN Land MedHat 14-36-20-1W4.

displays a primary screen of elements that are within the 95% confidence band, and is capable of storing and downloading up to 10 000 assays with full spectral data.

We analyzed the core samples by placing the exposure window of the analyzer, which measures 1.0 by 2.0 cm in diameter, in direct contact with flat core surfaces. We selected homogeneous-looking lithologies for analysis to reduce sample-matrix effects. None of the cores were from recent drilling, thus avoiding the need to dry the core, as moisture content can interfere with the analysis.

For the analyses, we operated the instrument in

- Soil Mode, which is calibrated for a soil-like matrix using a Compton backscatter calibration method. It provides accurate results in the limit of detection range 50–30 000 ppm. In this mode, elements from S (16)¹ to U (92) are excited by dividing them into three sections of voltage/current/filter combinations: 'low' for S (16) to Cr (24), 'main' for Cr (24) to Pd (46), and 'high'' for Pd (46) to Ba (56).
- Mining Mode, which is calibrated for any type of matrix using the fundamental parameters calibration method. It provides accurate results in the range 0.1%–100% for most elements. In this mode, elements from Mg (12) to U (92) are excited by dividing them into four sections of voltage/current/filter combinations: 'light element' for Mg (12) to Ca (20), 'low' for Ti (22) to Cr (24), 'main' for Cr (24) to Pd (46), and 'high' for Pd (46) to Ba (56). The different ranges ensure maximization of the three components controlling sensitivity, tube voltage, tube current and filter material, which increases the signal-to-noise ratio at specific areas of the spectrum.

Mining Mode is the only mode that allows the light element filter (i.e., Mining Mode has the ability to 'see' the light elements from Mg to P, which is not possible in Soil Mode), making this mode best suited for the evaporite samples measured in this report. A helium cylinder was coupled to the analyzer to lower the minimum limit of detection for the light element filter. Measurement times used during this study were 90 seconds: 15 seconds for the Soil Mode and 75 seconds for the Mining Mode.

5.3 Analytical Precision

Historically, XRF analyzers have generally been viewed as being suitable only for chemical screening estimates. Advances in technology and instrumentation, however, now enable this method to yield results that are fully comparable with chemical laboratory practices. For example, the Environmental Technology Verification Program (Environmental Technology Verification, 1998), which verifies the performance of innovative technologies that have the potential to improve protection of human health and the environment, has demonstrated good correlation between Pb levels measured by field-portable XRF analyzers and chemical laboratories.

In 2001, Eccles and Murphy (2005) compared results from a previous version of the portable XRF analyzer (the Niton XL-502S) and conventional geochemical methods, which included total-digestion inductively coupled plasma – optical emission spectrometry (ICP-OES) and XRF. They reported that the portable XRF analyzer exhibited high analytical precision for selected elements. In comparison with Pb, Zn and Fe analyzes by ICP-OES, they found a linear correlation coefficient (r^2) of 95%–100% for powdered XRF analysis and an r^2 of 79%–89% for spot XRF analysis (i.e., random 'spot' analyses directly on the rock and core specimens).

The XRF analyzer used in this report is three versions newer than the Niton XL-502S used by Eccles and Murphy (2005). Given the results of the Eccles and Murphy (2005) test and the objective of this report to

¹ numbers in parentheses are atomic numbers of the elements

take as many measurements as possible, we did not carry out a thorough comparison of results from the XL3_t 900S XRF analyzer versus laboratory geochemical data. Nevertheless, we discuss here analytical comparisons between the XRF analyzer and eight laboratory geochemical values from powdered samples obtained from three separate Prairie Evaporite Formation cores (10-30-42-9W4, 10-32-45-1W4 and 10-32-40-7W4). In addition, we compare XRF measurements for 22 sample duplicates and 11 measurements on Natural Resources Canada's Canadian Certified Reference Materials Project (CCRMP) Till-4 reference material.

