PETROGRAPHY AND CHEMICAL ANALYSES OF A CORE FROM THE DEVONIAN PRAIRIE EVAPORITE, SHERIDAN COUNTY, MONTANA

Richard B. Berg

Montana Bureau of Mines and Geology
Report of Investigation 20
2010

Cover image: Potash-rich interval of core from the Prairie Evaporite Formation. Length of core is 9 inches. The darkest red areas are mainly sylvite and the pale pink areas are halite. Photo by R.B. Berg.

TABLE OF CONTENTS

FIGURES

TABLES

ABSTRACT

The Great Northern Railway drilled an exploratory well into the middle Devonian Prairie Evaporite Formation in Sheridan County, Montana, in conjunction with their potash exploration program. The analyzed core from the potash-bearing interval is from a depth of 9,918 to 10,122 feet. Halite is the major mineral in the cored interval, with lesser clay (illite and chlorite and/or kaolinite), sylvite, dolomite, anhydrite, magnesite, and quartz. Two potash-rich intervals were identified, one with a maximum water-soluble-equivalent K_2O content of 8.55 percent and the other with a maximum value of 6.96 percent.

INTRODUCTION

The examination and analysis of this core from the middle Devonian Prairie Evaporite Formation was a cooperative project between the Great Northern Railway Company and the Montana Bureau of Mines and Geology. The 4-inch-diameter core is from the Farmers Union Central Exchange-Jayhawk well #43X-30 Nelson located in NE¼SE¼, sec. 30, T. 33 N., R. 56 E., Sheridan County, Montana (fig. 1), from a depth of 9,918 to 10, 122 ft. The hole was drilled in 1967 as part of a potash exploration program conducted by the Great Northern Railway. Analyses of this core were completed in 1967; permission to release these data was granted by Burlington Resources, the successor to the mineral resource group of the Great Northern Railway, in 2003. We thank the Company both for partial support for the original investigation and permission to publish the results.

The main purpose of this project was to determine the distribution and occurrence of potassium over the cored interval. With this information, a comparison could be made between the gamma ray log of this interval and the potassium content. Such a comparison would be of value in the interpretation of gamma ray logs of other intervals of similar lithology in the Prairie Evaporite Formation.

