

Sedimentology and Geochemistry of the Bakken Formation (Devonian-Mississippian) in Southern Saskatchewan

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The Bakken Formation is well known as the premier marker in the Williston Basin because it comprises a gray sandstone bed sandwiched between two distinctively thin radioactive black shales, easily recognized in cores or on gamma-ray geophysical well logs. The Bakken is widely considered to be a source of hydrocarbons within the basin (Murray, 1968; Hayes, 1985). Fifty three drill cores that penetrated the Bakken in southern Saskatchewan (Figure 1) were examined and about 600 samples collected for geochemical analysis. Conodont samples were also collected and identified.

1. Bakken Formation

The Bakken Formation is one of the most distinctive stratigraphic sequences in the Williston Basin. This formation and its equivalents straddle the Devonian-Mississippian boundary throughout in the western interior region of the North American continent. In the Williston Basin this transition zone consists of three members: the Lower Bakken Shale, Middle Bakken Sandstone and Upper Bakken Shale.

a) Lower Bakken Shale

The Lower Bakken Shale unconformably overlies the Big Valley and Torquay Formations and the contact is marked in places by a lag-concentrate bed, a basal conglomerate, or an erosion surface. It is composed of homogeneous non-calcareous, carbonaceous to bituminous, fissile, massive, unconnected lenticular to thinly laminated, waxy, hard, pyritic, radioactive, dark gray to black shale. In some areas vertical fissures are filled by white calcite and disseminated pyrite. Christopher (1961) interpreted these fissures as compressed mud cracks. This member thins from 11 m in the west to zero in the east.

b) Middle Bakken Sandstone

A regional diastem separating the Middle Bakken Sandstone from the underlying member is shown by basal conglomerate, a weathering pavement, and truncation of the underlying Torquay Formation. Christopher (1961) divided this member into two lithological units, whereas Thrasher (1987), using macrofossils, proposed three subdivisions of the sandstone member. One of the

authors (R.K.) found during core examination that both lithology and macrofossils should be used to distinguish the three units:

Unit I - The lowermost bed is 0 - 7 m thick, consists of a well-sorted, fine- to medium-grained, very calcareous, fossiliferous (brachiopods), unstratified (but in places shows traces of bedding), gray to dark brown, sandstone unit. Brachiopods are disarticulated, randomly oriented and indicate rapid sedimentation. This is supported by the lack of epifauna on the shells (Thrasher, 1987). The unit locally grades into an oolitic limestone or calcarenite bed (9-29-31-23W3, 8-20-31-23W3, 5-30-31-23W3). Pyrite nodules and disseminated pyrite grains are very common. In some areas this unit forms a good oil reservoir.

Unit II - The middle part of the sandstone member (1.5-7 m in thickness) comprises alternate dark gray to greenish gray shaley siltstone or sandstone beds that display numerous primary bedding features. Two interfingering sub-units can be recognized: 1) a pyritic, unfossiliferous, slightly calcareous, gray sandstone alternating laterally with thin, dark gray to black clay beds with predominant sedimentary features such as current bedding, ripple marks, cross bedding, channel fill and scour surfaces; and 2) a discontinuous bedding unit of silty sandstone to muddy siltstone, where the sandstone layers are spherically rolled into ellipsoids and broken into pebble size fragments along bedding surfaces.

Unit III - The topmost unit (0.6 to 2.5 m thick) consists of olive gray, non-calcareous, fossiliferous, bioturbated, pyritic, massive, argillaceous to silty shale.

c) Upper Bakken Shale

The upper Bakken shale conformably overlies the middle sandstone member and underlies the Lodgepole Formation. The member appears to have been formed during a repetition of the Lower Bakken shale depositional conditions as it has the same lithology.

