



GEOLOGICAL SURVEY OF CANADA

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Lithogeochemical database of Cretaceous strata in central Saskatchewan (part of NTS 73)

Volume 1

C.E. Dunn, W.A. Spirito, and S.W. Adcock

1994

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**LITHOGEOCHEMICAL DATABASE OF
CRETACEOUS STRATA IN CENTRAL
SASKATCHEWAN**

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FOREWORD

An Environmental Geochemistry programme was initiated in the Mineral Resources Division of the Geological Survey of Canada in 1989. A prime objective of this science is to examine the relationships between the composition of rocks and soils, and the health of plants, animals and humans. At the time that this programme was being developed, two papers were published which indicated that there may be a link between the chemistry of the ground (soils and waters) and the high incidence of multiple sclerosis in central Saskatchewan (Irvine et al., 1988, 1989). Regional baseline geochemical data which might assist in epidemiological studies were lacking.

As a first step in establishing a regional geochemical database of source rocks in central Saskatchewan, a project was initiated to analyze archived drill core chips from strata of Cretaceous age that subcrop beneath the Pleistocene cover. A contract was issued to Saskatchewan-based researchers to undertake a compilation of the most recent geological and hydrological data with respect to the Cretaceous rocks of Saskatchewan, and to retrieve for analysis rock chip samples from all wells drilled within a 100,000 km² area in the central part of the province (Christopher and Koziol, 1990).

This report is presented in two volumes. Volume 1 outlines the sampling and analytical procedures and discusses the results. Two sets of maps follow the text. The first (Appendix C) is a series of dot maps showing the distribution of elements in Cretaceous strata at the Pleistocene unconformity. The second set of maps (Appendix D) shows the predicted concentrations of several elements at the unconformity. A transparent overlay and a colour plot of the geology are provided at the back of volume 1 to assist in locating individual sites. Volume 2 contains the analytical data, descriptive notes on lithologies, and statistical summaries of the chemistry of the stratigraphic units. A study on the relevance of the lithogeochemical database to epidemiological studies is given in Dunn and Irvine (1993).

Regional, low density sampling geochemical databases of various sample media are fundamental to environmental studies. Ultimately it is the rock that sits at the bottom end of the food chain and provides the chemical elements which enter the foodstuffs that we eat.

LITHOGEOCHEMICAL DATABASE OF CRETACEOUS STRATA IN CENTRAL SASKATCHEWAN

GSC Open File 2491

C.E. Dunn, W.A. Spirito, and S.W. Adcock

INTRODUCTION

For many years government agencies have maintained archive collections of samples obtained during reconnaissance and exploration programs. The sample set used for the present study is that of rock cuttings stored by Saskatchewan Energy and Mines over the past 50 years from holes drilled to explore mostly for hydrocarbons.

The area studied is approximately 100 000 km² of central Saskatchewan (Fig. 1) within which 107 oil exploration holes have been drilled to depths of several hundred metres (Fig. 2). Archived rock-cuttings from 96 of these wells provided the source material for this study.

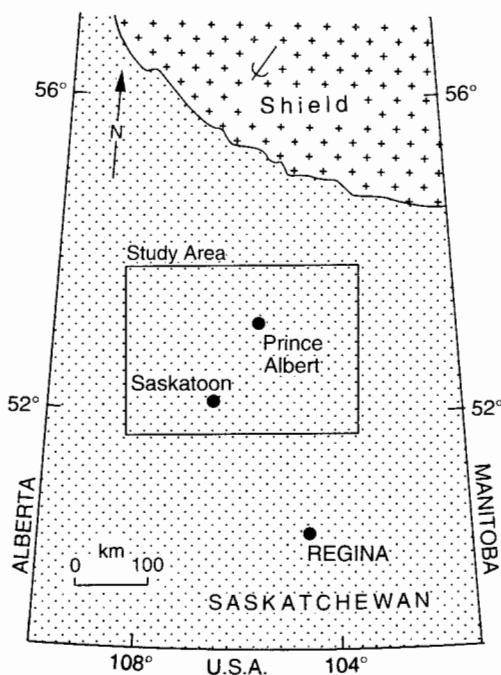


Fig. 1 - Location of study area. Simplified geology shows Precambrian Shield in the north with Phanerozoic sedimentary rocks to the south. The curved arrow shows the predominant direction of glacial movement.

