UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOCHEMICAL SURVEY OF THE WESTERN ENERGY REGIONS

Fourth Annual Progress Report, July 1977

By

U. S. Geological Survey
Denver, Colorado

Open-file Report 77-872
1977

A NOTE ON THE USE OF GEOCHEMICAL SUMMARIES IN ASSESSING SUSPECTED METAL POLLUTION

An attempt to assess metal pollution requires, at the very least, some knowledge of the natural levels of metal concentration to be expected in the material of interest in the area of interest. Armed with such information, a first "cut" at assessing metal pollution can be made very simply by asking the question "Is the metal level actually observed unnaturally high?" Note that this question is focused directly on whether or not the concentration level is unusual and not on what constitutes a potentially hazardous or toxic level.

Some of the tabular geochemical summaries in this report offer the interested reader a few geochemical properties which he or she may use to determine just what level of metal concentration should be viewed as unusual. These properties are the geometric mean (GM), the geometric deviation (GD) and, if available, the geometric error (GE). The estimation of what constitutes an unusual concentration may be approached in two slightly different ways, each based on the theory of the lognormal frequency distribution. The first approach estimates a range of concentrations expected under "ordinary" conditions, as follows: Approximately two-thirds of a randomly selected set of samples are expected to exhibit concentrations between a lower level computed as GM/GD and an upper level computed as GM·GD. About 95 percent of the samples are expected to fall within the range defined as $GM/(GD)^2$ and $GM \cdot (GD)^2$ and about 99.7 percent are expected to fall within the range $GM/(GD)^3$ and $GM \cdot (GD)^3$. Clearly, if one of these ranges is used to define the ordinary range of metal concentration, samples with concentrations outside such limits must be viewed as unusual or anomalous. Such concentrations need not necessarily reflect metal pollution but they would be worthy of further investigation. The choice of which of these three ranges (or some other similar range) to use depends on the degree of certainty one wishes to attach to a declaration that a metal value is anomalous. For example, any value lying above the 95 percent range has only 2½ chances out of 100 of reflecting natural variation in the environmental material under consideration.

Conventionally, in pollution studies little interest is attached to anomalously low concentrations and attention focuses on the upper limit alone. This suggests a second approach. The following formula may be used to determine limits above which a specified proportion of samples should fall under ordinary conditions (i.e., in the absence of metal pollution):

$$\text{Log } L = \text{Log } (GM) + f\text{Log } (GD) \qquad (1)$$

where Log L, Log (GM) and Log (GD) are logarithms of the specified upper limit, the geometric mean and the geometric deviation, respectively, and f is a multiplier. If the user wishes to define a limit above which only one sample in 10 is expected to fall under ordinary conditions, f is set equal to 1.28. If the limit is defined as that above which only about one in 20 should fall naturally, f is set to 1.65. A limiting value for one sample in 50 or one sample in 100 requires f to be equal to 2.05 and 2.33, respectively. The concentration of the chosen limit is found by computing Log L (equation 1) and taking the antilog.

(Continued on inside back cover)

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This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards or nomenclature

GEOCHEMICAL SURVEY OF THE WESTERN ENERGY REGIONS

July 1977

Fourth annual progress report describing current work in a broad- scaled reconnaissance geochemical study of landscape materials in the major coal-, uranium-, and oil shale-bearing lands of the western United States.

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Probable upper limits of concentration to be expected in ordinary landscape materials of the Western Energy Regions.

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The term "statistically significant" appears often in scientific literature--notably and sometimes confusingly in sampling studies that hold implications for public policy. Understanding its narrow meaning, as an element in the interpretation of degrees of scientific proof, is essential to grasping the import of a scientific statement bearing on public policy.

Generally, a sampling result or experimental result is deemed "statistically significant" when the calculated probability of its being solely an artifact of chance is below a specified low value. Many scientists disagree on what that low value should be. Customarily, many regard as "statistically significant" a result for which the probability of occurrence as a consequence of pure chance is less than five percent (the "0.05 probability level"). This concept is intended to reduce the likelihood that a result may be interpreted as attributable to factors under study when it may be, in fact, the happenstance of a random distribution.

(Adapted from the National Academy of Sciences' "News Report," Mid-June, 1976, v. XXVI, no. 8, p. 6)

WORK TO DATE

This is the fourth in a series of annual reports describing field studies in environmental geochemistry of the western energy regions. To date, field collections are complete for 36 regional landscape units spread throughout the Northern Great Plains, the Powder River, Bighorn and Wind River Basins, the oil shale region of Colorado, Utah and Wyoming, and the San Juan Basin of New Mexico (fig. 1). These units include bedrock formations, stream sediments, ground waters, and soils and plants of various kinds. Complete or partial chemical data have been received and evaluated for 30 of the 36 units; probable upper limits of concentration to be expected in these materials are given in Appendices I-IV.

In addition to the regional surveys, a wide variety of topical work has been undertaken (fig. 2), much of it focusing on problems of geochemical change in native vegetation due to powerplant operation or strip-mine reclamation. Topical work described in this report includes a brief examination of downstream geochemical effects below an abandoned strip mine (p. 6-13), additional work on potential element contamination around the Dave Johnston Powerplant, Wyoming (p. 14-54 and 65-76), standardization of laboratory techniques for studies of element availability in soils and rocks (p. 98-143), examination of geochemical zonation in oil shale (p. 144-155), and a study of trace element changes in wheat grown on strip-mine spoils (p. 180-184). Tables 4 and 5 list a large amount of chemical data on soils and sagebrush around the Dave Johnston Powerplant, and supplement similar data collections on potential powerplant impact released last year (see Appendix V, U. S. Geol. Survey, 1976).

The wealth of geochemical data generated in this work over the past four years should prove helpful to researchers requiring a knowledge of probable background geochemical compositions ("baselines"). Such data have proved to be of particular use in a number of limited circulation documents written in support of Federal environmental impact work in the western United States (Sargent and Hansen, 1976; Connor, 1977a, 1977b; Hayes and others, 1977).

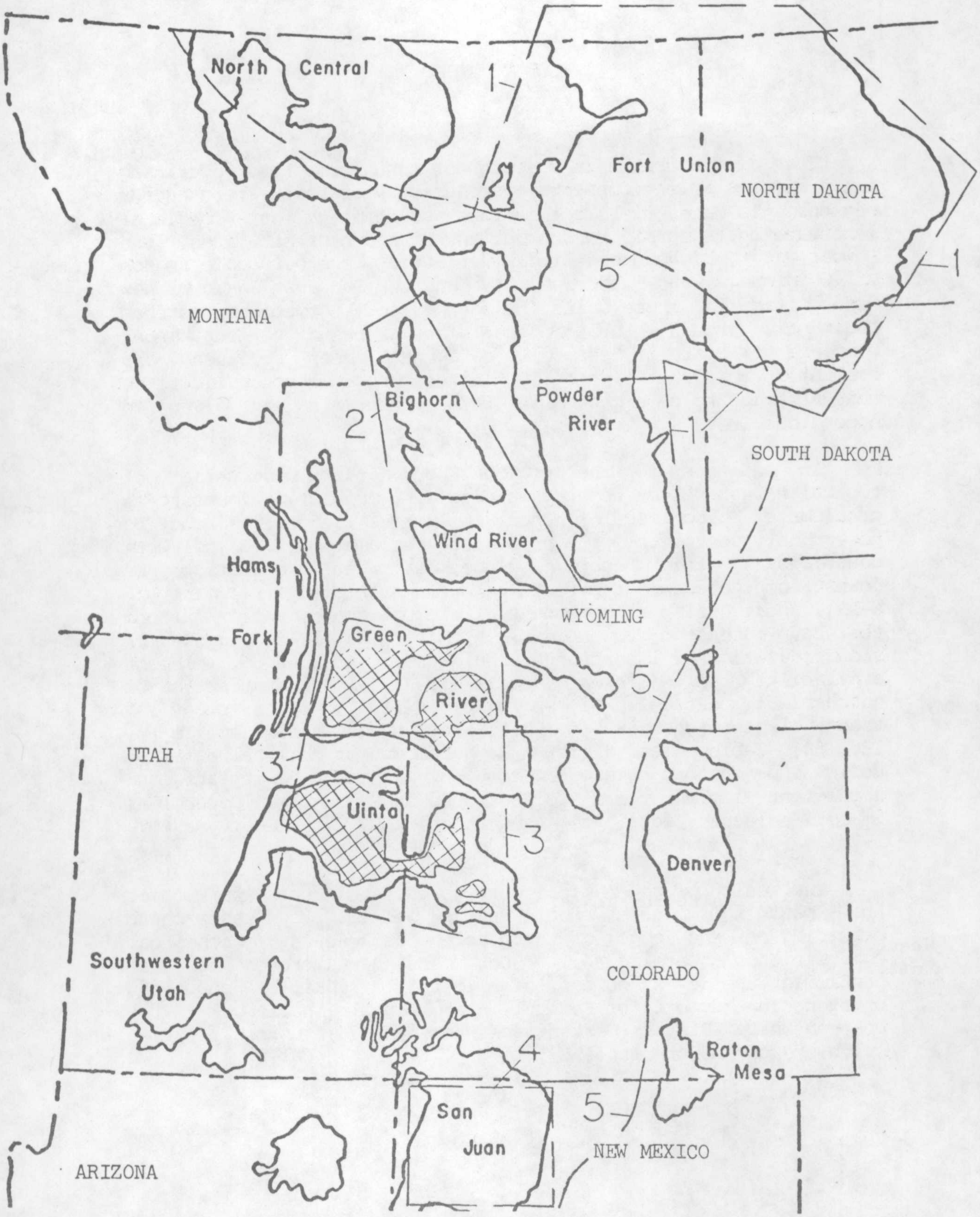

Figure 1. Index map showing location of regional studies. (Coal basins from Trumbull, 1959. Approximate area underlain by Green River Formation is cross-hatched).

Figure 1.--EXPLANATION

Map unit	Material sampled	Reference
1. Northern Great Plains	a. Sandstone	This report, p. 185-197.
	b. Shale	This report, p. 169-172, 185-197.
	c. Strip mine spoils, sweetclover	U.S. Geol. Survey (1975, p. 29-35).
	d. Soil	U.S. Geol. Survey (1976, p. 57-81).
	e. Soil availability	This report, p. 98-143.
	f. Soil, soil parent[1/]	U.S. Geol. Survey (1974, p. 6-29; 1975, p. 20-28, 50-57); Connor, Keith and Anderson (1976); Tidball and Ebens (1976).
	g. Stream sediments	This report, p. 91-97.
	h. Powder River sediments[1/]	U.S. Geol. Survey (1976, p. 30-36).
	i. Ground water	This report, p. 173-179; U.S. Geol. Survey (1976, p. 86-93).
	j. Wheat	This report, p. 180-184; Shacklette and others (in press).
	k. Sagebrush, lichen, grass[1/]	U.S. Geol. Survey (1974, p. 6-29); U.S. Geol. Survey (1975, p. 10-19); Connor, Keith, and Anderson (1976).
2. Bighorn and Wind River Basins	a. Soil	This report, p. 156-168.
3. Oil Shale Region	a. Oil shale	U.S. Geol. Survey (1976, p. 48-56).
	b. Soil	This report, p. 55-64, 77-90; U.S. Geo. Survey (1976, p. 101-111).
	c. Stream sediments	U.S. Geol. Survey (1976, p. 121-130).
	d. Sagebrush	U.S. Geol. Survey (1976, p. 47).
4. San Juan Basin	a. Soil	(no data as yet)
	b. Saltbush, grass, snakeweed	(no data as yet)
5. Western United States	a. Sagebrush (west of line)	(no data as yet)

[1/] Powder River Basin only.

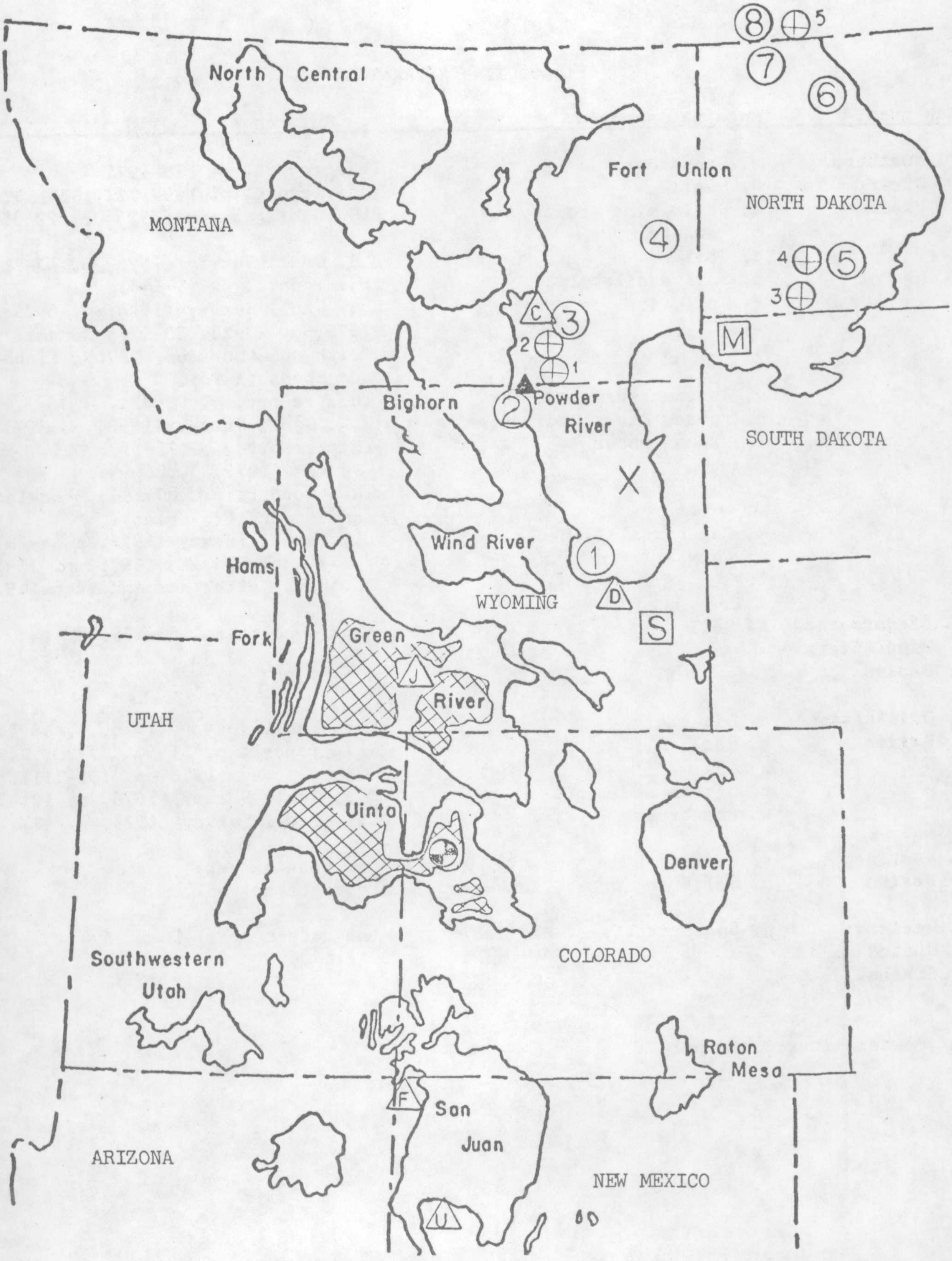

Figure 2. Index map showing location of topical studies. (Coal basins from Trumbull, 1959. Approximate area underlain by Green River Formation is cross-hatched).

Figure 2.--EXPLANATION

Symbol	Material sampled	Reference
⊕	Shale, cored overburden (Locations: 1. Bear Creek 2. Otter Creek 3. Dengate 4. Dunn Center 5. Estevan)	This report, p. 169-174; U.S. Geol. Survey (1976, p. 10-13).
◕	Oil Shale (Core hole Juhan 4-1)	This report, p.
X	Ground water	U.S. Geol. Survey (1974, p. 144-155).
▲	Pond water, sediments	This report, p. 6-13.
○	Strip-mine spoils and cover crops (Mines: 1. Dave Johnston 2. Welch 3. Big Sky 4. Savage 5. Beulah 6. Velva 7. Kincaid 8. Utility)	This report, p. 180-184; U.S. Geol. Survey (1975, p. 29-35; U.S. Geol. Survey (1976, p. 4-9, 82-85).
△	Coal-fired powerplants (Locations: C - Colstrip J - Jim Bridger D - Dave Johnston F - Four Corners)	This report, p. 14-54, 65-76; U.S. Geol. Survey (1974, p. 14-29; 1975, p. 50-57; 1976, p. 22-29, 37-47, 112-120).
△U	Uranium Mill	(no data as yet)
□	Miscellaneous vegetation (Type: S - Sagebrush M - Mixed grains)	(no data as yet)

SEDIMENT AND WATER CHEMISTRY IN MINED AND UNMINED WATERSHEDS, HIDDEN WATER CREEK AREA, WYOMING

by Todd K. Hinkley and Howard E. Taylor

Introduction

Geochemical data were collected from two watersheds in the Hidden Water Creek area of north-central Wyoming (shown as a solid triangle on fig. 2) in order to gain information on elemental concentrations in detrital material derived from disturbed and undisturbed land in western coal mining areas. One watershed was disturbed by surface mining activity over one-third of the area. This mined area was abandoned without reclamation 25 years ago and the sediment yield in the watershed is about 11 times greater than that in the undisturbed watershed. Pond water, pond sediment, channel sediment, and upstream source material were collected and analyzed from each watershed.

Sampling Area and Geologic Setting

The two ponds studied are located about six miles northeast of Ranchester, Wyoming, on the Monarch 7½ topographic quadrangle map (fig. 3). The pond in the mined watershed receives drainage from a larger area than the pond in the undisturbed watershed. At least one coal bed (the Carney Bed, which may be an aquifer) is cut by drainage to the pond and may supply ground water to the stream. The unmined watershed and its drainage apparently do not intersect any ground-water aquifers. The Carney Bed in this area lies entirely below the surface drainage, and the pond appears to be fed only by surface water. The geologic relationships described above are based on discussions with B. E. Barnum, U.S. Geological Survey, Denver, Colorado.

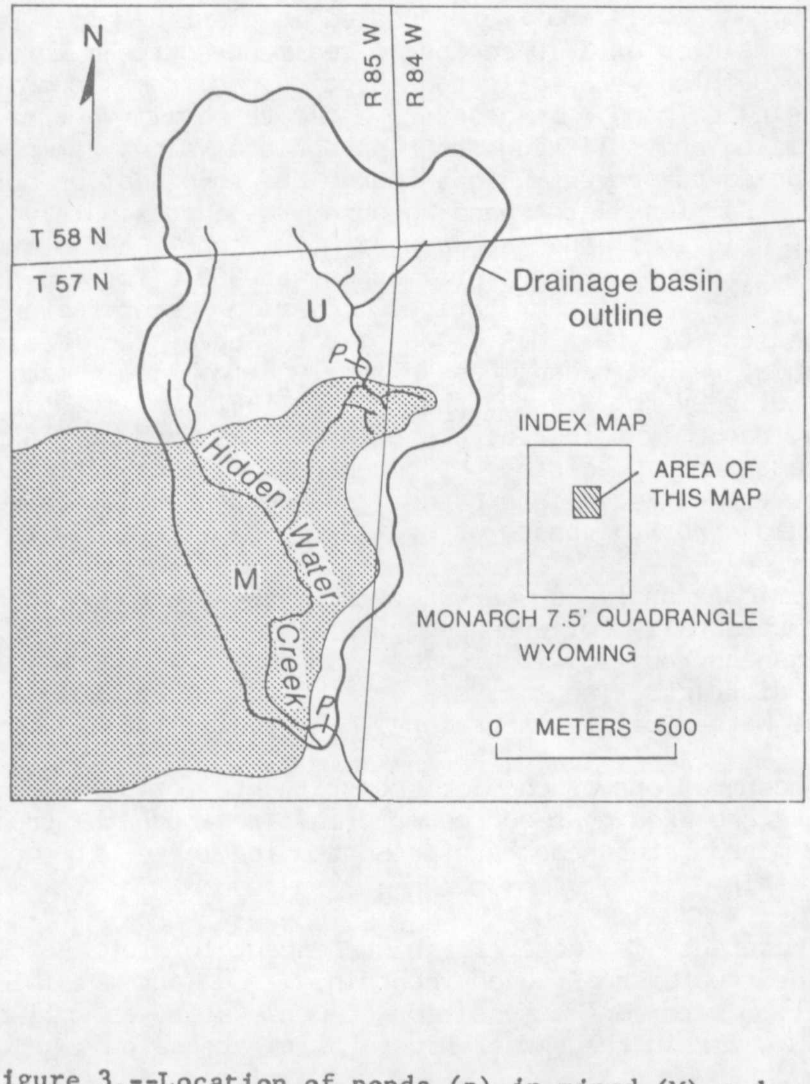

Figure 3.--Location of ponds (p) in mined (M) and unmined (U) watersheds of the Hidden Water Creek area.

Samples and Analytical Methods

Sediments from the ponds and from parts of the beds of streams draining into them were taken to a depth of about 15 cm with a plunger-corer, by wading or from a boat. These samples were placed in plastic bags, excess water decanted, and the bags sealed and frozen as soon as possible to prevent air oxidation.

Samples of nearly dry sediment-source material, whether from in-place strata, alluvium, or mine spoils, were collected with shovel or trowel and were sealed in plastic bags. Each such sample consisted of 2-10 scoops of sediment-source material. Some of these samples were collected in pairs, as from opposite ends of a single pond, in order to estimate sampling error. After homogenizing and splitting to appropriate size, samples were freeze-dried to prevent weight change due to oxidation during air drying. Samples were hand ground to approximately 200 mesh (without sieving) and subsampled by cone and quartering techniques. Subsamples were ashed at 350°C for two hours and analyzed by semiquantitative emission spectrography in laboratories of the U.S. Geological Survey in Menlo Park, California using techniques slightly modified from those described in Myers, Havens, and Dunton (1961). A fraction of the samples, randomly selected, was submitted as anonymous duplicates to assess the precision of preparation and analysis. All samples were analyzed in a randomized sequence to convert any systematic error to random error.

Chemical analyses on waters from the two ponds, consisting of four seasonally collected samples from each, were provided by D. Wangsness, U. S. Geological Survey. Resources Division, Wyoming district. The analyses were performed at the U.S.G.S. National Water Quality laboratory, Denver, Colorado..

Concentrations of chemical constituents for pond and channel sediment and sediment-source material, for both the undisturbed and the mined watersheds, are presented in Table 1, on a dry weight basis.

Ash content is generally high, except for four samples from the mined watershed which contained abundant visible coaly material. Data on composition of pond water, as well as other types of water in the Powder River Basin, are given in Tables 2 and 3.

Table 1.--Chemistry of source material, channel sediment and pond sediment in strip-mined and unmined watersheds.

[Semiquantitative 6-step spectrographic analysis[1]; concentrations on dry-weight basis; analyst, C. Heropoulos]

Element	Unmined watershed							Mined watershed												
	Composited source material, updrainage[2]		Channel sediment far above pond	Channel sediment near the pond	Cored pond sediment	Cored pond sediment, opposite end[2]		Source material: natural alluvium[2]		Source material: non-coaly spoil[2]		Source material: coaly spoil	Channel sediment: coaly[2]		Sediment from depression in channel: coaly	Sediment, opposite end of depression in channel: coaly[2]		Cored pond sediment	Cored pond sediment, opposite end[2]	
Fe -----	5.	3.	3.	3.	2.	3.	2.	5.	5.	3.	5.	3.	2.	3.	5.	3.	2.	3.	3.	2.
Mg -----	1.5	1.	.7	1.	1.	1.	1.	.7	.7	.7	.7	.3	.3	.5	.5	.5	.5	1.	1.	.7
Ca -----	3.	2.	1.	1.5	.7	1.	.5	2.	2.	.3	.3	.4	.5	1.	1.5	2.	1.	.5	1.5	2.
Ti -----	.7	.5	.7	.7	.5	.7	.3	.7	.7	.7	.7	.5	.3	.3	.2	.2	.3	.7	.7	.5
Al -----	10.	7.	10.	10.	10.	10.	7.	7.	10.	>15.	10.	4.	3.	>7.	3.	3.	3.	10.	7.	10.
Na -----	.5	.3	.7	.2	.2	.3	.2	.5	.7	.2	.2	.09	.1	.1	.3	.3	.2	.5	.3	.3
K ------	3.	3.	3.	5.	3.	5.	3.	2.	2.	3.	3.	.7	1.	1.	1.	1.	1.	5.	2.	3.
P ------	N	N	.2	.15	N	.1	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Mn -----	500	500	300	300	200	300	300	700	700	200	200	90	150	150	3000	300	300	300	200	200
Ag -----	<.7	<.7	<.7	<.7	<.7	<.7	<.7	.7	<.7	<.7	<.7	.3	.5	.5	N	.3	.3	<.7	<.7	<.7
B ------	150	150	200	200	150	200	150	100	100	150	200	200	100	100	100	200	300	200	200	150
Ba -----	1000	700	1000	1000	700	1000	700	700	1000	700	700	700	300	500	500	500	400	1000	700	700
Be -----	7	5	7	7	5	5	5	3	5	5	7	4	5	5	3	4	4	5	7	5
Co -----	10	10	10	15	7	5	7	15	15	15	10	7	7	15	30	10	10	20	15	10
Cr -----	50	50	100	70	70	100	50	50	50	70	50	20	30	50	30	40	30	70	50	50
Cu -----	50	30	50	50	30	50	30	30	30	50	30	20	70	70	30	30	40	50	30	30
La -----	70	50	100	70	50	70	50	70	70	50	50	20	30	30	30	40	30	70	50	70
Mo -----	N	N	N	N	N	N	N	N	N	N	N	3	3	5	N	N	3	N	N	N
Nb -----	10	15	15	15	10	10	10	15	15	10	7	3	7	5	7	3	4	10	10	15
Ni -----	30	30	50	30	30	30	30	30	50	30	30	30	30	50	50	40	40	30	30	30
Pb -----	30	30	30	30	30	30	30	30	30	50	30	30	10	20	10	20	30	30	30	30
Sc -----	20	15	20	20	15	20	15	15	15	15	15	7	10	10	7	10	10	20	15	15
Sn -----	5	5	7	7	7	7	5	5	5	7	7	4	3	5	5	4	3	10	5	5
Sr -----	150	150	200	150	100	150	100	200	200	70	70	70	70	100	100	300	100	150	150	150
V ------	150	100	150	100	150	100	100	150	150	150	100	70	70	70	50	50	40	150	150	150
Y ------	50	30	30	30	30	30	30	50	50	30	30	10	20	20	10	20	20	30	30	30
Zn -----	150	150	150	100	100	100	100	150	150	150	150	90	100	70	100	70	100	100	100	150
Zr -----	300	200	300	150	200	200	150	300	300	150	150	90	150	200	70	70	100	150	200	200
Ce -----	100	100	100	100	100	100	100	100	150	100	100	40	70	50	N	N	N	150	150	100
Ga -----	20	20	30	50	30	50	20	15	15	20	30	10	10	20	10	10	10	30	20	20
Yb -----	5	5	5	5	5	5	3	3	5	5	5	2	3	2	2	3	1	5	3	3
% Ash --	97	96	93.9	95.8	96.5	95.6	96.5	94.9	94.9	93.8	94.2	43.8	47.8	49.6	45.1	36.2	37.3	95.5	93.1	94

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[1] Fe, Mg, Ca, Ti, Al, Na, K, and P are reported in %; all others in ppm. Results are to be identified with geometric brackets whose boundaries are 1.2, .83, .56, .38, .26, .18, .12, etc., but are reported arbitrarily as mid-points of these brackets, 1., .7, .5, .3, .2, .15, .1, etc. except where ash content is less than 90%; in such cases the original concentration-in-ash values have been multiplied by the ash fraction and reported to a compatible number of significant figures. The precision of a reported value is approximately plus or minus one bracket at 68%, or two brackets at 95% confidence. N = not detected at limit of detection.

[2] Sample analyzed in duplicate, hence two columns of data under these headings.

Table 2.--Comparison of Hidden Water pond water to two possible source waters

[N.D., not determined]

	Hidden Water ponds[3]		Ft. Union Powder River basin well water[2]			50' spoil well at Hidden Water site[1]	Powder River basin surface waters[1]
	Unmined watershed	Mined watershed	$Ca\text{-}Mg\text{-}SO_4^=$ type	$Na\text{-}SO_4^=\text{-}HCO_3^-$ type	$Na\text{-}HCO_3^-$ type		
Ca	29	298	365	86	9.8	363	70
Mg	15	378	422	74	4.3	670	102
Na+K	17	232	292	631	472	155	97
HCO_3^-	158	366	565	973	1270	N.D.	N.D.
$SO_4^=$	24	2425	2626	1049	18	3134	546
Cl^-	2.8	19	17	11	17	1.7	7.7
TDS	169	3443	4030	2352	1160	5558	1056
SiO_2	2.3	12	N.D.	N.D.	N.D.	31	5.4
pH	7.6	8.1	7.3	7.6	8.0	5.9	8.7

[1] From Rahn (1976). Well data are average of 2 hr. and 26 hr. measurements. Surface water data are average of 4 Powder River basin samples.

[2] Each type is an average of 3 samples. Data from F. Visher, U.S. Geological Survey, Denver, Colorado.

[3] Data from D. Wangsness, U.S. Geological Survey, Denver, Colorado. Each value is average of 4 seasonal samples.

Table 3.--Seasonal variation in dissolved constituents in pond water from mined watershed

[Data from D. Wangsness, U.S. Geological Survey, Denver, Colorado; nd, no data; mg/l, milligrams per liter; ug/l, micrograms per liter]

	Aug., 1975	Feb., 1976	May, 1976	Aug., 1976
Total hardness (mg/l)	2700	2100	2500	2300
Sulfate (mg/l)	2700	2100	2300	2600
Residue (mg/l)	nd	3150	3510	3670
SiO_2 (mg/l)	13	18	11	7.7
Total Fe (ug/l)	190	40	2000	580
Mn (ug/l)	60	290	30	260

Results and Discussion

Within the limits of the accuracy and precision of the analytical techniques, there are few clearly recognizable differences in chemical character between analogous materials in the mined and unmined watersheds, or even between samples of different type. The channel samples from the mined area appear to contain perhaps half of the amount of aluminum, potassium, magnesium, chromium, lanthanum, niobium, and gallium found in the channel samples from the unmined area. These differences reflect dilution of shaly detritus by coaly material. This relationship is not observed for other major, minor and trace elements and the reasons are unclear. More precise analytical techniques could, no doubt, resolve differences among the materials sampled, but the present method clearly shows that mining in the one basin has not led to gross geochemical differences in sediments which parallel or approach in magnitude the eleven-fold difference in sediment yield rates observed between the mined and unmined watersheds (R. F. Hadley, personal comm., 1977). The similarity of sediment chemistry noted here makes it appear unlikely that sediment monitoring studies could prove to be a sensitive tool for detecting moderate environmental disruption due to coal mining in other areas.

In contrast to the chemistry of pond sediment and source material, the chemical contents of the pond waters of the two watersheds are very different (Table 2). Concentrations of nearly all constituents are higher in the pond of the mined watershed. Unfortunately, the complexities and current lack of knowledge of the details of ground and surface water regimes of the area preclude making a simple interpretation of the cause of concentration differences between the two ponds. Water in the pond of the <u>unmined</u> watershed is meteoric (surface water) with moderate additions of solutes derived from solid surficial materials; and water in the pond of the <u>mined</u> watershed is provided by sources of rather hard, sulfate-type ground waters typical of the ground water of the Powder River Basin-Northern Great Plains area. The geologic relationships noted above are consistent with this idea of distinct sources for the two ponds. It is also possible that there is an additional contribution of water from low-concentration surficial sources and a contribution of additional solute material from leaching of unconsolidated spoil materials.

The chemistry of the water in the pond of the unmined watershed points clearly to a surface-water source. Pond concentrations are far lower, for almost all constituents, than for any of the three general types of local ground water listed in table 2, commonly by about an order of magnitude. The pond concentrations are also distinctly lower than the typical local ground water listed in the table.

Chemistry of the pond in the mined watershed is clearly most similar to the calcium-magnesium sulfate type ground water shown in Table 2. But the same chemistry could be due to a combination of surface water influx and leaching of solute from spoil materials with evaporative concentration and possible contributions of other ground waters of the sodium-bicarbonate type and sodium-mixed bicarbonate-sulfate type. Such ground waters are the most likely to be supplied by any locally-cut coal bed aquifers. Water in such aquifers will be reduced in sulfate and will have exchanged calcium for sodium, but contact with spoil material could reconcentrate calcium and magnesium back to the values found in the pond water.

Seasonal concentration data (Table 3) are insufficient to resolve the possibility of periodic entry of masses of water of particular types into the pond. The seasonal variations for the selected parameters presented in Table 3 could be due to evaporative concentration, influx of various waters, changes in redox potential and metal solubility related to eutrophication and algal activity, or to unknown sampling and sample preparation and analytical errors such as variation in filtration and acidification techniques. In general, the consistency in total concentration of solute hints that seasonal variation in chemical properties is due to processes within the pond environment.

Further Work

Additional knowledge of local hydrologic parameters is needed to answer the fundamental question of the significance of the contribution of material leached from the disturbed spoils to the water chemistry of the pond. These include the expected balance between surface runoff to the pond, evaporation from the pond, chemistry of ground water from aquifers adjacent to the disturbed area which could be supplying the pond water, and more data on chemistry of local spoil water.

A NEW MULTI-TRAVERSE STUDY OF SOIL AND SAGEBRUSH CHEMISTRY AROUND THE DAVE JOHNSTON POWERPLANT, WYOMING

by Barbara M. Anderson and John R. Keith

In May 1973, a small set of soil and big sagebrush (Artemisia tridentata) samples was collected southeast (generally downwind) of the Dave Johnston powerplant, eight km east of Glenrock, Wyoming, in order to test for trace element trends in the local environment which could be attributed to the presence of the powerplant (Connor, Keith, and Anderson, 1976). A number of elements in either ash or dry weight of sagebrush were found in this work to exhibit a statistically significant reduction ($p < 0.05$) in concentration with increasing distance from the powerplant. The dashed line on figure 4 represents this sampling traverse.

Elemental trends found in this work prompted a more complete multitraverse sampling study which was completed in September 1974, and which forms the basis for this report. Eight traverses of the kind used in the earlier study were located symmetrically around the powerplant (fig. 4). Four major traverses were located north, east, south, and west of the powerplant and four minor traverses (NE, SE, SW, and NW) were positioned between each pair of major traverses. The north and east traverses consisted of seven sampling localities spread geometrically from approximately one to 64 km; the south and west traverses contained only six sampling localities spaced geometrically from approximately one to 32 km. Sampling localities along the NE and SE traverses were spaced geometrically from approximately eight to 64 km, but difficulty in locating the sampling target forced truncation of the SW and NW traverses to two and three localities, respectively.

At each locality (except the 16 km location along the SW traverse), two samples of silver sagebrush (Artemisia cana Pursh) and soil were collected up to 300 feet apart. Silver sagebrush rather than big sagebrush was collected in this study because chances of finding it at all localities were greater. A sample of silver sagebrush consisted of 100-200g of stems and leaves taken from over the crown of an individual plant. Rather than collecting separate samples of surface and subsurface soil as in the first study, the soil sample in this study consisted of a composite of material from 5-20 cm depth.

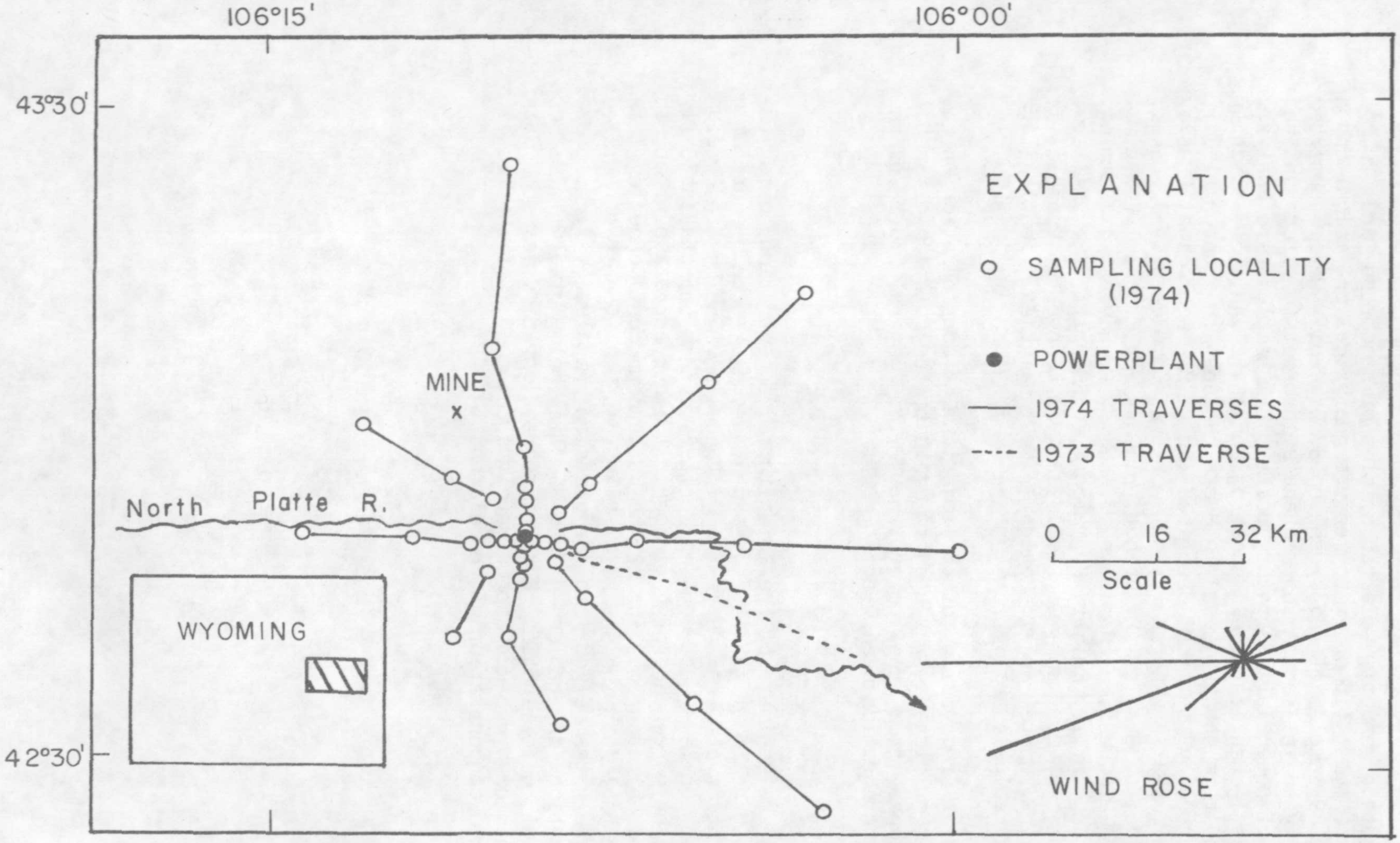

Figure 4.--Index map showing location of the Dave Johnston powerplant.

Eighteen randomly selected samples of sagebrush and 20 of soil were split (in order to measure analytical precision) and a total of 89 samples of sagebrush and 87 of soil were submitted and analyzed in randomized sequences in order to circumvent the effects of potential laboratory drift. All samples were analyzed by a semi-quantitatiive spectrographic technique slightly modified from that given in Myers, Havens, and Dunton (1961), supplemented by methods described in U.S. Geological Survey (1975, p. 69-81). The analytical work was completed by J. Baker, A. Bartel, L. Bradley, E. Brandt, W. Cary, J. Crock, I.Frost, J. Gardner, P. Guest, J. Hamilton, T. Harms, R. Havens, J. Hemming, C. Huffman, Jr., R. Knight, M. Malcolm, V. Merritt, H. Millard, W. Mountjoy, C. Papp, G. Riddle, R. Van Loenen, R. Vinnola, J. Wahlberg, R. White, and T. Yager. The analytical results are given in tables 4 and 5.

Linear regression of the logarithm of concentration on the logarithm of distance was used to evaluate the relation of metal to distance from the powerplant. The general form of the prediction equation used was:

$$\text{Log } X = a + b\text{Log } D$$

Log X is the estimate of the logarithmic concentration, b is the slope of the log-linear trend, and a is the expected logarithmic concentration at 1 km. D is the distance in km. The regression is based on a least-squares criterion, and the statistically significant percentage of variance in log concentration that is explained by each equation at the 95 percent confidence level is given in table 6. The SW and NW traverses have too few samples to lend themselves to regression analysis. Numerous determinations in tables 4 and 5` lie below the limits of analytical determination. For the regression analyses, such data were replaced by values approximately equal to 0.7 of the lowest determined concentration of the element.

Table 4.--Chemistry of silver sagebrush (Artemisia cana) near the Dave Johnston powerplant. Results given in percent (%) or parts per million (ppm); all analyses on ashed material except As, F, Hg, S, Sb, Se and ash; km, distance from powerplant in kilometers; N. not detected; L, less than limit of detection.

Lab. No.	SAMPLE	Latitude	Longitud	Dist. Km	As ppm	F %	Hg ppm	Total S%	Sb ppm	Se ppm
				Sagebrush north of Dave Johnston						
417829	JA1P1	42 50 46N	105 46 12W	1	0.05L	0.0026	0.02	0.20	0.15	1.20
417828	JA1P2	42 50 46N	105 46 12W	1	0.60	0.0030	0.01	0.14	0.15	0.80
417911	JA2P1	42 51 18N	105 46 12W	2	0.05L	0.0007	0.03	0.23	0.10	0.35
417836	JA2P2	42 51 18N	105 46 12W	2	0.05L	0.0008	0.02	0.18	0.10	0.50
417837	JA3P1	42 52 23N	105 46 12W	4	0.05	0.0010	0.03	0.19	0.15	0.35
417902	JA3P1X	42 52 23N	105 46 12W	4	0.05L	0.0007	0.02	0.19	0.05	0.30
417823	JA3P2	42 52 23N	105 46 12W	4	0.05L	0.0007	0.02	0.17	0.25	1.20
417835	JA4P1	42 55 01N	105 45 36W	8	0.05L	0.0008	0.01	0.27	0.10	1.00
417893	JA4P1X	42 55 01N	105 45 36W	8	0.05L	0.0005	0.02	0.26	0.05	1.00
417844	JA4P2	42 55 01N	105 45 36W	8	0.10	0.0008	0.02	0.25	0.05	2.00
417857	JA4P2X	42 55 01N	105 45 36W	8	0.20	0.0008	0.03	0.26	0.10	1.80
417913	JA5P1	42 58 37N	105 46 12W	16	0.05L	0.0006	0.02	0.21	0.05L	0.50
417854	JA5P1X	42 58 37N	105 46 12W	16	0.05L	0.0007	0.02	0.21	0.05	0.60
417864	JA5P2	42 58 37N	105 46 12W	16	0.05L	0.0008	0.02	0.18	0.05L	0.55
417860	JA5P2X	42 58 37N	105 46 12W	16	0.05L	0.0010	0.03	0.18	0.15	0.70
417919	JA6P1	43 07 34N	105 49 12W	32	0.05L	0.0006	0.02	0.21	0.05L	1.00
417867	JA6P2	43 07 34N	105 49 12W	32	0.05L	0.0008	0.03	0.21	0.05L	1.00
417850	JA6P2X	43 07 34N	105 49 12W	32	0.06	0.0006	0.03	0.22	0.05	1.20
417905	JA7P1	43 23 24N	105 47 24W	64	0.05L	0.0009	0.02	0.20	0.05	0.40
417880	JA7P1X	43 23 24N	105 47 24W	64	0.05L	0.0006	0.02	0.21	0.05L	0.55
417888	JA7P2	43 23 24N	105 47 24W	64	0.05	0.0010	0.02	0.21	0.05L	0.20
				Sagebrush northeast of Dave Johnston						
417878	JB1P1	42 52 37N	105 42 36W	8	0.05	0.0006	0.03	0.20	0.05L	0.35
417907	JB1P2	42 52 37N	105 42 36W	8	0.05L	0.0007	0.02	0.18	0.05L	0.30
417908	JB2P1	42 55 37N	105 39 00W	16	0.05L	0.0012	0.02	0.25	0.10	0.80
417831	JB2P2	42 55 37N	105 39 00W	16	0.05L	0.0014	0.02	0.16	0.15	1.00
417853	JB3P1	43 04 52N	105 26 24W	32	0.05L	0.0006	0.02	0.24	0.15	1.00
417839	JB3P2	43 04 52N	105 26 24W	32	0.05	0.0007	0.02	0.18	0.05	2.00
417869	JB3P2X	43 04 52N	105 26 24W	32	0.05L	0.0005	0.02	0.22	0.05L	1.60
417866	JB4P1	43 12 43N	105 15 36W	64	0.05L	0.0006	0.01	0.19	0.05L	0.30
417865	JB4P1X	43 12 43N	105 15 36W	64	0.05L	0.0006	0.02	0.19	0.05L	0.25
417915	JB4P2	43 12 43N	105 15 36W	64	0.05L	0.0006	0.02	0.20	0.05L	0.25
				Sagebrush east of Dave Johnston						
417917	JC1P1	42 50 13N	105 45 36W	1	0.50	0.0160	0.03	0.24	0.20	1.00
417900	JC1P2	42 50 13N	105 45 36W	1	0.45	0.0200	0.04	0.32	0.20	0.12
417862	JC2P1	42 50 13N	105 44 24W	2	0.05	0.0045	0.02	0.31	0.05	0.45
417845	JC2P2	42 50 13N	105 44 24W	2	0.25	0.0028	0.02	0.29	0.10	0.30
417891	JC3P1	42 50 24N	105 43 12W	4	0.09	0.0026	0.03	0.27	0.05	0.70
417910	JC3P2	42 50 24N	105 43 12W	4	0.05L	0.0022	0.03	0.25	0.10	0.80
417830	JC3P2X	42 50 24N	105 43 12W	4	0.05L	0.0028	0.03	0.23	0.15	0.70
417881	JC4P1	42 49 59N	105 40 12W	8	0.05L	0.0012	0.02	0.18	0.05L	0.60
417843	JC4P2	42 49 59N	105 40 12W	8	0.05L	0.0012	0.02	0.20	0.10	0.70
417856	JC5P1	42 50 20N	105 34 12W	16	0.01	0.0008	0.02	0.25	0.05	1.20

Table 4.--Continued.

Lab. No.	SAMPLE	Ash %	Al %	B ppm	Ba ppm	Ca %	Cd ppm	Co ppm	Cr ppm	Cu ppm
				Sagebrush north of Dave Johnston-continued						
417829	JA1P1	6.0	10.0	700	1000	12	14.0	5	70	150
417828	JA1P2	6.1	10.0	700	1500	14	3.0	4	100	150
417911	JA2P1	5.9	2.0	700	700	12	6.0	2	20	150
417836	JA2P2	4.5	2.0	700	500	10	5.0	2	15	100
417837	JA3P1	5.5	3.0	500	1000	16	5.5	2	30	100
417902	JA3P1X	5.4	3.0	500	700	14	4.5	4	15	100
417823	JA3P2	5.4	3.0	700	700	14	4.5	6	20	70
417835	JA4P1	5.8	2.0	500	500	12	5.5	1	20	150
417893	JA4P1X	6.2	2.0	700	500	12	5.5	3	15	150
417844	JA4P2	6.7	2.0	700	700	13	28.0	2	20	150
417857	JA4P2X	6.6	3.0	700	700	13	22.0	1	30	150
417913	JA5P1	5.9	2.0	500	500	19	14.0	1	15	100
417854	JA5P1X	6.7	2.0	700	700	17	16.0	1	20	100
417884	JA5P2	5.9	3.0	700	500	14	9.0	3	30	100
417860	JA5P2X	6.2	5.0	500	500	14	9.5	3	50	150
417919	JA6P1	4.9	2.0	500	150	13	7.5	1	15	150
417867	JA6P2	6.0	2.0	500	300	16	7.5	1	15	100
417850	JA6P2X	5.9	0.7	500	200	16	7.5	2	10	100
417905	JA7P1	5.8	3.0	300	700	14	2.5	2	20	100
417880	JA7P1X	5.9	3.0	500	1000	14	2.0	2	20	100
417888	JA7P2	8.0	2.0	300	1000	19	2.5	3	10	150
				Sagebrush northeast of Dave Johnston-continued						
417878	JB1P1	5.7	2.0	300	700	14	5.0	1	20	150
417907	JB1P2	5.6	2.0	500	500	16	3.5	1	15	100
417908	JB2P1	7.0	5.0	700	500	15	4.5	3	30	200
417831	JB2P2	6.2	5.0	500	1000	13	5.5	3	50	150
417853	JB3P1	7.3	2.0	300	700	16	6.5	2	20	150
417839	JB3P2	6.1	2.0	700	500	17	4.0	1	20	150
417869	JB3P2X	6.8	1.0	700	700	19	3.0	2	15	150
417866	JB4P1	5.3	2.0	500	500	12	5.0	3	150	150
417865	JB4P1X	5.0	2.0	300	300	12	7.5	3	15	150
417915	JB4P2	4.5	3.0	300	300	12	5.0	4	30	150
				Sagebrush east of Dave Johnston-continued						
417917	JC1P1	8.4	7.0	500	700	13	8.5	4	150	200
417900	JC1P2	11.3	10.0	700	1000	11	2.0	6	70	200
417862	JC2P1	7.0	7.0	500	500	11	6.0	4	50	150
417845	JC2P2	6.6	7.0	300	500	12	3.5	3	50	150
417891	JC3P1	7.7	7.0	700	700	12	5.0	4	70	150
417910	JC3P2	6.1	5.0	500	500	12	4.5	3	50	200
417830	JC3P2X	6.1	5.0	500	700	12	5.0	5	50	150
417881	JC4P1	5.4	5.0	700	700	15	9.0	2	30	150
417843	JC4P2	6.1	2.0	700	300	15	5.5	2	20	150
417856	JC5P1	6.0	2.0	700	500	12	15.0	3	20	200

Table 4.--Continued.

Lab. No.	SAMPLE	Fe %	Ga ppm	K %	Li ppm	Mg %	Mn ppm	Mo ppm	Na %	Ni ppm
Sagebrush north of Dave Johnston-continued										
417829	JA1P1	2.0	30	21	20	5	500	30	0.06	30
417828	JA1P2	2.0	30	16	25	5	500	30	0.07	30
417911	JA2P1	0.7	0 N	24	25	7	500	20	0.06	15
417836	JA2P2	0.5	0 N	27	30	7	500	15	0.04	20
417837	JA3P1	1.0	0 N	24	14	7	700	10	0.06	20
417902	JA3P1X	0.7	5	23	12	5	700	10	0.05	20
417823	JA3P2	0.7	0 N	24	14	5	700	10	0.04	20
417835	JA4P1	1.0	0 N	27	12	5	300	30	0.04	30
417893	JA4P1X	0.5	0 N	28	10	7	500	30	0.03	30
417844	JA4P2	0.7	0 N	22	14	7	300	20	0.06	20
417857	JA4P2X	0.7	0 N	24	14	7	300	15	0.07	30
417913	JA5P1	0.7	0 N	18	5	7	700	15	0.04	30
417854	JA5P1X	0.5	0 N	19	6	7	700	15	0.04	30
417884	JA5P2	1.0	0 N	22	14	7	300	10	0.11	20
417860	JA5P2X	1.0	7	21	16	7	300	7	0.18	15
417919	JA6P1	0.7	0 N	27	8	3	300	10	0.03	10
417867	JA6P2	0.5	0 N	21	12	5	300	0 N	0.02	15
417350	JA6P2X	0.3	0 N	24	10	5	300	10	0.02	20
417905	JA7P1	1.0	7	22	12	5	700	15	0.04	10
417880	JA7P1X	1.0	0 N	23	12	5	500	15	0.04	10
417888	JA7P2	0.5	0 N	22	6	3	1500	0 N	0.02	7
Sagebrush northeast of Dave Johnston-continued										
417878	JB1P1	0.7	0 N	27	6	5	500	10	0.04	15
417907	JB1P2	0.7	5	24	16	7	1000	15	0.04	20
417908	JB2P1	1.0	5	20	10	5	700	0 N	0.04	30
417831	JB2P2	1.5	10	20	16	5	300	0 N	0.04	20
417853	JB3P1	0.5	0 N	22	8	5	300	7	0.05	20
417839	JB3P2	0.5	0 N	20	16	5	200	10	0.04	10
417869	JB3P2X	0.5	0 N	19	10	5	200	0 N	0.02	10
417866	JB4P1	0.7	0 N	28	10	3	500	0 N	0.21	20
417865	JB4P1X	0.7	0 N	26	10	3	500	0 N	0.22	15
417915	JB4P2	1.0	5	24	10	5	700	10	0.16	15
Sagebrush east of Dave Johnston-continued										
417917	JC1P1	2.0	50	17	25	3	500	15	0.06	30
417900	JC1P2	2.0	50	16	25	5	700	10	0.09	20
417862	JC2P1	1.0	15	22	18	7	700	5	0.06	20
417845	JC2P2	1.0	15	24	35	7	700	10	0.09	20
417891	JC3P1	1.5	20	22	16	5	700	15	0.05	15
417910	JC3P2	1.0	15	25	14	3	1000	20	0.06	30
417830	JC3P2X	1.0	15	25	16	3	1000	30	0.06	30
417881	JC4P1	1.0	15	24	10	5	500	30	0.03	10
417843	JC4P2	0.7	0 N	26	10	5	500	15	0.03	20
417856	JC5P1	0.5	0 N	26	14	5	300	10	0.05	70

Table 4.--Continued.

Lab. No.	SAMPLE	P %	P ppm	Pb ppm	Sc ppm	Si ppm	Sr ppm	Ti %	U ppm	V ppm
				Sagebrush north of Dave Johnston-continued						
417829	JA1P1	3.0	24000	50	10	74000	1500	0.30	4.0	200
417828	JA1P2	5.0	24000	70	15	84000	1500	0.30	5.0	200
417911	JA2P1	5.0	48000	20	0 N	36000	1500	0.07	1.2	50
417836	JA2P2	5.0	36000	30	0 N	20000	1500	0.05	1.6	50
417837	JA3P1	5.0	36000	30	0 N	28000	1500	0.07	1.2	50
417902	JA3P1X	3.0	36000	20	0 N	30000	1500	0.05	1.2	50
417823	JA3P2	5.0	36000	30	0 N	12000	1500	0.05	1.2	30
417835	JA4P1	5.0	36000	15	0 N	20000	1500	0.05	1.2	50
417893	JA4P1X	5.0	36000	15	0 N	20000	2000	0.03	1.2	30
417844	JA4P2	3.0	24000	30	0 N	46000	2000	0.05	1.2	30
417857	JA4P2X	3.0	24000	30	0 N	39000	1500	0.05	1.2	50
417913	JA5P1	3.0	24000	30	0 N	30000	1000	0.05	1.2	50
417854	JA5P1X	5.0	24000	30	0 N	36000	1500	0.05	0.8	30
417884	JA5P2	2.0	12000	20	0 N	42000	1500	0.07	0.8	70
417860	JA5P2X	1.5	12000	30	0 N	50000	1500	0.07	1.6	70
417919	JA6P1	2.0	18000	10	0 N	32000	700	0.05	1.2	30
417867	JA6P2	2.0	18000	15	0 N	44000	500	0.03	1.2	30
417850	JA6P2X	3.0	24000	15	0 N	24000	700	0.02	1.2	10
417905	JA7P1	3.0	18000	30	0 N	53000	1500	0.05	1.2	30
417880	JA7P1X	2.0	18000	30	0 N	44000	1500	0.05	0.8	30
417888	JA7P2	2.0	18000	15	0 N	28000	1000	0.03	0.4	20
				Sagebrush northeast of Dave Johnston-continued						
417878	JB1P1	2.0	24000	20	0 N	27000	1000	0.05	0.8	30
417907	JB1P2	3.0	24000	30	0 N	27000	2000	0.05	1.2	50
417908	JB2P1	3.0	24000	15	0 N	60000	1500	0.10	1.6	70
417831	JB2P2	3.0	24000	20	5	70000	2000	0.15	1.2	70
417853	JB3P1	5.0	36000	20	0 N	31000	3000	0.05	4.0	30
417839	JB3P2	3.0	24000	15	0 N	27000	5000	0.05	4.0	30
417869	JB3P2X	3.0	24000	15	0 N	31000	3000	0.03	3.2	20
417866	JB4P1	3.0	24000	20	0 N	42000	2000	0.07	0.8	30
417865	JB4P1X	3.0	24000	20	0 N	41000	2000	0.07	1.2	30
417915	JB4P2	3.0	24000	30	0 N	54000	3000	0.10	1.2	70
				Sagebrush east of Dave Johnston-continued						
417917	JC1P1	3.0	18000	50	10	90000	1000	0.20	5.0	150
417900	JC1P2	2.0	12000	100	10	98000	1500	0.30	6.0	200
417862	JC2P1	3.0	36000	20	7	58000	1500	0.15	2.8	100
417845	JC2P2	3.0	24000	20	7	40000	2000	0.15	2.4	100
417891	JC3P1	3.0	18000	30	7	58000	2000	0.15	2.0	150
417910	JC3P2	3.0	24000	30	5	50000	2000	0.15	2.4	100
417830	JC3P2X	3.0	24000	30	7	54000	3000	0.15	2.4	150
417881	JC4P1	5.0	24000	30	5	36000	5000	0.07	2.0	70
417843	JC4P2	3.0	24000	15	0 N	26000	7000	0.05	2.0	70
417856	JC5P1	5.0	24000	15	0 N	27000	1500	0.05	1.6	50

Table 4.--Continued.

Lab. No.	SAMPLE	Y ppm	Yb ppm	Zn $^{\Delta}$ ppm	Zr ppm
			Sagebrush north of Dave Johnston-continued		
417829	JA1P1	30	3.0	280	100
417828	JA1P2	30	3.0	360	100
417911	JA2P1	0 N	0.0N	360	20
417836	JA2P2	0 N	0.0N	280	20
417837	JA3P1	0 N	0.0N	380	50
417902	JA3P1X	0 N	0.0N	360	50
417823	JA3P2	0 N	0.0N	460	20
417835	JA4P1	0 N	0.0N	440	30
417893	JA4P1X	0 N	0.0N	460	15
417844	JA4P2	0 N	0.0N	380	70
417857	JA4P2X	15	1.5	320	20
417913	JA5P1	0 N	0.0N	320	30
417854	JA5P1X	0 N	0.0N	400	20
417884	JA5P2	0 N	0.0N	320	50
417860	JA5P2X	0 N	0.0N	360	70
417919	JA6P1	0 N	0.0N	460	10
417867	JA6P2	0 N	0.0N	520	15
417850	JA6P2X	0 N	0.0N	580	15
417905	JA7P1	0 N	0.0N	240	50
417880	JA7P1X	0 N	0.0N	240	20
417888	JA7P2	0 N	0.0N	320	20
			Sagebrush northeast of Dave Johnston-continued		
417878	JB1P1	0 N	0.0N	300	20
417907	JB1P2	0 N	0.0N	380	20
417908	JB2P1	10	0.0N	360	70
417831	JB2P2	15	1.5	260	70
417853	JB3P1	0 N	0.0N	380	20
417839	JB3P2	0 N	0.0N	500	30
417869	JB3P2X	0 N	0.0N	460	15
417866	JB4P1	0 N	1.5	440	70
417865	JB4P1X	0 N	0.0N	360	50
417915	JB4P2	0 N	0.0N	500	70
			Sagebrush east of Dave Johnston-continued		
417917	JC1P1	30	3.0	670	100
417900	JC1P2	30	3.0	260	100
417862	JC2P1	20	1.5	420	70
417845	JC2P2	15	1.5	360	70
417891	JC3P1	15	1.5	200	70
417910	JC3P2	15	0.0N	280	70
417830	JC3P2X	15	1.5	280	70
417881	JC4P1	0 N	0.0N	420	50
417843	JC4P2	0 N	0.0N	420	20
417856	JC5P1	0 N	0.0N	440	20

Table 4.--Continued.

Lab. No.	SAMPLE	Latitude	Longitud	Dist. Km	As ppm	F %	Hg ppm	Total S%	Sb ppm	Se ppm
Sagebrush east of Dave Johnston-continued										
417855	JC5P2	42 50 20N	105 34 12W	16	0.05	0.0008	0.02	0.22	0.05	1.00
417898	JC6P1	42 49 34N	105 21 36W	32	0.05L	0.0006	0.02	0.18	0.05L	0.50
417887	JC6P2	42 49 34N	105 21 36W	32	0.05L	0.0006	0.03	0.23	0.10	0.55
417892	JC7P1	42 50 13N	105 03 36W	64	0.05L	0.0005	0.02	0.17	0.05L	0.25
417847	JC7P2	42 50 13N	105 03 36W	64	0.08	0.0010	0.03	0.21	0.05	0.90
Sagebrush southeast of Dave Johnston										
417849	JD1P1	42 48 14N	105 42 36W	8	0.08	0.0008	0.02	0.23	0.10	0.15
417916	JD1P2	42 48 14N	105 42 36W	8	0.05L	0.0009	0.02	0.16	0.05L	0.30
417858	JD2P1	42 45 07N	105 38 24W	16	0.15	0.0012	0.01	0.14	0.10	1.40
417899	JD2P2	42 45 07N	105 38 24W	16	0.05L	0.0005	0.03	0.16	0.05L	0.12
417868	JD3P1	42 36 00N	105 27 00W	32	0.05L	0.0006	0.01	0.18	0.05L	0.15
417871	JD3P1X	42 36 00N	105 27 00W	32	0.05	0.0006	0.01	0.18	0.05L	0.10
417838	JD3P2	42 36 00N	105 27 00W	32	0.05L	0.0012	0.01	0.21	0.10	0.30
417846	JD4P1	42 25 44N	105 13 12W	64	0.05L	0.0007	0.02	0.17	0.05	0.40
417890	JD4P2	42 25 44N	105 13 12W	64	0.05L	0.0004	0.01	0.17	0.05L	0.45
417875	JD4P2X	42 25 44N	105 13 12W	64	0.05L	0.0005	0.03	0.17	0.05L	0.60
Sagebrush south of Dave Johnston										
417833	JE1P1	42 49 41N	105 46 12W	1	0.09	0.0020	0.03	0.18	0.15	0.50
417886	JE1P2	42 49 41N	105 46 12W	1	0.08	0.0014	0.02	0.26	0.10	0.90
417903	JE2P1	42 49 08N	105 46 12W	2	0.10	0.0014	0.02	0.17	0.05	1.20
417894	JE2P1X	42 49 08N	105 46 12W	2	0.05	0.0012	0.02	0.16	0.10	1.00
417825	JE2P2	42 49 08N	105 46 12W	2	0.05L	0.0018	0.02	0.18	0.10	0.70
417909	JE3P1	42 47 53N	105 46 12W	4	0.05L	0.0008	0.02	0.20	0.05L	0.80
417861	JE3P2	42 47 53N	105 46 12W	4	0.05L	0.0007	0.02	0.18	0.05	0.60
417824	JE3P2X	42 47 53N	105 46 12W	4	0.05L	0.0007	0.01	0.17	0.05	0.55
417872	JE4P1	42 46 30N	105 46 12W	8	0.05L	0.0005	0.02	0.18	0.05L	0.35
417912	JE4P2	42 46 30N	105 46 12W	8	0.05L	0.0004	0.01	0.21	0.05	0.45
417885	JE4P2X	42 46 30N	105 46 12W	8	0.05L	0.0005	0.01	0.23	0.05	0.50
417906	JE5P1	42 41 24N	105 47 24W	16	0.09	0.0020	0.02	0.17	0.05	0.15
417834	JE5P2	42 41 24N	105 47 24W	16	0.05L	0.0020	0.02	0.21	0.05	0.55
417876	JE5P2X	42 41 24N	105 47 24W	16	0.05L	0.0014	0.02	0.21	0.05L	0.40
417882	JE6P1	42 33 47N	105 42 00W	32	0.09	0.0016	0.01	0.14	0.05	0.09
417914	JE6P2	42 33 47N	105 42 00W	32	0.10	0.0008	0.02	0.19	0.05	0.20
Sagebrush southwest of Dave Johnston										
417851	JF1P1	42 47 13N	105 49 48W	8	0.20	0.0016	0.02	0.24	0.20	0.25
417918	JF1P2	42 47 13N	105 49 48W	8	0.90	0.0080	0.02	0.24	0.05	0.70
417863	JF1P2X	42 47 13N	105 49 48W	8	0.80	0.0065	0.02	0.24	0.05	0.70
417842	JF2P1	42 41 46N	105 53 24W	16	0.07	0.0007	0.01	0.14	0.05L	0.10
Sagebrush west of Dave Johnston										
417901	JG1P1	42 50 20N	105 46 48W	1	0.45	0.0040	0.03	0.27	0.10	0.45

Table 4.--Continued.

Lab. No.	SAMPLE	Ash %	Al %	B ppm	Ba ppm	Ca %	Cd ppm	Co ppm	Cr ppm	Cu ppm
				Sagebrush east of Dave Johnston-continued						
417855	JC5P2	6.7	2.0	500	300	14	15.0	3	20	150
417898	JC6P1	4.8	2.0	1000	700	13	4.0	1	20	150
417887	JC6P2	5.2	3.0	700	300	12	7.5	3	20	300
417892	JC7P1	5.7	2.0	300	1000	17	2.0	3	15	150
417847	JC7P2	5.6	3.0	500	1500	17	2.5	2	20	150
				Sagebrush southeast of Dave Johnston-continued						
417849	JD1P1	6.5	3.0	700	1000	11	3.5	2	30	100
417916	JD1P2	6.4	5.0	500	1500	15	3.0	1	30	100
417858	JD2P1	4.5	3.0	500	1000	11	2.0	2	20	200
417899	JD2P2	5.6	0.7	500	1500	14	2.5	1 L	10	100
417868	JD3P1	5.0	2.0	700	700	12	2.0	2	15	150
417871	JD3P1X	4.5	2.0	700	700	11	2.0	2	15	150
417838	JD3P2	5.6	3.0	700	300	12	3.5	1	20	150
417846	JD4P1	6.2	1.5	500	2000	17	2.0	2	15	70
417890	JD4P2	5.4	0.7	500	700	15	2.0	2	10	150
417875	JD4P2X	5.8	1.5	500	700	15	3.0	1	10	100
				Sagebrush south of Dave Johnston-continued						
417833	JE1P1	4.9	5.0	500	700	13	3.0	2	50	150
417886	JE1P2	6.4	5.0	500	700	14	2.0	4	30	150
417903	JE2P1	6.1	5.0	700	700	11	1.5	4	30	100
417894	JE2P1X	6.2	7.0	700	1000	11	4.0	5	50	100
417825	JE2P2	6.3	7.0	700	1000	10	1.5	5	30	100
417909	JE3P1	5.9	3.0	500	500	13	1.0	1	20	30
417861	JE3P2	5.6	3.0	700	500	14	1.0	2	20	100
417824	JE3P2X	5.5	3.0	700	700	13	1.5	4	20	70
417872	JE4P1	4.7	2.0	700	700	10	4.5	1	15	70
417912	JE4P2	4.9	1.0	700	500	10	1.0	1	10	150
417885	JE4P2X	5.0	0.7	700	700	11	0.8	2	7	100
417906	JE5P1	6.3	5.0	300	500	16	6.0	3	50	150
417834	JE5P2	7.2	5.0	500	1000	11	3.0	2	30	100
417876	JE5P2X	7.0	5.0	700	1000	10	2.5	2	20	100
417882	JE6P1	5.5	7.0	500	1000	11	1.0	4	30	150
417914	JE6P2	5.5	2.0	300	700	14	2.5	1	50	150
				Sagebrush southwest of Dave Johnston-continued						
417851	JF1P1	7.8	3.0	500	1000	13	3.5	1	30	150
417918	JF1P2	13.0	7.0	500	500	10	2.0	3	50	100
417863	JF1P2X	12.0	7.0	500	700	8	3.5	5	30	100
417842	JF2P1	4.9	2.0	300	1500	18	11.0	2	20	150
				Sagebrush west of Dave Johnston-continued						
417901	JG1P1	8.9	7.0	700	500	12	3.0	5	70	150

Table 4.--Continued.