2. Conodont Identification

Thirteen conodont samples were collected from 11 wells representing both the Upper and Lower Shale. No conodonts from the Middle Sandstone Member have been

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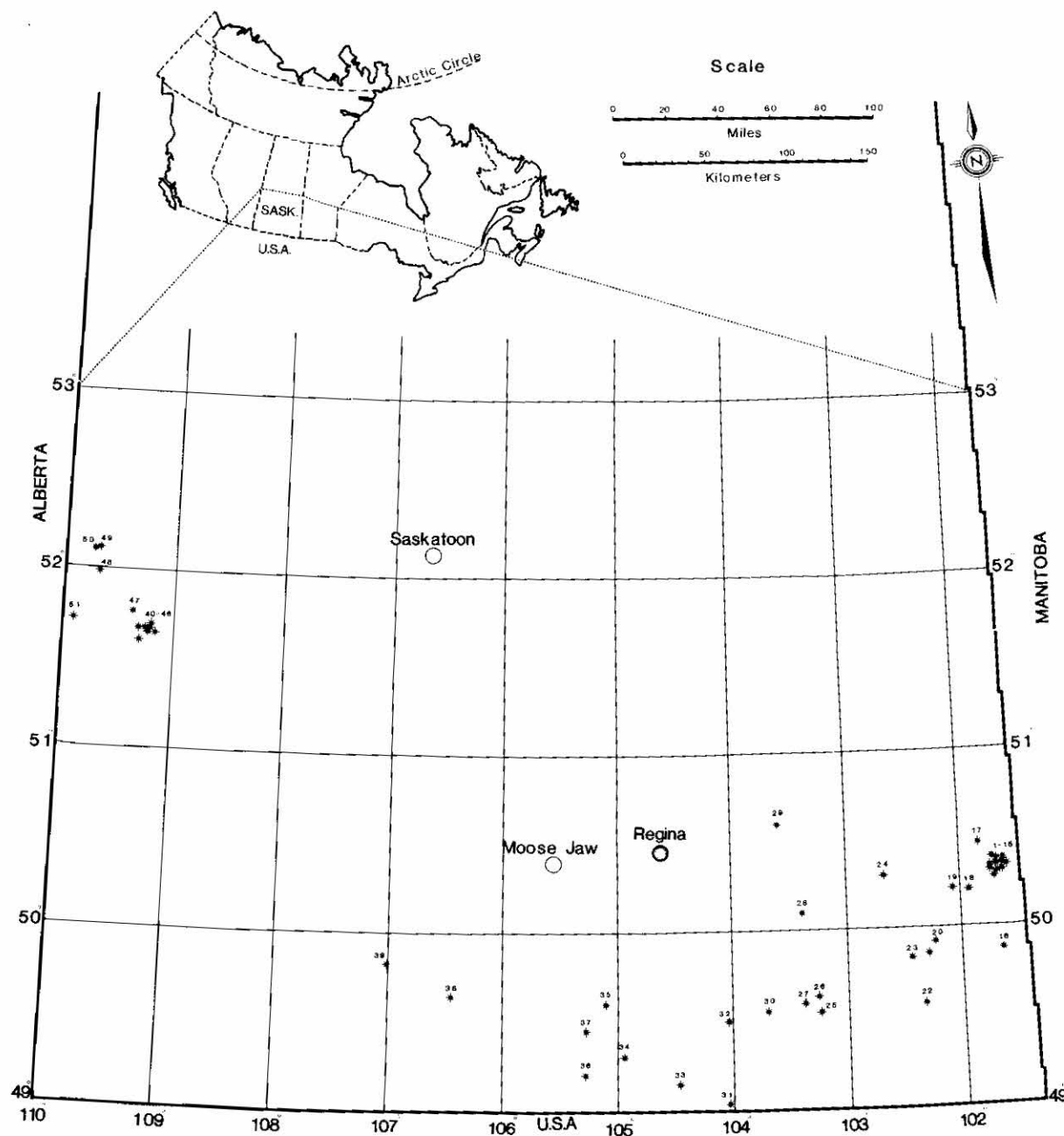


Figure 1 - Borehole and sample location map (Saskatchewan).

observed. Initial examination was done with the aid of a hand lens (10X) or binocular microscope and then a more detailed study was carried out by Dr. Tom Uyeno of the Geological Survey of Canada, Calgary (samples are now stored at ISPG in Calgary).

