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Baseline elemental-composition of selected plants and soils, and assessment of airborne element contamination, Theodore Roosevelt National Park, North Dakota

by

L. P. Gough, J. L. Peard, R. C. Severson, L. L. Jackson,
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CONTENTS

APPENDICES

ILLUSTRATIONS

TABLES

BASELINE ELEMENTAL-COMPOSITION OF SELECTED PLANTS AND SOILS, AND ASSESSMENT OF AIRBORNE ELEMENT CONTAMINATION, THEODORE ROOSEVELT NATIONAL PARK, NORTH DAKOTA

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SUMMARY

In July 1983 the U.S. Geological Survey and U.S. National Park Service signed an interagency agreement which facilitates joint investigations of the relative effects of known contamination sources on the sulfur and trace metal contents of plants and soils in selected national park units. Study designs and specific objectives differ from one park region to another and include: (1) the use of lichens (or other epiphytes) or selected vascular plant species as biomonitors of possible phytotoxic effects; and (2) the establishment of baseline biogeochemical and geochemical levels so that the magnitude of chemical changes with time can be monitored. This report presents results of FY-83 studies in and near Theodore Roosevelt National Park, North Dakota. The following is a summary of the results of those studies:

1. A procedure for the cleaning of the epiphytic lichen Parmelia sulcata was developed based on an analysis of the amount of sulfur lost from the thalli with increasing wash intensity. The overall decrease in sulfur content was about 0.01 percent (absolute) from the least intense (treatment 1) to the most intense (treatment 3) wash procedure. Treatments 1 and 2 and treatments 2 and 3 were not found to differ significantly ($p = 0.05$) in their sulfur content. Treatment 2 was chosen for all subsequent studies involving lichens. This procedure follows: (1) all thalli were floated in tap water and picked clean of miscellaneous plant material; (2) the thalli (about 50 g) were then placed in a 2-l beaker, covered with distilled water, and stirred for about 15 sec.; and (3) distilled water was discarded and the procedure was repeated another seven times (eight total).

2. Based on studies with lichens and other plant materials, Jackson, Engleman, and Peard (1985) give a combustion-infrared (IR) photometric procedure for the routine analysis of total sulfur. The combustion-IR method usually gave slightly higher sulfur concentrations than a turbidimetric method but resulted in greater laboratory efficiency. A relative standard deviation of about 7 percent was obtained by combustion-IR when total sulfur levels ranged from 0.05-0.20 percent (in lichens). Determination of sulfur in National Bureau of Standards orchard leaf reference material showed good agreement between the combustion-IR technique and other instrumental procedures.

3. Samples of green ash leaves, western wheatgrass leaves and culms, big sagebrush stems and leaves, Parmelia sulcata, and soils were collected to estimate the areal biogeochemical and geochemical variability. (Parmelia chlorochroa, a lichen that grows on soils, was also sampled but not according to the analysis-of-variance design used for the species listed above). Element concentration baselines for plant species collected within TRNP include some or all of the following elements: aluminum, arsenic, barium, boron, calcium, copper, iron, magnesium, manganese, mercury, nickel, phosphorus, strontium, sulfur, titanium, vanadium, and zinc. Baseline values

for soils associated with samples of either green ash, western wheatgrass, or big sagebrush include some or all of the following: aluminum, barium, beryllium calcium, cesium, chromium, copper, iron, magnesium, manganese, mercury, nickel, niobium, phosphorus, strontium, sulfur, titanium, vanadium, yttrium, and zinc.

The results of these studies show that very little (usually <10 percent) of the variability in the biogeochemical and geochemical data occurs on a regional scale; thus materials are chemically similar in both the north and south units of TRNP. In contrast, a relatively great proportion of the variability in these data (usually >40 percent) occurs between sampling sites separated <7.2 km; thus, in order to map the chemistry of the park units, numerous samples collected at close intervals (or composites of many samples representing a small area) would be required. In addition, because the concentrations of most elements in the materials sampled at random locations were fairly uniform (not a great deal of scatter in the data), extensive sampling was not necessary in order to establish the baselines presented.

These biogeochemical data should be useful in future studies when the chemistry of new samples, collected, prepared, and analyzed in the same manner as in this study, are compared to the baselines reported here.

4. Based upon an examination of literature summaries of toxicity thresholds for trace elements and sulfur (see, for example, Sauchelli, 1969; Underwood, 1971; Gough, Shacklette, and Case, 1979; and Kabata-Pendias and Pendias, 1984), we found no instances of phytotoxic or zootoxic conditions in the park. This assumption is based upon total-element concentration levels in the materials sampled. We did, however, find unusually high levels of zinc in Parmelia sulcata--levels that are considered to be above suspected toxicity thresholds for other species of epiphytic lichens.

5. Parmelia sulcata was found to have higher concentrations of most elements when compared to the vascular plant species or to Parmelia chlorochroa. We recommend that P. sulcata be used in TRNP, in preference to P. chlorochroa, or the other species studied, for use as an air-quality biomonitor because: (1) it is commonly found in the coulee habitat; (2) it had a greater number of concentration values above the lower limit of determination of the analytical methods used (than did the other species); and (3) element concentrations of P. sulcata were generally greater than concentrations in the other plant species by factors of two or more.

6. Of the element concentration values determined in three plant species (western wheatgrass, Parmelia chlorochroa, and little clubmoss) and soils collected downwind of a natural-gas processing facility, only sulfur in P. chlorochora, boron in little clubmoss, and sulfur in soil showed important inverse relations between element concentration and increasing distance away from the facility. Sulfur emissions from this natural-gas processing facility affect sulfur and boron levels in lichen and clubmoss material, respectively, up to about 4 km from the source. At distances between 0.1 and about 2.0 km there appears to be some additional influence of the facility on trace metal levels in plants (particularly copper in P. chlorochroa, manganese in wheatgrass, and zinc in clubmoss). We conclude, however, that the individual influence of these facilities on the regional air quality is minimal; their cumulative influence has yet to be determined quantitatively.

7. The following is a list of suggested new research based on the results of this report: (1) A wash study, similar to the one for sulfur in this report, designed to investigate metal retention (or, conversely, metal loss) by lichen thalli. (2) Changes in the biogeochemistry and geochemistry of the area can be assessed in the future by resampling the same materials.

Although the barbell design need not be repeated, the methods used to collect, process, and analyze that material must be the same as those used in this study. The concentration of an element in the new samples can then be compared to the baseline values in this report. The number of samples collected is not critical because the comparison will be between each individual new sample and the computed baseline value. If, however, the monitoring of chemical changes for a specific area in the park is desired, then a biogeochemical or geochemical map has to be prepared which would require a new program of extensive sampling because of the great amount of chemical variability found at the local level. (3) If the identification of sulfur sources is desired then dry deposition traps could be used to distinguish mineral forms of sulfur from biological forms. The analysis of stable sulfur isotopes in air, plant, and soil samples would help segregate anthropogenic from natural sources. (4) The traverse study could be repeated in the future and the regression trends compared. The new study should be identical to the old with resampling performed at the same sites (where contamination sources are investigated, then at least one additional traverse (upwind) should be included. Such a traverse would provide very valuable contrasting information. (5) Additional studies designed to identify the cause of the elevated zinc concentrations in some samples of Parmelia sulcata might be desired. (6) If, in the future, sulfur contamination of the park is proven, then greenhouse fumigation studies of selected susceptible plant species with SO_2 would be desirable.

INTRODUCTION

The purpose of this report is to summarize the results of element-concentration studies of plant and soil materials collected in and near Theodore Roosevelt National Park (TRNP), North Dakota (fig. 1). The investigations were divided into three tasks: Study 1--the comparison of preparation techniques for lichen samples and the development of a routine analytical method for the determination of sulfur in plant material; Study 2--the definition of element concentration baselines for selected plants and soils within TRNP; and Study 3--the assessment of the potenital influence of emissions from a natural-gas processing facility near TRNP on element levels of selected plants and soils.

TRNP is approximately 200 km west of Bismarck, North Dakota. The park is divided into three units: north, south, and Elkhorn. The north and south units are separated by about 70 km; the Elkhorn unit is an area of only about 218 acres between the north and south units. Collectively, the park is nearly 280 km^2; the south unit is almost twice as large as the north unit. These three U.S. Department of Interior administrative units are surrounded by the Little Missouri River National Grasslands and by a substantial amount of private land (not shown) (fig. 1).

TRNP is in the North Dakota badlands of the Missouri Plateau. During Pleistocene glaciation, the outlet of the Little Missouri River was diverted from the Yellowstone River to the Missouri River; the resulting erosion produced a highly dissected landscape which includes river valleys, badlands with steep slopes, coulees (draws between hills and buttes), and relatively level buttes adjacent to the river valleys. Surrounding the badlands are the moderately rolling prairies of the Great Plains.

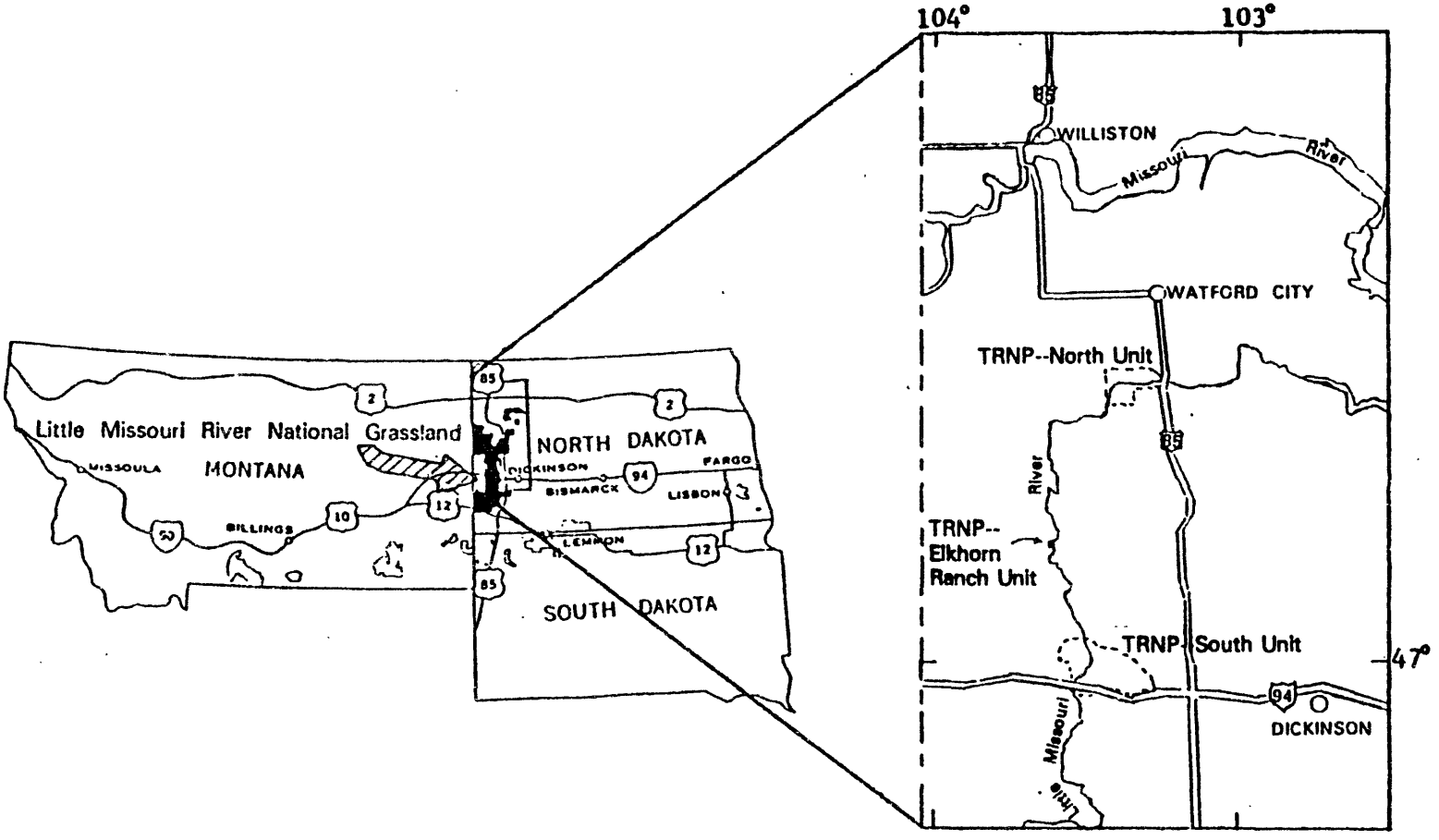

Figure 1.--Location of the north and south units of Theodore Roosevelt National Park (TRNP), North Dakota. Dark shaded region on small-scale map shows general area of the Little Missouri River National Grassland (modified from U.S. Department of Agriculture, 1974).

The climate is continental and semiarid, with annual precipitation averaging about 35 cm. Most moisture falls during spring and summer, with June being the wettest month. In general, cold winters and hot summers, with large daily fluctuations in temperature, are typical. The average maximum daytime temperature during July and August is about 30°C, with extremes over 38°C being common (National Park Service, 1983).

A national policy directed toward greater energy independence presents challenges not only in the evaluation of the distribution and reserves of an energy resource but also in the consequences of the utilization of such a resource. TRNP lies within the energy-rich Fort Union coal region and is surrounded by increased activities that are related to coal, oil, and natural-gas extraction, refinement, transportation, and combustion (Uman, 1982). Of particular concern to the National Park Service is the potential adverse effect on the air quality of TRNP by these activities. In addition, the introduction into the park of higher than normal sulfur concentrations (predominantly SO_2) and trace metals might adversely affect plant health. These constituents, including sulfur and trace metals, are known to be emitted from sources such as lignite-burning power generating stations and the natural-gas flares that characterize oil and gas wells and refining facilities. The Class I quality of the park is protected by the Clean Air Act against significant deterioration.

Co-authors S. W. Snow and J. P. Bennett, naturalist and ecologist, respectively, are with the National Park Service; the other co-authors are botanists, soil scientists, and chemists with the U.S. Geological Survey.

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METHODS OF INVESTIGATION

Study 1--Cleaning of Lichen Thalli

The details of this study and our results are published elsewhere and will not be repeated here (Jackson, Engleman, and Peard, 1985). Thalli of the epiphytic ("air plant") lichen Parmelia sulcata Tayl. were used in this experiment and were collected in May of 1983 from a 1-km^2 area approximately 15 km southwest of the north unit in Dunn County (fig. 2). This material was considered uniform, by gross morphological comparison, and was collected from trunks, stumps, and downed logs of Juniperus scopulorum Sarg. (Rocky Mountain juniper).