GEOLOGICAL SUMMARY

The Precambrian Shield is overlain throughout the southern half of Saskatchewan by Palaeozoic and Mesozoic sedimentary rocks that dip gently to the southwest (Figs 1 and 2). Shales and sandstones of Cretaceous age have been bevelled by pre-glacial erosion, and by ice movements during the Pleistocene Period that scoured the weathered Cretaceous surface. Cretaceous bedrock samples at this unconformity with the Pleistocene sediments show no obvious signs of weathering. The result is a subcrop pattern of parallel bands of Cretaceous strata beneath a thick cover (locally > 100 m) of sandy Pleistocene glacial deposits (Christopher, 1980, 1984; Caldwell, 1982). Figure 2 shows the main stratigraphic units in the area.

Lower Cretaceous Mannville Group rocks rest unconformably upon the pre-Cretaceous erosion surface. The sequence comprises laminated and cross-bedded sandstones (locally ferruginous), with lenticular mudstone zones. The Mannville Group rocks are overlain conformably by clastic sediments of the Lower Colorado Group. The Lower Colorado can not be subdivided with confidence in some of the older wells for which geophysical well logs have poor sensitivity. Consequently, in some wells samples from this sequence were picked simply as 'Lower Colorado'. In wells drilled more recently, geophysical well logs are sufficiently sensitive to determine three formations: a lowermost sequence of dark grey shales (Joli Fou Formation) conformably overlain by a thin (3-5 m) siltstone bed (Viking Formation), overlain in turn by an upper sequence (Big River Formation) of dark shales, similar to those of the Joli Fou Formation.

There is a minor erosional unconformity with the overlying White Speckled Shales (commonly known as the 'White Specks') comprising the lowermost unit of the Montana Group. The White Specks comprise a distinct but informal unit of dark kerogenous shale with framboidal pyrite and zones rich in carbonate derived largely from coccoliths. Overlying beds are mostly open marine bentonitic shales with sandy intercalations comprising the Lea Park, Judith River and Bearpaw Formations. Except for two isolated areas of Tertiary sediments east and south of Saskatoon, the youngest sedimentary rocks of the study area are the claystones and sandstones of the Upper Cretaceous Bearpaw Formation.

SAMPLE COLLECTION AND ANALYSIS

Each sample was a composite from two 10 ml glass vials of well-cuttings that comprise a 20 ft (6 m) interval of the stratigraphic sequence. In each drill hole, sampling commenced at the unconformity between sedimentary rocks of Cretaceous age and overlying Pleistocene deposits, and continued to a depth of 200 ft (60 m) into Cretaceous rocks. This provided a maximum of 10 samples per well, although locally fewer were available because of poor drill chip recovery. In total, 720 samples (including standards and duplicates) were submitted for analysis.