a) Conodont Biozonation

In Upper Devonian-Lower Mississippian time, rapidly evolving platform elements provide the basis for conodont zonation. The base of each zone is usually defined by the stratigraphic first occurrence of a par-

ticular taxon. Sandberg (1979) reviewed the conodont zonation in this part of the Paleozoic (Figure 2) and concluded that the first occurrence of *Siphonodella sulcata* can be used to mark the Devonian-Mississippian boundary.

b) Composition and Distribution

Bakken conodonts are placed in 21 taxa (Figure 3). The collection is composed mostly of platform elements and rare ramiform elements. Platform genera include (in decreasing order of abundance) *Siphonodella*, *Polyg-*

SERIES	STAGE	CONODONT ZONE or BIOFACIES			
LOWER MISSISSIPPIAN	KINDERHOOKIAN	SIPHONODELLA ISOSTICHA UPPER S. CRENULATA		PATROGNATHUS-PANDORNELLINA BIOFACIES	
		LOWER SIPHONODELLA CRENULATA			
		SIPHONODELLA SANDBERGI			
		SIPHONODELLA DUPLICATA	UPPER		
			LOWER		
		SIPHONODELLA SULCATA			
UPPER DEVONIAN	LATE FAMENNIAN	SIPHONODELLA PRAESULCATA	PROTOGNATHODUS ZONE ////////////////////		
		BISPATODUS COSTATUS		UPPER *	
				MIDDLE	
				LOWER	
		POLYGNATHUS STYRIACUS		UPPER	
				MIDDLE *	
				LOWER *	
		SCAPHIGNATHUS VELIFER		UPPER	
				MIDDLE	
LOWER *					

Figure 2 - Conodont biozonation after Saudbert (1979, Figures 2 and 3). Starred zones are those not recognized in the United States.

nathus, *Branmehla*, *Bispathodus*, *Pseudopolygnathus*, *Palmatolepis*, and "*Spathognathodus*". Distribution of the conodonts is mainly in the Upper and Lower Shales, being found mainly on shale bedding surfaces. Sixty-three per cent of the collection was obtained from the Upper Shale, the remainder from the Lower Shale.

c) Lower Shale

Based principally on the ranges established elsewhere (Sandberg, 1979; Holland *et al.*, 1987) the more diagnostic taxa in the Lower Shale include *Palmatolepis gracilis sigmoidalis*, *Palmatolepis rugosa rugosa* and *Bispathodus jugosus* (Uyeno, this study), and the absence of *Bispathodus aculeatus*, suggests that the Lower Bakken Shale can be assigned to the Upper *Polygnathus styriacus* zone (Lower-Middle *expansa* zone, Late Famennian).

d) Upper Shale

Since species identification requires three dimensional observation, the conodont evidence from this member is not precise because the fractured specimens of *Siphonodella* could not be extracted intact. However the presence of *Bispathodus aculeatus* suggests that the Upper Shale is no younger than the Lower *crenulata* Zone (Middle Kinderhookian). This is also confirmed by the presence of "*Spathognathodus*" *macer*. Hayes (1985) and Holland *et al.* (1987) also suggested a Lower *crenulata* age for this member in North Dakota.

e) Conodont Color Alteration Index (CAI)

Harris (1981) reported that "color alteration begins beyond the threshold of hydrocarbon generation and a CAI of 1.5 to 2 is at the deadline for oil and condensate production". Conodonts from both Upper and Lower Bakken Shale have CAI values (Epstein *et al.*, 1977) of 1 (pale yellow) to 1.5 (pale brown). Since the conodont samples were collected from depths ranging between 800 and 2350 m, this suggests that the enclosing rocks are thermally immature between these depths and therefore not sufficiently heated for hydrocarbon generation.