Study 2--Baseline Biogeochemical and Geochemical Determinations

Three vascular plant species, and their associated soils, and two lichen species were collected from specific physiographic areas of the park: Artemisia tridentata Nutt. (big sagebrush)--from microbenches (old river terraces or slump-block ledges); Agropyron smithii Rydb. (western wheatgrass)--from river flats, microbenches, and prairie uplands; Fraxinus

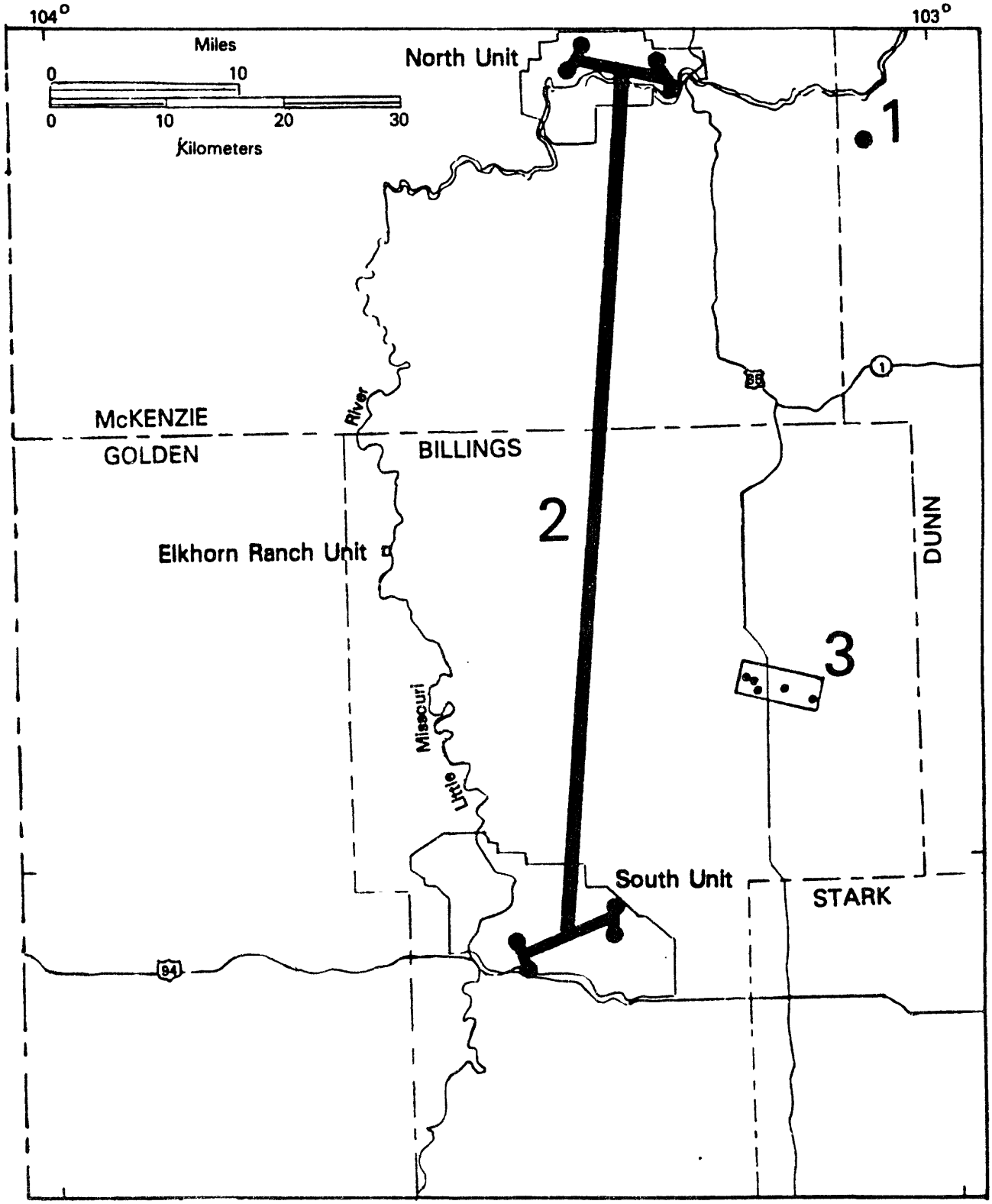

Figure 2.--Location of three biogeochemical studies: (1) Site of Parmelia sulcata samples used in wash treatment comparisons; (2) general position of barbell sampling design used in the definition of element baselines within the north and south units of TRNP; and (3) areas used for the positioning of a traverse in the assessment of element contamination from a natural-gas processing facility.

pennsylvanica Marsh. (green ash) and Parmelia sulcata--from coulees; and, Parmelia chlorochroa Tuck.--from microbenches and prairie uplands. Each of these physiographic areas are described below. Information on individual sampling sites is given in Appendix I. Additional descriptions of the habitat types in and around the Park can be found in Hansen and others, 1980; Wali and others, 1980; and Whitman, 1979.

The microbenches are found along the flanks and bases of the buttes adjacent to the river valley. Sampling sites were located on gentle slopes (0-10°) and at elevations of 610-820 m. Western wheatgrass and big sagebrush were collected in areas with a fairly dense covering of grass (dominated by western wheatgrass and Stipa sp.) with Artemisia frigida Willd., Carex sp., Ceratoides lanata (Pursh) J.T. Howell, and Agropyron trachycaulum (Link) Malte as common associates. Big sagebrush varied from locally abundant to absent. Parmelia chlorochroa was collected from patches of eroded ground, where the soil was bare or only sparsely covered with grasses. P. chlorochroa was found infrequently and then often only in very small amounts.

The dominant vegetation of the floodplains and slightly elevated river was Populus deltoides Marsh (cottonwood) and Artemisia cana Pursh. (silver sagebrush). Western wheatgrass was collected around the margins of these wooded areas and shrublands, at an elevation of 600-610 m. The ground was level, and individual culms were sparsely scattered over bare silt-flats. Melilotus officinalis (L.) Lam. (yellow sweetclover) was abundant.

The prairie uplands begin at the tops of the river buttes and extend to the surrounding prairies of the Great Plains. Western wheatgrass and Parmelia chlorochroa were collected on gently rolling terrain (slope <5°), at elevations of 710-840 m. Western wheatgrass often formed a dense sod. Some stands were almost pure wheatgrass; others had Stipa sp. and Carex sp. as common associates. As on the microbenches, P. chlorochroa occurred infrequently and was collected on bare soil.

The coulees are often wooded especially the more mesic, north-facing ones where most of our sampling sites were located (Appendix I). The slopes were steep (30-50°); however, most of our sites were on small, nearly level erosional terraces within the coulees (usually 0-10°). The vegetation of the coulees varies from pure stands of Rocky Mountain juniper at lower elevations to pure stands of green ash at higher elevations. Our sample sites were located at intermediate levels in order to find mixed stands of juniper and ash. This enabled us to sample both green ash and Parmelia sulcata (an epiphyte typically found in large patches on the dead branches and stumps of juniper). In most cases the understory was dense and included Rhus trilobata Nutt. (skunkbrush) and Prunus virginiana L. (chokecherry). In order to minimize the possible effects on thallus chemistry of variations in aspect (slope orientation), canopy throughfall, wind currents, and insolation, P. sulcata samples were taken from the upper, horizontal surfaces of stumps and dead branches. Sample P11111 was an exception and was collected from the vertical side of an upright stump.

Study 3--Point-Source Investigation

The study area was located approximately 20 km northeast of the TRNP south unit in Billings County on native mixed grass prairie with gentle slopes (0-5°) and at elevations of 810-840 m (fig. 2). Most sites were pasture lands that had been recently grazed or mowed for hay; consequently, samples often were taken along fence rows or in small areas that remained uncultivated. Western wheatgrass had begun to cure and typically possessed ripe seeds.

Wheatgrass was abundant, forming a dense sod with a mixture of other grasses. The occurrence of little clubmoss and P. chlorochroa ranged from very sparse to locally abundant.

Sampling was conducted from August 30 to September 3, 1983. During this period precipitation for the south unit was slightly above normal, while temperatures were well above normal (the daily maximum temperature was 5.2°C above average).

Sample Collection, Preparation, and Analysis

The Parmelia sulcata material of Study 1 was broken into uniformly sized pieces (diameters of about 2.5 cm), moistened in tap water, and adhering bark, moss, and other lichen species were removed with forceps. Pieces of thalli were randomly separated into three treatment groups, each to receive progressively more intense washings. Group 1 was set aside and labeled "grossly washed" (treatment 1). Groups 2 and 3 were recombined and washed in distilled water. This combined material (about 50 g) was floated in distilled water in a 2-l beaker and stirred for about 15 sec. Debris settled to the bottom, and the floating lichen layer was removed. This procedure was repeated for a total of eight washings. Thalli were then randomly separated into two groups. Group 2 received no further washing and was labeled "distilled-water washed" (treatment 2). Group 3 was additionally washed with an ultrasonic probe. The group 3 material (about 25 g) was covered with distilled water in a 600-ml beaker, and was treated with an ultrasonic probe and stirred for 15 sec. After debris settled, the floating lichen layer was removed. This was repeated a total of four times. The material was labeled "ultrasonically washed" (treatment 3).

The material of treatments 1, 2, and 3 were dried overnight at 40°C in a forced-air oven, ground in a blender, and then shaken for 10 min. in a ceramic container with a glass bead. Each group contained about 25 g of material, and following thorough homogenization, was separated into 16 analytical splits of about 1.5 g each. Each split was analyzed for total sulfur by combustion-infrared photometry (Jackson, Engleman, and Peard, 1985).

For Study 2 western wheatgrass, big sagebrush, and green ash (and their associated soils), and Parmelia sulcata were sampled within the north and south units of the park between July 8-24, 1983. Precipitation patterns were near normal; however, the mean maximum temperatures for late June and early July were about 3°C above average.

The areal chemical variation in plants and soils was estimated using a five-level, unbalanced, nested analysis-of-variance (ANOV) design (see, for example, Erdman and Gough, 1977). Sampling sites for each plant type were randomly located using a barbell sampling plan (Tidball and Ebens, 1976), with a major axis of 72 km (level 1), and progressively smaller axes of 7.2 (level 2), 0.72 (level 3), and 0.10 km (level 4). The fifth level measured the chemical variability between aliquots (splits) of individual samples. The five levels in the ANOV design were used as sample identifiers (Appendixes I, II, and III).

The major barbell axis (level 1) was situated so that the end points were randomly located in both the north and south units of the park (fig. 2). The smaller axes (levels 2, 3, and 4) were oriented by randomly selecting compass directions until the endpoints fell within the physiographic area where the desired plant occurred.

Each barbell had 11 end points, or sampling sites--six in the north unit and five in the south unit. For each plant type, three of the 11 samples were randomly selected to be split and analyzed in duplicate. Of the 33 soil samples, nine randomly selected samples were split and analyzed in duplicate. These sample splits of plants and soils represent the analytical-error level of the sampling design.

Parmelia chlorochroa occurs infrequently within the park; therefore it was not sampled randomly. Fourteen "grab" samples were taken, seven in each park unit.

Each plant material sample of Study 2 consisted of a composite of numerous individuals collected at each site. Western wheatgrass samples consisted of all material 5 cm above ground level that was collected within a 5x5-m area. The stage of maturity for wheatgrass ranged from pre-bloom to full-bloom. Big sagebrush samples consisted of the terminal 20 cm of the shoots from one bush. The samples generally represented the current year's growth, and in most instances, flower buds were abundant. Green ash samples consisted of healthy leaves and petioles collected from as many branches as possible around the perimeter of one tree. Lichen material was collected from within a 5x5-m area on juniper bark (Parmelia sulcata) and on soil (P. chlorochroa). At the collections site for each vascular plant, a well homogenized sample of the top 10 cm of soil was taken within 5 m of the plant sample. All collections were placed in paper bags of known element content (soils and lichens) or into canvas bags (vascular plants) and were stored at ambient temperature. Samples were processed in the laboratory within four weeks of collection.

All lichen samples of Study 2 were washed using the distilled water washing technique (treatment 2) detailed above. Western wheatgrass was the only vascular plant that was washed before chemical analysis; this washing was done because of obvious dust contamination. Unlike the lichen material the wheatgrass was given three tap water rinses, followed by one distilled-water rinse. All plant material was oven dried at 40°C for 48 hours. Vascular plant samples were ground in a Wiley mill to pass a 1-mm sieve. Lichen samples were pulverized in a stainless steel blender. Soil samples were dried at ambient temperature and then disaggregated using a ceramic mortar and pestle. The fraction passing a 10-mesh sieve was further ground to pass a 100-mesh sieve.

In Study 3 western wheatgrass and Selaginella densa Rydb. (little clubmoss) and their associated soils, and the lichen Parmelia chlorochroa, were collected along a northwest-to-southeast traverse that began at the Western Gas Processors, Ltd., Teddy Roosevelt Gas processing plant. Seven sampling sites were positioned essentially downwind (predominant wind directions are west and northwest) at approximate geometric intervals (figs. 2 and 3). In general, the sites were located well away from other sources of contamination such as major roadways, gas compressor sites, and drilling rigs. At each site two samples were collected within a distance of from 50-100 m; site-replicate samples provided an assessment of chemical variability over small distances. Wheatgrass, clubmoss, and P. chlorochroa were collected within 5x5-m areas at each site. P. chlorochroa samples were cleaned using the treatment 2 method of Study 1 and wheatgrass using the method of Study 2 (described above). Because of extensive dust contamination, samples of clubmoss were rinsed 15 times in tap water and then five times in distilled water; an ultrasonic probe was used to agitate the material during the distilled-water rinses.

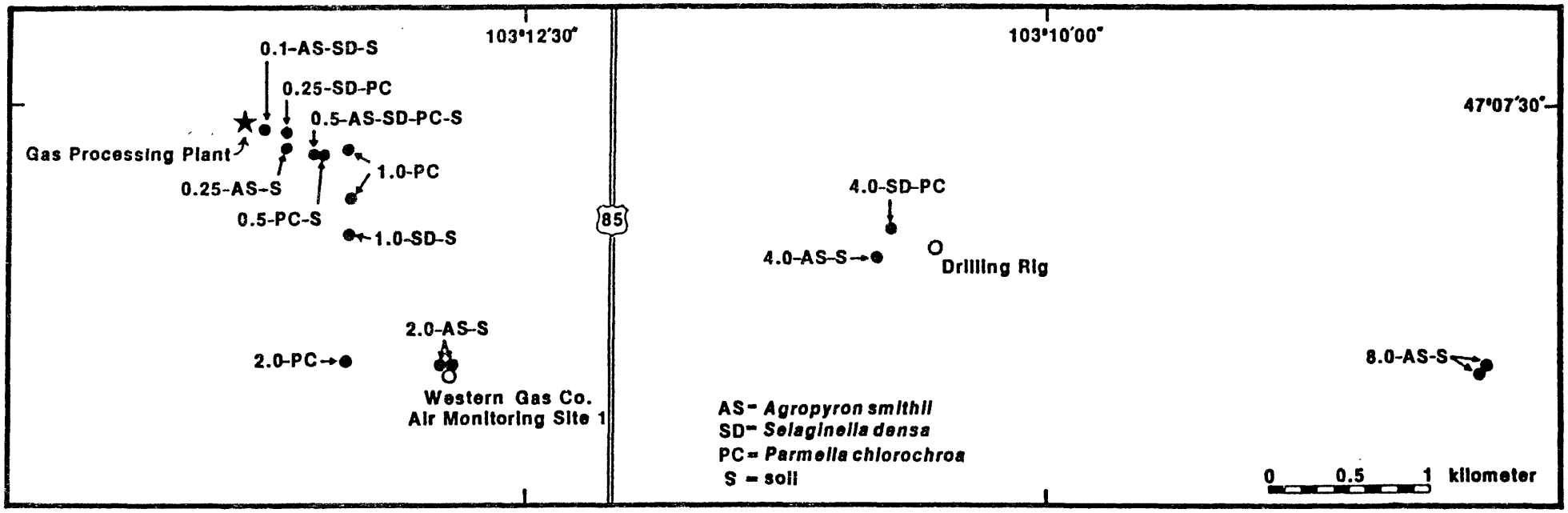

Figure 3.--Location of sampling sites for Agropyron smithii (AS), Selaginella densa (SD), Parmelia chlorochroa (PC), and soil (S) downwind of a natural-gas processing facility, Billings County, North Dakota.

The dry, ground plant material from Studies 1, 2, and 3 was analyzed as follows: arsenic by flame atomic absorption spectrophotometry; mercury by flameless atomic absorption spectrophotometry; sulfur by combustion-infrared photometry; and aluminum, barium, beryllium, boron, calcium, cesium, chromium, copper, iron, lead, magnesium, manganese, nickel, phosphorus, strontium, titanium, vanadium, yttrium, and zinc by inductively coupled plasma optical emission spectroscopy (after an acid digestion). A separate aliquot of ground material was ashed and then reweighed in order to determine percent ash yield. Soils were analyzed as follows: mercury by mercury-vapor absorption detector; sulfur by combustion-infrared photometry; and aluminum, barium, beryllium, calcium, cesium, chromium, copper, iron, lanthanum, lead, magnesium, manganese, nickel, niobium, phosphorus, strontium, titanium, vanadium, yttrium, and zinc by inductively coupled plasma optical emission spectroscopy (after an acid digestion).

RESULTS AND DISCUSSION

Study 1--Cleaning of Lichen Thalli

A detailed description of the results of the lichen thalli cleaning investigation (Study 1), which also includes the development of a new analytical method for the determination of total sulfur by combustion-infrared analysis, is given in Jackson, Engleman, and Peard (1985).

In their study they found a statistically significant difference in the sulfur concentrations in Parmelia sulcata that resulted from the different wash treatments. However, the difference could not be clearly attributed to the removal of extraneous matter or to the leaching of sulfur. Table 1 shows the mean sulfur concentrations in 16 samples after each treatment. An analysis of variance of these data showed statistically significant (p=0.01) differences among the three treatments. Further examination using Duncan's multiple range test (Duncan, 1955) failed to show a difference between the grossly-washed material and the distilled-water washed material. Duncan's test also failed to show a difference between the distilled-water washed material and the ultrasonically-washed material. A significant difference (p=0.05) was found between the least rigorous and the most rigorous washes; that is, between the grossly washed and ultrasonically washed material.