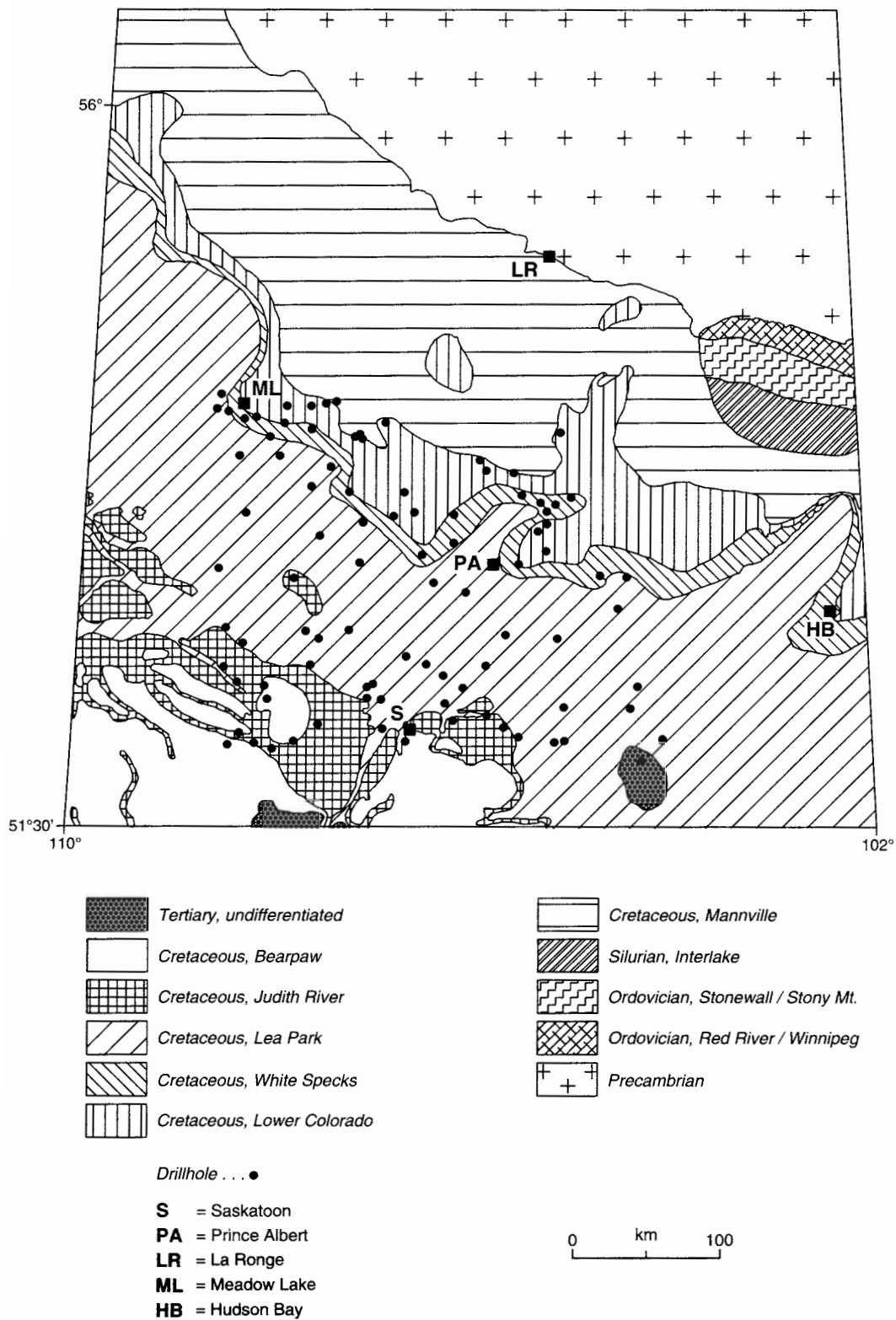


Figure 2: Sub-Pleistocene geology and locations of drill-holes from which samples were collected

Samples were retrieved under a contract to Dr. J. Christopher (Christopher and Koziol, 1990) in accord with the following specifications:

- a) Approximately 3 g of well-cuttings were collected from each of the specified 6 m intervals. A binocular microscope was used to examine the rock chips in order to select material that was representative of the stratigraphic interval. Formation limits and lithologies were determined from examination of geophysical well log signatures, and prior knowledge by the contractor of the lithological sequence. Sequences of drill core available from a few holes provided close control on the lithological sequence.
- b) A magnet was passed over each sample to remove any metallic contaminants derived from drilling and sample recovery operations. Plastic tweezers were used to collect rock chips, and then each sample was split into two portions for analysis by different chemical methods.
- c) From the microscope examination a brief description of each sample was made, systematically recording lithology, grain size, colour, and any other features considered worthy of note. In addition the well name, location, stratigraphic formation, and depth below surface were recorded. These data are presented in Appendix A.
- d) One 1 - 1.5 g split of each composited sample was accurately weighed into a numbered plastic vial and submitted for instrumental neutron activation analysis (INAA) at Activation Laboratories Ltd., Ancaster, Ontario. Data were obtained for Au, Ag, As, Ba, Br, Ca, Co, Cr, Cs, Fe, Hf, Hg, Ir, K, Mo, Na, Ni, Rb, Sb, Sc, Se, Sr, Ta, Th, U, W, Zn, and the rare-earth elements La, Ce, Nd, Sm, Eu, Tb, Yb, and Lu. INAA provides data on the total content of an element in the sample. Data were excluded from the following listings if they were either i) consistently below the level of detection (Ir [2 ppb], Hg [1 ppm], Ag [2 ppm]), or ii) values were of questionable quality because concentrations were mostly close to detection levels (Ni [50 ppm]; Ta [0.5 ppm]; Se [2 ppm]; Sr [300 ppm]; W [1 ppm]; and Mo [mostly 2 ppm, but variable detection level due to interference by U]). Of these elements acceptable data were obtained by inductively-coupled plasma emission spectroscopy (ICP-ES) for Ag, Ni, Se, Sr, and Mo: only the ICP-ES data are reported for these elements.
- e) A second 0.5 - 1 g split of each composited sample was submitted for analysis by ICP-ES at Acme Analytical Laboratories, Vancouver. Samples were hand-ground using an agate mortar and pestle, and a 0.5 g portion then digested with 3 ml 3-1-2 HCl-HNO₃-H₂O at 95°C for one hour and diluted to 10 ml with distilled water. This technique provides data for some elements which can not be determined readily by INAA (e.g. Pb, Cu, Cd, V, B). The ICP-ES package included determinations for Ag, Al, As, Au, Ba, B, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sr, Th, Ti, U, V, W, and Zn. This acid leach is partial for many elements, especially Mn, Fe, Na, K, Al, Sr, Ca, P, La, Cr, Mg, Ba, Ti, B, and W. The data are discussed below in the section on 'Data Quality'.