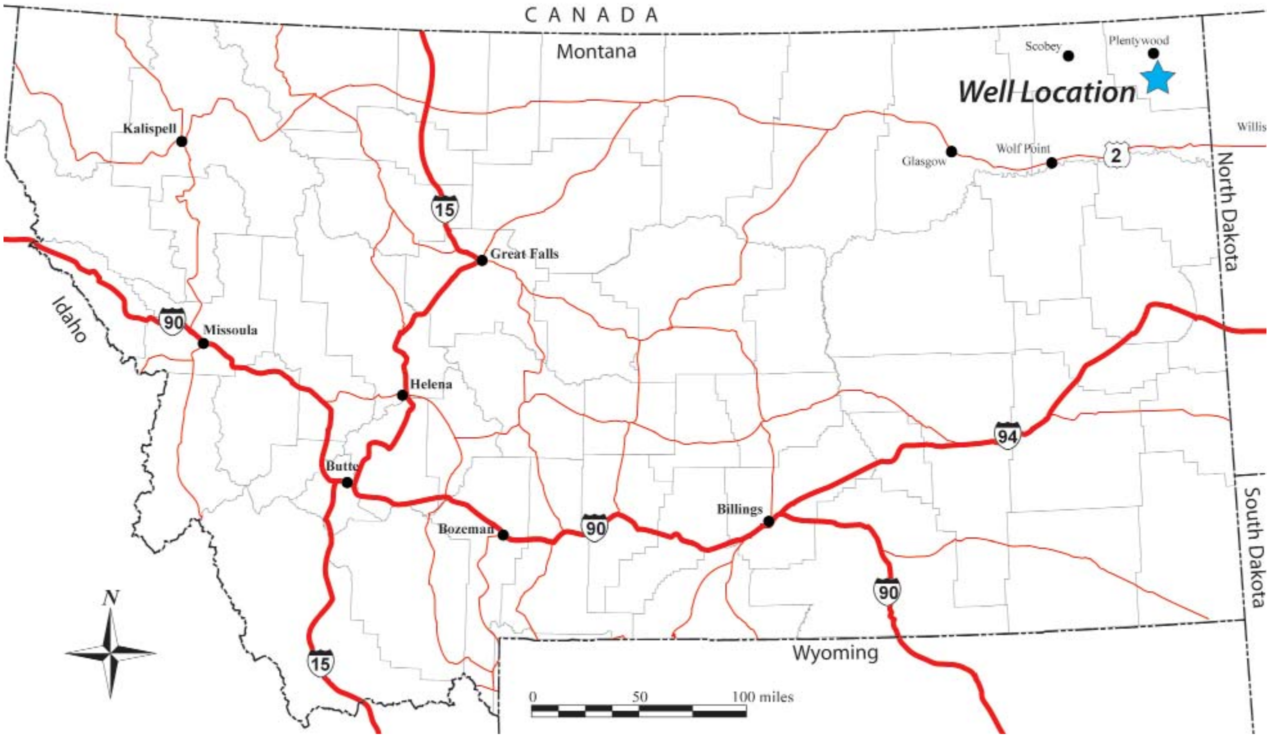

Figure 1. Location of well.

PROCEDURES

The core was received in relatively good condition with the exception of one interval that was badly broken, a missing interval from 9967.3 to 9981.5 ft, and several shorter missing intervals. Depths were clearly marked at 1-ft intervals on the previously sawed surface of the core. Comparison of the potassium content of the core with the gamma ray log shows a shift of about 9 ft in depth. We have no way to determine which is correct, and depths marked on the cores are used in the following descriptions. However, it seems likely that those depths should be shifted to match the wireline log.

Petrography

The sawed surface of each section of core was etched in tap water for 1.5–2 minutes. Numbers on the surfaces were preserved by first coating them with a plastic spray. This etching aided considerably in the differentiation between halite and sylvite. Because of its greater solubility, sylvite was etched to a greater depth. Since the dolomite, anhydrite, and clay were not etched appreciably, they stood out in positive relief compared to the more soluble halides. The entire section of etched core was examined under the binocular microscope. Identification of sylvite was based on its bitter taste, deeper etching than halite, index of refraction <1.53, and isotropic character when examined with the petrographic microscope. The index of refraction of sylvite is 1.490, compared to 1.544 for halite. Of these three criteria, the depth of etching was most useful in estimating the percent of sylvite and in observing textural relationships.

The following features were noted during the examination of the core:

1. modal composition;
2. grain size;
3. texture;
4. structures; and
5. size of pits on surface of core.

Potassium Analyses

Sample Preparation

The entire cored interval was divided into segments of fairly uniform lithology. Where the core was lithologically uniform over a considerable interval, it was generally divided into segments of 2–3 ft. A longitudinal slice was cut from each sample interval using a masonry saw. In those cases where the surface of the core was highly pitted as a result of solution of the salts during drilling, the slice was taken from the interior of the core. This slice was then crushed to -¼-inch mesh, pulverized to -10 mesh, rolled, and split down to about 50 g. This 50-g split was then dried for 24 hours at 105°C, cooled, and pulverized to -60 mesh.

Analytical procedure for water-soluble salts

Weigh 100 mg of the -60 mesh sample and place in a 100-ml beaker. Add 25 ml of distilled water at room temperature; cover; agitate every few minutes for half an hour; filter through filter paper into 100 ml graduated and stoppered cylinders; wash well with distilled water; add 5 ml of 5 N HCl; and dilute to 100 ml.

Analytical procedure for water-insoluble residue

Weigh 1 g of sample and dissolve; filter and wash as in water-soluble procedure; remove from funnel and place in a suitable platinum dish (about 100 ml capacity). Dry and ignite gently to destroy paper; cool the dish and contents; add 5 ml concentrated hydrofluoric acid and 1 ml of 1:1 sulfuric acid; and heat gently to complete dissipation of SO_2 fumes. If decomposition is incomplete, repeat the $HF–H_2SO_4$ treatment, again taking to dryness. Cool and add 5 ml of HCl; cover and boil gently to dissolve all salts and convert to the chlorides; dilute, filter, and wash as above; and dilute to 100 ml. Standards are made conventionally using C.P. sodium chloride and potassium chloride in the proportion of 5 Na:1 K. Standards must also have a normality of 0.25 with respect to HCl. All analyses were completed by Frank Jones, analytical chemist with the Montana Bureau of Mines and Geology, using a Beckman Model B Spectrophotometer.