Although the observed decrease in sulfur content with increasing wash intensity may have resulted from the leaching of soluble sulfur, it may also have been caused by the more effective physical removal of particulate matter with washing. An indication of these conclusions was the observed decrease in the ash content (14.9, 11.6, and 9.8 percent) with increasing wash intensity for the grossly-washed, distilled-water washed, and ultrasonically-washed material, respectively. Regardless of the cause, the overall decrease in sulfur of about 0.01% percent (absolute) is not considered important because it is small compared to the natural variability of sulfur concentrations in the lichen material. In order to minimize sample preparation time and yet provide an effective wash, the distilled-water washing procedure was chosen for routine analysis and was applied in subsequent studies.

Table 1.--Statistical summary of sulfur concentrations in 16 samples of *Parmelia sulcata* following three different wash treatments (after Jackson, Engleman, and Peard, 1985).

	Treatment		
	Grossly washed	Distilled-water washed	Ultrasonically washed
Range, percent	0.153 - 0.163	0.136 - 0.169	0.141 - 0.149
Relative standard deviation	2.4	4.8	1.7
Mean[1], percent	0.156	0.150	0.145

[1]Means underscored by the same dashed line are not significantly different (95 percent confidence level) according to the multiple-range test of Duncan (1955).

Study 2--Baseline Biogeochemical and Geochemical Determinations

Interpretations of the ANOV and Summary Statistics--Green ash leaves, big sagebrush stems and leaves, western wheatgrass culms and leaves, Parmelia sulcata, P. chlorochroa, and soils, were sampled using a barbell cluster design detailed above. The purpose of the study was to estimate at what intervals the areal variability in plant and soil chemical element composition occurred. This information was used to determine whether or not regional element patterns in plants and soils were present, and to determine the appropriate way to calculate biogeochemical and geochemical baselines.

Appendices II and III list the element concentrations for the plant and soil samples. Tables 2, 3, 4, and 5 give the results of the ANOV for element concentrations in green ash, wheatgrass, sagebrush, and P. sulcata, respectively, and also include the summary statistics (geometric mean (GM); geometric deviation (GD); observed range; and the expected 95 percent range) for each element. Tables 7, 8, and 9 give the same statistics plus the results of the ANOV for the soil samples that were collected in association with the ash, wheatgrass, and sagebrush collections. Because P. chlorochroa was collected where found, and not according to the barbell cluster design, only the observed ranges and percentiles are reported for this species (Table 6).

The number of samples with detectable concentrations to the total number of samples, for a particular plant material or soil, is given in the "ratio" column. The "total $\log_{10}$ variance" is the sum of the five variance components; the antilog of the square root of this value is the GD for that group of samples (n=13 or 14, Appendices II and III). The rest of the columns under "analysis of variance" contain the variance components as percentages of the total variance. Some of the element concentrations were recorded by the chemist as "less than" the lower limit of determination (LLD) for the analytical method used. A substitution of 0.7 times the LLD was used in the ANOV calculations if fewer than one-third of the values were below the LLD (see, for example chromium, Table 4). If greater than one-third of the values were below the LLD, only the ranges are listed.

The GM and GD of a lognormal distribution are better measures of central tendency and scatter than are the arithmetic mean and standard deviation. The geometric means and observed ranges in Tables 2-5 and Tables 7-9 are based on n=11 (or n=10); this is because three of the original 14 (or 13) samples are analytical splits (Appendices II and III). Where analytical splits were made, a new value equal to the average of the splits was used for the calculation of the GM. The expected 95 percent range is the "baseline", as first proposed by Tidball and Ebens (1976), and is calculated as a concentration range bracketed by the GM/GD^2 to the $GM \times GD^2$.

The proportion of the total $\log_{10}$ variance that is associated with each of the four distance increments, plus the proportion of the variability caused by analytical imprecision, are given for 18 elements plus ash yield in plant materials (Tables 2, 3, 4, and 5) and for 21 elements in soils (Tables 7, 8, and 9). The three ANOV levels of most interest are: (1) between "park units" (regional component, >7.2 km); (2) between "0-0.10 km distance" (local component or variability at a distance of less than 100 m); and (3) the component associated with variability due to analytical imprecision. When the analytical variance exceeded 50 percent of the total variability for an element, a baseline (expected 95% range) was not calculated. A baseline constructed from data with excessive analytical variance reflects predominantly analytical imprecision and not the natural variability in the data.

Table 2.--Variation in and summary statistics for the element concentrations in dry material of Fraxinus pennsylvanica leaves, North and South Units, Theodore Roosevelt National Park, North Dakota.

[Variance analysis based on 14 samples, summary statistics based on 11 samples (14 minus 3 analytical splits); *, component of variance was tested significant at the 0.05 probability level; ratio, proportion of the number of analyses having values above the lower limit of determination to the total number of analyses; leaders (--), no data available]

Element or ash yield	Ratio	Analysis of variance: Total log_{10} variance	Percentage of total variance between: Park units	.72-7.2 km distance	.10-.72 km distance	0-.10 km distance	Analyses	Summary statistics (n=11): Geometric mean (ppm)	Geometric deviation[1]	Observed range (ppm)	Expected 95 percent range (baseline, ppm)[2]
Ash, %	14:14	0.0050	24	13	<1	63	<1	5.8	1.18	4.5 - 6.8	4.2 - 8.1
Aluminum	14:14	.0090	<1	<1	80*	16	4.0	59	1.24	4 - 99	38 - 91
Arsenic	1:14	--	--	---	--	--	--	--	--	<.05 - .10	-- - --
Barium	14:14	.0194	<1	27	<1	72*	<1	41	1.38	30 - 55	22 - 78
Boron	14:14	.0130	56*	<1	<1	42*	1.3	4.2	1.30	3.0 - 5.6	2.5 - 7.5
Calcium	14:14	.0054	7.0	35	<1	56*	1.8	7400	1.18	5400 -8800	5300 -10000
Chromium	8:14	--	--	--	--	--	--	--	--	<4 - 6.5	-- - --
Copper	14:14	.1121	37	<1	59*	3.7	<1	11	2.16	6.2 - 42	2.4 - 51
Iron	14:14	.0744	<1	<1	20	74*	6.0	85	1.87	37 - 360	24 - 300
Magnesium	14:14	.0109	<1	21	38	40*	1.1	2000	1.27	1400 -3300	1200 - 3200
Manganese	14:14	.0289	16	9.0	<1	73*	1.2	25	1.48	16 - 38	11 - 55
Mercury	14:14	.0352	5.5	<1	87*	4.4	3.0	.027	1.54	.015- .07	.011- .064
Phosphorus	14:14	.0075	5.1	<1	76*	15	3.8	1400	1.22	1000 -1800	940 - 2100
Strontium	14:14	.0473	15	<1	33	51*	<1	50	1.65	24 - 100	18 - 140
Sulfur	14:14	.0084	16	<1	47	36*	1.3	2200	1.23	1800 -3000	1500 - 3300
Titanium	1:14	--	--	--	--	--	--	--	--	<.8 - .85	-- - --
Vanadium	0:14	--	--	--	--	--	--	--	--	--- - <.6	-- - --
Yttrium	0:14	--	--	--	--	--	--	--	--	-- - <.16	-- - --
Zinc	14:14	.0164	1	1	74	24*	1.5	25	1.34	18 - 38	14 - 45

[1]The geometric deviation is equal to the antilogarithm of the square root of the total log_{10} variance where n=14.

[2]Because of a significant regional variance component (between park units), baseline ranges for B are biased if applied to specific areas.

Table 3.--Variation in and summary statistics for the element concentrations in dry material of Agropyron smithii culms and leaves, North and South Units, Theodore Roosevelt National Park, North Dakota.

[Variance analysis based on 14 samples, summary statistics based on 11 samples (14 minus 3 analytical splits); *, component of variance was tested significant at the 0.05 probability level; ratio, proportion of the number of analyses having values above the lower limit of determination to the total number of analyses; leaders (--), no data available]

Element or ash yield	Ratio	Analysis of variance: Total log_{10} variance	Percentage of total variance between: Park units	.72-7.2 km distance	.10-.72 km distance	0-.10 km distance	Analyses	Summary statistics (n=11): Geometric mean (ppm)	Geometric deviation[1]	Observed range (ppm)	Expected 95 percent range (baseline, ppm)[2]
Ash, %	14:14	0.0113	<1	73*	22*	4.2	<1	6.9	1.28	5.2 - 9.5	4.2 - 11
Aluminum	14:14	.0905	2.3	<1	29*	<1	68	50	2.00	36 - 81	-- - --
Arsenic	4:14	--	--	--	--	--	--	--	--	<.05 - .05	-- - --
Barium	14:14	.0556	30	<1	54	13	3.0	23	1.72	12 - 37	7.8 - 68
Boron	14:14	.0357	42	<1	15	<1	43	1.4	1.55	.83 - 2.1	.58 - 3.4
Calcium	14:14	.0203	<1	15	20	<1	65	2000	1.39	1500 - 2900	-- - --
Chromium	9:14	--	--	--	--	--	--	--	--	<4.0 - 5.0	-- - --
Copper	14:14	.0334	28	<1	<1	68*	2.6	4.4	1.52	3.3 - 8.6	1.9 - 10
Iron	14:14	.1322	9.3	<1	32	<1	58	80	2.31	47 - 160	-- - --
Magnesium	14:14	.0086	<1	<1	15	59	26	720	1.24	580 - 930	470 - 1100
Manganese	14:14	.0603	<1	<1	49	49*	2.0	29	1.76	15 - 49	9.4 - 90
Mercury	14:14	.0173	<1	<1	4.2	48	48	.019	1.35	.012- .025	.011- .035
Phosphorus	14:14	.0215	<1	<1	86*	<1	14	1400	1.40	950 -2200	710 - 2700
Strontium	14:14	.0900	41	<1	52	4.5	2.7	13	2.00	6.6 - 32	3.2 - 52
Sulfur	14:14	.0249	21	<1	61	12	6.0	1900	1.44	1600 -3900	920 - 3900
Titanium	3:14	--	--	--	--	--	--	--	--	<.8 - 1.3	-- - --
Vanadium	0:14	--	--	--	--	--	--	--	--	-- - <.6	-- - --
Yttrium	0:14	--	--	--	--	--	--	--	--	-- - <.16	-- - --
Zinc	14:14	.0162	<1	<1	31*	<1	69	38	1.34	22 - 86	-- - --

[1]The geometric deviation is equal to the antilogarithm of the square root of the total log_{10} variance where n=14.

[2]Because of excessive analytical error (>50 percent), baselines for Al, Ca, Hg, and Zn were not calculated.

Table 4.--Variation in and summary statistics for the element concentrations in dry material of Artemisia tridentata stems and leaves, North and South Units, Theodore Roosevelt National Park, North Dakota.

[Variance analysis based on 14 samples, summary statistics based on 11 samples (14 minus 3 analytical splits); *, component of variance was tested significant at the 0.05 probability level; ratio, proportion of the number of analyses having values above the lower limit of determination to the total number of analyses; leaders (--), no data available]

Element or ash yield	Ratio	Analysis of variance: Total log_{10} variance	Percentage of total variance between: Park units	.72-7.2km distance	.10-.72 km distance	0-.10 km distance	Analyses	Summary statistics (n=11): Geometric mean (ppm)	Geometric deviation[1]	Observed range (ppm)	Expected 95 percent range (baseline, ppm)[2]
Ash, %	14:14	0.0088	<1	1.9	10	<1	88	5.7	1.24	5.0 - 6.8	3.7 - 8.8
Aluminum	14:14	.0389	4.1	<1	46	40	9.4	78	1.57	50 - 170	32 - 190
Arsenic	6:14	--	--	--	--	--	--	--	--	<.05 - .05	-- - --
Barium	14:14	.0893	<1	34	33	32*	<1	8.7	1.99	2.0 - 22	2.2 - 34
Boron	14:14	.0201	<1	10	<1	75	15	5.2	1.39	3.8 - 7.3	2.7 - 10
Calcium	14:14	.0092	<1	<1	58	22	19	3800	1.25	2900 - 4800	2400 - 5900
Chromium	13:14	.0252	13	<1	33	<1	54	5.1	1.44	<4.0 - 7.3	-- - --
Copper	14:14	.0163	<1	14	71*	<1	15	12	1.34	7.3 - 17	6.7 - 22
Iron	14:14	.1859	<1	<1	35	<1	65	150	2.70	78 - 475	-- - --
Magnesium	14:14	.0193	21	<1	<1	76	2.8	1100	1.38	660 - 1600	580 - 2100
Manganese	14:14	.0544	<1	25	<1	74	<1	27	1.71	14 - 54	9.2 - 79
Mercury	14:14	.0559	16	15	<1	56	12	.021	1.72	.015 - .05	.007 - .062
Phosphorus	14:14	.0117	5.4	<1	<1	84*	10	2300	1.28	1700 - 3200	1400 - 3800
Strontium	14:14	.0580	44	13	<1	43*	<1	34	1.74	13 - 67	11 - 100
Sulfur	14:14	.0155	4.6	<1	<1	86*	9.6	1800	1.33	1400 - 3000	1000 - 3200
Titanium	6:14	--	--	--	--	--	--	--	--	<.8 - 3.5	-- - --
Vanadium	0:14	--	--	--	--	--	--	--	--	<.6 - <.6	-- - --
Yttrium	0:14	--	--	--	--	--	--	--	--	<.16 - <.16	-- - --
Zinc	14:14	.1534	2.5	<1	4.3	<1	93	46	2.46	28 - 120	-- - --

[1]The geometric deviation is equal to the antilogarithm of the square root of the total log_{10} variance where n=14.

[2]Because of excessive analytical error (>50 percent), baselines for ash yield, Cr, Fe, and Zn were not calculated.

Table 5.--Variation in and summary statistics for the element concentrations in dry material of Parmelia sulcata, North and South Units, Theodore Roosevelt National Park, North Dakota.

[Variance analyses based on 14 samples, summary statistics based on 11 samples (14 minus 3 analytical splits); *, component of variance was tested significant at the 0.05 probability level; ratio, proportion of the number of analyses having values above the lower limit of determination to the total number of analyses; leaders (--), no data available]

Element or ash yield	Ratio	Analysis of variance: Total log_{10} variance	Percentage of total variance between: Park units	.72-7.2 km distance	.10-.72 km distance	0-.72 km distance	Analyses	Summary statistics (n=11): Geometric mean (ppm)	Geometric deviation[1]	Observed range (ppm)	Expected 95 percent range (baseline, ppm)[2]
Ash, %	2:14	--	--	--	--	--	--	--	--	9.0 - 14	-- - --
Aluminum	14:14	0.0240	<1	67	<1	13	2	2000	1.43	1300 - 3000	980 - 4100
Arsenic	14:14	.0188	<1	<1	33	65*	1.8	.97	1.37	.60 - 1.5	.52 - 1.8
Barium	14:14	.0389	<1	18	13	<1	69	79	1.57	60 - 100	-- - --
Boron	0:14	.--	--	--	--	--	--	--	--	<.4 - <.4	-- - --
Calcium	14:14	.0408	<1	42	21	<1	38	4400	1.59	2700 - 7500	1700 - 11000
Chromium	14:14	.0469	8.0	<1	6.0	<1	86	7.3	1.65	5.6 - 11	-- - --
Copper	14:14	.0909	2.1	30	<1	59*	8.7	24	2.00	12 - 120	6.0 - 96
Iron	14:14	.0283	<1	44*	<1	43	13	2700	1.47	1600 - 3900	1200 - 5800
Lead	14:14	.0571	<1	15	<1	<1	85	26	1.73	21 - 38	-- - --
Magnesium	14:14	.0137	<1	79*	6.9	10	3.8	730	1.31	540 - 1000	430 - 1300
Manganese	14:14	.0153	<1	68*	15	<1	17	72	1.33	57 - 110	41 - 130
Mercury	13:14	.0042	19	<1	<1	18	63	.14	1.26	<.12 - .16	-- - --
Nickel	12:14	.0646	<1	<1	38	48	14	6.6	1.80	<4 - 17	2.0 - 21
Phosphorus	14:14	.0409	13	<1	12	<1	75	790	1.59	560 - 1600	-- - --
Strontium	14:14	.0309	<1	51	<1	43	6.5	28	1.50	18 - 42	12 - 63
Sulfur	14:14	.0073	<1	72*	2.4	25*	<1	1200	1.22	920 - 1700	810 - 1790
Titanium	14:14	.0064	<1	15	<1	50	34	16	1.20	12 - 19	11 - 23
Vanadium	14:14	.0292	<1	58	<1	<1	42	4.4	1.48	2.7 - 5.7	2.0 - 9.6
Yttrium	14:14	.0683	<1	42	<1	<1	58	2.5	1.83	1.3 - 3.8	-- - --
Zinc	14:14	.0521	<1	42	45	1.9	11	95	1.58	60 - 320	38 - 240

[1]The geometric deviation is equal to the antilogarithm of the square root of the total log_{10} variance where n=14.