We obtained the laboratory geochemical values in this report (see bottom of Table 1) using the 'basic potash exploration package (soluble digestion and ICP-OES analysis)' of the Saskatchewan Research Council Geoanalytical Laboratories. The methodology can be summarized as

- pulverizing a sample to $\leq 106 \mu m$ using a puck-and-ring grinding mill;
- placing an aliquot of pulp in a test tube with 15 ml of 30°C de-ionized water and shaking it; and
- analyzing the soluble solution by ICP-OES.

The measurements with the $XL3_t900S$ XRF analyzer were made on aliquots of the same powders that were used in the geochemical laboratory analysis. Figure 7 shows a comparison between the results of the portable XRF analyzer and those determined by the geochemical laboratory for elements critical to this study. In general, the comparison shows moderate to excellent correlation. The r² values for K₂O, MgO, CaO and S are 82%, 96%, 71% and 97%, respectively. Keeping in mind that these results are based on powdered samples, we feel that the XL3_t900S XRF analyzer provides sufficient precision for these elements to conduct spot XRF analysis on the cores of interest.

During XRF analysis, we took duplicate measurements on 22 randomly selected separates and used the relative standard deviation (RSD) statistical method to evaluate the duplicate results for precision. The RSD is a measure of the relative dispersion of the values in a dataset and is calculated by dividing the standard deviation by the mean from a dataset (Le Maitre, 1982) and then multiplying the result by 100. Consequently, the lower the RSD value, the higher the level of precision. Table 5 presents the major-element RSD percentages for the duplicate analyses. With the exception of MnO and Cr₂O₃, the average RSD values for the major elements are between 3% and 19%. The oxides K₂O and MgO, which are critical for potash determination, have average RSD values of 12% and 19%, respectively. We therefore recommend that exploration companies use the potash values presented in this report with caution and that future exploratory work on these cores include laboratory chemical analysis. We reiterate that the reason for using the portable XRF analyzer was to obtain as many chemical data as possible without destroying these historical cores (i.e., not sampling the cores for laboratory analysis or powdering individual samples prior to XRF analysis for more robust results).

Lastly, eleven measurements were completed on reference material CCRMP Till-4, which has a certified potassium value of 3.25% K₂O or 2.69% K (Lynch, 1996). Measurements of the potassium content of Till-4 using the portable XRF analyzer were 2.828%, 2.348%, 3.148%, 2.359%, 2.277%, 2.333%, 2.41%, 2.37%, 2.26%, 2.369% and 2.367%; the average of these is 2.46% K and the standard deviation is 0.274. This error is on uncorrected data that could have a bias.

6 Salt Core Geochemical Evaluation: Results

6.1 Reporting Methodology

The mineral impurities in rock salt can be grouped into three categories: water-soluble minerals, waterinsoluble minerals and the mineral anhydrite, which is weakly soluble in water. The soluble mineral impurities in the Elk Point salts consist mainly of calcium, chloride and potassium (Hamilton, 1971). Laboratory geochemical analysis typically depends on soluble digestion followed by analysis of the



Figure 7. Portable x-ray fluorescence (XRF) versus geochemical laboratory inductively coupled plasma–optical emission spectroscopy (ICP-OES) analysis for selected elements. Analyses conducted on aliquots from the same sample powders.

RSD ¹	SiO ₂	Al_2O_3	Fe ₂ O ₃	MgO	CaO	K ₂ O	TiO ₂	MnO	Cr ₂ O ₃
Minimum	0.1	0.0	1.0	0.5	0.2	0.0	0.0	0.0	0.0
Maximum	73.4	59.0	24.4	84.3	14.3	60.8	68.4	106.1	97.9
Average	6.1	11.9	5.8	18.9	3.2	11.5	17.0	34.8	31.8
Median	2.6	4.1	4.3	12.5	2.1	5.6	9.6	28.3	28.3

Table 5. Relative standard deviation (RSD) of duplicate samples (major elements).

¹ Relative standard deviation is calculated by dividing the standard deviation by the mean from a dataset (Le Maitre, 1982).

soluble solution. The methodology of directly analyzing cores with the XRF analyzer does not allow for this separation. Thus, it is important to note that the results of this report provide a whole-rock geochemical measurement that, in the case of salt, combines all salt impurities.