PETROGRAPHY

The cores examined are of a 204-ft interval of the middle Devonian Prairie Evaporite Formation of the Elk Point Group. Halite is the most abundant mineral in this interval and occurs as euhedral to anhedral transparent grains ranging from 2 mm to >10 cm. Those intervals containing coarse-grained halite are generally lighter in color than those containing fine-grained halite because of the occurrences of clay along halite grain boundaries. The finer-grained halite has more grain boundaries and thus more clay than the coarser-grained halite. Halite also contains irregular inclusions of other minerals found in the core. In those intervals where anhydrite and dolomite are abundant, irregular masses of mixtures of these minerals are common in the halite. Along a fracture in the core at 10,082.5 ft, large halite crystals (about 40 mm) show curved cleavage planes, presumably the result of either tectonic deformation or deformation during coring.

Sylvite generally occurs in a fine-grained mixture with halite (sylvinite; fig. 2), identified by examining crushed material in an immersion mount of oil with an index of refraction of 1.53 using a petrographic microscope. The amount of sylvite in sylvinite was impossible to estimate accurately because of small grain size. Generally, the sylvinite is interstitial to halite or forms small veinlets cutting both halite and clay layers. At 9,997 ft, there are several near-vertical veinlets of sylvanite 2 to 12 mm thick in greenish-black clay (fig. 3).

In those intervals where sylvite is most abundant, it occurs as isolated grains of irregular shape. The larger grains are transparent to milky and are difficult to distinguish visually from halite until they are etched. Some red grains of relatively pure sylvite were found in those sections of the core with the greatest percent of sylvite. The largest grains of sylvite occur at 10,008 ft, where they range up to 15 mm in diameter. Even though many grains were checked in immersion mounts using the petrographic microscope, no potash salt other than sylvite was identified in this core.

Clay is abundant in many sections of the core (fig. 4). The clay is reddish-brown to green and occasionally occurs in horizontal to sub-horizontal layers, probably representing original beds, cut by small veinlets of halite several millimeters thick. Throughout the core, clay occurs interstitially to halite and sylvinite. Illite was identified by x-ray diffraction in two samples of the water-insoluble residue (10,012.0 and 10,016.5–10,017.4 ft). Lesser amounts of chlorite and/or kaolinite were also present in these two samples.

The largest halite crystals are found in the lower part of the core, some extending across the entire diameter of the core (fig. 4). Anhydrite and dolomite occur in a fine-grained mixture or as individual layers (fig. 5). These minerals become increasingly abundant in the lower part of the core below a depth of 10,074 ft (fig. 6; *click link to open the figure in a separate file*). The greenish-gray layers appear to be mainly dolomite and the gray layers appear to be mainly anhydrite. In one instance, there are alternating laminae of dolomite and anhydrite less than 0.5 mm thick. Generally, the layers that are composed of a mixture of dolomite and anhydrite range from 10 to 160 mm in thickness. Most of these layers are sub-horizontal and many are cut by halite veinlets.

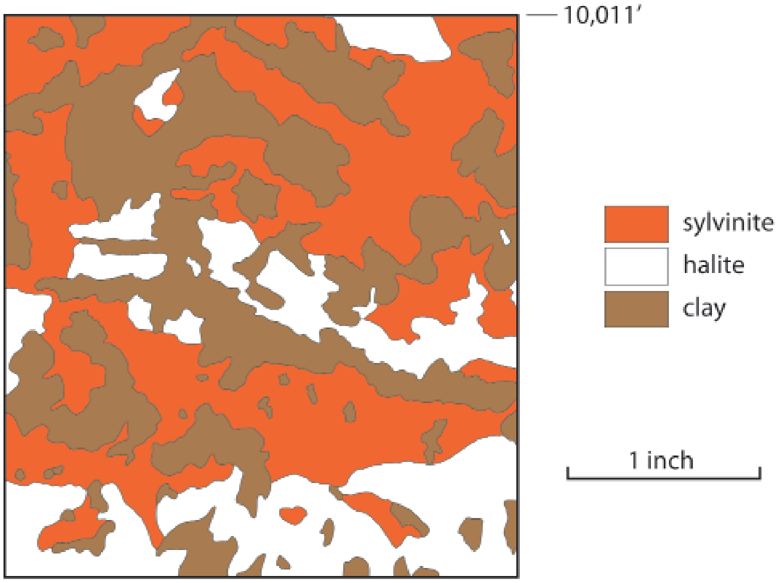

Figure 2. Tracing of core showing relationship between sylvinite, halite, and clay.