Lab. No.	SAMPLE	Fe %	Ga ppm	K %	Li ppm	Mg %	Mn ppm	Mo ppm	Na %	Ni ppm
Sagebrush east of Dave Johnston-continued										
417855	JC5P2	0.5	0 N	25	10	5	700	10	0.05	70
417898	JC6P1	0.7	0 N	24	6	7	500	15	0.03	15
417887	JC6P2	0.7	0 N	26	6	7	500	10	0.10	20
417892	JC7P1	0.7	0 N	23	4	5	700	30	0.03	10
417847	JC7P2	0.7	0 N	24	6	7	700	30	0.03	15
Sagebrush southeast of Dave Johnston-continued										
417849	JD1P1	1.0	7	27	12	5	1000	30	0.04	15
417916	JD1P2	1.0	7	25	14	5	700	30	0.12	10
417858	JD2P1	1.0	0 N	28	20	5	300	30	0.05	15
417899	JD2P2	0.3	0 N	29	6	3	500	15	0.02	15
417868	JD3P1	0.7	0 N	29	12	5	300	20	0.03	10
417871	JD3P1X	5.0	0 N	29	8	5	300	20	0.03	7
417838	JD3P2	1.0	0 N	25	6	5	500	15	0.03	20
417846	JD4P1	0.5	0 N	25	16	3	1000	20	0.04	7
417390	JD4P2	0.3	0 N	28	10	3	1000	20	0.03	10
417875	JD4P2X	0.5	0 N	28	8	3	1000	30	0.04	10
Sagebrush south of Dave Johnston-continued										
417833	JE1P1	1.0	15	24	18	5	500	20	0.05	15
417886	JE1P2	1.0	15	24	14	5	500	15	0.04	10
417903	JE2P1	1.5	15	25	20	5	500	20	0.08	10
417894	JE2P1X	1.5	15	24	18	7	500	20	0.10	10
417825	JE2P2	1.5	15	18	40	7	500	20	0.07	15
417909	JE3P1	0.7	5	25	55	3	500	70	0.05	10
417861	JE3P2	0.7	0 N	25	8	5	300	10	0.04	10
417824	JE3P2X	0.7	0 N	24	8	3	300	15	0.04	15
417872	JE4P1	0.5	0 N	31	12	7	1000	20	0.04	15
417912	JE4P2	0.5	0 N	30	18	7	500	30	0.07	20
417885	JE4P2X	0.3	0 N	27	16	7	500	30	0.08	15
417906	JE5P1	1.5	10	14	10	7	700	15	0.11	30
417834	JE5P2	1.5	7	22	35	7	700	15	0.11	30
417376	JE5P2X	1.5	0 N	20	25	10	700	15	0.09	20
417882	JE6P1	1.5	10	24	8	5	500	10	0.08	15
417914	JE6P2	1.0	0 N	25	10	7	700	7	0.06	20
Sagebrush southwest of Dave Johnston-continued										
417851	JF1P1	1.0	0 N	25	12	3	2000	30	0.07	30
417918	JF1P2	3.0	20	15	25	3	1500	70	0.38	30
417863	JF1P2X	2.0	15	17	25	3	1000	70	0.30	20
417842	JF2P1	1.0	0 N	18	14	10	700	15	0.05	30
Sagebrush west of Dave Johnston-continued										
417901	JG1P1	2.0	20	20	40	3	700	10	0.13	30

Table 4.--Continued.

Lab. No.	SAMPLE	P %	P ppm	Pb ppm	Sc ppm	Si ppm	Sr ppm	Ti %	U ppm	V ppm
Sagebrush east of Dave Johnston-continued										
417855	JC5P2	3.0	36000	15	0 N	30000	1500	0.05	1.2	50
417898	JC6P1	3.0	24000	20	0 N	21000	1500	0.05	2.0	20
417887	JC6P2	3.0	24000	30	0 N	26000	2000	0.05	2.0	30
417892	JC7P1	2.0	18000	15	0 N	25000	700	0.03	0.4	20
417847	JC7P2	3.0	24000	20	0 N	32000	2000	0.05	0.8	30
Sagebrush southeast of Dave Johnston-continued										
417849	JD1P1	5.0	36000	20	0 N	36000	1500	0.10	1.2	70
417916	JD1P2	3.0	24000	20	0 N	43000	3000	0.10	1.6	70
417858	JD2P1	3.0	24000	15	0 N	48000	3000	0.07	1.2	50
417899	JD2P2	3.0	24000	15	0 N	15000	1000	0.02	0.8	15
417866	JD3P1	3.0	36000	15	0 N	27000	1500	0.03	0.8	20
417871	JD3P1X	3.0	24000	15	0 N	31000	1500	0.03	0.8	20
417838	JD3P2	3.0	24000	15	0 N	32000	1500	0.07	1.2	50
417846	JD4P1	2.0	18000	20	0 N	18000	2000	0.03	0.8	20
417890	JD4P2	3.0	24000	15	0 N	17000	1500	0.02	0.4	15
417875	JD4P2X	3.0	24000	15	0 N	20000	1500	0.07	0.8	15
Sagebrush south of Dave Johnston-continued										
417833	JE1P1	3.0	24000	100	7	38000	3000	0.15	2.4	70
417886	JE1P2	3.0	36000	70	5	46000	3000	0.15	1.6	70
417903	JE2P1	3.0	24000	50	5	64000	1500	0.15	1.2	70
417894	JE2P1X	3.0	24000	70	7	62000	2000	0.15	1.2	70
417825	JE2P2	3.0	24000	70	7	92000	1500	0.15	2.0	100
417909	JE3P1	3.0	24000	15	0 N	44000	2000	0.05	1.2	50
417861	JE3P2	2.0	18000	20	7	35000	1000	0.07	1.2	50
417824	JE3P2X	2.0	24000	30	0 N	60000	1500	0.07	1.6	50
417872	JE4P1	5.0	36000	20	0 N	20000	1500	0.03	1.2	20
417912	JE4P2	5.0	36000	15	0 N	17000	700	0.03	0.8	20
417885	JE4P2X	3.0	36000	0 N	0 N	19000	700	0.02	0.4	15
417906	JE5P1	3.0	24000	20	0 N	76000	200	0.10	1.6	70
417834	JE5P2	3.0	24000	15	0 N	54000	2000	0.10	1.2	70
417876	JE5P2X	2.0	18000	15	0 N	58000	1500	0.15	1.2	50
417882	JE6P1	3.0	24000	50	7	57000	1000	0.15	0.8	70
417914	JE6P2	5.0	36000	30	0 N	32000	1500	0.05	0.8	30
Sagebrush southwest of Dave Johnston-continued										
417851	JF1P1	3.0	24000	20	0 N	42000	2000	0.07	1.6	50
417918	JF1P2	2.0	12000	20	7	122000	1000	0.20	4.0	70
417863	JF1P2X	1.5	18000	15	7	128000	1000	0.15	3.2	70
417842	JF2P1	3.0	24000	50	0 N	32000	1500	0.05	0.8	30
Sagebrush west of Dave Johnston-continued										
417901	JG1P1	3.0	24000	30	7	78000	1500	0.20	3.6	150

Table 4.--Continued.

Lab. No.	SAMPLE	Y ppm	Yb ppm	Zn ppm	Zr ppm
			Sagebrush east of Dave Johnston-continued		
417855	JC5P2	0 N	0.0N	520	20
417898	JC6P1	0 N	0.0N	600	20
417887	JC6P2	0 N	0.0N	920	20
417892	JC7P1	0 N	0.0N	300	30
417847	JC7P2	0 N	0.0N	320	50
			Sagebrush southeast of Dave Johnston-continued		
417849	JD1P1	15	0.0N	320	70
417916	JD1P2	0 N	0.0N	240	50
417858	JD2P1	0 N	0.0N	600	50
417899	JD2P2	0 N	0.0N	240	0 N
417868	JD3P1	0 N	0.0N	360	15
417871	JD3P1X	0 N	0.0N	400	15
417838	JD3P2	0 N	0.0N	340	50
417846	JD4P1	0 N	0.0N	200	15
417890	JD4P2	0 N	0.0N	280	15
417875	JD4P2X	0 N	0.0N	320	15
			Sagebrush south of Dave Johnston-continued		
417833	JE1P1	15	2.0	560	50
417886	JE1P2	15	1.5	420	70
417903	JE2P1	0 N	0.0N	420	50
417894	JE2P1X	0 N	1.5	560	70
417825	JE2P2	20	2.0	320	70
417909	JE3P1	0 N	0.0N	260	30
417861	JE3P2	20	1.5	300	50
417824	JE3P2X	0 N	0.0N	380	20
417872	JE4P1	0 N	0.0N	240	15
417912	JE4P2	0 N	0.0N	320	10
417885	JE4P2X	0 N	0.0N	300	10
417906	JE5P1	20	2.0	360	150
417834	JE5P2	20	2.0	220	70
417876	JE5P2X	15	1.5	200	100
417882	JE6P1	20	2.0	200	70
417914	JE6P2	0 N	0.0N	380	50
			Sagebrush southwest of Dave Johnston-continued		
417851	JF1P1	15	0.0N	280	70
417918	JF1P2	30	3.0	160	150
417863	JF1P2X	30	2.0	180	100
417842	JF2P1	0 N	0.0N	320	50
			Sagebrush west of Dave Johnston-continued		
417901	JG1P1	20	2.0	380	100

Table 4.--Continued.

Lab. No.	SAMPLE	Latitude	Longitud	Dist. Km	As ppm	F %	Hg ppm	Total S%	Sb ppm	Se ppm
Sagebrush west of Dave Johnston-continued										
417904	JG1P1X	42 50 20N	105 46 48W	1	0.35	0.0035	0.02	0.25	0.10	0.40
417895	JG1P2	42 50 20N	105 46 48W	1	0.10	0.0022	0.03	0.30	0.10	1.40
417840	JG2P1	42 50 13N	105 47 24W	2	0.20	0.0026	0.02	0.24	0.10	0.30
417859	JG2P2	42 50 13N	105 47 24W	2	0.20	0.0024	0.02	0.28	0.15	0.40
417896	JG3P1	42 50 13N	105 49 12W	4	0.10	0.0016	0.03	0.20	0.10	0.20
417874	JG3P2	42 50 13N	105 49 12W	4	0.20	0.0014	0.03	0.18	0.05	0.30
417873	JG4P1	42 50 02N	105 51 36W	8	0.10	0.0012	0.02	0.20	0.05L	0.25
417897	JG4P2	42 50 02N	105 51 36W	8	0.05L	0.0012	0.02	0.30	0.05L	0.60
417879	JG5P1	42 50 28N	105 58 12W	16	0.05L	0.0008	0.01	0.26	0.05	0.30
417827	JG5P2	42 50 28N	105 58 12W	16	0.05	0.0008	0.02	0.19	0.15	0.30
417889	JG6P1	42 50 38N	106 10 12W	32	0.05L	0.0006	0.02	0.22	0.05	0.30
417864	JG6P2	42 50 38N	106 10 12W	32	0.05L	0.0007	0.02	0.19	0.05L	0.70
Sagebrush northwest of Dave Johnston										
417841	JH1P1	42 54 04N	105 49 12W	8	0.05	0.0009	0.02	0.16	0.05L	0.60
417883	JH1P1X	42 54 04N	105 49 12W	8	0.05L	0.0007	0.02	0.15	0.05	0.55
417826	JH1P2	42 54 04N	105 49 12W	8	0.08	0.0012	0.02	0.18	0.10	0.55
417920	JH2P1	42 56 06N	105 54 00W	16	0.05L	0.0007	0.03	0.21	0.05	0.80
417848	JH2P1X	42 56 06N	105 54 00W	16	0.05L	0.0006	0.03	0.24	0.05	0.60
417870	JH2P2	42 56 06N	105 54 00W	16	0.05L	0.0004	0.02	0.20	0.05	1.20
417877	JH3P1	43 00 47N	106 03 36W	32	0.05L	0.0006	0.02	0.20	0.05L	0.70
417822	JH3P2	43 00 47N	106 03 36W	32	0.05L	0.0008	0.03	0.20	0.05	1.40

Table 4.--Continued.

Lab. No.	SAMPLE	Ash %	Al %	B ppm	Ba ppm	Ca %	Cd ppm	Co ppm	Cr ppm	Cu ppm
Sagebrush west of Dave Johnston-continued										
417904	JG1P1X	8.4	7.0	500	500	12	2.5	4	70	150
417895	JG1P2	8.1	7.0	700	700	12	1.5	4	50	200
417840	JG2P1	5.5	7.0	500	1000	13	0.2L	2	70	150
417859	JG2P2	7.8	7.0	500	1000	15	3.0	3	70	150
417896	JG3P1	5.6	5.0	1000	1500	16	3.0	3	50	100
417874	JG3P2	5.2	7.0	700	1000	12	4.0	4	70	100
417873	JG4P1	6.2	7.0	700	700	7	2.0	4	50	100
417897	JG4P2	7.8	5.0	1000	700	11	1.5	2	30	100
417879	JG5P1	7.0	3.0	500	300	15	5.5	3	20	150
417827	JG5P2	5.9	3.0	500	200	10	2.5	2	15	150
417889	JG6P1	5.3	3.0	700	700	13	1.0	2	20	150
417864	JG6P2	5.2	3.0	500	700	9	2.0	4	20	150
Sagebrush northwest of Dave Johnston-continued										
417841	JH1P1	5.3	3.0	500	700	11	2.0	2	50	100
417883	JH1P1X	5.4	3.0	700	700	10	2.0	3	30	70
417826	JH1P2	7.2	5.0	500	700	10	2.5	3	30	100
417920	JH2P1	6.0	2.0	700	1000	16	4.0	2	15	150
417848	JH2P1X	6.5	2.0	700	1000	14	3.0	3	20	100
417870	JH2P2	5.3	1.0	500	500	14	3.5	1	10	70
417877	JH3P1	6.6	1.5	700	700	18	3.0	1	15	50
417822	JH3P2	7.2	3.0	700	700	14	3.0	2	15	70

Table 4.--Continued.

Lab. No.	SAMPLE	Fe %	Ga ppm	K %	Li ppm	Mg %	Mn ppm	Mo ppm	Na %	Ni ppm
				Sagebrush west of Dave Johnston-continued						
417904	JG1P1X	2.0	20	20	40	3	700	10	0.11	30
417895	JG1P2	1.5	15	24	30	5	500	15	0.13	20
417840	JG2P1	1.5	20	19	16	7	700	20	0.06	20
417859	JG2P2	1.5	15	14	30	7	300	15	0.07	15
417896	JG3P1	1.0	15	18	10	5	700	10	0.05	10
417874	JG3P2	1.5	15	19	20	7	700	15	0.07	15
417873	JG4P1	1.5	15	26	30	7	700	7	0.12	20
417897	JG4P2	1.0	10	27	20	5	700	15	0.07	15
417879	JG5P1	0.7	10	25	14	2	500	0 N	0.06	15
417827	JG5P2	0.7	0 N	31	18	3	500	15	0.06	30
417889	JG6P1	0.7	0 N	23	25	10	700	20	0.05	7
417864	JG6P2	1.0	0 N	28	12	5	500	15	0.06	15
				Sagebrush northwest of Dave Johnston-continued						
417841	JH1P1	1.0	0 N	28	20	10	500	20	0.09	10
417883	JH1P1X	1.0	0 N	26	18	7	500	20	0.06	7
417826	JH1P2	1.0	7	22	12	7	300	30	0.06	15
417920	JH2P1	0.5	0 N	25	10	5	1000	7	0.04	20
417848	JH2P1X	0.7	0 N	25	10	5	1000	20	0.04	20
417870	JH2P2	0.5	0 N	25	16	7	700	10	0.04	15
417877	JH3P1	0.5	0 N	24	14	7	700	30	0.04	5
417822	JH3P2	0.7	0 N	24	16	7	500	20	0.05	10

Table 4.--Continued.

Lab. No.	SAMPLE	P %	P ppm	Pb ppm	Sc ppm	Si ppm	Sr ppm	Ti %	U ppm	V ppm
				Sagebrush west of Dave Johnston-continued						
417904	JG1P1X	3.0	24000	20	7	66000	1500	0.20	4.0	150
417895	JG1P2	3.0	36000	15	7	46000	1500	0.15	3.2	100
417840	JG2P1	5.0	36000	50	10	56000	1500	0.15	2.8	150
417859	JG2P2	3.0	18000	30	7	84000	1000	0.15	2.0	100
417896	JG3P1	3.0	24000	30	5	60000	1000	0.15	1.6	70
417874	JG3P2	5.0	36000	70	7	75000	2000	0.15	2.4	150
417873	JG4P1	5.0	36000	50	5	72000	1500	0.15	2.0	70
417897	JG4P2	5.0	24000	30	0 N	47000	1500	0.10	1.6	70
417879	JG5P1	3.0	24000	30	0 N	42000	2000	0.05	0.8	50
417827	JG5P2	5.0	36000	30	0 N	30000	1500	0.05	1.2	50
417889	JG6P1	5.0	36000	70	0 N	28000	3000	0.07	0.8	30
417864	JG6P2	3.0	36000	70	0 N	36000	3000	0.07	0.8	50
				Sagebrush northwest of Dave Johnston-continued						
417841	JH1P1	5.0	24000	100	0 N	36000	2000	0.07	2.4	50
417883	JH1P1X	3.0	36000	70	0 N	38000	1500	0.07	1.2	30
417826	JH1P2	5.0	24000	100	0 N	82000	1000	0.10	1.6	70
417920	JH2P1	3.0	24000	20	0 N	28000	1500	0.05	0.8	30
417848	JH2P1X	3.0	24000	20	0 N	32000	1500	0.05	0.8	30
417870	JH2P2	5.0	36000	20	0 N	19000	1000	0.02	0.4	15
417877	JH3P1	3.0	24000	20	0 N	27000	1500	0.03	0.8	20
417822	JH3P2	3.0	36000	30	0 N	40000	1500	0.05	0.8	30

Table 4.--Continued.

Lab. No.	SAMPLE	Y ppm	Yb ppm	Zn ppm	Zr ppm
Sagebrush west of Dave Johnston-continued					
417904	JG1P1X	20	2.0	380	100
417895	JG1P2	0 N	1.5	640	70
417840	JG2P1	15	1.5	380	70
417859	JG2P2	15	1.5	320	70
417896	JG3P1	0 N	1.5	380	70
417874	JG3P2	20	2.0	460	70
417873	JG4P1	20	2.0	280	100
417897	JG4P2	0 N	1.5	400	70
417879	JG5P1	0 N	0.0N	320	30
417827	JG5P2	0 N	0.0N	400	20
417889	JG6P1	0 N	0.0N	300	20
417864	JG6P2	0 N	0.0N	320	20
Sagebrush northwest of Dave Johnston-continued					
417841	JH1P1	15	0.0N	360	70
417883	JH1P1X	0 N	0.0N	300	30
417826	JH1P2	0 N	0.0N	310	50
417920	JH2P1	0 N	0.0N	320	10
417848	JH2P1X	0 N	0.0N	320	30
417870	JH2P2	0 N	0.0N	480	15
417877	JH3P1	0 N	0.0N	240	20
417822	JH3P2	0 N	0.0N	320	20

Table 5.--Chemistry of soils (5-20 cm depth) near the Dave Johnston powerplant. Results given in percent (%) or parts per million (ppm); km, distance from powerplant in kilometers; N, not detected; L, less than limit of detection; G, greater than given value; B, no data available.

Lab. No.	SAMPLE	Latitude	Longitud	Dist. Km	Al %	As ppm	B ppm	Ba ppm	Be ppm	Total C%
				Soil north of Dave Johnston						
174947	JA1S1	42 50 46N	105 46 20W	1	3	2.1	20	700	0.0N	0.30
174935	JA1S2	42 50 46N	105 46 20W	1	5	2.1	0 L	700	2.0	1.26
174955	JA2S1	42 51 20N	105 46 18W	2	5	2.6	15	1000	0.0N	0.41
174931	JA2S2	42 51 20N	105 46 18W	2	5	3.6	15	1000	0.0N	0.35
175003	JA2S2X	42 51 20N	105 46 18W	2	5	2.4	0 L	1000	2.0	0.45
175009	JA3S1	42 52 23N	105 46 21W	4	5	2.3	10	1000	0.0N	0.38
175013	JA3S1X	42 52 23N	105 46 21W	4	10	3.2	70	1000	0.0N	0.34
174975	JA3S2	42 52 23N	105 46 21W	4	5	1.5	0 L	700	1.5	2.71
174937	JA3S2X	42 52 23N	105 46 21W	4	7	2.7	0 N	1000	0.0N	0.24
174997	JA4S1	42 55 03N	105 45 47W	8	3	3.1	0 L	700	1.5	1.08
174988	JA4S1X	42 55 03N	105 45 47W	8	3	3.6	0 L	500	0.0N	0.96
174992	JA4S2	42 55 03N	105 45 47W	8	3	3.1	0 L	700	0.0N	0.40
174949	JA4S2X	42 55 03N	105 45 47W	8	5	3.5	20	1000	0.0N	0.53
175017	JA5S1	42 58 40N	105 46 42W	32	10	2.1	20	700	0.0N	0.35
175019	JA5S2	42 58 40N	105 46 42W	32	10	5.2	20	700	2.0	0.28
175018	JA5S2X	42 58 40N	105 46 42W	32	10 G	4.6	30	700	1.5	0.32
174983	JA6S1	43 07 37N	105 49 40W	32	7	5.6	30	500	3.0	1.23
174995	JA6S1X	43 07 37N	105 49 40W	32	7	5.7	30	500	3.0	1.47
174965	JA6S2	43 07 37N	105 49 40W	32	7	5.2	50	700	2.0	1.15
174940	JA7S1	43 23 27N	105 47 33W	64	7	4.3	0 N	1000	0.0N	1.01
174953	JA7S2	43 23 27N	105 47 33W	64	7	5.3	15	500	0.0N	2.66
				Soil northeast of Dave Johnston						
174958	JB1S1	42 52 38N	105 42 50W	8	7	2.4	15	1000	0.0N	0.24
175014	JB1S2	42 52 38N	105 42 50W	8	7	3.0	15	700	0.0N	0.22
174986	JB2S1	42 55 38N	105 39 12W	16	7	5.0	30	700	2.0	1.66
174946	JB2S1X	42 55 38N	105 39 12W	16	10	4.4	30	1000	1.5	1.76
174978	JB2S2	42 55 38N	105 39 12W	16	7	3.6	30	700	3.0	0.62
174954	JB3S1	43 04 55N	105 26 32W	32	10	5.5	15	700	1.5	1.08
175000	JB3S2	43 04 55N	105 26 32W	32	7	3.9	20	700	3.0	0.76
175004	JB4S1	43 12 45N	105 15 45W	64	5	4.8	30	1000	0.0N	0.26
174994	JB4S2	43 12 45N	105 15 45W	64	5	4.2	30	700	2.0	0.64
				Soil east of Dave Johnston						
174941	JC1S1	42 50 14N	105 45 52W	1	3	3.6	30	700	0.0N	0.47
174942	JC1S1X	42 50 14N	105 45 52W	1	3	4.0	30	700	0.0N	0.44
174952	JC1S2	42 50 14N	105 45 52W	1	3	4.6	20	700	0.0N	0.44
174976	JC2S1	42 50 14N	105 44 45W	2	7	3.6	30	1000	3.0	1.16
174960	JC2S2	42 50 14N	105 44 45W	2	10	2.7	30	1500	0.0N	1.01
174927	JC3S1	42 50 27N	105 43 25W	4	7	2.9	20	1000	1.5	0.44
174929	JC3S2	42 50 27N	105 43 25W	4	5	3.1	15	700	0.0N	0.52
174989	JC4S1	42 50 00N	105 40 15W	8	3	4.7	20	500	0.0N	0.00B
174987	JC4S1X	42 50 00N	105 40 15W	8	3	4.5	20	300	1.5	0.45
174998	JC4S2	42 50 00N	105 40 15W	8	5	5.2	20	700	3.0	0.81
174982	JC5S1	42 50 21N	105 34 34W	16	5	4.0	50	500	2.0	0.91

Table 5.--Continued.

Lab. No.	SAMPLE	Ca %	Co ppm	Cr ppm	Cu ppm	F %	Fe %	Ga ppm	Ge ppm	Hg ppm
Soil north of Dave Johnston-continued										
174947	JA1S1	0.5	0 N	15	7	0.04L	1.0	15	0.71	0.02
174985	JA1S2	0.5	0 L	15	7	0.04L	1.0	15	0.91	0.01
174956	JA2S1	0.7	0 L	20	7	0.04L	1.0	10	1.06	0.01L
174931	JA2S2	0.5	3	30	7	0.04L	1.0	15	1.04	0.02
175003	JA2S2X	0.5	0 L	20	7	0.04L	1.0	15	1.00	0.03
175009	JA3S1	0.5	0 N	15	5	0.04L	0.7	10	0.89	0.02
175013	JA3S1X	0.7	3	50	7	0.04L	1.5	20	1.33	0.02
174975	JA3S2	0.3	0 L	15	5	0.04L	1.5	15	0.67	0.02
174937	JA3S2X	0.5	0 L	15	5	0.04L	1.0	15	1.00	0.01
174997	JA4S1	0.2	0 L	30	7	0.04L	1.0	15	1.02	0.03
174988	JA4S1X	0.2	0 L	15	7	0.04L	1.0	15	1.07	0.02
174992	JA4S2	0.2	0 L	20	7	0.04L	0.7	15	0.93	0.02
174949	JA4S2X	0.7	3	30	7	0.04L	1.5	15	0.89	0.02
175017	JA5S1	0.3	5	20	7	0.04L	1.5	20	0.86	0.02
175019	JA5S2	0.7	7	30	10	0.04L	2.0	20	0.87	0.02
175018	JA5S2X	0.7	7	50	10	0.04L	2.0	30	0.79	0.02
174983	JA6S1	0.7	7	50	20	0.05	3.0	20	1.37	0.03
174995	JA6S1X	0.7	7	50	20	0.05	2.0	20	1.70	0.04
174965	JA6S2	0.5	7	70	20	0.04	1.5	20	1.30	0.03
174940	JA7S1	3.0	3	30	7	0.04L	2.0	20	0.76	0.03
174953	JA7S2	10.0	7	50	20	0.05	2.0	20	1.43	0.01
Soil northeast of Dave Johnston-continued										
174958	JB1S1	0.7	0 N	15	5	0.04L	1.5	15	0.88	0.02
175014	JB1S2	0.7	3	20	7	0.04L	1.5	15	1.14	0.02
174986	JB2S1	0.5	0 L	70	20	0.04L	2.0	20	1.12	0.03
174946	JB2S1X	0.7	7	100	30	0.04L	3.0	30	1.12	0.02
174978	JB2S2	0.3	7	70	15	0.04L	1.5	15	0.87	0.03
174954	JB3S1	0.7	7	100	20	0.04L	3.0	20	1.53	0.02
175000	JB3S2	0.5	7	70	20	0.04L	3.0	20	1.65	0.04
175004	JB4S1	0.5	7	50	10	0.04L	3.0	20	1.42	0.03
174994	JB4S2	0.3	7	50	15	0.04L	1.5	15	1.48	0.04
Soil east of Dave Johnston-continued										
174941	JC1S1	0.5	3	30	10	0.04L	1.5	15	0.79	0.02
174942	JC1S1X	0.3	3	20	10	0.04L	1.0	10	0.98	0.03
174952	JC1S2	0.3	0 L	15	7	0.04L	1.0	10	1.00	0.03
174976	JC2S1	0.5	7	30	15	0.04L	1.0	15	1.08	0.02
174960	JC2S2	0.7	5	50	15	0.04L	2.0	15	2.70	0.02
174927	JC3S1	0.5	3	30	7	0.04L	1.5	15	1.07	0.02
174929	JC3S2	0.3	5	30	7	0.04L	1.5	15	1.07	0.01L
174989	JC4S1	0.5	0 L	15	7	0.04L	1.5	15	1.20	0.02
174987	JC4S1X	0.5	0 L	30	7	0.04L	1.5	10	1.16	0.01
174998	JC4S2	1.0	7	30	15	0.04L	1.5	20	1.47	0.02
174982	JC5S1	0.3	20	70	15	0.04L	1.5	15	1.32	0.04

Table 5.--Continued.

Lab. No.	SAMPLE	K %	La ppm	Li ppm	Mg %	MgO %	Mn ppm	Mo ppm-S	Na %	Na2O %
Soil north of Dave Johnston-continued										
174947	JA1S1	3	0 N	10	0.20	0.37	150	0 N	1.0	1.53
174985	JA1S2	3	0 N	5	0.15	0.29	150	0 N	1.0	1.60
174956	JA2S1	3	0 N	10	0.30	0.40	150	0 N	1.0	1.65
174931	JA2S2	3	0 N	10	0.30	0.39	150	0 N	1.5	1.65
175003	JA2S2X	3	0 N	10	0.15	0.35	150	0 N	1.5	1.63
175009	JA3S1	3	0 N	6	0.20	0.31	150	0 N	1.0	1.46
175013	JA3S1X	3	30	7	0.50	0.33	200	0 N	2.0	1.53
174975	JA3S2	3	0 N	5	0.15	0.34	150	0 N	0.5	1.58
174937	JA3S2X	3	0 N	5	0.20	0.33	150	0 N	1.5	1.61
174997	JA4S1	3	0 N	5	0.15	0.34	150	0 N	0.7	1.01
174988	JA4S1X	3	0 N	5	0.15	0.35	150	0 N	0.7	1.03
174992	JA4S2	3	0 N	5	0.15	0.30	150	0 N	0.7	0.84
174949	JA4S2X	3	0 N	10	0.30	0.37	150	0 N	1.0	0.95
175017	JA5S1	3	30	5 L	0.30	0.34	150	0 N	1.5	1.46
175019	JA5S2	3	30	8	0.70	0.52	150	0 N	1.0	1.06
175018	JA5S2X	3	50	7	0.70	0.52	150	0 N	1.0	1.04
174983	JA6S1	3	50	20	0.70	1.37	150	0 N	0.3	0.22
174995	JA6S1X	3	0 L	25	0.70	1.35	150	0 N	0.3	0.22
174965	JA6S2	3	0 L	25	0.50	1.01	150	7	0.3	0.21
174940	JA7S1	3	0 N	10	1.00	0.89	200	0 N	0.5	0.40
174953	JA7S2	3	0 N	25	1.50	1.96	300	0 N	0.7	0.58
Soil northeast of Dave Johnston-continued										
174958	JB1S1	3	50	5	0.20	0.27	200	0 N	1.5	1.39
175014	JB1S2	3	0 N	6	0.30	0.31	200	0 N	1.5	1.66
174986	JB2S1	3	50	15	0.50	0.89	150	0 N	0.7	0.74
174946	JB2S1X	3	700	25	0.70	0.91	150	0 N	0.7	0.88
174978	JB2S2	3	50	15	0.30	0.83	200	3	0.7	0.70
174954	JB3S1	3	50	25	1.00	0.98	200	0 N	0.7	0.76
175000	JB3S2	3	0 N	20	0.50	0.94	200	0 N	0.7	0.69
175004	JB4S1	3	0 N	8	0.70	0.52	200	0 N	0.7	0.80
174994	JB4S2	2	0 N	10	0.30	0.67	150	0 N	0.7	0.73
Soil east of Dave Johnston-continued										
174941	JC1S1	2	0 N	10	0.30	0.36	150	0 N	0.7	0.85
174942	JC1S1X	3	0 N	10	0.20	0.36	150	5	0.7	0.83
174952	JC1S2	3	0 N	10	0.20	0.30	150	0 N	0.7	0.97
174976	JC2S1	3	0 L	15	0.50	0.93	300	3	0.7	0.64
174960	JC2S2	3	50	15	1.00	1.10	200	0 N	0.7	0.75
174927	JC3S1	3	0 N	15	0.70	0.52	200	0 N	1.0	1.04
174929	JC3S2	3	70	15	0.50	0.52	150	0 N	0.7	0.88
174989	JC4S1	2	0 L	10	0.30	0.69	150	0 N	0.3	0.75
174987	JC4S1X	2	0 L	10	2.00	0.69	150	7	0.3	0.19
174998	JC4S2	3	70	20	0.70	1.12	200	3	0.5	0.41
174982	JC5S1	2	0 L	20	0.30	0.63	150	7	0.3	0.32

Table 5.--Continued.

Lab. No.	SAMPLE	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Rb ppm	Sb ppm	Sc ppm	Se ppm	Si %
	Soil north of Dave Johnston-continued									
174947	JA1S1	0 N	0 B	5	15	90	1.0L	0 N	0.10	10 G
174985	JA1S2	15	0 B	5	15	75	1.0L	0 L	0.10L	10 G
174956	JA2S1	0 N	0 B	3	15	80	1.0L	3	0.10L	10 G
174931	JA2S2	7	0 B	5	15	85	1.0L	3	0.10L	10 G
175003	JA2S2X	15	0 B	0 L	15	90	1.0L	0 L	0.23	10 G
175009	JA3S1	0 N	0 B	5	15	65	1.0L	0 N	0.18	10 G
175013	JA3S1X	10	0 N	7	15	75	1.0L	3	0.10L	10 G
174975	JA3S2	15	0 B	5	15	80	1.0L	0 L	0.10L	10 G
174937	JA3S2X	0 N	0 B	5	15	85	1.0L	0 N	0.10L	10 G
174997	JA4S1	15	0 B	5	15	90	1.0L	0 L	0.45	10 G
174988	JA4S1X	15	0 B	5	15	105	1.0L	0 L	0.57	10 G
174992	JA4S2	15	0 B	0 L	15	95	1.0L	0 L	0.10L	10 G
174949	JA4S2X	0 N	0 B	7	15	90	1.0L	3	0.10L	10 G
175017	JA5S1	15	0 N	7	20	110	1.0L	3	0.22	10 G
175019	JA5S2	15	0 N	15	20	80	1.0L	5	0.10L	10 G
175018	JA5S2X	15	0 N	15	20	75	1.0L	7	0.10L	10 G
174983	JA6S1	30	0 L	15	15	95	1.0L	7	0.24	10 G
174995	JA6S1X	20	70	15	20	100	1.0	7	0.49	10 G
174965	JA6S2	20	0 L	15	20	95	1.0L	7	0.36	10 G
174940	JA7S1	0 N	0 B	10	15	90	1.0L	5	0.10L	10 G
174953	JA7S2	7	0 B	10	15	75	1.0L	5	0.10	10 G
	Soil northeast of Dave Johnston-continued									
174958	JB1S1	0 N	0 N	3	15	70	1.0L	3	0.10L	10 G
175014	JB1S2	15	0 B	7	20	75	1.0L	2	0.10L	10 G
174986	JB2S1	15	0 N	15	20	85	1.0L	7	0.47	10 G
174946	JB2S1X	7	700	15	30	105	1.0L	10	0.10	10 G
174978	JB2S2	20	70	15	15	80	1.0L	7	0.19	10 G
174954	JB3S1	7	0 N	15	15	90	1.0L	7	0.13	10 G
175000	JB3S2	20	0 B	20	20	90	1.0L	7	0.48	10 G
175004	JB4S1	15	0 B	10	15	60	1.3	5	0.42	10 G
174994	JB4S2	20	0 B	15	15	90	1.0L	7	0.24	10 G
	Soil east of Dave Johnston-continued									
174941	JC1S1	0 N	0 B	7	15	65	1.0L	3	0.10L	10 G
174942	JC1S1X	7	0 B	7	15	65	1.0L	0 N	0.12	10 G
174952	JC1S2	0 N	0 B	5	15	60	1.0L	0 N	0.10L	10 G
174976	JC2S1	20	0 L	15	15	85	1.0L	7	0.10L	10 G
174960	JC2S2	7	0 N	7	15	85	1.0L	5	0.10L	10 G
174927	JC3S1	7	0 B	10	15	75	1.0L	5	0.14	10 G
174929	JC3S2	7	0 N	10	15	80	1.0L	3	0.10L	10 G
174989	JC4S1	15	0 L	7	15	75	1.0L	0 L	0.47	10 G
174987	JC4S1X	15	0 N	10	15	60	1.0L	0 L	0.48	10 G
174998	JC4S2	15	0 N	10	20	85	1.1	5	0.25	10 G
174982	JC5S1	20	0 L	15	15	80	1.0L	7	0.20	10 G

Table 5.--Continued.

Lab. No.	SAMPLE	Sn ppm	Sr ppm	Th ppm	Ti %	U ppm	V ppm	Y ppm	Yb ppm	Zn ppm
Soil north of Dave Johnston-continued										
174947	JA1S1	0.10L	200	6.97	0.07	1.95	30	0 N	1.0	27
174985	JA1S2	0.57	150	9.37	0.07	1.70	30	15	1.5	25
174956	JA2S1	0.30	200	7.03	0.10	2.15	30	15	2.0	32
174931	JA2S2	1.52	200	8.52	0.10	2.16	30	15	1.5	31
175003	JA2S2X	0.67	200	8.06	0.10	1.90	30	15	2.0	31
175009	JA3S1	0.10L	200	11.36	0.10	1.16	20	10	1.5	26
175013	JA3S1X	0.61	200	11.60	0.15	0.97	50	15	2.0	27
174975	JA3S2	0.50	150	4.56	0.07	1.96	30	30	3.0	24
174937	JA3S2X	0.64	300	6.52	0.07	1.80	30	15	1.5	27
174997	JA4S1	0.51	100	12.24	0.10	2.47	30	15	2.0	30
174988	JA4S1X	0.73	70	11.89	0.10	2.30	30	15	2.0	34
174992	JA4S2	1.18	100	10.71	0.10	2.37	30	20	3.0	28
174949	JA4S2X	0.57	150	12.67	0.10	2.28	30	10	1.5	28
175017	JA5S1	0.41	100	23.61	0.15	1.17	70	15	1.5	27
175019	JA5S2	0.95	100	31.05	0.20	1.68	100	20	3.0	41
175018	JA5S2X	0.46	100	29.71	0.20	1.73	150	30	3.0	40
174983	JA6S1	1.29	100	11.06	0.15	4.52	100	30	3.0	82
174995	JA6S1X	1.79	100	16.40	0.15	4.22	70	30	3.0	84
174965	JA6S2	0.97	100	13.48	0.15	4.42	150	30	3.0	73
174940	JA7S1	0.60	150	13.98	0.20	2.44	50	20	2.0	32
174953	JA7S2	1.40	300	8.45	0.15	4.89	100	20	3.0	62
Soil northeast of Dave Johnston-continued										
174958	JB1S1	0.10L	200	8.07	0.10	1.71	30	10	1.5	55
175014	JB1S2	0.43	200	10.03	0.15	1.04	50	15	2.0	22
174986	JB2S1	0.95	150	14.55	0.15	3.56	100	30	3.0	66
174946	JB2S1X	1.21	200	11.44	0.20	3.73	100	70	7.0	65
174978	JB2S2	0.46	150	10.55	0.15	3.65	100	30	3.0	55
174954	JB3S1	1.91	200	10.41	0.20	4.02	100	30	3.0	71
175000	JB3S2	1.45	150	10.30	0.20	3.39	100	30	3.0	69
175004	JB4S1	0.86	100	14.38	0.30	2.69	50	30	5.0	38
174994	JB4S2	1.63	100	11.67	0.20	3.14	70	30	3.0	50
Soil east of Dave Johnston-continued										
174941	JC1S1	0.25	150	5.78	0.07	2.28	30	15	2.0	35
174942	JC1S1X	0.41	150	6.71	0.15	2.07	30	15	2.0	34
174952	JC1S2	0.13	150	4.63	0.10	2.30	30	20	2.0	30
174976	JC2S1	0.45	150	7.51	0.15	2.89	70	30	3.0	56
174960	JC2S2	0.49	300	8.33	0.20	2.93	70	30	3.0	53
174927	JC3S1	0.70	200	6.29	0.15	2.46	50	20	3.0	38
174929	JC3S2	0.97	150	6.35	0.15	2.33	30	20	2.0	37
174989	JC4S1	0.54	70	7.35	0.10	2.29	30	30	3.0	35
174987	JC4S1X	0.50	70	8.57	0.10	2.00	30	20	3.0	35
174998	JC4S2	1.21	150	10.17	0.15	2.86	70	30	3.0	58
174982	JC5S1	0.93	100	0.00B	0.15	4.21	100	30	3.0	69

Table 5.--Continued.

Lab. No.	SAMPLE	Zr ppm
	Soil north of Dave Johnston-continued	
174947	JA1S1	100
174985	JA1S2	150
174956	JA2S1	200
174931	JA2S2	150
175003	JA2S2X	150
175009	JA3S1	70
175013	JA3S1X	200
174975	JA3S2	150
174937	JA3S2X	100
174997	JA4S1	150
174988	JA4S1X	100
174992	JA4S2	150
174949	JA4S2X	100
175017	JA5S1	200
175019	JA5S2	200
175018	JA5S2X	200
174983	JA6S1	150
174995	JA6S1X	150
174965	JA6S2	150
174940	JA7S1	70
174953	JA7S2	150
	Soil northeast of Dave Johnston-continued	
174958	JB1S1	100
175014	JB1S2	200
174986	JB2S1	150
174946	JB2S1X	150
174978	JB2S2	200
174954	JB3S1	150
175000	JB3S2	150
175004	JB4S1	500
174994	JB4S2	300
	Soil east of Dave Johnston-continued	
174941	JC1S1	150
174942	JC1S1X	150
174952	JC1S2	150
174976	JC2S1	200
174960	JC2S2	300
174927	JC3S1	200
174929	JC3S2	300
174989	JC4S1	200
174987	JC4S1X	100
174998	JC4S2	150
174982	JC5S1	200

Table 5.--Continued.

Lab. No.	SAMPLE	Latitude	Longitud	Dist. Km	Al %	As ppm	B ppm	Ba ppm	Be ppm	Total C%
Soil east of Dave Johnston-continued										
174934	JC5S2	42 50 21N	105 34 34W	16	7	5.3	50	700	1.5	0.42
174939	JC6S1	42 49 36N	105 21 53W	32	5	3.9	0 N	700	0.0N	0.50
174944	JC6S1X	42 49 36N	105 21 53W	32	3	3.6	0 N	700	0.0N	0.49
174990	JC6S2	42 49 36N	105 21 53W	32	5	7.0	20	500	3.0	0.63
174959	JC6S2X	42 49 36N	105 21 53W	32	10	6.9	30	700	1.5	0.70
174993	JC7S1	42 50 15N	105 04 00W	64	3	4.9	30	300	0.0N	1.23
174962	JC7S2	42 50 15N	105 04 00W	64	7	3.0	0 N	1000	0.0N	0.92
Soil southeast of Dave Johnston										
174948	JD1S1	42 48 17N	105 42 52W	8	10	5.1	50	1500	1.5	1.19
174972	JD1S2	42 48 17N	105 42 52W	8	7	8.6	50	1500	3.0	1.94
175020	JD2S1	42 45 10N	105 38 56W	16	10 G	6.9	70	700	3.0	1.34
174957	JD2S2	42 45 10N	105 38 56W	16	7	6.1	30	700	1.5	1.10
174935	JD3S1	42 36 00N	105 27 15W	32	7	9.6	50	500	2.0	1.35
175006	JD3S2	42 36 00N	105 27 15W	32	5	3.9	30	500	0.0N	1.27
174925	JD3S2X	42 36 00N	105 27 15W	32	7	5.3	50	700	0.0N	1.33
174979	JD4S1	42 25 45N	105 13 45W	64	10	3.8	20	700	3.0	1.09
174969	JD4S2	42 25 45N	105 13 45W	64	10	4.8	30	700	2.0	1.90
174951	JD4S2X	42 25 45N	105 13 45W	64	10 G	4.7	30	1000	2.0	2.00
Soil south of Dave Johnston										
175005	JE1S1	42 49 42N	105 46 21W	1	7	6.7	30	700	0.0N	1.57
174964	JE1S2	42 49 42N	105 46 21W	1	5	5.8	30	500	1.5	1.10
174970	JE1S2X	42 49 42N	105 46 21W	1	5	4.0	30	500	1.5	1.12
174966	JE2S1	42 49 10N	105 46 20W	2	7	3.2	30	700	1.5	0.53
174938	JE2S2	42 49 10N	105 46 20W	2	10	5.5	50	1000	2.0	0.88
174984	JE3S1	42 47 55N	105 46 20W	4	5	6.6	30	700	3.0	1.27
174999	JE3S2	42 47 55N	105 46 20W	4	3	5.3	20	700	3.0	0.71
174980	JE4S1	42 46 32N	105 46 24W	8	7	2.5	20	700	3.0	2.05
175015	JE4S2	42 46 32N	105 46 24W	8	10	8.0	50	700	3.0	1.61
175001	JE5S1	42 41 24N	105 47 50W	16	3	4.0	0 L	300	0.0N	4.45
175016	JE5S2	42 41 24N	105 47 50W	16	10 G	5.5	50	1000	2.0	2.37
175010	JE5S2X	42 41 24N	105 47 50W	16	7	5.6	30	1000	1.5	1.88
174981	JE6S1	42 33 50N	105 42 02W	32	7	4.1	0 L	500	3.0	2.95
174963	JE6S2	42 33 50N	105 42 02W	32	10	6.0	0 N	1000	0.0N	1.47
174961	JE6S2X	42 33 50N	105 45 02W	32	10	5.1	15	1000	1.5	1.70
Soil southwest of Dave Johnston										
174926	JF1S1	42 47 15N	105 50 07W	8	10 G	6.6	50	1500	2.0	1.65
174950	JF1S2	42 47 15N	105 50 07W	8	10	5.7	70	1000	2.0	1.35
174967	JF2S1	42 41 47N	105 53 24W	16	7	5.9	30	700	3.0	1.27
Soil west of Dave Johnston										
174977	JG1S1	42 50 22N	105 47 09W	1	3	2.5	0 L	1000	0.0N	0.72

Table 5.--Continued.

Lab. No.	SAMPLE	Ca %	Co ppm	Cr ppm	Cu ppm	F %	Fe %	Ga ppm S	Ge ppm	Hg ppm
Soil east of Dave Johnston-continued										
174934	JC5S2	0.5	7	70	15	0.04L	2.0	20	1.53	0.01
174939	JC6S1	0.7	7	30	7	0.04L	2.0	15	1.16	0.01
174944	JC6S1X	0.5	7	50	10	0.04L	2.0	15	0.95	0.03
174990	JC6S2	0.3	7	70	15	0.04L	2.0	20	1.70	0.04
174959	JC6S2X	0.3	10	100	15	0.04L	3.0	15	3.03	0.03
174993	JC7S1	0.3	0 L	30	15	0.04L	1.0	15	1.36	0.03
174962	JC7S2	0.3	3	30	7	0.04L	1.5	15	2.40	0.02
Soil southeast of Dave Johnston-continued										
174948	JD1S1	5.0	7	70	15	0.05	3.0	20	0.91	0.02
174972	JD1S2	7.0	7	70	20	0.10	2.0	30	1.31	0.03
175020	JD2S1	7.0	15	70	50	0.04L	5.0	30	1.15	0.04
174957	JD2S2	1.0	7	70	20	0.05	3.0	20	1.12	0.03
174935	JD3S1	0.5	7	70	20	0.04	3.0	30	1.47	0.04
175006	JD3S2	3.0	5	30	15	0.05	3.0	20	0.76	0.01
174925	JD3S2X	3.0	7	30	15	0.04L	2.0	15	0.93	0.05
174979	JD4S1	5.0	7	150	15	0.05	3.0	15	0.88	0.02
174969	JD4S2	5.0	7	70	20	0.08	3.0	30	1.15	0.01
174951	JD4S2X	5.0	10	70	20	0.08	3.0	30	1.15	0.04
Soil south of Dave Johnston-continued										
175005	JE1S1	3.0	5	30	10	0.04L	3.0	15	1.35	0.03
174964	JE1S2	1.5	7	30	7	0.04L	1.5	15	1.19	0.04
174970	JE1S2X	1.0	7	30	7	0.04L	1.5	15	0.68	0.01
174966	JE2S1	0.7	7	50	7	0.04L	1.5	20	0.87	0.02
174938	JE2S2	1.0	5	50	15	0.04	3.0	20	1.08	0.02
174984	JE3S1	1.0	0 L	15	7	0.04L	1.5	15	1.24	0.03
174999	JE3S2	0.3	0 L	15	7	0.04L	1.5	15	1.44	0.02
174980	JE4S1	0.7	7	30	15	0.04	2.0	15	0.94	0.02
175015	JE4S2	2.0	7	70	20	0.07	3.0	30	1.55	0.02
175001	JE5S1	7.0	5	30	15	0.04L	1.5	15	0.82	0.01L
175016	JE5S2	1.5	10	150	30	0.04	5.0	30	1.34	0.02
175010	JE5S2X	1.0	7	70	20	0.04	3.0	20	1.26	0.03
174981	JE6S1	7.0	7	30	15	0.06	2.0	20	0.78	0.03
174963	JE6S2	1.5	7	30	20	0.05	3.0	20	3.03	0.03
174961	JE6S2X	1.5	7	50	20	0.05	3.0	20	2.38	0.02
Soil southwest of Dave Johnston-continued										
174926	JF1S1	7.0	7	70	20	0.07	3.0	30	1.14	0.02
174950	JF1S2	7.0	7	70	30	0.08	3.0	30	1.30	0.02
174967	JF2S1	0.5	10	50	15	0.04	1.0	30	0.78	0.04
Soil west of Dave Johnston-continued										
174977	JG1S1	0.7	0 L	15	7	0.04L	1.0	15	0.84	0.03

Table 5.--Continued.

Lab. No.	SAMPLE	K %	La ppm	Li ppm	Mg %	MgO %	Mn ppm	Mo ppm	Na %	Na2O %
Soil east of Dave Johnston-continued										
174934	JC5S2	3	0 N	20	0.50	0.53	150	7	0.5	0.31
174939	JC6S1	3	0 N	10	0.50	0.64	150	0 N	0.7	0.91
174944	JC6S1X	2	0 N	10	0.50	0.63	150	3	0.7	0.93
174990	JC6S2	3	0 L	20	0.30	1.06	150	0 N	0.7	0.60
174959	JC6S2X	3	0 N	30	1.00	1.05	150	0 N	0.7	0.74
174993	JC7S1	2	0 N	10	0.20	0.62	150	0 N	0.3	0.34
174962	JC7S2	5	0 N	5	0.50	0.60	150	2	0.7	0.72
Soil southeast of Dave Johnston-continued										
174948	JD1S1	3	50	25	1.50	1.60	200	5	1.0	1.21
174972	JD1S2	3	50	30	1.50	2.09	300	0 N	1.5	1.64
175020	JD2S1	3	70	36	2.00	2.42	300	0 N	1.0	0.82
174957	JD2S2	3	50	30	1.50	1.89	300	0 N	0.7	0.86
174935	JD3S1	3	100	30	1.50	1.61	300	5	0.7	0.65
175006	JD3S2	2	0 N	13	1.50	0.89	300	0 N	0.7	0.55
174925	JD3S2X	3	0 N	20	0.70	0.94	200	0 N	0.7	0.55
174979	JD4S1	3	70	15	1.50	1.89	300	3	1.0	2.18
174969	JD4S2	3	70	25	1.50	2.11	300	0 N	1.5	1.16
174951	JD4S2X	3	50	30	1.50	2.08	300	7	1.5	1.25
Soil south of Dave Johnston-continued										
175005	JE1S1	2	0 N	15	1.50	1.34	200	0 N	0.7	0.81
174964	JE1S2	3	0 L	15	0.50	1.04	300	7	0.7	0.80
174970	JE1S2X	3	0 L	15	0.50	1.02	200	0 N	0.7	0.80
174966	JE2S1	3	70	15	0.30	0.82	300	0 N	0.7	1.43
174938	JE2S2	3	50	20	1.00	0.90	200	0 N	1.0	1.40
174984	JE3S1	3	0 N	15	0.20	0.44	100	0 N	0.7	0.76
174999	JE3S2	2	0 L	20	0.20	0.46	100	0 N	0.5	0.61
174980	JE4S1	3	0 L	15	0.70	1.38	200	3	0.7	1.19
175015	JE4S2	3	50	23	1.50	1.72	300	0 N	0.7	0.76
175001	JE5S1	2	0 L	10	1.00	2.43	150	3	0.7	0.55
175016	JE5S2	3	50	19	1.50	1.36	700	0 N	1.5	1.15
175010	JE5S2X	3	0 N	21	1.00	1.36	300	0 N	1.0	1.20
174981	JE6S1	3	50	15	1.00	1.72	200	0 N	1.0	1.18
174963	JE6S2	3	50	20	1.50	1.30	300	5	2.0	2.00
174961	JE6S2X	3	50	20	1.50	1.30	300	3	1.5	1.86
Soil southwest of Dave Johnston-continued										
174926	JF1S1	7	70	30	1.50	0.53	300	0 N	3.0	1.33
174950	JF1S2	3	50	40	2.00	2.33	300	0 N	1.5	1.27
174967	JF2S1	3	50	20	0.70	1.01	300	0 N	1.0	1.42
Soil west of Dave Johnston-continued										
174977	JG1S1	3	0 L	10	0.30	0.68	150	5	0.7	1.35

Table 5.--Continued.

Lab. No.	SAMPLE	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Rb ppm	Sb ppm	Sc ppm	Se ppm	Si %
Soil east of Dave Johnston-continued										
174934	JC5S2	7	0 B	15	15	80	1.3	5	0.10L	10 G
174939	JC6S1	0 N	0 B	15	15	60	1.0L	5	0.14	10 G
174944	JC6S1X	7	0 B	20	15	60	1.0L	5	0.10L	10 G
174990	JC6S2	15	0 N	20	15	100	1.0	7	0.56	10 G
174959	JC6S2X	7	0 B	20	15	95	1.0L	7	0.11	10 G
174993	JC7S1	15	0 B	7	15	75	1.1	0 L	0.21	10 G
174962	JC7S2	0 N	0 B	7	15	105	1.0L	3	0.10L	10 G
Soil southeast of Dave Johnston-continued										
174948	JD1S1	15	0 N	15	15	85	1.0L	7	0.34	10 G
174972	JD1S2	20	0 L	15	20	95	1.0L	7	0.25	10 G
175020	JD2S1	20	0 N	30	30	100	1.0L	15	0.10L	10 G
174957	JD2S2	7	0 N	20	15	90	1.0L	10	0.10	10 G
174935	JD3S1	7	70	20	15	90	1.2	7	0.10L	10 G
175006	JD3S2	10	0 B	10	15	50	1.0L	5	0.21	10 G
174925	JD3S2X	7	0 B	15	15	60	1.0L	5	0.24	10 G
174979	JD4S1	15	70	30	15	95	1.0L	10	0.14	10 G
174969	JD4S2	20	70	20	20	100	1.0L	10	0.19	10 G
174951	JD4S2X	10	0 N	20	20	105	1.0L	10	0.26	10 G
Soil south of Dave Johnston-continued										
175005	JE1S1	10	0 B	10	15	70	1.0L	5	0.37	10 G
174964	JE1S2	20	0 N	15	15	70	1.0L	7	0.11	10 G
174970	JE1S2X	15	0 L	10	15	70	1.0L	0 L	0.10L	10 G
174966	JE2S1	15	70	10	30	75	1.0L	5	0.10L	10 G
174938	JE2S2	10	0 N	15	15	85	1.0L	7	0.16	10 G
174984	JE3S1	15	0 B	5	15	75	1.0L	0 L	0.17	10 G
174999	JE3S2	15	0 L	7	15	80	1.0L	0 L	0.30	10 G
174980	JE4S1	20	0 L	10	15	90	1.0L	7	0.10L	10 G
175015	JE4S2	20	0 N	20	20	80	1.0L	7	0.10L	10 G
175001	JE5S1	15	0 N	10	15	55	1.0L	0 L	0.34	10 G
175016	JE5S2	20	0 N	20	30	95	1.0L	10	0.26	10 G
175010	JE5S2X	10	0 B	15	20	100	1.0L	7	0.42	10 G
174981	JE6S1	15	0 L	15	15	75	1.0L	7	0.16	10 G
174963	JE6S2	10	0 N	15	20	110	1.0L	10	0.19	10 G
174961	JE6S2X	7	0 N	15	20	105	1.0L	10	0.18	10 G
Soil southwest of Dave Johnston-continued										
174926	JF1S1	7	0 N	15	20	110	1.0L	7	0.22	10 G
174950	JF1S2	7	0 N	15	20	110	1.0L	10	0.21	10 G
174967	JF2S1	15	70	15	20	100	1.0L	7	0.10L	10 G
Soil west of Dave Johnston-continued										
174977	JG1S1	15	0 N	7	15	70	1.0L	0 L	0.18	10 G

Table 5.--Continued.

LAB NO.	SAMPLE	Sn ppm	Sr ppm	Th ppm	Ti %	U ppm	V ppm	Y ppm	Yb ppm	Zn ppm
Soil east of Dave Johnston-continued										
174934	JC5S2	1.51	150	7.98	0.15	3.78	100	20	3.0	56
174939	JC6S1	0.61	70	11.21	0.15	1.67	50	10	1.5	35
174944	JC6S1X	0.33	70	8.11	0.10	1.85	70	15	1.5	33
174990	JC6S2	1.30	100	14.55	0.15	3.24	70	30	3.0	71
174959	JC6S2X	0.77	150	10.41	0.20	3.57	70	20	2.0	67
174993	JC7S1	1.21	70	7.26	0.15	2.38	50	20	3.0	43
174962	JC7S2	0.46	150	8.08	0.20	2.19	30	15	1.5	27
Soil southeast of Dave Johnston-continued										
174948	JD1S1	0.64	300	14.87	0.20	3.33	150	30	3.0	58
174972	JD1S2	1.24	300	11.70	0.15	4.35	100	30	3.0	70
175020	JD2S1	1.36	300	18.68	0.30	3.45	150	50	5.0	78
174957	JD2S2	0.92	150	9.10	0.20	3.24	70	30	3.0	67
174935	JD3S1	1.77	150	11.32	0.15	2.78	100	30	3.0	67
175006	JD3S2	0.16	150	15.87	0.15	1.32	70	20	3.0	47
174925	JD3S2X	0.83	150	10.70	0.15	3.21	70	20	3.0	50
174979	JD4S1	1.04	300	16.64	0.15	3.59	100	30	3.0	58
174969	JD4S2	1.29	300	13.85	0.30	4.13	70	30	3.0	76
174951	JD4S2X	0.97	500	19.26	0.20	3.99	100	30	3.0	78
Soil south of Dave Johnston-continued										
175005	JE1S1	0.86	150	16.93	0.15	1.17	70	20	3.0	57
174964	JE1S2	1.39	100	7.62	0.15	2.35	70	30	3.0	45
174970	JE1S2X	0.29	150	6.86	0.15	2.43	70	15	3.0	46
174966	JE2S1	0.70	200	7.27	0.15	2.73	70	30	3.0	48
174938	JE2S2	0.71	300	11.94	0.30	2.72	70	30	3.0	57
174984	JE3S1	1.37	100	8.78	0.07	2.73	50	20	2.0	37
174999	JE3S2	0.95	100	8.46	0.10	2.29	50	20	3.0	36
174980	JE4S1	0.62	150	19.22	0.15	3.81	70	30	5.0	63
175015	JE4S2	1.41	150	19.52	0.30	1.88	100	30	3.0	68
175001	JE5S1	0.41	150	9.14	0.07	2.12	70	15	1.5	46
175016	JE5S2	0.96	200	35.48	0.30	2.09	100	30	5.0	77
175010	JE5S2X	0.98	200	22.12	0.20	2.52	70	30	3.0	75
174981	JE6S1	0.70	200	16.86	0.15	2.95	70	30	3.0	55
174963	JE6S2	1.22	300	29.46	0.30	3.04	100	70	7.0	70
174961	JE6S2X	0.46	300	20.21	0.20	3.42	70	30	3.0	88
Soil southwest of Dave Johnston-continued										
174926	JF1S1	1.53	700	15.86	0.20	4.92	100	30	3.0	70
174950	JF1S2	1.20	700	11.12	0.20	9.25	100	30	3.0	83
174967	JF2S1	0.90	150	11.89	0.15	4.51	150	30	3.0	64
Soil west of Dave Johnston-continued										
174977	JG1S1	0.27	150	10.72	0.10	2.66	50	20	3.0	38

Table 5.--Continued.

Lab. No.	SAMPLE	Zr ppm-S
Soil east of Dave Johnston-continued		
174934	JC5S2	200
174939	JC6S1	70
174944	JC6S1X	50
174990	JC6S2	100
174959	JC6S2X	150
174993	JC7S1	150
174962	JC7S2	70
Soil southeast of Dave Johnston-continued		
174948	JD1S1	200
174972	JD1S2	150
175020	JD2S1	150
174957	JD2S2	100
174935	JD3S1	100
175006	JD3S2	100
174925	JD3S2X	150
174979	JD4S1	200
174969	JD4S2	150
174951	JD4S2X	150
Soil south of Dave Johnston-continued		
175005	JE1S1	150
174964	JE1S2	200
174970	JE1S2X	150
174966	JE2S1	300
174938	JE2S2	150
174984	JE3S1	70
174999	JE3S2	70
174980	JE4S1	200
175015	JE4S2	300
175001	JE5S1	70
175016	JE5S2	300
175010	JE5S2X	200
174981	JE6S1	100
174963	JE6S2	150
174961	JE6S2X	150
Soil southwest of Dave Johnston-continued		
174926	JF1S1	150
174950	JF1S2	150
174967	JF2S1	200
Soil west of Dave Johnston-continued		
174977	JG1S1	200

Table 5.--Continued.

Lab. No.	SAMPLE	Latitude	Longitud	Dist. Km	Al %	As ppm	B ppm	Ba ppm S	Be ppm	Total C%
Soil west of Dave Johnston-continued										
174996	JG1S2	42 50 22N	105 47 09W	1	7	6.1	0 L	1000	2.0	0.23
174933	JG1S2X	42 50 22N	105 47 09W	1	10	2.3	0 N	1500	1.5	0.23
174932	JG2S1	42 50 15N	105 47 50W	2	10	6.5	30	1000	0.0N	0.55
174930	JG2S2	42 50 15N	105 47 50W	2	10	2.2	0 N	1500	0.0N	0.10
174974	JG3S1	42 50 15N	105 49 18W	4	5	3.5	20	700	3.0	0.51
174973	JG3S2	42 50 15N	105 49 18W	4	7	5.5	20	700	3.0	1.27
174968	JG4S1	42 50 05N	105 52 01W	8	7	5.6	30	700	3.0	0.67
175012	JG4S2	42 50 05N	105 52 01W	8	10 G	7.1	50	1000	2.0	0.85
175011	JG5S1	42 50 31N	105 58 39W	16	10 G	5.2	70	1000	3.0	1.93
174971	JG5S2	42 50 31N	105 58 39W	16	10	9.6	50	500	3.0	2.10
174924	JG6S1	42 50 40N	106 10 26W	32	7	3.6	20	1000	1.5	0.39
174955	JG6S2	42 50 40N	106 10 26W	32	5	3.0	20	700	0.0N	0.50
174928	JG6S2X	42 50 40N	106 10 26W	32	7	2.4	20	1000	2.0	0.38
Soil northwest of Dave Johnston										
175003	JH1S1	42 54 07N	105 49 41W	8	5	3.0	15	1000	0.0N	0.58
174945	JH1S2	42 54 07N	105 49 41W	8	7	3.9	20	1000	0.0N	0.45
174991	JH2S1	42 56 09N	105 54 25W	16	5	2.4	0 L	700	0.0N	0.24
175002	JH2S2	42 56 09N	105 54 25W	16	5	2.5	0 L	1000	0.0N	0.10
174936	JH3S1	43 00 50N	106 03 45W	32	7	4.1	0 N	1000	0.0N	0.28
174943	JH3S1X	43 00 50N	106 03 45W	32	7	1.9	0 N	1500	0.0N	0.21
175007	JH3S2	43 00 50N	106 03 45W	32	5	2.1	10	1000	0.0N	0.19

Table 5.--Continued.

Lab. No.	SAMPLE	Ca %	Co ppm	Cr ppm	Cu ppm	F %	Fe %	Ga ppm	Ge ppm	Hg ppm
				Soil west of Dave Johnston-continued						
174996	JG1S2	0.7	7	30	7	0.04L	3.0	15	1.22	0.03
174933	JG1S2X	0.7	7	50	7	0.04L	5.0	20	0.71	0.01
174932	JG2S1	0.7	5	50	10	0.04L	2.0	20	0.82	0.02
174930	JG2S2	0.5	0 L	7	3	0.04L	0.7	15	0.92	0.01
174974	JG3S1	0.7	5	30	7	0.04L	0.7	15	1.22	0.03
174973	JG3S2	3.0	7	30	15	0.04L	1.5	15	1.17	0.03
174968	JG4S1	0.7	10	30	10	0.04	1.5	15	0.89	0.02
175012	JG4S2	3.0	10	70	15	0.04L	5.0	30	1.38	0.02
175011	JG5S1	1.5	10	100	30	0.07	5.0	30	1.45	0.05
174971	JG5S2	1.0	7	70	30	0.07	3.0	30	1.48	0.05
174924	JG6S1	0.7	7	50	7	0.04L	2.0	20	0.86	0.02
174955	JG6S2	0.7	3	30	7	0.04L	2.0	15	1.19	0.01
174928	JG6S2X	0.7	5	30	7	0.04L	3.0	15	0.63	0.01
				Soil northwest of Dave Johnston-continued						
175008	JH1S1	0.7	3	30	7	0.04L	1.0	15	1.06	0.02
174945	JH1S2	0.7	5	30	7	0.04L	1.5	15	1.21	0.02
174991	JH2S1	0.7	0 L	10	3	0.04L	0.7	15	1.11	0.01
175002	JH2S2	0.5	0 N	7	2	0.04L	0.7	15	1.26	0.01
174936	JH3S1	0.5	0 N	15	7	0.04L	1.0	15	1.06	0.01
174943	JH3S1X	0.5	0 N	15	5	0.04L	1.0	15	0.76	0.02
175007	JH3S2	0.7	0 N	15	5	0.04L	0.7	15	0.76	0.02

Table 5.--Continued.

Lab. No.	SAMPLE	K %	La ppm	Li ppm	Mg %	MgO %	Mn ppm	Mo ppm	Na %	Na2O %
Soil west of Dave Johnston-continued										
174996	JG1S2	3	300	5	0.20	0.42	700	0 N	1.5	1.79
174933	JG1S2X	3	150	5	0.50	0.44	700	5	2.0	1.93
174932	JG2S1	3	0 N	15	0.70	0.70	200	0 N	1.5	1.58
174930	JG2S2	5	0 N	5 L	0.20	0.21	150	0 N	2.0	2.10
174974	JG3S1	3	70	15	0.30	0.76	300	3	0.7	1.48
174973	JG3S2	3	0 L	15	0.70	1.08	300	0 N	0.7	1.18
174968	JG4S1	3	70	15	0.70	0.99	300	0 N	0.7	1.58
175012	JG4S2	3	30	21	2.00	2.01	300	0 N	3.0	1.93
175011	JG5S1	3	50	38	1.50	1.94	300	0 N	1.0	0.86
174971	JG5S2	3	50	40	1.00	2.06	300	0 N	0.7	0.83
174924	JG6S1	3	70	15	0.70	0.80	200	0 N	1.0	1.55
174955	JG6S2	3	0 N	15	0.50	0.72	150	0 N	0.7	1.47
174928	JG6S2X	3	50	15	0.70	0.71	300	0 N	1.0	1.45
Soil northwest of Dave Johnston-continued										
175008	JH1S1	3	0 N	9	0.30	0.44	200	0 N	1.0	1.31
174945	JH1S2	3	0 N	10	0.30	0.42	150	0 N	1.0	1.42
174991	JH2S1	3	0 N	5 L	0.15	0.24	100	0 N	1.0	1.73
175002	JH2S2	3	0 N	5 L	0.10	0.20	150	0 N	1.5	1.83
174936	JH3S1	3	0 N	5	0.30	0.28	150	0 N	2.0	1.60
174943	JH3S1X	3	0 N	5	0.20	0.26	150	0 N	2.0	1.61
175007	JH3S2	3	0 N	5	0.30	0.24	150	0 N	1.5	1.55

Table 5.--Continued.

Lab. No.	SAMPLE	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Rb ppm	Sb ppm	Sc ppm	Se ppm	Si %
Soil west of Dave Johnston-continued										
174996	JG1S2	15	150	7	20	75	1.0L	5	0.46	10 G
174933	JG1S2X	15	70	15	50	90	1.0L	3	0.11	10 G
174932	JG2S1	7	0 B	15	15	90	1.0L	3	0.34	10 G
174930	JG2S2	0 N	0 B	3	15	105	1.0L	0 N	0.10L	10 G
174974	JG3S1	15	0 L	15	15	75	1.0L	5	0.10L	10 G
174973	JG3S2	20	70	15	15	70	1.0L	5	0.10L	10 G
174968	JG4S1	15	70	15	15	80	1.0L	5	0.15	10 G
175012	JG4S2	15	0 N	20	30	85	1.0L	15	0.11	10 G
175011	JG5S1	10	0 N	20	30	120	1.0L	10	0.22	10 G
174971	JG5S2	20	70	20	20	115	1.0L	15	0.37	10 G
174924	JG6S1	7	0 N	10	15	75	1.0L	7	0.31	10 G
174955	JG6S2	7	0 B	7	10	70	1.0L	3	0.10L	10 G
174928	JG6S2X	7	0 N	10	15	75	1.0L	5	0.10L	10 G
Soil northwest of Dave Johnston-continued										
175008	JH1S1	10	0 B	5	15	65	1.0L	3	0.14	10 G
174945	JH1S2	7	0 B	7	15	80	1.0L	5	0.19	10 G
174991	JH2S1	0 L	0 B	0 L	15	90	1.0L	0 L	0.31	10 G
175002	JH2S2	0 N	0 B	0 L	15	85	1.0	0 N	0.40	10 G
174936	JH3S1	0 N	0 B	3	15	85	1.0L	0 N	0.10L	10 G
174943	JH3S1X	0 N	0 B	3	15	90	1.0L	0 N	0.10L	10 G
175007	JH3S2	7	0 B	3	15	70	1.0L	0 N	0.19	10 G

Table 5.--Continued.