[2]Because of excessive analytical error (>50 percent), baselines for Ba, Cr, Pb, Hg, P, and Y are not calculated.

Table 6.--Summary statistics for the element concentrations in dry material of *Parmelia chlorochroa*, North and South Units, Theodore Roosevelt National Park, North Dakota.

[Ratio, proportion of the number of analyses having values above the lower limit of determination to the total number of analyses; leaders (--), no data available]

Element or ash yield	Ratio	Observed range (ppm)	Percentiles (ppm) 50	75	95
Ash, %	10:14	9.6 - 20	12	13	18
Aluminum	14:14	410 - 2200	950	1000	2100
Arsenic	14:14	.25 - 1.6	.52	.75	1.3
Barium	14:14	14 - 69	32	35	65
Boron	0:14	-- - <.4	--	--	--
Calcium	14:14	2300 - 31000	16000	19000	28000
Chromium	13:14	<4 - 9.2	4.8	5.2	8.5
Copper	14:14	4.7 - 26	9.9	12	20
Iron	14:14	640 - 2500	1300	1600	2400
Magnesium	14:14	160 - 710	330	450	740
Manganese	14:14	16 - 69	34	38	55
Mercury	14:14	.07 - .11	.090	.092	.11
Phosphorus	14:14	200 - 1100	670	830	1000
Strontium	14:14	3.4 - 92	16	22	60
Sulfur	14:14	830 - 1300	1000	1100	1300
Titanium	14:14	3.9 - 27	12	14	25
Vanadium	13:14	<.6 - 5.1	1.8	2.1	4.8
Yttrium	14:14	.18 - 3.5	.92	1.3	2.8
Zinc	14:14	17 - 160	44	46	120

Table 7.--Variation in and summary statistics for the element concentrations in soils associated with Fraxinus pennsylvanica, North and South Units, Theodore Roosevelt National Park, North Dakota.

[Variance analyses based on 13 samples, summary statistics based on 10 samples (13 minus 3 analytical splits); *, component of variance was tested significant at the 0.05 probability level; ratio, proportion of the number of analyses having values above the lower limit of determination to the total number of analyses; leaders,(--), no data available]

		Analysis of variance						Summary statistics (n=10)			
			Percentage of total variance between:								
Element	Ratio	Total $\log_{10}$ variance	Park units	.72-7.2 km distance	.10-.72 km distance	0-.10 km distance	Analyses	Geometric mean (ppm)	Geometric deviation[1]	Observed range (ppm)	Expected 95 percent range (baseline, ppm)[2]
Aluminum	13:13	0.0056	14	<1	64	<1	22	6900	1.19	5600 - 8400	4900 - 9800
Barium	13:13	.0484	10	60	20	<1	9.5	250	1.66	150 - 570	91 - 690
Beryllium	13:13	.0087	<1	50	25	15	9.5	.57	1.24	.44 - .80	.37 - .88
Calcium	13:13	.1137	<1	48*	<1	52*	<1	9800	2.17	5000 -26000	2100 -46000
Cesium	12:13	.1770	<1	13	13	<1	75	19	2.63	<3.6 - 25	-- - --
Chromium	10:13	.0714	58	<1	23	<1	19	12	1.85	<9.5 - 34	3.5 - 41
Copper	13:13	.0383	5.1	<1	59*	35*	1.3	17	1.57	9.5 - 26	6.9 - 42
Iron	13:13	.0283	<1	54	<1	46*	<1	14000	1.47	7100 -17000	6500 -30000
Lead	1:13	--	--	--	--	--	--	--	--	<19 - 22	-- - --
Magnesium	13:13	.0756	<1	38	<1	61*	1.2	4600	1.88	2400 - 8500	1300 -16000
Manganese	13:13	.0557	<1	56	10	33*	<1	350	1.72	140 - 730	120 - 1000
Mercury	13:13	.1077	<1	2.6	34	<1	64	.047	2.13	.02 - .10	-- - --
Nickel	12:13	.0455	44	28	1.0	1.0	26	18	1.63	<9.6 - 34	6.8 - 48
Niobium	13:13	.0568	<1	57*	<1	23	20	5.8	1.73	3.0 - 11	1.9 - 17
Phosphorus	13:13	.0138	<1	69	26	1.5	2.6	610	1.31	420 - 780	360 - 1000
Strontium	13:13	.0582	<1	61	31	7.1*	<1	53	1.74	26 - 140	17 - 160
Sulfur	12:13	.3981	24	<1	50	24*	2.0	230	4.28	<50 - 3600	12 - 420
Titanium	13:13	.0752	<1	49*	<1	50*	1.0	6.7	1.88	3.0 - 13	1.9 - 24
Vanadium	13:13	.0259	22	35	<1	42*	<1	16	1.45	9,2 - 24	7.6 - 34
Yttrium	13:13	.0114	22	6.5	<1	68	3.9	6.1	1.28	4.5 - 8.0	3.7 - 10
Zinc	13:13	.0118	20*	<1	<1	<1	80	64	1.28	51 - 89	-- - --

[1]The geometric deviation is equal to the antilogarithm of the square root of the total $\log_{10}$ variance where n=13.

[2]Because of excessive analytical error (>50 percent), baselines for Ce, Hg, and Zn were not calculated.

Table 8.--Variation in and summary statistics for the element concentrations in soils associated with Agropyron smithii, North and South Units, Theodore Roosevelt National Park, North Dakota.

[Variance analyses based on 14 samples, summary statistics based on 11 samples (14 minus 3 analytical splits); *, component of variance was tested significant at the 0.05 probability level; ratio, proportion of the number of analyses having values above the lower limit of determination to the total number of analyses; leaders (--), no data available]

		Analysis of variance						Summary statistics (n=11)			
			Percentage of total variance between:								
Element	Ratio	Total $\log_{10}$ variance	Park units	.72-7.2km distance	.10-.72 km distance	0-.10 km distance	Analyses	Geometric mean (ppm)	Geometric deviation[1]	Observed range (ppm)	Expected 95 percent range (baseline, ppm)[2]
Aluminum	14:14	0.0084	<1	30	61*	2.3	6.0	6600	1.23	4400 - 8700	4400 - 10000
Barium	14:14	.0262	<1	<1	87*	12	<1	220	1.45	140 - 330	100 - 460
Beryllium	14:14	.0132	<1	51	15*	<1	4.0	.49	1.30	.29 - .63	.29 - .83
Calcium	14:14	.1468	<1	<1	99*	<1	<1	5900	2.42	3100 - 23000	1000 - 35000
Cesium	14:14	.0082	<1	34	28	17	20	20	1.23	17 - 32	13 - 30
Chromium	10:14	.1235	<1	3.2	39	<1	57	--	--	<13 - 80	-- - --
Copper	14:14	.0298	<1	<1	93*	3.7	2.9	15	1.49	9.5 - 24	6.8 - 33
Iron	14:14	.0058	1.8	<1	92*	1	6.1	15000	1.14	13000 - 20000	11000 - 20000
Lead	2:14	--	--	--	--	--	--	--	--	<19 - 21	-- - --
Magnesium	14:14	.0589	<1	<1	98*	1.0	<1	3800	1.75	2500 - 7900	1000 - 12000
Manganese	14:14	.0200	49*	<1	39	11*	<1	510	1.38	360 - 700	270 - 970
Mercury	14:14	.0294	2.0	<1	29	<1	69	.041	1.48	.02 - .06	-- - --
Nickel	14:14	.0163	<1	<1	95*	<1	5.2	20	1.34	15 - 30	11 - 36
Niobium	14:14	.0529	<1	<1	74	5.4	21	4.4	1.70	2.3 - 8.5	1.5 - 13
Phosphorus	14:14	.0103	23	<1	64	10	2.4	660	1.26	460 - 840	415 - 1000
Strontium	14:14	.0749	<1	<1	98*	1.9	<1	28	1.88	19 - 87	7.9 - 99
Sulfur	9:14	.2328	29	<1	57	13	1.1	--	--	<50 - 400	-- - --
Titanium	14:14	.2856	4.5	<1	89*	<1	6.7	11	3.42	5.6 - 120	.94 - 130
Vanadium	14:14	.0052	<1	8.3	89*	1.2	1.6	16	1.18	14 - 23	16 - 22
Yttrium	14:14	.0054	<1	56	27	9.7	6.6	6.5	1.18	5.5 - 7.6	4.7 - 9.0
Zinc	14:14	.0164	33*	<1	13	46	7.9	74	1.34	55 - 110	41 - 130

[1]The geometric deviation is equal to the antilogarithm of the square root of the total $\log_{10}$ variance where n=14.

[2]Because of excessive analytical error (>50 percent), baselines for Cr and Hg were not calculated.

Table 9.--Variation in and summary statistics for the element concentrations in soils associated with Artemisia tridentata, North and South Units, Theodore Roosevelt National Park, North Dakota.

[Variance analyses based on 14 samples, summary statistics based on 11 samples (14 minus 3 analytical splits); *, component of variance was tested significant at the 0.05 probability level; ratio, proportion of the number of analyses having values above the lower limit of determination to the total number of analyses; leaders (--), no data available]

		Analysis of variance						Summary statistics (n=11)			
			Percentage of total variance between:								
Element	Ratio	Total $\log_{10}$ variance	Park units	.72-7.2 km distance	.10-.72 km distance	0-.10 km distance	Analyses	Geometric mean (ppm)	Geometric deviation[1]	Observed range (ppm)	Expected 95 percent range (baseline, ppm)
Aluminum	14:14	0.0124	6.0	<1	68	20	6.1	7700	1.29	5000 - 11000	4600 - 13000
Barium	14:14	.0393	32	<1	<1	64*	4.5	220	1.58	120 - 390	80 - 550
Beryllium	14:14	.0256	7.4	<1	39	52	2.1	.60	1.45	.38 - .96	.28 - 1.3
Calcium	14:14	.1129	10	<1	<1	90*	<1	13000	2.17	3500 - 28000	2800 - 61000
Cesium	14:14	.0073	1.6	<1	76	<1	23	22	1.22	19 - 30	15 - 33
Chromium	12:14	.1281	<1	35	20*	<1	45	13	2.28	<9.0 - 25	2.5 - 68
Copper	14:14	.0444	10	<1	62	26*	1.9	19	1.62	9.7 - 34	7.2 - 50
Iron	14:14	.0132	17	<1	37	40	5.7	17000	1.30	12000 - 25000	10000 - 29000
Lead	3:14	--	--	--	--	--	--	--	--	<18 - 29	-- - --
Magnesium	14:14	.0214	30	<1	<1	67*	2.7	6900	1.40	4400 - 11000	3500 - 14000
Manganese	14:14	.0580	<1	11	<1	88*	<1	400	1.74	180 - 710	130 - 1200
Mercury	14:14	.0318	<1	<1	51	49	<1	.045	1.51	.02 - .06	.020 - .10
Nickel	14:14	.0307	<1	<1	66	33*	1.4	25	1.50	19 - 66	11 - 56
Niobium	14:14	.0301	57*	<1	19	<1	24	7.2	1.49	4.2 - 12	3.2 - 16
Phosphorus	14:14	.0120	<1	51	5.3	43*	1.1	610	1.29	470 - 800	370 - 1000
Strontium	14:14	.0223	<1	<1	<1	99*	<1	53	1.41	41 - 76	27 - 100
Sulfur	6:14	--	--	--	--	--	--	--	--	<50 - 3000	-- - --
Titanium	14:14	.2120	26*	<1	50	22*	1.3	28	2.89	7.5 - 120	3.3 - 230
Vanadium	14:14	.0154	17	3.9	66*	12*	<1	18	1.33	12 - 32	10 - 32
Yttrium	14:14	.0062	20	<1	12	63*	5.3	7.2	1.20	5.6 - 9.1	5.0 - 10
Zinc	14:14	.0340	<1	<1	51*	<1	48	77	1.53	48 - 130	33 - 180

[1]The geometric deviation is equal to the antilogarithm of the square root of the total $\log_{10}$ variance where n=14.

Tables 2, 3, 4, and 5 show that very little of the variability in the element concentrations for plants occurs "between park units". Significance tests at the 0.05 probability level and the distribution of the variance (expressed as percentages of the total variance) show the importance of the non-regional or "small-scale" components for all four plant species in this area. Of the elements examined, only boron in green ash showed significant units of the park (56 percent of the total variance). More than 40 percent of the total variance for most elements in green ash, wheatgrass, and sagebrush is associated with distances of 0.72 km or less. The data for P. sulcata show that more than 40 percent of the total variance for most elements is associated with distances of 7.2 km or less. The data for sagebrush are very similar to the data of Gough and Erdman (1983) which indicated that the variability in the concentrations of most elements in sagebrush from eight physiographic provinces of western U.S.A., was between samples collected at intervals of 5 km or less.

Examination of Tables 7, 8, and 9 shows that the distribution of the variance in soil chemistry is very similar to that of plants. Except for the soils associated with sagebrush (Table 9), less than one percent of the variance in the data for a majority of the elements was commonly found at the "between park units" level. Over large distances, therefore, soils in the geologic terrain in this part of North Dakota differ little in their overall chemistry. This conclusion is similar to that reported for soils collected in other areas of the Great Plains underlain by the Fort Union and Wasatch Formations of early Tertiary age (Tidball and Ebens, 1976; Severson and Tidball, 1979; and Severson, 1979). Also, as with the vascular plants, most of the significant variability in the soil-chemical data occurred at distances of <0.72 km. This means that if mapping plant biogeochemistry or soil geochemistry is important, then detailed small-scale sampling would be necessary. An alternative sampling plan would be to composite and homogenize a number of samples from areas 0.72 km across into single samples that then would represent the sampled areas.

Biogeochemical and Geochemical Baselines--The main conclusion from this study is that samples of these four plant species and of soils collected at the two park units tend to differ, in general, little more than samples taken only a few hundreds of meters apart. The concentrations of most elements are fairly uniform throughout the park (not a great deal of scatter in the data); thus, extensive sampling in order to establish element concentration baselines for the materials that we sampled is unnecessary for most elements.

The baseline biogeochemical and geochemical concentrations given in Tables 2-5 and 7-9 can be used as standard background concentrations for comparisons of any newly collected samples of the four plant species and soils assuming that future samples are collected, prepared for analysis, and analyzed by the same methods.

Examination of Tables 2-6 also shows that Parmelia sulcata and P. chlorochroa have, in general, higher concentrations of most elements as compared to green ash, wheatgrass, and sagebrush. This difference in concentration levels is not surprising because cryptogams are known to accumulate most elements (particularly metals) due both to physiological characteristics, such as cation exchange capabilities, and to their large surface-to-volume ratios (see, for example, Ferry and others, 1973; Martin and Coughtrey, 1982). For monitoring future changes in air quality in the park Peard and others (1984) recommend that P. sulcata be used in preference to P. chlorochroa. Not only was the former more common, but also P. sulcata had more elements present at detectable levels (Appendix II); also, most element

concentrations are about one-and-a-half to two times greater in P. sulcata than in P. chlorochroa (Tables 5 and 6). To what degree these differences in element concentration reflect dissimilarities in habitat (which would influence moisture levels and exposure to air currents and canopy throughfall) is unknown.

Element Concentration Comparisons--A very general comparison of the element levels in plant materials collected at TRNP with similar materials collected either in the northern Great Plains or the Powder River Basin is given in Table 10. Although different methods of sample preparation and analysis were used, depending on the studies being compared, these data show that, for most elements, the average chemical composition of the plants differed little among these three areas. Boron in sagebrush at TRNP was four-times lower than the levels found throughout the Great Plains and magnesium levels in P. chlorochroa were slightly less than those in samples from the Powder River Basin.