3. Geochemistry of the Bakken Formation

Some 569 samples were collected from the 53 subsurface cores shown in Figure 1 in an attempt to 1) establish the nature of the Bakken Formation gamma-ray response, 2) identify any regional trends in the "radioactivity", 3) determine general major and trace element concentrations, and 4) identify possible factors controlling elemental concentrations.

a) Analytical Methods

All samples were analyzed for SiO₂, TiO₂, Al₂O₃, total Fe₂O₃, MnO, MgO, CaO, P₂O₅ by ICP; Na₂O and K₂O by AAS; H₂O and LOI by gravimetry; Ba, Cr, Cu, Nb, Ni, Pb, Rb, Sr, Th, U, V, Y, Zn, Zr by XRF. FeO(c) was calculated as representing 90% of total Fe₂O₃ and it should be noted that LOI represents an approximation of combined, inorganic and organic carbon plus organic sulphur. In addition, all samples were analyzed for U and Th by NAA; the activation analyses are presented in the following tables as they are more precise than those obtained by XRF.

Since some samples contained significant pyrite, which is not readily accounted for by an LOI procedure, 23 samples of the Lower Shale, 30 samples of Middle Sandstone, and 28 samples of Upper Shale were analyzed for S by XRF. A limited number of samples (44 Lower Shale, 36 Middle Sandstone, 39 Upper Shale) were analyzed by NAA for 34 elements, namely: Au, Ag, As, Ba, Br, Ca, Co, Cr, Cs, Fe, Hf, Hg, Ir, Mo, Na, Ni, Rb, Sb, Sc, Se, Sr, Ta, Th, U, W, Zn, and the REE-La, Ce, Nd, Sm, Eu, Tb, Yb, Lu. Finally, seven samples of shale were subjected to solvent extraction and the rock residues and oil extracts were analyzed for 34 elements by NAA.

CONODONT TAXA	LOWER SHALE	UPPER SHALE	DEPTH (M)	SAMPLE & WELL LOCATION
Bispathodus aculeatus	*	*	1675.8	6-9-7-13 W2
	*	*	2324.7	2-14-1-16 W2
	*	*	792.75	9-29-31-23W3
	*	*	844-845	10-33-30-24W3
Bispathodus jugosus	*	*	1819.9	1-2-6-25W2
	*	*	849.7-851	10-33-30-24W3
Bispathodus stabilis	*	*	792.75	9-29-31-23W3
	*	*	844-845	10-33-30-24W3
Brannemelia inornata	*	*	1689.4	15-7-7-10W2
	*	*	1819.9	1-2-6-25W2
	*	*	835.9	5-30-31-23W3
	*	*	849.7-851	10-33-30-24W3
Palmatolepis gracilis sigmoidalis	*	*	1819.9	1-2-6-25W2
	*	*	849.7-851	10-33-30-24W3
Palmatolepis perlobata postera	*	*	849.7-851	10-33-30-24W3
Palmatolepis rugosa rugosa	*	*	849.7-851	10-33-30-24W3
Polygnathus communis	*	*	686.8	16-5-16-31W1
	*	*	1675.8	6-9-7-13W2
	*	*	2324.7	2-14-1-16W2
	*	*	792.75	9-29-31-23W3
	*	*	844-845	10-33-30-24W3
Polygnathus inornatus	*	*	1675.8	6-9-7-13W2
Polygnathus ?sp.	*	*	811.4	8-26-31-24W3
Pseudopolygnathus marginatus	*	*	654.1	16-11-16-31W1
	*	*	1675.8	6-9-7-13W2
	*	*	2324.7	2-14-1-16W2
	*	*	792.75	9-29-31-23W3
	*	*	844-845	10-33-30-24W3
Pseudopolygnathus primus	*	*	1675.8	6-9-7-13W2
Pseudopolygnathus sp. brevipennatus	*	*	849.7-851	10-33-30-24W3
Pseudopolygnathus sp.	*	*	792.75	9-29-31-23W3
Siphonodella sp.	*	*	792.75	9-29-31-23W3
Spathognathodus crassidentatus	*	*	792.75	9-29-31-23W3
Spathognathodus strigosus	*	*	1819.9	1-2-6-25W2
	*	*	849.7-851	10-33-30-24W3
"Spathogna - thodus" sp.	*	*	1689.4	15-7-7-10W2
	*	*	2324.5	2-14-1-16W2
	*	*	849.7-851	10-33-30-24W3
Spathognathodus elongatus	*	*	811.4	8-26-31-24W3
	*	*	1675.8	6-9-7-13W2
	*	*	2324.7	2-14-1-16W2
	*	*	792.75	9-29-31-23W3
	*	*	844-845	10-33-30-24W3
"Spathognathodus" macer	*	*	1784.95	3-26-6-16W2
	*	*	811.4	8-26-31-24W3
Ramiforms	*	*	2324.5	2-14-1-16W2