- f) The acid digest solutions obtained for ICP-ES were analyzed separately for those elements that form hydrides: As, Sb, Se, Te, Bi, and Ge (partial). Detection limits were considerably lower than could be achieved from the direct ICP-ES scan. In the data listings for ICP-ES (Appendix A), determinations reported for these 6 elements are those obtained by hydride evolution.

DATA QUALITY

Within each batch of 20 samples a standard and a duplicate sample were inserted at random in the numerical sequence to provide control on the accuracy and precision of the analytical methods (Tables 1, 2 and 3). The national geochemical reference standard sample (LKSD-2) used for quality control has a composition similar to the Cretaceous shales of Saskatchewan. It is an organic-rich centre lake sediment dredged from lakes on the Canadian Shield. The sample was collected by the GSC, homogenized, and its composition characterized by 30 government and commercial analytical laboratories in Canada. Data on its composition were compiled and published by Lynch (1990).

The amount of an element released during an acid digestion depends largely upon the mineralogy of the rock, and the location of the element in crystal lattices. Elements adsorbed on to grain and crystal surfaces, and those held in crystal lattices by weak bonds are released into the acid solution used for this study. Those elements bound tightly into crystal lattices (e.g. Cr in spinel) need a total digestion in stronger acid (HF) in order to release them. In the shales investigated in this study many elements are bound to clay minerals and are released by the aqua regia digestion used. Comparison of ICP-ES results with data from INAA and standards show that most analyses represent near total concentrations for elements other than those tightly bound in the crystal lattices of the aluminosilicate minerals (notably K, Al, Ti) and Ba, B, Sr, V and Cr (Table 2). Therefore, for some elements there are wide differences between the analytical results obtained by INAA (i.e. total concentration of an element) and those obtained by ICP-ES (partial concentration) - notably for K (mean of 2.4% by INAA and 0.2% by ICP-ES); Na (mean of 0.7% by INAA and 0.2% by ICP-ES); and Ba (mean of 708 ppm by INAA and 125 ppm by ICP-ES). Data listings by the two analytical techniques are provided for several elements to give an indication of the proportion of an element that is locked in crystal lattices, compared to the proportion that might be available for release into solution. Although the acidity of the sample digestion is far stronger than that found in natural environments, the data provide an upper limit on the amount of an element that might be released into groundwater.

Table 1: Analytical Accuracy: Mean and standard deviation values obtained for standard LKSD-2 (n=38) - analysis by instrumental neutron activation (INAA)

Element		Units of Measure	Mean	Standard Deviation	Accepted Values*
Arsenic	As	ppm	9.2	1.1	11
Gold	Au	ppb	3	4	3
Barium	Ba	ppm	702	84	780
Bromine	Br	ppm	14	1	18
Calcium	Ca	%	1.7	0.6	1.6
Cobalt	Co	ppm	17	1	17
Chromium	Cr	ppm	50	5	57
Cesium	Cs	ppm	2.2	0.3	3.0
Iron	Fe	%	4.79	0.23	4.3
Hafnium	Hf	ppm	6.4	0.6	7.0
Potassium	K	%	3.04	0.61	2.19
Sodium	Na	%	1.32	0.01	1.44
Rubidium	Rb	ppm	78	11	85
Antimony	Sb	ppm	0.9	0.2	1.1
Scandium	Sc	ppm	11.7	0.8	13
Thorium	Th	ppm	10.8	1.2	13.4
Uranium	U	ppm	6.5	0.7	7.6
Zinc	Zn	ppm	208	29	209
Lanthanum	La	ppm	60.9	6.4	68
Cerium	Ce	ppm	111	11	108
Neodymium	Nd	ppm	56	7	58
Samarium	Sm	ppm	10.1	1.1	11
Europium	Eu	ppm	1.55	0.21	1.9
Terbium	Tb	ppm	1.0	0.2	1.4
Ytterbium	Yb	ppm	3.85	0.44	4.00
Lutetium	Lu	ppm	0.59	0.07	0.60

* Lynch, J.J. (1990)

Table 2: Analytical Accuracy: Mean and standard deviation values obtained for standard LKSD-2 (n=38) - analysis by inductively-coupled plasma emission spectrometry (ICP-ES)