Potash beds in the Prairie Evaporite Formation have a simple mineralogy, consisting predominantly of halite (NaCl) and two potassium chloride minerals, sylvite and carnallite. Other constituents, termed insoluble materials, typically make up <10% of the rock and comprise iron oxides, dolomite, quartz and clay. Of the two potassium chloride minerals, sylvite is more desirable for potash exploitation due to the combination of elevated potassium and lower magnesium. Halabura and Hardy (2007) suggested that concentrations of greater than 0.25% Mg can affect processing-plant performance and require nonstandard processing, making carnallite and kieserite (MgSO₄·H₂O) less favourable than sylvite.

Sylvite is often described as a mixture of sylvite and halite \pm clay \pm anhydrite. Sylvite is mined and sold as KCl. A tonne of KCl contains the equivalent of 0.63 tonnes of K₂O. Sylvite-bearing intervals are typically determined by identifying all exploration drillhole intervals in which KCl and/or K₂O content exceeds a predetermined cut-off grade, which Holter (1969) suggested is 12% K₂O.

To report on data beyond major-element chemistry, we discuss the following evaporite minerals in this section:

- %Carnallite = %MgO \times 6.892
- $%MgCl_2 = %Mg \times 3.91$
- %Carnallite = %MgCl₂ \times 2.92
- %KCl_{carnallite} = %carnallite × 0.2684
- %KCl_{total} = %K₂O × 1.583
- $%KCl_{sylvite} = %KCl_{total} %KCl_{carnallite}$
- %NaCl = %Na₂O × 1.886
- %CaSO₄ = %CaO \times 2.428

With the exception of Calstan Pacific Marwayne and IMP Calstan Lake Newell, which contain mudstone and/or anhydrite (i.e., no salt, Table 4), cores from six other wells investigated in this report included halite with variable amounts of KCl_{carnallite} and KCl_{sylvite}. We discuss their chemical and physical properties below.

6.2 Halite (Sodium Chloride)

One drawback to using the XRF analyzer in this report was that sodium is too light an element for this version of the analyzer to detect. Halite content from historical geochemical data (Cole, 1948; Hamilton, 1971) and from laboratory geochemical analysis from this report (Table 1) averages 96.2 wt. % NaCl and ranges up to 99.4%. This implies that the solutions discussed in this section are always saturated with halite.

We have plotted the XRF data on the hexary (six-component) Na-K-Mg-Ca-Cl-SO₄-H₂O system of oceanic salts (Harvie and Weare, 1980). Figure 8 shows that the salt analyzed in this report is generally low in magnesium sulphate and rich in sodium sulphate.

6.3 KCI_{carnallite}

Other than halite and anhydrite, carnallite is prevalent in the 10%–20% range, which is equivalent to about 3%–5% KCl_{carnallite} (Figure 9). Table 6 shows the 20 highest halite-carnallite geochemical results from the XRF analyzer. Greater than 30% carnallite occurs in Pectal Dina, Vermilion Consolidated Oils #15, CDN Land MedHat and Newalta Hughenden. Carnallite is particularly common in Pectal Dina,



Figure 8. X-ray fluorescence data plotted on the hexary (six-component) Na-K-Mg-Ca-Cl-SO₄-H₂O system of Harvie and Weare (1980); all mineral zones are saturated with halite (NaCl). The small grey-filled circles are representative of Saskatchewan potash-bearing wells (after Holter, 1969), including CDR Pheasant Creek 1-11-21-10W2, Shell Insinger 11-11-28-9W2, UCP Dafoe No. 1 8-17-32-18W2, Dominion Potash Burr No. 4-18 4-18-35-23W2, Duval Aberdeen 3-30-37-2-W13, Alwinsal Iroquois 10-21-32-25-W2 and Placid Allan 4-29-32-28W2. The solid black elongated ellipsoid at the SO₄ apex represents sodium sulphate deposits from southern Alberta lakes (Govett, 1958).