Figure 3 - Distribution of conodonts obtained from the Lower and Upper Bakken Shales. Depths are from the core boxes.

The analytical work has just been completed and interpretation of the data about to commence. However, a few observations of a preliminary nature are noted in this report, based mainly on the analyses noted in the first paragraph of the above section on analytical methods.

b) Bakken Shale vs Other Shales and Black Shales

Table 1 shows the published values of shales and black shales with the average Bakken shale (379 samples) for some of the elements analyzed in this study. As expected the major elements are generally conformable, except that perhaps the Bakken is depleted slightly in FeO and enriched slightly in K₂O (a natural radioelement). Most of the trace elements are generally conformable, except that Cr, Ni, U, and especially V and Zn, are enriched. With Th values a little below average, it is clear that the gamma-ray response of the Bakken Formation on well logs is predominantly U generated.

c) Lower Shale Member

The 192 samples of Lower Shale (some selected analyses are shown in Table 2) have been subdivided into groups based on LOI and tables of basic statistics for these subgroups are available from the authors. The LOI boundaries used are 0-10%, 10-20%, 20-30%, 30-40% and >40%. The majority of samples fall in the 0-30% range. The 2 samples >40% have high CaO values because they are calcareous units.

The general observation is that U, V, Pb, Cr, Ni and Zn exhibit a clear positive correlation with LOI, while Th tends to have a negative correlation. A tentative conclusion is that these elements other than Th must have had their precipitation controlled by organic matter.

Adams and Weaver (1958), based on the Th/U ratio, reported three geochemical facies in sedimentary rocks and concluded (page 419) that the low Th/U ratio of

Table 1 - Comparison of Bakken Shale Average with Other Published Data.

Element	Average ⁽¹⁾ Exshaw shale	Black ⁽²⁾ Shale	Average ⁽³⁾ Shale	Average ⁽⁴⁾ Black Shale	Average Bakken Black Shales
SiO ₂	48.5	58.6	58.1	-	50.15
TiO ₂	0.30	0.42	0.77	0.33	0.55
Al ₂ O ₃	7.20	9.65	15.1	13.2	11.96
FeO	3.88	4.46	6.75	2.86	2.79
MnO	-	-	-	-	0.035
MgO	1.21	0.84	2.49	1.16	2.39
CaO	4.92	1.69	3.09	2.10	4.3
Na ₂ O	0.30	0.34	1.29	0.94	0.54
K ₂ O	2.67	3.32	3.20	2.41	4.89
P ₂ O ₅	-	-	-	-	0.31
H ₂ O	-	-	-	-	0.84
LOI	-	-	-	-	20.69
Ba	325	355	580	300	402.01
Cr	55.3	66	90	100	407.66
Cu	72	82	45	70	85.2
Nb	-	-	-	-	10.35
Ni	107	123	68	50	315.05
Pb	26	30	20	20	35.84
Rb	78	101	140	-	134.48
Sr	272	157	300	200	163.40
Th	9.2	10.7	12	-	8.34
U	15.6	15.9	3.7	-	52.81
V	227	267	130	150	4851.16
Zn	102	108	95	30	35.76
Zr	-	-	160	70	1041.42

(1) Average Exshaw shale values from Duke (1983)

(2) Black shale values from Duke (1983)

(3) Average shale values from Cambel et al. (1983) after Turekian and Wedepohl (1961)

(4) Average black shale values from Vine and Tourtelot (1970).