We have no comparison of element concentrations for P. sulcata from other areas of the west; however, Table 5 does show fairly large zinc concentrations as compared to P. chlorochroa or to the general lichen literature. Seaward (1974), suggested that heavy-metal moribund toxicity symptoms that he observed in Hypogymnia physodes (an epiphyte similar to P. sulcata) were caused primarily by excessive zinc. He also suggested that a zinc concentration of about 100 ppm (dry weight) might indicate toxicity threshold levels. Our zinc data range from 60-320 ppm with a GM=95 ppm. We did not, however, observe any obvious toxicity conditions in P. sulcata and we emphasize that large differences exist in the susceptibility of species to heavy metals (Martin and Coughtrey, 1982). The zinc concentrations are interesting, however, and merit further contemplation and study.

Similar comparisons of means for element concentrations in soils can be made by examining the data in Table 11. Again, these comparisons must be interpreted with some caution because of variability in the way samples were collected, prepared, or analyzed. Except for a few elements (for example, barium, beryllium, and strontium), the concentrations of elements found in soil samples at TRNP differed very little from those reported from other regions within the West or from the western U.S.A. as a whole.

Study 3--Point-Source Investigation

Evaluation Criteria--Strong evidence exists that a particular element in plant material may be associated with some source of contamination (such as the natural-gas processing facility), if the concentration of the element decreases with increasing distance from the suspected source. The element-concentration data in Appendix IV are ordered relative to increasing distance from the gas processing facility (top to bottom), and a cursory examination shows very few possible trends. Correlation coefficients were computed between site location (distance) and element concentration in dry plant material (Table 12), and only in a very few instances did a strong inverse (negative) relation occur. Our experience has shown (Gough and Erdman, 1977; Severson and Gough, 1979) that important cause-and-effect relations between emission sources and element levels in plant tissue are difficult to assign unless the covariation between logarithms of element concentration in plant or soil material and logarithms of distance along the traverse (the correlation coefficient, r) is statistically significant, negative, and greater in absolute value than about 0.60. A negative slope indicates an inverse relation between element concentration and distance from the suspected contamination source.

Table 10.--Average concentrations (geometric means) for fourteen elements in the dry material of Agropyron smithii, Artemisia tridentata, and Parmelia chlorochroa from Theodore Roosevelt National Park, the Northern Great Plains, and the Powder River Basin of Wyoming and Montana.

[Data are in parts per million, except where noted; leaders (--), no data available]

	Agropyron smithii		Artemisia tridentata		Parmelia chlorochroa	
Element or ash yield	Theodore Roosevelt Park	Northern Great Plains[1]	Theodore Roosevelt Park	Northern Great Plains[2]	Theodore Roosevelt Park	Powder River Basin[3]
Ash,%	6.9	6.6	5.7	4.6	--	14
Arsenic	--	--	--	.17	.57	.92
Barium	23	--	8.7	--	32	52
Boron	1.4	--	5.2	24[4]	--	--
Calcium	2000	2300	3800	--	14000	--
Copper	4.4	--	12	8.8[4]	10	9.8
Iron	80	73	150	140	1200	2000
Magnesium	720	700	1100	1600	364	900
Manganese	29	19	27	36	34	38
Mercury	.019	--	.021	.025	.089	.098
Phosphorus	1400	--	2300	1500	640	--
Strontium	13	--[5]	34	--	16	49
Sulfur	1900	1200	1800	1300	1000	670
Zinc	38	15	46	--	44	--

[1]Gough, Severson, and McNeal (1979).
[2]Gough and Erdman (1983).
[3]Erdman and Gough (1977).
[4]Arithmetic mean of two geometric means.
[5]Arithmetic mean over five years (from Lauenroth and Preston, 1984, table 4.3).

Table 11.--Average concentrations (geometric means) for selected elements in soils and surficial materials from Theodore Roosevelt National Park, Bighorn Basin, Wind River Basin, Powder River Basin, and the Western United States (modified from Severson, 1979).

[Data are in parts per million; leaders (--), no data available]

Element	Theodore Roosevelt Park[1]	Northern Great Plains[2]	Bighorn Basin[3]	Wind River Basin[3]	Powder River Basin[4]	Western United States[5]
Barium	230	--	1300	1500	720	560
Berylium	.55	1.7	2.0	2.4	.99	.6
Calcium	9600	10000	30000	22000	--	8700
Cesium	20	--	57	54	--	74
Chromium	12[6]	--	59	52	49	88
Copper	17	19	20	15	16	21
Iron	15000	21000	18000	15000	--	20000
Lead	<19[7]	15	8.6	13	17	18
Magnesium	5100	7000	8600	6300	--	7800
Manganese	420	720	400	320	230	389
Mercury	.044	--	.25	.020	.023	.055
Nickel	21	--	22	21	15	16
Niobium	5.8	--	8.9	6.9	6.2	11
Strontium	45	180	230	340	160	210
Zinc	72	--	57	43	61	51

[1]Arithmetic mean of three geometric means, except where noted.
[2]A-horizon soils from unglaciated terrain (Severson and Tidball, 1979).
[3]Severson (1979).
[4]Connor, Keith, and Anderson (1976).
[5]Surficial material; from Shacklette and others (1971a, b).
[6]Arithmetic mean of two geometric means.
[7]80% of the lead values were below the detection limit; largest value recorded was 29 ppm.

Table 12.--Correlation coefficients (r) for logarithms of the dry weight concentrations of selected elements in samples of Agropyron smithii, Parmelia chlorochroa, Selaginella densa, and soil versus logarithms of ash yield or distance from a natural-gas processing facility, Billings County, North Dakota.

[Leaders (--) mean data not available]

Element or ash yields	Agropyron smithii (western wheatgrass, n=12)		Parmelia chlorochroa (soil lichen, n=10)		Selaginella densa (little club-moss, n=10)		Soil (n=14)
	Distance	Ash yields	Distance	Ash yields	Distance	Ash yields	Distance
Ash	0.62	--	0.51	--	0.65	--	--
Aluminum	.74	.47	.66	.86	.83	.82	0.31
Arsenic	- .01	.15	.14	.40	.09	.11	--
Barium	.38	.48	.14	.55	- .59	- .06	--
Boron	.48	.12	.07	.39	- .71	- .52	--
Calcium	.11	.12	- .03	.77	- .10	.18	- .05
Chromium	--	--	.06	- .08	- .55	- .29	--
Copper	- .19	- .17	- .10	- .40	- .66	- .62	- .53
Iron	.69	.47	.35	.90	.45	.67	- .31
Magnesium	- .44	- .41	.51	.03	.14	.45	- .04
Manganese	- .50	- .08	.39	.47	- .40	.17	- .34
Mercury	.22	- .13	- .35	- .26	.10	.30	--
Phorphorus	.80	.69	.13	- .02	.46	.68	- .17
Strontium	- .36	- .29	.03	.03	.10	.01	.53
Sulfur	- .10	- .61		- .16	.08	.25	- .65
Titanium	- .35	- .21	.77	.89	.27	.26	- .35
Vanadium	--	--	.52	.80	.47	.69	.14
Yttrium	--	--	.58	.88	.49	.67	.30
Zinc	.04	.07	- .28	- .72	- .38	.24	- .06

Interpretation of Element-Concentration Trends--The only elements in Table 12 that have negative correlations greater than about 0.60 (r^2 about 0.36) are sulfur in soil lichen; barium, boron, and copper in clubmoss; and sulfur in soil. Plots of some of these relations are given in figs. 4 and 5. Assuming that the paired samples at each site (for example, soil lichen has 10 samples or 5 sample pairs) are not independent but that the individual sites (5 in this example) are independent, then the critical value for a correlation coefficient with 5 minus 2 degrees of freedom is 0.88 at the 0.05 probability level (Table 12). Clubmoss and soil have critical values of 0.88 and 0.75, respectively.

Regression equations are of the form:

$$\log Y = a + b \log X,$$

where Y is the estimate of the elemental concentration in the sample and X is the distance in km from the processing facility. The coefficients a and b were estimated by least-squares methods. Figures 4 and 5 give the regression equations for sulfur in soil lichen, boron in clubmoss, and sulfur in soil. Except for statistical significance of r, these three relations fit the criteria mentioned above for possible relations between element concentrations in sampled material and a contamination source.

These data suggest that the gas-processing facility has increased the sulfur concentrations in soil lichen and soil and the boron in clubmoss near the facility. The sulfur levels in soil lichen are not excessive (compared to baselines for the same material from the Powder River Basin; Erdman and Gough, 1977), and the range in the concentrations is narrow (0.094-0.123 percent sulfur). In general terms, the boron concentrations in clubmoss and the sulfur concentrations in soil are also not large (Ebens and Shacklette, 1982). Even though Figure 5 shows that at some locations there is a large amount of variability between replicate samples, a trend of decreasing concentration with increasing distance is present. This evidence suggests a cause-and-effect relation between sulfur in soil and the processing facility, especially in light of the sulfur trend observed for P. chlorochroa (fig. 4).

Other possible contamination sources are also present in the vicinity, namely several pipeline compressor stations. These, however, are small operations compared to the Teddy Roosevelt gas-processing facility, and the study sites were positioned as far from them as the availability of sample material would allow. The Little Knife River processing facility of Warren Petroleum is a major operation but is located about 15 km southeast of the TRNP north unit (fig. 2). Experience has shown that no detectable influence on element concentrations should exist at that great a distance. Also, the predominant winds are from the west and west-northwest, effectively making the Warren facility even less of a factor relative to contamination of TRNP.

Examination of the trace-element data (Appendix IV) offers some additional evidence for a point-source influence on the biogeochemistry of the area. Plots of distance from the gas-processing facility vs. element concentrations in plant materials show that strong inverse relations exist when only the first three sites are considered (up to almost 2 km). For example, a linear regression of zinc in clubmoss to distance (logarithmic values) yields a correlation coefficient of -0.97 (n=6). When all sites are included, r=-0.38 (n=10, Table 12). If only the first three sites are used in the calculations, similarly large negative coefficients exist for manganese in wheatgrass (r=-0.90) and copper in P. chlorochroa (r=-0.85). The soil data (Appendix V) show similar but weaker patterns for copper, lead, and manganese.

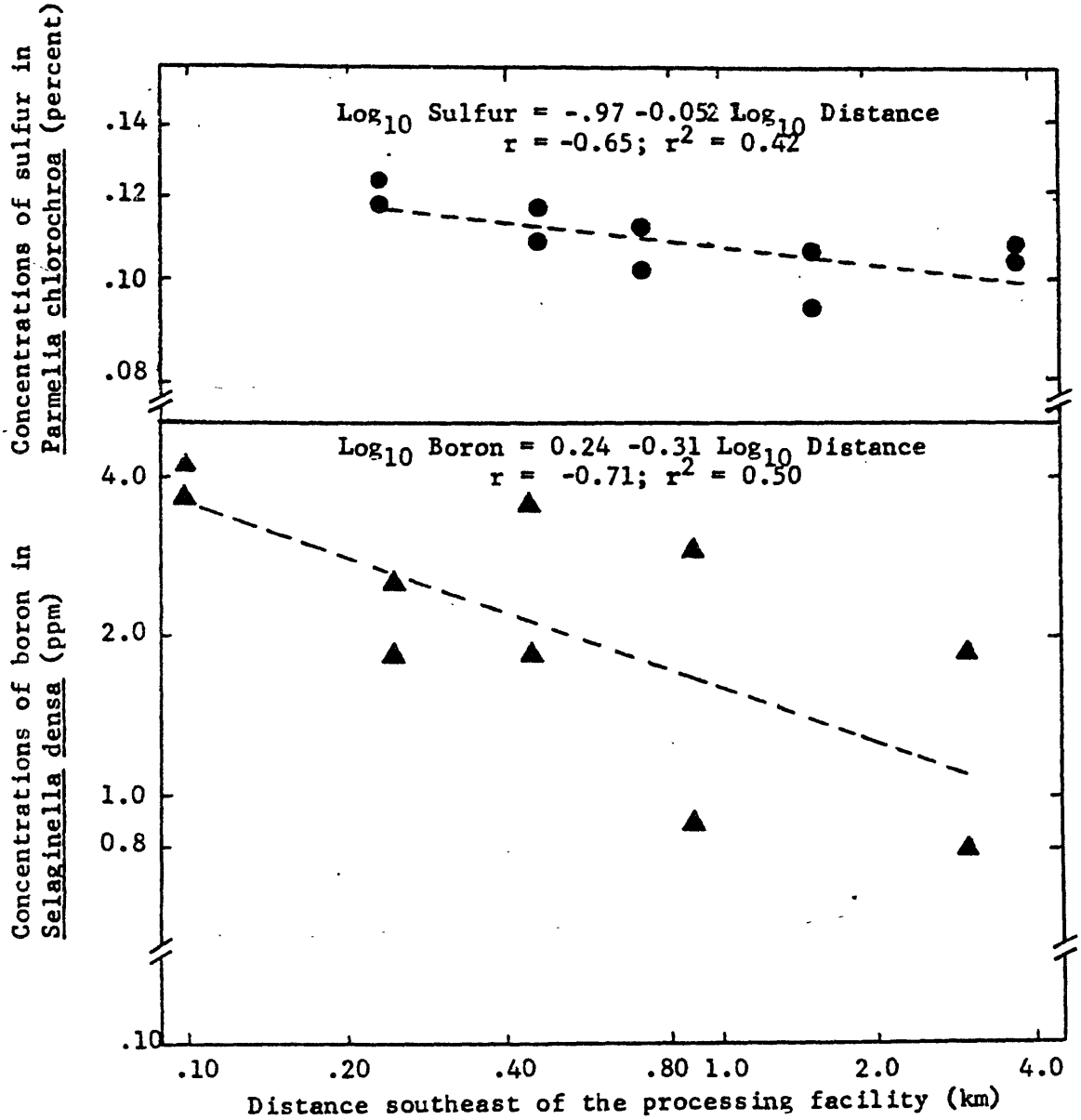

Figure 4.--Linear regressions for log sulfur concentrations in Parmelia chlorochroa and log boron concentrations in Selaginella densa versus log of the distance from a natural-gas processing facility, Billings County, North Dakota.

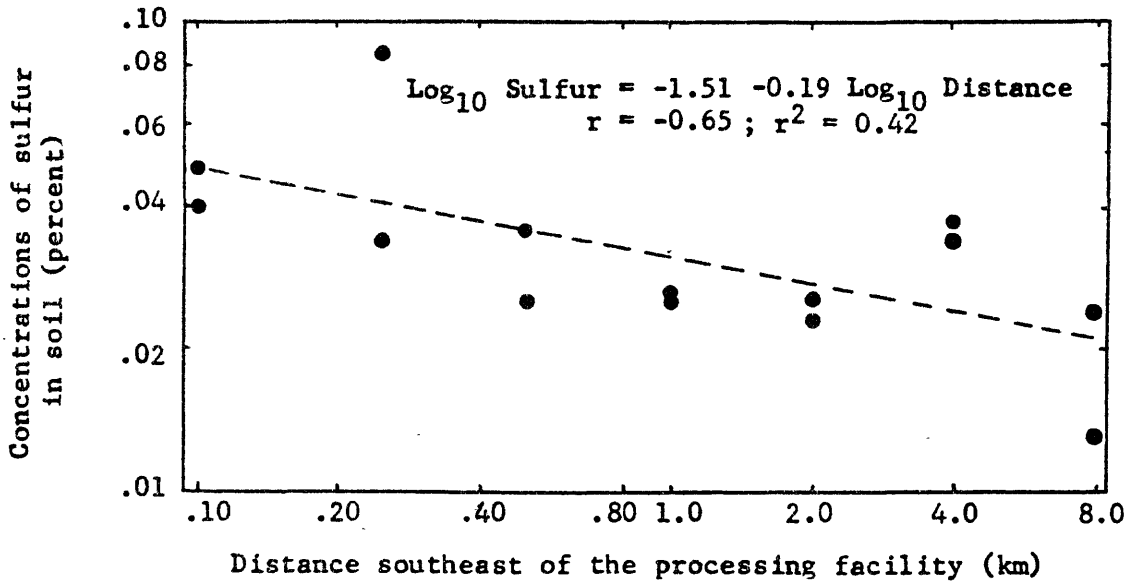

Figure 5.--Linear regression for log sulfur concnetrations in soil versus log of the distance from a natural-gas processing facility, Billings County, North Dakota.