Element		Units of Measure	Mean	Standard Deviation	Accepted Values [*]	
					Partial	Total
Silver	Ag	ppm	0.8	0.1	0.8	0.8
Aluminum	Al	%	1.52	0.09	-	6.51
Arsenic ^{**}	As	ppm	8.7	0.8	9	11
Boron	B	ppm	13	7	-	65
Barium	Ba	ppm	195	9	-	780
Bismuth ^{**}	Bi	ppm	1.3	0.4	-	1.0 (?)
Cadmium	Cd	ppm	1	0.7	0.8	0.8 (?)
Cobalt	Co	ppm	15	0.7	17	17
Chromium	Cr	ppm	29	2	29	57
Copper	Cu	ppm	37	2	36	37
Iron	Fe	%	3.45	0.17	3.5	4.3
Germanium ^{**}	Ge	ppm	0.1	0.09	-	-
Potassium	K	%	0.18	0.02	-	2.19
Lanthanum	La	ppm	58	3	-	68
Magnesium	Mg	%	0.61	0.04	-	1.01
Manganese	Mn	ppm	1649	80	1840	2020
Molybdenum	Mo	ppm	0.6	0.2	2	<5
Sodium	Na	%	0.02	0.00	-	1.44
Nickel	Ni	ppm	24	5	23	26
Phosphorus	P	%	0.11	0.01	-	0.12
Lead	Pb	ppm	40	5	40	44
Antimony ^{**}	Sb	ppm	0.5	0.2	1.2	1.1
Selenium ^{**}	Se	ppm	0.4	0.2	-	0.8 (?)
Strontium	Sr	ppm	27	2	-	220
Tellurium ^{**}	Te	ppm	0.2	0.2	-	-
Titanium	Ti	%	0.08	0.01	-	0.35
Vanadium	V	ppm	39	2	48	77
Zinc	Zn	ppm	203	14	200	209

^{*} Lynch, J.J. (1990); ^{**} hydride generation;
'partial' is the concentration in solution after a concentrated aqua regia digestion;
blank indicates no reported value;
? indicates a "provisional" value.

Table 3: Analytical Precision: Correlation coefficients (log-transformed data)
of duplicate analyses of 37 samples

INAA	R	ICP-ES	R
As	0.9478	Ag	0.5246
Au	0.4275	Al	0.9856
Ba	0.5265	As**	0.9105
Br	0.9037	B	0.8232
Ca	0.8862	Ba	0.9848
Co	0.9366	Bi**	0.5319
Cr	0.9595	Cd	0.8536
Cs	0.9877	Co	0.9177
Fe	0.9526	Cr	0.9534
Hf	0.9694	Cu	0.8485
K	0.8587	Fe	0.9487
Na	0.9929	Ge**	0.4327
Rb	0.9389	K	0.9903
Sb	0.9780	La	0.9839
Sc	0.9951	Mg	0.9508
Th	0.9881	Mn	0.7999
U	0.9775	Mo	0.9904
Zn	0.9432	Na	0.9978
La	0.9900	Ni	0.8917
Ce	0.9793	P	0.8225
Nd	0.9482	Pb	0.4265
Sm	0.9862	Sb**	0.8375
Eu	0.9785	Se**	0.9641
Tb	0.3930	Sr	0.9569
Yb	0.9832	Te**	0.3557
Lu	0.9678	Ti	0.8564
-	-	V	0.9834
-	-	Zn	0.8596

** hydride generation

In some samples concentrations of some elements were lower than the determination limits of the analytical techniques. For computational purposes a value of five-eighths of the determination level was assigned in these situations. Tables 4 and 5 list the determination and substitution values for each element by INAA and ICP-ES, respectively.

MAP PRODUCTION AND DATA HANDLING

The maps are drawn using the Lambert Conformal Conic projection, with a central meridian of 105° and standard parallels of 49° and 77°. A FORTRAN program developed within the Applied Geochemistry subdivision was used to produce the maps. The program runs on a Unix work-station, and output is to a Hewlett-Packard Laserjet III printer.

The geological contacts were digitized from 1:250000 scale maps using Tydig, a digitizing package developed by Intera-Tydac. The vectors were used as a base for the dot maps produced with Applied Geochemistry's mapping software.

The dot maps are based on a method first developed by Bjorklund and Gustavsson (1987). The dot size is proportional to the analytical value, according to the following formula (in FORTRAN notation):

$$\text{RADIUS} = \text{RSYM} * ((\text{RA}/\text{RV}) ** \text{RFOPT})$$

RSYM: the maximum dot radius, defined by the user in millimetres.
RA: the analytical value to be plotted
RV: the analytical value at a specified percentile
RFOPT: an exponentiation factor

If RA is greater than RV, then RA is set equal to RV. For this data set RV is set equal to the analytical value corresponding to the 95th percentile. All samples with values greater than RV will thus be plotted with a constant dot size equal to RSYM. If the calculated value of RADIUS drops below a certain minimum radius, as defined by the user, then a dot of that minimum radius is plotted. This ensures that dots do not become minuscule. RFOPT is defined by the user, and is usually set in the range 1 to 2. Increasing RFOPT serves to emphasise those samples with high values. Element concentrations below analytical detection limits were reduced to 5% of the determination limit for data plotting and statistical calculations. For samples with duplicate analyses, data from the first of each duplicate pair were used in the statistical analysis and for map production.