Major elements in weight percent, trace element in ppm

0.31 in the Heebner black shale indicated reducing conditions, favourable for carbonaceous material accumulation, as well as for extraction of the uranyl ion from the seawater during very slow rates of sedimentation. The Bakken Th/U ratio of 0.18 suggests even more extreme depositional conditions (of reduction) than were present for the Heebner shale.

d) Middle Sandstone Member

Table 3 shows a selection of sandstone analyses from the 196 samples analyzed. General statistics were calculated based on the same LOI subdivision was used for the Lower Shale data. Compared with the Lower Shale it is clear that the LOI in the Middle Sandstone is predominantly controlled by inorganic carbon because the CaO increases proportionally with the LOI. As a consequence the enhancements of U,

V, Pb, Cr, Ni, Zn noted in the Lower Shale with increasing LOI are either weak (Pb, Ni, Zn) or actually reversed (i.e. depletions of U, V, Cr).

Generally, the trace element contents are low; particularly U. On the other hand, the Th/U ratio is high (1.18).

e) Upper Shale Member

Analyses of the 178 samples in this member exhibit very similar elemental values to the other members (Table 4 - selected analyses). The conditions of formation of this

member must have been almost identical to those of the Lower Shale.

4. Nature of Elemental Bonding

It is perhaps premature, at this stage in the study, to present views on the bonding of the "anomalous" concentrations of trace elements; however, the results from the rock residues and extracted oils indicate that almost all the trace elements are, and remain in, the rock, not in the oil. Thus, although the organic material must have played an important part in the production of the right conditions for the precipitation of the trace elements, the actual precipitation and bonding was an inorganic process.

5. Acknowledgements

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Sincere thanks to the subsurface laboratory staff for their cooperation during core examination, to

Table 2 - Selected Analysis from Lower Bakken Shale Mean and S.D. Values based on all 192 Lower Bakken Shale Samples.

Sample#	25	32	150	224	263	313	401	420	450	528	556	Mean	S.D.
SiO ₂	86.22	49.24	56.12	60.99	53.61	64.73	57.19	45.03	40.79	2.94	52.09	53.83	10.25
TiO ₂	0.63	0.60	0.40	0.78	1.20	0.80	0.68	0.57	0.52	0.03	0.60	0.59	0.17
Al ₂ O ₃	7.22	14.41	8.67	18.57	12.39	16.62	15.74	11.87	11.63	0.56	16.90	12.98	3.71
Fe ₂ O ₃	0.07	0.34	0.14	0.38	0.29	0.36	0.31	0.27	0.36	0.01	0.31	0.32	0.21
MnO	0.00	0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.04	0.35	0.02	0.04	0.11
FeO(c)	0.59	2.77	1.14	3.04	2.32	2.94	2.53	2.16	2.93	0.10	2.47	2.57	1.70
MgO	0.76	1.85	1.67	1.83	1.01	1.95	1.52	2.32	2.54	0.46	1.72	2.08	0.87
CaO	0.09	0.58	4.22	0.14	5.14	0.30	0.16	2.31	5.37	54.93	0.67	3.09	5.30
Na ₂ O	0.17	0.53	0.53	0.53	0.53	0.59	1.88	0.52	0.41	0.05	0.59	0.59	0.29
K ₂ O	1.55	4.01	3.74	6.62	4.38	6.42	6.40	4.77	6.60	0.13	4.03	5.03	1.44
P ₂ O ₅	0.20	0.41	0.24	0.14	2.85	0.19	0.23	0.32	0.93	0.09	0.45	0.33	0.41
H ₂ O-	0.19	1.95	0.45	0.00	0.00	0.00	0.93	0.45	1.37	0.09	0.12	0.71	0.60
LOI	2.31	23.22	22.42	6.92	16.29	6.15	12.42	29.09	26.54	40.79	20.02	17.32	9.33
TOTAL	100.00	99.92	99.76	99.95	100.02	101.07	100.00	99.70	100.03	100.53	99.99		
Ba	168	247	115	322	377	293	261	164	206	1	319	308.37	529.77
Cr	97	151	91	124	160	132	1413	1151	714	1279	1077	460.02	477.94
Cu	7	83	39	198	312	40	110	67	92	8	63	71.71	93.00
Nb	12.0	12.0	8.0	14.0	23.0	14.0	15.0	11.0	15.0	1.0	14.0	11.15	3.26
Ni	8	36	345	130	205	310	957	533	601	12	497	286.57	216.50
Pb	7	30	9	106	84	61	27	26	193	5	32	29.15	25.25
Rb	61	176	107	235	176	202	176	128	111	22	135	150.59	47.24
Sr	44	99	46	206	204	59	66	50	117	220	356	207.24	1016.17
Th	0	1	4	13	13	9	16	8	8	1	17	8.58	3.31
U	5	52	126	460	240	86	110	180	1500	4	54	62.91	117.69
V	69	3182	1219	791	361	897	15407	12958	2266	29111	18609	5299.91	7619.12
Y	34	71	43	23	145	21	59	66	73	7	43	35.44	28.31
Zn	28	1292	1677	232	134	191	178	2189	3523	26	2986	859.54	3735.05
Zr	498	148	97	183	244	187	149	117	137	32	170	142.91	51.35