The plant analyses in particular show some general patterns of decreasing element concentration with increasing distance from the Teddy Roosevelt Gas-processing facility. The influence of this facility on the regional air quality (at distances greater than about 2 to 4 km) appears minimal; the cumulative influence of a large number of these types of facilities has yet to be quantified.

Table 12 shows a number of large but rarely significant, positive correlations between element concentrations and distance. Except for phosphorus in wheatgrass (r=0.80) the regressions are not signficant. In addition, most of the regression lines are disproportionately influenced by large concentrations in the samples at the farthest (8 km) site.

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Appendix I.--Description of study sites for the baseline biogeochemical and geochemical study.

Sample ID	Park unit	Physiographic area	Elevation (meters)	Slope and aspect
		Agropyron smithii (western wheatgrass)		
G11111/2*	North	River flat	610	0°
G11211	North	Microbench	650	0- 5° S-facing
G11221	North	Microbench	650	0- 5° S-facing
G12111	North	Microbench	610	0- 5° NW-facing
G12121	North	Microbench	620	0°
G12211	North	River flat	660	0°
G21111	South	Prairie upland	790	0- 5° SE-facing
G21211/2*	South	Prairie upland	800	0°
G22111	South	Prairie upland	800	0°
G22211/2*	South	Microbench	760	0- 5° S-facing
G22221	South	Microbench	760	0°
		Artemisia tridentata (big sagebrush)		
S11111/2*	North	Microbench	670	0- 5° SW-facing
S11121	North	Microbench	700	0- 5° S-facing
S11211	North	Microbench	630	5-10° S-facing
S11221	North	Microbench	620	0- 5° S-facing
S12111/2*	North	Microbench	660	0- 5° S-facing
S12211	North	Microbench	620	0- 5° SE-facing
S21111	South	Microbench	760	20° SE-facing
S21211	South	Microbench	740	5-10° NW-facing
S22111/2*	South	Microbench	750	0°
S22211	South	Microbench	800	5-10° SW-facing
S22221	South	Microbench	800	0- 5° S-facing
		Fraxinus pennsylvanica (green ash) and *Parmelia sulcata* (lichen)		
A11111/2* & P11111	North	Coulee	730	15-20° SE-facing
A11211 & P11211	North	Coulee	710	0- 5° NW-facing
A11221 & P11221/2*	North	Coulee	720	0- 5° NW-facing

Appendix I.--Description of study sites for the baseline biogeochemical and geochemical study (continued).

Sample ID	Park unit	Physiographic area	Elevation (meters)	Slope and aspect
		Fraxinus pennsylvanica (green ash) and *Parmelia sulcata* (continued)		
A12111 & P12111	North	Coulee	710	10-15° NE-facing
A12211 & P12211	North	Coulee	680	10° E-facing
A12221 & P12221	North	Coulee	690	0- 5° E-facing
A21111 & P21111/2*	South	Coulee	840	30° N-facing
A21211 & P21211	South	Coulee	820	5-10° N-facing
A21221 & P21221/2*	South	Coulee	840	20-30° NE-facing
A22111/2[1] & P22111	South	Coulee	740	25-30° SE-facing
A22211/2[1] & P22211	South	Coulee	740	30° N-facing
		Parmelia chlorochroa (soil lichen)		
C01	South	Prairie upland	840	0°
C02	South	Prairie upland	820	0- 5° SE-facing
C03	South	Prairie upland	800	0°
C04	South	Microbench	750	0°
C05	South	Microbench	760	0- 5° W-facing
C06	South	Microbench	760	0- 5° NW-facing
C07	South	Microbench	820	5-10° SE-facing
C08	North	Microbench	620	5° S-facing
C09	North	Microbench	640	10-20° E-facing
C10	North	Microbench	620	0- 5° SE-facing
C11	North	Prairie upland	710	0- 5° N-facing
C12	North	Microbench	720	20° N-facing
C13	North	Prairie upland	740	0°
C14	North	Microbench	630	5° SE-facing

*Analytical split.

APPENDIX II.--BASELINE BIOGEOCHEMICAL STUDY (DRY WEIGHT BASE)

[--, no data available; N, less than the instrumental lower limit of detection (see footnote); <; less than the analytical lower limit of determination (adjusted for solution and sample composition matrix effects)]

SAMPLE	ASH, %	AL, PPM	AS, PPM	B, PPM[1]	BA, PPM	BE, PPM[1]	CA, PPM	CE, PPM[1]
			FRAXINUS PENNSYLVANICA (GREEN ASH) LEAVES					
A11111	5.2	48	<.05	3.40	34.0	N	6,800	N
A11112	5.2	49	<.05	3.40	34.0	N	6,700	N
A11211	6.0	59	<.05	4.50	55.0	N	6,200	N
A11221	4.5	49	<.05	3.00	29.0	N	5,400	N
A12111	5.5	99	<.05	3.40	55.0	N	8,800	N
A12211	6.0	50	<.05	4.00	38.0	N	7,000	N
A12221	6.2	55	<.05	4.50	40.0	N	8,200	N
A21111	6.0	70	.10	5.30	50.0	N	8,800	N
A21211	6.8	62	<.05	4.90	51.0	N	8,600	N
A21221	6.0	55	<.05	4.70	42.0	N	6,800	N
A22111	6.0	60	<.05	4.40	39.0	N	7,600	N
A22112	6.0	60	<.05	4.10	37.0	N	7,200	N
A22211	6.5	60	<.05	5.70	29.0	N	8,500	N
A22212	6.5	54	<.05	5.60	30.0	N	8,500	N
			PARMELIA CHLOROCHROA (SOIL LICHEN)					
C01	9.6	850	.45	N	24.0	N	16,000	N
C02	--	1,100	1.60	N	69.0	.068	18,000	N
C03	14.0	2,000	.85	N	34.0	.140	20,000	N
C04	12.0	1,000	.45	N	32.0	.056	12,000	N
C05	12.0	690	.25	N	36.0	.043	24,000	N
C06	12.0	900	.50	N	30.0	.056	14,000	N
C07	15.0	1,400	1.00	N	61.0	.110	15,000	N
C08	--	410	1.00	N	14.0	N	2,300	N
C09	20.0	2,200	.60	N	52.0	.110	31,000	N
C10	--	780	.45	N	32.0	N	17,000	N
C11	12.0	450	.30	N	31.0	N	25,000	N
C12	12.0	1,000	.65	N	25.0	.055	13,000	N
C13	10.0	1,000	.55	N	31.0	.055	9,100	N
C14	--	730	.35	N	17.0	N	10,000	N
			AGROPYRON SMITHII (WESTERN WHEATGRASS) CULMS AND LEAVES					
G11111	9.5	68	.05	1.60	12.0	N	2,900	N
G11112	9.5	70	.05	1.50	12.0	N	2,900	N
G11211	9.0	51	.05	1.70	33.0	N	2,300	N
G11221	8.0	49	<.05	1.50	24.0	N	1,600	N
G12111	5.5	42	<.05	2.10	28.0	N	1,900	N
G12121	5.5	41	<.05	1.50	18.0	N	1,500	N
G12211	7.0	80	.05	1.50	14.0	N	1,500	N
G21111	8.2	35	<.05	1.40	30.0	N	2,500	N
G21211	7.0	130	<.05	.56	26.0	N	2,600	N
G21212	7.0	32	<.05	1.10	24.0	N	1,400	N

APPENDIX II.--BASELINE BIOGEOCHEMICAL STUDY (DRY WEIGHT BASE)

SAMPLE	CD, PPM[1]	CR, PPM[1]	CU, PPM	FE, PPM	HG, PPM	LA, PPM[1]	MG, PPM	MN, PPM
				FRAXINUS PENNSYLVANICA (GREEN ASH) LEAVES --CONTINUED				
A11111	N	4.0	8.9	57	.015	N	1,500	17
A11112	N	4.2	9.9	48	.015	N	1,500	16
A11211	N	N	9.0	85	.020	N	2,100	35
A11221	N	N	8.5	37	.020	N	2,000	23
A12111	N	N	8.9	360	.070	N	2,200	24
A12211	N	N	6.2	84	.020	N	1,400	17
A12221	N	N	8.4	49	.020	N	1,800	26
A21111	N	6.0	10.0	67	.030	N	2,000	23
A21211	N	6.5	14.0	190	.040	N	3,300	32
A21221	N	4.0	18.0	73	.030	N	2,500	18
A22111	N	4.5	10.0	80	.025	N	1,700	39
A22112	N	6.0	8.8	110	.030	N	1,600	36
A22211	N	4.6	42.0	84	.030	N	1,900	32
A22212	N	N	43.0	76	.030	N	1,900	31
				PARMELIA CHLOROCHROA (SOIL LICHEN)--CONTINUED				
C01	N	4.3	9.9	980	.090	N	400	33
C02	N	4.6	12.0	1,800	.090	N	330	35
C03	N	5.6	13.0	2,100	.070	N	710	69
C04	N	5.0	9.9	1,300	.080	N	510	41
C05	N	4.3	7.3	970	.080	N	330	36
C06	N	4.7	10.0	1,300	.110	N	330	37
C07	N	9.2	10.0	2,500	.090	N	570	38
C08	N	N	4.7	640	.080	N	160	16
C09	N	7.8	15.0	2,300	.100	N	770	32
C10	N	4.9	14.0	1,100	.080	N	260	38
C11	N	4.1	6.1	670	.090	N	250	33
C12	N	5.3	26.0	1,300	.110	N	320	33
C13	N	5.1	9.3	1,300	.095	N	380	34
C14	N	4.3	9.7	810	.090	N	250	23
				AGROPYRON SMITHII (WESTERN WHEATGRASS) CULMS AND LEAVES--CONTINUED				
G11111	N	5.0	5.3	180	.025	N	910	49
G11112	N	4.5	5.3	140	.020	N	870	48
G11211	N	4.4	4.1	110	.015	N	630	19
G11221	N	N	8.6	73	.025	N	720	29
G12111	N	N	4.1	53	.020	N	830	24
G12121	N	5.0	7.0	62	.015	N	820	26
G12211	N	4.7	3.7	160	.020	N	580	32
G21111	N	N	3.3	47	.025	N	760	19
G21211	N	5.0	4.4	210	.010	N	770	52
G21212	N	4.4	4.4	46	.015	N	620	45

APPENDIX II.--BASELINE BIOGEOCHEMICAL STUDY (DRY WEIGHT BASE)

SAMPLE	MO, PPM[1]	NI, PPM[1]	P, PPM	PB, PPM	S, %	SR, PPM	TI, PPM[1]	V, PPM[1]	Y, PPM[1]	ZN, PPM
				FRAXINUS PENNSYLVANICA (GREEN ASH) LEAVES --CONTINUED						
A11111	N	N	1,300	N	.209	80.0	N	N	N	27
A11112	N	N	1,300	N	.220	79.0	N	N	N	29
A11211	N	N	1,300	N	.193	52.0	N	N	N	24
A11221	N	N	1,400	N	.179	33.0	N	N	N	23
A12111	N	N	1,200	N	.232	100.0	N	N	N	27
A12211	N	N	1,200	N	.213	37.0	N	N	N	19
A12221	N	N	1,300	N	.220	67.0	N	N	N	25
A21111	N	N	1,500	N	.240	62.0	.85	N	N	38
A21211	N	N	1,800	N	.283	38.0	N	N	N	22
A21221	N	N	1,500	N	.208	24.0	N	N	N	28
A22111	N	N	1,100	N	.188	41.0	N	N	N	19
A22112	N	N	1,000	N	.186	38.0	N	N	N	18
A22211	N	N	1,700	N	.291	59.0	N	N	N	34
A22212	N	N	1,700	N	.299	60.0	N	N	N	34
				PARMELIA CHLOROCHROA (SOIL LICHEN)--CONTINUED						
C01	N	N	780	N	.131	8.6	12.00	1.00	.76	73
C02	N	N	570	N	.114	24.0	15.00	2.20	.76	45
C03	N	4.6	1,000	N	.089	29.0	27.00	4.40	2.10	52
C04	N	N	690	N	.113	17.0	10.00	1.90	.66	43
C05	N	N	650	8.2	.095	16.0	10.00	.94	1.20	37
C06	N	N	600	N	.105	12.0	12.00	1.40	.92	44
C07	N	4.8	1,100	N	.105	17.0	15.00	3.50	1.40	47
C08	N	N	200	N	.121	3.4	3.90	.74	.18	17
C09	N	N	920	N	.083	92.0	23.00	5.10	3.50	160
C10	N	N	550	N	.094	11.0	11.00	1.80	.93	44
C11	N	N	600	N	.088	28.0	7.60	N	1.20	26
C12	N	N	700	N	.100	19.0	12.00	1.90	1.40	46
C13	N	N	880	N	.094	13.0	12.00	2.00	.75	42
C14	N	N	390	N	.104	8.0	9.60	1.10	.61	36
				AGROPYRON SMITHII (WESTERN WHEATGRASS) CULMS AND LEAVES--CONTINUED						
G11111	N	N	2,200	N	.395	32.0	.95	N	N	30
G11112	N	N	2,100	N	.389	32.0	1.00	N	N	34
G11211	N	N	1,200	N	.217	17.0	N	N	N	31
G11221	N	N	950	N	.155	14.0	N	N	N	30
G12111	N	N	1,200	N	.172	11.0	N	N	N	28
G12121	N	N	1,200	N	.169	9.1	N	N	N	34
G12211	N	28.0	1,900	N	.201	27.0	1.30	N	N	82
G21111	N	N	1,300	N	.178	12.0	N	N	N	30
G21211	N	N	1,700	N	.151	7.2	N	N	N	150
G21212	N	N	1,400	N	.166	6.0	N	N	N	23

APPENDIX II.--BASELINE BIOGEOCHEMICAL STUDY (DRY WEIGHT BASE)--CONTINUED

SAMPLE	ASH, %	AL, PPM	AS, PPM	B, PPM[1]	BA, PPM	BE, PPM[1]	CA, PPM	CE, PPM[1]
G22111	5.2	50	<.05	1.20	19.0	N	2,400	N
G22211	6.2	37	<.05	1.10	41.0	N	2,300	N
G22212	6.2	35	<.05	1.30	33.0	N	1,900	N
G22221	6.5	39	<.05	1.10	34.0	N	1,900	N
			PARMELIA SULCATA (BARK LICHEN)--CONTINUED					
P11111	--	1,900	.70	N	88.0	.220	5,600	N
P11211	--	1,700	1.20	N	68.0	.180	3,500	N
P11221	--	1,400	.80	N	59.0	.170	2,800	N
P11222	--	1,400	.80	N	60.0	.160	2,600	N
P12111	--	2,400	.60	N	92.0	.290	4,000	N
P12211	--	2,500	1.50	N	88.0	.300	4,700	6.0
P12221	--	3,000	1.20	N	95.0	.360	4,400	4.4
P21111	--	1,900	1.00	N	88.0	.220	5,600	N
P21112	--	1,300	.90	N	35.0	.100	2,800	N
P21211	9.0	1,300	.80	N	67.0	.110	3,500	N
P21221	--	1,800	1.20	N	74.0	.190	3,500	N
P21222	--	2,000	1.20	N	76.0	.200	3,700	N
P22111	14.0	2,300	1.20	N	100.0	.240	7,200	N
P22211	--	2,100	.90	N	88.0	.210	7,500	N
			ARTEMISIA TRIDENTATA (BIG SAGEBRUSH) STEMS AND LEAVES--CONTINUED					
S11111	8.2	83	<.05	4.70	9.3	N	4,100	N
S11112	5.0	61	<.05	4.90	9.0	N	3,400	N
S11121	5.2	61	<.05	5.30	6.3	N	2,900	N
S11211	6.0	110	.05	5.40	9.3	N	4,800	N
S11221	6.0	99	.05	7.00	22.0	N	4,400	N
S12111	6.0	100	.10	4.60	20.0	N	5,200	N
S12112	6.0	90	.10	3.40	19.0	N	4,500	N
S12211	5.0	61	<.05	4.20	9.2	N	3,000	N
S21111	5.0	75	.10	5.10	5.9	N	3,700	N
S21211	5.0	50	<.05	7.30	2.0	N	2,900	N
S22111	5.2	47	<.05	3.80	15.0	N	4,000	N
S22112	5.2	52	<.05	3.90	15.0	N	4,000	N
S22211	6.0	170	.10	4.10	8.7	N	3,800	N
S22221	6.8	77	<.05	8.60	6.4	N	4,600	N