Figure 9. Histogram of selected elements, minerals and ratios from all 366 XRF measurements from this study.

Sample ID	Well Name	Well ID	Sample Depth (m)	Carnallite (%)	KCI _{carnallite} (%)	K/Mg Molar	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	K₂O	TiO₂	MnO	Cr ₂ O ₃	SO4
901	Pectal Dina	10-32-45-1W4	1064.16	47.48	12.74	1.07	5.41	2.07	0.24	6.89	7.34	5.35	0.300	0.009	0.015	3.62
903	Pectal Dina	10-32-45-1W4	1064.62	45.07	12.10	1.61	9.16	2.86	0.41	6.54	10.56	7.63	0.492	0.030	0.001	5.21
921	Pectal Dina	10-32-45-1W4	1069.38	44.96	12.07	0.23	4.20	1.73	0.21	6.52	10.46	1.07	0.482	0.019	0.003	5.00
924	Pectal Dina	10-32-45-1W4	Duplicate	42.30	11.35	1.58	2.45	1.02	0.25	6.14	4.91	7.04	0.237	0.013	0.009	3.74
876	Pectal Dina	10-32-45-1W4	1057	40.97	11.00	1.87	4.43	2.02	0.20	5.95	6.95	8.06	0.374	0.014	0.000	3.45
752	Vermilion Consolidated Oils #15	6-12-49-6W4	1061.19	40.25	10.80	0.32	19.60	7.96	0.71	5.84	10.65	1.36	0.137	0.009	0.012	13.30
955	Pectal Dina	10-32-45-1W4	1078.84	38.08	10.22	1.43	4.63	1.81	0.51	5.53	10.73	5.76	0.487	0.019	0.001	5.21
728	Newalta Hughenden	10-33-40-7W4	1381.78	37.18	9.98	0.42	18.01	3.33	1.25	5.39	12.37	1.64	0.200	0.021	0.015	3.75
902	Pectal Dina	10-32-45-1W4	1064.33	36.61	9.83	0.45	8.83	2.90	0.36	5.31	11.51	1.72	0.242	0.009	0.013	5.88
909	Pectal Dina	10-32-45-1W4	1066.03	35.72	9.59	0.34	9.21	3.04	0.23	5.18	7.35	1.28	0.224	0.010	0.000	3.82
774	Vermilion Consolidated Oils #15	6-12-49-6W4	1065.6	34.07	9.15	2.28	10.75	4.22	0.57	4.94	10.64	8.18	0.102	0.005	0.000	11.42
797	Vermilion Consolidated Oils #15	6-12-49-6W4	1075.81	33.65	9.03	0.70	14.43	5.29	0.68	4.88	9.85	2.47	0.105	0.013	0.000	6.97
895	Pectal Dina	10-32-45-1W4	1062.56	33.59	9.02	0.61	11.32	3.40	0.49	4.87	12.37	2.17	0.724	0.035	0.028	6.89
896	CDN Land MedHat	14-36-20-1W4	1691.31	33.28	8.93	0.01	5.81	1.32	0.38	4.83	12.42	0.05	0.157	0.009	0.000	11.41
777	Vermilion Consolidated Oils #15	6-12-49-6W4	1066.42	32.86	8.82	0.27	11.49	4.63	0.33	4.77	6.27	0.95	0.095	0.006	0.016	5.80
804	Vermilion Consolidated Oils #15	6-12-49-6W4	1084.34	32.48	8.72	0.45	14.34	5.93	0.29	4.71	4.85	1.54	0.063	0.000	0.003	1.95
805	CDN Land MedHat	14-36-20-1W4	1084.34	32.45	8.71	0.02	6.19	1.17	0.38	4.71	13.16	0.07	0.095	0.001	0.000	11.80
878	Pectal Dina	10-32-45-1W4	1057.71	32.15	8.63	0.76	9.85	3.74	0.64	4.67	6.60	2.56	0.105	0.015	0.000	2.41
764	Vermilion Consolidated Oils #15	6-12-49-6W4	1063.44	31.59	8.48	0.10	10.87	4.43	0.45	4.58	7.96	0.33	0.090	0.009	0.001	7.57
775	Vermilion Consolidated Oils #15	6-12-49-6W4	1065.85	30.84	8.28	0.16	10.30	3.15	0.39	4.47	9.18	0.51	0.080	0.013	0.000	8.30