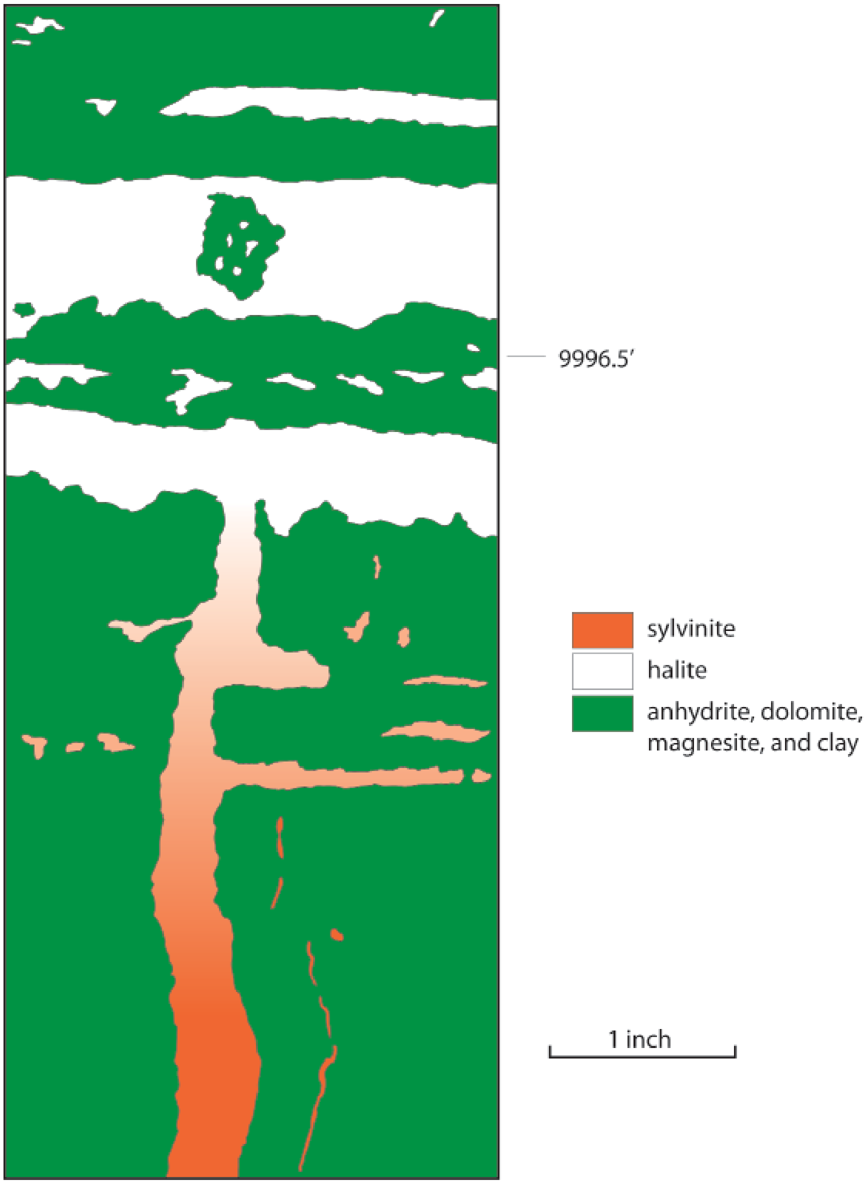

Figure 3. Tracing of core showing sylvinite veinlet cutting layers composed of a mixture of anhydrite, dolomite, magnesite, and clay. The sylvite content of the veinlet increases downward.