Table 3 - Selected Analyses from Middle Bakken Sandstone member. Mean and S.D. Values based on all 196 Middle Bakken Sandstone Samples.

Sample#	10	16	43	53	79	182	220	376	517	567	Mean	S.D.
SiO ₂	85.73	67.27	43.38	54.66	49.37	44.84	55.06	77.76	63.57	43.38	56.22	13.45
TiO ₂	0.40	0.79	0.45	0.25	0.49	0.22	0.34	0.32	0.59	0.41	0.38	0.14
Al ₂ O ₃	5.36	14.83	7.95	4.41	9.43	3.07	5.80	5.49	7.38	6.50	6.31	2.70
Fe ₂ O ₃	0.23	0.39	0.21	0.12	0.21	0.07	0.15	0.09	0.18	0.16	0.17	0.10
MnO	0.01	0.02	0.08	0.05	0.05	0.07	0.06	0.02	0.04	0.12	0.06	0.03
FeO(c)	1.84	3.19	1.73	0.95	1.68	0.54	1.20	0.72	1.49	1.31	1.38	0.83
MgO	0.78	1.26	6.94	4.63	5.47	6.96	6.76	2.10	3.82	3.41	4.87	2.43
CaO	0.23	0.34	13.78	16.21	11.09	19.26	11.68	4.38	6.56	20.30	11.74	6.23
Na ₂ O	0.18	0.32	0.45	0.35	0.65	0.37	0.55	0.96	0.22	0.20	0.53	0.35
K ₂ O	1.00	2.40	3.67	2.33	5.60	1.88	3.19	2.52	3.05	2.58	2.86	1.21
P ₂ O ₅	0.23	0.85	0.25	0.41	0.27	0.21	0.11	0.30	0.23	0.21	0.21	0.08
H ₂ O-	0.29	1.92	0.63	0.20	0.13	0.05	0.00	0.14	0.42	0.39	0.34	0.42
LOI	3.73	6.41	20.72	15.38	15.10	22.45	13.74	5.22	12.49	20.68	14.79	5.78
TOTAL	100.01	99.99	100.24	99.95	99.54	99.99	98.64	100.02	100.04	99.65		
Ba	116	1246	159	204	179	102	254	149	185	134	252.72	519.39
Cr	194	237	76	54	79	41	65	70	684	0	206.10	277.02
Cu	39	86	12	24	11	35	13	16	15	12	11.39	8.49
Nb	6.0	18.0	9.0	5.0	10.0	5.0	6.0	6.0	9.0	7.0	6.80	2.75
Ni	12	28	35	32	38	46	37	22	25	18	33.04	28.23
Pb	39	133	22	5	9	8	15	7	11	10	14.29	17.17
Rb	53	123	98	57	103	36	71	60	83	73	70.64	27.25
Sr	33	1461	71	124	174	138	76	143	65	98	123.52	236.91
Th	6	10	6	5	7	5	5	7	10	6	6.15	2.14
U	9	49	14	3	1	5	15	23	7	3	5.20	5.28
V	285	1906	88	54	108	79	61	112	691	0	433.47	1629.01
Y	51	99	32	26	24	22	19	26	25	28	23.16	7.83
Zn	64	102	153	10	41	43	169	7	21	19	59.04	154.58
Zr	394	417	188	302	181	329	227	254	307	184	248.20	89.50