Lab. No.	SAMPLE	Sn ppm	Sr ppm	Th ppm	Ti %	U ppm	V ppm	Y ppm	Yb ppm	Zn ppm
Soil west of Dave Johnston-continued										
174996	JG1S2	1.13	150	110.00	0.20	5.65	70	30	3.0	37
174933	JG1S2X	0.36	300	86.87	0.30	5.59	100	70	7.0	30
174932	JG2S1	1.20	200	11.28	0.15	2.28	70	20	3.0	42
174930	JG2S2	0.84	300	5.20	0.03	1.74	20	0 N	1.0	15
174974	JG3S1	1.05	150	6.52	0.15	3.19	70	30	3.0	45
174973	JG3S2	0.92	150	9.60	0.20	2.99	70	30	3.0	49
174968	JG4S1	1.59	200	11.81	0.15	2.58	70	30	3.0	53
175012	JG4S2	0.99	300	12.57	0.30	1.97	150	30	3.0	75
175011	JG5S1	1.07	200	16.14	0.20	2.55	150	30	3.0	108
174971	JG5S2	1.52	150	8.11	0.15	3.96	150	30	3.0	103
174924	JG6S1	0.86	300	5.32	0.20	2.70	70	50	5.0	50
174955	JG6S2	0.59	200	8.93	0.15	2.51	50	15	2.0	44
174928	JG6S2X	0.43	300	9.93	0.30	2.63	70	20	3.0	45
Soil northwest of Dave Johnston-continued										
175008	JH1S1	0.21	200	12.80	0.15	1.34	30	15	2.0	39
174945	JH1S2	0.60	300	7.55	0.15	2.24	50	15	2.0	30
174991	JH2S1	0.22	150	4.65	0.10	1.38	30	10	1.5	21
175002	JH2S2	0.70	150	5.61	0.03	1.23	15	10	1.5	16
174936	JH3S1	1.16	300	4.98	0.07	1.36	30	15	1.5	23
174943	JH3S1X	0.10L	200	2.54	0.05	1.48	30	10	1.0	19
175007	JH3S2	0.10L	200	7.77	0.07	0.85	20	15	2.0	25

Table 5.--Continued.

Lab. No.	SAMPLE	Zr ppm
Soil west of Dave Johnston-continued		
174996	JG1S2	100
174933	JG1S2X	150
174932	JG2S1	100
174930	JG2S2	50
174974	JG3S1	200
174973	JG3S2	300
174963	JG4S1	200
175012	JG4S2	150
175011	JG5S1	100
174971	JG5S2	100
174924	JG6S1	300
174955	JG6S2	100
174928	JG6S2X	500
Soil northwest of Dave Johnston-continued		
175008	JH1S1	150
174945	JH1S2	200
174991	JH2S1	100
175002	JH2S2	50
174936	JH3S1	100
174943	JH3S1X	50
175007	JH3S2	70

Table 6.--Percent of total observed logarithmic variation in silver sagebrush (Artemisia cana) and soil accounted for in terms of logarithmic distance from the Dave Johnston Powerplant

[A, sagebrush ash; DW, sagebrush dry weight; S, soil (5-20 cm depth); percentage indicates a decrease in concentration with distance unless it is in parentheses, when it indicates an increase in concentration with distance; blank, distance-related variation is not significant at the 0.05 probability level; elements ending in "-S" were determined by semiquantitative emission spectroscopy]

Constituent	Direction of sampling traverse																	
	North			Northeast			East			Southeast			South			West		
	A	DW	S	A	DW	S	A	DW	S	A	DW	S	A	DW	S	A	DW	S
Al - S	34		(44)				71	77		33	36					76	83	
As1/			(48)			(49)		43									71	
Ash1/								61									33	
B - S	62	50										45			32			
Ba - S												53					33	
Total C															(42)			
Ca	(30)						(44)										32	
Cd										36								
Co				(37)			39	50									31	
Co - S			(63)			(58)												
Cr - S	47	37	(50)			(37)	80	83		48	45					74	86	(31)
Cu - S			(36)					34							(47)			
F1/		30						82							(37)		93	
Fe - S			(52)			(31)	63	70			34					69	76	
Ga - S			(55)				66	69								80	88	
Ge						(58)												
Hg1/					43	(42)											32	
K							(42)	37								37		
Li	61	57					87	89									30	(42)
Mg - S			(60)	44	47	(31)				33	44							(38)
MgO			(52)															(30)
Mn - S								32										
Mo - S	44	36								33	37							
Na	32			(65)	(71)		31	51								36	41	
Na - S						60									(32)			
Na_2O			51			52												
Ni - S	49	39	(47)			(36)							(40)	(33)			30	
P - S	53	45						35		45	45							
P	40	31																
Pb - S	45	33					38	51					31	30				
S1/								55										
Sb1/		65						43						45			31	
Sc - S			(58)			(42)	85	84								77	94	
Se1/						(37)								63				
Si							75	74		40	49					52	63	
Sn						(57)			(41)									
Sr - S				(36)		65			35							(44)		
Th															(34)			
Ti - S	55	46	(78)			(73)	87	86		49	49					71	82	
U	55	50				(30)	73	81		57	56		52	42		88	90	
V - S	56	48	(53)				89	88		51	51					76	85	
Y - S						(58)	75	75									47	
Yb - S			(35)			(63)	45	57									46	
Zn			(35)	(48)	(25)								38	35		32	51	(31)
Zr - S						(48)	57	66		38	40					66	71	

1/ Plant material determined on dry weight.

Linear regression of log concentration in sagebrush (dry weight) on distance demonstrates statistically significant reduction in concentration with distance for 33 elements. Twenty-four of these occur along the E traverse. The W traverse shows 24 significant elements also, but differs from the E in that Cu, K, Mn, P, Pb and S are not significant and Ba, Ca, Hg, Ni, and Zn are. The dominant wind direction is out of the west and southwest, but winds from the east or northeast are not unusual. At the time of sampling, a large pile of flyash was located just east of the powerplant and it is probable that the wind blowing material from the ash pile can account for most of the close-in increase in element concentrations to the E, SE, and W. The elements Si, Al, Mg, and Fe compose most of the flyash with As, Sb, Cr, Pb, Ni, Se, Ti, Zn, and Cd among the other elements that are enriched (Swanson, 1972; also see table 11, this report). Ti and Si (figs. 5 and 6) exhibit statistically significant decreases along the E, SE, and W traverses. Both these elements have been associated with soil-dust contamination in other studies (U.S. Geol. Survey, 1976, p.37- 47). Ti is also significant along the N traverse (fig. 5), along with 12 other elements.

Hg and Mg are significant on the NE traverse. Se was listed as a very likely pollutant along a southeast traverse in the earlier study (Connor, Keith, and Anderson, 1976) but in this work, the S traverse is the only one along which Se was found to decrease in a statistically significant manner. The difference in plant species or time of collection (spring vs. fall) may account for this change. A detailed evaluation of the probable source for these and other elements found to be elevated in vegetation east of the powerplant is given on p. 65-76 of this report.

Statistically significant positive trends (an increase in concentration with distance) were found for seven elements in ash or dry weight of sagebrush. Ca was significant along the E and N traverses. Four elements (Co, Sr, Na and Zn) were significant along the NE traverse. Because element concentrations in vegetation along this traverse tend to increase at about the third sampling locality (32 km northeast of the powerplant), and because the strip mine which feeds the powerplant is located 24 km north of the powerplant, dust contamination from the mining activities might be responsible (the dominant wind direction is from the west). Ni along the S traverse and Sr along the W traverse both increase with distance, largely because of relatively high concentrations in the last one or two sampling localities; this may reflect a local geologic or substrate control.

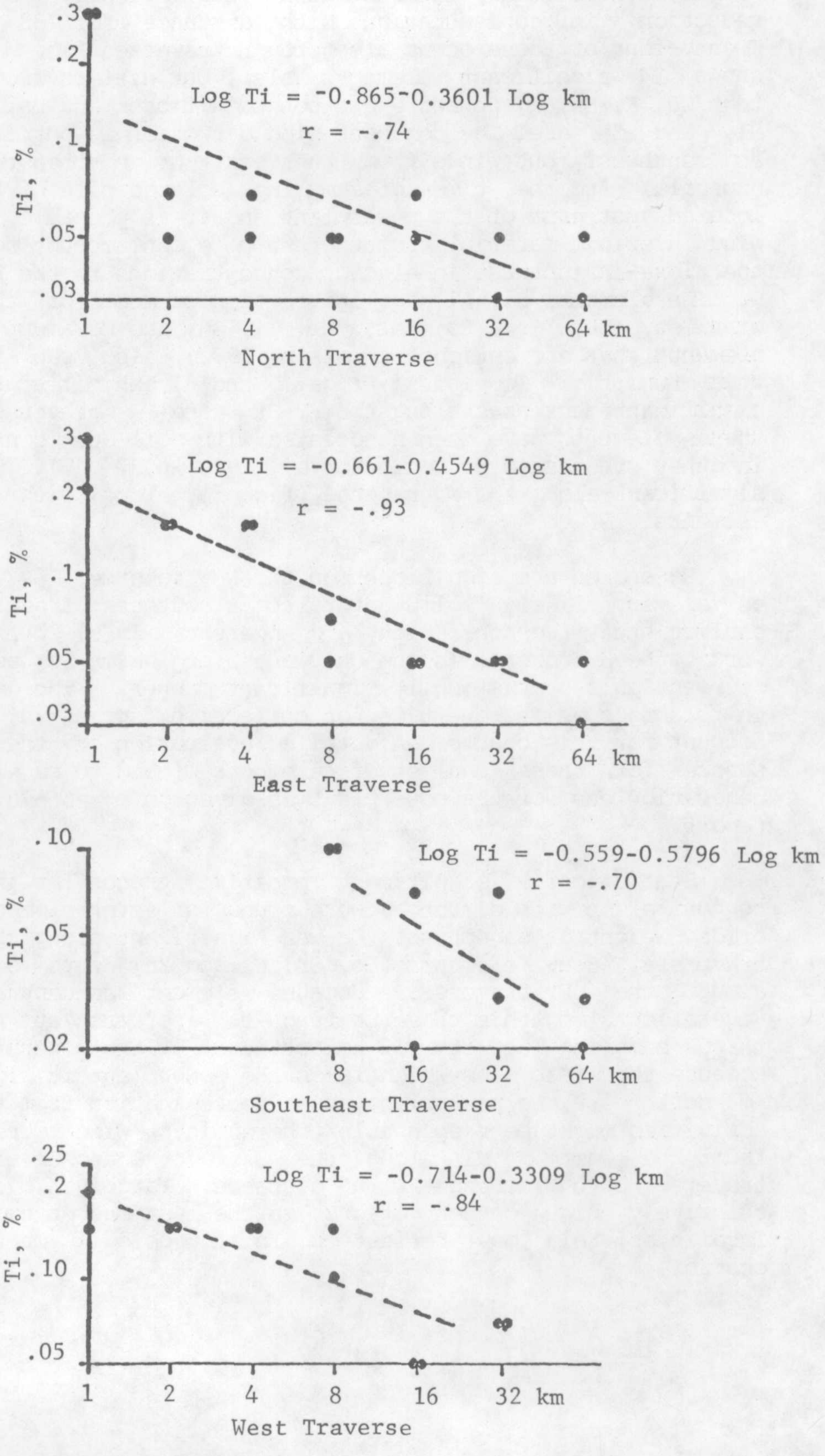

Figure 5.--Titanium in ash of sagebrush near the Dave Johnston Powerplant, Wyoming.

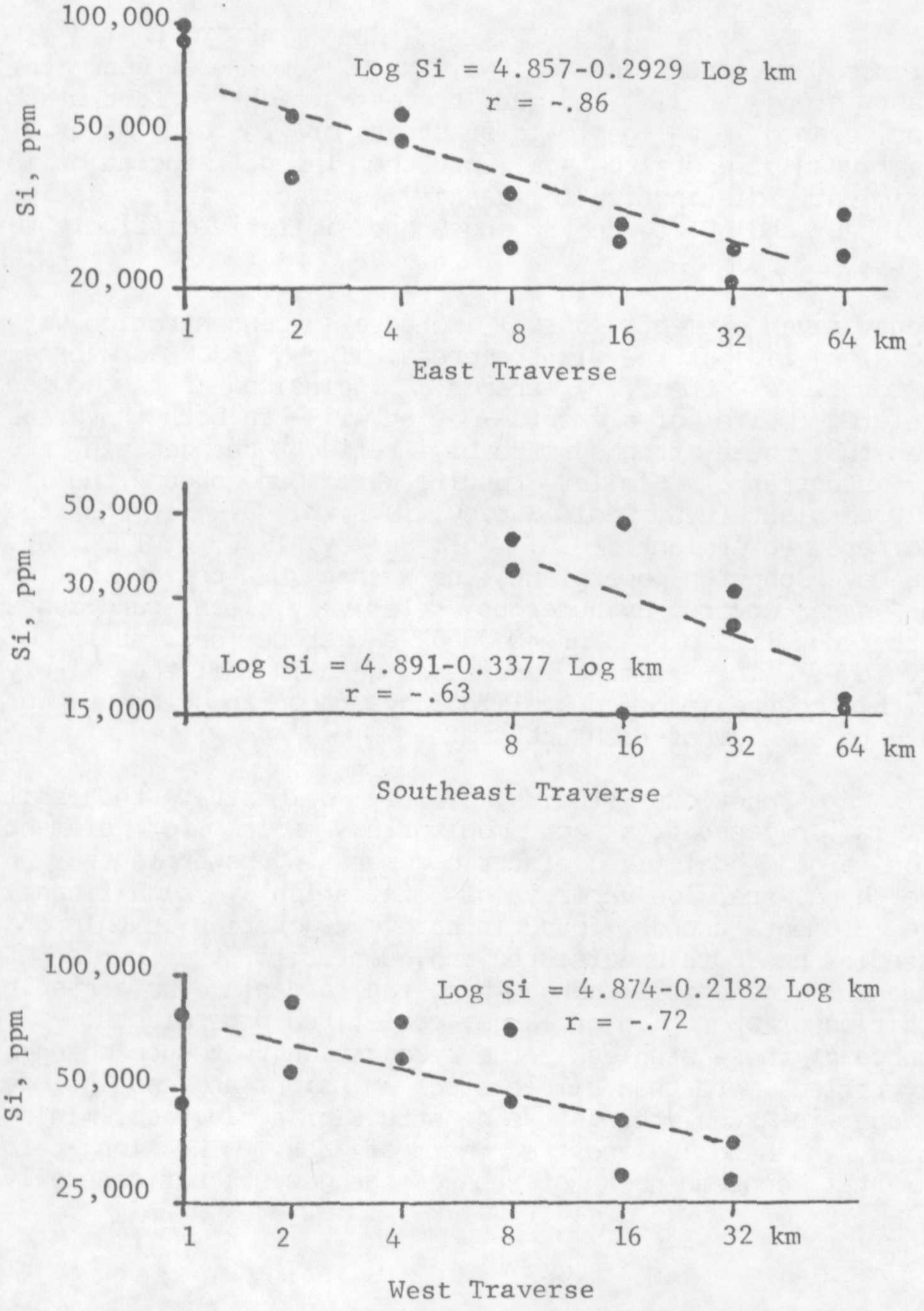

Figure 6.--Silicon in ash of sagebrush near the Dave Johnston Powerplant, Wyoming.

The elements with statistically significant negative trends in the soil material are:

Element	Traverse
B	SE, S
Ba	SE
Mo	N
Na	NE
Na_2O	N, NE
Sr	NE

The increased concentrations of Na, Na_2O, and Sc near the powerplant along the N and NE traverses might reflect stack emissions, change in the geologic substrate or windborne material from the flyash pile or from soil, but the element association is not sufficiently distinctive to identify source. The negative trends in B and Ba to the SE and S are similarly difficult to interpret.

Twenty-seven elements in soil increase in concentration with distance along five of the six traverses. The N and NE traverses account for 22 of these 27 trends. Inclusion of a common shale-related suite of elements--Ga, Sc, Ti-- in both traverses indicates that these trends probably reflect changes in the geologic substrate. Similar results were found around the Jim Bridger Powerplant (U.S. Geol. Survey, 1976, p. 37-47) and the Four Corners Powerplant (U.S. Geol. Survey, 1976, p. 112-120). Near the Dave Johnston powerplant, the N and NE traverses lie over an area covered by numerous, relatively clean, sand dunes and farther out lie over interbedded sandstone and shale of Tertiary age. The element increases seen in soil thus likely reflect this change in bedrock lithology from an element-poor substrate to an element-rich substrate.

This and previous studies clearly demonstrate that soil material is, in general, a poor monitoring medium for element pollution around coal-fired electric generating powerplants. On the other hand, the wide variety of statistically significant, negative element trends found in native vegetation in this and other studies has both underscored and quantified the kinds of environmental geochemical change which can take place as a result of the siting or operation of large, coal-fired powerplants. One consequence of these studies is the recognition that such changes commonly reflect more than simple stack emissions and can include change due to such things as construction activities, mining activities, and handling and treatment of ash. The long-term environmental consequences of these changes are not generally known.

CHEMICAL VARIATION IN ALLUVIAL SOILS OF THE OIL SHALE REGION

By Ronald R. Tidball and Ronald C. Severson

Introduction

A reconnaissance geochemical survey of alluvial soils has been completed in the Uinta and Piceance Creek Basins of Utah and Colorado, respectively. This region has been a focal point of interest for energy-resource development. This study was initiated simultaneously with, but independently of, two other studies in parts of the same region. One study by the Colorado School of Mines in the Piceance Creek Basin (U. S. Geological Survey, 1976, p.101-111) compared soils in valleys with those on ridge tops. They concluded there were no significant differences in the composition of soils from these two contrasting topographic positions. This is a particularly helpful conclusion because it implies that any sampling efforts in this deeply dissected area may be based on relatively uncomplicated sample designs. The second study (U. S. Geological Survey, 1976, p. 121-130) was based on stream-sediment sampling in several stream courses in both the Uinta and Piceance Creek Basins. No significant differences between basins were found. A number of elements exhibited significant differences between streams.

The objective of the present study is to measure the variance in the total composition of alluvial soils of selected watersheds within both the Uinta and Piceance Creek Basins. We determine whether there are significant differences between watersheds and whether samples from one part of a watershed will differ from those of another part.

Sampling design

Watersheds (WS) and stream-valley (SV) systems were identified as they appear on the 1:250,000 scale topographic maps (Army Map Service, 1964, 1973a, 1973b) in the area of northwestern Colorado and northeastern Utah. SV orders are designated as follows: 1st order is at the headwater, 2nd order is the merging of 2 or more 1st-order SV, and 3rd order is the merging of 2 or more 2nd-order SV. The average lengths of SV sampled were, as follows: 1st order, 9km; 2nd order, 15km; and 3rd order, 27km.

A 2-way factorial design (WSxSV) of randomized-blocks type with replication in each block was used. We randomly selected five of the 15 WS that lie predominantly within the bounds of the Uinta or Piceance Creek Basins (see figure 7). Within each WS we randomly selected two SV each of 1st, 2nd, and 3rd orders, respectively. The lower orders were not necessarily nested within the higher orders. The sampling locality, which was defined as a segment of valley extending 250m along the stream and 50m on either side, was randomly selected along the length of the SV. Each sampling locality is represented by one sample; a channel sample of the soil material from a depth of 0-40cm. The samples are designated in table 7 as X_{A11}, X_{A12}, etc. The physiographic types represented within the locality were either the floodplain or the first terrace. The soils are, therefore, all developed on recent alluvium with varying amounts of colluvium particularly in the narrow, upper parts of the valleys.

The soil material that passed a 2-mm stainless steel screen was analyzed in laboratories of the U. S. Geological Survey in Denver for total concentrations of 60 elements using methods described in U.S.Geological Survey (1975, p. 69-73, 79-81; 1976, p. 131-132). Of these elements only 23 exhibited concentrations in one or more samples within the limits of determination of the method and had an analytical error variance that was less than 50 percent of the total. Elements that were rejected because of excess censoring or error included Ag, Ba, Ce, Hg, La, Mn, Nb, and Sn.

The analytical error was estimated from duplicate analyses on splits of 15 samples. The splits and the samples were analyzed in a randomized sequence. All analytical data were transformed to logarithms because the frequency distributions are more nearly normal on a log scale.

The randomized-blocks design (Bennett and Franklin, 1954, p. 368ff; Snedecor and Cochran, 1967, p. 299ff) was used to test the effects of each factor and their interaction. Interaction between the two factors can be estimated because of the replication in each block. The sample design and analysis-of-variance are given in table 7. The test ratios are shown for the test of differences between WS and the test of differences between SV orders. The interaction was nonsignificant for all of the elements tested: therefore, it was pooled with the error term. The WS mean square was tested against the pooled error. The SV orders were tested against a reconstructed error term that includes a finite population-correction factor (Bennett and Franklin, 1954, p. 373).

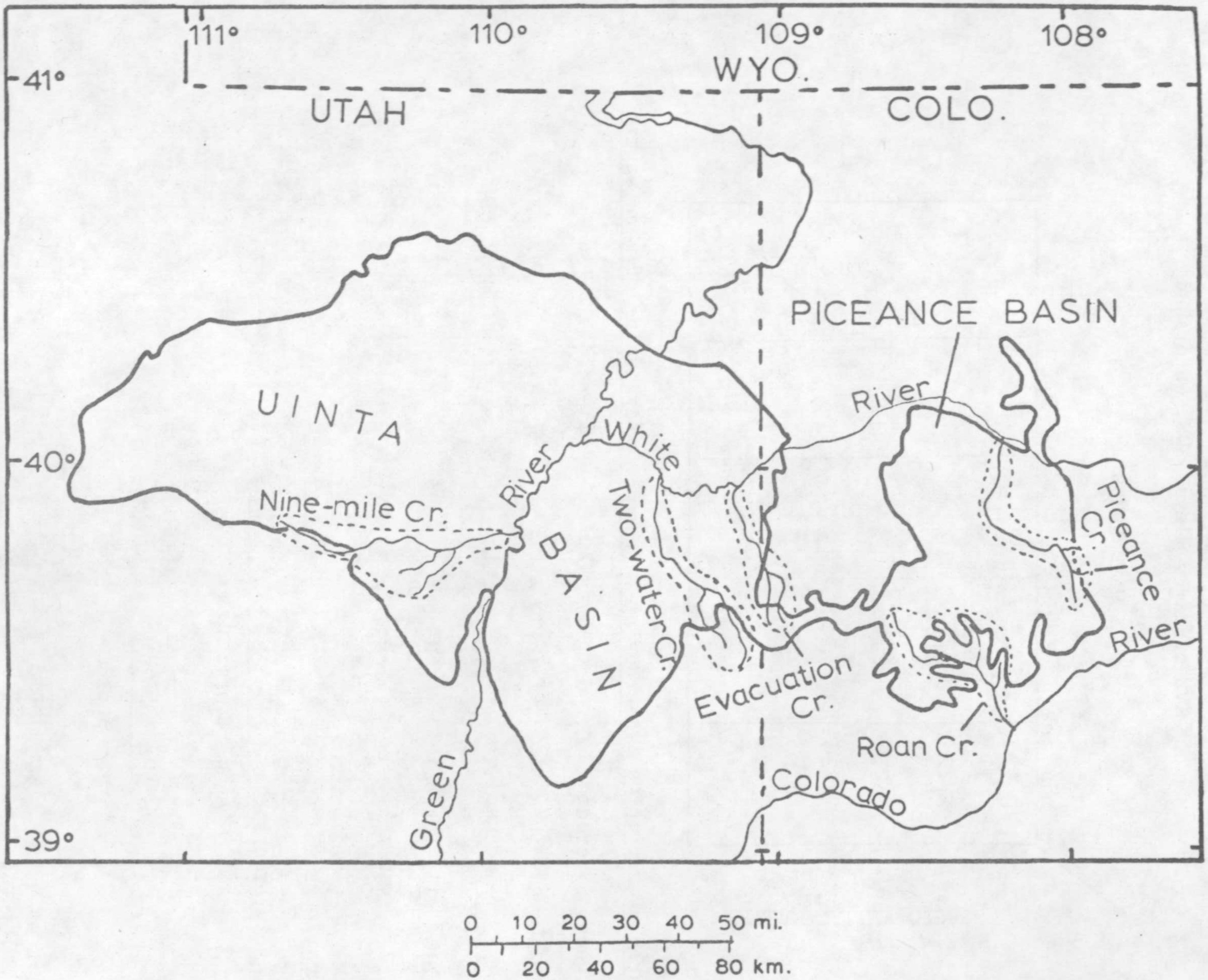

Figure 7. Third-order watersheds outlined by dotted lines in the Piceance Creek and Uinta Basins in which alluvial soils were sampled. (From Oetking, Feray, and Renfro, 1967),

Table 7.--Two-way analysis of variance scheme used in sampling alluvial soils in the Piceance and Uinta Basins

[SV, stream valleys. WS, watershed]

WATERSHEDS

STREAM-VALLEY ORDERS	A	B	C	D	E
1	X_{A11} X_{A12}	X_{B11} X_{B12}	. . .		
2	X_{A21} X_{A22}				
3	. . .				X_{E31} X_{E32}

Source of variation	Degrees of freedom	Average value of mean square
Between SV orders	$(p-1) = 2$	$\sigma^2 + n(1-\frac{q}{Q})\sigma_\lambda{}^2 + nq\sigma_\varepsilon{}^2$
Between WS	$(q-1) = 4$	$\sigma^2 + np\sigma_\eta{}^2$
Interaction	$(p-1)(q-1) = 8$	$\sigma^2 + n\sigma_\lambda{}^2$
Within cells (error)	$N-pq = 15$	σ^2
Total	$N-1 = 29$	

Tests:

SV orders: $$\frac{\sigma^2 + n(1-\frac{q}{Q})\sigma_\lambda{}^2 + nq\sigma_\varepsilon{}^2}{\sigma^2 + n(1-\frac{q}{Q})\sigma_\lambda{}^2} = F(2,5,.05) > 5.79$$

WS: $$\frac{\sigma^2 + np\sigma_\eta{}^2}{\sigma^2 \text{ pooled}} = F(4,23,.05) > 2.80$$

Interaction: $$\frac{\sigma^2 + n\sigma_\lambda{}^2}{\sigma^2} = F(8,15,.05) > 2.64$$

$P = p = 3$; $q = 5$; $Q = 15$; $n = 2$; $N = 30$

Table 8.--Methods of analysis, variance components, and estimates of n_r, E_r, and E_s for alluvial soils of the Piceance and Uinta Basins

[Methods of analysis: S, semiquantitative spectrograph; XRF, X-ray fluorescence; IF, induction furnace; SIE, specific-ion electrode; AA, atomic absorption; NA, neutron activation. WS, watersheds. SV, stream valleys. n_r, number of random samples required in each WS. E_r, maximum acceptable variance of the mean within WS. E_s, observed variance of the mean within WS. Asterisks, significance (*) at .05 and (**) .01 probability levels. Leadered entries (--), no calculation made because of zero variance component for WS]

		Percentage variance components							
Element	Method of analysis	WS	SV-order	Interaction	Within cell	Analytical error	n_r	E_r	E_s
Al--------	S	12.7	0	1.35	68.5	17.4	21	4.15	14.6
As--------	XRF	10.9	0	38.2	46.0	4.96	25	3.57	14.9
Be--------	S	19.4	0	13.8	33.3	33.4	37	2.18	13.4
C---------	IF	4.04	0	6.42	88.5	1.02	>60	<1.60	16.0
Ca--------	S	36.2**	6.44	0	19.8	37.5	7	8.18	9.56
Co--------	S	27.0*	0	0	53.7	19.3	9	8.11	12.2
Cr--------	S	33.0**	0	0	58.3	8.70	>60	<1.12	11.2
Cu--------	S	0	0	15.4	49.8	34.8	--	--	--
F---------	SIE	7.54	0	0	90.0	2.44	>60	<1.54	15.4
Fe--------	S	33.0*	0	9.43	42.3	15.3	8	8.38	11.2
Ga--------	S	20.7*	0	0	72.2	7.01	13	6.10	13.2
Ge--------	XRF	6.20	0	0	67.0	26.8	>60	<1.56	15.6
Li--------	AA	19.5	0	0	80.0	.531	14	5.75	13.4
Mg--------	AA	10.5	0	0	89.5	.069	27	3.32	14.9
Mo--------	S	2.02	1.55	0	69.2	27.3	>60	<1.61	16.1
Na--------	AA	32.8**	6.54	9.45	50.7	.541	8	7.58	10.1
Ni--------	S	33.1**	10.1	0	33.4	23.5	8	7.11	9.48
Pb--------	S	17.9	0	24.6	44.4	13.2	15	5.47	13.7
Rb--------	AA	26.0*	0	0	70.3	3.78	10	7.40	12.3
Th--------	NA	5.23	2.92	0	70.8	21.0	>60	<1.53	15.3
Ti--------	S	20.9*	0	0	64.7	14.4	13	6.09	13.2
U---------	NA	0	0	0	76.5	23.5	--	--	--
Zn--------	AA	15.0*	0	0	84.0	.966	18	4.72	14.2

Table 9.--Summary statistics for elements in alluvial soils with significant differences between watersheds in the Piceance and Uinta Basins

[Geometric means given in parts per million except as noted percent. Geometric deviation is a pooled estimater over all watersheds that excludes analytical error. Number in parentheses: (1) Nine-mile Creek, Uinta; (2) Two-water Creek, Uinta; (3) Evacuation Creek, Uinta; (4) Roan Creek, Piceance; (5) Piceance Creek, Piceance. Underscore, significant groups of means by Duncan's test]

Element	Geometric deviation	Geometric error	Ranked geometric means				
Ca, percent--	2.08	2.33	(3) 1.3	(5) 3.1	(2) 8.5	(4) 8.9	(1) 12.8
Co-----------	1.25	1.14	(3) 6.0	(1) 6.2	(2) 7.2	(5) 8.7	(4) 9.1
Cr-----------	1.39	1.14	(3) 35	(1) 44	(2) 45	(4) 58	(5) 75
Fe, percent--	1.24	1.11	(1) 1.9	(2) 2.0	(3) 2.3	(4) 2.8	(5) 2.8
Ga-----------	1.39	1.11	(3) 11	(1) 14	(2) 16	(4) 17	(5) 20
Na-----------	1.57	1.04	(3) .51	(4) 1.0	(2) 1.1	(1) 1.1	(5) 1.2
Ni-----------	1.27	1.19	(2) 16	(3) 17	(1) 18	(4) 26	(5) 26
Rb-----------	1.21	1.05	(3) 71	(1) 78	(2) 92	(4) 92	(5) 102
Ti, percent--	1.26	1.12	(3) .29	(1) .29	(2) .37	(5) .40	(4) .40
Zn-----------	1.37	1.03	(1) 55	(2) 55	(3) 60	(5) 79	(4) 80

Results

Tests for significance in the analysis of variance show that no significant interactions (at 0.05 probability level) are present in the data (see table 8). Also there are no significant differences between SV orders for any of the elements measured. Significant differences (at the 0.05 probablity level) were found between WS for Co, Fe, Ga, Rb, Ti, and Zn at the 0.05 probability level and Ca, Cr, Na, and Ni at the 0.01 probability level.

These results indicate that for a given element there is a real difference at least between the WS with the lowest and the highest means, respectively. Differences between other means were tested by Duncan's test (Duncan, 1955); these differences are shown in table 9. The WS means, each expressed as a geometric mean, are arranged in ascending order and groups of means within which there are no significant differences at the 0.05 probability level are underscored. As a generalization means for WS 1, 2, and 3 (Nine-mile Creek, Two-water Creek, and Evacuation Creek) tend to be on the low end of the range for most elements. Means for 4 and 5 (Roan Creek and Piceance Creek) tend to be on the high end of the range.

Are the individual means as estimated from the present data sufficiently stable (reproducible) to describe the differences in element concentration between the 5 WS? If not, then how many samples will be required to estimate a stable mean? Answers to these questions are based on calculations described by Miesch (1976a).

The threshold measure of stability is expressed by E_r, the maximum acceptable variance of the mean within a WS. The observed variance of the mean within a WS, E_s, is estimated from the variance components given in table 8, and will exceed the maximum accpetable variance if the number of samples is too small. Accordingly, the threshold of stability is defined by the inequality, $E_s \leqslant E_r$. The calculation of E_s is as follows:

$$E_s = \frac{K_i + K_e}{n_{sv} \cdot n_e} + \frac{K_a}{n_{sv} \cdot n_e \cdot n_a}$$

where K_i is the percentage variance component for interaction, K_e is the percentage variance component for within-cell error, and K_a is the percentage variance component for analytical error. The n's are the number of items that contribute to the estimate of the respective variance components.

When the appropriate values of the n's are used, the equation reduces to:

$$E_s = \frac{K_i + K_e + K_a}{6}$$

The value of E_r is calculated as:

$$E_r = \frac{K_{sv} + K_i + K_e + K_a}{n_r}$$

where n_r is the minimum number of random samples required within each WS. The value of n is read from a curve (Miesch, 1976a) as a function of the ratio of the variance between WS to the variance within WS.

The values of E_s, E_r, and n_r are shown in table 8. Without exception, the observed variance exceeds the maximum acceptable variance for all elements; none of the estimated WS means is considered to be stable. What, then, can be said about the composition of the soils?

The best available estimates for background composition of the soils based on the samples "in-hand" are, as follows: elements that have nonsignificant differences between WS are best estimated by a grand mean (see table 10), and elements that have significant differences between WS are best estimated by the individual means (see table 9). The latter means are subject, however, to limitations discussed previously regarding stability, and should be used cautiously.

Table 10.--Summary statistics for elements in alluvial soils without significant differences between watersheds in the Piceance and Uinta Basins

[Geometric means and geometric deviations estimated from all data. Means and 95 percent expected ranges in parts per million except as noted in percent. See inside cover for calculation of expected range]

Element	Geometric mean	Geometric deviation	Geometric error	Expected 95% range
Al, percent----	7.6	1.41	1.15	4.1-14
As-------------	9.3	1.58	1.11	3.8-23
Be-------------	2.0	1.48	1.23	1.0-3.9
C, percent-----	2.8	1.74	1.06	.93-8.4
Cu-------------	30	1.79	1.41	12-77
F--------------	610	1.69	1.09	215-1700
Ge-------------	1.1	1.27	1.16	.75-1.6
Li-------------	37	1.77	1.04	12-116
Mg, percent----	1.4	1.74	1.02	.46-4.2
Mo-------------	5.7	1.64	1.23	2.3-14
Pb-------------	12	1.69	1.18	4.4-32
Th-------------	9.3	1.53	1.18	4.2-20
U--------------	3.5	1.31	1.11	2.1-5.7

Discussion

The distribution of the variance within the sampled population indicates that the larger part is within cells (error), i.e., between localities of the same SV order within a given WS. We believe this results from the influence of local sediments derived from side valleys or from local colluvium being superimposed upon the contributions from upstream sources. However, when the variation between localities is averaged across the WS, the variance ascribed to SV orders is remarkably small. Thus the composition of soil materials tends to be uniform throughout the length of the SV system. The conclusion is that WS means (or geochemical maps) may be based on samples that are collected without regard for SV order. (See p. 91-97,this report, for a similar conclusion with respect to stream sediment geochemistry over the Northern Great Plains). The failure to demonstrate interaction means that differences between SV orders in one WS are the same on the average as those in another WS, or the differences between several WS for one given SV order are the same as those for another SV order. The data in this study provide no evidence to reject these hypotheses. Thus, although soil variation within SV orders could reflect differences in the mode or intensity of sedimentation factors such as distance of transport, mixing or segregation of sediments, leaching or scavenging of ions, and so forth, there is no evidence that such factors are operating differently in different WS.

Regional trends in the mean concentrations of several elements probably exist. Estimates for the Piceance Creek Basin are generally higher than the Uinta Basin (see table 9). Ca is an exception; the highest mean is in the Nine-mile Creek (1) WS. Outcrops of calcareous algal reefs in the Green River Formation near the basin margin at the headwaters of Nine-mile Creek may account for this anomaly. The low Na concentration in Evacuation Creek soils (3) is unexpected, inasmuch as nodules of nahcolite ($NaHCO_3$) have been dissolved from solution cavities in the sandstone cliffs along the valley sides. Such solution, however, appears not to have visibly affected the soil chemistry. Reasons for the distribution of other elements are unknown.

TRACE ELEMENT EMISSIONS, DAVE JOHNSTON POWERPLANT, WYOMING

By Jon J. Connor

A brief survey of the literature dealing with element partitioning in coal-fired powerplants across the country implicates 24 elements or their compounds as stack emittents (Kaakinen and others, 1974; U. S. Environ. Prot. Agency, 1975; Gordon and Tourangeau, 1975; Turner and Strojan, 1976; Connor,Keith and Anderson, 1976). They are antimony, arsenic, boron, barium, cadmium, chlorine, chromium, cobalt, copper, fluorine, lead, nickel, nitrogen, manganese, mercury, molybdenum, scandium, selenium, silver, strontium, sulfur, vanadium, uranium, and zinc.

Theoretically, of course, all naturally occurring elements will appear in the stack gas in some concentration, however small. A more important concern, in an environmental context, is not if an element can be measured in the emissions, but whether its effects can be observed in the local environment. Connor, Keith and Anderson (1976), Gough and Erdman (1976), and Anderson and Keith (this report, p. 14-54) have found an unusually large number of element trends in native vegetation near the Dave Johnston powerplant in Wyoming which indicate that the powerplant is acting as an element point-source in the local landscape.

Table 11 lists elements for which statistically significant decreasing trends have been observed in the dry weight of three species of native vegetation downwind of the powerplant (based on data in U. S. Geological Survey, 1976, Appendix V, and table 4, this report). An example of these trends is shown in figure 8. Figure 9 shows the theoretical downwind ground level air concentrations predicted by a conventional source-depletion model using assumed model parameters. Figure 10 shows the downwind vegetation sampling localities within 10km of the powerplant, and their relation to the probable stack plume. The plume boundaries are taken from the model boundaries (fig. 9) for the two major wind directions at the powerplant. Plume shape will be relatively stable under reasonably varying model assumptions, and plume position is primarily dependent on wind direction. Plume density is a function of stack emission rate and wind velocity but the general area of heaviest concentrations shown is probably realistic.

Table 11.--Percentage of total geochemical variation in dry weight of three species of native vegetation describable as a decreasing trend downwind of the Dave Johnston Powerplant

[Percentages are statistically significant at $p<.05$; ?, possible decreasing trend downwind, but data insufficient to test statistically; --, no decreasing trend downwind; nd, no data]

Element	Sagebrush (*Artemisia tridentata*) Collected May 25, 1973	Sagebrush (Artemisia cana) Collected Sept. 11-16, 1974	Lichen (Parmelia chlorochroa) Collected Nov. 9-10, 1974
Aluminum-------	32	77	42
Antimony-------	--	43	--
Arsenic--------	?	43	--
Calcium--------	--	--	77
Chromium-------	30	83	42
Cobalt---------	39	50	nd
Copper---------	31	34	--
Fluorine-------	--[1]	82	56
Gallium--------	47	69	48
Iron-----------	25	70	--
Lead-----------	--	51	--
Lithium--------	42	89	61
Magnesium------	--	32	45
Manganese------	--	--	44
Nickel---------	30	--	--
Phosphorus-----	--	35	--
Scandium-------	?	84	--
Selenium-------	82	--	61
Silicon--------	--[1]	74	--
Sodium---------	--	51	--
Strontium------	64	--	91
Sulfur---------	72	55	nd
Titanium-------	46	86	47
Uranium--------	46	81	52
Vanadium-------	52	87	39
Ytterbium------	nd	57	35
Yttrium--------	nd	75	49
Zinc-----------	51	--	--
Zirconium------	23	66	--

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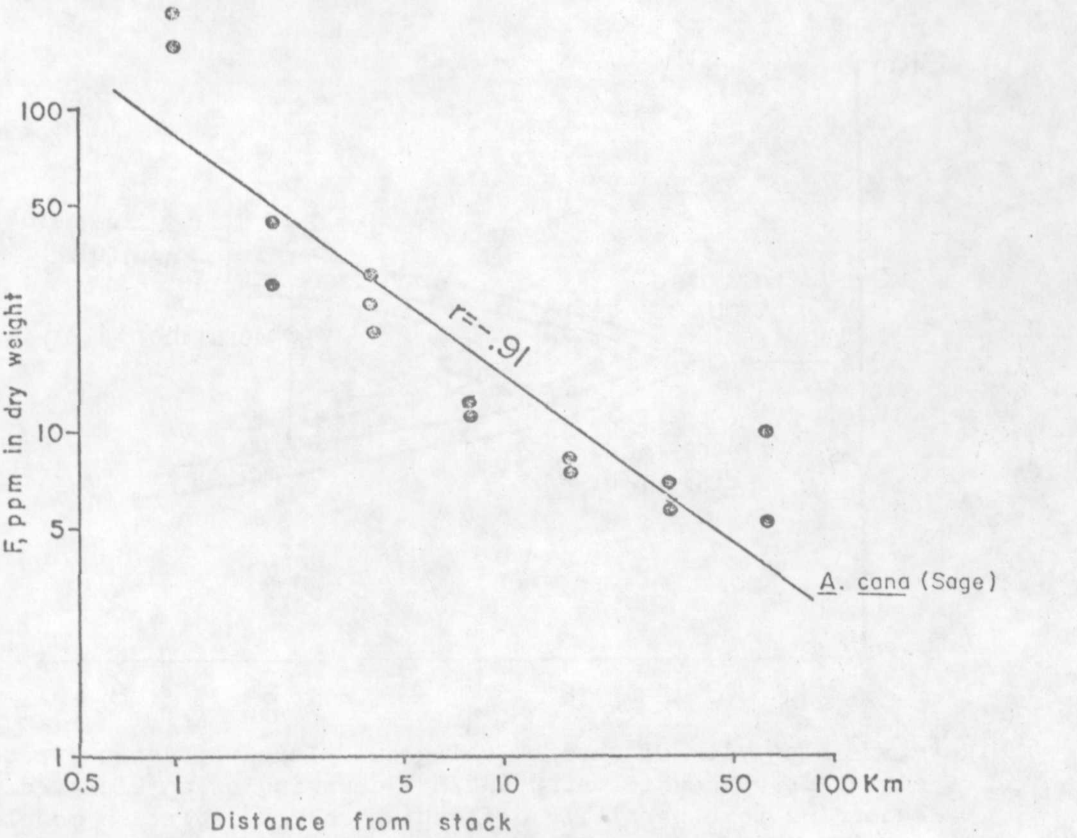
[1] Log-linear trend is not significant at $p<.05$, but log-curvilinear trend is.



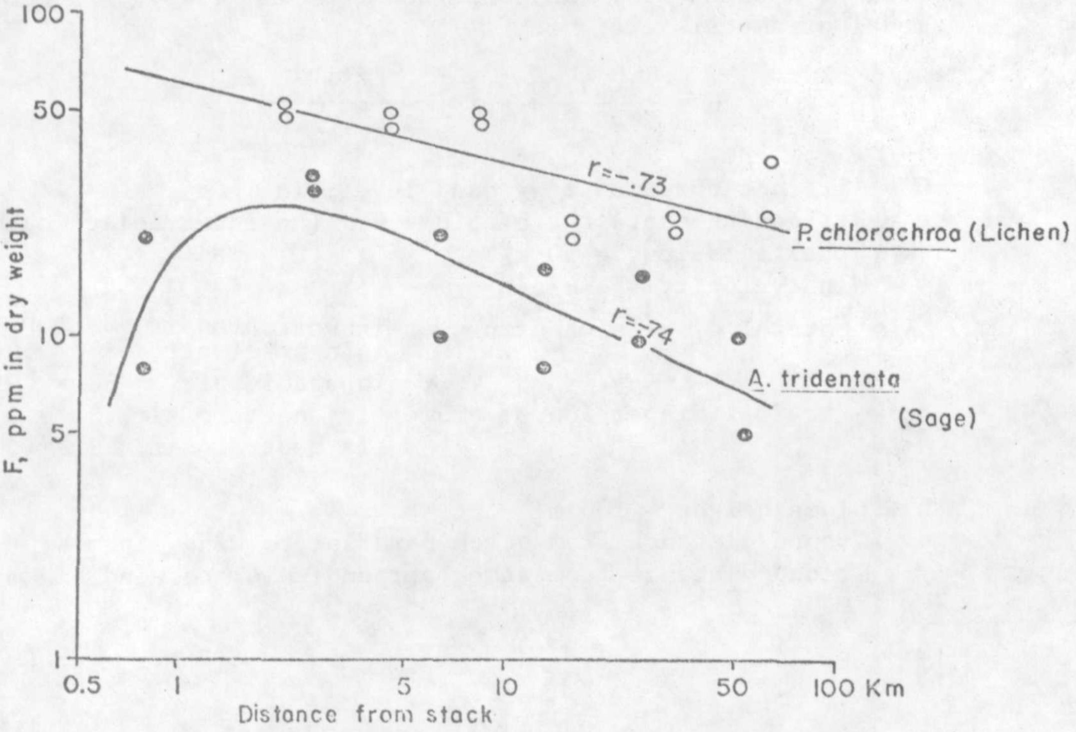


Figure 8. Statistically significant decreases with distance of fluorine in three species of native vegetation downwind of the Dave Johnston Powerplant, Wyoming. Correlation of distance with concentration denoted by r.

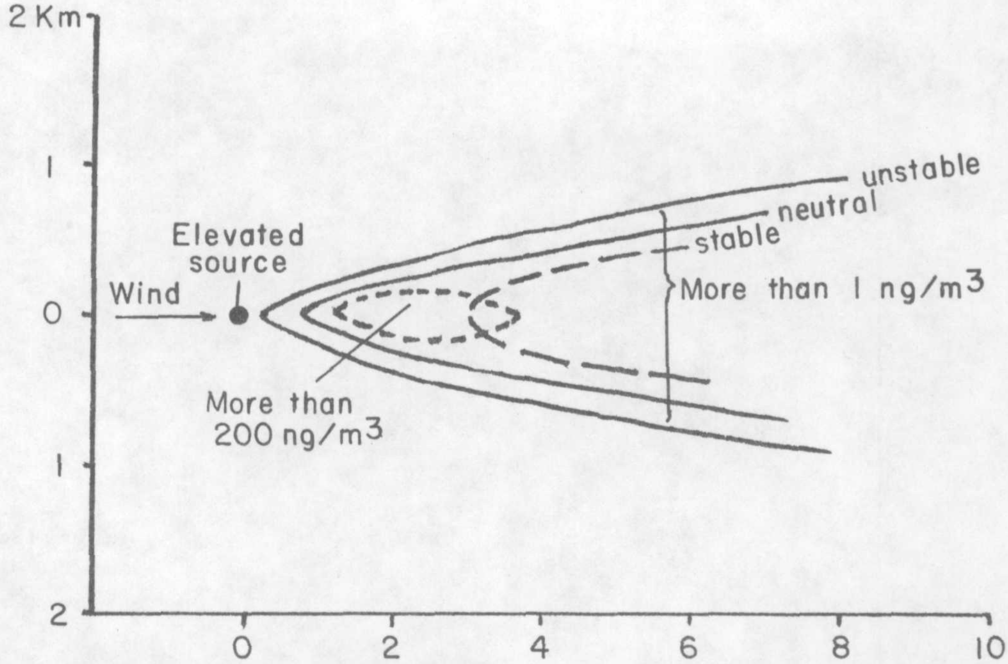


Figure 9.--Plan view of theoretical ground-level air concentrations in nanograms per cubic meter (ng/m^3) downwind of an elevated point source according to a partially deflecting source depletion model (adapted from R. Hosker, U.S. ERDA, personal comm., 1976). The model and the model parameters are:

$$C = \frac{(1+a)10^9 Q}{2\pi v S_y S_z} \exp\left(-\frac{y^2}{2S_y^2} - \frac{h^2}{2S_z^2}\right)$$

C = Air concentration at ground level, in ng/m^3
a = Reflecting character of plume = 0 (an intermediate case)
Q = Stack emissions = 50 g/sec
v = Wind velocity = 1 m/sec
S_y = Lateral dispersion of plume: in unstable air, $S_y = 0.2x$
in neutral air, $S_y = .06x$
in stable air, $S_y = .05x$
S_z = Vertical dispersion of plume: in unstable air, $S_z = 0.2x$
in neutral air, $S_z = .03x$
in stable air, $S_z = .01x$
h = plume height = 100 m
x = Ground distance from stack parallel to wind, in m
y = Ground distance from stack perpendicular to wind, in m

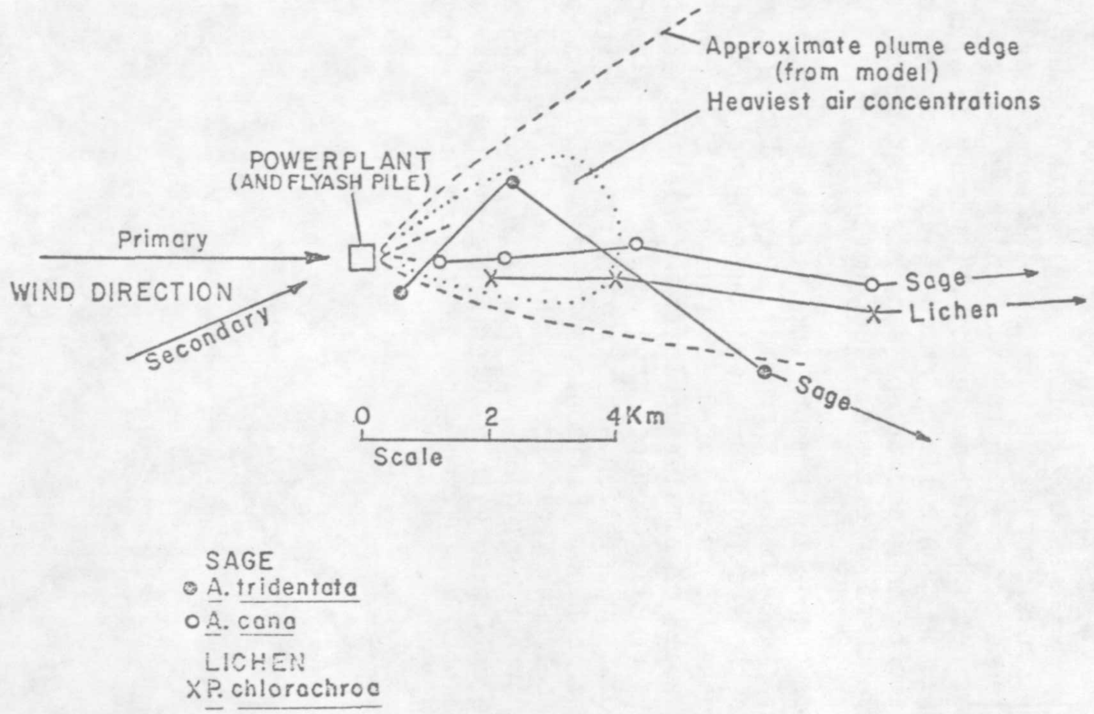


Figure 10. Nearby sampling localities and probable average position of stack plume at ground level downwind of the Dave Johnson Powerplant, Wyoming.

The right-angle bend in the *Artemisia tridentata* Nutt. sample traverse (fig. 10), where the second locality falls within the denser part of the assumed stack plume, and the first and third localities do not, appears to explain an intriguing feature of many of the element trends seen in the *A. tridentata* data. The highest element concentrations in that study tend to be found in samples from the second locality (see fig. 8, for example); this is in accord with the plume effect as diagrammed (fig. 10).

The most puzzling feature about the trends seen in vegetation downwind from the Dave Johnston powerplant is their variety (table 11). A large number of trace elements measured in vegetation exhibit trends consistent with a point source at the powerplant. Such trends are seen in the "volatile" elements (like selenium and fluorine) as well as in the refractory ones (like titanium and zirconium). Even silicon, which is a major rather than a minor element in vegetation ash, has a statistically significant negative trend in *Artemisia cana* Pursh.

The presence of trends in elements like aluminum, gallium, scandium, silicon, titanium and zirconium (a typical geological association) raises the question as to whether some or all of the element trends seen in these studies reflect a downwind contamination by soil or similar geologic material rather than stack emissions. Figure 11 compares the silicon-iron-aluminum proportions of soil, vegetation ash, flyash, typical illite (a clay) and coal after ashing. Silicon, iron and aluminum are widespread and important geologically but generally, except at trace levels, unimportant biologically. The soil, vegetation ash and flyash all were collected within 10km of the powerplant. The ashed coal represents coal from the Northern Great Plains (Swanson and others, 1976).

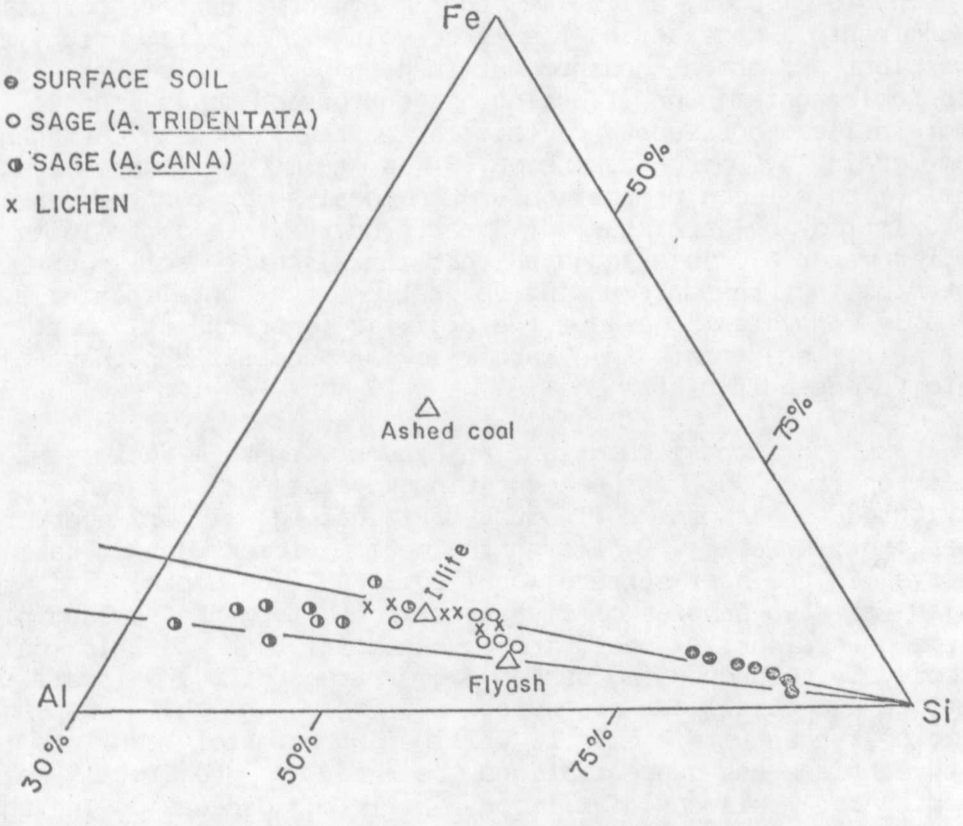


Figure 11.--Proportions of silicon, iron, and aluminum in samples of surface soil (0-2.5 cm depth), sagebrush (*Artemisia tridentata* and *A. cana*), ground lichen (*Parmelia chlorochroa*), ideal illite, flyash and ash of coal. All samples but ashed coal were collected from within 10 km downwind of the Dave Johnston Powerplant. Ashed coal represents average of lignite and subbituminous coal of the Northern Great Plains Coal Province (from Swanson and others, 1976).

Vegetation ash, flyash and illite all have about the same ratio of iron to aluminum (1:9) as the local soil. The ratio in the ash of Northern Great Plains coal is based on ashing coal in the laboratory and not burning in a powerplant, but even if such material were available to be dispersed into the local environment, its iron to aluminum ratio is much too high for it to serve as a contaminant dust. Both illite (or a similar argillic material) and flyash can reasonably serve as contaminant sources insofar as their ratios of iron to aluminum are concerned.

The local soil, which is the most obvious of potential contaminants, considering the large volume of traffic around the powerplant and the attendant dust suspension, can also serve as a reasonable contaminant if during air suspension it is winnowed to a more silica-poor substance (similar to the winnowing of chaff from grain by air suspension). In terms of figure 11, the aluminum to silicon proportion of the local soil can be easily approximated by a mixture of 2 parts quartz to 1 part illite or similar material. This suggests that if airborne soil dust is contaminating the surrounding vegetation, the contaminating dust probably consists largely of the argillic (non-quartz) part of the soil, and that this argillic part comprises perhaps one-third to one-half of the soil.

Based on such speculation, an attempt may be made to assess the proportion of an element in vegetation ash which can be attributed to airborne soil dust originating at or near the powerplant. Table 12 lists the median element concentrations observed in the near-surface local soil (0-2.5cm depth) and the median of two samples of flyash collected from the exposed pile at the powerplant. If one-third to one-half of the soil is being selectively winnowed and suspended for transport, and if all the elements except silicon are contained only in that suspended fraction, then its chemistry will be approximately equal to two to three times the concentrations observed in the total soil, except for silicon. Silicon will be decreased in this hypothetical airborne fraction by an amount equal to the one-half to two-thirds of quartz left behind. When so estimated, this hypothetical airborne fraction of soil dust is seen to be compositionally similar to flyash, except that flyash is distinctly high in boron, calcium and copper and the soil is distinctly high in germanium.

Table 12.--Typical (median) concentrations in samples of surface soil, flyash, hypothetical windborne contaminants and vegetation ash collected within 10 km downwind of the Dave Johnston Powerplant

[Concentrations in parts per million except where noted as percent (%); nd, not determined]

Element	Surface dust[1]	Flyash[2]	Hypothetical windborne dust[3]	Contaminant[4]		Sage[5]	Sage[6]	Lichen[7]
				flyash	dust			
Aluminum, %---	5	12	10-15	4	4	3	7	6
Arsenic-------	2.5	4.3	5-7.5	1	2	<5	.9	12
Barium--------	700	1700	1400-2100	600	600	850	600	400
Beryllium-----	1	6.6	2-3	2	.8	nd	nd	nd
Bismuth-------	.1	nd	.2-.3	nd	<.1	nd	nd	nd
Boron---------	20	340	40-60	100	20	300	500	50
Cadmium-------	nd	<1	nd	<.4	nd	4.5	5	3
Calcium, %----	.89	10	1.8-2.7	3	.8	10	12	27
Chlorine, %---	<.1	<.1	<.3	<.1	<.1	nd	nd	nd
Chromium------	30	130	60-90	40	30	40	50	70
Cobalt--------	5	14	10-15	5	4	3.5	4	2
Copper--------	10	170	20-30	60	8	150	150	40
Fluorine------	<400	<400	<1200	<200	<400	300	500	420
Gallium-------	15	28	30-45	9	10	15	15	18
Germanium-----	1.9	1.1	3.8-5.7	.4	2	nd	nd	nd
Iron, %-------	2	2.2	4-6	.7	2	.7	1	1.8
Lanthanum-----	30	nd	60-90	nd	30	nd	nd	nd
Lead----------	20	39	40-60	10	20	70	30	100
Lithium-------	20	43	40-60	10	20	19	16	8
Magnesium, %--	.84	1.3	1.7-2.5	.4	.7	2	5	.6
Manganese-----	200	720	400-600	200	200	500	700	200
Mercury-------	.02	.03	<.1	<.1	<.1	.3	.35	.64
Molybdenum----	nd	31	nd	10	nd	15	15	nd
Nickel--------	15	44	30-45	10	10	18	20	10
Niobium-------	10	22	20-30	7	8	nd	nd	nd
Phosphorus, %-	<.04	<.04	<.13	<.1	<.1	2	2.4	.6
Potassium, %--	1.8	1.1	3.6-5.4	.4	.2	26	23	1.4
Rubidium------	nd	78	nd	30	nd	nd	nd	nd
Scandium------	5	21	10-15	7	4	13	7	7
Selenium -----	<.1	.5	<.3	.2	<.1	9.3	13	11
Silicon, %----	37	25	17-27	8	7	6	5.4	11
Silver--------	nd	1.2	nd	.4	nd	<1.5	nd	nd
Sodium, %-----	.93	1.2	1.9-2.8	.4	.8	<.1	1.2	<.1
Strontium-----	200	870	400-600	300	200	1300	2000	400
Sulfur, %-----	<.04	.11	<.12	<.1	<.1	3.5	4.6	nd
Thorium-------	10	17	20-30	6	8	nd	nd	nd
Tin-----------	.3	<.1	.6-.9	<.1	.3	<30	nd	nd
Titanium, %---	.24	.63	.5-.7	.2	.2	.2	.15	.15
Uranium-------	2.6	19	5.2-7.8	6	2	1.6	2.4	3.2
Vanadium------	70	220	140-210	70	60	100	100	100
Ytterbium-----	1.5	5.7	3-4.5	2	1	<2	1.5	6
Yttrium-------	15	36	30-45	10	10	<20	15	70
Zinc----------	47	52	94-140	20	40	520	360	160
Zirconium-----	150	140	300-450	50	100	70	70	85

[1] Median of seven analyses of surface soil (0.2-5 cm depth)

[2] Median of two analyses of flyash collected at powerplant by R. J. Ebens, 1974.

[3] Estimated as surface soil with quartz removed if quartz comprises one-half to two-thirds of total soil mass.

[4] Amount contributed to vegetation ash by contaminant if ash is composed of one-third contaminant.

[5] Median of six analyses of *Artemisia tridentata*.

[6] Median of nine analyses of *Artemisia cana*.

[7] Median of six analyses of *Parmelia chlorochroa*.

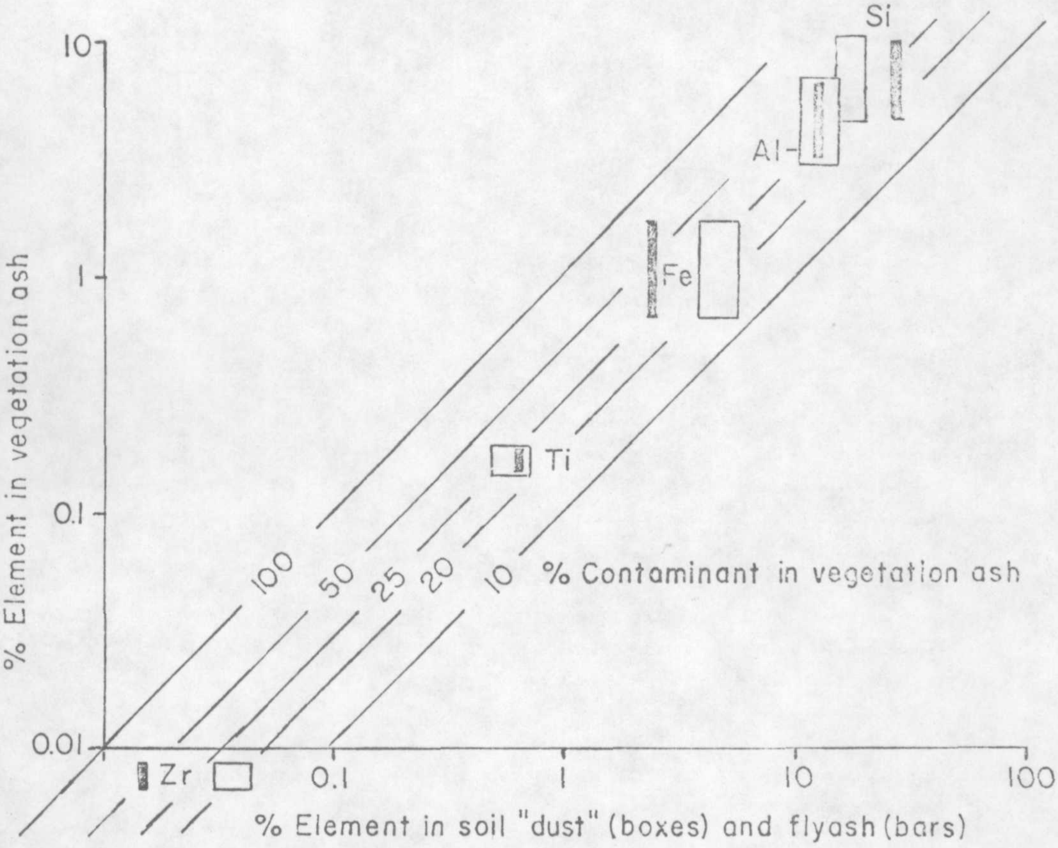


Figure 12.--Graph showing proportions of element observed in vegetation ash of samples within 10 km downwind of the Dave Johnston powerplant which can be accounted for by the addition to the ash of hypothetical soil "dust" or flyash. Ranges in proportions based on median concentrations in columns 2 and 3 of table 2.

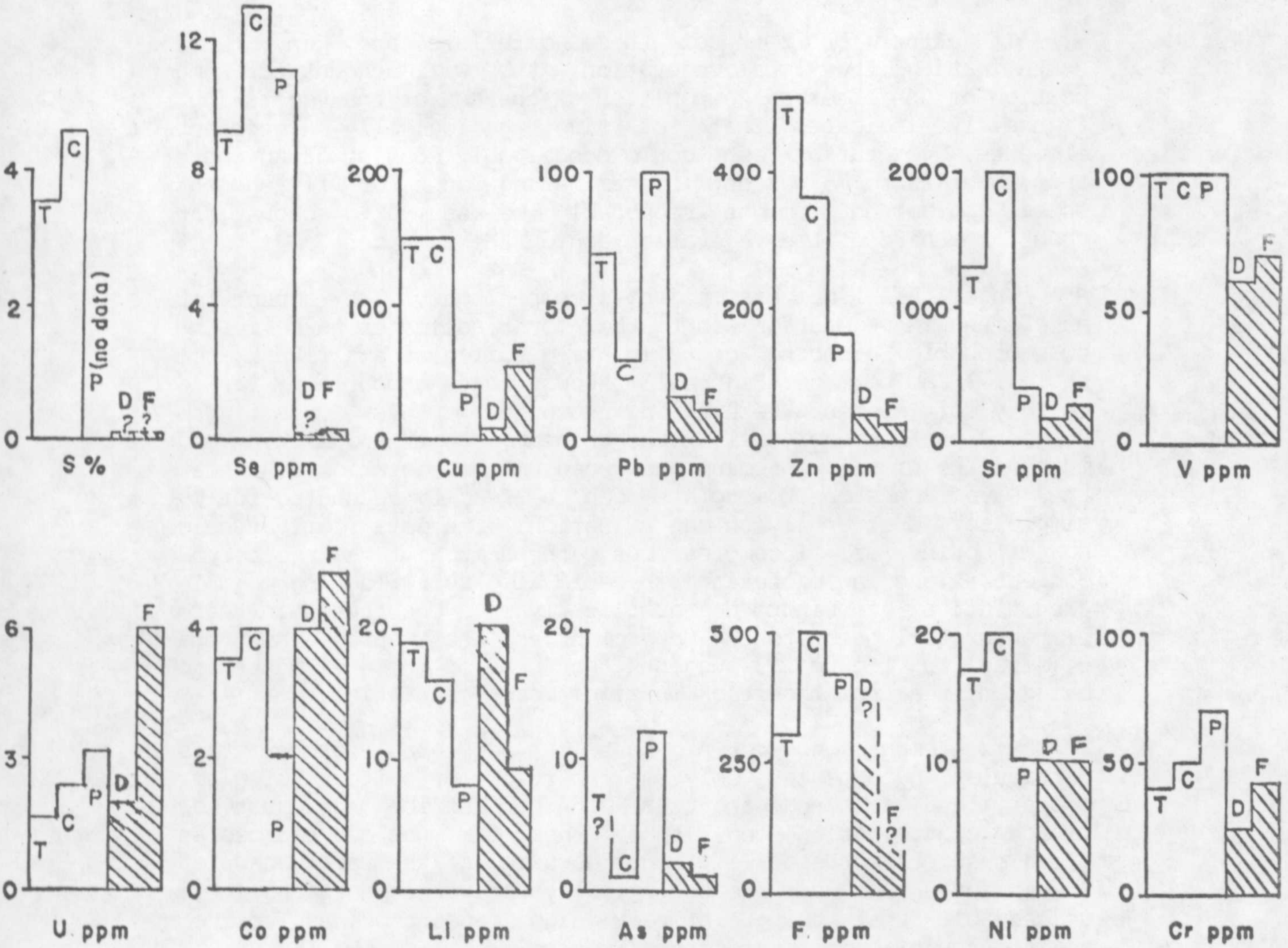


Figure 13.--Elements in ash of sagebrush (T = <u>Artemisia tridentata</u>, C = <u>A. cana</u>) and ground lichen (P = <u>Parmelia chlorochroa</u>), and in two probable contaminants, soil "dust" (D) and flyash (F). Data based on samples collected within 10 km downwind of the Dave Johnston Powerplant.

If either or both of these materials are, in fact, contaminating the local vegetation, they will account for some portion of the observed composition of the ash of the vegetation. Figure 12 indicates that for five geologically important elements, vegetation ash could conceivably consist of anywhere from about 10 to 75 percent contaminating dust or flyash but these contaminants might reasonably be assumed to account for about one-third of the vegetation ash on the average.

Under this final assumption, a comparison of the amount of an element in vegetation ash to the amount estimated to be in the two probable airborne contaminants (soil dust and flyash, see table 12) can be made. Figure 13 shows this comparison for a variety of elements exhibiting downwind trends. This figure suggests that probably all of the uranium, cobalt and lithium and much of the nickel, chromium and vanadium in vegetation ash near the Dave Johnston powerplant can be readily accounted for by simple soil dust or flyash contamination. The data for arsenic and fluorine are incomplete but perhaps much of their observed concentrations in vegetation ash could also be reflecting simple accumulation of windborne dust or flyash. The trends in these elements still point to the powerplant as the source, but the evidence in figure 13 suggests that none of these elements are being emitted from the stack in significant quantities.