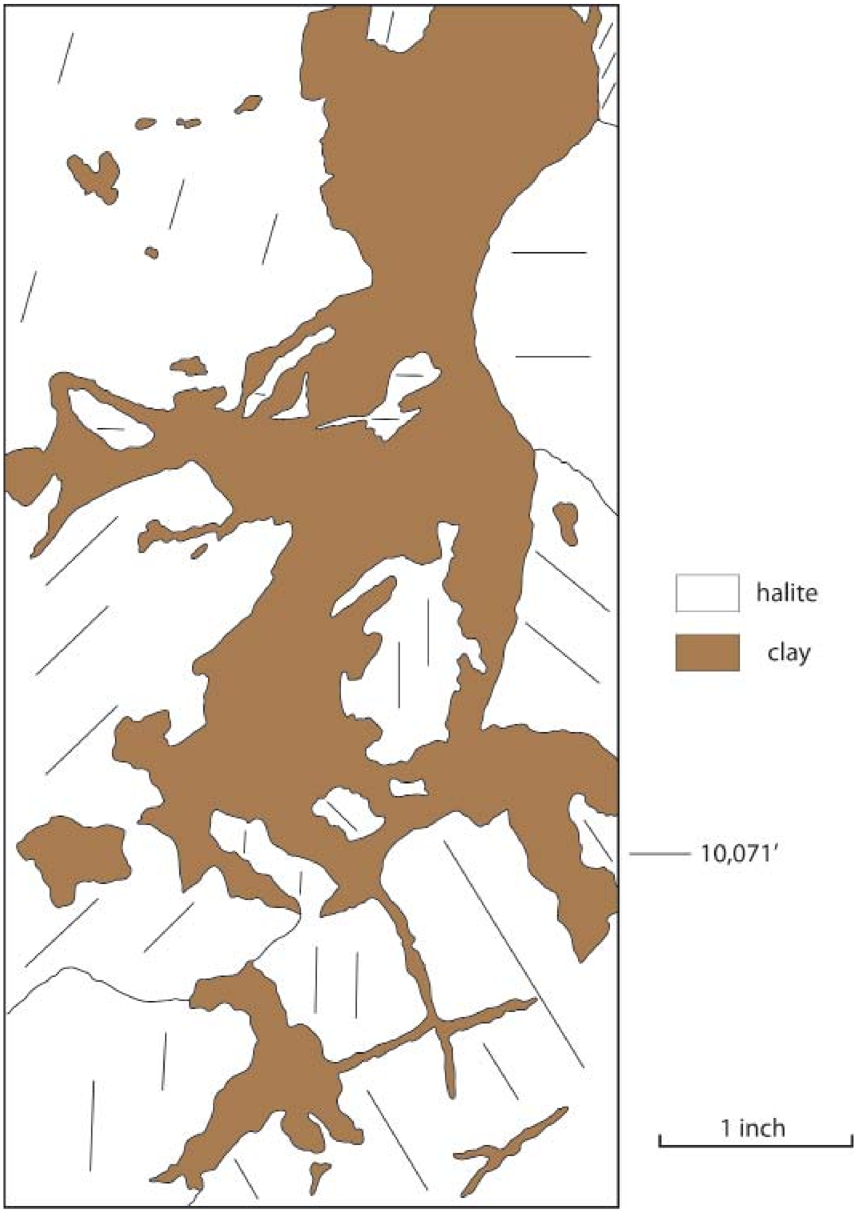

Figure 4. Tracing of core showing relationship between clay and coarse-grained halite. Lines represent the traces of halite cleavage in the plane of the sawn surface.

Blebs, probably of anhydrite and dolomite, are common in the halite. The halite in this lower part of the core frequently occurs as euhedral grains.

The bulk mineralogy of several samples from the core was determined by x-ray diffraction analyses (table 1). Those samples that did not contain recognizable halite or sylvite were chipped from the core at the indicated depths. With the exception of the two samples mentioned above, no attempt was made to identify the clays present. Quartz was identified by x-ray diffraction analysis, but not identified by visual examination of the core.

Some sections of the core show the effect of extensive solution evidently produced during the coring operation. This solution has produced irregular pits on the surface of the core. Many pits range from 3 to 10 mm in length, and more rarely there are pits as long as 6 cm. The larger pits are confined to those sections of the core containing the most sylvite. The sylvite dissolved because the drilling fluid was saturated with respect to NaCl, but not KCl.

The equivalent water-soluble K_2O was calculated from analyses of water-soluble K (table 2). Water-insoluble K_2O was determined for selected samples and is attributed to K in illite. Water-insoluble residues from several samples were analyzed by x-ray diffraction analyses.