Table 4: Determination limits and substitution values
for elements analyzed by INAA

Element		Units of Measure	Determination Limit	Substitution Value
Arsenic	As	ppm	0.5	*
Gold	Au	ppb	2	1.25
Barium	Ba	ppm	10	*
Bromine	Br	ppm	1	0.625
Calcium	Ca	%	1.0	0.625
Cobalt	Co	ppm	1	0.625
Chromium	Cr	ppm	1	0.625
Cesium	Cs	ppm	0.5	0.3125
Iron	Fe	%	0.05	*
Hafnium	Hf	ppm	0.5	*
Potassium	K	%	0.05	*
Sodium	Na	ppm	10	*
Rubidium	Rb	ppm	5	3.125
Antimony	Sb	ppm	0.1	0.0625
Scandium	Sc	ppm	0.1	*
Thorium	Th	ppm	0.1	*
Uranium	U	ppm	0.1	*
Zinc	Zn	ppm	20	12.5
Lanthanum	La	ppm	0.1	*
Cerium	Ce	ppm	3	*
Neodymium	Nd	ppm	5	3.125
Samarium	Sm	ppm	0.1	*
Europium	Eu	ppm	0.01	*
Terbium	Tb	ppm	0.5	0.3125
Ytterbium	Yb	ppm	0.05	*
Lutetium	Lu	ppm	0.05	0.03125

* all values above the determination limit

Table 5: Determination limits and substitution values
for elements analyzed by ICP-ES

Element		Units of Measure	Determination Limit	Substitution Value
Silver	Ag	ppm	0.2	0.125
Aluminum	Al	%	0.01	*
Arsenic**	As	ppm	0.2	0.125
Boron	B	ppm	2	*
Barium	Ba	ppm	1	*
Bismuth**	Bi	ppm	0.2	0.125
Cadmium	Cd	ppm	2	1.25
Cobalt	Co	ppm	2	1.25
Chromium	Cr	ppm	2	1.25
Copper	Cu	ppm	2	1.25
Iron	Fe	%	0.01	*
Germanium**	Ge	ppm	0.2	0.125
Potassium	K	%	0.02	0.0125
Lanthanum	La	ppm	3	1.875
Magnesium	Mg	%	0.01	*
Manganese	Mn	ppm	1	*
Molybdenum	Mo	ppm	2	1.25
Sodium	Na	%	0.02	0.0125
Nickel	Ni	ppm	2	1.25
Phosphorus	P	%	0.001	*
Lead	Pb	ppm	3	1.875
Antimony**	Sb	ppm	0.2	0.125
Selenium**	Se	ppm	0.2	0.125
Strontium	Sr	ppm	1	*
Tellurium**	Te	ppm	0.2	0.125
Titanium	Ti	%	0.02	0.0125
Vanadium	V	ppm	2	1.25
Zinc	Zn	ppm	1	*

* all values above the determination limit

** hydride generation

RESULTS

The results are presented in four main groupings:

- 1. Appendix A** lists the location, lithological data and well information for each sample. Details of the abbreviations and code numbers used are given at the beginning of Appendix A. Data for each set of samples occupy four pages:

e.g. on page A 1, samples are identified in the first column by a 'JC' number, which corresponds on page A 2 to the analytical data by INA for that sample; on page A 3 the well and lithological data shown on page A 1 are repeated for ease of comparison with the ICP-ES data shown on page 4. The pattern repeats on p.A5 - A8, p.A9 - A12, etc.
- 2. Appendix B** shows, for each element, a cumulative frequency plot, and a statistical breakdown of the data for the entire data set, and by geological formation or group. Details of the abbreviations are given at the beginning of Appendix B. The data in these listings are summarized in Table 6 (INAA), and Table 7 (ICP-ES).
- 3. Element Distribution Maps** are superimposed upon outline maps of the geology at the Pleistocene/Cretaceous unconformity. They show relative concentrations of each element, according to dot size assigned to percentile values, in rock chip samples of Cretaceous strata at the unconformity. Although only 54 wells had samples at the unconformity, many maps reveal distinct patterns of element concentrations attributable to the different formations. A transparent overlay shows the locations of the wells, and the number of each sample used in the compilation of these maps.
- 4. Predictive Maps.** Contour plots show the projected concentrations of several elements in Cretaceous rocks at the unconformity with the Pleistocene deposits. Each map is an interpretation of the chemistry to be expected, based upon consideration of the regional geochemistry of each stratigraphic unit. The maps are hand-produced plots, not computer generated. Contours represent the 50th, 70th, and 90th percentile values of the entire data set. The geochemistry of any given stratum within the study area is sufficiently uniform to be able to plot these data with reasonable confidence. Regional lithogeochemical maps of this type have potential use in epidemiological studies (Dunn, 1990; Dunn and Irvine, 1993).