Six elements, however, cannot be accounted for by this particular hypothesis. Only small portions of sulfur, selenium, copper, lead, zinc and strontium can be ascribed to dust or flyash contamination and, thus, these six must be regarded as prime suspects for stack emittents downwind of the Dave Johnston Powerplant. All six are biologically active elements and it is conceivable that the relatively high concentrations reflect active accumulation regardless of source.

FACTOR ANALYSIS OF SOIL CHEMISTRY, PICEANCE CREEK BASIN, COLORADO

by Walter E. Dean, Charles D. Ringrose,[1/]
and Ronald W. Klusman[1/]

Introduction

Commercial development of oil shale in the Green River Formation (Eocene) in the Piceance Creek Basin of western Colorado requires the prior establishment of trace element concentrations in surficial materials as part of any effort to construct practical geochemical baselines with which to measure change during oil shale production and subsequent land reclamation.

Ringrose and others (U.S. Geol. Survey, 1976, p. 101-111) demonstrated that there is essentially no difference in the concentrations of major, minor, and trace elements in surface soils developed on ridge tops and those developed in valley bottoms in the Piceance Creek basin, but that eight elements (Ca, Fe, Mg, Ti, Be, Cu, Li, and Zn) exhibit strong regional patterns across the basin. The purpose of this report is to further quantify this regional variability using extended Q-mode factor analysis. We thank A. T. Miesch and R. R. Tidball for many helpful suggestions with the factor analysis. George Saulnier provided helpful information on water chemistry of the Piceance Creek Basin.

Statistical Methods

The main program used for the factor analysis is a terminal-oriented interactive version of the extended CABFAC program described by Klovan and Miesch (1976) which is applicable when the row-sums of the data matrix are constant. Detailed descriptions and applications of the interactive Q-mode programs can be found in Miesch (1976b and 1976c). In the work described here, the data consist of a 2-dimensional matrix of element concentrations in weight percent or parts per million (columns) for each of 140 samples (rows). For the factor analysis, these data are converted to oxides, row-normalized by adjusting the sum of all oxides to 100, and transformed so that the concentration of each oxide is expressed as a proportion of the total range of concentrations for that oxide. At this point in the analysis, all data are on a scale of 0.0 to 1.0.

Next, a factor-variance diagram is constructed so that the smallest number of factors that will account for the largest

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[1/] Department of Chemistry and Geochemistry, Colorado School of Mines, Golden, Colorado proportion of the variance in the largest number of oxides can be selected. The number of factors chosen will be the number of factors (end members) used in the Q-mode factor model. The extended Q-mode factor analysis program (Miesch, 1976b) can then be used to compute composition scores, in weight percent, for each end member, and can also be used to compute composition loadings for each sample. These loadings are the mixing proportions for each of the end members that are required to approximate each sample composition. Finally, estimates of the original data are computed using the composition scores and loadings and are compared to the original data as a test of the "goodness-of-fit" of the factor model. The factor-variance diagrams for the Piceance Creek Basin soil chemistry are given in figure 14.

These diagrams show at a glance how much of the total variance for each element can be accounted for by adding factors (end members) to the Q-mode model. A compromise must be reached in which as much of the variance as possible for as many elements as possible can be accounted for by as few factors as possible. For example, in figure 14, it is obvious that a much higher proportion of the variance for most elements is achieved by increasing the number of factors from three to four, but that little is gained by increasing the number of factors from four to five or more. A four-factor (four end member) model was chosen to describe the chemistry of the surface soils of the Piceance Creek basin.

Each end member in the model is described in terms of the concentrations of the 29 oxides used in the analysis. Each soil sample can then be viewed as a particular mixture of the four end members. For computational purposes, the end members may be theoretical compositions or actual compositions taken from the data matrix. For this study, we decided to use four actual soil samples as the four end members in the model, and chose them following examination of the varimax rotation (Miesch, 1976c). Both the observed and the computed compositions of these four end member samples are shown in table 13. The factor loadings are listed in table 14, and indicate the mixing proportions for each sample. For example, the "recipe" for making sample 111111KP (table 14) is to mix 0.65 parts of end member 1 (sample 252111 KP), 0.05 parts of end member 2 (sample 191111KP), 0.29 parts of end member 3 (sample 151111KP), and 0.01 parts of end member 4 (sample 142111KP).

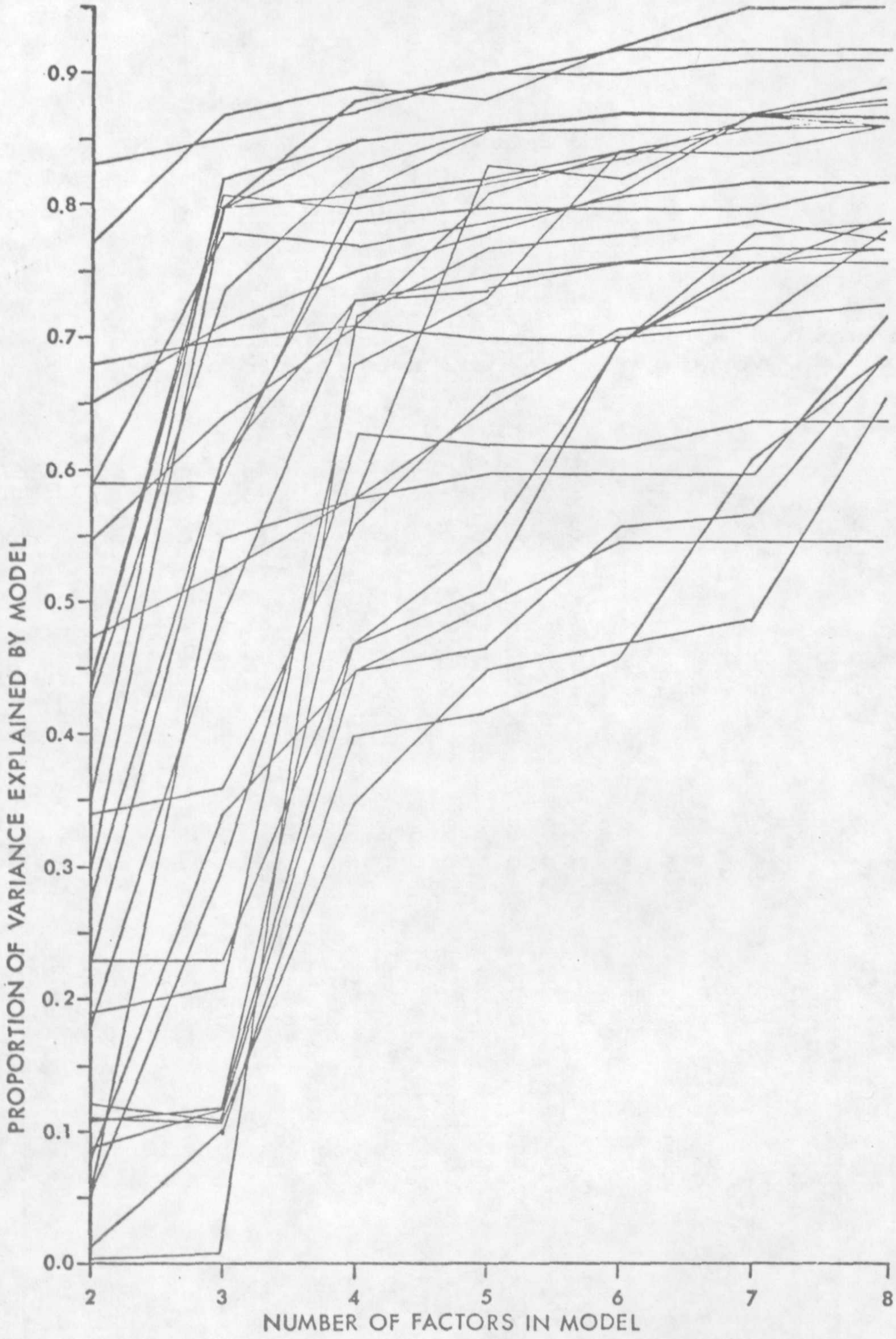


Figure 14. Factor-variance diagram for the chemistry of soil samples from the Piceance Creek Basin. The variation accounted for in each of 29 elements is diagramed for factor models containing 2 to 8 factors.

oxide	end member for Factor 1 is sample number 252111 observed composition	computed composition	end member for Factor 2 is sample number 191111 observed composition	computed composition	end member for Factor 3 is sample number 151111 observed composition	computed composition	end member for Factor 4 is sample number 142111 observed composition	computed composition
Al_2O_3	12.5	12.8	6.8	7.2	8.2	11.1	14.4	12.3
CaO	1.0	1.1	11.4	13.8	2.4	2.1	2.1	2.2
Fe_2O_3	3.3	3.8	2.1	1.9	1.7	2.4	2.9	2.6
MgO	1.4	2.4	4.8	3.8	0.92	1.1	1.9	0.92
K_2O	3.7	3.8	2.3	2.3	0.94	2.8	2.2	2.8
SiO_2	57.6	59.2	35.5	39.8	74.4	70.6	67.1	69.2
Na_2O	1.0	0.98	1.7	0.48	0.24	2.50	5.2	4.3
TiO_2	0.61	0.66	0.27	0.32	0.55	0.50	0.55	0.49
CO_2	18.5	14.8	34.8	30.2	10.5	6.8	3.5	5.0
As_2O_3	0.0009	0.0015	0.0022	0.0018	0.0006	0.0010	0.0007	0.0002
B_2O_3	0.0030	0.0034	0.0211	0.0208	0.0082	0.0134	0.0142	0.0160
BeO	0.0009	0.0011	0.0003	0.0003	0.0004	0.0005	0.0009	0.0008
CoO	0.0017	0.0020	0.0003	0.0002	0.0003	0.0003	0.0018	0.0015
Cr_2O_3	0.0116	0.0152	0.0032	0.0015	0.0018	0.0047	0.0137	0.0137
CuO	0.0076	0.0110	0.0034	0.0032	0.0013	0.0000	0.0022	0.0026
Ga_2O_3	0.0037	0.0043	0.0005	0.0005	0.0003	0.0007	0.0050	0.0040
Li_2O	0.0190	0.0158	0.0155	0.0137	0.0037	0.0043	0.0047	0.0012
MnO	0.14	0.14	0.063	0.057	0.0214	0.0039	0.063	0.106
MoO_3	0.0017	0.0020	0.0001	0.0001	0.0001	0.0000	0.0015	0.0012
NiO	0.0049	0.0056	0.0009	0.0007	0.0005	0.0008	0.0040	0.0036
PbO	0.0060	0.0061	0.0008	0.0006	0.0004	0.0000	0.0057	0.0045
Rb_2O	0.019	0.019	0.010	0.010	0.0044	0.0103	0.0054	0.0104
Sc_2O_3	0.0021	0.0020	0.0003	0.0004	0.0003	0.0002	0.0018	0.0015
SrO	0.023	0.031	0.053	0.053	0.0073	0.0107	0.053	0.049
V_2O_3	0.0173	0.0164	0.0042	0.0053	0.0044	0.0031	0.0012	0.0089
Y_2O_3	0.0028	0.0034	0.0009	0.0016	0.0012	0.0009	0.0022	0.0021
Yb_2O_3	0.0005	0.0006	0.0000	0.0001	0.0001	0.0000	0.0002	0.0003
ZnO	0.018	0.016	0.012	0.012	0.0057	0.0086	0.0096	0.0069
UO_2	0.0004	0.0004	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002
total	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

Table 13. Observed and computed compositions for each of the four end members used in the extended Q-mode factor model for soils in the Piceance Creek Basin, Colorado. All values are in weight percent.

Table 14. - Factor loadings for the four factors used in the extended Q-mode model of soils in the Piceance Creek basin.

[Samples used as end members for each of the four factors are indicated by F.1, F.2, F.3, and F.4]

SAMPLE	Factor 1 Sample No. 252111	Factor 2 Sample No. 191111	Factor 3 Sample No. 151111	Factor 4 Sample No. 142111
111111KP	0.6549	0.0498	0.2875	0.0078
111121KP	0.4740	0.1918	0.4525	-0.1183
111122KP	0.5986	0.1971	0.2393	-0.0350
111211KP	-0.0201	0.6717	0.3060	0.0424
112111KP	-0.0832	0.1459	0.5868	0.3506
112211KP	0.0149	0.4017	-0.0497	0.6332
112212KP	0.0597	0.4099	-0.1259	0.6563
112221KP	0.1156	0.1900	0.1730	0.5214
121111KP	0.1199	0.4834	-0.1719	0.5687
121211KP	-0.0546	0.6018	-0.3149	0.7677
121212KP	-0.0666	0.6026	-0.2036	0.6676
121221KP	-0.1548	0.4679	0.0555	0.6314
121222KP	-0.2129	0.5236	0.2875	0.4017
122111KP	0.1790	0.0021	0.4183	0.4005
122121KP	0.1700	0.1834	0.4042	0.2424
122211KP	0.3127	-0.0979	0.5909	0.1943
131111KP	0.3317	0.0559	0.7733	-0.1609
131121KP	0.1249	0.0985	0.4816	0.2950
131211KP	-0.0623	0.1506	0.1513	0.7605
131212KP	-0.0672	0.1762	0.1729	0.7180
132111KP	0.3588	0.0649	-0.1042	0.6806
132211KP	0.3696	-0.0780	0.0810	0.6284
132221KP	0.4334	-0.1384	0.1909	0.5141
132222KP	0.3587	-0.1325	0.4352	0.3386
141111KP	0.5881	0.0088	0.1995	0.2037
141112KP	0.3916	0.0063	0.6767	-0.0746
141121KP	0.5544	0.0373	0.0127	0.3956
141122KP	0.3878	0.0214	0.2248	0.3659
141211KP	0.3663	-0.0934	0.1440	0.5831
142111KP F.4 →	0.0000	0.0000	0.0000	1.0000
142211KP	0.4492	-0.0329	0.1764	0.4074
142221KP	0.5464	-0.0543	-0.2587	0.7665
151111KP F.3 →	0.0000	0.0000	1.0000	0.0000
151211KP	0.4109	-0.0908	0.2761	0.4038
151221KP	0.5247	0.0280	0.4215	0.0257
151222KP	0.7954	-0.0049	0.2150	-0.0055
152111KP	0.5857	-0.0517	0.1266	0.3394
152211KP	0.1724	-0.0954	0.9926	-0.0696
152212KP	0.4174	-0.1240	0.1058	0.6008
152221KP	0.3871	-0.0214	0.0402	0.5942
161111KP	0.4338	0.2842	-0.0266	0.3086
161112KP	0.2889	0.2735	0.3245	0.1131
161211KP	0.0936	0.0135	-0.0276	0.9204
161221KP	0.0405	0.0153	-0.0166	0.9608
162111KP	0.5588	-0.0943	0.4249	0.1107
162112KP	0.6114	-0.0685	0.3734	0.0836
162211KP	0.4715	-0.0730	0.0936	0.5079
162221KP	0.4055	-0.1524	0.2777	0.4692
171111KP	0.5633	-0.1255	0.5012	0.0610
171112KP	0.6622	-0.0037	-0.0816	0.4231
171211KP	0.4064	-0.2292	0.2135	0.6093
171221KP	0.2293	-0.0981	0.8021	0.0666
172111KP	0.5213	-0.0188	0.2093	0.2882
172211KP	0.8022	-0.1502	0.1401	0.2079
172221KP	0.8491	-0.1062	0.0169	0.2401
181111KP	0.8248	-0.0363	0.1796	0.0319
181211KP	0.3497	0.2151	0.5485	-0.1133
181221KP	0.4284	0.2915	0.1207	0.1594
182111KP	0.9214	-0.0824	0.4106	-0.2496
182211KP	0.6953	-0.1598	0.5186	-0.0541
182212KP	0.6930	-0.1469	0.3014	0.1524
182221KP	0.7256	-0.1887	0.4331	0.0300
191111KP F.2 →	0.0000	1.0000	0.0000	0.0000
191211KP	0.3864	0.3590	0.0058	0.2488
191221KP	0.2672	0.7932	-0.3237	0.2633
192111KP	0.5181	-0.0728	0.2934	0.2613
192211KP	0.5753	0.4443	-0.0880	0.0684
192221KP	0.3929	0.5607	-0.0617	0.1081
211111KP	-0.0512	0.8084	-0.4237	0.6665
211112KP	-0.1058	0.7559	-0.1955	0.5454
211211KP	0.1411	0.7349	-0.2756	0.3996
211221KP	0.1034	0.5034	0.4220	-0.0287
211222KP	0.2903	0.5908	-0.2064	0.3253
212111KP	0.1852	0.2020	0.6551	-0.0424
212121KP	0.3162	0.2384	0.1723	0.2730
212211KP	-0.0866	0.6886	0.3484	0.0496
221111KP	0.0700	0.5218	0.0251	0.3831
221112KP	0.0998	0.3684	0.0860	0.4457
221121KP	-0.0796	0.9350	-0.2875	0.4321
221211KP	0.0962	0.1078	-0.1646	0.9605
222111KP	0.0366	0.3732	-0.1362	0.7264
222112KP	0.0052	0.3883	0.1482	0.4584
222121KP	0.1032	0.1630	0.0448	0.6890
222122KP	0.0828	0.1647	0.2767	0.4759

Table 14. - Factor loadings for the four factors used in the extended Q-mode model (continued)

SAMPLE	Factor 1 Sample No. 252111	Factor 2 Sample No. 191111	Factor 3 Sample No. 151111	Factor 4 Sample No. 142111
222211KP	-0.0516	0.8018	-0.4677	0.7175
231111KP	-0.0253	0.6280	-0.3616	0.0357
231121KP	0.0734	0.5648	-0.0838	0.4456
231211KP	0.1044	0.2077	0.0391	0.6487
232111KP	0.3104	0.2248	-0.2595	0.7244
232112KP	0.1606	0.2072	0.2703	0.3620
232211KP	0.0784	0.1251	0.2377	0.5588
232212KP	0.1644	0.1317	-0.2042	0.9081
232221KP	0.0207	0.1287	0.4783	0.3723
232222KP	0.1572	0.1102	0.2766	0.4559
241111KP	0.2167	0.2375	-0.1092	0.6549
241211KP	-0.0095	0.1107	0.1956	0.7032
241212KP	-0.0923	0.1742	0.4371	0.4810
241221KP	0.0425	0.2363	0.3549	0.3663
242111KP	-0.0067	0.1532	0.5814	0.2722
242112KP	0.1411	0.1322	-0.0134	0.7400
242211KP	0.1495	0.2126	-0.2638	0.9018
242212KP	0.0480	0.2203	0.1512	0.5805
251111KP	0.4884	0.0773	0.0160	0.4183
251112KP	0.3199	0.0336	0.3708	0.2756
251211KP	0.3939	-0.0751	0.3753	0.3060
251221KP	0.6857	-0.1070	0.1618	0.2595
252111KP	F.1 → 1.0000	0.0000	0.0000	0.0000
252112KP	0.8593	-0.0408	0.3454	-0.1639
252121KP	0.9911	-0.0418	0.0472	0.0035
252211KP	0.8620	-0.0686	0.3014	-0.0948
261111KP	0.3457	0.1748	-0.1938	0.6733
261112KP	0.3424	0.1838	-0.0970	0.5708
261211KP	0.1196	0.0947	0.2794	0.5062
261221KP	0.1573	0.0325	0.3028	0.5074
262111KP	0.5035	0.0024	0.2624	0.2318
262121KP	0.5789	-0.0559	0.3439	0.1330
262211KP	0.3245	0.6122	-0.0875	0.1507
262212KP	0.2540	0.6032	0.1334	0.0094
271111KP	0.5351	-0.0263	0.4276	0.0637
271211KP	0.4627	0.0011	0.2589	0.2773
271221KP	0.6384	-0.0504	-0.1424	0.5544
272111KP	0.1765	0.4823	0.0216	0.3196
272121KP	0.1620	0.8166	-0.3062	0.3276
272211KP	0.5366	-0.0975	0.0075	0.5534
272212KP	0.2662	-0.0144	0.6996	0.0486
281111KP	0.1485	0.7603	-0.1063	0.1975
281121KP	0.1328	0.6852	-0.1623	0.3442
281122KP	0.0457	0.6949	-0.0686	0.3280
281211KP	0.4176	0.1682	0.4704	-0.0562
282111KP	0.2201	0.6065	0.1295	0.0440
282211KP	0.3249	0.5398	-0.0985	0.2338
282221KP	0.4238	0.4946	-0.1435	0.2250
291111KP	0.6782	-0.0967	0.2974	0.1211
291112KP	0.7296	-0.1167	0.0705	0.3166
291121KP	0.5613	-0.0326	0.5432	-0.0720
291211KP	0.2114	-0.0912	0.8649	0.0149
292111KP	0.0562	0.6638	0.2903	-0.0102
292112KP	0.1858	0.6583	-0.1565	0.3124
292121KP	0.2266	0.7311	-0.3251	0.3674
292211KP	0.1451	0.7485	-0.2709	0.3772

	Al_2O_3	CaO	Fe_2O_3	MgO
K_2O	SiO_2	Na_2O	TiO_2	As_2O_3
B_2O_3	BeO	CoO	Cr_2O_3	CuO
Ga_2O_3	Li_2O	MnO	MoO_3	NiO
PbO	Rb_2O	Sc_2O_3	SrO	V_2O_3
Y_2O_3	Yb_2O_3	ZnO	CO_2	UO_2
MEANS OF OBSERVED DATA				
	11.266930	4.264207	2.807058	2.007036
3.000204	60.446146	2.250756	0.508059	0.001042
0.021907	0.000754	0.001209	0.010242	0.004787
0.002860	0.008695	0.091446	0.001007	0.003176
0.003476	0.012728	0.001208	0.038285	0.009519
0.002181	0.000299	0.010952	13.224518	0.000317
MEANS OF COMPUTED DATA				
	11.247841	4.193904	2.800595	1.987197
3.010476	60.434923	2.236168	0.508755	0.001045
0.022012	0.000742	0.001197	0.010251	0.004773
0.002856	0.008649	0.091320	0.001028	0.003173
0.003478	0.012759	0.001222	0.038265	0.009519
0.002201	0.000303	0.010982	13.354050	0.000317
STD DEVS OF OBSERVED DATA				
	1.639022	3.629863	0.604524	0.873745
0.527291	7.800148	0.983403	0.089891	0.000530
0.005623	0.000229	0.000477	0.003646	0.003102
0.001088	0.004402	0.038930	0.000473	0.001282
0.001483	0.003235	0.000420	0.014881	0.003197
0.000627	0.000118	0.002418	6.712670	0.000066
STD DEVS OF COMPUTED DATA				
	1.444124	3.627917	0.474540	0.659816
0.381451	7.687929	0.805448	0.086197	0.000330
0.004265	0.000186	0.000441	0.003388	0.002267
0.001010	0.003189	0.028787	0.000466	0.001176
0.001436	0.002252	0.000418	0.013589	0.002797
0.000491	0.000126	0.002036	6.007391	0.000045
PROPORTIONS OF VARIANCES ACCOUNTED FOR BY MODEL				
	0.711994	0.886503	0.564585	0.583728
0.470320	0.891287	0.678168	0.813763	0.345732
0.473560	0.705335	0.809756	0.770958	0.626702
0.798313	0.577728	0.581629	0.882444	0.831669
0.848142	0.448763	0.833662	0.787222	0.726087
0.450042	0.690563	0.722931	0.754660	0.370435

Table 15. - Summary statistics of observed data and data computed by the 4-factor extended Q-mode factor model of soils in the Piceance Creek basin.

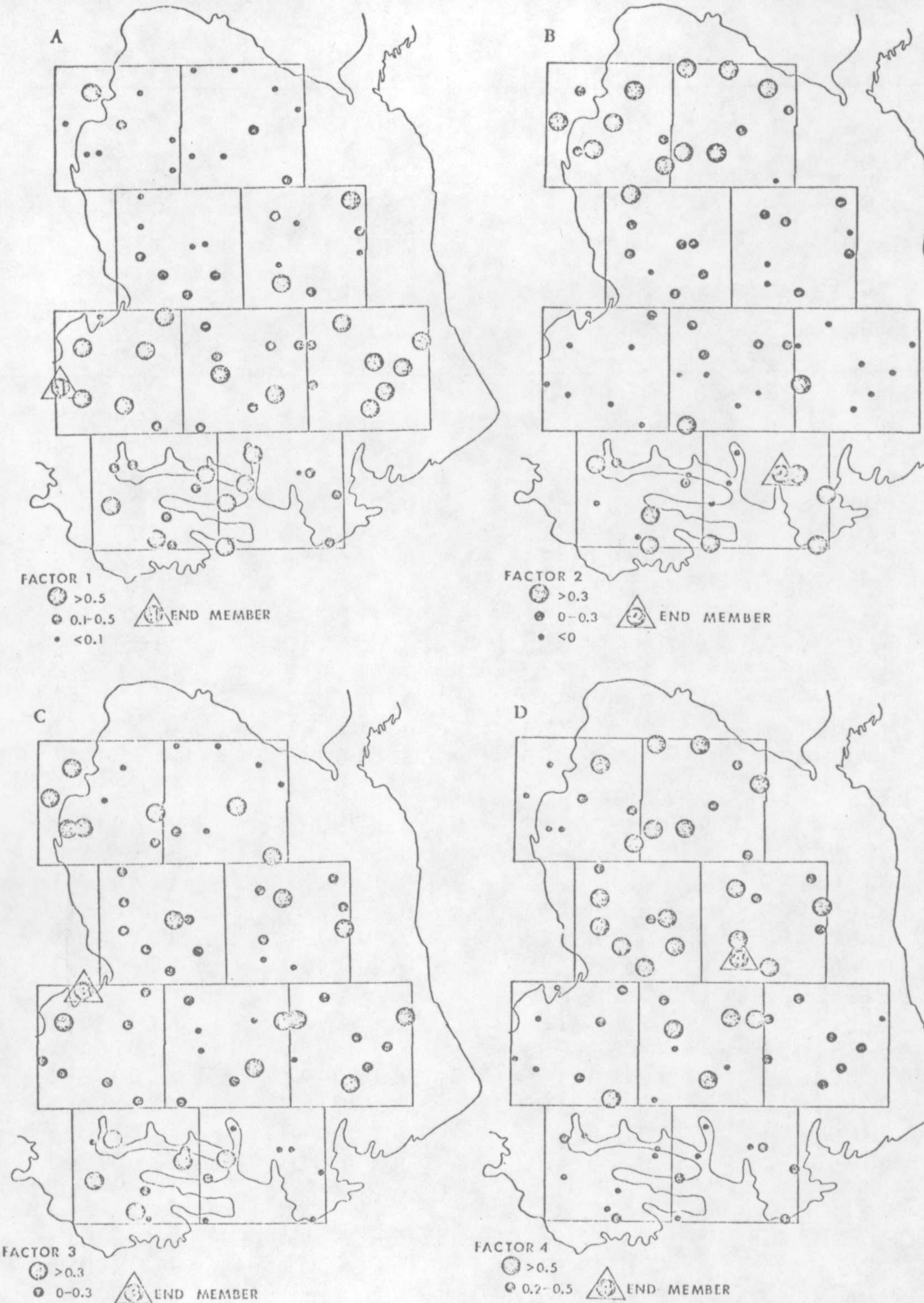


Figure 15.--Q-mode factor loadings for soils in the Piceance Creek Basin.

By following the mixing-proportion recipes for each element, compositions based on the Q-mode model can be computed for each sample and compared with the observed compositions for goodness of fit. Summary statistics of the observed (original) data and of those computed from the factor model are given in table 15.

The loadings (mixing proportions) are of use in evaluating the regional geochemical variability of surface soils within the Piceance Creek basin (fig. 15). In each map in figure 15, the loadings were grouped into three classes. The size of the circle assigned to each class, and plotted on each map, increases with increasing magnitude of the factor loading. For example, sample localities in figure 15A having the largest circles have the highest loadings for factor 1 (that is, those samples are most like end member 1), and those with the smallest circles have the lowest loadings for factor 1 (they are most unlike end member 1).

Results

Table 13 indicates that samples with high loadings on end member 1, (most like end member 252111KP) are probably the most trace-element rich of all samples in the study inasmuch as both the observed and computed compositions for the end member are distinctly high in oxides of Fe, K, Ti, Cu, Li, Mn, Mo, Ni, Pb, Rb, Sc, V, Y, Yb, and Zn. The prominence of transition elements in this composition suggests that the end member for factor 1 is distinctly clay-rich. Samples with highest loadings on factor 1 occur in the southern part of the Piceance Creek basin (fig. 15A).

Samples with high loadings on end member 2 will probably tend to be high in carbonate because of the prominence of the oxides of Ca, Mg, and carbon in this factor. Samples with high loadings on factor 2 occur in both the northern and southern parts of the basin (fig. 15B); samples with lowest loadings for factor 2 occur over most of the central part of the basin.

Soil samples with high loadings on factor 3 are scattered throughout the basin (fig. 15C), and should have relatively high concentrations of Si. Soil samples with high loadings on factor 4 were collected from the northern and central parts of the basin (fig. 15D), and tend to have relatively high concentrations of Na.

In general, samples which are compositionally similar to end members 1 and 4 will be distinctly high in the transition elements compared to samples similar to end members 2 and 3.

Discussion

The factor map patterns (fig. 15) can be related in a general way to the regional geology and hydrology of the Piceance Creek basin. Many soils in the northern and central parts of the study area are developed on sandstone of the Uinta Formation, and most soils in the southern part of the area are developed on finer-grained marlstones of the underlying Green River Formation (fig. 16). A few samples used in this investigation are from soils developed on sandstone of the Wasatch Formation which underlies the Green River Formation (fig. 16). In general, the Green River Formation contains higher concentrations of most trace and minor elements than sandstones of Eocene age in the same area (table 16). Therefore, soils developed on the Green River Formation would be expected to contain higher concentrations of most trace elements than soils developed on sandstones of either the underlying Wasatch Formation or the overlying Uinta Formation.

In a general way, the map pattern of factor 1 loadings (fig. 15A) is the inverse of the map pattern of factor 4 loadings (fig. 15D); samples with highest loadings for factor 1 are in the southern part of the basin, and those with highest loadings for factor 4 are in the central and northern parts of the basin. The end member sample for factor 1 is a soil developed on the upper part of the Parachute Creek Member of the Green River Formation, and the end member sample for factor 4 is a soil developed on sandstone of the Uinta Formation.

Ringrose and others (U.S. Geol. Survey, 1976, p. 101-111) have shown that several trace elements in these soils have concentration gradients across the basin, increasing from northeast to southwest similar to the map of factor 1. This pattern probably reflects an increasing contribution of Green River Formation to soil development. Samples with high loadings on factor 4 occur in the central and northern parts of the basin where concentrations of many trace elements in soils are lowest. These samples also tend to be Si-rich (table 13), reflecting the fact that most of these soils are developed on sandstone.

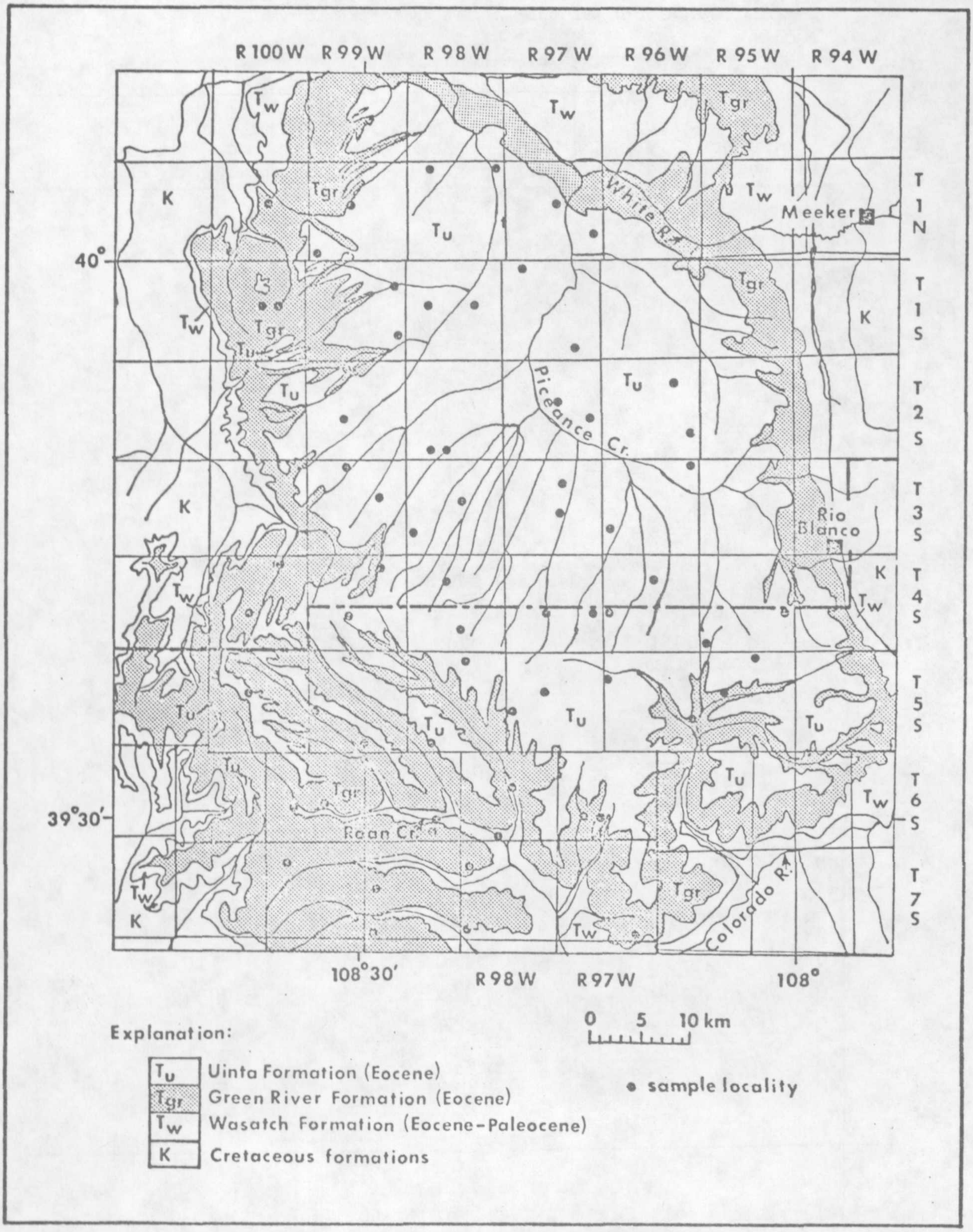


Figure 16. Geologic map of the Piceance Creek Basin (taken from Tweto, 1976).

Table 16 - Typical composition in percent of Green River oil shale and sandstone of the Wasatch Formation.

[-, no data]

oxide	probable average values for Green River oil shale (1)	geometric mean for Mahogany Zone of Green River Fm. (3)	geometric mean for Wasatch Formation, Piceance Cr. Basin (4)
Al_2O_3	6.8 (2)	-	6.0
CaO	7.2 (2)	-	2.0
Fe_2O_3	2.9	-	0.77
MgO	3.7	-	0.53
K_2O	2.6	-	1.3
SiO_2	31 (2)	-	81
Na_2O	2.1	-	0.68
TiO_2	0.22	-	0.27
CO_2	-	-	1.3
As_2O_3	0.0046	0.0038	-
B_2O_3	0.0230	0.0240	0.0052
BeO	-	0.0005	-
CoO	0.0013	0.0012	0.0004
Cr_2O_3	0.0051	0.0700	0.0012
CuO	0.0050	0.0061	0.0008
Ga_2O_3	0.0013	0.0013	0.0010
Li_2O_3	0.0210	0.0030	-
MnO	0.0320	0.0320	0.0150
MoO_3	0.0015	0.0026	-
NiO	0.0032	0.0420	0.0008
PbO	0.0022	0.0003	0.0008
Rb_2O	-	0.0013	-
Sc_2O_3	0.0012	0.0011	-
SrO	0.0350	0.1100	0.0110
V_2O_3	0.0150	0.0160	0.0034
Y_2O_3	-	0.0034	0.0010
Yb_2O_3	-	-	-
ZnO	0.0093	0.0022	-
UO_2	-	0.0005	0.0002

sources of data:

(1) U.S. Geol. Survey, 1976, p. 48-56.
(2) USGS Green River oil shale standard, SGR-1, Flanagan, 1976.
(3) Geometric mean of 12 composite samples from the Mahogany Zone, Poulson and others, 1977.
(4) Geometric mean of 12 composite samples from the Wasatch Formation, Piceance Creek Basin, Vine and Tourtelot, 1973.

The relatively high concentrations of Na and Sr in factor 4 soils are probably related to increased discharge of ground water containing high concentrations of these elements in the northern part of the basin (Weeks and others, 1974). For example, Coffin and others (1971) reported that Na concentrations in Piceance Creek increase from 600 mg/l in the headwaters in the east-central part of the basin to 2,000 mg/l at the confluence with the White River along the northern margin of the basin. This increase is the result of irrigation. Weeks and others (1974) estimate that approximately 80% of the runoff from Piceance Creek is due to ground-water discharge. The Na in the saline waters in the northern part of the basin is probably derived mainly from dissolution of nahcolite ($NaHCO_3$) within the Parachute Creek Member of the Green River formation. Ground waters in the northern part of the basin are also commonly saturated with respect to strontianite ($SrCO_3$) (George J. Saulnier, Jr., personal commun., 1977).

The loadings on factor 2 outline a pattern of high-carbonate soils in the northern and southern parts of the basin (fig. 15B). The occurrence of more carbonate-rich soils in the southern part of the basin is probably related in part to the fact that most soils there are developed on carbonate-rich strata of the Green River Formation. However, ground water may also contribute to the relatively high carbonate content of soils in the southern part of the basin. For example, the end member sample for factor 2 is from a soil developed on the upper part of the Parachute Creek Member of the Green River Formation in a zone characterized by numerous springs (Chew, 1974) that precipitate a white coating of calcium carbonate. In fact, calcium carbonate-rich springs are common both above and below the Mahogany Zone in the upper part of the Parachute Creek Member in the southern part of the basin.

Ground water may also be an important contributor of carbonate to soils in the northern part of the basin. Springs in the northern part of the basin usually form white coatings, travertine mounds, and flowstone of calcium carbonate. Many of the springs are associated with a fracture system that trends approximately N 70 W across the northern part of the basin (George J. Saulnier, Jr., personal commun., 1977). This fracture system apparently acts as a means of transporting ground water from a lower aquifer consisting of fractured marlstone in the Parachute Creek Member of the Green River Formation. The lower aquifer in the northern part of the basin is characterized by very high concentrations of sodium and bicarbonate (several thousands of mg/l each) resulting from the dissolution of nahcolite from the lower part of the Parachute Creek Member (Weeks and others, 1974).

Above the Mahogany Zone is a second aquifer in fractured marlstone of the Parachute Creek Member and fractured sandstone of the lower part of the overlying Uinta Formation. Water in the upper aquifer is also high in sodium and bicarbonate, but concentrations are about an order of magnitude lower than concentrations in the lower aquifer (hundreds rather than thousands of mg/l). The upper aquifer also contains about 50 mg/l each of magnesium and calcium, about an order of magnitude higher than concentrations of these two ions in the lower aquifer (Weeks and others, 1974). Ground waters from both aquifers are usually saturated or supersaturated with respect to calcium carbonate. Waters from either of these two aquifers, or a mixture of the two, introduced into soils by springs could result in precipitation of calcium carbonate and possibly sodium carbonate.

Samples with high loadings on factor 3 are scattered throughout the basin and show no regional trend (fig. 15C). The end member sample for factor 3 is from a soil developed on sandstone of the Wasatch Formation underlying the Green River Formation. Table 13 indicates that factor 3 soils tend to be among the most silica-rich in the basin. They may represent a residuum of high-Si samples which do not fit into factor 4 because of low Na and Sr. Because the high concentrations of Na and Sr in factor 4 soils may reflect additions of ground water, factor 3 and factor 4 soils may both be sandstone-derived soils but with the addition of dissolved salts from ground-water as a distinguishing characteristic of factor 4 soils.

STREAM SEDIMENT GEOCHEMISTRY OF THE NORTHERN GREAT PLAINS

by James M. McNeal

The sampling design, sample collection and preparation procedures used in this study were described in U.S. Geological Survey (1976, pp. 14-21). Total element chemical analyses for an additional 32 elements have been completed and preliminary results are reported here. For completeness, the 8 elements previously reported are included. A sample location map is shown in Figure 17.

Two analysis of variance designs were used in this study. The first is a two-way design used to test differences between stream orders and between regions. The second is a nested one-way design which is used to determine the magnitude of regional geochemical variablity due to differences between regions, differences between streams, error due to sampling, and error due to all other effects including the analytical procedures. Linear correlation coefficients between element concentrations and stream drainage basin size for each of the three orders were examined to determine the effect of drainage area on stream sediment composition.

Chemical Analyses

The samples were analyzed by chemists of the U.S. Geological Survey. W. Mountjoy, I. C. Frost, and L. Lee used atomic absorption to determine Li, MgO, Na_2O and Rb. Zn was determined by a J. G. Crock using atomic absorption. A wet-digestion procedure followed by flameless atomic absorption analysis was used by J. A. Thomas and G. O. Riddle to determine Hg. V. E. Shaw analyzed the samples for total carbon. Delayed neutron activation analysis was used to determine U and Th. The analysts were H. T. Millard, P. J. Knight, A. J. Bartel, J. P. Hemming, R. J. White, R. J. Vinnola, and E. Brandt. X-ray fluorescence was used by J. S. Wahlberg, W. J. Walz, and J. W. Baker to determine Al_2O_3, CaO, Fe_2O , K_2O, P_2O_5, S, SiO_2, and TiO_2. As, Ge, Se, and Sn were determined by J. S. Wahlberg and J. W. Baker using a sulfide precipitation procedure and analysis by X-ray fluorescence. The remaining elements (B, Ba, Be, Ce, Co, Cr, Cu, Ga, La, Mn, Mo, Ni, Pb, Sc, V, Y, Yb, and Zr) were determined by J. M. Gardner, K. E. Horan, R. M. Lambert, and M. W. Solt using emission spectrography. The details for these procedures are given in U.S. Geological Survey (1975).

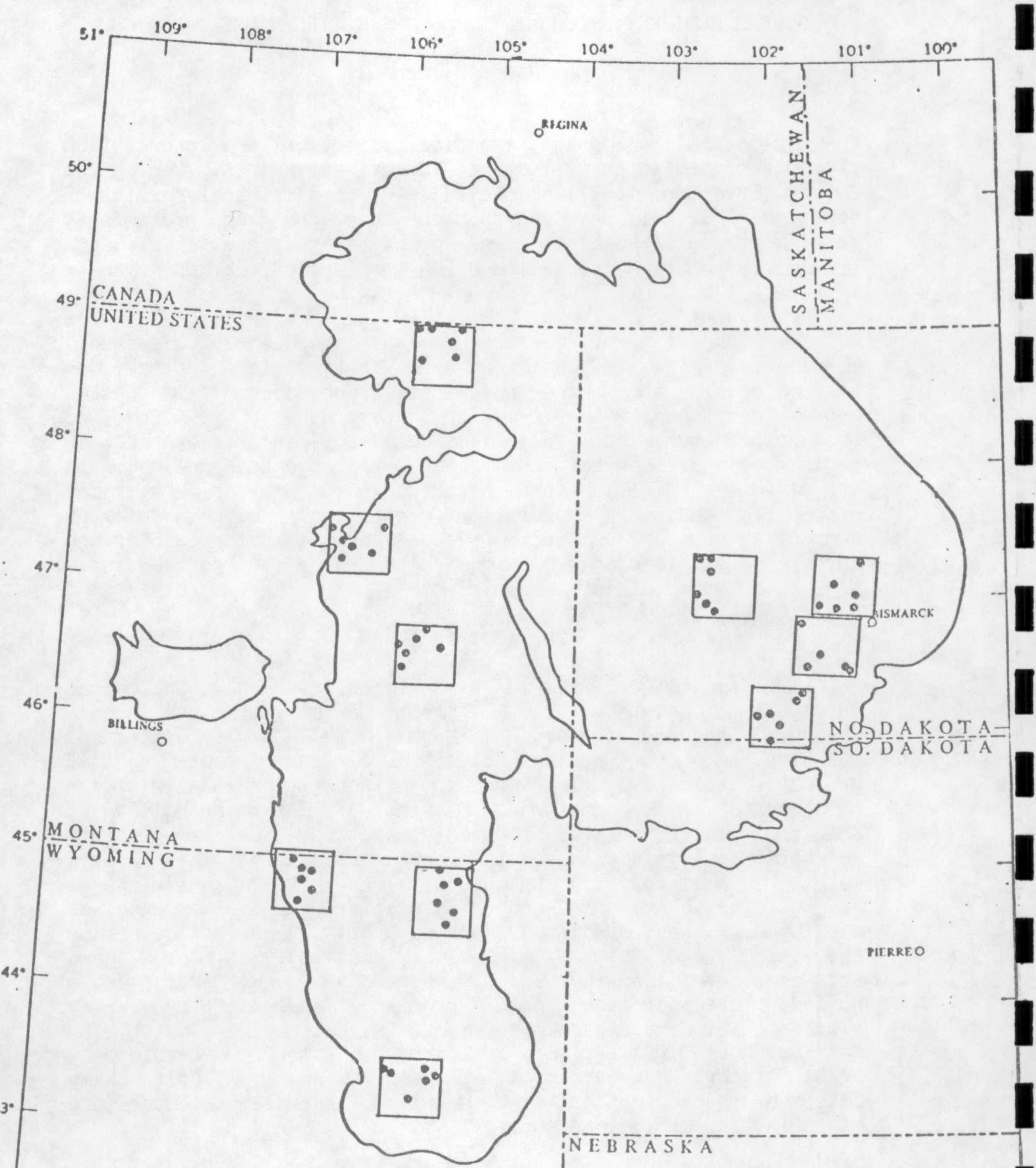


Figure 17.--Stream sediment sampling localities in selected regions of the Northern Great Plains. Regions are 50 km^2.

Results and Discussion

The results of the two-way analysis of variance test are shown in Table 17. This test was based on two stream sediment samples for each of three stream orders in each of 10 regions for a total of 60 samples. The test compared variances for regions, stream orders, and a region by stream order interaction against an error variance. Of the 40 elements shown in Table 17 only U had a significant ($\alpha \leqslant .05$) interaction. For the remaining 39 elements, the interaction variance was pooled with the error variance and the F-ratios shown in Table 17 are from the pooled estimates.

The results in Table 17 indicate that only C, MgO, and TiO_2 have significant differences ($\alpha \leqslant .05$) between stream orders. This means that in general the size of a stream is not an important control on the composition of stream sediments of the Northern Great Plains. However, Table 17 does show that 18 elements vary significantly between the 10 regions, indicating regional controls on composition. These controls include climate, topography, and the nature of the bedrock.

The results of the one-way nested analysis of variance design are given in Table 18. The nested levels included in this design were: 1. between regions, 2. between streams, 3. sampling error, and 4. analytical error. Because the two-way analysis of variance showed that only three elements differed between stream orders, the two streams of each of the three orders have been combined giving six streams for each region for the remaining 37 elements or oxides. The results for the between regions test for both one-way and two-way analysis of variance tests are similar. There were 16 elements that showed significant differences by both tests; 2 elements showed significant differences only by one-way analysis of variance; and 2 additional elements showed significant differences between regions only by two-way analysis of variance. Baseline data are presented in Table 18 for the 23 elements that showed no significant differences by either of the analysis of variance tests. Only 10 of 46 entries in Table 18 show a sampling error that accounts for more than a fifth of the total variance, indicating that the method of collecting a composite sample from over several tens of meters stream length can provide a fairly representative sample of stream sediment for a stream segment of several hundred meters in length. The results in Table 18 also show that 35 elements exhibit significant differences at the between streams level. Thus, for the most part, streams from within a 50 km^2 region are likely to be of significantly different chemical composition and mineralogy.

Table 17.--F-ratios for two-way analysis of variance design for stream sediments of the Northern Great Plains, testing differences between ten regions and three stream orders

[An asterisk (*) or double asterisks (**) indicates that the F-ratios are significantly different at the 0.05 or 0.01 probability levels, respectively]

	F-ratio				
Element	Stream order	Region	Element	Stream order	Region
Al_2O_3 --	0.37	1.69	Mo ----	0.67	1.10
As -----	2.45	1.02	Na_2O --	.57	21.4**
B ------	2.27	2.34*	Nb ----	1.75	1.13
Ba -----	1.21	3.73**	Ni ----	1.11	3.72**
Be -----	1.80	1.41	Pb ----	.68	2.30*
C ------	3.54*	1.10	Rb ----	.58	3.19**
CaO ----	2.02	1.59	S -----	.05	1.99
Ce -----	1.28	1.15	Sc ----	.19	1.51
Co -----	.16	2.74*	Se ----	1.13	1.22
Cr -----	1.18	2.30*	SiO_2 --	2.95	.28
Cu -----	.53	2.54*	Sn ----	1.37	2.22*
Fe as Fe_2O_3-	2.65	1.05	Sr ----	.74	1.42
Ga -----	.77	2.26*	Th ----	.45	2.27*
Ge -----	1.34	.86	TiO_2 --	4.03*	3.21**
Hg -----	.73	5.27**	U[1/] ----	1.21	10.8**
K_2O ----	.75	3.47**	V -----	.93	2.36*
La -----	2.87	1.00	Y -----	1.64	.82
Li -----	1.33	1.04	Yb ----	.52	.83
MgO ----	3.46*	8.68**	Zn ----	1.44	1.78
Mn -----	1.57	1.28	Zr ----	1.47	.75

1/ Significant (α = .05) interaction term.

Table 18.--Geochemical variation in stream sediments of the Northern Great Plains

[*An asterisk* (*) *indicates* that the *variance* component is *significantly* different from zero of the 0.05 probability level. Data in parts per million, except when given as percent]

Constituents, and stream order, if given	Total Log_{10} variance	Variance components, as percent of total				Summary statistics			Expected 95 percent range (baseline)	Detection ratio	v_m	80 percent n_r
		Between regions	Between streams	Sampling error	Analytical error	Geometric mean	Geometric deviation	Geometric error				
Al_2O_3, % ---	0.0059	12*	45*	< 1	43	9.47	1.19	1.12	7.25-12.37	110/110	0.95	7
As ---------	.0336	< 1	34*	18	48	5.5	1.53	1.34	3.0-10.1	110/110		
B ----------	.0125	14*	17	< 1	69	56	1.29	1.24	-------	110/110	.98	6
Ba ---------	.0158	35*	29*	< 1	36	540	1.34	1.19	-------	109/110	1.62	3
Be ---------	.0377	6	30*	< 1	64	2.0	1.56	1.43	1.2-3.4	110/110		
C, total),%, 1	.0738	26	58*	16*	< 1	2.25	1.87	< 1.06	.64-7.87	37/37		
2	.0277	< 1	51	49*	< 1	2.62	1.47	< 1.04	1.21-5.66	37/37		
3	.0206	11	60*	29*	< 1	1.80	1.39	< 1.03	.93-3.48	36/36		
CaO, % -----	.0518	10	84*	6*	< 1	3.51	1.69	< 1.05	1.24-9.96	110/110		
Ce ---------	.0808	4	15*	< 1	81	57	1.92	1.80	32-101	108/110		
Co ---------	.0163	27*	51*	< 1	22	7.3	1.34	1.15	-------	110/110	1.48	4
Cr ---------	.0453	25*	4	40*	32	72	1.63	1.32	-------	110/110	1.33	4
Cu ---------	.0239	24*	43*	22*	11	22	1.43	1.13	-------	110/110	1.26	4
Fe_2O_3, % ---	.0119	< 1	84*	15*	< 1	3.33	1.29	< 1.03	2.02-5.49	110/110		
Ga ---------	.0263	12*	51*	< 1	37	11	1.45	1.26	-------	110/110	.95	7
Ge ---------	.0158	5	35*	< 1	61	1.2	1.34	1.25	.8-1.7	110/110		
Hg ---------	.0158	24*	30*	11	35	.055	1.34	1.19	-------	110/110	1.26	4
K_2O, % -----	.0014	30*	62*	7*	2	1.99	1.09	1.01	-------	110/110	1.71	4
La ---------	.0127	2	23	< 1	75	35	1.30	1.25	27-45	110/110		
Li ---------	.0057	< 1	60*	36*	3	19	1.19	1.03	13-27	110/110		
MgO, %, 1 --	.0110	50*	45*	5*	< 1	1.63	1.27	< 1.02	-------	37/37		
2 --	.0251	55*	42*	4*	< 1	1.90	1.44	< 1.04	-------	37/37		
3 --	.0263	87*	13*	< 1	< 1	1.62	1.45	< 1.04	-------	36/36		
Mn ---------	.0421	4	71*	13*	12	440	1.60	1.18	180-1,070	110/110		
Mo ---------	.0849	< 1	25*	< 1	75	4.8	1.96	1.79	2.4-9.4	99/110		
Na_2O, % ----	.0792	83*	14*	3*	< 1	.96	1.91	< 1.07	-------	110/110	9.76	2
Nb ---------	.0499	< 1	21*	< 1	78	7.2	1.67	1.58	4.4-11.7	110/110		
Ni ---------	.0199	36*	38*	3	24	24	1.38	1.17	-------	110/110	1.69	3
Pb ---------	.1032	19*	20*	< 1	62	5.9	2.10	1.79	-------	104/110	1.17	5
Rb ---------	.0056	36*	33*	18*	13	70	1.19	1.06	-------	110/110	1.69	3
S(total), %	.0734	19*	45*	17*	19	.12	1.87	1.31	.04-.37	86/110	1.17	5
Sc ---------	.0349	9	48*	< 1	42	7.8	1.54	1.32	4.0-15.0	108/110		
Se ---------	.0630	< 1	29*	6	65	.19	1.78	1.59	.10-.38	90/110		
SiO_2, % ----	.0014	< 1	75*	23*	3	63.1	1.09	1.02	53.2-74.8	110/110		
Sn ---------	.0191	6	39*	< 1	55	.97	1.37	1.27	.63-1.49	110/110		
Sr ---------	.0221	8	71*	2	19	300	1.41	1.16	162-556	110/110		
Th ---------	.0153	32*	< 1	26	5	9.4	1.33	1.07	-------	107/110	1.41	3
TiO_2, %, 1 -	.0026	< 1	79*	9	11	.54	1.12	1.04	-------	37/37		
2 -	.0045	30	60*	4	6	.55	1.17	1.04	-------	37/37		
3 -	.0070	27	51*	22*	1	.60	1.21	1.02	-------	36/36		
U ----------	.0200	47*	24*	13	16	3.4	1.38	1.14	-------	110/110	2.66	3
V ----------	.0165	19*	43*	14	24	73	1.34	1.16	-------	110/110	1.17	5
Y ----------	.0090	< 1	35*	26	39	21	1.24	1.15	15-30	109/110		
Yb ---------	.0169	< 1	29*	< 1	71	3.0	1.35	1.29	2.2-4.1	110/110		
Zn ---------	.0076	< 1	61*	2	37	71	1.22	1.13	52-98	110/110		
Zr ---------	.0307	< 1	< 1	37	63	350	1.50	1.38	214-572	109/110		

Simple correlation coefficients between elements and drainage basin area were examined to determine if the size of drainage basin or the distance sediment may have traveled influenced the element content of the stream sediments. Four sets of comparisons were made; one for each of the three stream orders and one for all three stream orders included together. At most only six significant ($\alpha \leqslant .05$) correlations were found for the 160 correlation coefficients examined. Five of the six were negative. The six are: log Ce ($r = -.461$) for first order streams; log Li ($r = -.450$), log Rb ($r = -.453$), and log Zn ($r = .444$) for second order streams; none for third order streams; and log TiO_2 ($r = .324$) and log Zn ($r = -.300$) for all three orders. Thus stream drainage basin size does not appear to influence the composition of these stream sediments to any important degree. This is in agreement with the results of the two-way analysis of variance test which also showed that stream orders do not significantly influence the element content of stream sediments.

Summary statistics for the elements determined in this study are listed in Table 18. The detection ratio is the number of samples in which the constituent was determined compared to the total number of samples analyzed. For the analysis of variance tests values below the detection limit were replaced with a value .7 times the log value of the detection limit. The variance mean ratio, V_m, is the ratio of variance among regions to the error variance within regions. This value is an indication of the stability of the observed differences seen among the region averages. Where V_m is at least 1.0, minimal stability is present. The value N_r is the estimated number of random samples required from each region in order to describe at least the gross compositional differences between regions. For the three elements that have significant differences due to stream order, C, MgO, TiO_2, the summary statistics are given for each stream order. All data discussed in this report were logarithmically transformed before any computations were made. Expected 95% ranges (baselines) are given for those elements that were found not to have significant differences between stream orders by two-way analysis of variance and that do not have significant differences between regions by one-way analysis of variance. The geometric means do not include analytical duplicates or samples collected to test for sampling error. Thus each mean is derived from 20 samples or 60 samples depending on whether there were differences between stream orders.

Conclusions

The results of this study lead to three tentative conclusions. The first is that compositing stream sediments from over a few tens of meters of stream length gives a reliable sample for a several hundred meter portion of the stream. The second is that the size of a stream as indicated by stream order or the size of the drainage basin does not greatly affect the composition of the stream sediments. The third is that the chemical composition of the sediments tends to vary at regional (>50 km) and local (.1 - 5 km) levels. This means that stream sediment samples from the Northern Great Plains can generally be collected without regard to stream size. It should be noted that the streams in this study included both dry streams and flowing streams, and drainage basin size ranged from about 10 km^2 to 4000 km^2.

AVAILABILITY OF ELEMENTS IN SOILS TO NATIVE PLANTS, NORTHERN GREAT PLAINS

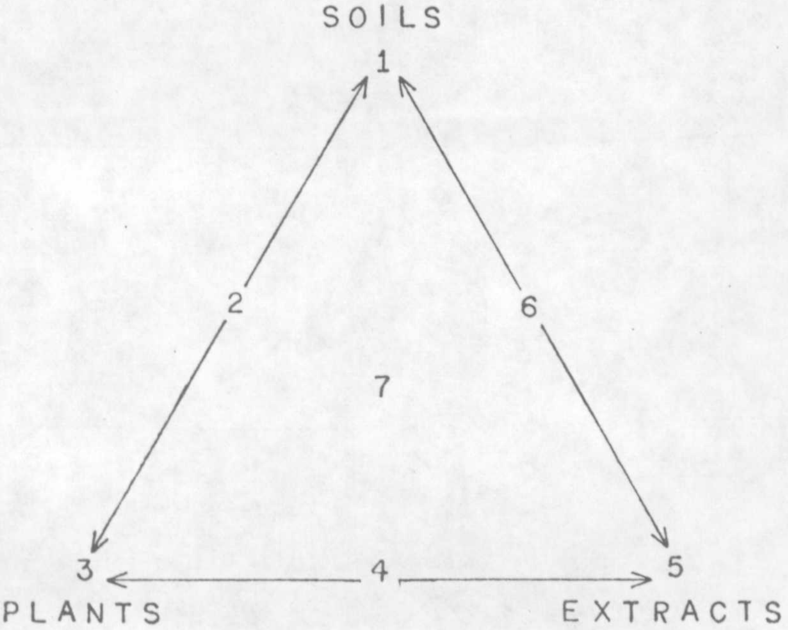
By Ronald C. Severson, Larry P. Gough and James M. McNeal

INTRODUCTION

The investigation of functional relations between element concentrations in plants and supporting soils over large geographic areas has not received much attention in the literature. Where information is available, the general conclusion is that most correlations are dubious (Erdman, Shacklette, and Keith, 1976; Gough and Severson, 1976; Lounamaa, 1956; Prince, 1957; Severson and Gough, 1976; Shacklette, Sauer, and Miesch, 1970). In all of these studies, the soils were completely dissolved or fused before analysis and the reported values were for total element concentrations.

Other authors have had success in relating plant chemistry to soil chemistry over limited geographic areas when the elements in soil were measured in a soil extract of some kind (Follett and Lindsay, 1971; Lindsay and Norvell, 1969; Randall, Schulte, and Corey, 1976; Rule and Graham, 1976; Shuman and Anderson, 1974). In general, these types of studies have focused on increases in yield of field crops following addition of elements to soils.

In the pilot study discussed here, we attempt to assess the relation between the chemistry of native plants and uncultivated soils over a broad geographic region. We are presently working in areas that have been, or may be, subject to strip-mining and subsequent reclamation. It is our purpose to evaluate chemical soil-extraction methods and to identify those methods that best estimate element utilization by native plants growing on uncultivated or mine-reclaimed soils. In addition, we are investigating other selected chemical, physical, and mineralogical properties of soil that appear to influence element availability. A diagrammatic representation of the relations that are examined in this study is shown in Figure 18.



RELATIONS

- 1 Within soils
  - A horizon
  - C horizon
- 2 Between soils and plants
- 3 Within plants
  - wheatgrass
  - sagebrush
  - biomass
- 4 Between plants and extracts
- 5 Within extracts
  - DTPA unground soil
  - DTPA ground soil
  - DTPA sieved soil
  - EDTA unground soil
  - oxalate unground soil
- 6 Between extracts and soils
- 7 Between soils, plants, and extracts

Figure 18. Diagram showing soil-plant-extract relations.

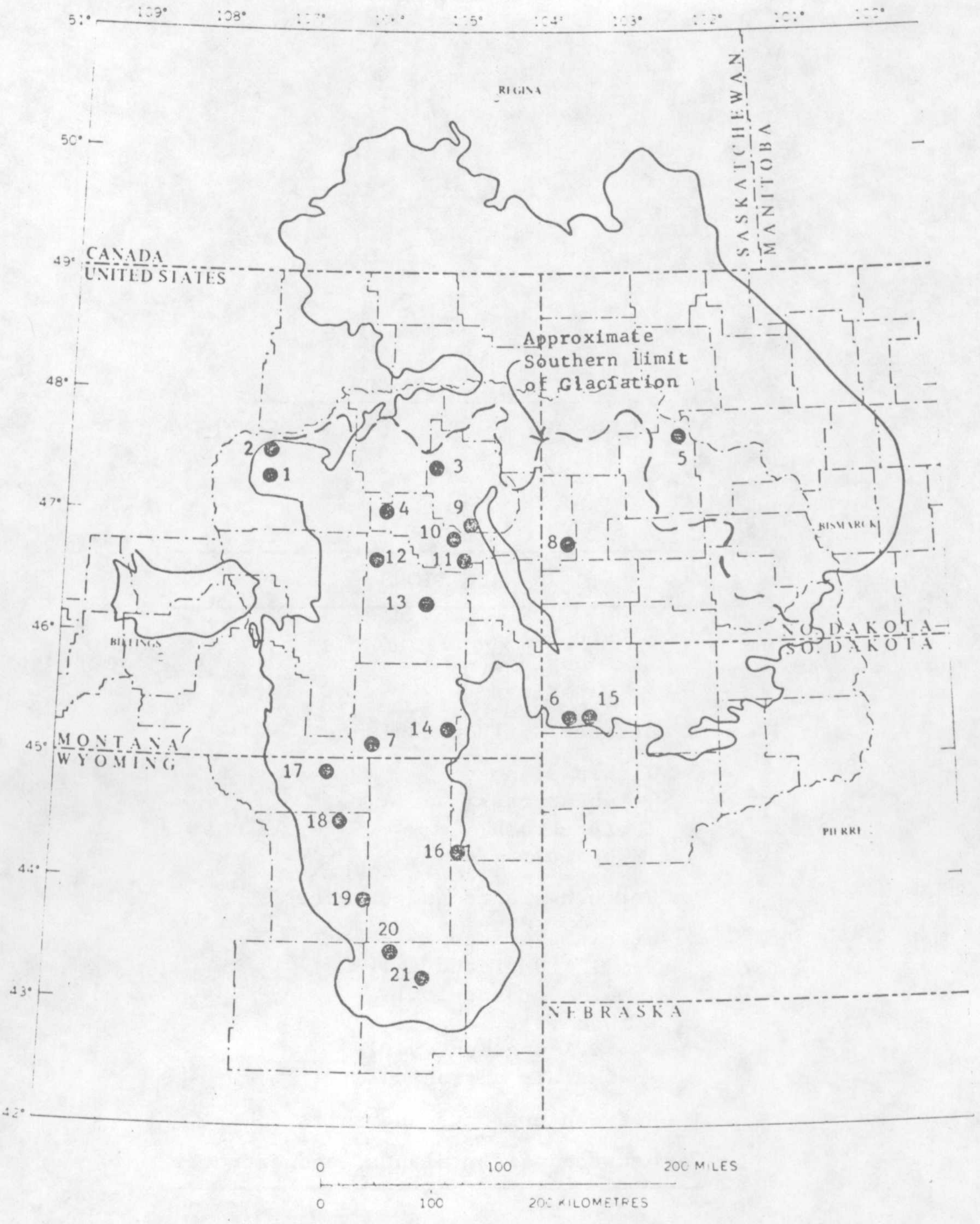


Figure 19.--Map showing sample site locations in the Northern Great Plains.

METHODS

Sampling Locations

Samples were collected in the unglaciated portion of the Northern Great Plains Coal Province (Fig. 19). We selected this area because of its potential for large-scale surface mining and because previous work on spatial variability in total soil chemistry was available (U. S. Geol. Survey, 1976, p. 57-81). Data from that report were used to classify potential sampling locations based on diversity in soil chemistry. From Q-mode factor analysis of the chemical compositions of 88 potential sampling sites, we extracted four factors that accounted for 90 percent of the total observed variance. These factors were considered to represent the minimum number of fundamentally different kinds of soil (or end member compositions) within the study area. Four locations (three in the case of one of the factors) of each kind of soil were selected as being representative of each end member composition. Three additional locations were chosen that exhibited compositions intermediate to all of the factors. Finally, another three locations, whose composition was only poorly defined by the four factors, were selected. Thus, a total of 21 sampling sites were chosen, 15 with high loadings on one of the four factors, three with intermediate loadings on all factors, and three representing samples of unusual composition based on a four-factor model. Summary statistics for total chemistry of these sampling sites is given in Table 19 and their factor loadings are given in Table 20.

In the field, samples were collected close to 19 of the 21 preselected locations. Sites 6 and 7 were relocated because of unavoidable obstacles in the field.

Plant Samples

Field Collection

We collected Agropyron smithii Rydb. (western wheatgrass) and a sample representative of the standing crop (grasses, forbs, and shrubs) at all 21 sampling sites. We collected Artemisia cana Pursh (silver sagebrush) at 19 of the 21 sites. All samples consisted of current year's growth, and therefore the sagebrush and standing crop samples were composed mainly of leaves, stems, and inflorescences; due to grazing, however, most of the wheatgrass samples lacked inflorescences and consisted only of leaves and stems.

Wheatgrass and sagebrush represent a diversity in growth form, physiology, rooting behavior, and overall grassland niche. These forms also represent different utilization by wild and domestic animals. By sampling more than one kind of plant, therefore, we hoped to better assess the utility of several soil extractants.

The sampling sites were defined by a single 50 m^2 macroplot (7.07 X 7.07 m) located as close as possible to the sites from which the original geochemical survey soil samples were obtained. The position of the macroplot, however, was ultimately dictated by the presence of the target plant species. Each corner of the macroplot was clearly marked and the area photographed.

Three 1 m^2 circular quadrats were randomly located within the macroplot. All herbaceous vegetation inside the quadrats was clipped and composited along with the current year's growth of any woody shrubs that hung over Prior to clipping, an inventory of the circular quadrats was made noting the species present and their relative dominance using a cover-abundance scale.

Laboratory Preparation

A standing crop estimate (in units of kg/ha of dry plant material) was made by first drying the samples for seven days at 40°C and then weighing them. The weight of the samples was then divided by three (as the samples were composites of clippings from three individual square-meter microplots) to arrive at units of g/m^2.

Contamination of plant material by dust can potentially confuse any meaningful relations between plant chemistry and soil chemistry. It is important, therefore, that samples of plant material judged to be "excessively" contaminated be washed in a manner most effective in removing colloidal-sized as well as granular-sized particles. It should be realized, however, that any washing procedure may leach elements and substances from the intra- and intercellular plant spaces. In this study, the wheatgrass and standing crop samples all were judged to be excessively contaminated and all were washed using the method of Gough and Severson (1976). The sagebrush samples were not washed because we found, in a chemical comparison of several suites of sagebrush samples, that the washing procedure seems to make little difference.

Table 19.--Summary statistics for total element composition of 21 surface soil samples from the unglaciated area of the Northern Great Plains coal region (data from R. R. Tidball and R. C. Severson, personal communication, 1977).

Element, unit of measure	Arithmetic mean	Observed range
C, %------	1.8	0.7 - 3.8
Ca, %-----	1.4	.01 - 7.0
Co, ppm---	7.4	2.8 - 23
Cr, ppm---	46	15 - 85
Cu, ppm---	18	4.3 - 31
Fe, %-----	2.3	.88 - 6.5
K, %------	1.9	1.5 - 2.7
Mg, %-----	.84	.24 - 2.2
Mn, %-----	.049	.011- .38
Mo, ppm---	3.8	.74 - 11
Na, %-----	.81	.22 - 1.5
Ni, ppm---	12	4.3 - 64
Pb, ppm---	18	10 - 31
Rb, ppm---	78	52 -101
S, %------	.064	.028- .26
Zn, ppm---	62	14 -174

Table 20.--Loadings on four Q-mode factors for 21 samples, selected from a suite of 88 surface soil samples, from the unglaciated area of the Northern Great Plains coal region (data from R. R. Tidball and R. C. Severson, personal communication, 1977).