Table 1. Bulk mineralogy of water-insoluble material as determined by x-ray diffraction analyses.

Depth	**Mineralogy**
9,996.3′	magnesite, anhydrite, quartz
9,996.8′	magnesite, anhydrite, dolomite, quartz
10,073.0′	anhydrite, dolomite, quartz
10,080.0′	dolomite, anhydrite, quartz
10,106.8′	anhydrite, dolomite, quartz
10,107.0′	dolomite, anhydrite, quartz

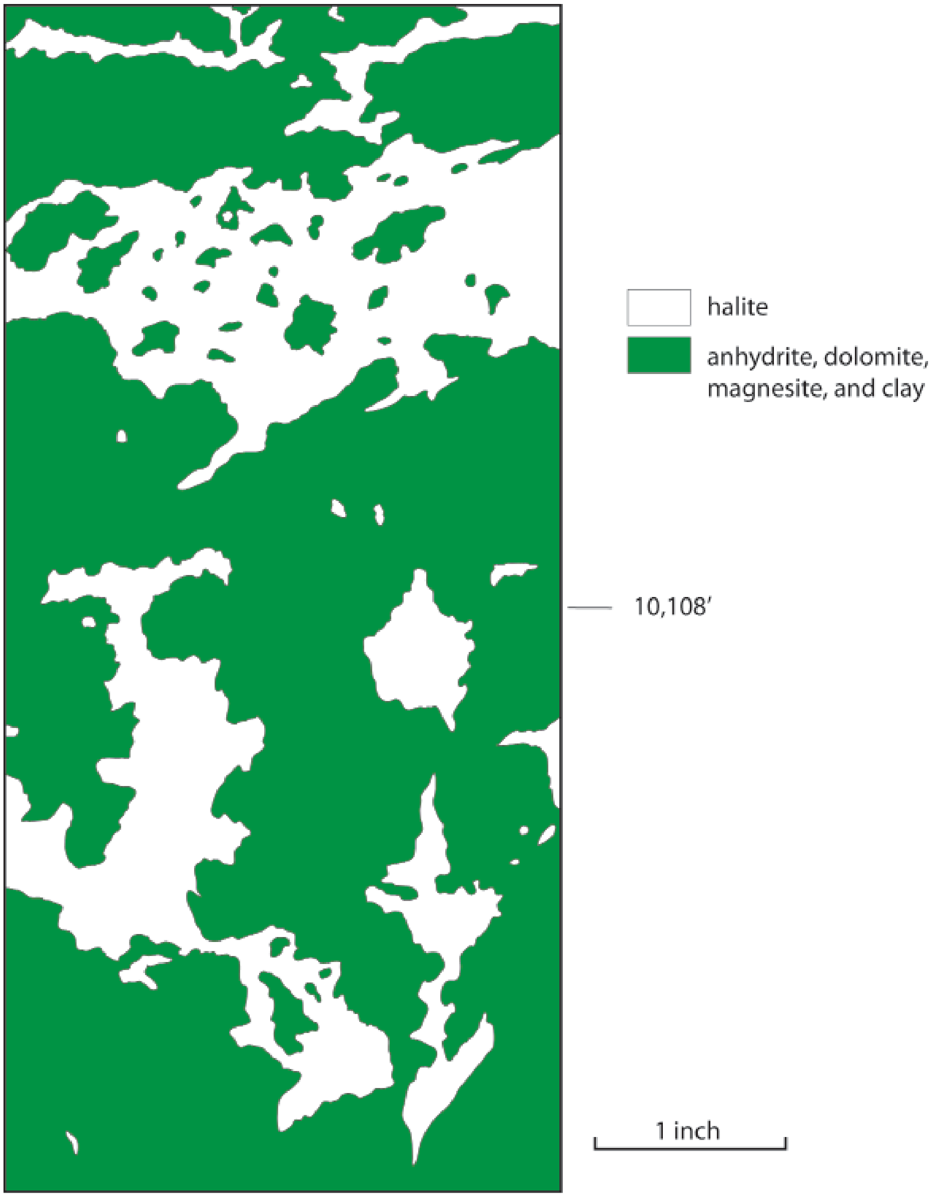

Figure 5. Tracing of core showing relationship between halite and a mixture of anhydrite, dolomite, and magnesite.