DISCUSSION

Tables 6 and 7 show the average element content of each stratigraphic interval. The most striking feature is the relatively high level of many elements in the kerogenous and calcareous dark shales that comprise the White Specks. The main features are:

- 1) The White Specks are strongly enriched in Ca, Mo, Ni, Sb, Se, U and V. There is also enrichment in As, Br, Cd, Cu, Sr, and Zn. Relative to most other units there is depletion in Na. This pattern of enrichment is typical of black shales (Reichenbach, 1993).
- 2) The Mannville Group is enriched in Mn and Fe, and depleted in Al, Na, K, P, Ba and many trace elements. This composition reflects the dominance of sandstones comprising this basal sequence.
- 3) The Cretaceous strata above the White Specks (Lea Park, Bearpaw and Judith River formations), when compared to the lower sequence, have relative enrichment of Al, Ba, Cr, Mg, Mn, Na (total), Ni, Sb, and Ti.

From low density sampling, the lithogeochemical database provides information on the lateral and vertical distribution of elements in the Cretaceous sedimentary strata. There is sufficient lateral uniformity in the analyses of samples from each stratigraphic interval to predict the regional patterns of element concentrations, and therefore produce geochemical maps of a large area from few control points. The maps provide the framework for assessing which chemical elements are available for release into the surficial environment. Rock fracturing, structure, erosion and physicochemical conditions will ultimately determine which elements may be released by water movements.

Prior to glacial erosion during the Pleistocene period, Cretaceous strata extended farther to the north, and the Cretaceous surface was probably deeply weathered during the relatively hot conditions that prevailed during Tertiary time. The fine-grained metalliferous shales of the White Specks cropped out between Prince Albert and La Ronge. They, with the other strata, were scoured, ground to fine particles, and transported southwestward to be deposited as a dispersion train within the glacial sediments. The fine particles provide large surface areas from which elements can be released. Discussion of potential metal release into the subsurface environment is given in Dunn and Irvine (1993).

Table 6: Average concentrations of elements (by stratigraphic interval) analyzed by INAA.

	All Units	Mannville Gp	Lower Colorado Gp	Joli Fou Fm	Viking Fm	Belly River Fm	White Specks	Lea Park Fm	Judith River Fm	Bearpa w Fm
No. of Samples	645	59	68	16	11	69	53	311	41	6
Au ppb	2.5	2.5	1.6	1.7	1.4	1.9	3.6	2.8	1.5	2.0
As ppm	13.5	8.5	9.6	8.8	9.5	13.6	25.0	14.4	8.1	9.4
Ba ppm	708	339	579	597	706	590	624	849	750	845
Br ppm	4.4	3.2	4.6	4.3	3.6	5.0	9.3	3.7	4.0	4.8
Ca%	3.2	4.7	1.6	1.1	2.4	3.6	10.2	2.2	2.7	2.7
Co ppm	12	8.6	10	11	9.5	11	14	13	11	13
Cr ppm	72	34	60	67	58	62	68	86	73	77
Cs ppm	4.7	1.7	4.7	5.6	4.5	5.3	4.0	5.4	3.4	3.9
Fe%	4.7	6.3	4.0	4.1	4.0	4.1	3.8	5.0	3.8	4.2
Hf ppm	4.3	4.9	5.6	5.0	5.1	4.5	3.0	3.9	4.9	5.4
K%	2.4	1.3	2.2	2.7	2.4	2.5	2.0	2.8	2.2	2.5
Na%	0.74	0.25	0.70	0.65	0.58	0.73	0.51	0.85	1.0	0.90
Rb ppm	86	41	88	95	85	97	70	96	75	74
Sb ppm	1.5	0.5	0.7	0.9	1.0	1.2	5.8	1.4	1.0	1.3
Sc ppm	12	8.3	9.8	11	9.2	10	8.8	14	10	11
Th ppm	8.1	5.1	11	11	9.2	11	6.7	7.6	7.5	8.5
U ppm	4.0	2.1	3.6	3.3	3.2	5.1	12	3.2	2.9	3.1
Zn ppm	140	106	109	131	90	141	221	146	115	119
La ppm	28	19	35	35	33	35	27	26	26	29
Ce ppm	59	43	75	75	69	74	56	55	57	63
Nd ppm	25	18	31	31	29	31	25	23	24	28
Sm ppm	4.8	3.4	5.9	5.9	5.4	5.8	4.6	4.5	4.5	5.2
Eu ppm	0.9	0.6	1.0	1.0	0.9	1.0	0.8	0.9	0.9	1.0
Tb ppm	0.5	0.5	0.7	0.6	0.6	0.7	0.5	0.5	0.5	0.5
Yb ppm	2.6	2.3	3.0	3.0	2.7	3.0	2.4	2.5	2.5	2.8
Lu ppm	0.36	0.31	0.42	0.43	0.37	0.42	0.36	0.35	0.35	0.39