Sample number	Communality	Loading on factor 1	2	3	4
1	0.95	0.24	0.90	-0.19	-0.22
2	.96	.86	.26	-.40	-.07
3	.94	.32	.47	-.50	-.62
4	.61	.29	.26	-.58	-.35
5	.98	.89	.26	-.34	-.04
6	.97	.84	.30	-.41	-.05
7	.93	.54	.42	-.57	-.37
8	.76	.19	.44	-.37	-.63
9	.94	.39	.35	-.49	-.65
10	.97	.17	.86	-.33	-.30
11	.94	.23	.94	-.10	-.01
12	.67	.43	.30	-.62	-.02
13	.94	.42	.53	-.69	-.27
14	.97	.63	.50	-.58	-.10
15	.98	.92	.21	-.15	-.26
16	.94	.30	.21	-.87	-.21
17	.94	.20	.41	-.80	-.33
18	.65	.35	.29	-.59	-.30
19	.96	.34	.31	-.80	-.33
20	.84	.19	.16	-.33	-.82
21	.97	.43	.23	-.79	-.33
	Percent variance explained	26.2	22.1	30.9	11.8

All samples were ground to pass a stainless steel screen with 1-mm openings, homogenized, and then ashed and digested using standard methods in U. S. Geological Survey (1975, p. 74-78). Concentrations of 12 elements were determined using a Perkin-Elmer Model 306 atomic absorption spectrophotometer.[1] Concentrations of Ca, Cu, Fe, K, Mg, Mn, Na, and Zn were determined from a digestate using 1 g of ash (either in a 1/50 or a 1/2500 dilution); concentrations of Cd, Co, Ni, and Pb were determined by DADC-MIBK chelation-extraction on the 1/50 dilution. All sample preparations and analyses were performed by the authors.

Laboratory error for individual elements was determined by analyzing splits of the standing crop samples. Nineteen splits were added to the 64 field samples and the entire suite of 83 samples was analyzed in a randomized order.

Soil Samples

Field Collection

At each site, a soil pit was excavated by hand adjacent to, but outside of, the 50 m^2 macroplot. Each of the soil horizons and its morphologic features were described using standard techniques and criteria (U. S. Dept. Agriculture, 1951). A- and C-horizon soils were collected from each of the three 1 m^2 circular quadrats.

Samples of the A horizon were collected by shaving the soil with a garden spade from the surface down to the underlying soil horizon contact. The material collected was passed through a stainless steel sieve with 1 cm openings. Large roots, plant debris, and rocks that did not pass the screen were discarded. The three A-horizon sieved samples were composited in the field. Commonly, more than 95 percent of the A-horizon soil material passed the 1 cm sieve.

A sample of the C horizon was collected at each of the three 1 m^2 quadrats by augering to the overlying soil horizon contact (this point was previously defined from examination of the soil pedon in the pit exposure) and extracting a 30 cm section. In cases where a lithologic discontinuity was noted at depths of less than 30 cm into the C horizon, the sample consisted of only soil collected between the top of the C horizon and the top of the discontinuity. The three C-horizon samples were sieved (1 cm screen) with the fine material being composited to make one sample. Material larger than 1 cm was discarded. More than 95 percent of the C-horizon material passed the 1 cm sieve in all

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[1] The use of trade names throughout this report is for the convenience of the reader and does not constitute endorsement by the U. S. Geological Survey.

cases.

Laboratory Preparations

All soil samples were dried in the laboratory at ambient temperature with forced air. The samples were disaggregated in a mechanical mortar-and-pestle and passed through a 10 mesh (2-mm) stainless steel sieve. For all samples, more than 95 percent of the material passed the 10 mesh sieve. After disaggregating, 10 of the 21 A-horizon samples and 10 of the C-horizon samples were randomly selected for splitting and used for duplicate analyses. This resulted in a total suite of 62 samples.

The minus 2-mm material was split into three parts. For the first split, no further preparation was required; the second split was ground in a ceramic mill to pass a 100 mesh sieve (150 um), and the third split was dry sieved (100 mesh) with the material passing the sieve being saved. Therefore, three types of soil material for each of the A- and C- horizon samples were analyzed; <2 mm, <2 mm ground to <150 um, and <2 mm sieved through a 150 um sieve. All sample preparations were performed by Jane Dixon, R. E. McGregor, Mike Pantea and the authors.

Soil Extraction and Chemical Analyses

Three different extraction solutions were used in this study. The first, DTPA (diethylenetriaminepentaacetic acid), is essentially that of Lindsay and Norvell (1969) which consists of a solution of 0.005 M DTPA, 0.1 M triethanolamine, and 0.01 M calcium chloride at pH 7.30. It is obvious that the use of calcium chloride in this extracting solution precludes the possibility of determining Ca removed from the soil. This extraction is commonly used in testing soil for the availability of elements in soils to plants. The second extract, EDTA (ethylenediaminetetraacetic acid), consists of 0.01 M EDTA in a solution of 1.0 M of ammonium acetate at pH 7.0. As the sodium salt of EDTA was used in preparing the solution, Na could not be determined in the extractant solution. This extractant was selected because it was one of the best reported by Randall, Schulte, and Corey (1976) in predicting plant manganese content from extractable soil Mn and other soil factors. In addition, ammonium acetate is a commonly used extractant for other soil tests. The third extractant was 0.2 M ammonium oxalate at pH 3.0. The procedure is essentially that of McKeague and Day (1966). The ammonium oxalate dissolves Fe and Mn oxides. In light the solution dissolves amorhphous and well-crystallized Fe and Mn oxides, but in darkness it dissolves only the more amorphous of these oxides. As the bulk of the available elements in soils may be associated with the amorphous Fe and Mn oxides, the reaction was performed in darkness for this experiment.

Soil extractions were performed by the following method: 15.0g of soil was placed in a 125 ml Erlynmeyer flask; 30.0 ml of the extracting solution was added (soil:solution ratio is 1:2); the flasks were stoppered and placed on a reciprocal shaker for 2 hours. After shaking, the solution was decanted into a 50 ml test tube and centrifuged at 1900-2000 rpm for 30 minutes using an International No. 2 centrifuge. After centrifuging, the organics and other coarse material remaining in suspension were removed by filtering through a coarse, acid-washed filter paper (Whatman 541) and the solution was collected in acid-washed polyethylene bottles. The solutions were acidified to about pH 3 with 5 drops of concentrated nitric acid in order to prevent adsorption of the elements by the bottle.

The samples were analyzed for Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, and Zn by atomic absorption using a Perkin-Elmer Model 306 spectrophotometer. The recommended standard procedures were generally used except when the element being determined was well above background and the response was not linear. In these cases either the burner head was rotated to a position not parallel to the beam or a less intense line was used. Improved sensitivity was possible with Cd and Pb as electrodeless discharge lamps were used. Calcium and Mg, and sometimes K or Na, were determined on a solution of 1/50 dilution containing 1% La. The other elements were determined on the stock solution. All standards had the same bulk chemical composition as the samples in order to reduce matrix differences between standards and samples. All analyses were performed by Jane Dixon and the authors.

Total Soil Analyses

All 62 soil samples were analyzed in laboratories of the U. S. Geological Survey, Denver, Colorado. Total carbon was determined by a combustion-thermal-conductivity detection method and carbonate carbon was determined by a gasometric method (Miesch, 1976a, p. 12-14). Organic carbon was measured as the difference between total and carbonate carbon. Ca, Cu, Fe, K, Mg, Na, and Zn were determined in solution by atomic absorption following dissolution of the sample (Miesch, 1976a, p. 12-14). Data from a semi-quantitative, multi-element, emission spectrograph were used for the remaining elements and this analytical method is detailed in Myers, Havens, and Dunton (1961) and in Miesch (1976a, p 14-15). The sample preparations and analyses were performed by P. H. Briggs, J. G. Crock, Carol Gent, M. J. Malcolm, R. E. McGregor, and G. O. Riddle.

Soil Chemical Properties

We determined cation-exchange capacity (CEC), pH, and carbon (two independent methods) on both A- and C-horizon soils. The method for determining CEC is detailed by Chapman (1965). To summarize, the soil is first saturated with Na, the Na is then replaced with NH_4, and the displaced Na is analyzed for by atomic absorption spectrophotometry. Soil pH was determined following the method of Peech (1965) in which equal parts of air-dry soil and deionized water are mixed to form a slurry and pH is determined by a glass-calomel electrode combination.

Carbon was determined by two independent methods. The Walkley-Black method is detailed by Allison (1965). In this method, soil organic matter is oxidized by adding an excess of Cr_2O_7 solution to the soil. The excess Cr_2O_7 remaining, after the reaction has gone to completion, is determined by titrating with Fe. The results are expressed as organic carbon and do not include H, O, S, or other constituents of organic matter in soil. The reaction temperature is sufficient to oxidize only active forms of organic carbon. Therefore, a factor has been developed and tested to convert Walkley-Black carbon values to more realistic values for total organic carbon. The factor is generally quoted in the literature as 1.33. To convert from organic carbon to organic matter (organic matter includes the mass of H, O, S, and other constituents of organic materials) a factor of 2.72 has generally been applied to the organic carbon value.

The second method used to determine carbon is detailed by Dean (1974). This method is gravimetric; a soil sample is brought to constant weight at 105°C and then heated to 550°C in a muffle furnace. The carbon value is taken as the weight loss on ignition. This method estimates organic matter and not strictly carbon. Additionally, percent water was determined from the difference between air-dry and oven-dry (105°C) sample weights.

Soil Physical Properties

We determined particle-size distribution and percent water for air-dry samples of both A- and C-horizon soils. The method for percent water is described in the previous paragraph. Particle-size distribution was determined by the hydrometer method described by Day (1965) but included modifications described by Grigal (1974).

Soil Mineralogy

A semiquantitaitive determination of the soil mineralogy was made using X-ray diffraction data and a computer program by J. C. Hathaway modified by L. G. Schultz (1977, personal communication). The soil samples are hand-ground with a mortar and pestle to an impalpable powder. The samples are then ground for an additional three minutes. The finely ground samples are then packed into a sample holder in such a manner that the sample has a grid pattern texture on the surface. Experience has shown that this sample preparation procedure tends to ensure random orientation of the sample constituents, particularly the clays. The X-ray data are recorded on magnetic tape and later read into the computer.

The computer program calculates the percentage of each mineral in the sample using a mineral library. The library consists of names of minerals, the d-spacings for up to 50 reflections, the relative intensity of each reflection and various other data. The minerals for the library are as pure as can be obtained and the data are obtained for the mineral library by X-ray analysis in the same manner as an unknown. The program smooths the X-ray trace, determines background, locates peaks that are sufficiently greater than background, identifies the various peaks, and, from the peak intensities and the mass absorption coefficient for each mineral, calculates the percentage of each of the identifiable minerals in the sample. The program also indicates the degree of certainty with which each mineral has been identified. All analyses were performed by Jane Dixon, Mike Pantea, and the authors.

RESULTS

Plant Biogeochemistry

This section describes a novel sampling approach to regional geochemical survey studies. We use a single composite biomass sample to represent the biogeochemistry of an area. In addition to sampling selected individual species (western wheatgrass and silver sagebrush), total above-ground biomass (standing crop) was collected. Theoretically, these samples represent the biogeochemical "load" in the vegetation. Further, we propose that the use of a composite biomass sample will enable us to correlate particular soil tests with the overall vegetation of a region.

Our study sites occurred within the major vegetational unit referred to by Weaver and Albertson (1956) as the Mixed Prairie Climax. Because of very heavy grazing pressures, much of the vast northern Great Plains supports the disturbance-climax short-grasses (blue grama and buffalograss) as well as the once more dominant nondisturbance-climax mid-grasses (wheatgrass, Junegrass, and needlegrass). Küchler's (1964) subdivisions of our particular study region show that most of our sites (55 %) fall within the grama-needlegrass-wheatgrass unit whereas 30 % are within the more eastern wheatgrass-needlegrass unit, 10 % are in sagebrush steppe, and 5 % are in eastern ponderosa forest. Table 21 lists the 42 taxa catalogued while collecting the biomass samples. In all, 8 shrub, 15 graminoid, and 19 forb species were encountered. Most species were collected as voucher specimens and are stored in a U. S. Geological Survey herbarium, Denver, Colorado. Assistance in the identification of species was given by D. L. Buckner, J. A. Erdman, and H. T. Shacklette.

Table 21.--Plants encountered in the collection of the standing crop samples--common name, corresponding scientific name, and relative frequency of occurrence.

[Relative frequency equals the number of sample sites at which a species occurred / the total number of sample sites X 100]

		Relative frequency
Shrubs		
Big sagebrush	Artemisia tridentata Nutt.	19
Broom snakeweed	Gutierrezia sarothrae (Pursh) Britt. & Rusby	19
Linear-leaved wormwood	Artemisia dracunculus L.	10
Pasture (fringed) sagebrush	A. frigida Willd.	67
Pricklypear	Opuntia fragilis (Nutt.) Haw.	5
Pricklypear	O. polyacantha Haw.	24
Silver sagebrush	Artemisia cana Pursh	43
Winterfat	Eurotia lanata (Pursh) Moq.	5
Grasses and sedges		
Blue grama	Bouteloua gracilis (H.B.K.) Lag.	86
Buffalograss	Buchloe dachtyloides (Nutt.) Engelm.	5
Canada bluegrass	Poa compressa L.	5
Cheatgrass brome	Bromus tectorum L.	14
Japanese brome	B. japonicus Thunb.	48
Junegrass	Koeleria gracilis Pers.	24
Kentucky bluegrass	Poa praetensis L.	5
Little bluestem	Schizachyrium scoparium (Michx.) Nash	5
Narrow-leaf sedge	Carex filifolia Nutt.	5
Needle-and-thread	Stipa comata Trin. & Rupr.	86
Plains bluegrass	Poa arida Vasey	5
Red threeawn	Aristida longiseta Steud.	10
Sand dropseed	Sporobolus cryptandrus (Torr.) Gray	10
Side-oats grama	Bouteloua curtipendula (Michx.) Torr.	5
Western wheatgrass	Agropyron smithii Rydb.	100
Forbs		
Annual buckwheat	Eriogonum annuum Nutt.	5
Ball cactus	Coryphantha vivipara (Nutt.) Britt. & Brown	5
Cut-leaved goldenweed	Haplopappus spinulosus (Pursh) DC.	10
Goldenrod	Solidago missouriensis Nutt.	5
Golden aster	Heterotheca villosa (Pursh) Shinners	5
Goosefoot	Chenopodium sp.	5
Gumweed	Grindelia squarrosa (Pursh) Dunal.	5
Jim Hill mustard	Sisymbrium altissimum L.	5
Nipple cactus	Coryphantha missouriensis (Sweet) Britt. & Rose	5
Peppergrass	Lepidium campestre (L.) R. Br.	5
Prairie coneflower	Ratibida columnifera (Nutt.) Wooten & Standley	5
Prairie sage	Artemisia ludiviciana Nutt.	5
Psoralea	Psoralea lanceolata Pursh	10
Pussytoes	Antennaria sp.	5
Ragweed	Ambrosia psilostachya DC.	5
Skeletonweed	Lygodesmia juncea (Pursh) D. Don	43
Woolly plantain	Plantago patagonica Jacq.	10
Yarrow	Achillea lanulosa Nutt.	14
Yellow sweetclover	Melilotus officinalis (L.) Lam.	5

Table 22.--Location, principal composition, and biomass of standing crop samples.

[Leaders (--) in columns mean the absence of a particular growth form; cover-abundance classes are in parentheses 1/]

	Location		Dominant occurring species			Above-ground biomass 2/	
Site no.	state	county	shrub	grass	forb	g/m^2	kg/ha
1	Mont.	Garfield	pasture sagebrush (x)	red threeawn (2)	--	130	1300
			silver sagebrush (x)	western wheatgrass (1)	--		
2	Mont.	Garfield	pasture sagebrush (x)	needle-and-thread (3)	golden aster (x)	88	880
			--	western wheatgrass (1)	--		
3	Mont.	Dawson	pasture sagebrush (x)	needle-and-thread (3)	ragweed (x)	50	500
			linear-leaved wormwood (x)	blue grama (3)	--		
4	Mont.	Prairie	pasture sagebrush (x)	western wheatgrass (3)	--	120	1200
			--	blue grama (x)	--		
5	N. Dak.	Dunn	pasture sagebrush (x)	western wheatgrass (3)	skeletonweed (x)	100	1000
			linear-leaved wormwood (x)	needle-and-thread (3)	peppergrass (x)		
6	S. Dak.	Harding	silver sagebrush (2)	blue grama (4)	woolly plantain (x)	90	900
			--	needle-and-thread (2)	ball cactus (x)		
7	Mont.	Big Horn	silver sagebrush (1)	western wheatgrass (3)	gumweed (x)	170	1700
			pricklypear (x)	blue grama (2)	yarrow (x)		
8	N. Dak.	Golden Valley	pasture sagebrush (x)	western wheatgrass (4)	skeletonweed (x)	130	1300
			silver sagebrush (x)	needle-and-thread (2)	--		
9	Mont.	Prairie	--	blue grama (4)	skeletonweed (x)	120	1200
			--	western wheatgrass (2)	--		
10	Mont.	Prairie	broom snakeweed (x)	blue grama (4)	skeletonweed (x)	20	200
			pasture sagebrush (x)	western wheatgrass (1)	cut-leaved goldenweed (x)		
11	Mont.	Prairie	pasture sagebrush (1)	needle-and-thread (3)	skeletonweed (x)	120	1200
			broom snakeweed (x)	western wheatgrass (1)	--		

Table 22.--cont.

	Location		Dominant occurring species			Above-ground biomass 2/	
Site no.	state	county	shrub	grass	forb	g/m^2	kg/ha
12	Mont.	Custer	silver sagebrush (x)	western wheatgrass (2)	--	80	800
			--	Canada bluegrass (x)	--		
13	Mont.	Custer	big sagebrush (2)	blue grama (3)	skeletonweed (x)	110	1100
			pasture sagebrush (x)	cheatgrass brome (1)	prairie coneflower (x)		
14	Mont.	Carter	silver sagebrush (x)	buffalograss (4)	skeletonweed (x)	100	1000
			pasture sagebrush (x)	blue grama (3)	--		
15	S. Dak.	Harding	pasture sagebrush (1)	blue grama (3)	psoralea (x)	150	1500
			big sagebrush (x)	western wheatgrass (2)	yarrow (x)		
16	Wyo.	Crook	silver sagebrush (x)	western wheatgrass (4)	skeletonweed (x)	110	1100
			--	cheatgrass brome (1)	--		
17	Wyo.	Sheridan	--	western wheatgrass (4)	prairie sage (1)	180	1800
			--	Kentucky gluegrass (1)	--		
18	Wyo.	Sheridan	big sagebrush (x)	western wheatgrass (4)	--	100	1000
			winterfat (x)	Japanese brome (x)	--		
19	Wyo.	Johnson	pasture sagebrush (x)	western wheatgrass (5)	yellow sweetclover (x)	100	1000
			--	sand dropseed (x)	--		
20	Wyo.	Converse	pasture sagebrush (x)	blue grama (3)	cut-leaved goldenweed (x)	90	900
			silver sagebrush (x)	Junegrass (2)	--		
21	Wyo.	Converse	big sagebrush (x)	western wheatgrass (2)	woolly plantain (x)	50	500
			pricklypear (x)	Junegrass (x)	--		

1/ x = sparsely or very sparsely present; cover very small.
1 = plentiful but of small cover value.
2 = very numerous, or covering at least 5% of the area.
3 = any number of individuals covering 25% to 50% of the area.
4 = any number of individuals covering 50% to 75% of the area.
5 = covering more than 75% of the area.

2/ Dry weight base.

The biomass for each site is presented in Table 22. These values, which range from 200 kg/ha at the heavily grazed Site 10 (Fig. 19) in Montana to 1,800 kg/ha at Site 17 (Fig. 19) in Wyoming, compare favorably with biomass yields reported in the literature for shortgrass prairies (Pearson and others, 1976; Munshower and DePuit, 1976). The range of biomass yields are reflective of both differences in grazing pressure and vegetational composition; however the former condition was by far the more important. The vegetational components of each site, expressed in a cover-abundance scale, are also given in Table 22. Only the principal plants responsible for the overall physiognomy of the site are given. The relative frequency of occurrence (RF) for each species (Table 21) was calculated using the formula:

$$RF = \frac{n}{N} \times 100$$

where N is the number of sample sites and n is the number of sample sites at which a given species occurred. The RF values in Table 21 show that the samples were composed predominantly of grass with some shrub material and still fewer forbs. The codominant perennial grasses (occurring in 86 to 100 % of the samples) were needle-and-thread, blue grama, and western wheatgrass. Further, the winter annual cheatgrass brome occurred in nearly half of the samples. The most common shrubs were pasture sagebrush (RF = 67 %) and silver sagebrush (RF = 43 %). The only forb occurring with any regularity was skeletonweed (RF = 43 %).

A comparison of splits of 19 samples (Table 23) indicates that except for Co, the percent error variance is sufficiently small so as not to obscure natural sample variability. Despite the large percent error variance, Co was included in all statistical analyses. Interpretation of Co relations, however, are made with caution.

Frequency distributions of the data for all 12 elements, and percent ash yield, were found to be more nearly normal using log-transformed data. Table 23, therefore, presents the geometric mean (GM), geometric deviation (GD), and observed range for these variables. Prior to the statistical tests, the concentration values determined for the ashed material were recalculated to a dry weight base using the formula.

$$C(d) = C(a) \times \frac{A}{100}$$

where C(d) is the concentration in the dry material, C(a) is the concentration in ash, and A is the percent ash yield.

Table 23.--Statistical evaluation of element concentrations in dry plant material, Northern Great Plains.

[GM = geometric mean, GD = geometric deviation; because of censored data for Cd, Co, and Ni in wheatgrass, Cd and Co in biomass, and Co in sagebrush, summary statistics for these were calculated using the technique of Cohen (1959)]

Element or ash	Approximate LLD_d [1/]	Laboratory error variance components		Summary statistics											
		Total $\log_{10}$ error variance	Percent of total variance	Western wheatgrass				Silver sagebrush				Biomass			
				Detection ratio	GM	GD	Observed range	Detection ratio	GM	GD	Observed range	Detection ratio	GM	GD	Observed range
Ash, %----	--	0.0052	44	21:21	6.6	1.236	4.6-8.8	19:19	5.2	1.139	3.7-7.0	21:21	6.7	1.204	4.8-9.1
Ca, %-----	0.06	.0247	7	21:21	.23	1.297	0.11-0.38	19:19	.57	1.330	0.23-0.79	21:21	.40	1.496	0.23-0.91
Cd, ppm---	.03	.1031	43	17:21	.03	1.945	0.01-0.08	19:19	.30	1.905	0.09-0.67	19:21	.07	2.364	0.02-0.43
Co, ppm---	.05	.1205	57	17:21	.11	1.939	0.04-0.39	16:19	.12	1.990	0.04-0.29	15:21	.11	3.168	0.01-0.43
Cu, ppm---	.16	.0181	19	21:21	.56	1.569	0.34-1.5	19:19	5.8	1.289	4.0-9.8	21:21	1.3	1.322	0.72-1.9
Fe, ppm---	6.0	.0675	2	21:21	73	1.988	18-320	19:19	120	1.852	52-440	21:21	120	1.938	52-510
K, %------	.05	.0455	< 1	21:21	.31	1.464	0.14-0.49	19:19	1.1	1.161	0.70-1.3	21:21	.29	1.538	0.13-0.64
Mg, %-----	.01	.0488	< 1	21:21	.07	1.362	0.04-0.14	19:19	.22	1.297	0.14-0.33	21:21	.11	1.747	0.05-0.48
Mn, ppm---	6.0	.0223	< 1	21:21	19	1.510	7.2-35	19:19	38	1.464	15-69	21:21	25	1.434	9.4-55
Na, ppm---	1.0	.0307	1	21:21	24	1.790	8.6-67	19:19	67	2.426	18-500	21:21	54	1.464	37-150
Ni, ppm---	.10	.0624	8	12:21	.13	2.260	0.07-0.67	19:19	1.1	1.512	0.46-2.0	21:21	.38	1.787	0.17-1.2
Pb, ppm---	.10	.0491	11	21:21	.63	1.957	0.20-2.4	19:19	1.1	1.232	0.80-1.8	21:21	1.0	1.797	0.43-4.0
Zn, ppm---	1.0	.0100	6	21:21	15	1.534	5.7-34	19:19	34	1.378	19-64	21:21	27	1.219	19-41

[1/] $\underline{LLD}_d = \underline{LLD}_a \times 5.2/100$, where $\underline{LLD}_d$ is the lower limit of determination on a dry weight base, $\underline{LLD}_a$ is the lower limit of determination on an ash base, and 5.2 is the lowest mean ash percent of the three plant groups.

Even though it was collected at sites known to be diverse geochemically, the herbage sampled showed very little variability in concentrations of the elements looked for. Thus even though plants vary in their nutrient element requirements and in their ability to concentrate elements, it would appear that homeostatic mechanisms generally prevented extreme concentrations of any element in the herbage. The ranges of concentrations presented in Table 23, for the plants studied, therefore, may be considered as representative of concentrations adequate for growth and development.

An examination of Table 23 shows that, in general, sagebrush contains much higher concentrations of most elements than wheatgrass. For example, the Ni and Cd values are orders of magnitude greater. Higher concentrations for some elements are also evident when comparing sagebrush and biomass. The high proportion of grass material in each biomass sample dominates the geometric means for wheatgrass, which compare rather well with those of biomass. Where differences occur, the biomass samples possess generally higher values (Cu, Na, and Ni). This probably reflects a greater proportion, in these samples, of the more "elementally rich" shrubs and forbs (Munshower and DePuit, 1975).

Table 24 presents biogeochemical load values for the herbage at each site based on the concentrations of each element in the biomass samples (ppm or %) and on the biomass yields (kg/ha). These data, plus the cover-abundance information given in Table 22 for each site, can be used to assess the biogeochemical load in forage potentially utilized by native and domestic animals. Even though the biomass samples are composed of all herbage (both the utilized and non-utilized species) the total biogeochemical load may be a useful way of presenting forage nutritive values rather than selecting only one or two species that are most heavily utilized.

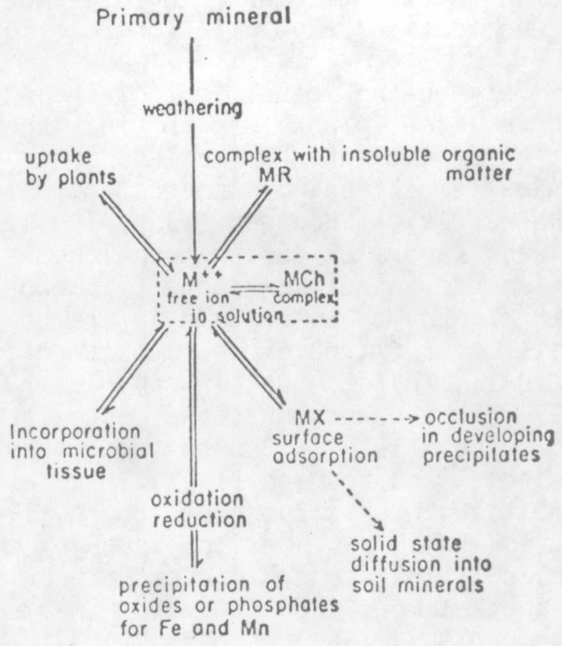
Table 24--Estimated biogeochemical load of 12 elements for vegetation at 21 sites in the northern Great Plains.

	Biomass	Biogeochemical load (g/ha)											
Site no.	(kg/ha)	Ca	Cd	Co	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	Zn
1	1,300	2,900	0.20	0.52	1.4	88	3,600	840	12	50	0.47	1.1	34
2	880	5,200	0.07	0.37	1.6	250	2,300	1,300	18	50	0.67	1.3	23
3	500	1,700	0.02	0.05	0.6	46	1,600	600	13	20	0.08	0.4	9
4	1,200	3,200	0.06	0.06	1.3	150	1,800	720	28	60	0.28	2.8	30
5	1,000	3,000	0.07	0.13	1.0	110	1,800	830	26	50	0.26	1.5	19
6	900	4,300	0.18	0.16	1.8	80	5,700	1,400	24	90	0.69	0.8	30
7	1,700	15,000	0.08	0.58	1.6	130	5,900	8,100	93	120	0.56	1.8	45
8	1,300	3,600	0.06	0.30	1.4	160	1,700	720	27	66	0.30	3.4	35
9	1,200	10,000	0.13	0.29	2.2	470	3,200	1,700	37	170	0.71	4.8	49
10	200	1,000	<0.01	<0.01	0.3	18	930	330	7	9	0.33	0.1	7
11	1,200	3,400	0.04	0.06	1.4	98	2,300	1,000	21	46	0.04	2.0	33
12	800	2,200	0.03	0.16	0.9	410	2,100	590	22	96	1.00	1.0	24
13	1,100	5,000	0,11	0.12	1.8	180	3,000	1,800	30	56	0.38	1.2	35
14	1,000	4,200	0.12	0.08	1.4	94	2,300	2,000	25	37	0.26	1.2	26
15	1,500	4,100	0.12	0.11	1.9	120	4,500	1,200	32	66	0.81	0.8	34
16	1,100	3,600	0.48	0.36	1.2	130	4,200	1,000	32	53	0.48	0.7	27
17	1,800	8,300	0.03	0.06	1.8	110	6,700	2,200	28	92	0.28	1.0	56
18	1,000	2,600	0.02	0.01	0.7	53	2,700	610	23	38	0.34	0.4	19
19	1,000	3,100	0,07	0.36	1.5	310	1,800	580	22	53	0.51	1.3	26
20	900	5,300	0.23	0.35	1.7	47	5,200	1,000	22	55	0.45	0.7	23
21	500	3,000	0.01	0.21	0.9	12	2,600	1,300	22	19	1.10	0.3	17

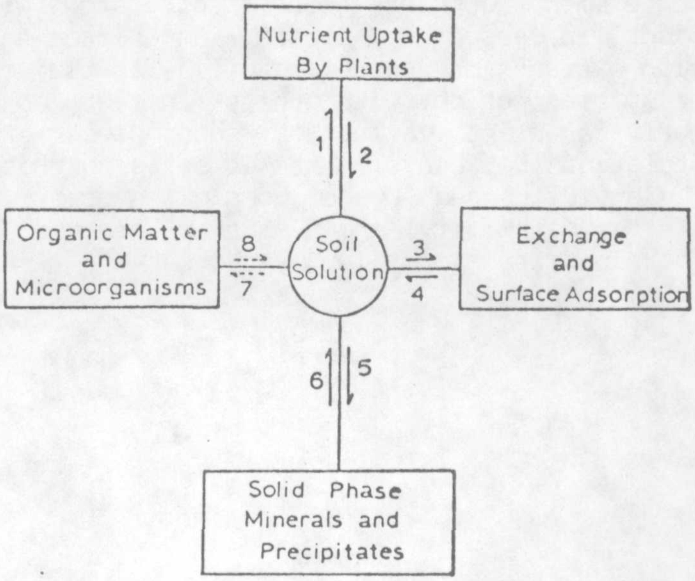
Correlation Between Elements in Three Native Plants and Chemical and Physical Properties of soils

Relations between the measurement of the soil's ability to supply elements for plant growth and the plant's actual utilization of these elements has recieved much attention in the literature. Papers stressing concepts and principles have been published by Bates (1970), Hodgson (1963, 1969), Lindsay (1972), and Lisk (1972). Papers stressing techniques of soil extraction and relating elements in soil extracts to actual concentrations of elements in plants, or to changes in element concentration as measured by soil extracts, have been published by Bradford, Bair, and Hunsaker (1971), Follett and Lindsay (1971), Miller, Hassett, and Koeppe (1976), Prabhakarannair and Cottenie (1969), Randall, Schulte, and Corey (1976), Shuman and Anderson (1974), and Sorenson, Oelsligle, and Knudsen (1971). Several of these papers stress the multivariate nature of the soil-plant system; the authors measured soil pH, cation-exchange capacity, organic matter content, soil texture and various other soil properties in addition to the element concentration in a soil extract. The papers by Hodgson (1963, 1969), Lindsay (1972), and Lisk (1972), consider forms of nutrients in soils and factors that affect their availability. Diagrammatic representations of the dynamic and multivariate nature of the soil system are presented in Figure 20.

In the laboratory, available levels of elements are generally defined by analysis of various soil extractants. An "Index of Availability" so derived is generally only of academic interest; on the practical side it has little meaning unless extractable element concentrations correlate with element concentrations in associated plants. Experience has shown that soil solution extracts may correlate well with the chemistry of some plant species but not with others--in fact, correlation may differ greatly for plant varieties, subspecies, or cultivars. Assessing relations between elements in soils to those in plants, therefore, is influenced by a complex system in which soil factors affect availability, and a plant's genetic constitution affects uptake and translocation.



From Hodgson (1963, p. 141).



From Lindsay (1972, p. 38).

Fig. 20.--Multivariate nature of the soil system controlling element availability (reproduced with permission).

Simple correlation analysis was used to assess the relation between element concentration in three plant materials (western wheatgrass, silver sagebrush, and biomass) and soil-extracted elements (using DTPA, EDTA, and ammonium oxalate), total soil elements, and soil physical properties. Table 25 presents correlation coefficients (r) for those relations found to be significant ($p < 0.05$). Even though several relations qualified as being highly significant ($p < 0.01$) none of the coefficients of determination (r^2) exceeded 0.50. This means that of the important relations, less than 50% of the variation between the variables was explained by the correlation.

Using the information in Table 25, several general conclusions are made. 1) The following importance ranking of the extracts as measures of availability is evident if both A and C horizons are considered: DTPA (ground) > DTPA (unground) > EDTA (unground) > ammonium oxalate (unground) > total soil. 2) Considering all extracts, more than twice as many important relations were determined for the A horizon (15 relations) than for the C horizon (6 relations). 3) Sagebrush, when compared with the extracts, showed significant relations for many more elements (7 relations) than did biomass (2 relations) or wheatgrass (1 relation). 4) Species differences are great as there were no obvious similarities among species based on either elements or extracts.

Significant simple correlations of elements in plants with physical properties of soil (% clay, % sand, % silt, % water) or with additional chemical properties (pH, organic matter, organic carbon, and cation-exchange capacity) showed few consistent patterns. Significant relations between pH and elements in plants, however, were more numerous than those between the elements and any of the other properties. Of the three plant materials, shallow-rooted wheatgrass showed the most significant positive r values between pH and elements in the A horizon (Ca, Cu, Fe, Mg, Na, Ni, and Zn). Wheatgrass showed no relations for the C horizon. Biomass and sagebrush relations were the same for Cd and Fe (significantly negative for Cd and positive for Fe). None of the three plant materials (including deep-rooted sagebrush) showed consistent significant relations in the C horizon.

Table 21--Significant simple correlation coefficients between element concentration in native plants and concentrations in various soil extracts, total soil, or soil physical properties

[*, significant (p <0.05); **, highly significant (p <0.01); A = soil A horizon, C = soil C horizon]

	Extraction or total soil										Soil physical and chemical properties															
	DTPA (ground)1/		DTPA (unground)		EDTA (unground)		Ammonium oxalate (unground)		Total soil		pH		Organic matter		Organic carbon		Cation exchange capacity		Sand (%)		Silt (%)		Clay (%)		Water (%)	
Element	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
WHEATGRASS (n = 21)																										
Ca--------											0.61**															
Cd--------																				-0.45*				-0.47*		
Cu--------											.49*															
Fe--------											.47*															
K---------											-.63**															
Mn--------											.48*			0.49*		0.46*			0.62**		0.60**	0.45*	0.55*			
Na--------	0.59**						0.64**				.62**															
Ni--------											.48*															
Pb--------																						.44*				
Zn--------									0.57**		.61**								-.58**		.56**		.52*			
BIOMASS (n = 21)																										
Cd--------											-0.67**															
Cu--------	-0.54*	-0.49*	-0.53*	-0.45*	-0.45*		-0.59**		-0.68**	-0.46*			-0.53*	-0.44*	-0.49*	-0.58*	-0.56*		0.60**		-0.51*		-0.61**		-0.58**	
Fe--------											.44*															
K---------											-.52*	-0.48*							.47*			-0.47*	-.44*			
Na--------	.66**																									
Ni--------														-.54*						0.44*						
Pb--------												.65**										.44*				-0.44*
SAGEBRUSH (n = 19)																										
Cd--------											-0.47*															
Co--------	0.63**																									
Cu--------	.45*		0.47*		0.45*												0.53*									
Fe--------					-.47*						.66**							-0.53*								-0.45*
K---------		0.51*																								
Mn--------												0.60**														
Ni--------	.61**		.47*	0.46*	.63**												.51*									
Pb--------								-0.47*																	0.52*	
Zn--------				.64**																						

1/ Ground to pass a 100 mesh sieve (<150 μm).

Multiple regression analysis was employed in an attempt to improve the prediction of plant-available elements in soils (that is, explain a greater proportion of the total variance between plant and soil relations). Multivariate relations were investigated between elements in plants (dependent variables) and independent variables such as extracted elements and additional physical and chemical properties of soil (pH, CEC, mineralogy, and others, see tables 26 and 27). In addition, we examined multivariate relations of plant element content with total soil element concentration and with additional chemical and physical properties of the soil (tables 28-30). In general, more than two-thirds of the significant ($p < 0.05$) multivariate relations explained less than 50% of the variation between variables. Of those relations explaining more than 50 %, independent variables such as mineralogy (percent calcite, dolomite, plagioclase, and quartz) and soil pH occurred most commonly.

Several additional conclusions regarding multivariate relations are made. 1) The following ranking of the extracts as measures of availability is evident if both A and C horizons are considered: DTPA (unground) > DTPA (ground) > total soil element concentrations > EDTA (unground) > ammonium oxalate (unground). 2) Ammonium oxalate extracts used in conjunction with chemical and physical properties of soil appear to be extremely poor predictors of availability for wheatgrass and biomass. 3) Where significant relations were observed between an element in plants and soil factors based on the various extractants, similar independent variables were usually involved in the regression equation.

Effects of Soil Grinding on DTPA Extractable Elements

Previous studies (Jacober and Sandoval, 1971; Soltanpour, Khan, and Lindsay, 1976) have established that varying techniques of soil sample preparation affect the values obtained from subsequent chemical determinations. We investigated the differences in DTPA-extractable Cd, Co, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, and Zn between soil material disaggregated to pass a 10 mesh sieve and similar material (10 mesh) ground further to pass a 100 mesh sieve using A- and C-horizon soils collected throughout the Northern Great Plains Coal Province.

Soltanpour, Khan, and Lindsay (1976) found that increased grinding time and force increased concentrations of Fe, Mn and Zn in DTPA extracts of soil. For Cu, no significant increase in concentration was noted. Their samples were from cultivated fields in Colorado, and therefore, we assume they represented the A horizon, or at least the "plow zone".

Table 26.--Multivariate relations between element concentrations in wheatgrass, biomass, and sagebrush and DTPA extracted elements from unground soils, soil mineralogy, and other soil chemical and physical properties for A- and C-horizon soils of the Northern Great Plains

[Only independent variables significant at the 0.05 probability level are included; DTPA extractions were on unground <2 mm soil fraction; mineralogical variables were calcite, clay, dolomite, microcline, plagioclase, quartz, and siderite; DTPA extracted elements were Cd, Co, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, and Zn; other soil chemical and physical property variables were sand, silt, clay, cation-exchange-capacity (CEC), water (air dry to oven dry), pH, carbon by Walkley-Black method (C-wb), carbon by ignition at 550°C (C-550), and organic matter calculated from organic carbon (C-om)]

Element, and soil horizon	Percent of total variance explained	Significant variables in order of decreasing standard partial regression coefficient				
		Wheatgrass (n = 21)				
Cd, C	62	CEC 0.54	Ni -0.49	Calcite 0.41		
Cu, A	52	pH 1.39	Fe .97			
Fe, A	58	Siderite .52	Na .46	Plagioclase -.42		
K, A	60	pH -.67	Plagioclase -.45			
Mg, A	59	Zn .95	K -.75	Plagioclase -.40		
Na, A	51	pH 1.24	Fe .71			
Ni, A	73	Ni -.93	Siderite .88	Cu .70	Na 0.37	
		Biomass (n = 21)				
K, A	62	pH -0.83	Mn -0.68			
Na, A	53	Dolomite .88	Na .61	pH -0.55		
Ni, C	52	C-550 -.68	Na .50			
		Sagebrush (n = 19)				
Cu, C	51	Zn 0.71				
Fe, A	57	pH .58	Calcite 0.38			
C	52	CEC -.74	Co .53			
Mg, A	78	Cd .92	K -.49	Calcite -0.44	Mg -0.39	
Mn, C	75	pH .72	Siderite -.36	Pb .36		
Na, A	59	Mg .77	Microcline -.45			
Ni, A	57	Co .76				
C	72	Fe .95	Clay[1/] -.58			
Pb, C	83	Co .70	Calcite .67	Cu -.62	Zn .42	Water -0.34
Zn, C	51	Pb .72				

1/ Determined by X-ray diffraction.

Table 27.--Multivariate relations between element concentrations in wheatgrass, biomass, and sagebrush and DTPA extracted elements from ground soils, soil mineralogy, and other soil chemical and physical properties for A- and C-horizon soils of the Northern Great Plains

[Only independent variables significant at the 0.05 probability level are included; DTPA extractions were on soils ground to pass a 100 mesh (150 µm) sieve; mineralogical variables were calcite, clay, dolomite, microcline, plagioclase, quartz, and siderite; DTPA extracted elements were Cd, Co, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, and Zn; other soil chemical and physical property variables were sand, silt, clay, cation-exchange-capacity (CEC), water (air dry to oven dry), pH, carbon by Walkley-Black method (C-wb), carbon by ignition at 550°C (C-550), and organic matter calculated from organic carbon (C-om)]

Element, and soil horizon	Percent of total variance explained	Significant variables in order of decreasing standard partial regression coefficient					
		Wheatgrass (n = 21)					
Cu, A ------	72	Siderite 0.51	Na 0.44	pH 0.36	Plagioclase -0.30		
C ------	52	C-wb -.57	Fe -.43				
Fe, A ------	57	Water -.75	Cd .66				
K, A ------	60	pH -.67	Plagioclase -.45				
C ------	80	Mn 1.00	Ni .90	Dolomite -.90	Pb .54		
Na, A ------	61	pH .52	Na .49				
Pb, C ------	59	Dolomite .58	Ni -.37				
Zn, A ------	72	Clay .65	Mn -.38	Plagioclase -.35			
		Biomass (n = 21)					
Cu, A ------	55	Quartz 0.50	Cd -0.38				
C ------	52	C-wb -.57	Fe -.43				
K, C ------	80	Mn -1.00	Ni .90	Dolomite -0.90	Pb 0.54		
Na, A ------	68	Na .69	Dolomite .43	Zn .35			
Ni, A ------	63	Cd -.61	Fe .49	Na .32			
Pb, C ------	59	Dolomite .58	Ni -.37				
		Sagebrush (n = 19)					
Cu, C ------	77	Ni -0.76	Mn 0.70	Fe 0.41	Siderite -0.32		
Fe, A ------	57	pH .58	Calcite .38				
K, C ------	66	Cd -.59	Fe .41	K .39			
Mn, C ------	99	pH 1.29	C-wb -.66	Ni .62	Pb .51	Clay[1/] 0.46	Dolomite 0.43
		Siderite -.37	C-om .20	Zn .11			

[1/] Determined by particle size distribution.

Table 28.--Multivariate relations between element concentrations in wheatgrass and soil mineralogy, total soil element analysis, and other soil chemical and physical properties for A- and C-horizon soils of the Northern Great Plains

[Only independent variables significant at the 0.05 probability level are included in the table unless otherwise noted; soil mineralogical variables included, calcite, clay, dolomite, microcline, plagioclase, quartz, siderite; total soil analysis variables included, Al, Ba, total carbon (C-total) Ca, Cu, Fe, K, Mg, Mn, Sr, Ti, Zn; other soil chemical and physical property variables included, sand, silt, clay, cation-exchange capacity (CEC), water (air dry to oven dry), pH, carbon by Walkley-Black method (c-wb), carbon by ignition at 550°C (C-550), carbonate carbon ($C\text{-}CO_3$), organic matter calculated from organic carbon (C-om)]

Element, and soil horizon	Percent of total variance explained	Significant variables in order of decreasing standard partial regression coefficient			
Ca, A	69.2	pH 0.66	Siderite 0.65	Oligoclase -0.62	
C[1/]	14.4	Calcite .38			
Cd, A	42.7	K .47	Calcite -.47		
C	22.2	Clay[3/] .47			
Co, A[1/]	32.1	Siderite .52	Oligoclase -.39		
C[2/]					
Cu, A	46.0	pH .49	Siderite .41		
C[2/]					
Fe, A	67.2	Al .57	Oligoclase -.53	Mn -.38	Siderite 0.37
C[2/]					
K, A	59.3	pH -.67	Oligoclase -.45		
C	41.4	Calcite -.52	Na -.41		
Mg, A[1/]	67.3	Ca -1.02	K -.68	Mg .66	Calcite .32
C[2/]					
Mn, A	46.3	Clay[4/] .68			
C	54.6	C-total 1.32	Ca -.82		
Na, A	38.7	pH .62			
C[1/]	51.3	Silt 1.44	Sand 1.32	Calcite .36	
Ni, A	39.3	Siderite .47	C-carbonate .39		
C[2/]					
Pb, A[1/]	54.7	Siderite .68	Silt .65		
C	25.3	Calcite .50			
Zn, A	67.8	Clay[4/] 1.29	Quartz 1.00	Ca .444	
C					

1/ Independent variables significant at the 0.10 probability level.

2/ No independent variables significant at the 0.10 probability level.

3/ Determined by particle size distribution.

4/ Determined by X-ray diffraction.

Table 29.--Multivariate relations between element concentrations in biomass and soil mineralogy, total soil element analysis, and other soil chemical and physical properties for A- and C-horizon soils of the Northern Great Plains

[Only independent variables significant at the 0.05 probability level are included in the table unless otherwise noted; soil mineralogical variables included, calcite, clay, dolomite, microcline, plagioclase, quartz, siderite; total soil analysis variables included, Al, Ba, total carbon (C-total) Ca, Cu, Fe, K, Mg, Mn, Sr, Ti, Zn; other soil chemical and physical property variables included, sand, silt, clay, cation-exchange capacity (CEC), water (air dry to oven dry), pH, carbon by Walkley-Black method (c-wb), carbon by ignition at 550°C (C-550), carbonate carbon ($C-CO_3$), organic matter calculated from organic carbon (C-om)]

Element and soil horizon	Percent of total variance explained	Significant variables in order of decreasing standard partial regression coefficient							
Ca, A	24.0	Quartz 0.49							
C[1]									
Cd, A	23.5	Mg -.49							
C	36.2	Clay[2] -.60							
Co, A[3]	18.5	C-total -.43							
C[3]	90.1	C-total -2.07	Dolomite 1.17	K -0.91	Fe 0.79	C- om 0.72	Sand -0.69	Siderite 0.34	CEC -0.30
Cu, A	48.8	Fe -.70							
C	53.8	C-wb -.58							
Fe, A	18.9	pH .44							
C[1]									
K, A	62.4	Fe -1.33	Clay[4] .72						
C	34.6	Ca -.59							
Mg, A	28.3	Quartz .53							
C[3]	16.8	Water .41							
Mn, A[3]	32.2	Plagioclase -.80	Na .58						
C[3]	16.9	Clay[2] .41							
Na, A	20.4	Dolomite .45							
C[1]									
Ni, A	47.4	Mn -.56	Calcite .47						
C	37.1	C-total -.61							
Pb, A[3]	17.2	Mg .42							
C	45.9	Dolomite .68							
Zn, A[1]									
C[1]									

[1] No independent variables significant at the 0.10 probability level.

[2] Determined by X-ray diffraction.

[3] Independent variables significant at the 0.10 probability level.

[4] Determined by particle size distribution.

Table 30.--Multivariate relations between element concentrations in sagebrush and soil mineralogy, total soil element analysis, and other soil chemical and physical properties for A- and C-horizon soils of the Northern Great Plains

[Only independent variables significant at the 0.05 probability level are included in the table unless otherwise noted; soil mineralogical variables included, calcite, clay, dolomite, microcline, plagioclase, quartz, siderite; total soil analysis variables included, Al, Ba, total carbon (C-total) Ca, Cu, Fe, K, Mg, Mn, Sr, Ti, Zn; other soil chemical and physical property variables included, sand, silt, clay, cation-exchange capacity (CEC), water (air dry to oven dry), pH, carbon by Walkley-Black method (c-wb), carbon by ignition at 550°C (C-550), carbonate carbon (C-CO_3), organic matter calculated from organic carbon (C-om)]

Element and soil horizon	Percent of total variance explained	Significant variables in order of decreasing standard partial regression coefficient			
Ca, A[2/]					
C[1/]	35.7	Siderite -0.54	C-total -0.46		
Cd, A	33.5	Dolomite -.58			
C	23.8	C-total -.49			
Co, A[1/]	48.0	Ca .84	Al -.61	K 0.37	
C[2/]					
Cu, A	66.4	CEC 1.04	C-total -.66	K -.39	
C[1/]	32.5	Siderite -.52	Calcite -.38		
Fe, A	82.9	pH 1.39	C-CO_3 -.83	Calcite .80	Quartz 0.54
C	28.1	CEC -.53			
K, A	52.4	Microcline -.70	Siderite -.38		
C[1/]	19.4	Water -.44			
Mg, A[2/]					
C[1/]	15.5	C-total .39			
Mn, A	42.9	Na .51	Mn .45		
C	65.9	pH .71	Siderite -.55		
Na, A	30.0	Calcite .55			
C	47.9	Mn .62	Water -.44		
Ni, A	68.9	Water .68	C-CO_3 -.42	K -.37	
C[1/]	19.4	K -.44			
Pb, A	33.4	Siderite .58			
C[1/]	35.3	Calcite .88	Mg -.62		
Zn, A[1/]	39.1	Ca .85	Dolomite -.63		
C	30.0	Siderite -.55			

[1/] Independent variables significant at the 0.10 probability level.

[2/] No independent variables significant at the 0.10 probability level.

Our study showed that disaggregating and grinding had a significant effect over disaggregating alone on concentrations in DTPA soil extracts for Fe, K, Mg, Mn, and Na in the A horizon and for Cd, Fe, K, Mg, Mn, and Zn in the C horizon (Table 31). No effect of grinding was noted for Co, Cu, Ni, Pb, and Zn in A-horizon soil, or Cu, Na, Ni, and Pb in C-horizon soil (Table 31).

We agree with Jacober and Sandoval (1971) and Soltanpour, Khan, and Lindsay (1976), that a standard method for soil preparation should be used between laboratories in order to produce analytical results that will stand the test of inter- and intra-laboratory comparisons. However, our method, like the other methods of sample preparation cited, demonstrates that, depending on the element, a single method of sample preparation has different effects on element extracts. It seems to us that the standard method selected should be one that most nearly eliminates operator bias and provides a sample that is readily homogenized. Our data (Table 32), and the data of Soltanpour, Khan, and Lindsay (1976), show that it is possible, for many elements, to relate element concentrations in DTPA extracts of soil to the various methods of sample preparation used.

Soil Mineralogy

In this study two soil horizons (A and C) were examined, and are treated separately. There are 21 samples of each horizon and 10 of these were randomly chosen for duplicate analysis. The 31 samples were placed in a randomized sequence prior to analysis. After analyzing all of the samples by X-ray diffraction the 10 pairs of samples for both the A and C horizons were separated and the analytical error estimated. The data for the minerals are shown in Table 33. The data indicate that the precision between analyses is good, the error variance comprising generally less than 10% of the total variance for the major minerals. Microcline, calcite and siderite exhibit high analytical variance, because they are present in such small amounts or are identified in the program with a low degree of certainty.

Multivariate Relations Between Element Concentrations in Soil Extracts versus Total Element Concentration, Chemical Properties, and Physical Properties of Soil

Our purpose in this part of the study is to examine the relations between element concentrations in DTPA, EDTA, and oxalate extracts of soil, and the total element concentration in the soil sample and other chemical and physical properties of the sample.

The observed range in concentration is of particular interest to us. We selected sampling sites to maximize the diversity in soil properties between sites and to obtain samples that were representative, not only of the extremes, but also representative over the entire range of values. We are satisfied with the diversity in the data for most elements and other soil properties as indicated by the observed range (Tables 34-39). The three extractants varied greatly in their ability to extract elements from soil. The element concentration in all soil extracts was substantially less than the total element concentration in soil. However, no extractant consistently proved to provide a maximum extracting power for all elements.

A single, universal relation between total element concentration in soil and element concentrations in EDTA, oxalate, or DTPA extracts, for a suite of elements, remains obscure. However, the multivariate relations of extractable element concentrations in soil with total element concentration and other independently measured soil properties are strong for a large proportion of the elements tested (Tables 40-44). For workers interested in individual elements, the multivariate relations should provide insight as to which soil properties, in addition to total chemistry, to measure. This information can be used to relate total concentrations of an element in soil to extractable element concentrations in soil, in order to arrive at a "ballpark" figure for the potentially extractable portion of the total element concentration.

Future Studies

We have not, as of this writing, thoroughly analyzed all of the data that we collected. In this report, however, we have detailed our methods, presented the data in summary form, and have discussed some of the highlights of our work. We intend, in later reports, to investigate in more detail the relations between plant and soil composition based on the data we have in hand, and possibly on additional data on soil composition. In addition, we intend to investigate the nature of the soil systems that apparently influence the amount of an element that is extracted from soil by the various extracting agents. The possibility exists that further analysis of the data will lead to the formulation of a soil extractant that will provide better relations between element concentrations in native plants and in uncultivated soils.

The general analytical methods to be used and properties to be measured in future studies are summarized in table 45.

Table 31.--Variance analysis of DTPA extractable elements in A- and C-horizon soil material less than 2 mm in size and less than 2 mm in size further ground to pass a 150 μm sieve

[Total variance is computed on logarithmically transformed data; *, variance component is significantly different from zero at the 0.05 probability level; estimates for each soil horizon are based on analyses of 62 samples]

Element	Total $\log_{10}$ variance	Percentage of total variance between		
		Methods	Samples	Analyses
		A horizon		
Cd----------	0.0465	0	61.0*	39.0
Co----------	.0725	3.0	48.9*	48.1
Cu----------	.0552	0	97.0*	3.0
Fe----------	.1780	46.5*	50.6*	2.9
K-----------	.0359	24.0*	73.9*	2.1
Mg----------	.0468	38.0*	61.1*	.9
Mn----------	.1068	63.7*	33.1*	3.2
Na----------	.2580	21.9*	51.4*	26.8
Ni----------	.0865	0	85.2*	14.8
Pb----------	.0248	0	84.6*	15.4
Zn----------	.1084	0	99.5*	.5
		C horizon		
Cd----------	0.1410	14.3*	37.8*	48.0
Co----------	.1676	5.5	0	94.5
Cu----------	.0527	0	98.5*	1.5
Fe----------	.1357	69.9*	21.1*	9.0
K-----------	.0471	66.2*	25.5*	8.2
Mg----------	.0943	16.4*	81.0*	2.6
Mn----------	.1145	38.4*	58.4*	3.2
Na----------	.5449	0	98.9*	1.1
Ni----------	.1176	0	59.3*	40.7
Pb----------	.0197	0	65.8*	34.2
Zn----------	.1244	52.9*	29.4*	17.7

Table 32--Relation between element concentration in a DTPA extract of less than 2 mm soil material and less than 2 mm soil material further ground to pass a 100 mesh (150 µm) sieve for A- and C-horizon soils of the Northern Great Plains Coal Region.

[All element concentrations are in parts per million; only independent variables significant at the 0.05 probability level are included in the prediction equation; X, element concentration in less than 2 mm soil material further ground to pass a 100 mesh sieve; Y, element concentration in less than 2 mm soil material; ---, variables not significant at the 0.05 probability level]

Element	Regression equation	Percent of variance explained
	A horizon	
Cd	$Y = 0.06 + 0.49X$	36.5
Co	---	
Cu	$Y = .05 + .77X$	96.6
Fe	$Y = -.40 + .41X$	70.8
K	$Y = 23 + 1.2X$	96.1
Mg	---	
Mn	$Y = 4.8 + .20X$	41.1
Na	$Y = -4.3 + .80X$	80.4
Ni	$Y = -.005 + .84X$	86.6
Pb	$Y = -.003 + .99X$	92.6
Zn	$Y = .01 + .87X$	98.7
	C horizon	
Cd	---	
Co	---	
Cu	$Y = 0.01 + 0.89X$	97.6
Fe	$Y = 2.8 + .21X$	33.2
K	$Y = 73 + .30X$	19.6
Mg	---	
Mn	$Y = -.67 + .57X$	86.4
Na	$Y = 7.7 + .85X$	98.9
Ni	$Y = -.009 + .85X$	71.2
Pb	$Y = .005 + .94X$	74.9
Zn	$Y = .01 + .38X$	42.6

Table 33.--Mineralogy of the less-than 2 mm size fraction of A- and C-horizon soils of the Northern Great Plains

[Summary statistics are in percent; detection ratio, number of samples in which the element was found in measurable amounts relative to the number of samples analyzed]

Mineral	Total variance	Percent of total variance between Samples	Percent of total variance between Analyses	Summary statistics Arithmetic mean	Summary statistics Standard deviation	Summary statistics Standard error	Observed range	Detection ratio
				A horizon				
Quartz--------------	28.1	92	8	50.1	8.8	1.5	29.5-67.1	21:21
Plagioclase---------	51.8	90	10	9.6	7.9	2.3	0 -33.4	19:21
Total clay----------	72.1	89	11	28.4	10.7	2.8	7.3-55.9	21:21
Microcline----------	12.3	27	77	4.9	5.2	3.1	0 -19.4	13:21
Calcite-------------	.0125	0	100	.05	.17	.11	0 - .7	9:21
Dolomite------------	1.09	90	10	.75	.94	.33	0 - 3.5	16:21
Siderite------------	.0085	0	100	.03	.11	.09	0 - .5	2:21
				C horizon				
Quartz--------------	145	98	2	46.8	10.7	1.7	25.8-62.3	21:21
Plagioclase---------	69.0	99	1	8.7	7.2	.8	.6-26.4	21:21
Total clay----------	54.7	86	14	30.1	9.1	2.8	16.1-45.1	21:21
Microcline----------	7.88	80	20	3.8	4.0	1.3	0 -15.9	13:21
Calcite-------------	37.2	98	2	5.3	5.2	.86	0 -14.8	19:21
Dolomite------------	21.2	99	1	3.3	3.5	.46	0 -11.7	20:21
Siderite------------	.047	0	100	.03	.09	.22	0 - .3	2:21

Table 34--Statistical summaries for total element concentration and other properties of A- and C-horizon soils of the Northern Great Plains

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Soil property, unit of measure	Total $\log_{10}$ variance	Percent of total variance between		Summary statistics				
		Samples	Analyses	Geometric mean	Geometric deviation	Geometric error	Observed range	Detection ratio
				A horizon				
C-carbonate, %-------	0.4718	51.7	48.3	0.035	5.39	3.00	0.007-0.42	11:21
C-organic, %---------	.0605	99.1	.9	1.9	1.86	1.06	.49-8.7	21:21
C-total, %-----------	.0456	99.9	.1	2.0	1.82	1.02	.62-8.7	21:21
C-Walkley Black, %---	.0731	99.0	1.0	1.5	1.49	1.07	.3-6.7	21:21
C-550°C, %-----------	.0204	99.1	.9	5.2	1.67	1.03	2.3-19	21:21
Ca, %---------------	.0351	99.9	.1	.97	1.63	1.01	.42-2.0	21:21
C.E.C., m.e./100 g[1/]	60.53	84.9	15.1	31	11.47	3.02	18-62	21:21
Clay, %[1/]-----------	77.14	97.7	2.3	26	10.44	1.33	12-52	21:21
Cu, ppm-------------	.0184	86.6	13.4	12	1.71	1.12	3.0-30	20:21
Fe, %---------------	.0154	99.5	.5	2.7	1.34	1.02	1.5-4.6	21:21
K, %----------------	.0016	96.9	3.1	2.3	1.12	1.02	2.0-3.0	21:21
Mg, %---------------	.0400	99.9	.1	.97	1.57	1.01	.46-1.8	21:21
Mn, ppm-------------	.0150	99.7	.3	380	1.36	1.02	220-670	21:21
Na, %---------------	.0441	99.9	.1	.92	2.01	1.01	.09-2.4	21:21
Ni, ppm-------------	.0210	62.5	37.5	6.3	1.58	1.23	3.5-15	18:21
pH[1/]----------------	.4605	98.2	1.8	7.1	.68	.09	6.2-8.2	21:21
Sand, %[1/]-----------	293.2	99.8	.2	44	20.07	.84	13-76	21:21
Silt, %[1/]-----------	79.68	95.9	4.1	30	11.14	1.82	9-45	21:21
Zn, ppm ------------	.0090	97.1	2.9	58	1.37	1.04	25-86	21:21
				C horizon				
C-carbonate, %------	0.9505	64.5	35.5	0.45	5.87	3.81	0.007-3.2	19:21
C-organic, %--------	.0319	82.8	17.2	.64	1.69	1.19	.29-2.0	21:21
C-total, %----------	.1309	99.3	.7	1.4	2.04	1.07	.35-3.7	21:21
C-Walkley Black, %--	.0306	96.7	3.3	.40	1.67	1.08	.19-1.4	21:21
C-550°C, %----------	.0502	98.2	1.8	3.9	1.54	1.07	1.9-7.7	21:21
Ca, %---------------	.2643	86.3	13.7	3.2	2.60	1.55	.52-12	21:21
C.E.C., m.e./100g[1/]-	50.22	67.6	32.4	28	7.92	4.03	.16-45	21:21
Clay, %[1/]-----------	175.9	98.5	1.5	32	11.68	1.61	15-57	21:21
Cu, ppm-------------	.0255	51.6	48.4	14	1.54	1.29	6.0-36	21:21
Fe, %---------------	.0087	62.8	37.2	3.1	1.30	1.14	1.9-5.1	21:21
K, %----------------	.0023	85.6	14.4	2.2	1.14	1.04	1.8-2.9	21:21
Mg, %---------------	.1105	99.6	.4	1.6	1.80	1.05	.59-4.3	21:21
Mn, ppm-------------	.0055	85.1	14.9	380	1.43	1.07	230-890	21:21
Na, %---------------	.0758	97.9	2.1	.84	1.86	1.10	.22-2.4	21:21
Ni, ppm-------------	.0163	73.0	27.0	7	1.59	1.17	3.5-15	20:21
pH[1/]----------------	.0964	97.2	2.8	8.3	.38	.05	7.0-8.9	21:21
Sand, %[1/]-----------	426.3	99.9	.1	42	20.42	.79	22-68	21:21
Silt, %[1/]-----------	99.65	95.7	4.3	26	11.08	2.08	10-45	21:21
Zn, ppm-------------	.0076	73.0	27.0	54	1.28	1.11	28-89	21:21

[1/] Logarithmic transformation was not performed on the data before statistical analysis.