SUMMARY

The mineralogy of this cored interval is relatively simple. Sylvite is the main source of potassium; lesser amounts of potassium occur in illite (table 2). Figure 6 shows the approximate modal composition of this core. The percent of either clay or the mixture of anhydrite, dolomite, and magnesite was estimated visually and thus may be subject to considerable error. The percent sylvite as plotted in figure 6 was calculated from the potassium analyses of the water-soluble minerals. It can be seen from this log that the highest concentration of potassium is confined to two intervals near the middle of the cored interval.

Figure 7 (*click link to open the figure in a separate file*) shows the percent water-soluble-equivalent K_2O, which has been plotted for easy comparison to the gamma ray log. A comparison between this log and the gamma ray log shows, as would be expected, a good correlation between the water-soluble-equivalent K_2O content of the core and the intensity of gamma radiation. However, it must be noted that the depths marked at 1-ft intervals on the core as received do not match the depths indicated on the gamma ray and resistivity logs.

By comparing the gamma ray and conductivity logs from this hole, one can pick out those areas of high sylvite content as shown by our analyses. It should be possible to locate sylvite-rich zones in other holes through sediments of the same lithologies by using gamma ray logs.

Table 2. Analyses of water-soluble potassium of prairie evaporite core and mineralogy of water-insoluble residue from selected intervals.

Sample number	Sample interval (ft)	Water-soluble % Equiv. K_2O	Water-insoluble % K_2O	Mineralogy of water-insoluble residue
1	9.918.0–9,920.5	0.23		
2	9,920.5–9,920.9	0.25		
3	9,920.9–9,926.0	0.19		
4	9,926.0–9,931.3	0.19		
5	9,931.3–9,932.0	0.19		
6	9,932.0–9,935.2	0.19		
7	9,935.2–9,938.0	0.28		
8	9,938.0–9,941.0	0.27		
9	9,941.0–9,944.7	0.32		
10	9,944.7–9,947.9	0.24		
11	9,947.9–9,949.0	0.44	0.34	dol., anh., qtz
12	9,949.0–9,952.0	0.28		
13	9,952.0–9,954.7	0.30		
14	9,954.7–9,957.0	0.30		
15	9,957.0–9,595.4	0.25		
16	9,957.4–9,962.0	0.18		
17	9,962.0 - 9,966.0	0.24		
18	9,966.0–9,967.0	0.24		
19	9,967.0–9,967.9	0.34		
20	9,981.5–9,982.5	0.42		
21	9,982.5–9,984.0	0.42		
22	9,984.0–9,987.3	0.32	0.12	
23	9,987.3–9,989.3	0.54		
24	9,989.3–9 991.7	0.30		
25	9,991.7–9 993.8	0.20		
26	9,993.8–9,995.3	0.30		
27	9,995.3–9 996.0	0.27		
28	9,996.0–9,997.5	0.87		
29	9,997.5–10,000.1	2.10	0.80	dol, qtz., mag.
30	10,000.1–10,001.8	0.50		
31	10,001.8–10,003.1	0.56		
32	10,003.1–10,004.3	0.64		
33	10,004.3–10,004.9	0.84		
34	10,004.9–10,006.8	2.51	0.34	
35	10,006.8–10,007.8	0.54		
36	10,007.8–10,008.2	3.30		
37	10,008.7–10,008.9	5.04		
38	10,008.9–10,009.5	4.20		
39	10,009.5–10,009.8	3.42		
40	10,009.8–10,010.3	3.18		
41	10,010.3–10,011.0	3.42		
42	10,011.0–10,011.3	3.54		
43	10,011.3–10,011.7	2.94		
44	10,011.7–10,012.7	4.02		
45	10,012.7–10,013.0	6.36		
46	10,013.0–10,013.7	2.86		
47	10,013.7–10,014.1	2.19		
48	10,014.1–10,015.0	8.55	0.25	mag., qtz., anh.
49	10,015.0–10,016.5	0.79		
50	10,016.5–10,017.4	1.74	0.19	qtz., mag., anh.