APPENDIX II.--BASELINE BIOGEOCHEMICAL STUDY (DRY WEIGHT BASE)--CONTINUED

SAMPLE	CD, PPM[1]	CR, PPM[1]	CU, PPM	FE, PPM	HG, PPM	LA, PPM[1]	MG, PPM	MN, PPM
G22111	N	4.4	3.5	48	.025	N	610	49
G22211	N	4.3	3.9	48	.025	N	1,000	16
G22212	N	N	3.3	64	.020	N	860	14
G22221	N	N	3.6	76	.015	N	610	34
			PARMELIA SULCATA (BARK LICHEN)--CONTINUED					
P11111	N	6.3	19.0	2,700	.110	N	690	64
P11211	N	7.5	29.0	3,300	--	N	590	68
P11221	N	5.7	20.0	1,900	.130	N	550	59
P11222	N	17.0	19.0	2,000	.150	N	540	55
P12111	N	8.1	24.0	3,300	.120	N	740	72
P12211	N	7.6	120.0	3,600	.160	4.5	910	110
P12221	N	7.4	28.0	3,900	.120	4.1	1,000	100
P21111	N	5.9	20.0	2,500	.160	N	690	64
P21112	N	5.3	32.0	1,800	.130	N	620	50
P21211	N	6.1	20.0	1,600	.140	N	710	61
P21221	N	9.0	19.0	2,300	.150	N	560	60
P21222	N	6.8	16.0	2,500	.130	N	600	68
P22111	N	6.5	12.0	3,000	.150	N	880	79
P22211	N	7.8	14.0	2,700	.130	N	840	82
			ARTEMISIA TRIDENTATA (BIG SAGEBRUSH) STEMS AND LEAVES--CONTINUED					
S11111	N	4.4	13.0	130	.020	N	870	22
S11112	N	7.1	10.0	95	.030	N	840	21
S11121	N	7.0	13.0	90	.010	N	1,400	54
S11211	N	4.7	15.0	210	.025	N	1,200	35
S11221	N	5.6	12.0	170	.015	N	1,100	30
S12111	N	4.8	7.2	120	.015	N	1,700	18
S12112	N	6.3	7.4	830	.015	N	1,500	20
S12211	N	4.1	12.0	110	.015	N	1,200	14
S21111	N	4.5	17.0	140	.015	N	660	21
S21211	N	4.1	11.0	84	.020	N	1,200	35
S22111	N	N	9.5	76	.020	N	770	26
S22112	N	4.0	8.7	81	.025	N	780	26
S22211	N	7.3	14.0	410	.050	N	1,400	41
S22221	N	5.0	14.0	160	.050	N	890	24

APPENDIX II.--BASELINE BIOGEOCHEMICAL STUDY (DRY WEIGHT BASE)--CONTINUED

SAMPLE	MO, PPM[1]	NI, PPM[1]	P, PPM	PB, PPM[1]	S, %	SR, PPM	TI, PPM[1]	V, PPM[1]	Y, PPM[1]	ZN, PPM
G22111	7.1	5.8	1,300	N	.163	16.0	N	N	N	56
G22211	N	N	1,400	N	.144	11.0	N	N	N	24
G22212	N	N	1,100	N	.175	8.9	N	N	N	19
G22221	N	N	1,400	N	.187	7.1	N	N	N	30
			PARMELIA SULCATA (BARK LICHEN)--CONTINUED							
P11111	N	4.9	860	32.0	.167	28.0	19.00	4.40	2.50	72
P11211	N	8.1	590	22.0	.131	32.0	16.00	4.20	2.20	73
P11221	N	6.5	910	19.0	.138	18.0	12.00	3.50	2.10	100
P11222	N	8.4	840	23.0	.137	19.0	13.00	2.80	1.80	84
P12111	N	5.0	630	32.0	.103	42.0	19.00	5.00	3.80	94
P12211	N	17.0	560	32.0	.110	25.0	16.00	5.70	3.60	130
P12221	N	6.5	650	38.0	.092	37.0	17.00	7.40	4.60	89
P21111	N	4.5	860	33.0	.109	28.0	18.00	4.50	2.50	74
P21112	N	N	2,300	9.7	.113	22.0	14.00	2.50	.82	110
P21211	N	15.0	1,000	16.0	.142	20.0	12.00	2.70	1.30	66
P21221	N	7.8	740	26.0	.119	17.0	16.00	4.00	2.20	59
P21222	N	7.8	750	27.0	.121	18.0	16.00	4.00	2.30	60
P22111	N	N	880	28.0	.125	37.0	19.00	5.20	2.80	96
P22211	N	4.4	700	30.0	.129	33.0	17.00	4.80	2.70	320
			ARTEMISIA TRIDENTATA (BIG SAGEBRUSH) STEMS AND LEAVES--CONTINUED							
S11111	N	N	2,100	N	.154	33.0	N	N	N	210
S11112	N	N	1,900	N	.186	32.0	1.00	N	N	33
S11121	N	N	2,100	N	.175	39.0	N	N	N	34
S11211	N	N	2,700	N	.179	67.0	1.10	N	N	38
S11221	N	N	1,900	N	.184	44.0	1.50	N	N	42
S12111	N	N	2,600	N	.155	65.0	N	N	N	78
S12112	N	N	2,200	N	.147	63.0	.83	N	N	27
S12211	N	N	2,000	N	.183	42.0	N	N	N	40
S21111	N	N	1,700	N	.191	24.0	.88	N	N	40
S21211	N	N	2,600	N	.204	13.0	N	N	N	48
S22111	N	N	3,200	N	.165	33.0	N	N	N	27
S22112	N	N	3,200	N	.150	32.0	N	N	N	28
S22211	N	N	1,800	N	.144	19.0	3.50	N	N	49
S22221	N	11.0	3,000	N	.295	43.0	N	N	N	51

[1] N values (ppm): B= 0.4; Be= 0.024; Ce= 3.6; Cd= 0.8; Cr= 4.0; La= 4.0; Mo= 1.6; Ni= 4.0; Pb= 8.0; Ti= 0.8; V= 0.6; Y= 0.16.

APPENDIX III.--BASELINE SOIL GEOCHEMISTRY STUDY

[N, less than the instrumental lower limit of detection (see footnote); <; less than the analytical lower limit of determination (adjusted for solution and sample composition matrix effects)]

SAMPLE	AG, PPM[1]	AL, PPM	B, PPM[1]	BA, PPM	BE, PPM	CA, PPM	CD, PPM[1]	CE, PPM[1]	CO, PPM[1]	CR, PPM	CU, PPM	FE, PPM	HG, PPM	LA, PPM
SOILS ASSOCIATED WITH GREEN ASH AND PARMELIA SULCATA														
SA11111	N	7,300	N	170	.46	8,000	N	19.0	N	13.0	14.0	15,000	.02	11
SA11211	N	8,400	N	150	.67	13,000	N	24.0	<9.3	18.0	25.0	17,000	.04	14
SA11221	N	7,600	N	180	.60	5,000	N	21.0	N	14.0	16.0	16,000	.04	11
SA12111	N	7,900	N	240	.69	8,800	N	19.0	N	16.0	22.0	15,000	.06	12
SA12112	N	6,700	N	240	.61	8,600	N	N	N	12.0	20.0	15,000	.06	11
SA12221	N	6,000	N	150	.57	8,300	N	17.0	N	34.0	15.0	13,000	.04	10
SA21111	N	7,100	N	150	.49	6,100	N	25.0	N	<9.5	9.6	7,300	.02	13
SA21112	N	6,700	N	220	.45	6,500	N	19.0	N	<7.9	9.5	7,100	.08	11
SA21211	N	5,900	N	330	.54	5,800	N	24.0	N	11.0	18.0	8,600	.10	12
SA21221	N	5,800	N	270	.44	11,000	N	16.0	N	<8.2	24.0	14,000	.10	10
SA21222	N	6,400	N	270	.47	11,000	N	18.0	N	10.0	26.0	14,000	.06	11
SA22111	N	8,200	N	560	.80	21,000	N	24.0	<8.8	12.0	19.0	21,000	.04	15
SA22211	N	5,600	N	570	.59	26,000	N	19.0	N	11.0	13.0	17,000	.04	13
SOILS ASSOCIATED WITH WESTERN WHEATGRASS														
SG11111	N	4,400	N	140	.29	9,400	N	17.0	N	<6.9	9.5	13,000	.04	12
SG11211	N	5,600	N	280	.42	6,900	N	18.0	N	10.0	15.0	13,000	.04	10
SG11221	N	5,800	N	220	.43	8,200	N	18.0	N	<9.2	16.0	14,000	.04	11
SG12111	N	6,900	N	210	.57	3,100	N	21.0	N	14.0	12.0	14,000	.02	12
SG12112	N	7,600	N	210	.61	3,200	N	26.0	<9.0	13.0	14.0	15,000	.04	14
SG12121	N	6,400	N	180	.53	3,600	N	18.0	N	11.0	15.0	14,000	.04	10
SG12211	N	8,400	N	230	.55	23,000	N	32.0	N	18.0	24.0	20,000	.06	19
SG21111	N	7,700	N	260	.68	3,500	N	24.0	N	14.0	16.0	16,000	.04	12
SG21112	N	8,000	N	270	.65	3,600	N	22.0	N	12.0	17.0	17,000	.04	12
SG21211	N	7,800	N	250	.59	3,600	N	22.0	N	<13.0	15.0	14,000	.04	<12
SG22111	N	8,100	N	140	.57	14,000	N	21.0	N	80.0	23.0	19,000	.06	14
SG22112	N	8,700	N	140	.63	14,000	N	21.0	N	18.0	23.0	18,000	.04	14
SG22211	N	5,900	N	280	.44	3,400	N	17.0	N	<8.7	10.0	14,000	.04	10
SG22221	N	6,100	N	330	.44	3,600	N	19.0	N	16.0	12.0	14,000	.04	11
SOILS ASSOCIATED WITH BIG SAGEBRUSH														
SS11111	N	7,200	N	120	.70	16,000	N	23.0	N	13.0	16.0	15,000	.04	15
SS11121	N	8,700	N	210	.74	5,200	N	23.0	N	14.0	22.0	17,000	.06	13
SS11211	N	7,900	N	170	.67	14,000	N	23.0	N	13.0	23.0	19,000	.06	13
SS11221	N	6,100	N	260	.38	12,000	N	19.0	N	11.0	13.0	12,000	.04	12
SS11222	N	6,800	N	270	.40	13,000	N	19.0	N	14.0	15.0	14,000	.04	13
SS12111	N	5,500	N	240	.42	7,200	N	17.0	N	<9.0	9.7	13,000	.04	10
SS12211	N	9,100	N	140	.50	14,000	N	30.0	N	12.0	20.0	15,000	.06	17
SS21111	N	8,100	N	230	.69	28,000	N	22.0	N	11.0	23.0	16,000	.06	15
SS21112	N	8,900	N	290	.76	28,000	N	25.0	N	13.0	23.0	16,000	.06	16
SS21211	N	5,800	N	230	.56	23,000	N	20.0	N	<7.7	17.0	17,000	.04	13

SAMPLE	MG, PPM	MN, PPM	MO, PPM[1]	NB, PPM	NI, PPM	P, PPM	PB, PPM[1]	SR, PPM	S, %	TI, PPM	V, PPM	Y, PPM	ZN, PPM
SOILS ASSOCIATED WITH GREEN ASH AND PARMELIA SULCATA--CONTINUED													
SA11111	5,700	500	N	6.6	21.0	700	<15.0	26	.006	11.0	17.0	5.9	61
SA11211	5,300	450	N	8.3	34.0	670	<19.0	56	<.005	11.0	24.0	8.0	70
SA11221	3,400	480	N	5.7	22.0	750	<19.0	43	.010	5.9	19.0	6.9	74
SA12111	5,100	380	N	5.8	24.0	520	<17.0	72	.016	5.8	20.0	7.1	78
SA12112	4,400	350	N	5.0	23.0	480	<15.0	70	.025	5.0	19.0	6.7	62
SA12221	3,700	410	N	4.9	17.0	700	<16.0	61	.049	4.3	16.0	5.2	72
SA21111	2,700	140	<3.1	5.2	12.0	540	<16.0	50	.022	5.5	9.7	5.1	55
SA21112	2,600	140	N	3.0	<9.6	530	<11.0	53	.029	5.9	9.2	4.7	56
SA21211	2,400	170	N	3.0	15.0	440	<16.0	40	.031	3.0	10.0	6.7	51
SA21221	5,400	300	N	4.8	11.0	420	<14.0	34	.094	5.6	15.0	4.5	89
SA21222	5,800	310	N	5.8	13.0	450	<16.0	34	.084	5.9	15.0	4.8	54
SA22111	8,500	350	<1.9	11.0	20.0	700	22.0	140	.356	8.2	19.0	5.9	67
SA22211	8,000	730	N	8.0	20.0	780	<8.8	68	.007	13.0	19.0	6.6	53
SOILS ASSOCIATED WITH WESTERN WHEATGRASS--CONTINUED													
SG11111	3,700	300	N	2.5	21.0	460	N	44	<.005	30.0	14.0	5.5	58
SG11211	4,600	490	N	4.6	20.0	660	<13.0	25	.006	6.6	14.0	5.5	63
SG11221	4,700	500	N	4.4	21.0	690	<12.0	23	<.005	8.1	14.0	5.8	87
SG12111	3,000	450	N	4.5	18.0	520	<14.0	20	.006	5.9	17.0	6.9	55
SG12112	3,200	470	N	6.8	20.0	540	20.0	20	.008	10.0	17.0	7.4	59
SG12121	2,600	360	N	3.4	19.0	580	<12.0	24	.014	5.0	16.0	6.2	59
SG12211	7,900	620	N	8.2	30.0	830	<15.0	87	<.005	120.0	23.0	9.0	94
SG21111	3,000	640	N	6.1	20.0	650	21.0	23	.040	7.1	19.0	7.6	84
SG21112	2,800	610	N	4.1	18.0	600	<17.0	23	.039	6.2	19.0	7.2	85
SG21211	3,000	590	N	4.5	20.0	740	<17.0	21	.020	5.6	15.0	7.1	74
SG22111	7,200	670	N	7.4	27.0	750	<13.0	43	<.005	12.0	20.0	6.5	91
SG22112	7,900	700	N	8.5	29.0	760	<19.0	44	<.005	21.0	19.0	6.9	110
SG22211	2,500	550	N	2.3	15.0	700	<11.0	19	.022	6.5	16.0	6.1	62
SG22221	2,700	580	N	3.3	16.0	840	<12.0	19	.034	6.2	16.0	6.0	97
SOILS ASSOCIATED WITH BIG SAGEBRUSH--CONTINUED													
SS11111	8,000	530	N	6.9	21.0	630	<18.0	48	<.005	20.0	16.0	7.5	69
SS11121	4,400	180	N	5.1	20.0	480	<19.0	76	.015	20.0	17.0	6.1	69
SS11211	6,300	640	N	6.7	28.0	610	<17.0	69	.009	40.0	20.0	8.2	72
SS11221	6,400	350	N	5.2	21.0	780	<11.0	44	<.005	12.0	16.0	6.4	63
SS11222	6,800	370	N	6.7	22.0	800	<11.0	46	<.005	15.0	16.0	6.6	130
SS12111	4,500	310	N	4.2	19.0	680	N	35	.011	7.5	16.0	5.6	48
SS12211	8,100	360	N	7.6	26.0	510	<19.0	53	<.005	31.0	12.0	7.5	74
SS21111	10,000	310	N	8.5	20.0	490	<20.0	63	.290	57.0	18.0	8.8	93
SS21112	11,000	320	N	12.0	22.0	520	24.0	65	.301	55.0	18.0	9.1	95
SS21211	8,300	370	N	7.0	18.0	470	<14.0	44	<.005	20.0	16.0	6.9	79

APPENDIX III.--BASELINE SOIL GEOCHEMISTRY STUDY--CONTINUED

SAMPLE	AG, PPM[1]	AL, PPM	B, PPM[1]	BA, PPM	BE, PPM	CA, PPM	CD, PPM[1]	CE, PPM[1]	CO, PPM[1]	CR, PPM	CU, PPM	FE, PPM	HG, PPM	LA, PPM
SS22111	N	6,900	N	390	.41	22,000	N	19.0	N	45.0	12.0	14,000	.02	13
SS22112	N	7,300	N	380	.44	24,000	N	23.0	N	12.0	13.0	14,000	.02	15
SS22211	N	11,000	N	330	.96	3,500	N	25.0	<15.0	25.0	33.0	25,000	.04	14
SS22221	N	9,600	N	180	.71	16,000	N	25.0	N	22.0	34.0	24,000	.06	15

SAMPLE	MG, PPM	MN, PPM	MO, PPM[1]	NB, PPM	NI, PPM	P, PPM	PB, PPM[1]	SR, PPM	S, %	TI, PPM	V, PPM	Y, PPM	ZN, PPM
SS22111	7,700	470	N	7.6	19.0	800	<9.2	55	<.005	14.0	17.0	6.3	54
SS22112	8,300	500	N	9.4	20.0	800	<14.0	57	<.005	17.0	18.0	6.9	53
SS22211	5,600	450	4.7	9.2	66.0	630	29.0	41	.085	120.0	32.0	9.0	120
SS22221	8,400	710	N	11.0	39.0	730	23.0	73	<.005	80.0	32.0	7.5	98

[1] N values (ppm): Ag= 0.8; B= 0.4; Cd= 0.8; Ce= 3.6; Co= 8.0; Mo= 1.6; Pb= 8.0.