Table35.--Statistical summaries for EDTA extractable element concentration of the less than 2 mm fraction of A- and C-horizon soils of the Northern Great Plains

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Element, unit of measure	Total $\log_{10}$ variance	Percent of total variance between		Summary statistics				
		Samples	Analyses	Geometric mean	Geometric deviation	Geometric error	Observed range	Detection ratio
				A-horizon				
Ca, %--------	0.0376	99.6	0.4	0.20	1.60	1.03	0.10-.51	21:21
Cd, ppm------	.0434	51.5	48.5	.1	1.61	1.40	.06-.42	21:21
Co, ppm------	.0361	53.0	47.0	.3	1.57	1.35	.2-.7	21:21
Cu, ppm------	.0150	90.5	9.5	.8	1.64	1.09	.3-2.2	21:21
Fe, ppm------	.2954	93.7	6.7	5.4	3.44	1.37	.5-42	21:21
K, ppm-------	.0177	98.1	1.9	330	1.55	1.04	170-1300	21:21
Mg, %--------	.0259	99.6	.4	.034	1.57	1.02	.018-.10	21:21
Mn, ppm------	.0403	90.1	9.9	12	1.60	1.16	4.9-44	21:21
Ni, ppm------	.0296	77.0	23.0	.7	1.68	1.21	.2-2.5	21:21
Pb, ppm------	.0165	87.9	12.1	2	1.54	1.11	1-5	21:21
Zn, ppm------	.0766	99.2	.8	1.6	2.14	1.06	.5-14	21:21
				C-horizon				
Ca, %---------	0.0306	95.6	4.4	0.19	1.42	1.09	0.09-.35	21:21
Cd, ppm-------	.4370	53.1	46.9	.03	2.75	2.84	.001-.11	21:21
Co, ppm-------	.0551	0	100.0	.3	1.58	1.72	.1-.5	21:21
Cu, ppm-------	.0283	86.6	13.4	.9	1.97	1.15	.08-1.7	21:21
Fe, ppm-------	.0809	87.8	12.2	2.3	1.92	1.26	.8-11	21:21
K, ppm--------	.0113	38.1	61.9	130	1.39	1.21	60-250	21:21
Mg, %---------	.0719	99.7	.3	.068	1.76	1.04	.026-.15	21:21
Mn, ppm-------	.0364	94.7	5.3	2	1.70	1.11	.8-10	21:21
Ni, ppm-------	.0810	72.4	27.6	.7	1.55	1.41	.4-2.1	21:21
Pb, ppm-------	.0101	84.6	15.4	1	1.29	1.10	1-2	21:21
Zn, ppm-------	.0276	82.5	17.5	.3	1.39	1.17	.2-.5	21:21

Table36.--Statistical summaries for Oxalate extractable element concentrations of the less than 2 mm fraction of A- and C-horizon soils of the Northern Great Plains

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Element, unit of measure	Total $\log_{10}$ variance	Percent of total variance between		Summary statistics				
		Samples	Analyses	Geometric mean	Geometric deviation	Geometric error	Observed range	Detection ratio
				A horizon				
Ca, ppm------	0.8432	72.6	27.4	4.0	7.08	3.03	0.5-57	21:21
Cd, ppm------	.0174	43.4	56.6	.03	1.97	1.26	.003-.07	21:21
Co, ppm------	.0880	83.3	16.7	2.1	2.33	1.32	.2-5.3	21:21
Cu, ppm------	.0905	91.0	9.0	2.0	2.64	1.23	.01-6.8	21:21
Fe, ppm------	.0257	68.5	31.5	480	1.60	1.23	150-1100	21:21
K, ppm-------	.0120	95.3	4.7	280	1.47	1.06	150-940	21:21
Mg, ppm------	.0871	96.7	3.3	520	1.88	1.13	230-1700	21:21
Mn, ppm------	.3403	77.5	22.5	97	5.65	1.89	.5-330	21:21
Na, ppm------	.1523	64.3	35.7	15	2.82	1.71	2.9-81	21:21
Ni, ppm------	.1983	90.2	9.8	1.5	3.60	1.38	.05-9.8	21:21
Pb, ppm------	.0813	52.8	47.2	.3	2.05	1.57	.05-.9	21:21
Zn, ppm------	.3122	88.3	11.7	2.0	4.73	1.55	.02-11	21:21
				C horizon				
Ca, ppm------	1.060	54.9	45.1	1.9	11.1	4.91	0.5-37	21:21
Cd, ppm------	.3316	0	100	.01	2.69	3.77	.001-.05	21:21
Co, ppm------	.4608	88.8	11.2	.7	3.82	1.69	.05-5.8	21:21
Cu, ppm------	.4548	91.9	8.1	.5	4.43	1.56	.05-3.8	21:21
Fe, ppm------	2.061	94.3	5.7	25	19.2	2.21	.3-1300	21:21
K, ppm-------	.0201	88.2	11.8	93	1.45	1.12	44-180	21:21
Mg, ppm------	.0495	87.1	12.9	830	1.56	1.20	350-1600	21:21
Mn, ppm------	1.952	98.1	1.9	4	17.8	1.55	.05-190	21:21
Na, ppm------	.5113	89.1	10.9	48	7.09	1.72	2.4-1700	21:21
Ni, ppm------	.6917	91.5	8.5	.5	5.38	1.75	.05-6.1	21:21
Pb, ppm------	.2292	52.7	47.3	.1	2.54	2.13	.05-.8	21:21
Zn, ppm------	.6310	63.9	36.1	.2	6.21	3.00	.01-1.9	21:21

Table 37.--Statistical summaries for DTPA extractable element concentrations of the less than 2 mm fraction of A- and C-horizon soils of the Northern Great Plains

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Element, unit of measure	Total $\log_{10}$ variance	Percent of total variance between		Summary statistics				
		Samples	Analyses	Geometric mean	Geometric deviation	Geometric error	Observed range	Detection ratio
				A-horizon				
Cd, ppm------	0.0471	52.8	47.2	0.1	1.66	1.41	0.04-.3	21:21
Co, ppm------	.0282	21.8	78.2	.2	1.65	1.41	.06-.4	21:21
Cu, ppm------	.0304	91.1	8.9	.4	1.77	1.13	.1-1.2	21:21
Fe, ppm------	.1225	98.1	1.9	11	2.13	1.12	2-50	21:21
K, ppm-------	.0128	93.8	6.2	190	1.50	1.07	110-720	21:21
Mg, ppm------	.0132	94.8	5.2	330	1.72	1.06	190-2400	21:21
Mn, ppm------	.0327	90.7	9.3	8.9	1.51	1.14	3.7-15	21:21
Na, ppm------	.2216	97.4	2.6	5.0	2.90	1.19	1.6-83	21:21
Ni, ppm------	.0659	68.5	31.5	.6	2.21	1.39	.2-2.7	21:21
Pb, ppm------	.0147	52.5	47.5	.6	1.50	1.21	.3-1.4	21:21
Zn, ppm------	.1021	99.4	.6	.6	2.32	1.06	.2-5.3	21:21
				C-horizon				
Cd, ppm------	0.2189	47.5	52.5	0.02	3.12	2.18	001-1.0	21:21
Co, ppm------	.2166	0	100	.2	2.28	2.92	.01-.4	21:21
Cu, ppm------	.0439	98.9	1.2	.4	1.72	1.05	.1-.8	21:21
Fe, ppm------	.0316	94.0	6.0	7	1.60	1.11	3-19	21:21
K, ppm-------	.0064	94.5	5.5	87	1.21	1.04	59-120	21:21
Mg, ppm------	.0658	99.5	.5	700	2.14	1.04	260-7800	21:21
Mn, ppm------	.0446	89.7	10.3	3.4	1.87	1.17	1.1-14	21:21
Na, ppm------	.5186	99.8	.2	61	6.06	1.07	5.0-1400	21:21
Ni, ppm------	.1546	58.6	41.4	.5	1.96	1.79	.1-2.1	21:21
Pb, ppm------	.0206	70.0	30.0	.3	1.40	1.20	.2-.6	21:21
Zn, ppm------	.0959	64.0	36.0	.05	2.03	1.53	.01-.15	21:21

Table38.--Statistical summaries for DTPA extractable element concentrations of the less than 2 mm fraction, further ground to pass a 150 µm (100 mesh) sieve, of A- and C-horizon soils of the Northern Great Plains

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Element, unit of measure	Total $\log_{10}$ variance	Percent of total variance between		Summary statistics				
		Samples	Analyses	Geometric mean	Geometric deviation	Geometric error	Observed range	Detection ratio
				A horizon				
Cd, ppm-------	0.0369	62.0	38.0	0.09	1.71	1.31	0.04-.4	21:21
Co, ppm-------	.0701	32.0	68.0	.2	2.26	1.65	.03-.6	21:21
Cu, ppm-------	.0349	98.2	1.8	.4	1.83	1.06	.1-1.6	21:21
Fe, ppm-------	.0757	89.3	10.7	30	1.93	1.23	8-81	21:21
K, ppm--------	.0127	94.2	5.8	140	1.57	1.07	69-570	21:21
Mg, ppm-------	.0114	98.9	1.1	200	1.35	1.03	130-420	21:21
Mn, ppm-------	.0440	91.4	8.6	22	1.61	1.15	7.3-51	21:21
Na, ppm-------	.2267	44.0	56.0	13	2.58	2.31	2.7-97	21:21
Ni, ppm-------	.0418	88.4	11.6	.8	1.99	1.17	.1-3.1	21:21
Pb, ppm-------	.0097	93.2	6.8	.6	1.49	1.06	.3-1.3	21:21
Zn, ppm-------	.0785	99.5	.5	.7	2.12	1.05	.2-6.3	21:21
				C horizon				
Cd, ppm-------	0.0238	13.6	86.4	0.04	1.53	1.39	0.01-.1	21:21
Co, ppm-------	.1620	38.2	61.8	.1	2.60	2.07	.01-.4	21:21
Cu, ppm-------	.0439	97.6	2.4	.4	1.76	1.08	.1-.8	21:21
Fe, ppm-------	.0306	26.3	73.7	19	1.58	1.41	7.8-54	21:21
K, ppm--------	.0229	67.7	32.3	48	1.50	1.22	21-140	21:21
Mg, ppm-------	.0602	92.5	7.5	440	1.62	1.17	190-1000	21:21
Mn, ppm-------	.0641	95.6	4.4	7	1.88	1.13	2.0-23	21:21
Na, ppm-------	.4545	97.5	2.5	75	5.37	1.28	5.9-1700	21:21
Ni, ppm-------	.1483	78.6	21.4	.6	2.17	1.51	.06-1.8	21:21
Pb, ppm-------	.0191	61.8	38.2	.3	1.37	1.22	.2-.6	21:21
Zn, ppm-------	.0241	60.9	39.1	.1	1.52	1.25	.06-.4	21:21

Table 39.--Statistical summaries for DTPA extractable element concentration of the less than 150 µm (100 mesh) fraction that was separated from the less than 2 mm fraction by dry sieving, of A- and C-horizon soils of the Northern Great Plains

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Element, unit of measure	Total $\log_{10}$ variance	Percent of total variance between		Summary statistics				
		Samples	Analyses	Geometric mean	Geometric deviation	Geometric error	Observed range	Detection ratio
				A horizon				
Cd, ppm--------	0.0854	51.4	48.6	0.1	2.20	1.60	0.02-.5	21:21
Co, ppm--------	.0260	44.4	55.6	.2	1.54	1.32	.08-.5	21:21
Cu, ppm--------	.0321	97.4	2.6	.8	1.70	1.07	.4-2.6	21:21
Fe, ppm--------	.1178	99.3	.7	24	2.04	1.07	5.6-88	21:21
K, ppm---------	.0144	99.2	.8	170	1.50	1.03	93-640	21:21
Mg, ppm--------	.0107	98.8	1.2	210	1.30	1.03	130-370	21:21
Mn, ppm--------	.0639	95.7	4.3	19	1.68	1.13	5.7-40	21:21
Na, ppm--------	.1570	18.8	81.2	11	2.52	2.28	3.0-84	21:21
Ni, ppm--------	.1163	88.9	11.1	.6	2.32	1.30	.09-3.4	21:21
Pb, ppm--------	.0140	88.5	11.5	1.2	1.48	1.10	.6-2.4	21:21
Zn, ppm--------	.1083	99.7	.3	1.2	2.18	1.05	.3-9.8	21:21
				C horizon				
Cd, ppm--------	0.1493	34.8	65.2	0.07	2.66	2.05	0.009-.7	21:21
Co, ppm--------	.0423	12.3	87.7	.2	1.63	1.56	.06-.4	21:21
Cu, ppm--------	.0493	99.6	.4	1.0	1.65	1.03	.4-2.0	21:21
Fe, ppm--------	.0427	92.4	7.6	12	1.55	1.14	4.8-29	21:21
K, ppm---------	.0064	93.6	6.4	61	1.27	1.05	34-86	21:21
Mg, ppm--------	.0647	99.8	.2	460	1.66	1.03	190-1200	21:21
Mn, ppm--------	.0543	94.5	5.5	6.8	1.69	1.13	2.6-21	21:21
Na, ppm--------	.3759	98.1	1.9	86	4.89	1.21	7.1-2200	21:21
Ni, ppm--------	.1846	84.4	15.6	.4	2.66	1.48	.04-1.7	21:21
Pb, ppm--------	.0204	76.6	23.4	.7	1.40	1.17	.3-1.1	21:21
Zn, ppm--------	.0562	70.6	29.4	.1	1.78	1.34	.03-.3	21:21

Table 40.--Relative influence of total element concentration and other soil properties on EDTA extractable element concentrations of the less than 2 mm fraction of A- and C-horizon soils of the Northern Great Plains

[Only independent variables significant at the 0.05 probability level are included in the prediction equations unless otherwise noted]

Element in soil extract	Regression constant	Independent variables and their partial regression coefficients											Percent of variance explained
		Total element concentration	Carbon					Cation exchange capacity	Clay	pH	Sand	Silt	
			Carbonate	Organic	Total	Walkley Black	Ignition at 550°C						
						A-horizon							
Ca--------	-0.083	0.044						0.0022	0.0072				94.8
Cd--------	.053	2/				0.058							81.5
Co--------	-.0049	2/						.011					60.4
Cu--------	.33	.053	-1.09										67.7
Fe--------	96.0									-12.1			58.9
K---------	78.8			129									91.1
Mg--------	-.0057								.0017				86.6
Mn--------	.53			22.6	-18.0						0.11		93.5
Ni--------	2.68	.088								-.35			42.6
Pb--------	.44	2/			-1.02		0.72						82.0
Zn--------	.55			1.84					-.092				90.7
						C-horizon							
Ca--------	0.032							0.0061					47.7
Cd--------	.028	2/	-0.026									0.0017	61.3
Co[3/]------	.16	2/							0.0099			-.0075	60.1
Cu--------	.46	0.035											34.9
Fe--------	43.6									-4.89			56.1
K[3/]-------	555	-46.7		-30.6					2.51	-44.8			71.6
Mg--------	-.52						-0.014		.0048	.061			82.0
Mn--------	37.4									-4.39		.057	78.2
Ni--------	7.53									-.82			51.7
Pb--------	.41	2/				0.40		.018					49.6
Zn[1/]------	.23		-.074									.0056	41.8

1/ Independent variables significant at the 0.10 probability level.

2/ No data available for total element concentration.

3/ Relations are suspect because of excessive analytical error.

Table 41--Relative influence of total element concentration and other soil properties on Oxalate extractable element concentrations of the less than 2 mm fraction of A- and C-horizon soils of the Northern Great Plains

[Only independent variables significant at the 0.05 probability level are included in the prediction equations unless otherwise noted]

Element in soil extract	Regression constant	Independent variables and their partial regression coefficients											Percent of variance explained
		Total element concentration	Carbon				Ignition at 550°C	Cation exchange capacity	Clay	pH	Sand	Silt	
			Carbonate	Organic	Total	Walkley Black							
A horizon													
Ca-----------	26.9		54.9								-0.40		42.9
Cd[1]---------		[2]											
Co-----------	1.67	[2]	-5.96						0.060				61.3
Cu-----------	.56	0.19	-5.24										79.6
Fe-----------	175							11.4					32.0
K------------	94.7			91.4									91.3
Mg-----------	1073		1510								-13.9		84.5
Mn-----------	-12	.54	-362										85.6
Na-----------	-127									21.2			40.9
Ni-----------	.20	.31											28.5
Pb-----------	1.51	[2]								-.16			31.0
Zn-----------	1.31		-6.12			1.48							81.0
C horizon													
Ca-----------	-41.1	-41.8		109	118								67.4
Cd[3]---------	.0099	[2]		.015									21.5
Co-----------	29.8	[2]								-3.41			48.6
Cu-----------	21.0									-2.40			51.4
Fe-----------	6510									-.076			68.9
K------------	586									-63.4		1.52	62.6
Mg-----------	579	170											30.1
Mn-----------	1081			-47.5						-121			68.2
Na[1]---------													
Ni-----------	26.7						-0.40			-2.84			56.5
Pb-----------	3.24									-.36			40.8
Zn-----------	7.80									-.88			33.5

[1] No independent variables significant at the 0.10 probability level.

[2] No data available for total element concentration.

[3] Relations are suspect because of excessive analytical error.

Table 42.--Relative influence of total element concentration and other soil properties on DTPA extractable element concentrations of the less than 2 mm fraction of A- and C-horizon soils of the Northern Great Plains

[Only independent variables significant at the 0.05 probability level are included in the prediction equations unless otherwise noted]

Element in soil extract	Regression constant	Independent variables and their partial regression coefficients											Percent of variance explained
		Total element concentration	Carbon					Cation exchange capacity	Clay	pH	Sand	Silt	
			Carbonate	Organic	Total	Walkley Black	Ignition at 550°C						
A horizon													
Cd---------	0.050	3/	-0.098			0.042							79.1
Co4/ -------	.18	3/			-0.20	.29							38.7
Cu---------	.96								0.032	-0.15		-0.0086	87.4
Fe---------	96.9									-11.6			59.0
K----------	52.0			70.5									89.1
Mg2/ -------													
Mn---------	4.91	0.025	-10.5						-.16				82.8
Na---------	-13.2			70.7		-100			1.76				54.5
Ni---------	.30	.095	-1.70										46.8
Pb---------	-.013	3/						0.021					74.1
Zn---------	.15			.70					-.034				89.7
C horizon													
Cd4/ -------	0.31	3/				0.039				-0.035			43.3
Co4/ -------	1.65	3/								-.18			35.6
Cu---------	.15	0.020											47.8
Fe---------	61.8									-6.58			45.4
K----------	174						-8.69				-1.17		65.3
Mg2/ -------													
Mn---------	34.4					6.88				-4.02			70.8
Na2/ -------													
Ni---------	6.58									-.72			33.5
Pb2/ -------		3/											
Zn1/ -------	-.0080	.0012											15.2

1/ Independent variables significant at the 0.10 probability level.

2/ No independent variables significant at the 0.10 probability level.

3/ No data available for total element concentration.

4/ Relations are suspect because of excessive analytical error.

Table 43.--Relative influence of total element concentration and other soil properties on DTPA extractable element concentrations of the less than 2 mm fraction, further ground to pass a 150um (100 mesh) sieve, of A- and C-horizon soils of the Northern Great Plains

[Only independent variables significant at the 0.05 probability level are included in the prediction equations unless otherwise noted]

Element in soil extract	Regression constant	Independent variables and their partial regression coefficients: Total element concentration	Carbon: Carbonate	Carbon: Organic	Carbon: Total	Carbon: Walkley Black	Carbon: Ignition at 550°C	Cation exchange capacity	Clay	pH	Sand	Silt	Percent of variance explained
						A horizon							
Cd	0.036	[3]				0.039							42.5
Co[4]	-.020	[3]							0.0092				43.4
Cu	1.03								.042	-0.17		-0.013	91.7
Fe	144							1.22		-23.6	0.51		79.1
K	31.5			55.6									82.7
Mg	59.8								5.89				79.9
Mn	-1.23	0.065		15.5			-6.02						86.8
Na[2]													
Ni	.16	.11											36.0
Pb	.019	[3]						.020					73.1
Zn	.16			.81					-.039				90.6
						C horizon							
Cd[1][4]	0.24	[3]								-0.023			17.2
Co[4]	1.53	[3]								-.17			46.1
Cu	.020	0.013							0.0087				60.7
Fe[2]													
K[2]													
Mg	-178	171						11.8					74.7
Mn	67.8					9.66				-7.66			68.8
Na[2]													
Ni	8.38									-.92			56.0
Pb	.29	[3]				.16							20.5
Zn[2]													

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[1] Independent variables significant at the 0.10 probability level.

[2] No independent variables significant at the 0.10 probability level.

[3] No data available for total element concentration.

[4] Relations are suspect because of excessive analytical error.

Table 44.--Relative influence of total element concentration and other soil properties on DTPA extractable element concentrations of the less than 150 μm (100 mesh) fraction that was separated from the less than 2 mm fraction by dry sieving, for A- and C-horizon soils of the Northern Great Plains

[Only independent variables significant at the 0.05 probability level are included on the prediction equations unless otherwise noted]

Element in soil extract	Regression constant	Independent variables and their partial regression coefficients											Percent of variance explained
		Total element concentration	Carbon					Cation exchange capacity	Clay	pH	Sand	Silt	
			Carbonate	Organic	Total	Walkley Black	Ignition at 550°C						
A horizon													
Cd	-0.0019	[3/]										0.0058	19.2
Co[4/]	.14	[3/]	-0.31					0.0052					49.2
Cu	-.97								0.10	-0.28	0.028		87.0
Fe	190									-22			60.2
K	89			126			-32						80.1
Mg	-117	37							7.6		2.2		83.2
Mn	6.9	.044	-32										55.8
Na[2/]													
Ni	.078	.097											23.9
Pb	.11	[3/]						.036					55.0
Zn	.23			1.3					-.055				91.0
C horizon													
Cd[2/]		[3/]											
Co[2/]		[3/]											
Cu	0.086	0.030							0.018				63.1
Fe	97									-10			42.1
K[1/]	87		-12								-0.36		31.5
Mg	-154	242						16				-9.6	81.4
Mn	56					8.8				-6.3			72.8
Na[2/]													
Ni	6.7									-.74			39.9
Pb[1/]	.55	[3/]	.20										15.7
Zn[1/]	.11					.096							14.0

[1/] Independent variables significant at the 0.10 probability level.

[2/] No independent variables significant at the 0.10 probability level.

[3/] No data available for total element concentration.

[4/] Relations are suspect because of excessive analytical error.

Table 45 .-- Summary of analytical methods to be used in studies of element availability in rocks and soils.

[This group of determinations is labeled, Regional Methods-Availability; DTPA extract, Lindsay and Norvell, 1969; Soltanpour and Schwab, 1977; water saturation extract, Bower and Wilcox, 1965; Richards, 1954; cation-exchange capacity, Chapman, 1965; exchangable bases, Heald, 1965, Pratt, 1965a, 1965b; hot water extract, Burger and Truog, 1939; Naftel, 1939; Wear, 1965; soil pH, Peech, 1965]

DTPA extract	Water saturation extract	Cation-exchange capacity, and Exchangable cations	Hot water extract	Soil pH	Other[1]
Cd	Ca	Ca	B	pH	As
Co[2]	K	K			Hg
Cu	Mg	Mg			Mo
Fe	Na	Na			Se
Mn	Cl	NH_4[3]			C-organic
Ni[2]	SO_4				C-carbonate
Pb	Specific-conductance				C-total
Zn					

1/ These properties will not be determined from a soil extract. Data for total chemical analysis will be used for information on these properties.

2/ May require an organic extraction and concentration because of detection limits.

3/ Cation-exchange capacity determination.

STATISTICAL ZONATION OF OIL SHALE CORE JUHAN 4-1, COLORADO

by Walter E. Dean and John R. Dyni

Introduction

Stratigraphic logs generally consist of graphs of some measured attribute of the sediments, rocks, or interstitial fluids in the stratigaphic sequence (y) plotted against depth within the stratigraphic sequence (x). Core hole data may be in the form of a series of continuous or discrete down-hole measurements made on cuttings or cores. By the very nature of stratigraphic sequences, the measured x-axis (depth) is an implied time axis, although time is rarely measured directly.

The main purpose for measuring any variable (y) as a function of depth or time (x) within a stratigraphic sequence is to distinguish portions of the sequence that are distinctive in the measured variable (e.g. high oil-yield vs. low oil-yield portions of a sequence of oil shale), or to isolate specific horizons of interest (e.g. a sharp change from low to high porosity). Locating these distinctive zones is usually done subjectively by the geologist looking at the log, usually at a distance or at an oblique angle, and deciding which portions of the log appear distinctive. Some objectivity may be injected into the zonation decisions by selecting a predetermined cutoff value (e.g. all portions of an oil shale sequence yielding more than some minimum volume of oil).

The purpose of this paper is to describe several objective statistical techniques that have been used to isolate zones of distinctive chemical characteristics within the saline facies of the Green River Formation (Eocene) in the Piceance Creek basin, northwestern Colorado. The data consist of measured concentrations of Al_2O_3, Si, Na, S, Fe, K, Ca, and Sr in 374 samples, each approximately 0.61m thick, collected through a 232m section of the saline facies of the Green River Formation in the Juhan 4-1 core hole, Rio Blanco County, Colorado (Dyni, 1974). Concentrations of these elements (except for Na) were determined by X-ray fluorescence. Na was determined by semi-quantitative optical emission spectroscopy. oil yields were also determined.

Saline facies of the Green River Formation

The saline facies occurs in the lower part of the Parachute Creek Member of the Green River Formation in the Piceance Creek basin (Smith and Milton, 1966; Hite and Dyni, 1967; Dyni and others, 1970; Trudell and others, 1970; Young and Smith, 1970; Beard and others, 1974; Dyni, 1974; Robb and Smith, 1974). It underlies an area of approximately 660 sq. km in the north central part of the basin, with thicknesses on the order of 30 to 300m and a maximum thickness of 344m (Dyni, 1974). The top of the present occurrence of water-soluble saline minerals is a dissolution surface that cuts across stratigraphic boundaries with as much as 140m of stratigraphic relief. Solution breccias and cavities, which occur for as much as 250m above the dissolution surface, are evidence of the former occurrence of saline minerals throughout the section. This dissolution has formed a highly permeable hydrologic unit, usually referred to as the "leached zone", that is the principal ground-water aquifer in the Piceance Creek basin (Coffin and others, 1970).

The saline facies differs from the overlying nonsaline part of the Parachute Creek Member mainly by the occurrence of nahcolite ($NaHCO_3$; naturally occurring soda ash), dawsonite ($NaAl(OH)_2CO_3$), and, in some cores, halite ($NaCl$) in the typical fine-grained marlstone ("oil shale") matrix of dolomite, calcite, quartz, feldspars, and kerogen. The marlstone containing saline minerals has relatively high oil yields of 20 to 30 gallons per ton (85 to 127 liters per tonne) which is equivalent to 30 to 40 gallons per ton (127 to 169 liters per tonne) on a nahcolite-free basis. The nahcolite facies is even more distinct from the kerogen-rich shale of the underlying Garden Gulch Member, which is characterized by lack of saline minerals (except for some dawsonite in the upper 15 to 18m of the Member), a lower content of dolomite than the Parachute Creek Member, and a much higher content of clay, mostly illite (Hite and Dyni, 1967).

Both nahcolite and dawsonite are present in quantities that are considered economic, particularly if extracted as a byproduct of oil shale. Total estimates of nahcolite in the Piceance Creek basin are on the order of 30 billion metric tons (Beard and others, 1974; Dyni, 1974). Total resources of dawsonite in the Piceance Creek basin are on the order of 17 billion metric tons, which would yield about 6 billion metric tons of alumina (Beard and others, 174). Dawsonite occurs mainly as fine-grained (<5um) crystals disseminated through the marlstone. Nahcolite also occurs as disseminated fine-grained material, but most occurs as nonbedded crystalline aggregates (nodules and rosettes) scattered through the marlstone, and laterally-continuous beds of micro- to coarse-grained crystals (Hite and Dyni, 1967; Dyni, 1974). The nahcolite aggregates are roughly spherical, up to 90 cm in diameter, with most on the order of 2 to 10 cm. Beds of nahcolite, as thick as 9m, grade laterally into interbedded halite and nahcolite in the depocenter of the saline facies. The nahcolite aggregates are clearly diagenetic, and formed after deposition of the enclosing dolomitic marlstone. However, bedded nahcolite is interpreted as a true evaporite that precipitated during higher salinity phases of the lake.

Halite occurs interlayered with nahcolite and marlstone forming beds up to 20m thick. These paired layers are interpreted to be the result of seasonal cycles of evaporite sedimentation representing high-salinity analogues of the varves that characterize most of the dolomitic marlstone of the Green

River (Dyni and others, 1970). Beds of halite thin away from the depocenter of the saline facies, and grade laterally into beds of nahcolite.

Halite is not present in the Juhan 4-1 core used for this investigation, but the core does contain approximately 200m of dawsonite- and nahcolite-bearing marlstone.

Statistical Techniques

Analysis of Variance Zonation:

Details of the analysis of variance zonation technique have been described by Testerman (1962) and Gill (1970). The data matrix usually consists of a distance or time axis (x) and a concentration axis ($y = f(x)$) that is normally in units of intensity of a measured variable (% porosity, ppm Sr, % arboreal pollen, etc.).

The technique begins by computing between- and within-zone variances for all possible two-zone subdivisions based on concentrations of the measured variable in stratigraphic sequence. The first observation (e.g., % Na in sample 1) is the first zone and all other observations (2 through N) constitute the second zone. Between- and within-zone variances are computed, and a coefficient of zonation, R, is computed according to the equation: $R = (B-W)/B$, where B and W are the between- and within-zone variances respectively. For an optimum zone boundary, $W = 0$ and $R = 1$. If the data are homogeneous, $B = 0$ and R is undefined. If W is greater than B, R will be negative, but all negative values are considered zero for purposes of interpretation. We are looking for a zone boundary that will give a value of R as close to 1.0 as possible. This boundary will have the effect of minimizing W and maximizing B.

After the first value of R is computed, the first and second observations are grouped as the first zone, all other observations (3 through N) taken as the second zone, and a second value of R computed. A third value of R is computed with observations 1, 2, and 3 as the first zone, etc. until the Nth value of R is computed using the Nth observation as the second zone and all other observations (1 through N-1) as the first zone.

The values of R are then searched, and the highest value taken as the zone boundary. For example, for values of % Na in 100 samples in ordered stratigraphic sequence, suppose the 37th value of R was the highest at 0.94. Then the zone boundary would be drawn between samples 37 and 38; zone 1 would contain samples 1 through 37, and zone 2 would contain samples 38 through 100.

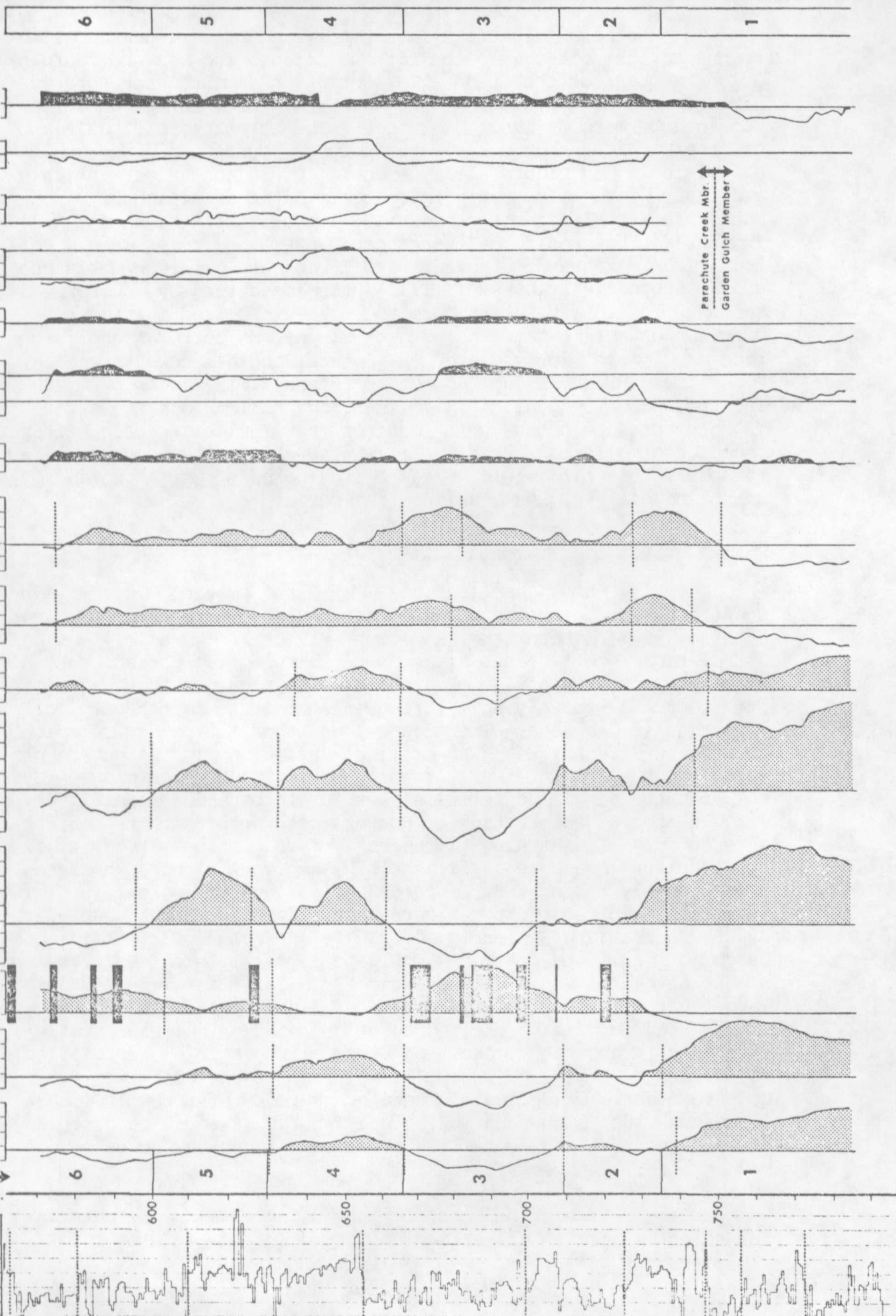
After the first zone boundary has been established, each of the two zones is examined separately for the next best 2-zone boundary. This boundary divides the data into three zones. The procedure is repeated until the values of R begin to decrease with the addition of new zones, or until a predetermined number of zones is reached.

In general, this procedure will probably not produce zone boundaries that could not have been intuitively chosen by any qualified observer. The advantages of the technique are that the boundaries are based on strict objective criteria, and the order in which boundaries are selected provides a relative ranking of importance of the zone boundaries. For details of the computational methods, the interested reader is referred to papers by Testerman (1962) and Gill (1970).

The analysis of variance zonation technique was applied to measured values of Al_2O_3, Si, Na, S, Fe, K, Ca, and Sr in the 374 samples of the Juhan core hole. In general, five or six zones were optimum for each of the 8 variables. The stratigraphic positions of each zone are plotted as dotted lines in figure 21.

The curves for each variable plotted in figure 21 are based on smoothed values of the raw data using a 31-sample moving average. Smoothing removes the small-scale variability ("noise") in the raw data and helps to visually isolate portions of the curves with unusually high or low values. Note that the tops of the curves in figure 21 do not correspond to the stratigraphic positions of the uppermost data point (561.1 to 561.8m). This is because each 31-sample average is plotted at the midpoint depth of the averaged interval, which would be the depth at 16 data points down from the top of the interval. A vertical line is drawn at the geometric mean value for each of the 8 variables, and portions of the curves with values greater than the geometric mean are filled in with a stippled pattern. The curve of % Na in figure 21 is truncated at about 750m because all values below this depth are below the detection limit (0.7%) by semi-quantitative optical emission spectroscopy.

Figure 21.--Profiles of concentrations of Al_2O_3, Si, Na, S, Fe, K, Ca, and Sr, and 31-sample moving correlation coefficients between selected pairs of elements for the saline facies and Garden Gulch Member in the Juhan 4-1 core of the Green River formation. Concentrations of each element have been smoothed using a 31-sample moving average. Vertical lines through the profiles of smoothed element concentration are plotted at the value of the geometric mean for each element. Portions of the profiles greater than the geometric mean are shaded with a stippled pattern. Vertical lines through the profiles of moving correlation coefficients are plotted at values that are significant at the 99 percent significance level ($r = 0.45$ for $n = 31$). Portions of the profiles with correlation coefficients >0.45 are solid black. Portions of the profiles with correlation coefficients <-0.45 are shaded. Stratigraphic positions of zone boundaries selected by the analysis of variance zonation technique are indicated by dashed lines on the smoothed profiles of element concentration. Subjective average boundaries of the six zones discussed in the text are indicated by numbers one through six on the left and right sides of the illustration. Subjective zone boundaries based on rich and lean oil-yield data (Dyni, 1974) are indicated by numbers two through ten to the left of the profile of oil-yield (in gallons per ton). Stratigraphic positions of laterally-persistent beds of disseminated nahcolite (from Dyni, 1974) are indicated by the shaded boxes on the smoothed profile of Na concentrations.


analysis of variance zone
6
5
4
3
2
1
MOVING CORRELATION COEFFICIENTS
Al vs Si r
Na vs Al r
Ca vs Na r
Na vs S r
Fe vs S r
oil vs Fe r
oil vs S r
Parachute Creek Mbr.
Garden Gulch Member
ppm Sr
% Ca
% K
% Fe
% S
% Na
% Si
% Al_2O_3
analysis of variance zones
oil (gal. per ton)
600
650
700
750
800 meters
oil yield zone
10
9
8
7
6
5
4
3
2

To further illustrate the analysis of variance zonation technique, the oil- yield log for the saline facies and Garden Gulch Member of the Green River Formation in the Juhan core was divided into 10 zones using the nine highest zone boundaries obtained by methods described above. The stratigraphic positions of the 9 zone boundaries are indicated by dashed lines on the oil-yield log in figure 21. The choice of 10 zones was entirely arbitrary for illustrative purposes. After selection of 9 zone boundaries, coefficients of zonation were still high (> 0.9) indicating that additional zones could easily be determined. For comparison, zones of alternating oil-rich and oil-lean marlstone chosen subjectively by Dyni (1974) are indicated by numbers 3 through 10 to the left of the oil-yield log in figure 21. Descriptions of these rich and lean zones, and correlations with rich and lean zones used by Donnell and his coworkers (e.g. Donnell and Blair, 1970; Cashion and Donnell, 1972) can be found in the paper by Dyni (1974). The rich and lean oil shale zones in this core are not as well defined as in saline-free cores because of dilution by saline minerals. Statistical zonation on the basis of oil yield data could perhaps be improved by computing oil yield on a saline-free basis.

Moving Correlation Coefficient:

Details and applications of the moving correlation coefficient technique have been described elsewhere (Anderson and others, 1972; Dean and Anderson, 1974a and b). Moving correlation coefficients are computed between two variables in a stratigraphic sequence in much the same way that moving averages are computed for a single variable in order to smooth out local variation in the data. The purpose of the moving correlation coefficient technique is to examine variations in the degree of association between two variables that might be hidden by computing a single correlation coefficient based on a relatively large number of observations. For example, suppose that we are interested in examining the degree of association between % oil and % sulfur in a core of oil shale. Samples for these analyses are commonly taken every foot (0.305m) or every two feet (0.61m) in a core. Therefore, for a core 1,000m long, we might have over 3,000 observations. Clearly a single correlation coefficient based on all observations would be almost meaningless because almost any value would be statistically significant with such a large value of N. The moving correlation coefficient technique can be used to examine the degree of correlation within smaller intervals along the core, perhaps all possible correlation coefficients with N = 100. Using this technique, we would compute a correlation coefficient for samples 1 through 100, then 2 through 101, 3 through 102, etc. The result would be a series of N-100 correlation coefficients referred to as a sequence of moving corelation coefficients.

Moving correlation coefficients using a 31-sample interval for selected pairs of variables are plotted in figure 21.

Vertical lines are drawn on each curve at values that are significant at the 99% significance level (r= 0.45 for N=31). Areas of the curves with positive correlation coefficients >0.45 are solid black, and areas with negative correlation coefficients <-0.45 are shaded. Correlations based on all samples and on samples from the saline zone and the underlying Garden Gulch zone are given in table 46.

Results and Discussion

Results of the analysis of variance zonation and the moving correlation analysis plotted in figure 21 suggest that the saline facies and underlying Garden Gulch Member of the Green River Formation can be divided into six geochemical zones with the following approximate depth boundaries: 735 to 793m (bottom of the core), 710 to 735m, 665 to 710m, 630 to 665m, 600 to 630m, and 561 to 600m. These boundaries are obviously not the same for all elements, but represent subjective averages of objective boundaries picked by the analysis of variance technique.

Zone 1 - 735 to 793m:

The lowermost zone extends downward from the lowest occurrence of nahcolite in dolomitic marlstone of the Parachute Creek Member, and includes the underlying clay-rich Garden Gulch Member. The Garden Gulch Member is characterized by laminated claystone, siltstone, and shale, with illite, quartz, albite, K-feldspar, dolomite, and calcite as the dominant minerals (Hite and Dyni, 1967; Trudell and others, 1970). Some disseminated dawsonite occurs in the upper 15 to 18m. Most of the Si and Al in the Garden Gulch resides in silicate minerals, chiefly illite, feldspars and quartz. Na is present in concentrations less than 0.7% (the detection limit by optical emission spectroscopy), and is present mainly in plagioclase feldspar. Some Na and Al are accounted for by minor dawsonite in the upper part of the Garden Gulch, increasing in the transition with the nahcolite- and dawsonite-rich saline facies of the Parachute Creek Member.

Zone 1 is the only zone of the six described here in which Si is not highly correlated with Al (fig. 21; table 46). In the saline zone, Si and Al are present mainly in quartz and dawsonite respectively. The abundance of these two minerals in the saline facies is highly correlated (Hite and Dyni, 1967; Dyni, 1974) which accounts for the high positive correlations between Si and Al, regardless of their relative abundances. The Al and Si in dawsonite and quartz in the saline facies were probably derived from diagenetic alteration of pre-existing aluminosilicate minerals (mostly clays and (or) tuffaceous material) in hypersaline brines (Hite and Dyni, 1967). The top of zone 1 corresponds to the disappearance of clay and the appearance of nahcolite.

Table 46. - Correlation coefficient matrices of the Juhan 4-1 core data.

[▲, significant at the 99% probability level]

Correlation coefficients, Juhan 4-1 core, 561 to 793 meters (saline zone and Garden Gulch Member) N = 374; 99% significance level = ±0.13

	% oil	% Fe	%Al203	% S	% Ca	% K	% Na	% Si	ppm Sr
% oil	1.0000	-0.0293	-0.1382▲	0.3846▲	0.3481▲	-0.0302	-0.2391▲	-0.0516	0.2050
% Fe	-0.0293	1.0000	0.8941▲	0.6428▲	-0.4319▲	0.7015▲	-0.7227▲	0.7774▲	-0.5120▲
%Al203	-0.1382▲	0.8941▲	1.0000	0.5174▲	-0.4201▲	0.7544▲	-0.7475▲	0.8398▲	-0.4540▲
% S	0.3846▲	0.6428▲	0.5174▲	1.0000	-0.2244▲	0.3545▲	-0.5536▲	0.5160▲	-0.3380▲
% Ca	0.3481▲	-0.4319▲	-0.4201▲	-0.2244▲	1.0000	-0.2007▲	-0.0729	-0.2812▲	0.8696▲
% K	-0.0302	0.7015▲	0.7544▲	0.3545▲	-0.2007▲	1.0000	-0.6692▲	0.6510▲	-0.2771▲
% Na	-0.2391▲	-0.7227▲	-0.7475▲	-0.5536▲	-0.0729	-0.6692▲	1.0000	-0.8295▲	0.0545
% Si	-0.0516	0.7774▲	0.8398▲	0.5160▲	-0.2812▲	0.6510▲	-0.8295▲	1.0000	-0.3555▲
ppm Sr	0.2050	-0.5120▲	-0.4540▲	-0.3380▲	0.8696▲	-0.2771▲	0.0545	-0.3555▲	1.0000

Correlation coefficients, Juhan 4-1 core, 561 to 740 meters (saline zone) N = 288; 99% significance level = ±0.15

	% oil	% Fe	%Al203	% S	% Ca	% K	% Na	% Si	ppm Sr
% oil	1.0000	0.2524▲	0.2304▲	0.6181▲	0.2449▲	0.1665▲	-0.4603▲	0.2463▲	0.0653
% Fe	0.2524▲	1.0000	0.8741▲	0.6257▲	-0.2670▲	0.6634▲	-0.6845▲	0.7889▲	-0.4300▲
%Al203	0.2304▲	0.8741▲	1.0000	0.4447▲	-0.1867▲	0.7615▲	-0.7582▲	0.8822▲	-0.3269▲
% S	0.6181▲	0.6257▲	0.4447▲	1.0000	-0.1311	0.3320▲	-0.4545▲	0.4186▲	-0.3103▲
% Ca	0.2449▲	-0.2670▲	-0.1867▲	-0.1311	1.0000	-0.0598	-0.3143▲	-0.0163	0.8982▲
% K	0.1665▲	0.6634▲	0.7615▲	0.3320▲	-0.0598	1.0000	-0.6794▲	0.7340▲	-0.1908▲
% Na	-0.4603▲	-0.6845▲	-0.7582▲	-0.4545▲	-0.3143▲	-0.6794▲	1.0000	-0.8467▲	-0.0922
% Si	0.2463▲	0.7889▲	0.8822▲	0.4186▲	-0.0163	0.7340▲	-0.8467▲	1.0000	-0.1837▲
ppm Sr	0.0653	-0.4300▲	-0.3269▲	-0.3103▲	0.8982▲	-0.1908▲	-0.0922	-0.1837▲	1.0000

Correlation coefficients, Juhan 4-1 core, 747 to 793 meters (Garden Gulch Member) N = 75; 99% significance level = ±0.30

	% oil	% Fe	%Al203	% S	% Ca	% K		% Si	ppm Sr
% oil	1.0000	-0.2193	-0.5385▲	0.4963▲	0.2854	-0.4313▲		-0.3438▲	-0.0515
% Fe	-0.2193	1.0000	0.6678▲	-0.0873	-0.4042▲	0.7177▲		-0.2663	-0.1067
%Al203	-0.5385▲	0.6678▲	1.0000	-0.2315	-0.5623▲	0.8623▲		0.0504	-0.2082
% S	0.4963▲	-0.0873	-0.2315	1.0000	0.1777	-0.2208		-0.1182	-0.0010
% Ca	0.2854	-0.4042▲	-0.5623▲	0.1777	1.0000	-0.3215▲		-0.5657▲	0.5995▲
% K	-0.4313▲	0.7177▲	0.8623▲	-0.2208	-0.3215▲	1.0000		-0.3029▲	-0.0206
% Si	-0.3438▲	-0.2663	0.0504	-0.1182	-0.5657▲	-0.3029▲		1.0000	-0.4500▲
ppm Sr	-0.0515	-0.1067	-0.2082	-0.0010	0.5995▲	-0.0206		-0.4500▲	1.0000

Zone 1 contains higher concentrations of Fe and S than any other zone. The Fe and S are present as ferrous sulfide minerals which are disseminated throughout as fine-grained crystal aggregates. However, the lack of significant correlation between S and Fe in this zone (fig. 21; table 46) suggests that other Fe and S phases are also important. In fact, the only other variable that does correlate with sulfur in this zone is oil, suggesting that much of the sulfur is present as organic-S. Correlations between oil and Fe exhibit a surprising amount of variation from strong positive correlations to strong negative correlations, with an overall correlation of near zero (table 46). In particular, iron (mostly in the form of pyrite) is positively related to oil content when nahcolite is abundant (zones 3 and 6), and negatively related to oil content when nahcolite is scarce but some dawsonite is present (transition between zones 1 and 2, and zone 4). Some Fe may also be present in illite, substituting for Al in octahedral positions in the crystal structure (Grim, 1953).

Concentrations of both Ca and Sr are low in zone 1, reflecting lower contents of dolomite and calcite in the Garden Gulch Member relative to the dolomitic marlstone of the overlying Parachute Creek Member.

Zone 2 - 710 to 735m:

This zone contains the lowest occurrence of nahcolite in the saline facies. The nahcolite is present as disseminated aggregates of coarse-grained bladed crystals, and as one distinct, laterally continuous bed of disseminated nahcolite (shaded box on the Na-profile in figure 21) containing up to 62% nahcolite (nahcolite unit 21 of Hite and Dyni, 1967). In general, this zone appears to be a transition between the nahcolite-poor marlstone in the upper part of zone 2 and the nahcolite-rich marlstone of zone 3. In addition to intermediate concentrations of Na (present mainly as nahcolite), this zone contains intermediate concentrations of Si and Al (present mainly as quartz and dawsonite, respectively), and Fe and S (present mainly as pyrite). Concentrations of Fe and S exhibit significant positive correlations here as they do throughout most of the saline facies (fig. 21).

Zone 3 - 665 to 710m:

Zone 3 contains the highest concentrations of Na and lowest concentrations of Al, Si, Fe, and S in the six zones described. The abundance of nahcolite is indicated by the high concentrations of Na and by the presence of five distinct beds of disseminated nahcolite ranging from 30 to 64% nahcolite by weight (Dyni, 1974). A bed containing 25% nahcolite disseminated in marlstone is equivalent to 6.8% Na by weight, which is about the average for zone 3. Additional minor amounts of Na are also contributed by dawsonite and Na-feldspar.

Si and Al are mainly concentrated in quartz and dawsonite respectively as they are throughout the saline facies; clay minerals are conspicuously absent. Marlstone containing 10% dawsonite (an approximate average value for the saline facies; Hite and Dyni, 1967; Beard and others, 1974) would yield 1.6% Na and 1.9% Al (3.6% Al_2O_3).

Pyrite occurs mainly as finely disseminated crystal aggregates in both marlstone and nahcolite, but also occurs as a coating on the outsides of nahcolite aggregates. For this reason we were somewhat surprised to find a negative association between Na and both Fe and S throughout most of the saline facies, and particularly in zones 3 and 6 (fig. 21). Only the moving correlation coefficient curve for Na vs. S is plotted in figure 21 because the curve for Na vs. Fe is almost identical. Both Fe and S are also negatively correlated with Ca and Sr (table 46), indicating that, in general, pyrite and carbonates (nahcolite, dolomite, and calcite) are not closely associated. The high positive correlations between oil and Fe in zones of high salinity (as interpreted from zones of high nahcolite content), and low negative correlations between oil and Fe in zones of lower salinity (zones 1 and 4), suggest that the effect of organic content on iron diagenesis, probably through controls on pH and Eh, was maximized by whatever geochemical conditions were unique to the Green River lake during deposition of nahcolite. Also, Fe and S are most closely associated in zones of highest nahcolite content (zones 3 and 6), even though the absolute amounts of Fe and S in the marlstone are at a minimum.

The dominant mineral residence of Na is in coarse-crystalline nahcolite, whereas the dominant residences of Ca, Si, Fe and S, Al, K, and oil are in dolomite and calcite, quartz, pyrite, dawsonite, K-feldspar, and kerogen, respectively, which are all part of the fine-grained marlstone matrix. Therefore the negative correlation between Na and all other elements (fig. 21; table 46) in zones 3 and 6 in particular, and in the saline facies in general, may be due to dilution of the marlstone matrix by crystal aggregates of nahcolite. For example, Dyni (1974) has shown that oil yields from marlstone in the saline facies can be increased by about one third with the removal of nahcolite. However, when sulfur is computed on a nahcolite-free basis, it is still lowest in abundance in the high-nahcolite zones. Beginning with a marlstone matrix containing 3% pyrite (1.6% S and 1.4% Fe), and diluting the marlstone with 20% nahcolite, the pyrite content of the resulting bulk sediment would only be reduced to 2.4% (equivalent to 1.2% S and 1.1% Fe). The variations shown in figure 1 are clearly much greater than this, suggesting that at least some of the negative associations with Na are real and are not due simply to dilution by nahcolite.

Zone 4 - 630 to 665m:

Zone 4 is a low-nahcolite zone in which geochemical associations are almost the exact opposite from those in the high-nahcolite zones. This zone is characterized by low concentrations of Na, and high concentrations of Al, Si, Fe, S, and K. This is the only zone in the saline facies in which Na exhibits a significant positive correlation with both Fe and S ; the associations are mostly negative throughout the rest of the saline facies. The nahcolite content of this zone is the lowest of any zone in the saline facies, and much, if not most, of the Na resides in dawsonite. This is further indicated by the fact that this is the only zone in which Na and Al do not exhibit a strong negative association. The correlations illustrated in figure 21 suggest that, in general, pyrite is more closely associated with dawsonite than with nahcolite. However, conditions controlling the role of organic content in iron diagenesis were at a minimum during deposition of zone 4, as suggested by the abrupt change from significant positive to significant negative correlations between oil and Fe.

Zone 5 - 600 to 630m:

This zone is similar to zone 2 in that it appears to represent a transition between a low-nahcolite, high-Si, high-Al zone and a high-nahcolite, low-Si, low-Al zone. This zone contains one bed of disseminated nahcolite that averages about 10% nahcolite by weight. Zone 5 differs from low-nahcolite zone 2 mainly by the higher pyrite content of Zone 5.

Zone 6 - 561 to 600m:

The upper zone of the saline facies in the Juhan 4-1 core immediately below the dissolution surface (Dyni, 1974) exhibits most of the characteristics of high-nahcolite zone 3, containing high concentrations of Na, and low concentrations of Al, Si, Fe, and S. This zone contains four distinct laterally-persistent beds of nahcolite ranging from 20 to 53% nahcolite by weight (Dyni, 1974). Most of the characteristics and associations for high-nahcolite zones discussed under zone 3 also apply to zone 6.

REGIONAL SOIL CHEMISTRY IN THE BIGHORN AND WIND RIVER BASINS, WYOMING AND MONTANA

By Ronald C. Severson

Introduction

The study area consists of the Bighorn and Wind River Basins in Wyoming and Montana. The geographic extent of each basin is defined as the area of outcrop of geologic units of Tertiary age or younger. The boundaries for the basins were taken from published geologic maps (Andrews, Pierce, and Eargle, 1947; and Whitcomb and Lowry, 1968). The major portion of the total area of each basin comprises three geologic map units (fig. 22). The excluded area in the Wind River Basin is underlain by pre-Tertiary sedimentary rocks, Tertiary intrusive rocks, and Precambrian rocks.

An unbalanced, nested, analysis-of-variance design was chosen to estimate components of chemical variation reflecting differences between geologic map units within basins, and differences associated with various distances within map units. This design was implemented by randomly locating barbells in each of the three geologic map units within each of the basins (Fig. 22). The major axis of each barbell was 25 km long, and the sequentially smaller axes of each barbell were 10, 5, and 1 km long, respectively. All axes were oriented by selecting a compass direction at random. The barbell is shown diagrammatically in fig. 23; a soil sample was collected at each "X". In each of the six barbells, 12 samples were collected resulting in a total of 72. The analysis-of-variance design used in this study is shown in table 47.

Samples and Analyses

At each sampling location, the soil sample consisted of a channel composite of material, excluding cobbles and rocks, from a depth of 0 to 40 cm. In the laboratory, all samples were air dried under forced air at ambient temperature. The samples were disaggregated with a mechanical mortar-and-pestle and the fraction passing a 10-mesh sieve (2 millimeter) was saved. The minus-2 mm fraction was further ground to pass a 100-mesh sieve (150um) and this material was used for all chemical analyses. The 96 samples (72 plus 24 splits) were submitted to, and analyzed in, the laboratory in a randomized sequence so that any systematic errors in sample preparation and analysis would be effectively converted to random errors and not bias the interpretation of results.

Chemical analyses were done in the U. S. Geological Survey laboratories, in Denver, Colorado. Sample preparation and analyses were performed by; James S. Baker, A. J. Bartel, E. L.

Brandt, J. G. Crock, I. C. Frost, Johnnie M. Gardner, Patrica Gayle Guest, Raymond G. Havens, J. P. Hemming, Kathryn E. Horan, Claude Huffman, Jr., J. O. Johnson, R. J. Knight, R. M. Lemert, R. E. McGregor, Violet M. Merritt, H. T. Millard, Jr., Wayne Mountjoy, G. O. Riddle, V. E. Shaw, M. W. Solt, J. A. Thomas, Michele L. Tuttle, R. E. Van Loenen, R. J. Vinnola, J. S. Wahlberg, and R. J. White.

All computations were done on a Honeywell-MULTICS computer using statistical programs in the U. S. Geological Survey's STATPAC Library (VanTrump and Miesch, 1977).

Analytical Error Variance

Of the 12 samples collected at each barbell, four samples were randomly selected to be split and analyzed twice. Therefore, a total of 24 samples were split and analyzed in duplicate. These sample splits represent the analytical-error level of the sampling design (table 47).

The distribution of variance components for 38 elements in soils of the two basins are shown in tables 48 and 49. For six elements in the Bighorn Basin and 11 elements in the Wind River Basin, the analytical error variance accounts for more than 50 percent of the total observed variation. This error is judged to be excessive and no further interpretation of the data for these elements will be attempted.

Statistical Summaries and Baseline Values

In table 48, only one entry (Zn) exhibits a significant component among map units, whereas in table 49, eight entries (excluding Rb, which has excessive analytical error) show such significance. Looked at the other way, 31 elements in soils of the Bighorn Basin and 19 elements in soils of the Wind River Basin do not exhibit statistically significant among-unit variability. Thus, a single estimate of a baseline may be used to describe the total concentration for these elements in soils of both these basins (tables 50 and 51). The baseline is defined as the probable range of concentration to be expected in samples of natural soils in the basins (see Tidball and Ebens, 1976).

For elements exhibiting a significant variance component among map units for the Bighorn Basin (table 48) or the Wind River Basin (table 49), statistical summaries and baselines are given for each of the map units sampled (tables 52 and 53).

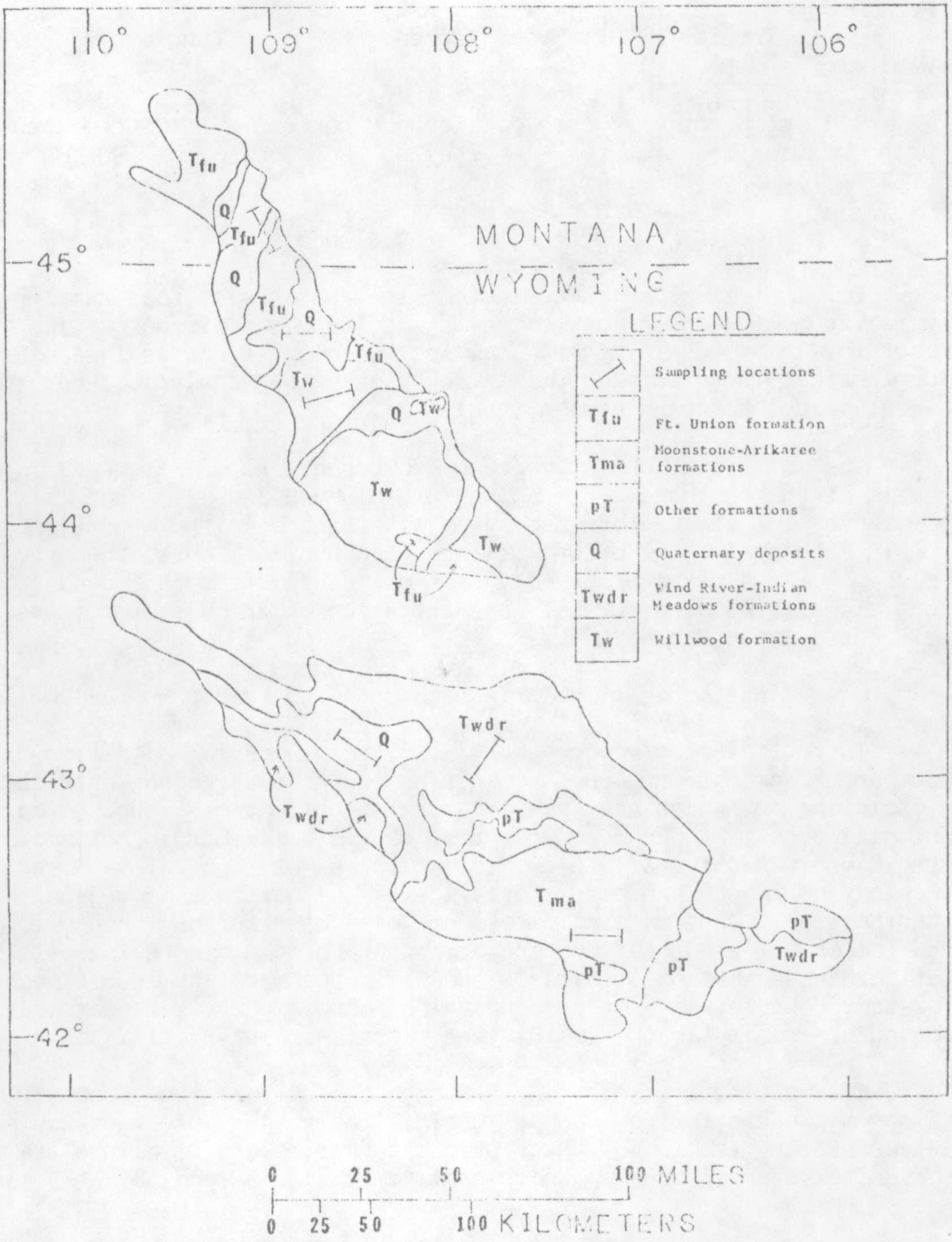


Figure 22.--Map showing locations of the Bighorn and Wind River Basins of Montana and Wyoming with mapping units that were sampled and barbell locations included in the illustration. Geology is adapted from Andrews, Pierce, and Eargle (1947), and Whitcomb and Lowry (1968).

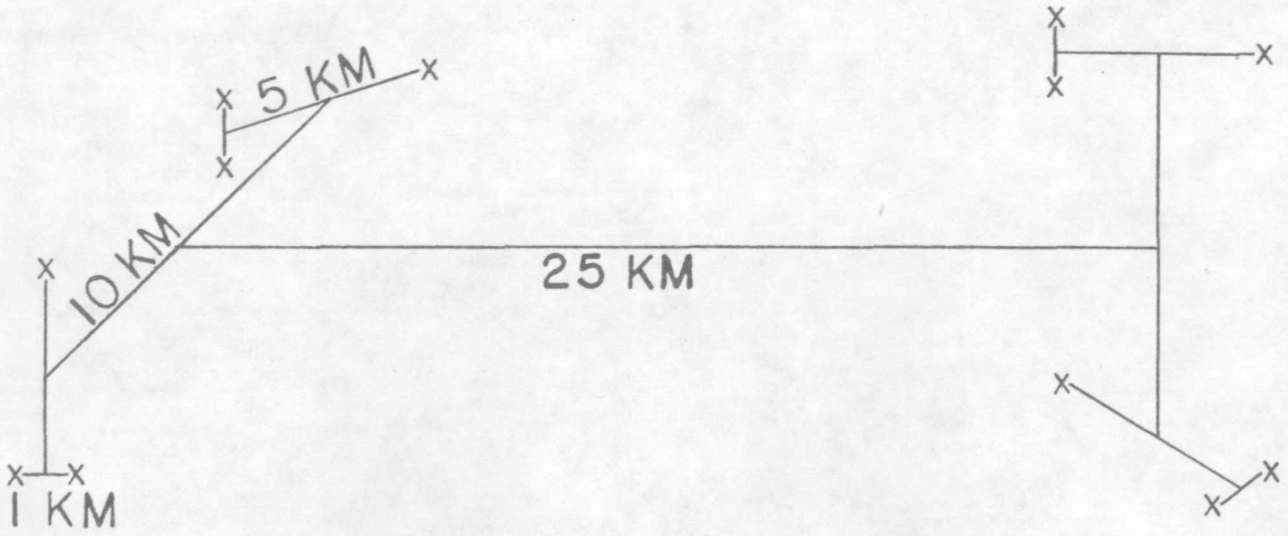


Figure 23.--Diagrammatic representation of a barbell design with sampling locations shown as x's.

Table 47.--Analysis-of-variance scheme for sampling the Bighorn and Wind River Basins

Level	Source of variation	Degrees of freedom	Mean-square estimates	F-ratio	Variance component
1	Between units	2	$MS_1 = s_a^2+1.5s_1^2+2.3s_5^2+4.1s_{10}^2+8.1s_{25}^2+16s_u^2$	$\frac{MS_1}{MS_2}$	$s_u^2 = \frac{MS_1-MS_2}{16} \sim \sigma_u^2$
2	Between 25 km distance within units	3	$MS_2 = s_a^2+1.5s_1^2+2.3s_5^2+4.0s_{10}^2+7.9s_{25}^2$	$\frac{MS_2}{MS_3}$	$s_{25}^2 = \frac{MS_2-MS_3}{7.9} \sim \sigma_{25}^2$
3	Between 10 km distance within 25 km distance	6	$MS_3 = s_a^2+1.4s_1^2+2.3s_5^2+4.0s_{10}^2$	$\frac{MS_3}{MS_4}$	$s_{10}^2 = \frac{MS_3-MS_4}{4.0} \sim \sigma_{10}^2$
4	Between 5 km distance within 10 km distance	12	$MS_4 = s_a^2+1.3s_1^2+1.7s_5^2$	$\frac{MS_4}{MS_5}$	$s_5^2 = \frac{MS_4-MS_5}{1.7} \sim \sigma_5^2$
5	Between 1 km distance within 5 km distance	12	$MS_5 = s_a^2+1.2s_1^2$	$\frac{MS_5}{MS_6}$	$s_1^2 = \frac{MS_5-MS_6}{1.2} \sim \sigma_1^2$
6	Between analyses	12	$MS_6 = s_a^2$		$s_a^2 \sim \sigma_a^2$

Table 48.--Variance analysis of total soil chemistry in the Bighorn Basin

[The sample consisted of a composite from 0 to 40 cm depth; total variance is computed on logrithmically transformed data; n_r, number of randomly selected samples needed to establish a value for a stable mean in an area 25 km square; *, variance component is significantly different from zero; n.d., not determined because n_r is infinitely large; estimates are based on analyses of 48 samples]

		Percent of total variance						
Element	Total variance	Between units	10-25 km	5-10 km	1-5 km	0-1 km	Analytical error	n_r
Al-------	0.0205	10.2	0	0	51.2*	31.1*	7.5	8
As-------	.1143	0	14.1*	0	0	26.3	59.6	--
B--------	.0189	5.9	0	0	21.3	56.8*	16.1	13
Ba-------	.0335	10.6	2.0	6.3	0	0	81.1	--
Be-------	.0282	0	5.3	0	51.4*	13.8	29.5	13
C--------	.0826	0	58.9*	0	24.2*	11.2*	5.6	2
Ca-------	.1085	0	27.1*	0	27.7	45.1*	.2	4
Ce-------	.0314	0	27.9*	0	0	17.7	54.4	--
Co-------	.0183	16.5	0	10.1	34.6	20.8	18.0	5
Cr-------	.0434	5.4	0	0	77.7*	8.8	8.2	13
Cu-------	.0610	8.1	0	0	56.1*	16.0	19.8	9
Fe-------	.0239	23.0	0	8.8	46.3*	17.9*	4.0	4
Ga-------	.0365	11.7	0	0	42.3	29.7*	16.3	7
Ge-------	.2257	0	0	6.6	14.7	0	78.7	--
Hg-------	.0210	5.1	0	17.5	0	57.1*	20.3	13
K--------	.0081	0	7.7	0	39.0	42.2*	11.1	10
La-------	.0096	0	0	0	9.2	50.8	40.0	n.d.
Li-------	.0189	10.5	0	0	49.9*	29.4*	10.3	8
Mg-------	.0120	10.0	0	32.2	10.4	46.4*	.8	8
Mn-------	.0277	0	25.3	0	22.2	44.8*	7.7	4
Mo-------	.0396	7.6	0	0	43.2	26.9	22.2	10
Na-------	.0435	42.2	17.4	7.3	0	32.7*	.3	2
Nb-------	.0230	2.5	4.2	0	8.3	0	85.0	--
Ni-------	.0229	12.7	0	0	41.5	34.4*	11.4	6
Pb-------	.0337	3.6	0	0	0	46.5	49.9	20
Rb-------	.0223	0	15.2	0	44.0*	0	40.9	6
Sc-------	.0452	3.6	11.9	0	40.2	31.4*	13.0	6
Si-------	.0022	19.3	0	31.0	15.3	28.6*	5.8	5
Sn-------	.1678	0	0	20.9	3.4	0	75.7	--
Sr-------	.0246	11.1	17.2	14.7	13.9	38.4*	4.8	4
Th-------	.0161	0	2.3	0	27.9	51.0*	18.8	n.d.
Ti-------	.0083	.7	0	0	26.8	67.6*	5.0	n.d.
U--------	.0101	0	0	10.6	20.7	65.1*	3.6	n.d.
V--------	.0253	0	2.2	0	61.6*	30.7*	5.5	n.d.
Y--------	.0165	0	0	0	58.5*	19.8	21.7	n.d.
Yb-------	.0187	0	0	3.1	65.1*	20.5*	11.3	n.d.
Zn-------	.0212	15.3*	0	1.5	46.4*	26.6*	10.3	6
Zr-------	.0253	0	0	32.4	0	17.7	48.1	n.d.

Table 49.--Variance analysis of total soil chemistry in the Wind River Basin

[The sample consisted of a composite from 0 to 40 cm depth; total variance is computed on logrithmically transformed data; n_r, number of randomly selected samples needed to establish a value for a stable mean in an area 25 km square; *, variance component is significantly different from zero; n.d., not determined because n_r is infinitely large; estimates are based on analyses of 48 samples]

Element	Total variance	Percent of total variance						n_r
		Between units	10-25 km	5-10 km	1.5 km	0-1 km	Analytical error	
Al-------	0.0069	33.1*	0	2.8	5.9	43.2*	15.0	3
As-------	.1012	3.2	.4	0	62.7*	13.1	20.6	25
B--------	.0272	14.0	0	0	27.1	44.7*	14.2	6
Ba-------	.0082	0	0	4.9	17.9	0	77.2	--
Be-------	.0184	11.4	0	24.4	21.7	0	42.5	7
C--------	.0494	5.4	0	20.8	13.7	50.9*	9.2	12
Ca-------	.0987	11.8	0	21.6	37.6*	28.8*	.3	7
Ce-------	.1290	1.0	1.3	.2	0	0	97.5	--
Co-------	.0333	15.2	0	8.4	34.9	28.9*	12.6	6
Cr-------	.0566	65.4*	0	0	5.9	25.2*	3.5	2
Cu-------	.0731	11.7	0	0	22.6	38.5*	27.2	7
Fe-------	.0228	7.9	0	29.4	0	59.2*	3.5	10
Ga-------	.0229	12.4	6.2	0	51.0*	9.7	20.7	5
Ge-------	.1575	0	0	5.4	15.9	14.0	64.7	--
Hg-------	.0267	0	23.6	0	10.2	23.4	42.8	4
K--------	.0042	12.0*	0	0	67.6*	5.7	14.7	7
La-------	.1116	.6	1.4	4.8	0	0	93.2	--
Li-------	.0359	3.4	0	14.7	21.8	57.6*	3.1	17
Mg-------	.0528	37.1	0	15.1	0	46.9*	1.0	3
Mn-------	.0305	26.3*	0	0	34.9	26.2*	12.6	4
Mo-------	.0441	22.1*	0	0	16.9	42.4*	18.6	4
Na-------	.0115	0	0	16.4	69.8*	12.8*	1.0	n.d.
Nb-------	.0340	.2	0	0	33.9	0	65.9	--
Ni-------	.0492	47.9*	0	0	14.9	29.2*	8.1	3
Pb-------	.0395	0	0	0	8.2	0	91.8	--
Rb-------	.0240	15.6*	0	6.8	0	14.0	63.6	--
Sc-------	.0342	16.6	0	22.3	14.3	22.3	24.5	6
Si-------	.0011	0	2.3	9.5	53.7*	14.0	20.6	n.d.
Sn-------	.2108	0	0	0	13.0	16.7	70.3	--
Sr-------	.0258	2.5	32.6	31.4*	7.5	14.7	11.4	3
Th-------	.0238	33.8	12.2	0	30.1*	16.0*	7.9	3
Ti-------	.0098	12.6	0	25.9	13.3	40.4*	7.8	6
U--------	.0097	15.6*	0	0	.6	79.7*	4.2	6
V--------	.0195	10.6*	0	0	18.9	59.5*	11.0	8
Y--------	.0410	0	4.4	0	11.8	0	83.9	--
Yb-------	.0639	0	5.1	0	11.7	0	83.2	--
Zn-------	.0163	24.0	0	2.8	10.4	55.2*	7.5	4
Zr-------	.0247	9.4	0	0	0	0	90.6	--

Mapping Requirements

In addition to providing statistical summaries and baseline values for the total element concentrations in soil of the Bighorn and Wind River Basins, data from the analysis of variance are useful in providing a means for estimating the number of samples that would need to be collected and analyzed within an area of specified size in order to prepare a reproducible map of total chemistry.

Cells, 25 km on a side, were arbitrarily chosen as a geographic unit useful in preparing maps of regional variation. Such variation may be easily mapped as differences among cell averages, but the number of random samples needed within each cell in order to produce stable averages of total element concentration in soil in the Bighorn and Wind River Basins must be estimated. The methods for calculating the number of samples required in each cell (n_r) were developed by Miesch (1976a). The minimum number of samples (n_r) that need to be collected at random from each 25km cell is determined from the following equation;

$$F = 1 + n_r v$$

where n is adjusted so that the sum, $(1 + n_r v)$, exceeds the critical F-statistic at the 80 percent confidence interval with 1 and $2n - 2$ degrees of freedom. The parameter v (above) is the ratio of the variance observed between 25km cells to that observed within the 25km cells.

Tables 48 and 49 show the number of samples needed to map total chemistry of soils at an interval of 25km for the Bighorn and the Wind River Basins, respectively. Table 54 summarizes the number of mappable elements in each basin for increasing n_r values.