Table 6. Top 20 geochemical results for KCI_{carnallite}.

reaching up to 48%. Two core measurements, including one from Pectal Dina (1057 m) and one from Vermilion Consolidated Oils #15 (1065.6 m), yielded 8% K₂O, and three XRF measurements from Pectal Dina had KCl_{carnallite} values of 12%–13%. Pectal Dina contains the thickest zone of carnallite recorded in this report, with a 35 m intersection (1049–1084 m) of >20% carnallite and 5%–13% KCl_{carnallite}.

6.4 KCL_{sylvite}

Histograms of XRF data from this study show that K₂O and KCl_{sylvite} are dominantly <10% and <18%, respectively (Figure 9). Table 7 presents the 20 highest potassium results from the XRF analyzer as K₂O, KCl_{total} and KCl_{sylvite}. Measurements from six of the eight wells analyzed in this report yielded >5 wt. % K₂O and >5% KCl_{sylvite}. Comparison of KCl versus carnallite shows that sylvite is present in Vermilion Consolidated Oils #15, Husky DH Wildmere, CDN Land MedHat, Newalta Hughenden and Blackfoot Devonian Test Syndicate No. 1. Halite-sylvite is also evident for these wells on the Na-K-Mg-Ca-Cl-SO₄-H₂O plot (Figure 8). The inclusion of the Pectal Dina data in the field of sylvite on Figure 8 is a reflection of the low Mg and high K in these samples.

Of the 339 XRF analyses completed in this report, two from Vermilion Consolidated Oils #15 returned values greater than the cut-off grade suggested by Holter (1969; 12 wt. % K₂O). Measurements at 1061.4 m and 1062.1 m yielded 18.6 wt. % (29.4% KCl and 27.9% KCl_{sylvite}) and 12.9 wt. % K₂O (20.4% KCl and 16.9% KCl_{sylvite}), respectively. Vermilion Consolidated Oils #15 also has the thickest zone of high KCl. Seven samples representing more than 9 m (1061.4–1070.6 m) of continuous core yielded an average grade of 10.6 wt. % K₂O. This section of core is translucent to translucent pinkish orange (halite-sylvite), with less common brownish red to translucent (halite with minor sylvite-carnallite).

Lastly, three of the high-KCl samples have molar K/Mg ratios of between 31 and 41 (i.e., low Mg, Table 7), demonstrating that these particular salt core intersections from Vermilion Consolidated Oils #15, Newalta Hughenden and Blackfoot Devonian Test Syndicate No. 1 have the potential to be amenable to conventional potash processing.

6.5 Other Impurities and Observations

The Prairie Evaporite Formation is deficient in late-forming magnesium sulphate but enriched in sulphate (e.g., Figure 8). Precipitation of sodium sulphate minerals such as thenardite (Na₂SO₄; Figure 8) is generally characteristic of saline-lake terrestrial evaporite deposits (e.g., Govett, 1958). However, the presence of mudstone, high bromine in formation waters (Hitchon et al., 1993) and the presence of carnallite indicate that much of the section in this area has a marine origin. This apparent contradiction could be explained by 1) salt accumulation by evaporation in flooded areas (Meijer Drees, 1994); 2) early calcium enrichment in the brine, which would lead to sulphate depletion by precipitation of calcium sulphate (Williams-Stroud, 1994); and/or 3) formation of brine lakes during the sub–Watt Mountain unconformity (Meijer Drees, 1988) or local erosional unconformities within the Elk Point succession (e.g., First and Second Red Beds; Meijer Drees, 1994).