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Table 4 - Selected Analyses from Upper Bakken Shale Member. Mean and S.D. Values based on all 178 Upper Bakken Shale Samples.

Sample#	2	5	8	9	56	227	316	372	380	413	538	Mean	S.D.
SiO ₂	62.93	66.67	60.74	51.12	42.68	34.43	55.22	37.21	36.79	39.50	34.76	46.46	10.57
TiO ₂	0.44	0.57	0.77	0.64	0.50	0.39	0.66	0.40	0.43	0.45	0.44	0.50	0.12
Al ₂ O ₃	9.94	11.82	16.49	12.33	9.78	8.96	14.40	9.41	10.25	9.06	8.79	10.94	3.17
Fe ₂ O ₃	0.15	0.27	0.38	0.29	0.18	0.37	0.41	0.37	0.49	0.19	0.29	0.30	0.13
MnO	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.02
FeO(c)	1.22	2.18	3.11	2.31	1.45	2.99	3.32	2.98	3.94	1.54	2.31	2.40	1.03
MgO	1.14	1.38	1.65	1.33	2.43	1.69	2.44	1.81	1.40	1.83	1.30	2.70	1.72
CaO	9.91	0.09	0.10	0.08	2.93	2.16	4.09	2.30	1.13	1.75	3.56	5.52	6.28
Na ₂ O	0.34	0.34	0.43	0.34	0.64	1.19	0.55	0.88	0.80	0.35	0.31	0.49	0.22
K ₂ O	2.35	3.26	3.75	2.80	4.28	4.28	6.57	4.53	4.49	4.23	3.21	4.75	1.34
P ₂ O ₅	0.40	0.20	0.25	0.22	0.31	0.42	0.38	0.27	0.29	0.31	0.22	0.29	0.15
H ₂ O-	0.58	1.07	1.30	1.10	0.79	0.00	1.29	1.73	1.66	0.29	1.64	0.97	0.69
LOI	10.63	11.45	10.93	27.46	33.25	43.12	10.64	38.12	38.29	39.48	34.58	24.07	11.22
TOTAL	100.05	99.31	99.91	100.03	99.24	100.02	99.99	100.03	99.99	99.00	91.43		
Ba	133	237	308	182	127	170	229	96	131	105	140	495.65	1431.62
Cr	101	119	137	217	124	113	153	0	109	1256	500	355.31	448.77
Cu	29	38	37	127	97	102	72	119	238	126	113	98.69	125.74
Nb	8.0	9.0	15.0	12.0	9.0	6.0	12.0	10.0	10.0	10.0	10.0	9.55	2.62
Ni	19	124	100	397	443	586	220	512	1048	597	784	343.53	209.56
Pb	19	28	41	54	24	81	8	158	91	41	36	42.53	46.41
Rb	88	131	175	122	109	94	174	92	107	97	95	118.37	36.78
Sr	114	50	107	100	56	49	108	60	39	43	119	119.56	265.71
Th	8	7	10	8	6	7	7	7	8	8	11	7.89	2.28
U	3	22	116	262	54	75	14	260	190	91	37	42.71	41.19
V	220	369	456	3033	2071	1432	1217	0	1358	19044	3438	4402.41	7286.56
Y	40	21	39	69	44	45	51	40	85	34	20	36.08	15.53
Zn	84	162	81	3487	404	3151	57	9707	6271	410	24342	1223.29	3143.97
Zr	117	210	202	290	137	89	133	88	89	115	164	136.88	45.62

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