Table 50.--Statistical summary of total element concentrations in soils of the Bighorn Basin

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Element, unit of measure	Geometric mean	Geometric deviation	Geometric error	Expected 95% range (baseline)	Detection ratio
Al, %-----	4.0	1.32	1.09	2.4-4.8	36:36
B, ppm----	50	1.33	1.14	30-83	36:36
Be, ppm---	2.0	1.40	1.23	1.2-3.4	36:36
C, %------	1.5	1.72	1.17	.53-4.2	36:36
Ca, %-----	3.0	1.78	1.03	.95-9.5	36:36
Co, ppm---	6.3	1.33	1.14	3.8-10	36:36
Cr, ppm---	59	1.55	1.15	26-135	36:36
Cu, ppm---	20	1.65	1.29	8.4-47	36:36
Fe, %-----	1.8	1.38	1.07	.96-3.4	36:36
Ga, ppm---	11	1.47	1.19	5.5-22	36:36
Hg, ppm---	.026	1.33	1.16	.016-.042	36:36
K, %------	1.5	1.19	1.07	1.1-2.1	36:36
La, ppm---	36	1.20	1.15	28-45	36:36
Li, ppm---	18	1.31	1.11	11-30	36:36
Mg, %-----	.86	1.41	1.04	.4-1.7	36:36
Mn, ppm---	400	1.38	1.11	220-740	36:36
Mo, ppm---	4.8	1.47	1.24	2.5-9.1	35:36
Na, %-----	.53	1.53	1.03	.23-1.2	36:36
Ni, ppm---	22	1.37	1.13	12-39	36:36
Pb, ppm---	8.6	1.44	1.35	5.7-13	36:36
Rb, ppm---	55	1.32	1.25	40-77	36:36
Sc, ppm---	5.9	1.59	1.19	2.5-14	32:36
Si, % ----	32	1.10	1.03	27-38	36:36
Sr, ppm---	230	1.39	1.08	120-440	36:36
Th, ppm---	8.5	1.27	1.13	5.6-13	36:36
Ti, %-----	.26	1.22	1.05	.18-38	36:36
U, ppm----	2.7	1.25	1.05	1.7-4.2	36:36
V, ppm----	68	1.34	1.09	39-120	36:36
Y, ppm----	20	1.28	1.15	13-30	36:36
Yb, ppm---	2.7	1.33	1.11	1.6-4.6	36:36
Zr, ppm---	320	1.35	1.29	230-440	36:36

Table 51.--Statistical summary of total element concentrations in soils of the Wind River Basin

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Element, unit of measure	Geometric mean	Geometric deviation	Geometric error	Expected 95% range (baseline)	Detection ratio
As, ppm---	3.6	1.90	1.39	1.2-10.8	36:36
B, ppm----	28	1.38	1.15	16-50	36:36
Be, ppm---	2.4	1.29	1.23	1.8-3.2	36:36
C, %------	.85	1.62	1.17	.34-2.1	36:36
Ca, %-----	2.2	1.93	1.04	.59-8.2	36:36
Co, ppm---	5.5	1.49	1.16	2.6-12	36:36
Cu, ppm---	15	1.70	1.38	6.5-35	36:36
Fe, %-----	1.5	1.36	1.07	.82-2.7	36:36
Ga, ppm---	15	1.32	1.17	9.5-24	36:36
Hg, ppm---	.020	1.45	1.28	.011-.035	35:36
Li, ppm---	15	1.49	1.08	6.9-33	36:36
Mg, %-----	.63	1.54	1.05	.27-1.5	36:36
Na, %-----	1.3	1.26	1.03	.8-2.1	36:36
Sc, ppm---	5.3	1.47	1.23	2.8-10	34:36
Si, %-----	31	1.07	1.03	28-35	36:36
Sr, ppm---	340	1.42	1.13	180-660	36:36
Th, ppm---	12	1.43	1.10	6.0-24	36:36
Ti, %-----	.22	1.22	1.07	.15-.32	36:36
Zn, ppm---	43	1.31	1.08	26-72	36:36

Table 52.--Statistical summary of total element concentrations in soils overlying the three major geologic units in the Bighorn Basin

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Element, unit of measure	Geometric mean	Geometric deviation	Geometric error	Expected 95% range (baseline)	Detection ratio
		Willwood Formation			
Zn, ppm----	51	1.32	1.11	30-85	12:12
		Ft. Union Formation			
Zn, ppm----	66	1.36	1.11	37-118	12:12
		Quaternary deposits			
Zn, ppm-----	55	1.26	1.11	36-83	12:12

Table 53.--Statistical summary of total element concentrations in soils overlying the three major geologic units in the Wind River Basin

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Element, unit of measure	Geometric mean	Geometric deviation	Geometric error	Expected 95% range (baseline)	Detection ratio
Moonstone, Arikaree Formations					
Al, %-----	4.4	1.18	1.08	3.3-5.9	12:12
Cr, ppm---	27	1.45	1.11	13-55	12:12
K, %------	2.1	1.13	1.06	1.7-2.6	12:12
Mo, ppm---	3.7	1.64	1.23	1.5-9.1	11:12
Mn, ppm---	270	1.50	1.15	130-580	12:12
Ni, ppm---	12	1.56	1.16	5-28	12:12
U, ppm----	2.6	1.15	1.05	2.0-3.4	12:12
V, ppm----	43	1.44	1.11	21-86	12:12
Wind River, Indian Meadows Formations					
Al, %-----	5.0	1.16	1.08	3.9-6.4	12:12
Cr, ppm---	52	1.36	1.11	29-93	12:12
K, %------	2.0	1.09	1.06	1.8-2.3	12:12
Mo, ppm---	5.0	1.43	1.23	2.8-9.0	12:12
Mn, ppm---	320	1.29	1.15	210-490	12:12
Ni, ppm---	21	1.39	1.16	12-38	12:12
U, ppm----	2.9	1.27	1.05	1.8-4.6	12:12
V, ppm----	48	1.22	1.11	34-67	12:12
Quaternary deposits					
Al, %-----	5.5	1.17	1.08	4.2-7.2	12:12
Cr, ppm---	61	1.24	1.11	42-89	12:12
K, %------	1.9	1.12	1.06	2.6-2.3	12:12
Mo, ppm---	5.8	1.43	1.23	3.2-10	12:12
Mn, ppm---	420	1.32	1.15	260-680	12:12
Ni, ppm---	23	1.25	1.16	16-32	12:12
U, ppm----	2.8	1.14	1.05	2.2-3.6	12:12
V, ppm----	53	1.26	1.11	35-80	12:12

Table 54.--Number of random samples needed (n_r) in a 25 kilometer square to map total element concentrations in soils of the Bighorn and Wind River Basins at the 80 percent confidence level

	Mappable elements in	
n_r	Bighorn Basin	Wind River Basin
2	C, Na	Cr
3		Al, Mg, Ni, Sr, Th
4	Ca, Fe, Mn, Sr	Hg, Mn, Mo, Zn
5	Co, Si	Ga
6	Ni, Rb, Sc, An	B, Co, Sc, Ti, U
7	Ga	Be, Ca, Cu, K
8	Al, Li, Mg	V
9	Cu	
10	K, Mo	Fe
12		C
13	B, Be, Cr, Hg	
17		Li
20	Pb	
25		As

GEOCHEMISTRY OF FINE-GRAINED ROCKS IN CORES OF THE FORT UNION FORMATION

by Todd K. Hinkley and Richard J. Ebens

The rearrangement of rock strata during mining and reclamation commonly exposes buried strata to weathering processes which may accelerate mineral alteration and chemical release. Shale or mudstone is the most abundant rock type in coal overburden in the Northern Great Plains Coal Province and is most likely to appear as the major "exotic" constituent of a reclaimed landscape. Hinkley and Ebens (U.S. Geological Survey, 1976, p. 10-13) presented data on the mineralogical composition and variation of these rocks with the goal of aiding understanding of the environmental needs for handling such strata during, or following, strip mining. This report deals with the concentration and variation of the chemical constituents of these rocks. As in the previous report, an attempt is made here to quantify the magnitude of the spatial variation in the rocks at different intervals: 1) distances greater than 5 km, 2) distances from 0-5 km, and 3) distances within a vertical core of the rock column of less than 100m. All samples were collected from cores drilled through the overburden sections of surface- mineable coal deposits in the Fort Union Formation or equivalents.

Sample sites and sampling design

Samples were taken from each of five widely separated sites ($\geq$50 km), two in southeastern Montana, two in southwestern North Dakota and one in southeastern Saskatchewan (fig. 2). Four rock samples were taken at each site from each of two drill holes which were separated by 1-5 km. The samples taken from each core were separated by a vertical distance of 0-100 m and each sample consisted of 30 cm of a homogeneous stratum of shale or mudstone. Only three samples were collected from each of the two drill holes at Estevan, Saskatchewan, because of the paucity of fine-grained horizons in these cores. In all, 38 samples were collected. Twelve samples were split and submitted in duplicate to estimate analytical precision as distinct from geographical variability, bringing the number of actual analyses to 50. All samples were analyzed in a randomized sequence. For analysis of variance, concentrations reported by the laboratory only as less than some specified value were replaced by a value 0.7 times the minimum value in the data set.

Cores from three of the five sites (Bear Creek and Otter Creek, Montana, and Dunn Center, North Dakota) were obtained through the Energy Minerals Rehabilitation Inventory and Analysis (EMRIA) program of the U.S. Bureau of Land Management, which is intended to gather a variety of environmental information at potential coal-mining sites. Cores from Dengate, North Dakota were obtained from C. S. V. Barkley (U. S. Geological Survey). Cores from Estevan, Saskatchewan were obtained from the

Industrial Minerals Division, Department of Mineral Resources, Saskatchewan.

Analytical methods

The rock samples were crushed in a jaw crusher and then ground in a vertical Braun pulverizer with ceramic plates set to pass the 80 mesh fraction. Analyses were performed in the U.S. Geological Survey laboratories by emission spectrographic, atomic absorbtion, X-ray fluorescence, and delayed neutron activation techniques as described in U.S. Geological Survey (1975, p. 69-71, 79-81; 1976, p. 131-132). The data are summarized in Table 55.

Geochemical variation

The major and minor chemical species MgO, CaO, Na_2O, Ba, and TiO_2 vary significantly at the highest spatial scale at the 0.05 confidence level. The minerals plagioclase, calcite, dolomite and chlorite, among others, were reported to vary at this same scale (U.S. Geological Survey, 1976, p. 10-13), and their correspondence with the variation of MgO, CaO and Na_2O was expected.

In addition, the trace elements B, Co, Cr, Cu, Ge, Ni, Sc, Th, V, Y, Zr, and Yb also exhibit statistically significant regional variation. They are less clearly associated with the mineralogy of the rock. It is possible that some of the variation at this scale for all these elements is due to contamination by drilling equipment (hardware, muds or greases), but the presence of so many clay-related elements in this suite (particularly TiO_2, Sc and Zr) suggests rather that the regional effect reflects variation in the amount of one or more clay minerals. The more prominent of the potentially toxic trace elements (As, Hg, Pb, and perhaps Se) do not appear to vary significantly in overburden at regional scales.

Table 55.--Statistical summary of the chemical composition of fine-grained rocks cored from the Ft. Union Formation, Northern Great Plains Coal Province

[*, indicates significance of the variance component at the 0.05 probability level; p, indicates significance of this component against more than one other components pooled together; leaders (---) indicate insuffient data for analysis of variance calculation; Ratio is number of analyses in which element was detected in measurable amounts to total number of analyses]

	Total $\log_{10}$ variance	Variance component as percent of total				Summary statistics				
		Among sites	Between holes	Among samples within hole	Between analytical duplicates	Ratio	Geometric mean (ppm except as noted)	Geometric deviation	Observed range Minimum (ppm except as noted)	Observed range Maximum (ppm except as noted)
SiO_2 -------	0.00190	0.0	4.0	94.2*	1.7	50:50	58%	1.11	45.5%	69.6%
Al_2O_3 ------	.00823	10.3	.0	85.4*	4.3	50:50	15%	1.20	7.4%	21.9%
MgO --------	.0474	36.9*,p	.0	63.0*	.2	50:50	2.4%	1.55	.78%	4.8%
CaO --------	.313	20.5*	.0	79.4*	.0	50:50	1.7%	3.24	.13%	13.1%
Na_2O -------	.0724	48.6*	2.5	48.8*	.1	50:50	.86%	1.77	.24%	2.1%
K_2O --------	.00924	3.7	.0	95.4*	1.0	50:50	2.6%	1.24	1.7%	3.8%
Total Fe_2O_3-	.0383	10.0	.0	89.5*	.5	50:50	4.3%	1.54	1.6%	11.1%
TiO_2 -------	.00458	22.8*	.0	73.4	3.8	50:50	.63%	1.16	.42%	.79%
Mn ---------	.174	4.4	.0	91.1*	4.5	50:50	300	2.55	32.9	2020
F ----------	.0374	12.9	.0	66.9*	20.2	45:50	.06%	1.51	<.03%	.12%
As ---------	.667	.0	.0	98.0*	2.0	49:50	3.6	2.74	<.38	16.2
Ge ---------	.0250	22.0p	1.2	68.3*	8.5	49:50	1.0	1.38	<.32	1.6
Hg ---------	.0441	7.7	18.3	69.1*	4.9	50:50	.10	1.55	.03	.25
Li ---------	.00888	.0	5.4	93.1*	1.5	50:50	32	1.24	18.0	54.0
Rb ---------	.0125	.2	.3	96.5*	2.9	50:50	110	1.29	65.0	165
Se ---------	.0887	.0	.0	8.4	91.6	38:50	.16	2.28	<.08	.62
Sn ---------	.0644	13.9	.0	51.4*	34.7	50:50	1.3	1.74	.11	3.1
Th ---------	.0330	19.0p	.0	39.0	42.0	50:50	13	1.46	5.4	28.9
U ----------	.0139	5.6	20.6	65.0*	8.9	50:50	3.7	1.31	2.4	9.3
Zn ---------	.0230	29.5	1.2	68.7*	.6	50:50	100	1.49	27.0	183
B ----------	.0138	10.4p	.0	17.1	72.5	50:50	59	1.32	29.5	106
Ba ---------	.0121	27.6p	2.3	54.1*	16.0	50:50	420	1.30	223	646
Be ---------	.0235	7.4	.0	46.9	45.7	50:50	2.0	1.38	1.1	3.6
Co ---------	.0521	20.6*,p	.0	70.4*	9.0	50:50	8.7	1.61	2.3	35.8
Cr ---------	.0216	35.0*,p	.0	56.1*	8.9	50:50	72	1.39	29.4	124
Cu ---------	.0468	20.8p	6.7	26.4	46.1	50:50	38	1.64	15.1	92.1
La ---------	.0110	2.3	.0	32.3	65.4	50:50	33	1.26	19.6	61.8
Mo ---------	.0724	4.8	1.0	.0	94.2	50:50	6.1	1.64	2.2	13.3
Nb ---------	.0413	11.5	.0	42.0	46.5	50:50	6.8	1.51	2.6	19.4
Ni ---------	.0603	40.4*,p	.0	56.1*	3.5	49:50	30	1.72	<8.3	94.2
Pb ---------	.0503	4.6	.0	68.7*	26.7	49:50	11	1.66	<2.8	28.6
Sc ---------	.0386	12.8p	6.3	38.3	42.6	48:50	11	1.64	<3.3	24.2
V ----------	.0290	31.3p	1.7	53.5*	13.4	50:50	86	1.47	31.9	
Y ----------	.0188	26.9p	5.0	10.4	57.7	50:50	19	1.33	8.5	35.4
Zr ---------	.0270	25.5p	.0	37.7	36.8	50:50	200	1.44	98.7	492
Ce ---------	.0503	.0	9.6	.0	90.4	50:50	65	1.55	22.4	161
Ga ---------	.0253	9.0	.0	66.7*	24.3	50:50	18	1.42	8.1	40.2
Yb ---------	.0150	17.5p	14.5	31.0	36.9	50:50	2.9	1.31	1.4	5.1
Total S ----	---	---	---	---	---	27:50	.066%	2.58	<.059%	.55%
Total C ----	.0995	.0	14.4	82.4*	3.3	50:50	2.1%	1.90	.57%	11.2%
Ash --------	.00346	.0	23.3	66.0*	10.7	50:50	92%	1.05	75.6%	97.1%

Essentially no chemical variation exists between the paired holes (1-5km separation) within the individual sites. This was also found to be true of the mineralogy (U. S. Geological Survey, 1976, p. 10-13), and suggests that the chemistry and mineralogy are nearly uniformly distributed in overburden over areas approximately the size of a surface mine in this part of the western coal regions. If further investigations confirm this uniformity, then characterization of overburden rocks a few km across becomes a relatively inexpensive task, because detailed study of only two or three scattered cores should suffice for such characterization.

Most of the spatial variation in chemistry of the rocks occurs between samples separated by <100m within the same drill hole; this is to be expected because contrasting lithic types alternate rapidly with vertical distance in Fort Union rocks. The same was found to be true for the mineralogical variation. For a preliminary discussion of the chemistry of these same rocks in outcrop, see p. 185-197 of this report.

Analytical variation

For several of the elements determined, major variation occurs at the fourth level, that involving preparation and analysis of samples. In particular, Se, B, Mo, Y and Ce exhibit more than half of their total variability at this level, and these data should be used judiciously.

GEOCHEMISTRY OF GROUND WATERS IN THE POWDER RIVER COAL REGION

by Gerald L. Feder, Roger W. Lee,
John F. Busby, and Linda G. Saindon

Since the last progress report, field work in the Powder River coal region and most laboratory analyses have been completed. Statistical analysis of the available data are presented here. An analysis of variance was performed on the combined data from the Powder River and Fort Union coal regions. The sampling and statistical analysis procedures used for the Fort Union coal region data are described in U.S. Geological Survey (1976, p. 86-93).

Sampling design

The sampling plan used in the Powder River coal region was similar to that used in the Fort Union coal region (U.S. Geological Survey, 1976, p. 86-93). The locations of the sampling sites in the Powder River Basin are shown in figure 24. The chemical data received to date represent 20 randomly chosen sampling sites within the basin. In order to obtain an estimate of variance between closely spaced wells, three sampling sites were randomly chosen and an additional well within 5 km of each of these sites was sampled. In order to estimate errors caused by sample collection and shipping procedures, and laboratory errors, four of the 23 samples were randomly chosen and a duplicate sample was collected at the same time the original sample was collected.

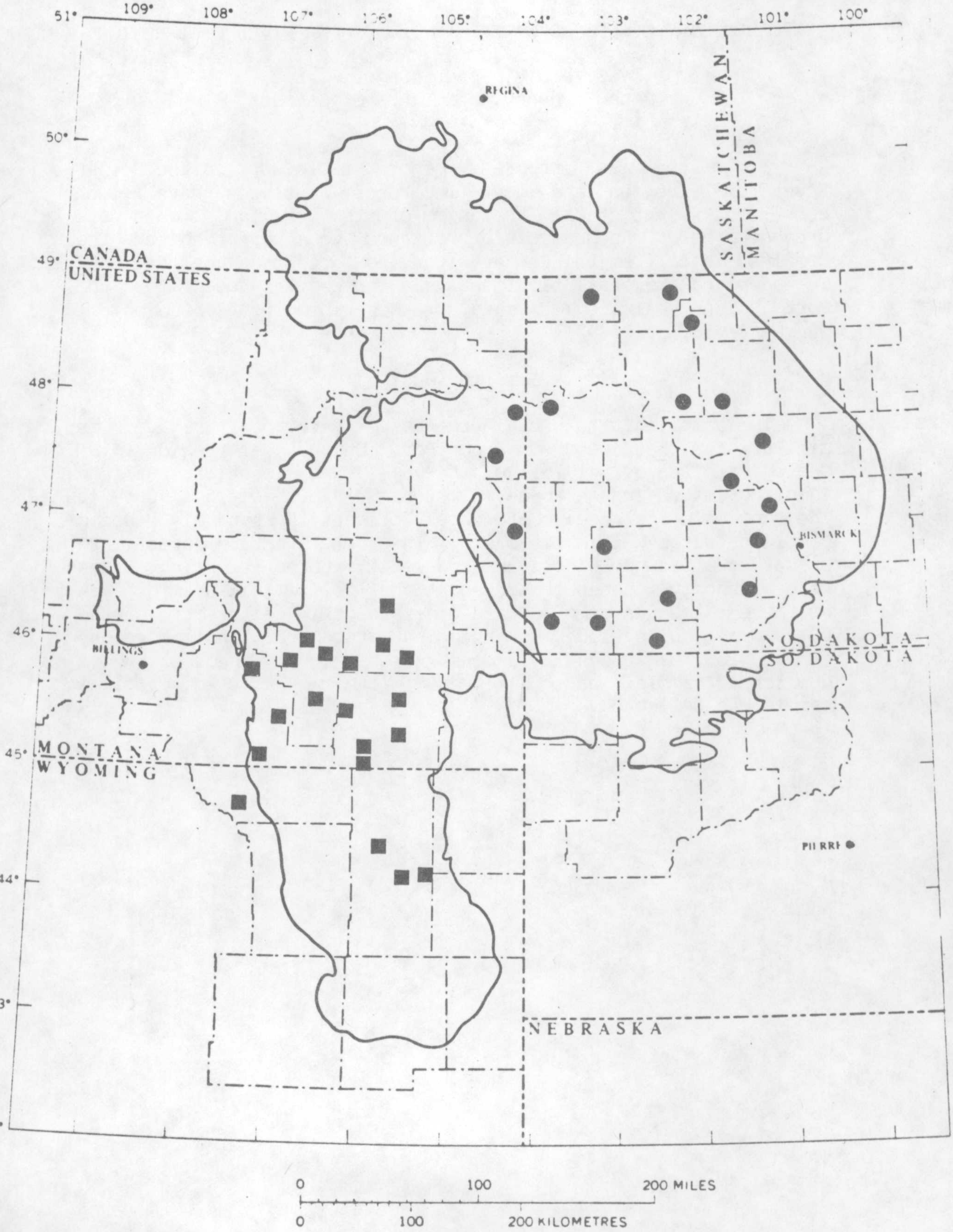


Figure 24.--Locations of ground water sampling sites in the Northern Great Plains coal region. Circles are Fort Union coal region sampling sites; squares are Powder River coal region sampling sites.

For the analysis of variance the data from the Fort Union and Powder River coal regions have been combined to handle a four-level model (see Miesch, 1976a),

$$\mathrm{Log}\ X_{ijkl} = M + R_i + T_{ij} + S_{ijk} + E_{ijkl}$$

where the logarithm of the concentration of a chemical constituent for a given ground-water sample, as reported by the analyst (log X_{ijkl}), deviates from the true logarithmic average for that material (M) by the cumulative effect of four independent sources of variation. R_i represents the differences between the Fort Union and Powder River coal regions, T_{ij} represents broad scale differences observed between townships with the two regions, S_{ijk} represents differences between wells spaced within 5 km of each other, and E_{ijkl} represents non-geographic effects, including errors caused by sample collection and shipping procedures, and analytical errors. The merging of two time-independent studies (work in the Fort Union and the Powder River regions) is arbitrary and assumes that no time-related bias exists in the data from the two regions. Because sample collection was undertaken in both regions by a common set of guidelines, and analyses were performed by the same laboratories, it is assumed that any such bias is either lacking or insignificant.

All samples in the present study were collected from geologic formations above the Pierre Shale, and only wells used for human consumption or livestock water supplies were chosen, regardless of depth. The average well depth is about 100 m.

Chemical variability of Ground Waters

Results of an analysis of variance of the combined data from ground-water samples from the Fort Union and Powder River coal regions are similar to the results reported previously (U.S. Geol. Survey, 1976, p. 86) for the Fort Union coal region alone. The results indicate that for most of the constituents analyzed there are no significant geochemical differences between ground waters of the two regions (Table 56), and even the two constituents shown to be significantly different have only a small percentage of their total variance represented by between region variance. This suggests that the same geochemical processes are operating in both regions. A change in water chemistry from a Ca, Mg, SO_3, HCO_3 water with pH below 8.0 to a Na, HCO_3 water with pH above 8.0 occurs in both areas, and the low concentrations of most trace metals are common to both. This important change in water chemistry which occurs in both these regions accounts for the large total log variance observed for most constituents in table 56, and is also reflected in table 57 in the large geometric deviations and maximum and minimum values shown for most chemical constituents.

Table 56.--Analysis of logarithmic variance of ground water in Powder River and Fort Union coal regions

Constituent	Total $\log_{10}$ variance	Variance Component (percent)			
		Between regions	Within regions	Between wells	Between samples
Al	.111	1.9	*59	0.0	39
B	.140	.0	*81	12	6.5
Ca	.560	.0	*88	12	.0
Fe	1.06	9.4	.0	*91	.0
Hardness	.765	.0	*70	.0	30
K	.099	4.6	*86	9	.0
Li	.093	5.6	*77	14	3.0
Mg	.627	.0	*83	*17	.0
Mn	4.09	16	.0	*84	.2
Na	.205	.0	*88	*12	.2
pH[1/]	.332	.0	*90	9.9	.0
Ra	.300	12	*37	.0	50
Sr	.254	1.4	*85	7.6	6.0
U	1.07	12	*74	.0	15
Zn	4.56	12	.0	*88	.4
Cl	.185	.4	*99	1.0	
F	.286	.4	*85	14	
HCO_3	.068	11	*80	8.2	
SiO_2	.046	13	*79	8	
SO_4	1.02	3.2	*92	4.3	
Total Dissolved solids	.207	.0	.0	100	

*Component is significantly different from zero at the 0.05-probability level.

1/ Not logarithmically transformed.

Table 57.--Geochemical summary of ground water from the Powder River coal region, Montana and Wyoming

[Detection ratio: number of samples in which constituent was determined to total number of samples analyzed.]

Parameter	Detection ratio	Geometric mean	Geometric deviation	Maximum	Minimum
Al (μg/L)	19/19	17	1.9	60	6.0
Ba (μg/L)	9/15	24	2.7	128	6.0
B (μg/L)	19/19	148	2.2	422	32.0
Cu (μg/L)	4/19	---------	---------	14	<1.0
Li (μg/L)	20/20	36	2.4	180	10.0
Sr (μg/L)	15/16	444	4.1	2,754	19.0
As (μg/L)	6/20	---------	---------	6	<1.0
Se (μg/L)	5/20	---------	---------	12	<1.0
Cd (μg/L)	3/20	---------	---------	1	<1.0
Hg (μg/L)	4/20	---------	---------	.2	<.10
Zn (μg/L)	20/20	50	5.5	1,800	.70
Fe (μg/L)	20/20	170	10.5	28,000	7.0
Mn (μg/L)	20/20	21	9.5	4,800	.70
Br (mg/L)	13/20	.15	2.0	.7	<.10
F (mg/L)	20/20	.68	2.8	14	.10
I (mg/L)	4/20	.01	1.4	.02	<.01
Cl (mg/L)	20/20	8.7	2.1	47	1.9
SO_4 (mg/L)	20/20	292	5.1	1,800	5.5
HCO_3 (mg/L)	20/20	504	1.6	1,400	195.0
Ca (mg/L)	20/20	24	6.5	530	1.9
Mg (mg/L)	20/20	13	7.0	150	.60
K (mg/L)	20/20	3.9	2.0	12	1.5
Na (mg/L)	20/20	173	3.0	1,000	24.0
SiO_2 (mg/L)	20/20	11	1.6	26	5.8
THD (mg/L)	20/20	112	6.9	1,900	7.0
pH [1]	20/20	7.7	.6	8.5	6.5
Specific conductance (mhos/cm)	20/20	1,494	1.8	4,000	582.0
TDS (mg/L)	20/20	1,076	1.9	3,190	345.0
$NO_3 + NO_2$ (mg/L)	18/20	.08	8.3	3.2	<.01
SAR [2]	20/20	6.9	6.0	73	.40
Ra (pCi/L)	17/18	.23	2.0	.80	<.10
U (μg/L)	16/18	.25	6.0	7.3	<.01
Beta (pCi/L as Cs-137)	12/18	6.6	1.8	14	<4.0

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[1] Arithmetic mean and standard deviation.

[2] Sodium adsorption ratio.

Most of the variance observed is between sites within the regions. It is surprising that the between-well (within sites) variance does not show higher values since no effort was made to restrict closely spaced wells to the same formations, and because generally shallow formations in recharge areas contain the Ca, Mg, SO_3, HCO_3 type waters, while the deeper formations contain the Na, HCO_3 type waters. However, this may be a result of the propensity for ranchers and well drillers in a given area to seek ground water from a single formation known to yield adequate supplies.

Table 58 shows two analyses for samples which represent the shallow recharge-type and deeper discharge-type waters referred to above. The samples do not represent a single flow system, and actually were collected from widely separated areas, but do represent the type of ground water obtained in recharge areas (Sample A) and discharge areas (Sample B). The Ca/Mg ratios, and the SO_3, Na, and pH vary considerably in the recharge waters, but they are characterized by their high total hardness, and pH below eight, while the discharge waters are characterized by their low total hardness and pH above eight. The sodium adsorption ratio (SAR) can also be used to distinguish these water types, as low SAR's occur in the recharge waters.

Further sampling of ground waters in the western coal regions will concentrate on establishing the extent of the geochemical similarity of waters in the remaining coal regions to those in the Fort Union and Powder River coal regions. Due to the similarities of lithology and structure among most of the Cretaceous and Tertiary coal regions in the Northern Great Plains and Rocky Mountain coal provinces, it is anticipated that the same general geochemical processes occur throughout the area.

Table 58.--Chemical analyses of samples representing a typical recharge water (sample A) and a typical discharge water (sample B) in the Powder River coal region

Parameter	Sample A	Sample B
Ca (mg/L)---------	180	1.9
Mg (mg/L)---------	82	.6
Total hardness (as $CaCO_3$) (mg/L)	790	7
HCO_3 (mg/L)-------	362	1,150
Na (mg/L)---------	250	450
SO_4 (mg/L)--------	1,100	5.5
SAR[1]--------------	3.9	73
pH----------------	6.8	8.3
TDS (mg/L)--------	1,830	1,110
SiO_2 (mg/L)-------	11	7.8
Cl (mg/L)---------	6.1	47
K (mg/L)----------	9.3	1.5
F (mg/L)----------	.5	14
I (mg/L)----------	<.01	.07
Br (mg/L)---------	.1	.7
Al (µg/L)---------	20	20
As (µg/L)---------	<1.0	<1.0
Ba (µg/L)---------	<6	100
B (µg/L)----------	80	240
Cd (µg/L)---------	<1.0	<1.0
Cu (µg/L)---------	<6	<5
Fe (µg/L)---------	2,500	30
Hg (µg/L)---------	<.1	<.1
Pb (µg/L)---------	180	<15
Li (µg/L)---------	40	20
Mn (µg/L)---------	2,200	10
Mo (µg/L)---------	<12	12
Se (µg/L)---------	<1.0	<1.0
Sr (µg/L)---------	2,000	160
Zn (µg/L)---------	40	200
U (µg/L)----------	.30	.09
Ra (pCi/L)--------	.1	.2

[1] Sodium adsorption ratio.

COMPARISON OF THE ELEMENT CONTENT OF WHEAT FROM FARMS IN THE NORTHERN GREAT PLAINS AND FROM COAL MINE SPOILS AT THE BIG SKY MINE, MONTANA

by James A. Erdman and Larry P. Gough

Introduction

In the fall of 1974 we sampled small grains from 71 farms throughout the Northern Great Plains, including the southern edge of Saskatchewan, Canada. Our intent was to learn about the variability in the element concentrations of both hard red spring and hard red winter wheat (Triticum aestivum L.) at various geographic scales. Eventually these data will be displayed on maps, and baseline statistics will be given to facilitate the monitoring and evaluation of chemical changes in wheat grown on the geochemically altered materials that might occur on reclaimed surface-mined lands. Recent studies have demonstrated significant changes in the element composition of sweetclover and wheatgrass when grown on reclaimed land (U.S. Geological Survey, 1976, p. 4-9, p. 82-85; Erdman, Ebens, and Case, 1978).

Three samples of wheat were collected in July, 1974 from a reclaimed spoil area at the Big Sky Mine in eastern Montana. The wheat had been sown as a cover crop to enhance the establishment of perennial grasses. To our knowledge, this is the first report which compares the chemistry of a cereal grain grown in spoil material with the element composition of a similar grain grown throughout its range of production. There is good reason for an interest in the effects of surface mining on agriculture in the Northern Great Plains. Projections indicate that surface coal production will have the greatest increase in this region, even exceeding that in the Eastern or Appalachian Region (Carter, 1976, p. 438). Mining reclamation regulations require that the land be returned to its former use which, in great measure, is small-grain production.

Methods

Wheat was sampled from storage bins located on 71 farms (fig. 25) according to an unbalanced nested analysis of variance design similar to that described in U.S. Geological Survey (1975, p. 36-49). A grid of twenty-five cells 100 km on a side was established over the coal province of the Northern Great Plains, and within each cell two of the four 50-km subcells available for sampling were selected at random. Finally, two random points were located in one of these subcells and one in the other. The grain samples were taken from the farm closest to each point on the map. Samples from only 47 subcells out of 50 were obtained because wheat production was not found in three of them.

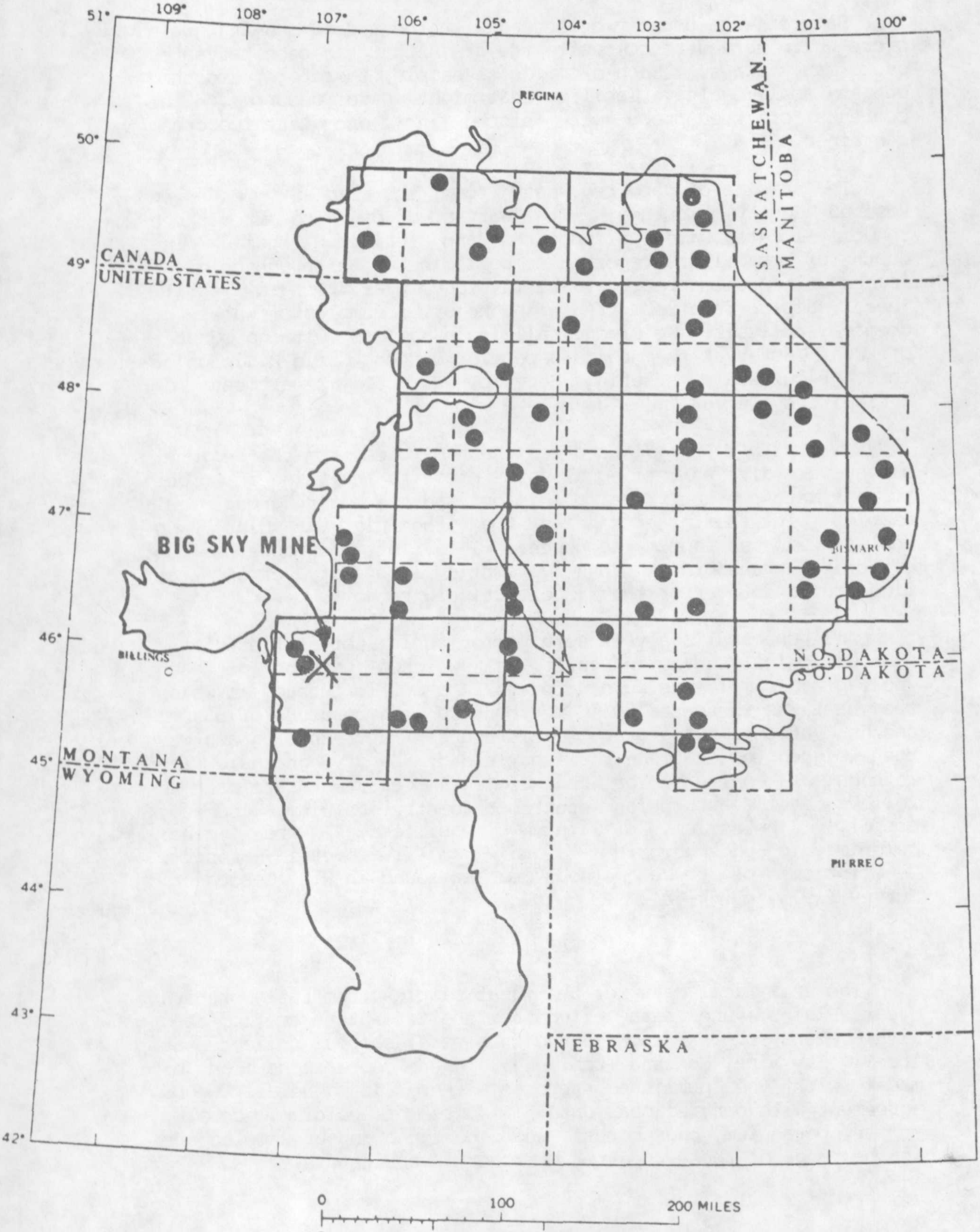


Figure 25.--Grain sampling localities (farms) in the Northern Great Plains Coal Province. Cells with solid outlines are 100 km on a side; those with dashed lines are 50 km on a side. Wheat production is either too scattered or minimal in that portion of the Province occurring in Wyoming, and therefore was excluded from the sampling design.

Samples were usually collected with the aid of a 6-ft grain probe which served to composite the grain that had been harvested over many acres. Such a composite sample, therefore, smoothed out any small-scale variability that might have occurred. The contents of the probe were placed in a one-quart ice cream container.

The samples of hard red wheat from the Big Sky Mine in Rosebud County, Montana, were harvested by hand from three randomly-located sites on contoured and reclaimed spoil. The depth of topsoil was reported to be 15 inches, although only 4-6 inches of topsoil appeared to be in place over the raw spoil. These samples were submitted with the other samples of wheat for chemical analysis. We cleaned all grain samples with a Carter Dockage Tester at the Grain Inspection Branch, Grain Division of the Agricultural Marketing Service, U. S. Department of Agriculture, Denver.

Twenty of the 71 hard red wheat samples from the regional survey were divided into equal parts prior to analysis in order to estimate the analytical precision, and the entire group of 91 samples (plus the three samples from the Big Sky Mine) was analyzed in a random sequence. This last procedure has the effect of transforming any systematic laboratory error that might occur into error that is effectively random.

All chemical analyses were performed in laboratories of the U.S. Geological Survey in Denver. A weighed portion of each whole grain sample was burned to ash in a muffle furnace in which the heat was increased 50° C per hour to a temperature of 550° C and held at this temperature for 14 hours. The resulting ash was then weighed to determine the ash yield of the dry grains. The methods of analysis for the elements reported here are as follows: atomic absorption spectrophotometry--calcium, cadmium, copper, potassium, lithium, silicon, and zinc; colorimetric--phosphorus; and fluorometric--uranium. Descriptions of these methods can be found in U.S. Geological Survey (1975, p. 74-78).

Results

The analytical data for the wheat samples from the Northern Great Plains, and data cited from the literature are compared with element concentrations found in several samples collected at the Big Sky Mine, Montana (table 59). Where comparisons can be made with the published reports, there is generally good agreement with our regional data; amounts of calcium, cobalt, copper, potassium, phosphorus, and zinc found in our samples are in the range of those reported by other investigators.

Table 59.--Summary of chemical elements in wheat (dry basis)

[Means for data from the literature are assumed to be arithmetic and thus should be slightly higher than the corresponding geometric means; n = number of samples; leaders (--) indicate no data]

	Summary statistics										
	Data from the literature						Data from Northern Great Plains wheat study		Concentrations in wheat from reclaimed spoils of the Big Sky Mine		
	Greaves and Hirst, 1929 (n = 1755)		Clagett and others, 1952 (n = 36)		Czerniejewski and others, 1964 (n = 10)				Sample No.		
Element	Mean	Observed range	Mean	Observed range	Mean	Observed range	Geometric mean	Central 95% range (baseline)	BS04	BS06	BS10
Ca, %-----	0.090[1]	0.028-0.29	0.035	0.030-0.037	0.045	0.034-0.053	0.030	0.020-0.045	0.042	0.035	0.031
Cd, ppm---	--	--	--	--	--	--	.035	.016-.077[2]	.013	.010	.026
Co, ppm---	--	--	--	--	.026	.016-.046	.017[3]	.0070-.041	<.016	.012	.10
Cu, ppm---	--	--	--	--	5.3	3.8-8.0	4.4	2.9-6.6	6.2	5.0	5.2
K, %------	.48	.31-.96	.48	.42-.52	.45	.39-.53	.38	.26-.57	.48	.46	.34
Li, ppm---	--	--	--	--	--	--	.029[4]	.0027-.31	<.064	<.048	<.052
P, %------	.33	.15-.46	.40	.30-.51	.43	.38-.49	.28	.17-.45	.19	.22	.16
Si, ppm---	--	--	--	--	--	--	120	55-260	130	--	--
U, ppm----	--	--	--	--	--	--	.0062[5]	.0052-.0074	<.0064	<.0048	--
Zn, ppm---	--	--	--	--	35	30-46	35	19-65	67	64	44

[1] Greaves and Hirst (1929) stated that the average calcium content of the grains they analyzed was about double that of earlier reports. The mean we report, therefore, agrees well with values in the literature.

[2] This range compares favorably with that found in wheat from Australia, being 0.012-0.036 ppm (Williams and David, 1973).

[3] Only 52 of the 71 samples had detectable levels of cobalt; the estimated mean was derived from a technique for treating censored data (Cohen, 1959).

[4] The detection ratio for lithium is 17:71, where the numerator is the number of data values that are unqualified and the denominator is the total number of samples that were analyzed (Cohen Technique used).

[5] The detection ratio for uranium is 7:71 (Cohen Technique used).

Our data were transformed logarithmically because most element concentrations in plant materials tend to be lognormally distributed. The geometric means given in table 59, therefore, are antilogs of the arithmetic means of the logarithms of the analytical values. The geometric mean is a measure of central tendency in a lognormal distribution and, as such, estimates the typical or most common concentration in lognormally distributed concentration data.

Whereas observed ranges are commonly given in the literature as a measure of scatter, we have used the central or expected 95% range. This statistic estimates the range that 95% of a suite of randomly-collected samples of an area (in this case, the Northern Great Plains) should exhibit. The central 95% range has a lower limit equal to the geometric mean (GM) divided by the square of the geometric deviation (GD), and an upper limit equal to the GM x the square of the GD, and is used here as an estimate of chemical baselines in hard red wheat from the Northern Great Plains. This concept of baseline was first proposed by Ebens and others (1973, p. 6), who viewed this range to be a suitable one in assessing geochemically anomalous or unusual samples. This concept was discussed in considerably more detail by Tidball and Ebens (1976). We have chosen, therefore, to define normal concentrations as those that are within the central 95% range of concentrations found in comparable materials considered unaffected by pollution; anomalous concentrations are those that occur outside this range.

The data in table 59 suggest that spoil with a minimum of topsoiling is affecting the element composition of wheat. Zinc appears to be high in wheat from the Big Sky Mine. Zinc levels are also anomalous in samples of sweetclover and alfalfa from this mine when compared to levels in baseline samples (unpublished data of the authors). On the other hand, phosphorus and cadmium levels appear to be low. The low availability of phosphorus in spoil materials has been reported by Sandoval and others (1973), and phosphorus levels in crested wheatgrass from spoils at the Dave Johnston Mine in Wyoming were significantly lower than those in control grasses (U. S. Geological Survey, 1976, p. 82-85). The depressed concentrations of phosphorus in the wheat, therefore, were anticipated. Deficiencies of essential elements can usually be corrected by soil amendments or foliar spraying. Possible excesses of trace metals in soils are more difficult to manage. The high zinc observed, however, may present no problem--zinc is generally considered non-toxic to animals (Sauchelli, 1969), or at least is only possibly toxic at very high levels in the diet (Church and others, 1971). Probable dietary zinc requirements for ruminants are 30-40+ ppm, according to Church and others (1971), and are even higher in dairy cows (Sauchelli, 1969).

GEOCHEMISTRY OF FORT UNION SHALE AND SANDSTONE IN OUTCROP IN THE NORTHERN GREAT PLAINS COAL PROVINCE

by Richard J. Ebens and James M. McNeal

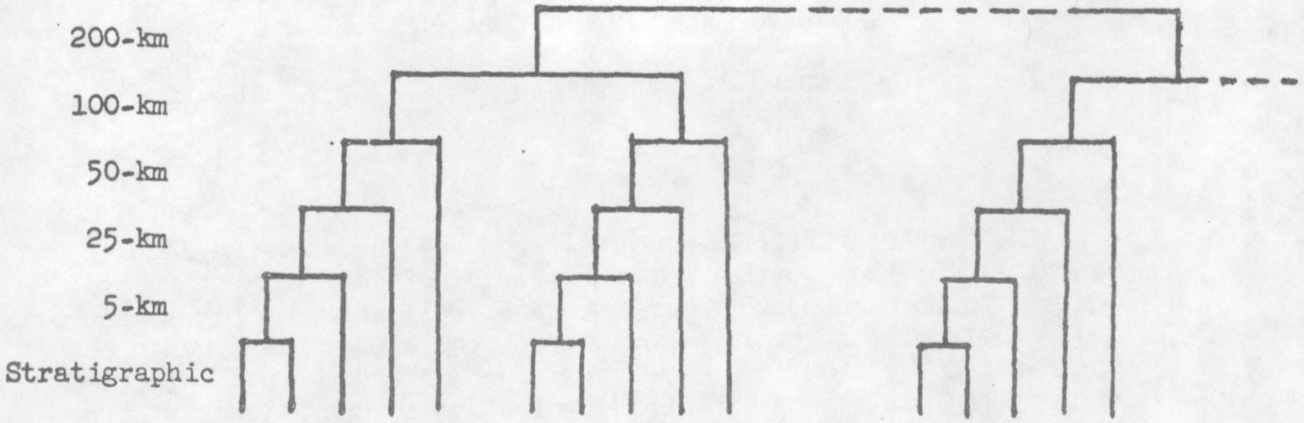
Introduction

The Northern Great Plains Coal Province includes the lignite deposits in the Northern Great Plains of eastern Montana and western North Dakota and South Dakota as well as the bituminous and subbituminous coal deposits in the Powder River Basin of northeastern Wyoming and southeastern Montana. Most of the strippable coal beds in this region are in the Paleocene Fort Union Formation. This formation consists of interbedded siltstone, claystone, and sandstone deposited in a deltaic floodplain-floodbasin environment. Any substitution, even partial, of these overburden rock materials for natural soils in areas of strip mining, may cause substantial changes in the chemical composition of the surface environment in these areas. A knowledge of the geochemistry of potential overburden rock materials may indicate which, if any, of these materials could be substituted for soil with minimal chemical change.

To acquire this knowledge, a suite of shale and sandstone samples was collected from outcrops of the Fort Union Formation throughout the Northern Great Plains Coal Province during the summer of 1975. The sample design employed and some preliminary chemical data were described in U.S. Geological Survey (1976, p. 94-100). Complete analytical results are given here.

Sampling design and analytical procedures

Samples for this study were collected according to a staggered nested analysis of variance design (Leone and others, 1968). The sampling design, which is shown in figure 26, has five geographic "levels," one stratigraphic "level" and a "level" of laboratory error. Geographic variability was estimated by nesting 5-km cells within 25-km cells, 25-km cells within 50-km cells, 50-km cells within 100-km cells, and 100-km cells within 200-km cells. Laboratory error was estimated by splitting 20 of the 60 samples into two parts resulting in a total analytical load of 80. Sampling localities are shown in figure 27; each consists of a randomly selected outcrop of the Fort Union Formation within a 5-km cell. At ten of the 40 localities shown, two samples of each rock type (shale and sandstone) were collected from a stratigraphic section in order to estimate stratigraphic variability within each type.



Level	Source of variation	Number of units at each level	Degrees of freedom
1	Between 200-km cells	6	5
2	Between 100-km cells	12	6
3	Between 50-km cells	24	12
4	Between 25-km cells	36	12
5	Between 5-km cells	48	12
6	Stratigraphic	60	12
7	Laboratory	80	20

Figure 26. Analysis of variance scheme for sampling shale and sandstone of the Fort Union Formation in outcrop.

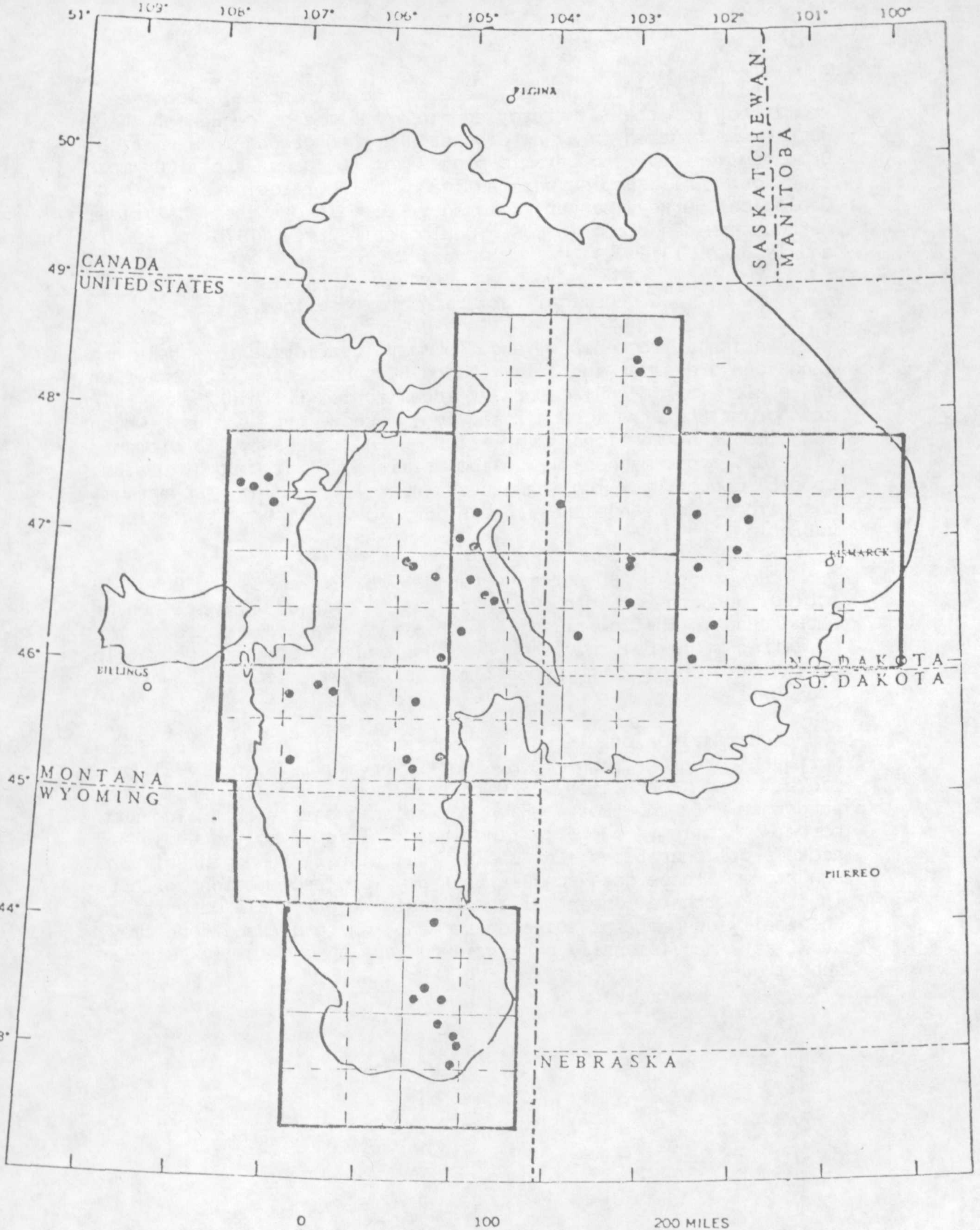


Figure 27.--Sampling localities of shale and sandstone of the Fort Union Formation in the Northern Great Plains Coal Province. Large squares are 200 km on a side; intermediate squares, 100 km; and small squares, 50 km. Dots indicate sampling localities. Map adapted from U.S. Geological Survey (1974a) and Whitaker and Pearson (1972).

The two sample groups, shale and sandstone, were each submitted to the laboratories in randomized sequence. Each sample was crushed in a jaw crusher and then ground in a vertical Braun pulverizer with ceramic plates set to pass the 100 mesh fraction. All samples were analyzed in laboratories of the U.S. Geological Survey, Denver, Colorado. Details of the analytical methods are described in U.S. Geological Survey (1975, p. 69-81, and 1976, p. 131-132).

Geochemical variation and baselines

Variance components and summary statistics for shale and sandstone are given in tables 60 and 61. Most of the variation in shale (table 60) occurs at local scales (within 25-km cells and across the stratigraphic section) except for sodium, which has important regional variation. In contrast, 15 elements (calcium, iron, magnesium, sodium, silicon, total carbon, cerium, cobalt, copper, gallium, manganese, nickel, scandium, strontium, and zinc) in sandstone (table 61) have important regional variation.

The expected 95-percent ranges of elements included in tables 60 and 61 can be used as provisional baselines or backgrounds. The lower limit of this range was calculated as the geometric mean (GM) divided by the square of the geometric deviation (GD) and the upper limit as the GM times the square of the GD.

A comparison of element concentrations in soils from the Northern Great Plains (U.S. Geol. Survey, 1976, p. 57-81, and Tidball and Ebens, 1976) with concentrations in shale and sandstone of the Fort Union formation suggests that aluminum, boron, chromium, copper, fluorine, gallium, molybdenum, and nickel concentrations in shale are higher than in soil and sandstone. These data suggest that any land reclamation efforts in the Northern Great Plains should treat shale material as chemically suspect for soil replacement, whereas sandstone may, at least provisionally, be viewed as a chemically similar substitute.

Table 60.--Statistical analysis of the chemistry of shale of the Fort Union formation, Northern Great Plains Coal Province

[*, significantly greater than zero at the 0.05 probability level]

Constituent	Analysis of logarithmic variance								v_m 1/	Summary statistics			
		Percent of total variance											
	Total Log_{10} variance	Between 200-km cells	Between 100-km cells	Between 50-km cells	Between 25-km cells	Between 5-km cells	Strati-graphic	Labora-tory	(200-km cells)	Geometric mean	Geometric deviation	Ratio	Expected 95 percent range (baseline)
Al, % ------	0.0138	< 1	14	< 1	12	52*	19*	3	--	7.0	1.31	80/80	4.1-12
Ca, % ------	.3868	< 1	20*	8	< 1	51*	21*	< 1	--	1.4	4.19	80/80	.08-25
Fe, % ------	.1028	< 1	< 1	11	< 1	74*	14*	< 1	--	2.4	2.09	80/80	.55-10
K, % -------	.0890	1	18*	< 1	< 1	79*	2	< 1	--	1.9	1.99	80/80	.48-7.5
Mg, % ------	.1757	7	8	< 1	< 1	74*	9*	1	0.2	1.4	2.63	80/80	.20-9.7
Na, % ------	.1620	39*	< 1	1	20	28*	10*	2	1.6	.42	2.53	79/80	.066-2.7
Si, % ------	.0042	9	< 1	52*	< 1	23*	15*	2	.2	27	1.16	80/80	20-36
Ti, % ------	.0171	8	< 1	< 1	< 1	78*	12*	3	.3	.34	1.35	80/80	.19-.62
C, total % -	.2700	< 1	17*	2	< 1	29	30*	23	--	.93	3.31	80/80	.085-10
Ag, ppm ----	.0545	< 1	< 1	9	20*	< 1	28	43	--	.36	1.71	69/80	.12-1.1
As, ppm ----	.1192	< 1	5	7	< 1	30	49*	8	--	5.1	2.21	80/80	1.0-25
B, ppm -----	.0206	5	6	< 1	25	36*	< 1	27	.2	98	1.39	77/80	51-190
Ba, ppm -----	.0230	< 1	9	7	< 1	67*	8	9	--	940	1.42	80/80	470-1,900
Be, ppm -----	.0700	< 1	6	9	< 1	67*	11*	6	--	3.3	1.84	80/80	.98-11
Ce, ppm -----	.1150	< 1	5	< 1	44*	< 1	23	28	--	67	2.18	77/80	14-320
Co, ppm -----	.0780	< 1	17	4	< 1	< 1	68*	11	--	9.1	1.90	80/80	2.5-33
Cr, ppm -----	.0215	< 1	9	< 1	29	29*	14	18	--	84	1.40	80/80	43-160
Cu, ppm -----	.1086	< 1	6	14	< 1	4	47*	30	--	34	2.14	80/80	7.4-160
F, ppm ------	.0296	< 1	15	7	< 1	53*	12	14	--	690	1.49	77/80	310-1,500
Ga, ppm -----	.0314	< 1	16	< 1	35	14	17	18	--	26	1.50	80/80	12-59
Ge, ppm ----	.0353	< 1	30*	< 1	29	29*	< 1	12	--	1.4	1.54	80/80	.59-3.3
Hg, ppm ----	.0930	10*	3	9	< 1	57*	19*	2	.3	.060	2.02	80/80	.015-.25
La, ppm ----	.0390	< 1	8	< 1	44	26*	< 1	21	--	42	1.58	80/80	17-100
Li, ppm ----	.0631	< 1	17*	< 1	< 1	78*	3	2	--	31	1.78	80/80	9.8-98
Mn, ppm ----	.3491	14*	< 1	16	< 1	51*	17*	3	.4	320	3.90	80/80	21-4,900
Mo, ppm ----	.1123	< 1	< 1	8	< 1	60*	21	10	--	8.1	2.16	80/80	1.7-38
Nb, ppm ----	.0324	< 1	< 1	< 1	8	47*	< 1	45	--	39	1.51	80/80	17-89
Ni, ppm ----	.0766	< 1	27*	< 1	< 1	8	60*	5	--	31	1.89	80/80	8.7-110
Pb, ppm ----	.0731	< 1	20	< 1	2	33*	12	33	--	15	1.86	80/80	4.3-52
Rb, ppm ----	.0708	3	19*	< 1	< 1	76*	2	< 1	.1	110	1.85	80/80	32-380
S, total ---	-----	---	---	---	---	---	---	---	--	550	4.96	37/80	22-14,000
Sc, ppm ----	.0300	< 1	11	< 1	10	44*	19*	16	--	12	1.49	80/80	5.4-27
Sn, ppm ----	.0523	< 1	7	< 1	< 1	56*	< 1	36	--	1.4	1.69	80/80	.49-4.0
Sr, ppm ----	.0692	< 1	< 1	48	< 1	29*	16*	7	--	170	1.83	80/80	51-570
Th, ppm ----	.0159	9*	9	< 1	< 1	48*	21*	14	.3	13	1.34	80/80	7.2-23
U, ppm -----	.0298	< 1	38*	< 1	9	49*	4	< 1	--	4.1	1.49	80/80	1.8-9.1
V, ppm -----	.0325	< 1	15*	12	13	34*	4	22	--	97	1.51	80/80	43-220
Y, ppm -----	.0354	< 1	11	< 1	54*	7	6	23	--	22	1.54	80/80	9.3-52
Yb, ppm ----	.0338	< 1	< 1	< 1	59*	8	14	19	--	3.7	1.53	80/80	1.6-8.7
Zn, ppm ----	.0727	< 1	< 1	35*	< 1	45	20	< 1	--	80	1.86	80/80	23-280
Zr, ppm ----	.0286	< 1	< 1	49*	< 1	28*	1	22	--	320	1.48	80/80	150-700

1/ Variance mean ratio for 200-km cells. See text for explanation.

Table 61.--Statistical analysis of the chemistry of sandstone of the Fort Union Formation, Northern Great Plains Coal Province

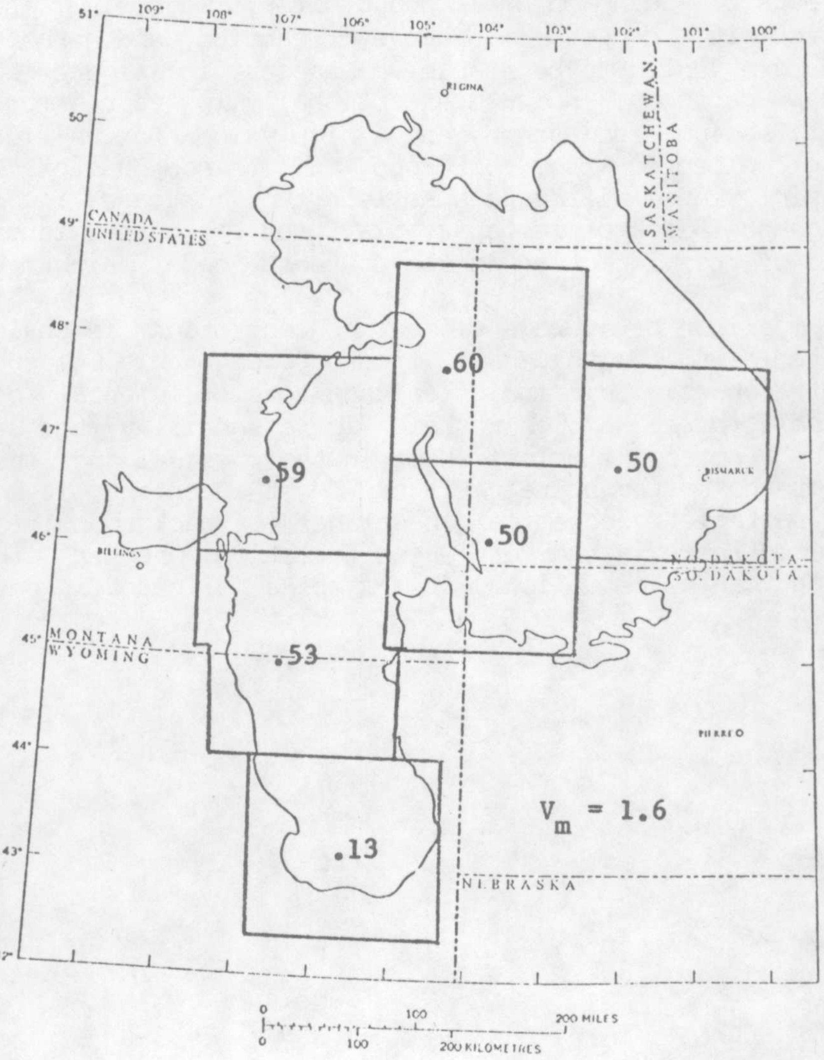
[*, significantly greater than zero at the 0.05 probability level]

Constituent	Analysis of logarithmic variance									Summary statistics			
	Total Log_{10} variance	Percent of total variance							v_m 1/				
		Between 200-km cells	Between 100-km cells	Between 50-km cells	Between 25-km cells	Between 5-km cells	Strati-graphic	Labora-tory	(200-km cells)	Geometric mean	Geometric deviation	Ratio	Expected 95 percent range (baseli
Al, % -------	0.0298	< 1	27*	< 1	< 1	51*	18*	4	--	4.1	1.49	80/80	1.8-9
Ca, % -------	.4098	17*	6	8	4	42*	< 1	28	0.6	2.4	4.37	76/80	.13-46
Fe, % -------	.0885	45*	12*	< 1	7	10	27*	< 1	2.3	1.5	1.98	80/80	.38-5
K, % --------	.0181	< 1	< 1	49*	3	9	38*	< 1	--	1.4	1.36	80/80	.76-2.6
Mg, % -------	.2483	42	20*	< 1	18	1	18*	< 1	1.8	1.1	3.15	80/80	.11-11
Na, % -------	.1914	50*	< 1	22	< 1	26*	2*	< 1	1.9	.49	2.74	80/80	.065-3.
Si, % -------	.0170	28*	< 1	8	23*	32*	8	< 1	.9	27	1.35	80/80	15-49
Ti, % -------	.0281	< 1	21*	< 1	37	31*	9*	2	--	.23	1.47	80/80	.11-.5
C, total %---	.5666	32*	21*	< 1	15	10	13*	9	1.2	1.1	5.66	80/80	.034-35
Ag, ppm -----	--	--	--	--	--	--	--	--	--	.16	2.73	40/40	.022-1.2
As, ppm -----	.0838	< 1	13	< 1	< 1	44	40*	3	--	4.4	1.95	80/80	1.2-17
B, ppm ------	.0522	5	< 1	26	9	42*	9*	7	.1	51	1.69	80/80	18-15
Ba, ppm -----	.0538	6	6	< 1	< 1	< 1	41	47	.3	700	1.71	80/80	240-2000
Be, ppm -----	.0583	< 1	11*	15	2	1	62*	9	--	1.4	1.74	80/80	.46-4.
Ce, ppm -----	.0613	18*	< 1	< 1	21	< 1	27	34	.8	55	1.77	78/80	18-170
Co, ppm -----	.0887	38*	12*	8	< 1	20	16*	7	1.6	5.4	1.99	79/80	1.4-21
Cr, ppm -----	.0886	11	22*	< 1	19	< 1	36*	12	.4	45	1.98	80/80	11-18
Cu, ppm -----	.1316	33*	7	< 1	2	< 1	52*	6	2.0	13	2.31	80/80	2.4-69
F, ppm ------	--	--	--	--	--	--	--	--	--	370	1.50	54/80	160-83
Ga, ppm -----	.0515	21	25*	2	< 1	< 1	43*	10	.8	11	1.69	80/80	3.9-31
Ge, ppm -----	.0389	< 1	< 1	48*	< 1	12	33*	7	--	1.1	1.57	80/80	.45-2.7
Hg, ppm -----	.0649	4	8	< 1	14	< 1	61*	13	.2	.032	1.80	80/80	.0099-.1
La, ppm -----	.0288	2	21*	< 1	11	< 1	22	44	.1	35	1.48	80/80	16-77
Li, ppm -----	.0187	< 1	< 1	44*	3	23	29*	1	--	15	1.37	80/80	8.0-28
Mn, ppm -----	.3025	38*	9	< 1	< 1	31*	20*	2	1.8	280	3.55	79/80	22-35
Mo, ppm -----	.1155	12	28*	< 1	< 1	< 1	44*	15	.5	5.0	2.19	77/80	1.0-24
Nb, ppm -----	.0341	< 1	16*	8	6	< 1	5	65	--	7.6	1.53	80/80	3.2-18
Ni, ppm -----	.1790	15*	17	< 1	56*	1	9*	2	.4	16	2.65	80/80	2.3-11
Pb, ppm -----	.1675	< 1	40*	< 1	< 1	< 1	44*	16	--	5.2	2.57	80/80	.79-34
Rb, ppm -----	.0179	< 1	< 1	36*	< 1	36*	26*	2	--	58	1.36	80/80	31-11
S, total ----	--	--	--	--	--	--	--	--	--	280	5.46	26/80	9.4-83
Sc, ppm -----	.0984	21	14*	< 1	< 1	< 1	57*	8	1.0	5.7	2.06	69/80	1.3-24
Se, ppm -----	.0851	< 1	< 1	2	< 1	< 1	13	84	--	.19	1.96	68/80	.050-.7
Sn, ppm -----	.0484	17	< 1	< 1	24	24	15	20	.6	1.1	1.66	80/80	.40-3.
Sr, ppm -----	.0853	39*	< 1	33*	1	< 1	22*	4	1.3	160	1.96	80/80	42-610
Th, ppm -----	.0268	< 1	21*	17	21*	1	15	25	--	7.1	1.46	79/80	3.3-15
U, ppm ------	.0227	< 1	< 1	29	4	11	55*	2	--	2.7	1.41	80/80	1.4-5.
V, ppm ------	.0512	3	26*	< 1	11	< 1	37*	23	.1	46	1.68	79/80	16-130
Y, ppm ------	.0566	3	17*	< 1	28*	< 1	39*	13	.1	17	1.73	79/80	5.7-51
Yb, ppm -----	.0872	2	19*	< 1	47*	< 1	22*	10	.1	2.1	1.97	79/80	.54-8.1
Zn, ppm -----	.0463	24*	< 1	34*	8	9	1	23	.7	44	1.64	80/80	16-120
Zr, ppm -----	.0512	< 1	23*	< 1	42*	7	8	20	--	270	1.68	80/80	96-76

1/ Variance mean ratio for 200-km cells. See text for explanation.

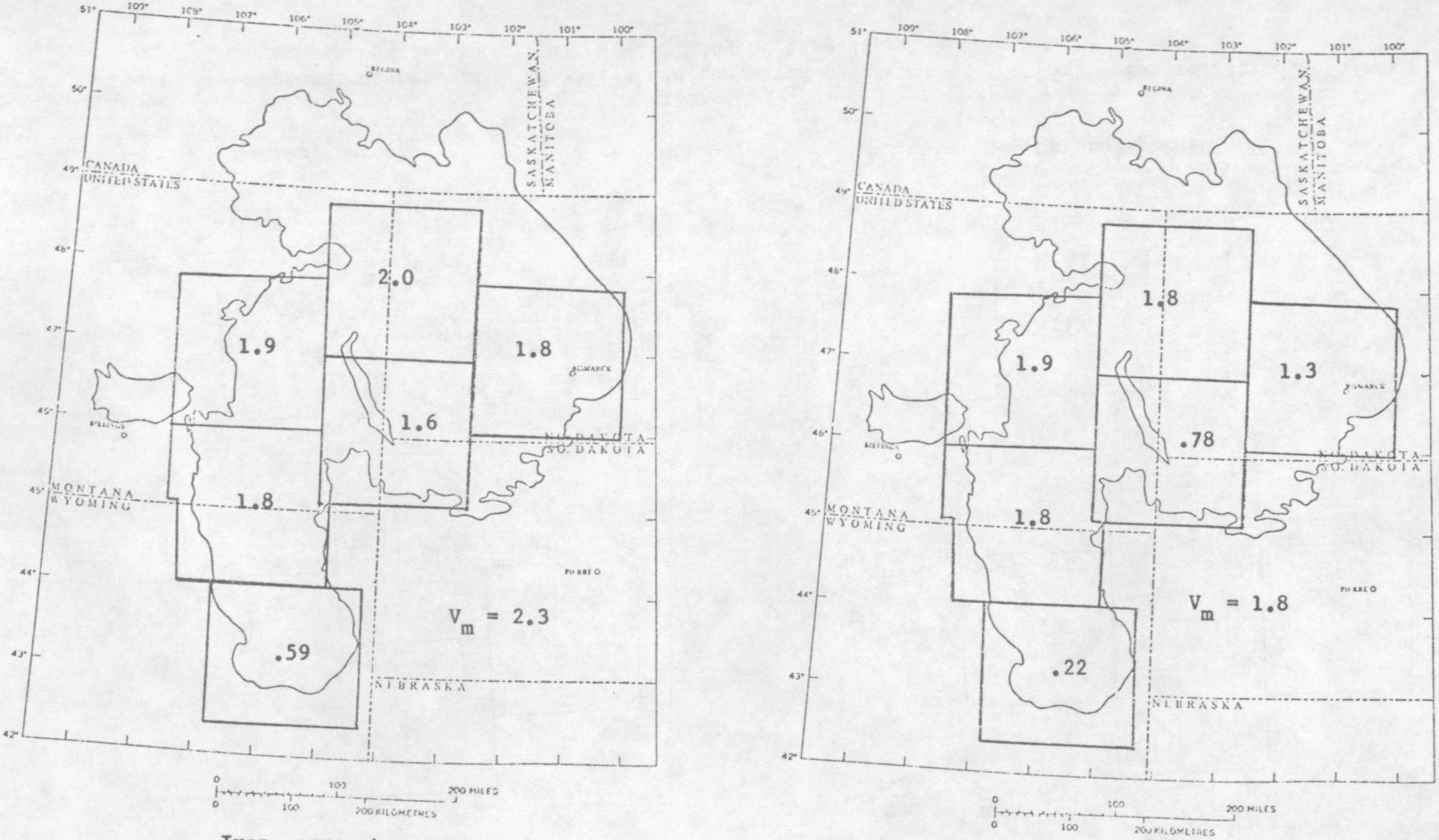
The variance mean ratio, v_m, (Miesch, 1976a) was calculated to determine the feasibility of mapping those elements that have significant variation among 200-km cells. This ratio (tables 60 and 61) is an index of the stability of a map pattern. A ratio of one or greater indicates that differences among 200-km cell means are sufficiently stable at about the 80-percent confidence level. Maps of sodium in shale and of iron, magnesium, sodium, carbon, cobalt, copper, manganese, scandium, and strontium in sandstone are judged to be stable and appear in figures 28-33. These map patterns indicate exceptionally low values for iron, magnesium, sodium, and carbon, and a high value for silicon in sandstone collected from outcrops in the southeastern Powder River Basin. These differences reflect the increase in quartz and a general lack of feldspar, clay, and carbonate minerals in sandstone of this formation in the southern Powder River Basin.