Better yet, the sodium sulphate (Na_2SO_4) shown in Figure 8 and discussed above is probably better described as calcium sulphate $(CaSO_4)$ or anhydrite. Macroscopic core observations and a positive correlation between SO₄ and CaO in Figure 10 provide evidence that the major impurity in the Prairie Evaporite salt investigated in this study is mainly in the form of the early-precipitated anhydrite. Potash composition aside, the degree of calcium sulphate abundance is another criterion for differentiating between the low–CaO-SO₄ brine that epitomizes the Saskatchewan potash deposits and the high–calciumsulphate salt reported in this study (Figure 10).

Lastly, distinct linear CaO-SO₄ trends in Figure 10 are likely related to differing conditions of evaporite precipitation. For example, Pectal Dina has considerably higher calcium relative to Vermilion Consolidated Oils #15, and these wells are only 60 km apart. This suggests chemical variation within the

Sample ID	Well Name	Well ID	Sample Depth (m)	KCI _{total} (%)	KCI _{sylvite} (%)	K/Mg Molar	Carnallite (%)	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	K₂O	TiO ₂	MnO	Cr ₂ O ₃	SO4
753	Vermilion Consolidate Oils #15	6-12-49-6W4	1061.36	29.40	27.88	31.03	5.68	3.11	1.22	0.20	0.82	0.72	18.57	0.027	0.005	0.003	0.74
757	Vermilion Consolidate Oils #15	6-12-49-6W4	1062.10	20.37	16.91	9.46	12.90	1.97	1.14	0.08	1.87	0.88	12.87	0.018	0.005	0.000	4.52
1051	Husky DH Wildmere	10-3-49-6W4	1119.21	18.20	16.36	15.91	6.86	1.45	0.41	0.07	0.99	0.29	11.50	0.017	0.005	0.000	0.00
702	Newalta Hughenden	10-33-40-7W4	1376.83	15.35	14.75	40.87	2.25	3.19	1.18	0.15	0.33	2.83	9.70	0.005	0.009	0.003	2.13
1015	CDN Land MedHat	14-36-20-1W4	1673.98	16.41	13.39	8.74	11.24	1.21	0.77	0.05	1.63	2.63	10.37	0.107	0.004	0.000	6.09
1014	CDN Land MedHat	14-36-20-1W4	1673.98	15.76	13.02	9.26	10.19	1.19	0.79	0.03	1.48	2.56	9.95	0.087	0.005	0.009	5.89
1012	CDN Land MedHat	14-36-20-1W4	1673.45	14.35	11.54	8.22	10.46	1.52	0.81	0.11	1.52	3.25	9.06	0.073	0.006	0.004	7.01
845	Black Foot Devonian Test Syndicate # 1	12-15-50-2W4	1030.31	11.07	10.53	33.35	1.99	2.83	0.68	0.14	0.29	1.60	6.99	0.028	0.000	0.000	1.80
1006	CDN Land MedHat	14-36-20-1W4	1670.80	13.83	10.49	6.66	12.43	0.08	0.20	0.03	1.80	0.56	8.73	0.052	0.009	0.000	0.76
1007	CDN Land MedHat	14-36-20-1W4	1671.28	12.62	10.23	8.50	8.90	0.33	0.25	0.10	1.29	1.41	7.97	0.018	0.001	0.000	1.99
767	Vermilion Consolidate Oils #15	6-12-49-6W4	1064.16	13.77	10.21	6.23	13.24	6.92	2.30	0.25	1.92	3.96	8.70	0.035	0.004	0.007	5.93
765	Vermilion Consolidate Oils #15	6-12-49-6W4	1063.76	14.62	9.75	4.83	18.13	6.86	2.78	0.41	2.63	2.73	9.23	0.083	0.004	0.000	3.02
759	Vermilion Consolidate Oils #15	6-12-49-6W4	1062.39	12.24	9.30	6.69	10.96	6.11	2.53	0.16	1.59	2.19	7.73	0.073	0.003	0.000	3.31
766	Vermilion Consolidate Oils #15	6-12-49-6W4	1063.99	14.61	8.62	3.92	22.30	8.10	2.72	0.22	3.24	4.04	9.23	0.047	0.008	0.000	7.31
954	Petcal Dina	10-32-45-1W4	1078.22	9.91	8.14	8.96	6.63	0.86	0.42	0.10	0.96	4.62	6.26	0.235	0.019	0.006	1.85
784	Vermilion Consolidate Oils #15	6-12-49-6W4	1070.61	12.87	6.47	3.23	23.86	7.07	3.12	0.31	3.46	3.13	8.13	0.065	0.008	0.000	2.39
693	Newalta Hughenden	10-33-40-7W4	1374.79	10.94	6.16	3.68	17.79	5.34	2.14	0.21	2.58	3.00	6.91	0.047	0.006	0.004	2.12
1030	Suncor Clarke	2-32-89-12W4	Duplicate	9.82	5.55	3.70	15.93	12.01	3.39	0.30	2.31	5.65	6.21	0.050	0.008	0.012	5.55
1029	Suncor Clarke	2-32-89-12W4	425.41	10.41	5.40	3.35	18.64	12.00	3.38	0.29	2.70	5.59	6.57	0.050	0.014	0.013	5.58
838	Blackfoot Devonian Test Syndicate No. 1	12-15-50-2W4	1028.38	8.31	5.14	4.23	11.78	8.82	3.19	0.23	1.71	8.11	5.25	0.072	0.004	0.003	15.39