51	10,017.4–10,018.5	0.48		
52	10,018.5–10,019.1	0.60		
53	10,019.1–10,020.8	0.42		
54	10,020.8–10,022.8	0.44		
55	10,022.8–10,024.6	0.48		
56	10,024.6–10,026.8	0.54		
57	10,026.8–10,028.7	0.50		
58	10,031.0–10,032.6	0.59		
59	10.032.6–10,034.0	0.44		
60	10,034.0–10,036.7	0.30		
61	10,036.7–10,039.3	0.47		
62	10,039.3–10,040.3	0.26		
63	10,040.3–10,040.9	0.54		
64	10,040.9–10,042.4	0.22		
65	10.042.4–10,043.3	.026		
66	10,043.3–10,044.2	0.28		
67	10,044.2–10,044.7	1.14		
68	10,044.7–10,047.1	0.37		
69	10,047.1–10,048.1	2.46		
70	10,048.1–10,049.9	6.96		
71	10,049.9–10,050.3	0.35		
72	10,050.3–10,050.9	0.19		
73	10,050.9–10,053.0	0.19		
74	10,053.0–10,055.1	0.18		
75	10,055.1–10,056.4	0.17		
76	10,056.4–10,257.5	0.12		
77	10,057.5–10,058.0	0.19		
78	10,059.0–10,059.3	0.19		
79	10,059.3–10,061.4	0.15		
80	10,061.4–10,062.7	0.20		
81	10,062.7–10,064.0	0.19		
82	10,064.0–10,066.6	0.16		
83	10,066.6–10,068.1	0.14		
84	10,068.1–10,071.3	0.15		
85	10,071.3–10,073.0	0.14		
86	10,073.9–10,074.4	0.10	0.10	anh., dol., qtz.
87	10,074.4–10,077.5	0.10		
88	10,077.5–10,079.9	0.14		
89	10,079.9–10,082.0	0.14		
90	10,082.0–10,083.9	0.12		
91	10,083.9–10,086.1	0.10		
92	10,086.1–10,088.2	0.12		
93	10,088.2–10,090.8	0.14		
94	10,090.8–10,092.0	0.15		
95	10,092.0–10,095.0	0.12		
96	10,095.0–10,096.5	0.13		
97	10,096.5–10,098.1	0.14		
98	10,098.1–10,101.0	0.13		
99	10,101.0–10,104.1	0.17		
100	10,104.1–10,106.7	0.15		
101	10,106.7–10,109.7	0.18	0.26	dol., anh., qtz.
102	10,109.7–10,112.5	0.07		
103	10,112.5–10,115.0	0.10		
104	10,115.0–10,117.3	0.08		
105	10,117.3–10,120.1	0.08		
106	10,120.1–10.122.3	0.08		

Note. dol., dolomite; anh., anhydrite; qtz., quartz; mag., magnesite.

ACKNOWLEDGMENTS

Reviews by Ron Geitgey, Mark Cocker, and John Metesh improved this report. Very careful review, particularly of the logs, by Ed Deal resulted in significant improvement and is appreciated.

SELECTED BIBLIOGRAPHY

July, 1967

Clark, A.R., and Schwerdtner, W.M., 1966, Petrofabric analysis of potash rock, Esterhazy, Saskatchewan, in 2nd Symposium on Salt: Cleveland, Ohio, 1965, Northern Ohio Geological Society, p. 102–121.

Pearson, W.J., 1965, Geology of Saskatchewan potash deposits: Western Miner, v. 38., no. 12, p. 35–41.

Schwerdtner, W.M., 1964, Genesis of potash rocks in Middle Devonian Prairie Evaporite Formation of Saskatchewan: Bulletin of American Association of Petroleum Geologists, v. 48, p. 1108–1115.

Wardlaw, N.C., 1964, Comparison of a Middle Devonian Evaporite profile in Saskatchewan with hypothetical model, in Third International Williston Basin Symposium: Saskatchewan Geological Society, p. 266–269.

Van der Plank, A., 1962, Petrology and geochemistry of some diamond drill cores from the Saskatchewan potash deposits: Madison, University of Wisconsin, M.S. thesis.

Wardlaw, N.C., and Schwerdtner, W.M., 1966, Halite–anhydrite seasonal layers in the Middle Devonian Prairie Evaporite Formation, Saskatchewan, Canada: Geological Society of America Bulletin, v. 77, p. 331–342.