A comparison of average element concentrations in shale from cores (table 55) with shale from outcrop (table 60) shows no major differences. This indicates that total elemental content of "fresh" (core samples) shale is essentially the same as "weathered" (outcrop samples) shale in the physical and chemical setting of the Northern Great Plains. Most important, it appears that a suitable geochemical baseline (or background) for all fine-grained rocks in the Fort Union formation, whether cropping out or not, can be established from samples collected in outcrop.



Sodium, percent

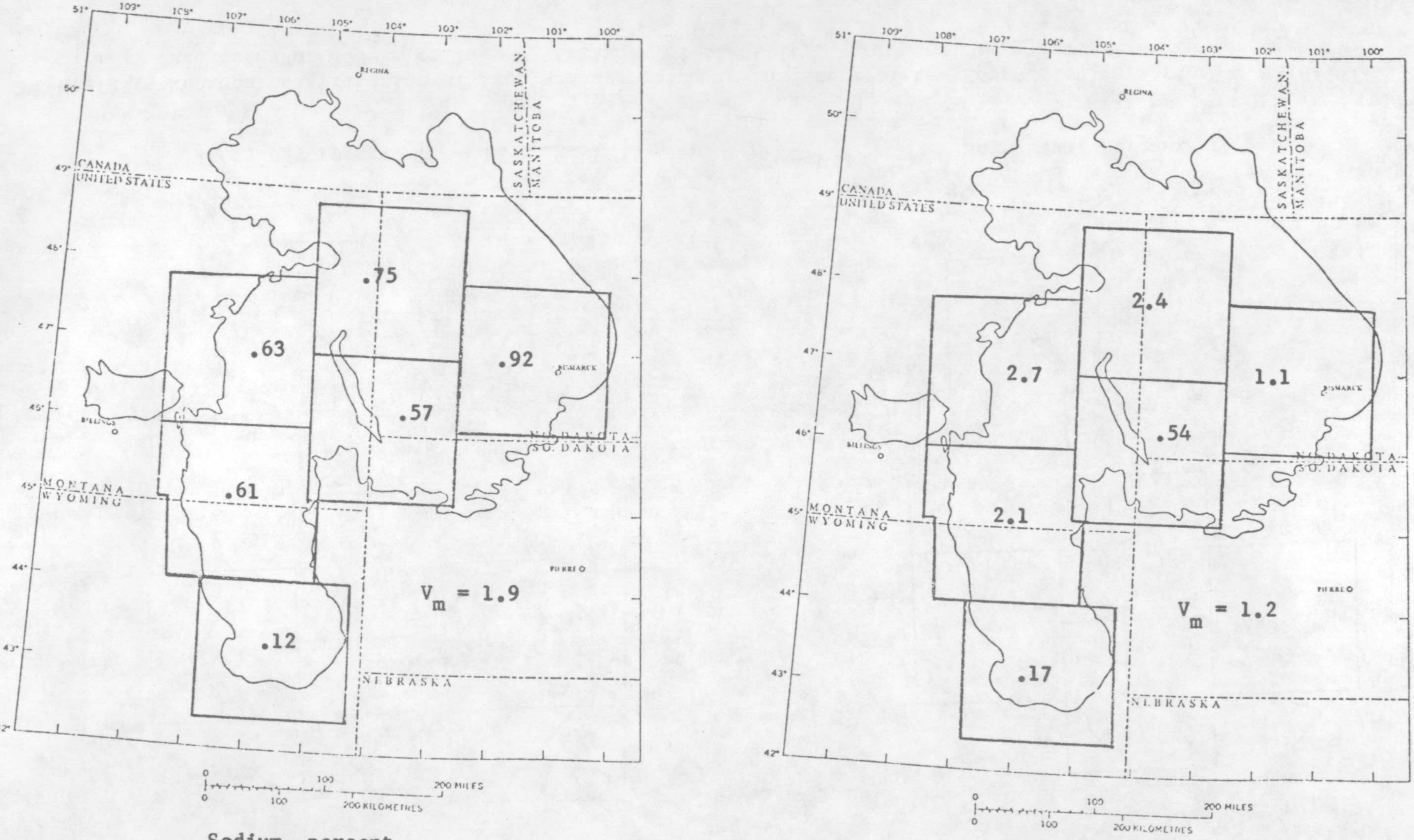
Figure 28.--Regional distribution of sodium in shale of the Fort Union formation. Values are means (in percent) of 200-km cells. V_m is index of stability.



Iron, percent

Magnesium, percent

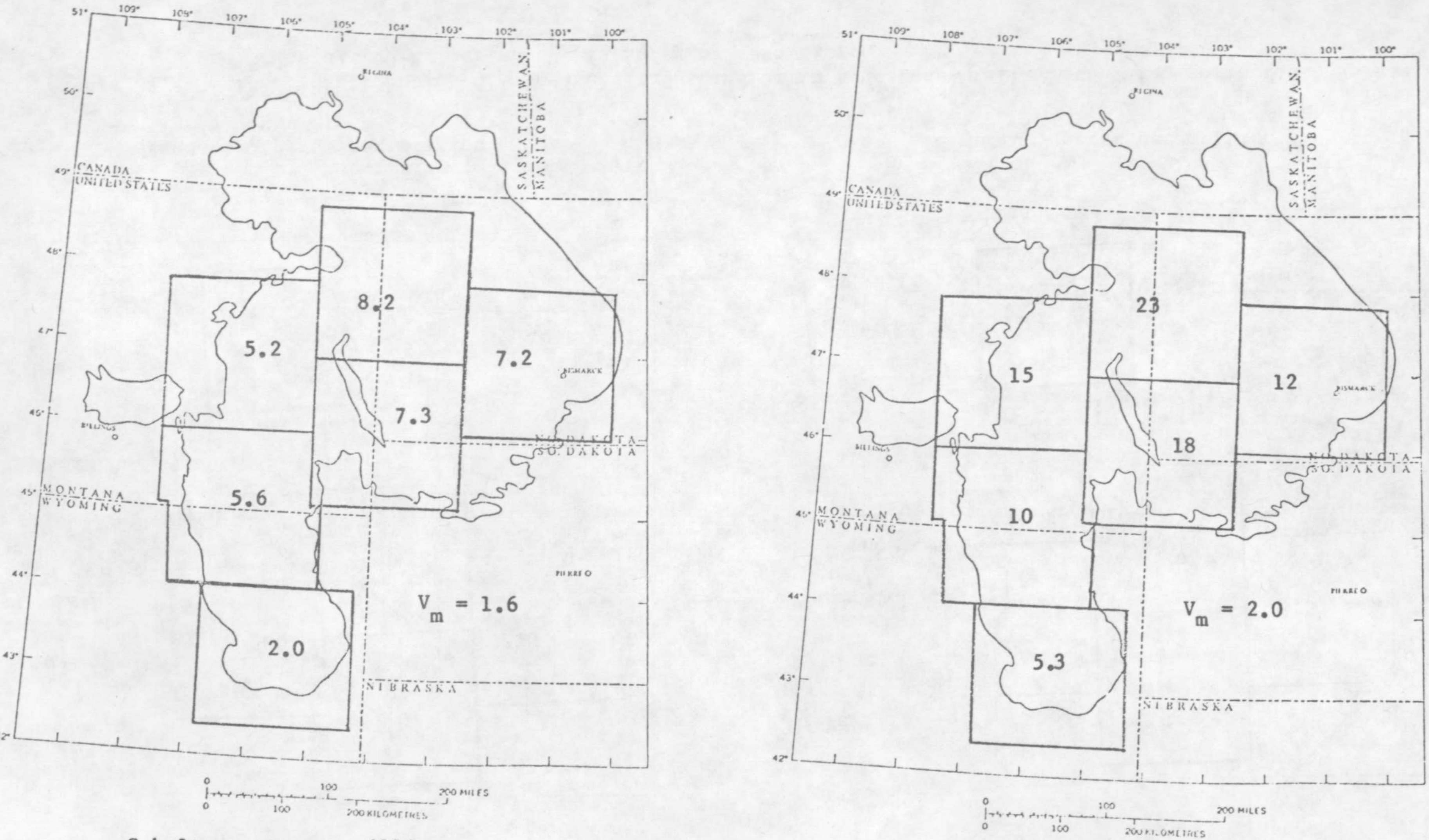
Figure 29.--Regional distribution of iron and magnesium in sandstone of the Fort Union formation. Values are means of 200-km cells. V_m is index of stability.



Sodium, percent

Carbon, percent

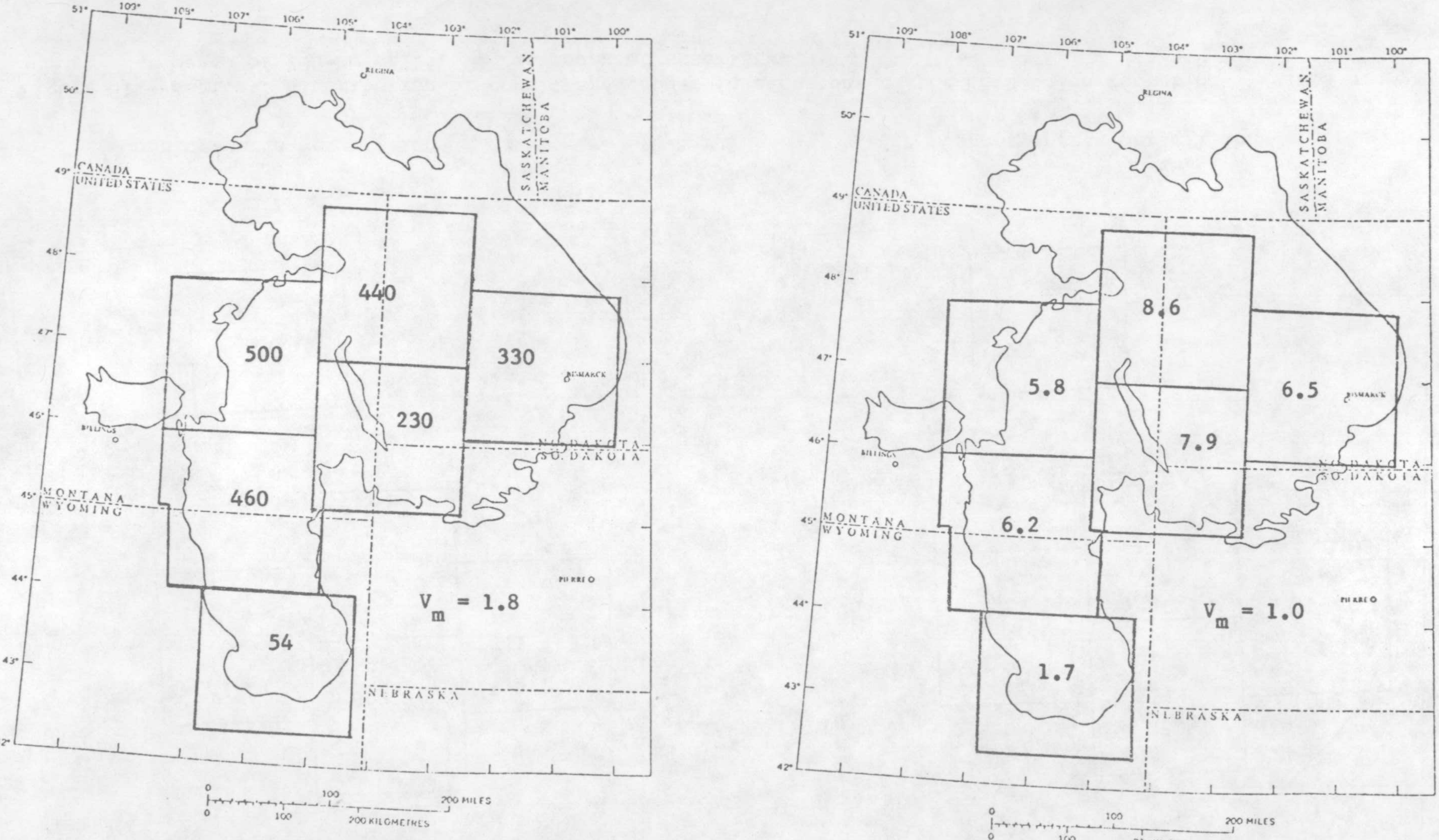
Figure 30.--Regional distribution of sodium and carbon in sandstone of the Fort Union formation. Values are means of 200-km cells. V_m is index of stability.



Cobalt, parts per million

Copper, parts per million

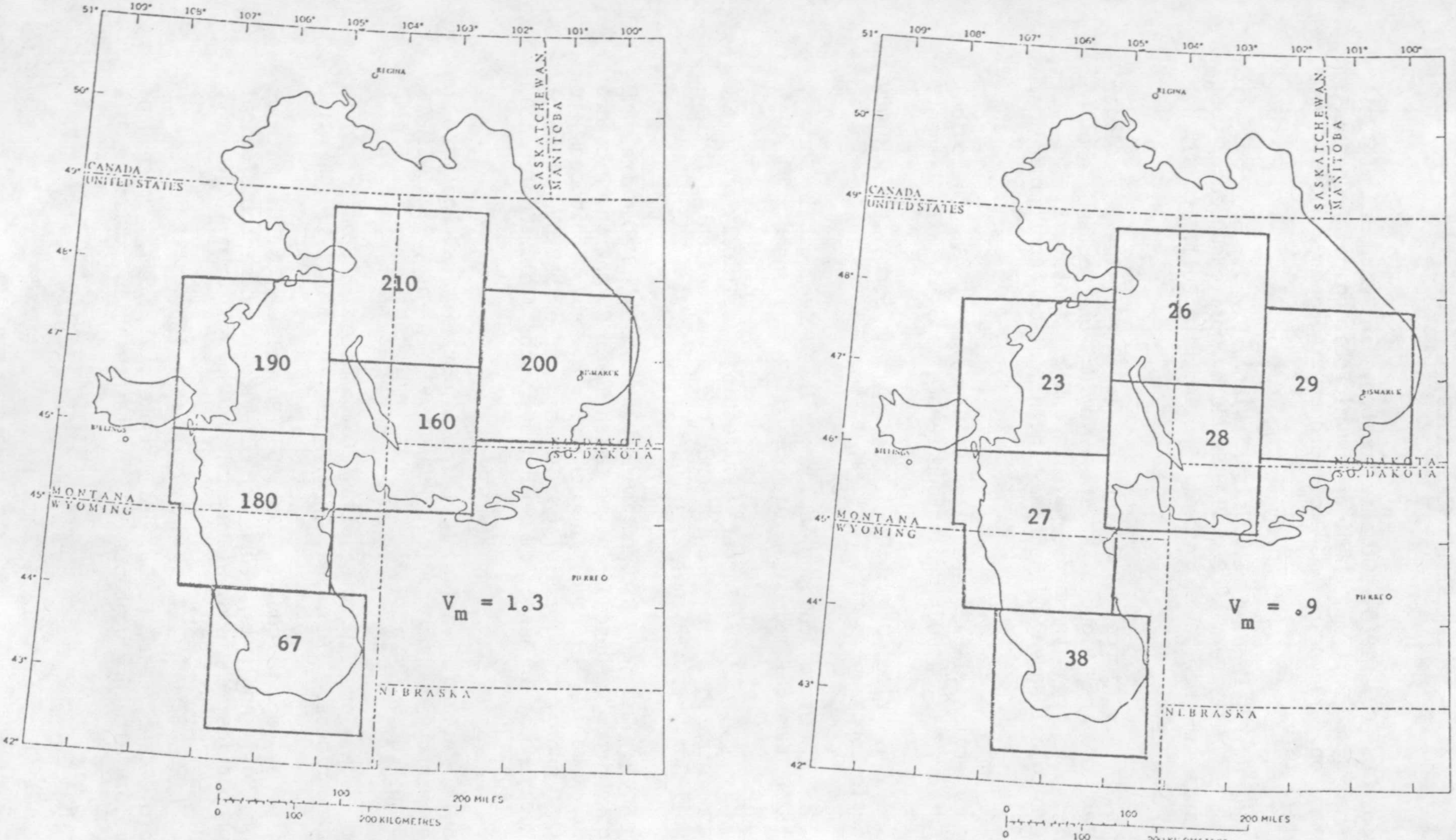
Figure 31.--Regional distribution of cobalt and copper in sandstone of the Fort Union formation. Values are means of 200-km cells. V_m is index of stability.



Manganese, parts per million

Scandium, parts per million

Figure 32.--Regional distribution of manganese and scandium in sandstone of the Fort Union formation. Values are means of 200-km cells. V_m is index of stability.



Strontium, parts per million

Silicon, percent

Figure 33.--Regional distribution of strontium and silicon in sandstone of the Fort Union formation. Values are means of 200-km cells. V_m is index of stability.

REFERENCES CITED

Allison, L. E., 1965, Organic carbon, in Methods of Soil Analysis; Part 2, Chemical and microbiological properties: Madison, Wisconsin, Am. Soc. Agronomy (Agronomy, no. 9), p. 1373-1376.

Anderson, R. Y., Dean, W. E., Jr., Kirkland, D. W., and Snider, H. I., 1972, Permian Castile varved evaporite sequence, west Texas and New Mexico: Geol. Soc. America Bull., v. 83, no. 1, p. 59-86.

Andrews, D. A., Pierce, W. G., and Eargle, D. H., 1947, Geologic map of the Bighorn Basin, Wyoming and Montana, showing terrace deposits and physiographic features: U. S. Geological Survey Oil and Gas Investigations Preliminary Map 71.

Army Map Service, 1964, Leadville, Colorado: U. S. Geological Survey, 1:250,000 scale topographic map, NJ 13-1, 1 sheet.

_____, 1973a, Price, Utah: U. S. Geological Survey, 1:250,000 scale topographic map, NJ 12-2, 1 sheet.

_____, 1973b, Grand Junction, Colorado: U. S. Geological Survey, 1:250,000 scale topographic map, NJ 12-3, 1 sheet.

Bates, T. E., 1970, Factors affecting critical nutrient concentrations in plants and their evaluation: a review: Soil Sci., v. 112, no. 2, p. 116-130.

Beard, T. N., Tait, D. B., and Smith, J. W., 1974, Nahcolite and dawsonite resources in the Green River Formation, Piceance Creek basin, Colorado, in Murray, D. K., ed., Guidebook to the energy resources of the Piceance Creek basin, Colorado: Rocky Mountain Assoc. of Geologists 25th Field Conference, p. 101-110.

Bennett, C. A. and Franklin, N. L., 1954, Statistical analysis in chemistry and the chemical industry: New York, John Wiley & Sons, Inc., 724 p.

Berger, K. C., and Truog, E., 1939, Boron determination in soils and plants: Ind. Eng. Chem. Anal. Ed., v. 11, p. 540-545.

Bower, C. A., and Wilcox, L. V., 1965, Soluble salts, in Methods of Soil Analysis; Part 2, Chemical and microbiological properties: Madison, Wisconsin, Am. Soc. Agronomy (Agronomy, no. 9), p. 933-951.

Bradford, G. R., Bair, F. L., and Hunsaker, V., 1971, Trace and major element contents of soil saturation extracts: Soil

Sci., v. 112, no. 4, p. 225-230.

Carter, R. P., 1976, Land reclamation program description: Coal extraction and land reclamation, Argonne National Laboratory, U.S. Energy Research and Development Administration.

Cashion, W. B., and Donnell, J. R., 1972, Chart showing correlation of selected key units in the organic-rich sequence of the Green River Formation, Piceance basin, Colorado, and Uinta basin, Utah: U.S. Geol. Survey Oil and Gas Inv. Chart OC-65.

Chapman, H. D., 1965, Cation-exchange capacity, in Methods of soil analysis; Part 2, Chemical and microbiological properties: Madison, Wisconsin, Am. Soc. Agronomy (Agronomy, no. 9) p. 899-900.

Chew, R. T., III, 1974, Geology, hydrology, and extraction operations at the Occidental Petroleum Corporation oil shale pilot plant near De Beque, Colo., in Murray, D. K., ed., Guidebook to the energy resources of the Piceance Creek Basin, Colo.: Rocky Mountain Assoc. of Geologists 25th Field Conference, p. 135-140.

Church, D. E., Smith, G. E., Fontenot, J. P., and Rallston, A. T., 1971, Digestive physiology and nutrition of ruminants, vol. 2--nutrition: Oregon State Univ.

Clagett, C. O., Stoa, T. E., Klosterman, H. J., Kingsley, A. F., and Sisler, W. W., 1952, The soil depleting power of the flax crop compared with that of hard red spring wheat, oats and barley: North Dakota Agr. Expt. Sta. Bull. 378, 26 p.

Cohen, A. C., Jr., 1959, Simplified estimators for the normal distribution when samples are singly censored or truncated: Technometrics, vol. 1, p. 217-237.

Coffin, D. L., Welder, F. A., and Glanzman, R. K., 1971, geohydrology of the Piceance Creek structural basin between White and Colorado Rivers, northwestern Colorado: U.S. Geol. Survey Hydrol. Inv. Atlas HA-370.

Connor, J. J., 1977a, Environmental geochemistry, in Summary of the geology, mineral resources, environmental geochemistry and engineering geology characteristics of the Northern Powder River Coal Region, Montana, F. W. Osterwald, Compiler: U. S. Geol. Survey Open-File Report 77-292, 124 p.

_______, 1977b, Environmental geochemistry, in Summary report of the geology, mineral resources, engineering geology and environmental geochemistry of the Sweetwater-Kemmerer area, Wyoming, Part C.: U. S. Geol. Survey Open-File Report

77-362, 22 p.

Connor, J. J., Keith, J. R., and Anderson, B. M., 1976, Trace-metal variation in soils and sagebrush in the Powder River Basin, Wyoming and Montana: U. S. Geol. Survey Jour. Research, v. 4, p. 49-59.

Czerniejewski, C. P., Shank, C. W., Bechtel, W. G., and Bradley, W. B., 1964, The minerals of wheat, flour, and bread: Cereal Chem., vol. 41, p. 65-72.

Day, P. R., 1965, Particle fractionation and particle-size analysis, *in* Methods of Soil Analysis; Part 1, Physical and mineralogical properties, including statistics of measurement and sampling: Madison, Wisconsin, Am. Soc. Agronomy (Agronomy, no. 9), p. 562-566.

Dean, W. E., Jr., 1974, Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods: Jour. Sed. Petrology, v. 44, no. 1, p. 242-248.

Dean, W. E., Jr., and Anderson, R. Y., 1974a, Application of some correlation coefficient techniques to time-series analysis: Mathematical Geology, v. 6, no. 4, p. 363-372.

__________, 1974b, Trace and minor element variations in the Permian Castile Formation, Delaware basin, Texas and New Mexico, revealed by varve calibration, *in* Symposium on salt, 4th, vol. 1: Cleveland, Ohio, Northern Ohio Geol. Society, p. 275-285.

Donnell, J. R., and Blair, R. W., Jr., 1970, Resource appraisal of three oil-shale zones in the Green River Formation, Piceance Creek basin, Colorado: Colorado School of Mines Quart., v. 65, no. 4, p. 73-87.

Duncan, D. B., 1955, Multiple range and multiple F-tests: Biometrics , Vol. 11, No. 1, p. 1-42.

Dyni, J. R., 1974, Stratigraphy and nahcolite resources of the saline facies of the Green River Formation in northwest Colorado, *in* Murray, D. K., ed., Guidebook to the energy resources of the Piceance Creek basin, Colorado: Rocky Mountain Assoc. of Geologists 25th Field Conference, p. 111-122.

Dyni, J. R., Hite, R. J., and Raup, O. B., 1970, Lacustrine deposits of bromine-bearing halite, Green River Formation, northwestern Colorado, *in* Symposium on salt, 3rd, vol. 1: Cleveland, Ohio, Northern Ohio Geol. Society, p. 166-180.

Ebens, R. J., Erdman, J. A., Feder, G. L., Case, A. A., and Selby, L. A., 1973, Geochemical anomalies of a claypit area, Callaway County, Missouri, and related metabolic imbalance in beef cattle: U.S. Geol. Survey Prof. Paper 807, 24 p.

Erdman, J. A., Ebens, R. J., and Case, A. A., 1978, Molybdenosis: a potential problem in ruminants grazing on coal-mine spoils: J. Range Management (in press).

Erdman, J. A., Shacklette, H. T., and Keith, J. R., 1976, Elemental composition of selected native plants and associated soils from major vegetation-type areas in Missouri: U. S. Geol. Survey Prof. Paper 954-C, 87 p.

Flanagan, F. J., 1976, Descriptions and analyses of eight new USGS rock standards: U. S. Geol. Survey Prof. Paper 840, 192 p.

Follett, R. H., and Lindsay, W. L., 1971, Changes in DTPA-extractable zinc, iron, manganese, and copper in soils following fertilization: Soil Sci. Soc. Am. Proc. v. 35, no. 4, p. 600-602.

Gill, Dan, 1970, Application of a statistical zonation method to reservoir evaluation and digitized-log analysis: Am. Assoc. Petroleum Geologists Bull., v. 54, no. 5, p. 719-729.

Gordon, C. C., and Tourangeau, Phillip C., 1975, Biological effects of coal-fired powerplants *in* Proc. Fort Union Coal Field Symp., v. 5 , Terrestrial Ecosystems Section: Mont. Acad. Sci., Billings, Mont., p. 509-530.

Gough, L. P., and Erdman, J. A., 1977, Influence of a coal-fired powerplant on the element content of *Parmelia chlorochroa*: The Bryologist, v. 80, n. 3 (in press).

Gough, L. P., and Severson, R. C., 1976, Impact of point source emissions from phosphate processing on the element content of plants and soils, Soda Springs, Idaho, *in* Hemphill, D. D., ed., Trace Substances in Environmental Health-X: Columbia, Univ. of Mo., p. 225-233.

Greaves, J. E., and Hirst, C. T., 1929, The mineral content of grain: Jour. Nutrition, vol. 1, p. 293-298.

Grigal, D. F., 1974, Note on the hydrometer method of particle-size analysis: Minnesota Forestry Research Notes, no. 245, 4 p.

Grim, R. E., 1953, Clay Mineralogy: New York, McGraw-Hill, 384 p.

Heald, Walter R., 1965, Calcium and magnesium, in Methods of Soil Analysis; Part 2, Chemical and microbiological properties: Madison, Wisconsin, Am. Soc. Agronomy (Agronomy, no. 9) p. 1000-1001.

Hite, R. J., and Dyni, J. R., 1967, Potential resources of dawsonite and nahcolite in the Piceance Creek basin, northwest Colorado, in Symposium on oil shale, 4th: Colorado School of Mines Quart., v. 62, no. 3, p. 25-38.

Hodgson, J. F., 1963, Chemistry of the micronutrient elements in soils: Advances in Agronomy: v. 15, p. 119-159.

_______, 1969, Chemistry of trace elements in soils with reference to trace element concentration in plants in Hemphill, D. D., ed., Trace Substances in Environmental Health-III: Columbia, Univ. of Mo., p. 45-58.

Jacober, F., and Sandoval, F., 1971, Effect of soil grinding, suction, and extraction time on salt concentration of saturation extracts: Soil Sci., v. 112, n. 4, p. 263,266.

Kaakinen, John W., Jorden, Roger M., and West, Ronald E., 1974, Trace element study in a pulverized coal-fired powerplant: 67th Ann. Mtg., Air Pollution Control Assoc., June 8-13, 1974, Denver, Colo., n. 74-8, 22 p.

Klovan, J. E., and Miesch, A. T., 1976, Extended CABFAC and QMODEL computer programs for Q-mode factor analysis of compositional data: Computers and Geosciences, v. 1, n. 3, p. 161-178.

Kuchler, A. W., 1964, Potential natural vegetation of the conterminous United States: Am. Geog. Soc. Spec. Pub. 36, map and 116 p. text.

Leone, F. C., Nelson, L. S., Johnson, N. L., and Eisenstat, Stan, 1968, Sampling distributions of variance components 2, Empirical studies of unbalanced nested designs: Technometrics, v. 10, no. 4, p. 719-737.

Lindsay, W. L., 1972, Influence of the soil matrix on the availability of trace elements to plants, in Hopps, H. C., and Cannon, H. L., eds., Geochemical Environment in Relation to Health and Disease: New York Acad. Sci. Annals, v. 199, p. 37-45.

Lindsay, W. L. , and Norvell, W. A., 1969, Development of a DTPA micronutrient soil test: Agronomy Abst., Am. Soc. Agronomy, Madison, Wisconsin, p. 84.

Lisk, Donald J., 1972, Trace metals in soils, plants, and animals: Advances in Agronomy, v. 24, p. 267-325.

Lounamaa, K. J., 1956, Trace elements in plants growing wild on different rocks in Finland: Ann. Bot. Soc. 'Vanamo', v. 29, p. 1-196.

McKeague, J. A., and Day, J. H., 1966, Dithionite- and oxalate-extractable Fe and Al as aids in differentiating various classes of soils: Can. Journ. Soil Sci., v. 46, no. 1, p. 13-22.

Miesch, A. T., 1976a, Geochemical survey of Missouri--methods of sampling, laboratory analysis, and statistical reduction of data, with sections on laboratory methods by P. R. Barnett, A. J. Bartel, J. I. Dinnin, G. L. Feder, T. F. Harms, Claude Huffman, Jr., V. J. Janzer, H. T. Millard, Jr., Harriet G. Neiman, M. W. Skougstad, and J. S. Wahlberg: U. S. Geol. Survey Prof. Paper 954-A, 39p.

_______,1976b, Interactive computer programs for petrologic modeling with extended Q-mode factor analysis: Computers and Geosciences, v. 2, n. 4, p. 439-492.

_______, 1976c, Q-mode factor analysis of Geochemical and petrologic data matrices with constant row sums: U. S. Geol. Survey Prof. Paper 574-G, 47 p.

Miller, Joseph E., Hassett, John J., and Koeppe, D. E., 1976, Uptake of cadmium by soybeans as influenced by soil cation exchange capacity, pH, and available phosphorus: Jour. Environ. Quality, v. 5, no. 2, p. 157-160.

Munshower, F. F., and DePuit, E. J., 1975, The effects of stack emissions on the range resource in the vicinity of Colstrip, Montana: Mont. Agr. Exp. Sta. Res. Rept. 71, Bozeman, Mont., 73 p.

_______, 1976, The effects of stack emissions on the range resource in the vicinity of Colstrip, Montana: Mont. Agr. Exp. Sta. Res. Rept. 98, Bozeman, Montana, 112 p.

Myers, A. T., Havens, R. G., and Dunton, P. J., 1961, A spectrochemical method for the semiquantitative analysis of rocks, minerals, and ores: U. S. Geol. Survey Bull. 1084-I, p. 207-229.

Naftel, J. A., 1939, Colorimetric micro determination of boron: Ind. Eng. Chem. Anal. Ed., v. 11, p. 407-409.

Oetking, P., Feray, D. E., and Renfro, H. B., 1967, Geological highway map of the southern Rocky Mountain region: Tulsa, Okla., Amer. Assoc. Petroleum Geologists, 1 sheet.

Pearson, R. L., Tucker, C. J., and Miller, L. D., 1976, Spectral mapping of shortgrass prairie biomass: Photogrammetric

Engineering and Remote Sensing, v. 42, p. 317-323.

Peech, Michael, 1965, Hydrogen-ion activity, in Methods of Soil Analysis;; Part 2, Chemical and microbiological properties: Madison, Wisconsin, Am. Soc. Agronomy (Agronomy, no. 9), p. 922-923.

Poulson, R. E., Smith, J. W., Young, N. B., Robb, W. A., and Speeding, T. J., 1977, Minor elements in oil shale and oil-shale products: Energy Research and Development Administration, Laramie Enery Research Center, Report of Investigations, LERC/RI-77/1, 17p.

Prabhakarannair, K. P., and Cottenie, A., 1969, A study of the plant uptake in relation to changes in extractable amounts of native trace elements from soil profiles using the Neubauer seedling method: Soil Sci., v. 108, no. 1, p. 74-78.

Pratt, P. F., 1965a, Potassium, in Methods of Soil Analysis; Part 2, Chemical and microbiological properties: Madison, Wisconsin, Am. Soc. Agronomy (Agronomy, no. 9) p. 1025-1026.

_______, 1965b, Sodium, in Methods of Soil Analysis; Part 2, Chemical and microbiological properties: Madison, Wisconsin, Am. Soc. Agronomy (Agronomy, no. 9) p. 1033-1034.

Prince, A. L., 1957, Trace element delivering capacity of 10 New Jersey soil types as measured by spectrographic analyses of soils and mature corn leaves: Soil Sci., v. 84, p. 413-418.

Rahn, Perry H., 1976, Potential of coal strip mine spoils as aquifers in the Powder River Basin, Project Completion Report: Old West Regional Commission, Billings, Mont., 108 p.

Randall, G. W., Schulte, E. E., and Corey, R. B., 1976, Correlation of plant manganese with extractable soil manganese and soil factors: Soil Sci. Soc. Am. Jour., v. 40, no. 2, p. 282-287.

Richards, L. A., 1954, Diagnosis and improvement of saline and alkali soils: U. S. Dept. Agr. Handbook 60, 160 p.

Robb, W. A., and Smith J. W., 1974, Mineral profile of oil shales in Colorado core hole no. 1, Piceance Creek basin, Colorado, in Murray, D. K., ed., Guidebook to the energy resources of the Piceance Creek basin, Colorado: Rocky Mountain Asso. of Geologists twenty-fifth field conference, p. 91-100.

Rule, J. H., and Graham, E. R., 1976, Soil labile pools of manganese, iron, and zinc as measured by plant uptake and DTPA equlibrium: Soil Sci. Soc. Am. Jour., v. 40, no. 6, p.

853-857.

Sandoval, F. M., Bond, J. J., Power, J. F., and Willis, W. O., 1973, Lignite mine spoils in the northern Great Plains--characteristics and potential for reclamation: North Dakota Geol. Survey Education Series 5, p. 1-24.

Sargent, K. A., and Hansen, D. E., compilers, 1976, General geology and mineral resources of the coal area of south-central Utah, with sections on Landslide hazards by R. B. Colton, Coal-mine subsidence by C. R. Dunrud, and Landscape geochemistry by J. J. Connor: U. S. Geol. Survey Open-file report 76-811, 122 p.

Sauchelli, Vincent, 1969, Trace elements in agriculture: New York, Van Nostrand Reinhold Co., 248 p.

Severson, R. C., and Gough, L. P., 1976, Concentration and distribution of elements in plants and soils as related to phosphate processing, Pocatello, Idaho: Jour. Environ. Quality, v. 5, no. 4, p. 476-482.

Shacklette, H. T., Erdman, J. A., Harms, T. F., and Papp, C. S. E., Trace elements in plant foodstuffs, in Oehme, F. W., ed., Toxicity of heavy metals in the environment: New York, Marcel Dekker, in press.

Shacklette, H. T., Sauer, H. I., and Miesch, A. T., 1970, Geochemical environments and cardiovascular mortality rates in Georgia: U. S. Geol. Survey Prof. Paper 574-C, 139 p.

Shuman, L. M., and Anderson, O. E., 1974, Evaluation of six extractants for their ability to predict manganese concentrations in wheat and soybeans: Soil Sci. Soc. Am. Proc., v. 38, no. 5, p. 788-790.

Smith, J. W., and Milton, C., 1966, Dawsonite in the Green River Formation of Colorado: Econ. Geology, v. 61, p. 1029-1042.

Snedecor, G. W. and Cochran, W. G., 1967, Statistical methods (6th ed.): Ames, Iowa, Iowa State Univ. Press, 593 p.

Soltanpour, P. N., Khan, A., and Lindsay, W. L., 1976, Factors affecting DTPA-extractable Zn, Fe, Mn, and Cu from soils: Commu. in Soil Sci. and Plant Analysis, v. 7, no. 9, p. 797-821.

Soltanpour, P. N., and Schwab, A. P., 1977, A new soil test for simultaneous extraction of macro- and micronutrients in alkaline soils: Commun. in Soil Sci. and Plant. Analysis, v. 8, no. 3, p. 195-207.

Sorensen, R. C., Oelsligle, D. D., and Knudsen, Delno, 1971, Extraction of Zn, Fe, and Mn from soils with 0.1 N hydrochloric acid as affected by soil properties, solution:soil ratio, and length of extraction period: Soil Sci., v. 111, no. 6, p. 352-359.

Swanson, V. E., 1972, Composition and trace-element content of coal and powerplant ash, Part 2, in Appendix J, Southwest Energy Study: U. S. Geol. Survey Open-file Report, 61 p.

Swanson, Vernon E., Medlin, Jack H., Hatch, Joseph R., Coleman, S. Lynn, Wood, Gordon H., Jr., Woodruff, Scott D., and Hildebrand, Ricky T., 1976, Collection, chemical analysis, and evaluation of coal samples in 1975: U. S. Geological Survey Open-file Report 76-468, 503 p.

Testerman, J. D., 1962, A statistical reservoir zonation technique: Jour. Petroleum Technology, v. 14, no. 8, p. 889-893.

Tidball, R. R., and Ebens, R. J., 1976, Regional geochemical baselines in soils of the Powder River Basin, Montana-Wyoming, in Laudon, R. B., ed., Geology and energy resources of the Powder River Basin: Wyo. Geol. Assoc. Guidebook, 28th Ann. Field Conference, Casper, Wyo., Sept., 1976, p. 299-310.

Turner, Frederick B., and Strojan, Carl L., 1976, Coal combustion, trace element emissions, and mineral cycles: Laboratory of Nuclear Medicine and Radiation Biology, Univ. Cal., Los Angeles (unpublished).

Trudell, L. G., Beard, T. N., and Smith, J. W., 1970, Green River Formation lithology and oil shale correlations in the Piceance Creek basin, Colorado: U.S. Bur. Mines Rept. Inv. 7357, 11p.

Trumbull, James, 1959, Coal fields of the United States, Sheet 1: U. S. Geol. Survey [1960]

Tweto, O. L., 1976, Preliminary geologic map of Colorado: U. S. Geol. Survey Misc. Field Studies, Map MF-788.

U. S. Department of Agriculture, 1951, Soil survey manual: U. S. Dept. Agriculture Handbook 18, 503 p.

U. S. Environmental Protection Agency, 1975, Coal-fired powerplant trace element study, A three station comparison, v. 1: U. S. Env. Prot. Agency, Denver, Colo., 50 p.

U. S. Geological Survey, 1974a, Stripping coal deposits of the Northern Great Plains, Montana, Wyoming, North Dakota, and South Dakota: U. S. Geol. Survey Misc. Field Studies Map

MF-590, 1 sheet.

_______, 1974b, Geochemical Survey of the Western Coal Regions, 1st Annual Progress Report, July 1974: U. S. Geol. Survey Open-file Report 74-250, 38p.

_______, 1975, Geochemical survey of the Western Coal Regions, 2nd Annual Progress Report, July 1975: U.S. Geol. Survey Open-file Rept. 75-436, 132p..

_______, 1976, Geochemical Survey of the Western Energy Regions (formerly Geochemical Survey of the Western Coal Regions), 3rd Annual Progress Report July 1976: U. S. Geol. Survey Open-file Report 76-729, 138p.

VanTrump, George, Jr., and A. T. Miesch, 1977, The U. S. Geological Survey RASS-Statpac system for management and statistical reduction of geochemical data: Computers and Geoscience (in press).

Vine, J. D., and Tourtelot, E. B., 1973, Geochemistry of Lower Eocene sandstones in the Rocky Mountain Region: U. S. Geological Survey Prof. Paper 789, 36p.

Wear, John I., 1965, Boron, in Methods of soil analysis; Part 2, Chemical and microbiological properties: Madison, Wisconsin, Am. Soc. Agronomy (Agronomy, no. 9) p. 1059-1063.

Weaver, J. E., and Albertson, F. W., 1956, Grasslands of the Great Plains: Lincoln, Neb., Johnsen Publ. Co., 395 p.

Weeks, J. B., Leavesley, G. H., Welder, F. A., and Saulnier, George J., jr., 1974, Simulated effects of oil shale development on the hydrology of Piceance Basin, Colorado: U. S. Geol. Survey Prof. Paper 908, 84 p.

Whitaker, S. H., and Pearson, D. E., 1972, Geological map of Saskatchewan: Saskatchewan Dept. Mineral Resources and Saskatchewan Research Council, 1 sheet.

Whitcomb, H. A., and M. E. Lowry, 1968, Ground-water resources and geology of the Wind River Basin area, Central Wyoming: U. S. Geological Survey Hydrologic Investigations Atlas HA-270.

Williams, C. H., and David, D. J., 1973, The effect of superphosphate on the cadmium content of soils and plants: Aust. J. Soil Res., vol. 11, p. 43-56.

Young, N. B., and Smith, J. W., 1970, Dawsonite and nahcolite analyses of Green River Formation oil-shale sections, Piceance Creek basin, Colorado: U.S. Bur. Mines Rept. Inv. 7445, 22 p.

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY
Denver, Colorado

APPENDICES TO
GEOCHEMICAL SURVEY OF THE WESTERN ENERGY REGIONS
Fourth Annual Progress Report, July, 1977

APPENDIX I. Probable upper limits of element concentration to be expected in ordinary landscape materials of the Powder River Basin, Wyoming and Montana.

APPENDIX II. Probable upper limits of element concentration to be expected in ordinary landscape materials of the Northern Great Plains, Montana, North Dakota and South Dakota.

APPENDIX III. Probable upper limits of element concentration to be expected in ordinary landscape materials of the Oil Shale Region, Utah, Wyoming and Colorado.

APPENDIX IV. Probable upper limits of element concentration to be expected in ordinary landscape materials of the Bighorn and Wind River Basins, Wyoming.

Open-file Report 77-872
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This report is preliminary and has not been
edited or reviewed for conformity with U. S.
Geological Survey standards or nomenclature

APPENDIX I

Probable upper limits of concentration to be expected in ordinary landscape materials of the Powder River Basin.

[The limits are estimated as those above which only about one sample in 20 of a randomly selected suite is expected to fall due to natural causes alone. Values expressed as parts per million except as indicated. Limits given to two significant figures except those in parentheses, which are given to only one significant figure because they are judged to be less stable. Leaders (--) indicate insufficient data to estimate limit]

Property	Landscape Material[1/]																
	Rock		Soil					Powder River Sediment				Plant Ash					Ground water
	Shale	Sandstone	Surface		Subsurface							Sagebrush		Lichen	Grass		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Al, %	11	7.8	7.3	--	--	7.7	8.2	12	5.6	6.9	(10)	7.6	--	(6)	5.0	--	35×10^{-7}
Sb	--	--	--	(2)	1.8	--	--	--	--	--	--	--	--	--	--	--	--
As	16	13	--	12	17	--	--	--	--	--	--	--	--	1.2[2/]	(2)[2/]	--	(<.006)
Ba	1,600	1,300	910	990	1,200	890	1,000	1,400	1,400	1,500	(1,500)	--	1,100	710	760	--	(.1)
Be	8.8	3.3	--	1.7	1.9	--	--	--	--	--	1.4	--	--	--	--	--	--
B	160	120	57	54	50	60	--	25	16	41	90	460	400	--	180	--	.34
Br	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.47
Cd	--	--	--	--	--	--	--	--	--	--	--	25	16	(9)	2.0	(2)	(<.001)
Ca, %	15	(20)	2.3	--	--	4.3	11	4.2	3.8	3.0	5.5	--	11	--	6.1	(4)	(.05)
C(total), %	5.2	(2)	--	--	--	2.2	3.0	2.6	1.3	1.0	1.8	--	--	--	--	--	--
Ce	200	(100)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cl	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	29
Cr	140	130	98	69	71	87	110	(80)	(60)	75	190	73	39	67	(70)	--	--
Co	25	(5)	16	10	13	18	16	11	6.3	4.3	8.6	6.1	5.1	6.5	8.6	(1)	--
Cu	97	(20)	31	30	36	49	90	(50)	26	16	160	--	--	(100)	200	--	--
F	1,300	720	730	--	--	830	840	--	--	--	--	--	17[2/]	(50)[2/]	(100)[2/]	(6)[2/]	3.1
Ga	48	25	20	18	19	--	26	(26)	17	15	21	--	--	--	17	--	--
Ge	2.7	2.3	--	2.2	2.0	--	--	--	--	--	--	--	--	--	--	--	--
I	--	--	--	--	--	--	--	--	--	--	--	--	--	5.5[2/]	--	--	.017
Fe, %	8.1	(1)	3.8	--	--	3.8	5.0	6.1	2.7	2.5	3.9	2.1	--	1.9	2.2	--	(8)
La	82	57	--	--	50	--	180	--	--	--	(100)	--	--	--	--	--	--
Pb	35	22	30	21	36	26	23	(20)	13	12	--	--	100	(200)	(40)	--	--
Li	79	25	--	34	41	43	44	(20)	19	17	21	--	25	11	16	(40)	.15
Mg, %	6.8	(1)	1.5	--	--	1.6	4.8	(2)	(.7)	.97	1.2	3.4	--	1.0	1.5	--	(.03)
Mn	(3,000)	(300)	830	560	500	770	810	480	360	350	(600)	1,000	910	600	1,300	--	(.8)
Hg	(.2)	.079	.041	.024	.032	.053	.061	.42	(.05)	.046	.047	.037[2/]	.034[2/]	.13[2/]	(.04)[2/]	(.01)[2/]	(<.0002)

Mo ----------	27	17	--	--	--	--	--	--	--	--	--	15	18	--	24	--	--
Nb ----------	64	12	--	--	--	--	--	--	8.1	(19)	18	--	--	--	--	--	--
Ni ----------	86	(80)	37	24	29	38	49	(30)	11	8.3	16	28	29	17	14	--	--
P, % --------	--	--	--	--	--	--	--	--	--	--	--	2.5	--	--	1.1	(3)	--
K, % --------	5.9	2.3	(3)	--	--	--	(4)	(4)	2.8	2.5	3.3	--	38	--	3.4	(20)	.0012
Rb------------	300	96	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sc------------	22	(5)	14	11	15	15	20	3.3	--	5.7	(9)	--	--	--	--	--	--
Se------------	--	.30	.57	(.4)	.42	.71	.58	--	--	--	--	1.3[2]	2.1[2]	(.6)[2]	.53[2]	(.6)[2]	(<.01)
Si, %---------	(30)	--	40	--	--	38	40	--	--	--	--	--	12	(20)	39	(30)	.0023
Ag------------	.86	.84	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Na, %---------	(.2)	(.4)	.86	--	--	.90	1.01	(.9)	.68	(.7)	(.7)	--	.22	.064	(.1)	--	.11
Sr------------	450	(200)	230	300	280	350	490	310	170	(200)	230	--	1,100	900	290	--	(5)
S(total), %---	(.8)	(.5)	--	--	--	--	--	--	--	--	--	--	.16[2]	.10[2]	.072[2]	(.3)[2]	(4,000)[3]
Th------------	(20)	12	--	13	15	--	--	--	--	--	--	--	--	--	--	--	--
Sn------------	2.8	2.3	--	3.4	3.0	--	--	--	--	--	--	--	--	--	--	--	--
Ti, %---------	.55	.43	.39	--	--	.39	.42	(.2)	.16	(.3)	(.6)	.29	.16	.30	.29	--	--
U-------------	7.9	4.7	--	4.5	4.8	--	--	--	--	--	--	--	1.4	5.5	2.0	(1)	(.003)
V-------------	180	98	130	110	150	130	170	(200)	74	79	150	120	80	85	110	--	--
Yb------------	7.0	6.1	--	2.1	2.5	--	--	(3)	3.5	(4)	13	--	--	--	--	--	--
Y-------------	41	39	--	23	27	--	--	(30)	--	29	(97)	--	--	52	--	--	--
Zn------------	220	(90)	110	91	110	100	120	110	56	48	89	--	610	--	(1,000)	(400)	(.8)
Zr------------	570	580	470	260	240	340	340	(100)	120	(700)	(4,000)	--	104	110	(300)	--	--
pH------------	--	--	7.38	--	--	--	--	--	--	--	--	--	--	--	--	--	8.7
Rad[4]---------	(100)	(70)	(50)		--	--	--	--	--	--	--	--	--	--	--	--	--

In water only

Bicarbonate																	1,000
Total hardness																	(2,000)
Specific conductance, mhos/cm																	3,900
Nitrate and nitrite																	(3)
Sodium adsorption ratio																	(100)
Gross β,pCi/l as Cs-137																	17

Footnotes and references on next page.

APPENDIX I (continued)

Probable upper limits of concentration to be expected in ordinary landscape materials of the Powder River Basin

1/ Identification of landscape materials and sources of data (references at end of footnotes):
- (1) Fort Union formation, outcrops south of 44°N. Latitude (USGS, 1977, table 60, fig. 28).
- (2) Do. Latitude (USGS, 1977, table 61, figs. 29-33).
- (3) 0-2.0 cm depth, <2 mm fraction (USGS, 1974, table 1; USGS, 1975, table 1).
- (4) 0-2.5 cm depth, <2 mm fraction (USGS, 1975, table 1).
- (5) 15-20 cm depth, <2 mm fraction (USGS, table 9; Connor, Keith, and Anderson, 1976, table 1).
- (6) "B-horizon", <2 mm fraction (USGS, 1975, table 6; see also Tidball and Ebens, 1976).
- (7) "C-horizon", <2 mm fraction (USGS, 1975, table 6; see also Tidball and Ebens, 1976).
- (8) 200μ-2 mm fraction (USGS, 1976, table 5).
- (9) 100μ-200μ fraction (USGS, 1976, table 5).
- (10) 63μ-100μ fraction (USGS, 1976, table 5).
- (11) 63μ fraction (USGS, 1976, table 5).
- (12) Washed *Artemisia tridentata* (USGS, 1974, table 1).
- (13) Unwashed *Artemisia tridentata* (USGS, 1975, table 1, except data for Ca, F, Hg, K, Na, S, which are unpublished).
- (14) Washed *Parmelia chlorachroa* (USGS, 1975, table 1).
- (15) Washed *Bouteloua gracilis* (USGS, 1975, table 1).
- (16) Unwashed Fairway strain of *Agropyron cristatum* (USGS, 1976, table 11; samples from near Dave Johnston mine only, southern Powder River Basin).
- (17) From domestic or livestock wells, average depth 100 m (USGS, 1977, table 57).

2/ Determined on dry weight.

3/ SO_4 only.

4/ Radioactivity in picocuries/gram. Computed as 4.81(ppm U)+1.1(ppm Th)+8.5(%K). From John Rosholt (U.S. Geological Survey, written commun., 1976).

References:

Connor, Jon J., Keith, John R., and Anderson, Barbara M., 1976, Trace metal variation in soils and sagebrush in the Powder River Basin, Wyoming and Montana *in* Journal Research: U.S. Geol. Survey, v. 4, no. 1, p. 49-59.

Tidball, Ronald R., and Ebens, Richard J., 1976, Regional geochemical baselines in soils of the Powder River Basin, Montana-Wyoming: 28th Ann. Field Conf.-1976, Wyoming Geol. Assoc. Guidebook, p. 299-310.

USGS, 1974, Geochemical Survey of the Western Coal Regions, First Annual Progress Report, July, 1974: U.S. Geol. Survey Open-file Report 74-250, 38 p.

USGS, 1975, Geochemical Survey of the Western Coal Regions, Second Annual Progress Report, July 1975: U.S. Geol. Survey Open-file Report 75-436, 132 p.

USGS, 1976, Geochemical Survey of the Western Energy Regions (formerly Geochemical Survey of the Western Coal Regions), Third Annual Progress Report, July, 1976: U.S. Geol. Survey Open-file Report 76-729, 138 p.

USGS, 1977, Geochemical Survey of the Western Energy Regions, Fourth Annual Progress Report, July, 1977: U.S. Geol. Survey Open-file Report 77-872, 208 p.

Probable upper limits of concentration to be expected in ordinary landscape materials of the Northern Great Plains

[The limits are estimated as those above which only about one sample in 20 of a randomly collected suite is expected to fall due to natural causes alone. Values expressed as parts per million (milligrams per liter in water) except as indicated. Limits given to two significant figures except those in parentheses, which are given to only one significant figure because they are judged to be less stable. Leaders (--) indicate data insufficient to estimate limit]

Property	Landscape Material[1]								
	Rock			Soil		Sediment	Ground water	Wheat[2]	
	Shale		Sandstone						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Al, % ----	11	11	7.8	(7)	(8)	--	79x10^{-7}	--	--
As -------	18	18	13	--	--	--	--	--	--
B --------	160	(70)	--	79	91	--	.91	--	--
Ba -------	1,600	(600)	1,300	--	--	--	.024	--	--
Be -------	8.8	3.1	3.3	--	--	--	--	--	--
Br --------	--	--	--	--	--	--	1.1	--	--
C(total), %	5.2	6.8	(14)	(10)	(6)	(5)	--	--	--
Ca, % -----	15	(8)	(20)	3.5	(15)	--	(.02)	--	.042
Cd --------	--	--	--	--	--	--	--	(.1)	.067
Ce --------	200	84	(100)	--	--	--	--	--	--
Cl --------	--	--	--	--	--	--	.012	--	--
Cr --------	140	(100)	130	--	82	--	--	(.03)	--
Co --------	25	(20)	(20)	11	12	--	--	(.06)	.035
Cu --------	97	(70)	(40)	38	35	--	--	(5)	6.1
F ---------	1,300	1,100	720	--	--	--	(4)	(1)	--
Fe, % -----	8.1	6.1	(4)	3.7	3.8	--	.0004	--	--
Ga --------	48	31	25	--	--	--	--	--	--
Ge --------	2.7	(2)	2.3	--	--	--	--	--	--
HCO$_3$ ------	--	--	--	--	--	--	1,500	--	--
Hg --------	(.2)	.20	.079	(.05)	.066	--	--	(.01)	--
K, % ------	5.9	3.1	2.3	(2)	(2)	--	.0012	--	.53
La --------	82	42	57	--	--	--	--	--	--
Li --------	79	45	25	33	39	26	.12	(.2)	.20
Mg, % -----	6.8	(3)	(6)	1.5	(4)	(2)	(.03)	--	--
Mn --------	(3,000)	1,300	(2,000)	(1,000)	(2,000)	--	--	--	--
Mo --------	27	7.8	17	--	--	--	--	(3)	--
Na, % -----	(2)	(2)	(2)	(1)	1.4	(2)	.13	--	--
Nb --------	64	12	12	--	--	--	--	--	--
Ni --------	86	(70)	(80)	30	(40)	--	--	(.6)	--
P, % ------	--	--	--	--	--	--	--	--	.41
Pb --------	35	23	22	--	30	--	--	(.1)	--
Ra --------	--	--	--	--	--	--	2.6[3]	--	--
Rb --------	300	170	96	(100)	(100)	91	--	--	--

APPENDIX II (continued)

Probable upper limits of concentration to be expected in ordinary landscape materials of the Northern Great Plains

Property	Landscape Material[1]								
	Rock			Soil		Sediment	Ground water	Wheat[2]	
	Shale		Sandstone						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
SO_4, % -----	(.8)[4]	(.3)[4]	(.5)[4]	--	--	--	(.2)	--	--
Sc ---------	22	(20)	(20)	--	--	--	--	--	--
Se ---------	--	.36	.30	--	--	--	--	(2)	--
Si, % ------	(30)	32	--	(40)	(40)	--	.0031[5]	--	.023
Ag ---------	.86	--	.84	--	--	--	--	--	--
Sr ---------	450	--	(400)	(300)	(400)	--	(2.3)	--	--
Th ---------	(20)	(20)	12	(10)	--	(10)	--	--	--
Sn ---------	2.8	2.8	2.3	--	--	--	--	--	--
Ti, % ------	.55	(.5)	.43	1.2	1.6	--	--	--	--
U ----------	7.9	5.7	4.7	(4)	(5)	(6)	(.05)	--	.0071
V ----------	180	(200)	98	--	(100)	--	--	(.02)	--
Yb ---------	7.0	(4)	6.1	--	--	--	--	--	--
Y ----------	41	(30)	39	--	--	--	--	--	--
Zn ---------	220	180	90	(100)	87	95	(.9)	(50)	58
Zr ---------	570	(300)	580	--	--	--	--	--	--
Rad[6] ------	(100)	(80)	(70)	(50)	--	--	--	--	--
In water only									
Alkalinity							(1,000)		
Dissolved solids (180°C)							3,000		
Hardness (Total as $CaCO_3$)							(2,000)		
Temperature, °C							14		
pH (standard units)							8.9		
Gross β							15[3]		
Specific conductance, micromhos/cm							(4,000)		
Sodium absorption ratio							(100)		

Probable upper limits of concentration to be expected in ordinary landscape materials of the Northern Great Plains

1/ Identification of landscape materials and sources of data (references at end of footnotes).
  (1) Fort Union formation, outcrop (USGS, 1977, table 60, fig. 28).
  (2) Fort Union formation, core (USGS, 1977, table 55).
  (3) Fort Union formation, outcrop (USGS, 1977, table 61, figs. 29-33).
  (4) "A-horizon", <2 mm fraction (USGS, 1976, table 9, figs. 15-27).
  (5) "B-horizon", <2 mm fraction (USGS, 1976, table 9, figs. 15-27).
  (6) <150μ fraction (USGS, 1977, table 18).
  (7) From domestic or livestock wells, average depth 30 m (USGS, 1976, table 13).
  (8) Grains of *Triticum aestivum* and *T. durum* (Shacklette and others, 1976).
  (9) Grains of *Triticum aestivum* L. (USGS, 1977, table 59).

2/ Determined on dry weight.

3/ Radioactivity in picocuries per liter.

4/ Total S.

5/ As SiO_2.

6/ Radioactivity in picocuries/gram. Computed as 4.81(ppm U)+1.1(ppm Th)+8.5(%K). From John Rosholt (U.S. Geological Survey, written commun., 1976).

References:

Shacklette, H. T., Erdman, J. A., Harms, T. F., and Papp, C. S. E., 1976. Trace elements in plant foodstuffs *in* Oehme, F. W., ed., Toxicity of Heavy Metals in the Environment: Marcel Dekker, New York (in press).

USGS, 1976, Geochemical Survey of the Western Energy Regions (formerly Geochemical Survey of the Western Coal Regions), Third Annual Progress Report, July, 1976: U.S. Geol. Survey Open-file Report 76-729, 138 p.

USGS, 1977, Geochemical Survey of the Western Energy Regions, Fourth Annual Progress Report, July, 1977: U.S. Geol. Survey Open-file Report 77-872, 208 p.

APPENDIX III

Probable upper limits of concentration to be expected in ordinary landscape materials of the Oil Shale Region

[The limits are estimated as those above which only about one sample in 20 of a randomly collected suite is expected to fall due to natural causes alone. Values expressed as parts per million except as indicated. Limits given to two significant figures except those in parentheses, which are given to only one significant figure because they are judged to be less stable. Leaders (--) indicate data insufficient to estimate limit]

Property	Landscape material[1/]				
	Soil		Sediments		Sagebrush ash, Green River Basin
	Piceance Creek Basin (1)	Piceance Creek and Uinta Basins (2)	(3)	(4)	(5)
Al, % ------	7.0	12	--	(8.0)	4.7
As ---------	19	18	20	--	.64[2/]
B ----------	(100)	--	(70)	(65)	(260)
Ba ---------	2,200	--	(1,000)	1,300	670
Be ---------	(4)	3.3	5.9	--	--
C (total), %	6.9	6.7	(6)	--	--
Ca, % ------	(9)	--	(10)	9.2	13
Cd ---------	--	--	--	--	6.7
Co ---------	15	--	(10)	14	4.6
Cr ---------	(100)	--	130	180	34
Cu ---------	(60)	59	33	27	160
F ----------	830	1,300	30	--	33[2/]
Fe, % ------	(3)	--	(4)	3.5	1.4
Ga ---------	(40)	--	(30)	(23)	--
Ge ---------	2.1	1.5	--	--	--
Hg ---------	.17	--	--	--	.034[2/]
K, % -------	3.2	--	(3)	3.6	36
La ---------	--	--	--	--	--
Li ---------	(70)	90	(60)	--	27
Mg, % ------	(2)	3.4	(2)	1.9	(2)
Mn ---------	650	--	(500)	400	750
Mo ---------	14	9.7	--	--	14
Na, % ------	3.2	--	(4)	(3)	.54

APPENDIX III -- Continued

Probable upper limits of concentration to be expected in ordinary landscape materials of the Oil Shale Region

Property	Landscape material[1]				
	Soil				
	Piceance Creek Basin (1)	Piceance Creek and Uinta Basins (2)	Sediments (3)	(4)	Sagebrush ash, Green River Basin (5)
Nb --------	12	--	(18)	--	--
Ni --------	48	--	100	(24)	21
P, % ------	--	--	.10	--	4.8
Pb --------	59	23	(20)	26	73
Rb --------	160	--	--	--	--
S (total) %	--	--	--	--	.21[2]
Sb --------	1.7	--	--	--	--
Sc --------	12	--	(20)	13	--
Se --------	.59	--	--	--	--
Sn --------	3.0	--	--	--	.072[2]
Si, % -----	(30)	--	--	--	19
Sr --------	510	--	(700)	560	770
Th --------	--	15	--	--	--
Ti, % -----	(.4)	--	.049	.42	.17
U ---------	--	4.8	--	--	1.5
V ---------	100	--	(100)	110	64
Y ---------	(20)	--	(40)	30	--
Yb --------	(6)	--	(4)	2.9	--
Zn --------	(100)	--	660	--	560
Zr --------	410	--	(400)	390	130
Rad[3] ------	(70)	--	--	--	--

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[1] Identification of landscape materials and sources of data (references at end of footnotes):
(1) Bulk surface soil (U.S. Geol. Survey, 1976, tables 15, 16).
(2) <2 mm alluvial soil, 0-40 cm depth (U.S. Geol. Survey, 1977, tables 9,10).
(3) <150μ fraction (U.S. Geol. Survey, 1976, tables 18, 19).
(4) <150μ fraction (U.S. Geol. Survey, 1976, table 20).
(5) Unwashed *Artemisia tridentata* (U.S. Geol. Survey, 1976, table 7).

[2] Determined on dry weight.

[3] Radioactivity in picocuries/gram. Computed as 4.81(ppm U)+1.1(ppm Th)+8.5(% K). From John Rosholt (U.S. Geol. Survey, written commun., 1976).

References:

USGS, 1976, Geochemical Survey of the Western Energy Regions (formerly Geochemical Survey of the Western Coal Regions), Third Annual Progress Report, July, 1976: U.S. Geol. Survey Open-file Report 76-729, 138 p.

_____1977, Geochemical Survey of the Western Energy Regions, Fourth Annual Progress Report, July, 1977: U.S. Geol. Survey Open-file Report 77-872, 208 p.

APPENDIX IV

Probable upper limits of concentration to be expected in some ordinary landscape materials of the Bighorn and Wind River Basins.

[The limits are estimated as those above which only about one sample in 20 of a randomly selected suite is expected to fall due to natural causes alone. Values expressed as parts per million except as indicated. Limits given to two significant figures except those in parentheses, which are given to only one significant figure because they are judged to be less stable. Leaders (--) indicate insufficient data to estimate limit]

Property	Bighorn Basin Soil[1/]	Wind River Basin Soil[2/]
Al, %	6.2	(6)
As	--	8.9
B	76	45
Be	1.3	3.1
C (total), %	3.5	1.8
Ca, %	7.8	6.5
Co	9.6	10
Cr	120	(80)
Cu	41	30
Fe, %	3.0	2.5
Ga	19	22
Hg	.039	.032
K, %	2.0	(2)
La	44	--
Li	27	29
Mg, %	1.5	1.3
Mn	660	(500)
Mo	8.1	(8)
Na, %	1.1	1.9
Ni	36	(30)
Pb	12	--
Rb	72	--
Sc	12	9.1
Sr	390	580
Th	12	21
Ti, %	.36	.30
U	3.9	(3)
V	110	(70)
Y	28	--
Yb	4.2	--
Zn	(90)	66
Zr	420	--
Rad[3/]	(50)	(50)

1/ 0-40 cm depth (USGS, 1977, tables 50, 52).

2/ 0-40 cm depth (USGS, 1977, tables 51, 53).

3/ Radioactivity in picocuries/gram. Computed as 4.81(ppm U)+1.1(ppm Th)+8.5(%K). From John Rosholt (U.S. Geol. Survey, written commun., 1976).

References:

USGS, 1977, Geochemical Survey of the Western Energy Regions, Fourth Annual Progress Report, July, 1977: U.S. Geol. Survey Open-file Report 77-872, 208 p.

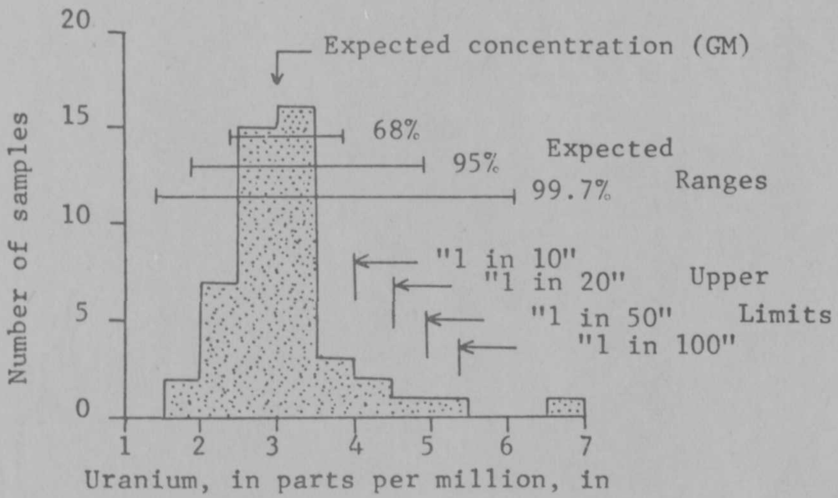
(Continued from inside front cover)

The GE, if available, can be used to correct for laboratory error hidden in GD. Where possible, GD prior to undertaking any of the above calculations should be replaced by GD_n, computed as follows:

$$GD_n = \text{Antilog} \sqrt{(\text{Log GD})^2 - (\text{Log GE})^2} \qquad (2)$$

Although the use of logarithms and square roots may be bothersome, reasonably-priced hand calculators are available for solution of such functions.

The following example will help clarify the ideas expressed above. Forty-eight samples of about 200 grams each collected from the top 2.5 centimetres of soil in the Powder River Basin of Wyoming and Montana were analyzed for uranium. The frequency distribution of these samples is given below. The asymmetry of the distribution suggests that the properties of the distribution should be summarized on a logarithmic basis. The expected value (GM) is computed as 3.0 parts per million (ppm). The GD for this study is 1.28 and the GE is 1.04. The correction of GD (equation 2) gives a GD_n of 1.276. Based on this value, the 68 percent range (to two significant figures) is estimated as 2.4 to 3.8 ppm uranium, the 95 percent range is estimated as 1.8 to 4.9 ppm and the 99.7 percent range as 1.4 to 6.2 ppm. The limit above which one sample in 10 of a random selection is expected to fall (equation 1) is 4.1 ppm, the limit for "1 in 20" is 4.5, for "1 in 50" it is 4.9, and "1 in 100" is 5.3 ppm. Conceivably, any of these upper limits may be acceptable as an upper level of uranium for "ordinary" surface soil in the basin depending on the reason for the study and the reasonings of the investigator.



Uranium, in parts per million, in

Surface soil, Powder River Basin