Table 7. Top 20 geochemical results for $\text{KCl}_{\text{sylvite}}.$



Figure 10. X-ray fluorescence data plotted on the CaO-SO₄ diagram. The grey-filled polygon represents Saskatchewan potash-bearing wells (after Holter, 1969), including CDR Pheasant Creek 1-11-21-10W2, Shell Insinger 11-11-28-9W2, UCP Dafoe No. 1 8-17-32-18W2, Dominion Potash Burr No. 4-18 4-18-35-23W2, Duval Aberdeen 3-30-37-2-W13, Alwinsal Iroquois 10-21-32-25-W2 and Placid Allan 4-29-32-28W2.

Prairie Evaporite strata of the Central Alberta sub-basin, even at the reconnaissance scale of this study. Given our limited exposure to these rocks and therefore inadequate knowledge of the thermal and dynamic metamorphism of the Prairie Evaporite Formation in Alberta, it is possible that chemical variations in local areas could include elevated KCl or sylvite.

7 Conclusions

Historical data and the new geochemical results presented in this report provide a preliminary overview of the potash potential in Alberta. Past studies suggesting that carnallite increases toward the margins of each member of the Prairie Evaporite Formation are generally in agreement with our results. Greater than 30% carnallite occurs in four of the six salt-bearing cores investigated, including the Pectal Dina, Vermilion Consolidated Oils #15, CDN Land MedHat and Newalta Hughenden wells, with carnallite reaching 48% in Pectal Dina.

However, >10% KCl_{sylvite} is present in five of the six salt-bearing cores, including Vermilion Consolidated Oils #15, Husky DH Wildmere, CDN Land MedHat, Newalta Hughenden and Blackfoot Devonian Test Syndicate No. 1. The locations of these wells span a vast portion of southeastern Alberta from Township 20 to 50, or from Medicine Hat to Lloydminster. In addition, seven samples representing more than 9 m of continuous core from Vermilion Consolidated Oils #15 yielded an average grade of 11 wt. % K₂O, and ranged up to 19 wt. % K₂O (29% KCl and 28% KCl_{sylvite}). These results indicate that there is potential for the presence of potash pockets in the uppermost Prairie Evaporite Formation of eastern Alberta.

High-potassium formation waters are present in the Swan Hills Member of the Beaverhill Lake Group, which represents early Beaverhill Lake reefing, of west-central Alberta. The ultimate relationship, if any, between the Swan Hills area and the Prairie Evaporite Formation is unknown, but these waters should be examined both by hydrodynamic modelling to explain the origin of the potassium and as an economic prospect for direct potassium extraction from the water.

8 References

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