APPENDIX IV--DOWNWIND TRAVERSE STUDY (DRY WEIGHT BASE)

SAMPLE	NI, PPM[1]	P, PPM	PB, PPM[1]	S, %	SR, PPM	TI, PPM[1]	V, PPM[1]	Y, PPM[1]	ZN, PPM
AGROPYRON SMITHII (WESTERN WHEATGRASS)--CONTINUED									
0.10AS11	N	810	N	.148	25	N	N	N	26
0.10AS21	N	1,300	N	.176	19	2.20	N	N	38
0.25AS11	N	1,100	N	.179	33	N	N	N	31
0.25AS21	N	1,200	N	.211	25	N	N	N	28
0.50AS11	N	1,000	N	.201	36	N	N	N	29
0.50AS21	N	1,100	N	.333	23	2.60	N	N	31
2.00AS11	N	2,000	N	.180	17	1.40	N	N	34
2.00AS12	N	2,000	N	.180	18	.82	N	N	38
2.00AS21	N	1,600	N	.178	29	5.40	N	N	47
4.00AS11	N	1,700	N	.211	20	2.10	N	N	37
4.00AS21	N	1,500	N	.211	23	N	N	N	33
8.00AS11	N	1,800	N	.189	20	1.30	N	N	25
8.00AS21	N	1,600	N	.128	21	1.40	N	N	27
8.00AS22	N	1,700	N	.130	21	N	N	N	23
PARMELIA CHLOROCHROA (SOIL LICHEN)--CONTINUED									
0.25PC11	N	940	N	.123	18	19.00	1.8	1.40	53
0.25PC21	N	880	N	.117	18	16.00	1.2	1.00	65
0.50PC11	15.0	1,100	13	.108	23	14.00	N	.50	170
0.50PC21	6.0	1,000	N	.116	25	30.00	4.2	1.60	46
1.00PC11	10.0	1,000	N	.102	30	38.00	2.6	2.00	37
1.00PC21	9.3	1,200	N	.111	20	33.00	4.1	2.20	46
2.00PC11	8.2	980	N	.101	25	32.00	3.0	2.20	46
2.00PC12	8.2	970	N	.098	25	28.00	2.8	2.20	59
2.00PC21	N	1,100	N	.094	26	23.00	1.6	1.30	44
4.00PC11	6.9	870	N	.106	18	39.00	2.9	2.10	55
4.00PC21	11.0	920	N	.104	19	61.00	5.5	2.60	48
4.00PC22	11.0	890	N	.111	18	24.00	4.2	2.50	48
SELAGINELLA DENSA (SELAGINELLA)--CONTINUED									
0.10SD11	N	1,200	N	.146	25	15.00	2.0	.87	150
0.10SD21	N	1,200	N	.168	25	16.00	1.5	.63	140
0.25SD11	N	1,200	N	.160	24	19.00	2.1	.97	110
0.25SD21	N	1,200	N	.162	23	16.00	1.4	.44	91
0.25SD22	N	1,200	N	.160	24	15.00	2.3	.43	110
0.50SD11	N	1,100	N	.142	29	14.00	1.1	.60	95
0.50SD21	N	950	N	.147	19	16.00	1.3	.56	91
1.00SD11	N	1,100	N	.145	30	16.00	1.0	.40	130
1.00SD21	N	1,400	N	.153	26	16.00	2.1	.97	120
4.00SD11	N	1,300	N	.154	24	14.00	2.3	1.10	120
4.00SD21	4.1	1,500	N	.170	25	23.00	4.5	1.80	88
4.00SD22	N	1,400	N	.164	23	20.00	3.8	1.80	78

[1] N values (ppm): B=0.4; Be=0.024; Ce=3.6; Cd=0.8; Cr=4.0; La=4.0; Mo=1.6; Ni=4.0; Pb=8.0; Ti=0.8; V=0.6; Y=0.16.

APPENDIX IV.--DOWNWIND TRAVERSE STUDY (DRY WEIGHT BASE)

SAMPLE	CD, PPM[1]	CR, PPM[1]	CU, PPM	FE, PPM	GE, PPM	HG, PPM	LA, PPM[1]	MG, PPM	MN, PPM	MO, PPM[1]
				AGROPYRON SMITHII (WESTERN WHEATGRASS)--CONTINUED						
0.10AS11	N	N	3.3	76	N	.015	N	1,400	67	N
0.10AS21	N	N	6.2	150	N	.020	N	960	52	N
0.25AS11	N	N	3.3	140	N	.020	N	2,200	53	N
0.25AS21	N	N	6.1	110	N	.015	N	2,000	49	N
0.50AS11	N	N	4.5	140	N	.015	N	1,700	41	N
0.50AS21	N	N	3.9	280	N	.020	N	2,200	37	N
2.00AS11	N	N	4.6	150	N	.015	N	1,200	39	N
2.00AS12	N	N	5.1	170	N	.015	N	1,200	40	N
2.00AS21	N	N	5.3	330	N	.015	N	1,700	49	N
4.00AS11	N	N	4.7	180	N	.015	N	780	55	N
4.00AS21	N	N	5.2	160	N	.025	N	1,600	32	N
8.00AS11	N	4.3	1.9	280	N	.020	N	950	42	N
8.00AS21	N	N	5.0	350	N	.020	N	1,100	44	N
8.00AS22	N	N	2.0	290	N	.020	N	1,100	43	N
				PARMELIA CHLOROCHROA (SOIL LICHEN)--CONTINUED						
0.25PC11	N	7.2	10.0	2,100	N	.110	N	530	59	N
0.25PC21	N	7.7	11.0	1,400	N	.070	N	490	44	N
0.50PC11	N	71.0	10.0	950	N	.090	N	900	38	N
0.50PC21	N	5.7	9.9	2,600	N	.090	N	810	52	N
1.00PC11	N	17.0	8.2	2,400	N	.050	N	650	58	N
1.00PC21	N	17.0	9.0	3,100	N	.090	N	690	67	N
2.00PC11	N	6.2	11.0	2,300	N	.075	N	930	87	N
2.00PC12	N	15.0	10.0	2,200	N	.085	N	930	87	N
2.00PC21	N	5.3	9.0	1,400	N	.060	N	720	61	N
4.00PC11	N	13.0	9.0	2,300	N	.080	N	680	53	N
4.00PC21	N	19.0	11.0	2,800	N	.070	N	830	59	N
4.00PC22	N	17.0	13.0	2,700	N	.070	N	810	58	N
				SELAGINELLA DENSA (SELAGINELLA)--CONTINUED						
0.10SD11	N	4.7	53.0	1,300	N	.030	N	1,700	160	N
0.10SD21	N	4.9	34.0	1,500	N	.030	N	1,600	160	N
0.25SD11	N	4.3	13.0	2,000	N	.040	N	1,500	210	N
0.25SD21	N	N	54.0	1,300	N	.030	N	1,300	150	N
0.25SD22	N	N	44.0	1,400	N	.025	N	1,300	150	N
0.50SD11	N	N	52.0	1,100	N	.030	N	1,500	120	N
0.50SD21	N	4.4	9.8	1,300	N	.025	N	1,300	110	N
1.00SD11	N	N	9.6	1,300	N	.025	N	1,400	140	N
1.00SD21	N	4.8	11.0	1,800	N	.025	N	1,500	220	N
4.00SD11	N	4.4	11.0	1,600	N	.040	N	1,600	120	N
4.00SD21	N	4.3	11.0	2,300	N	.030	N	1,700	120	N
4.00SD22	N	N	7.3	2,300	N	.030	N	1,600	120	N

APPENDIX IV.--DOWNWIND TRAVERSE STUDY (DRY WEIGHT BASE)

[N, less than the instrumental lower limit of detection (see footnote); <; less than the analytical lower limit of determination (adjusted for solution and sample composition matrix effects; DIST. means distance in km southeast of the processing facility]

SAMPLE	DIST. KM	ASH, %	AL, PPM	AS, PPM	B, PPM[1]	BA, PPM	BE, PPM[1]	CA, PPM	CE, PPM[1]
				AGROPYRON SMITHII (WESTERN WHEATGRASS)					
0.10AS11	.10	9	23	<.05	2.10	55	N	5,700	N
0.10AS21	.10	9	56	<.05	3.40	43	N	3,700	N
0.25AS11	.20	9	48	<.05	3.20	49	N	4,700	N
0.25AS21	.20	9	32	.05	3.90	16	N	3,800	N
0.50AS11	.45	9	50	.05	2.70	25	N	4,900	N
0.50AS21	.45	8	120	.10	3.60	18	N	4,200	N
2.00AS11	1.95	11	60	.10	3.40	39	N	3,500	N
2.00AS12	1.95	11	70	.10	3.30	43	N	3,400	N
2.00AS21	1.95	11	140	.20	3.00	38	N	4,300	N
4.00AS11	3.90	9	77	<.05	3.80	45	N	3,600	N
4.00AS21	3.90	9	68	<.05	3.50	49	N	4,800	N
8.00AS11	7.70	11	130	.05	4.10	49	N	5,400	N
8.00AS21	7.70	11	160	.05	3.40	67	N	5,200	N
8.00AS22	7.70	11	140	.05	4.20	67	N	5,300	N
				PARMELIA CHLOROCHROA (SOIL LICHEN)					
0.25PC11	.25	9	640	.70	N	42	.063	20,000	N
0.25PC21	.25	8	430	.60	1.20	36	N	18,000	N
0.50PC11	.50	6	370	.90	1.60	21	N	15,000	N
0.50PC21	.50	12	940	.90	1.60	40	.081	25,000	N
1.00PC11	.80	16	840	.65	2.70	29	.066	34,000	N
1.00PC21	.80	17	1,100	1.10	N	35	.091	30,000	N
2.00PC11	1.63	10	1,100	.55	N	24	.110	16,000	N
2.00PC12	1.63	10	990	.40	.44	24	.100	17,000	N
2.00PC21	1.63	9	650	.55	1.40	22	.063	18,000	N
4.00PC11	4.00	14	980	.90	.84	47	.110	22,000	N
4.00PC21	4.00	16	1,300	.90	3.00	48	.140	19,000	N
4.00PC22	4.00	16	1,100	1.00	N	45	.130	18,000	N
				SELAGINELLA DENSA (SELAGINELLA)					
0.10SD11	.10	15	440	.35	3.80	120	.058	4,100	N
0.10SD21	.10	14	460	.60	4.40	120	.047	4,600	N
0.25SD11	.25	15	580	.80	1.80	120	.062	4,600	N
0.25SD21	.25	14	440	.50	2.90	130	N	4,100	N
0.25SD22	.25	14	390	.45	2.20	120	N	4,200	N
0.50SD11	.45	13	430	.40	1.80	87	.046	4,200	N
0.50SD21	.45	14	470	.50	3.60	81	.049	3,200	N
1.00SD11	.90	15	530	.40	2.90	96	.040	4,400	N
1.00SD21	.90	16	730	.45	.89	94	.064	4,400	N
4.00SD11	4.00	17	740	.45	1.80	94	.078	4,100	N
4.00SD21	4.00	16	990	.70	.80	97	.110	4,200	N
4.00SD22	4.00	17	1,000	.80	N	93	.120	3,900	N

APPENDIX V.--ELEMENT CONCENTRATIONS IN SOIL SAMPLES, DOWNWIND TRAVERSE STUDY

[N; less than the instrumental lower limit of detection (see footnote); DIST. means distance in km southeast of the processing facility]

SAMPLE	DIST. KM	AL, PPM	BA, PPM	BE, PPM	CA, PPM	CE, PPM	CR, PPM[1]	CU, PPM	FE, PPM	LA, PPM	MG, PPM
0.10DI11	.10	7,500	250	.48	3,800	20	N	11.0	18,000	10.0	2,900
0.10DI12	.10	7,200	240	.48	3,600	20	N	11.0	18,000	10.0	2,800
0.10DI21	.10	7,300	270	.48	3,900	18	11.0	12.0	22,000	9.6	2,900
0.25DI11	.25	7,600	150	.43	3,000	17	N	8.5	19,000	9.0	3,100
0.25DI21	.25	8,100	240	.58	4,600	18	N	15.0	24,000	9.9	4,400
0.25DI22	.25	8,000	270	.60	4,700	18	N	15.0	26,000	10.0	4,300
0.50DI11	.50	7,200	320	.48	7,200	19	N	9.8	18,000	11.0	5,500
0.50DI21	.50	9,000	160	.40	3,300	23	4.8	8.7	14,000	12.0	3,900
1.00DI11	1.00	7,300	130	.39	2,800	17	N	7.7	16,000	8.9	2,900
1.00DI21	1.00	6,700	100	.32	4,500	17	N	5.5	14,000	8.9	3,500
2.00DI11	2.00	10,000	220	.75	3,300	27	N	14.0	25,000	13.0	3,900
2.00DI21	2.00	8,700	220	.70	2,900	23	N	13.0	22,000	12.0	3,400
2.00DI22	2.00	9,600	230	.78	3,300	26	N	14.0	23,000	13.0	3,600
4.00DI11	4.10	7,500	190	.41	3,300	20	N	7.8	14,000	10.0	3,100
4.00DI21	4.10	7,900	200	.44	3,400	20	N	8.3	14,000	10.0	3,100
8.00DI11	8.00	7,800	280	.43	5,500	19	N	6.2	18,000	10.0	3,200
8.00DI12	8.00	7,700	270	.43	5,400	19	N	6.1	18,000	10.0	3,200
8.00DI21	8.00	8,000	240	.40	3,600	18	6.6	4.9	17,000	9.5	3,400

SAMPLE	MN, PPM	NI, PPM	P, PPM	PB, PPM	TOT. S,%	SR, PPM	TI, PPM	V, PPM	Y, PPM	ZN, PPM
0.10DI11	970	14	670	15	.049	23	9.6	18	5.0	56
0.10DI12	870	14	600	16	.050	22	4.1	18	4.9	54
0.10DI21	810	14	600	12	.040	21	5.1	20	4.0	45
0.25DI11	450	13	480	12	.034	18	4.4	19	3.9	39
0.25DI21	1,000	19	630	15	.088	24	3.4	21	5.2	54
0.25DI22	1,000	19	630	14	.087	25	5.1	21	5.1	54
0.50DI11	440	21	500	11	.037	47	2.3	20	5.8	45
0.50DI21	230	19	400	13	.025	30	2.1	21	6.1	43
1.00DI11	530	12	480	12	.027	20	4.7	18	3.7	41
1.00DI21	370	13	470	10	.027	22	1.6	17	3.9	37
2.00DI11	500	21	550	18	.023	24	7.8	28	6.9	49
2.00DI21	460	20	460	16	.022	21	4.1	23	6.8	43
2.00DI22	490	21	490	16	.028	24	4.0	25	7.7	45
4.00DI11	470	13	550	14	.034	31	4.1	18	5.3	54
4.00DI21	440	14	540	15	.037	30	2.5	19	5.7	50
8.00DI11	620	17	630	12	.024	41	2.9	20	5.2	46
8.00DI12	610	17	620	12	.025	39	3.7	20	5.3	45
8.00DI21	520	17	470	11	.013	39	2.0	20	4.5	42

[1] N value for Cr = 4.0 ppm.