Elements arranged alphabetically by chemical symbol, except the rare earth elements which are listed beneath Zn and arranged by increasing atomic weights from La → Lu.

Table 7: Average concentrations of elements (by stratigraphic interval) analyzed by ICP-ES.

	All Units	Mannville Gp	Lower Colorado Gp	Joli Fou Fm	Viking Fm	Belly River Fm	White Specks	Lea Park Fm	Judith River Fm	Bearpaw Fm
No. of Samples	645	59	68	16	11	69	53	311	41	6
Ag ppm	0.2	0.2	<0.2	<0.2	<0.2	0.2	0.5	0.2	0.2	0.4
Al%	1.1	0.40	0.78	0.86	0.74	0.77	0.77	1.5	1.0	1.1
As* ppm	11.2	7.6	7.9	8.2	8.9	11	22	12	6.6	8.0
B ppm	24	25	22	29	18	27	23	26	21	3.5
Ba ppm	125	47	88	97	100	89	75	163	160	188
Bi* ppm	0.3	<0.2	0.3	0.4	0.4	0.5	0.4	0.3	0.3	0.2
Cd ppm	<2	<2	<2	<2	<2	<2	4.7	<2	<2	<2
Co ppm	10	8.9	8.1	8.6	7.7	8.7	11	11	9.1	9.7
Cr ppm	19	10	11	12	11	9.2	18	25	22	20
Cu ppm	28	14	18	20	16	23	51	30	29	24
Fe %	3.1	5.3	2.0	2.1	2.0	2.1	2.5	3.5	2.1	2.8
Ge* ppm	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.4	0.3
K%	0.20	0.08	0.19	0.20	0.15	0.23	0.21	0.22	0.16	0.20
La ppm	16	10	21	20	25	19	15	15	17	18
Mg%	0.61	0.59	0.39	0.37	0.35	0.29	0.39	0.77	0.78	0.86
Mn ppm	563	1368	342	260	271	209	306	598	566	600
Mo ppm	5.0	<2	2.3	<2	<2	5.5	35	<2	<2	<2
Na%	0.20	0.03	0.30	0.24	0.19	0.33	0.20	0.20	0.14	0.09
Ni ppm	31	14	21	20	18	26	70	33	25	27
P%	0.08	0.04	0.08	0.08	0.09	0.10	0.08	0.09	0.05	0.06
Pb ppm	18	12	19	22	16	21	15	20	11	13
Sb* ppm	0.82	0.29	0.34	0.33	0.44	0.59	3.6	0.66	0.54	0.62
Se* ppm	1.7	<0.2	0.59	0.25	0.39	1.2	12	0.81	0.27	0.35
Sr ppm	103	80	109	87	76	114	166	97	75	78
Te* ppm	0.23	<0.2	0.24	0.30	0.24	0.21	0.23	0.23	0.22	0.38
Ti%	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.04	0.03
V ppm	39	19	14	14	14	18	126	42	28	28
Zn ppm	107	55	77	82	69	91	194	117	90	78

Arranged alphabetically by chemical symbol. Note that concentrations are partial for some elements (see text).

* by hydride evolution

DIGITAL DATA

The data listed in Appendix A are available in digital form from:

Publications Distribution
Geological Survey of Canada
601 Booth Street
Ottawa
ONT. K1A 0E8

(Tel. 613 995-4342)

The data will be supplied on MS-DOS (IBM-PC) 3.5" 1.44 Mb diskettes, as both an RBASE UNLOAD file (ASCII format; can be read by any text editing software; can be imported directly into an RBASE database), and as a .DBF file, which can be read by any DBASE-compatible software.

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