

Geochemical Variability of Natural Soils and Reclaimed Mine-Spoil Soils in the San Juan Basin, New Mexico

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1134-C



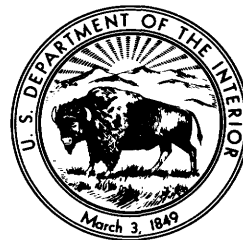
Geochemical Variability of Natural Soils and Reclaimed Mine-Spoil Soils in the San Juan Basin, New Mexico

By R. C. SEVERSON *and* L. P. GOUGH

GEOCHEMICAL SURVEY OF THE WESTERN ENERGY REGIONS

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1134-C

*A study providing background information for total and
extractable element composition of soils in areas
likely to be affected by energy-related development*



UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, *Secretary*

GEOLOGICAL SURVEY

Doyle G. Frederick, *Acting Director*

Library of Congress Cataloging in Publication Data

Severson, R. C. (Ronald Charles), 1945-

Geochemical variability of natural soils and reclaimed mine-spoil soils in the San Juan Basin, New Mexico.

(Geochemical survey of the western energy regions)

(Geological Survey Professional Paper 1134-C)

Bibliography: p. 38

Supt. of Doc. no.: I 19.16:1134-C

1. Soils--New Mexico--Composition. 2. Soils--San Juan River watershed (Colo.-Utah)--Composition.

3. Coal mine waste--New Mexico--Farmington region--Composition. 4. Reclamation of land--New Mexico.

5. San Juan River watershed (Colo.-Utah)

I. Gough, L. P. II. Title. III. Title: Mine-spoil soils in San Juan Basin, New Mexico. IV. Series.

V. Series: Geological Survey Professional Paper 1134-C.

S599.N6S46

631.6'4

81-607985 AACR2

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

	Page
Abstract	1
Introduction	1
Acknowledgments	2
Methods	2
Sampling	2
Analysis	4
Use of variance components	4
Results and Discussion	5
Soil variability	5
Study 1	5
Study 2	9
Study 3	13
Summary	15
Soil composition	29
Study 1	29
Study 2	30
Study 3	34
Summary	34
Conclusions	37
References cited	38

ILLUSTRATIONS

	Page
FIGURE 1. Map showing geology and location of the study areas within the San Juan Basin	2
2. Photograph showing a typical landscape in the San Juan Basin	2
3. Map showing the nested sampling design and sampling locations in the area likely to be affected by energy-related development in the San Juan Basin	3
4. Map showing generalized sampling locations in the area containing soils considered to have potential for use as topsoil in mined-land reclamation	3
5. Photograph showing a reclaimed area of the San Juan mine	4
6. Maps showing regional trends in amounts of various parameters measured in soils in the area likely to be affected by energy-related developments in the San Juan Basin:	
6A. Total arsenic, A horizon	7
6B. Total arsenic, C horizon	7
6C. Total aluminum, C horizon	7
6D. Total barium, C horizon	7
6E. Carbonate carbon, C horizon	8
6F. Total carbon, C horizon	8
6G. Total calcium, C horizon	8
6H. Exchangable calcium, C horizon	8
6I. DTPA (diethylenetriamine penta acetic acid) extractable lead, C horizon	9
6J. Total lithium, A horizon	9
6K. Total magnesium, C horizon	9
6L. Total mercury, C horizon	9
6M. Total molybdenum, A horizon	10
6N. Total nickel, C horizon	10
6O. Total potassium, A horizon	10

FIGURE 6—Continued

	Page
6 P. Total silicon, C horizon	10
6 Q. Total sodium, C horizon	11
6 R. Total strontium, A horizon	11
6 S. Total strontium, C horizon	11
7. Maps showing average values for soil parameters within cells 25 km on a side measured in the area likely to be affected by energy-related developments in the San Juan Basin:	
7 A. Water-soluble calcium, A horizon	12
7 B. Water-soluble calcium, C horizon	12
7 C. Clay-size particles, C horizon	12
7 D. Total copper, C horizon	12
7 E. Total germanium, A horizon	13
7 F. Total iron, A horizon	13
7 G. DTPA extractable iron, A horizon	13
7 H. Total lanthanum, C horizon	13
7 I. Total magnesium, A horizon	14
7 J. Water-soluble magnesium, C horizon	14
7 K. DTPA extractable manganese, A horizon	14
7 L. DTPA extractable nickel, A horizon	14
7 M. Total potassium, C horizon	15
7 N. Total rubidium, A horizon	15
7 O. Total sulfur, C horizon	15
7 P. Total thorium, A horizon	15
7 Q. Total uranium, A horizon	16
7 R. Total yttrium, C horizon	16
7 S. Total zirconium, C horizon	16

TABLES

	Page
TABLE 1. Variance analysis of parameters of soils from the area likely to be affected by energy-related developments	5
2. Summary statistics of parameters of soils from the area likely to be affected by energy-related developments.	17
3. Variance analysis of soils from the area containing soils considered to have potential for use as topsoil in mined-land reclamation	20
4. Summary statistics of parameters measured of soil from the area containing soils considered to have potential for use as topsoil in mined-land reclamation	21
5. Variance analysis of parameters for topsoil and mine spoil from the San Juan mine	24
6. Summary statistics of parameters of topsoil and mine spoil from the San Juan mine	25
7. Taxonomy of soils sampled in the San Juan Basin	29
8. Parameter values measured for seven soil great groups in the area likely to be affected by energy-related developments in the San Juan Basin	31
9. Parameter values measured for five soil families sampled in the area containing soils considered to have potential for use as topsoil in mined-land reclamation in the San Juan Basin	35

GEOCHEMICAL VARIABILITY OF NATURAL SOILS AND RECLAIMED MINE-SPOIL SOILS IN THE SAN JUAN BASIN, NEW MEXICO

By R. C. SEVERSON and L. P. GOUGH

ABSTRACT

An inventory of total and extractable element concentrations in soils was made for three areas of the San Juan Basin in New Mexico: (1) the broad area likely to be affected by energy-related development, (2) an area of soils considered to have potential for use as topsoil in mined-land reclamation, and (3) an area of the San Juan coal mine that has been regraded, topsoiled, and revegetated. Maps made of concentrations of 16 elements in area 1 soils show no gradational pattern across the region. Further, these maps do not correspond to those showing geology or soil types. Sodic or saline problems, and a possible but unproven deficiency of zinc available to plants, may make some of the soils in this area undesirable for use as topsoil in mined-land reclamation. Taxonomic great groups of soil in this area cannot be distinguished because each great group tends to have a large within-group variability if compared to the between-group variability. In area 2 the major soils sampled were of the Sheppard, Shiprock, and Doak association. These soils are quite uniform in chemical composition and are not greatly saline or sodic. As in area 1 soils, zinc deficiency may cause a problem in revegetating most of these soils. It is difficult to distinguish soil taxonomic families by using their respective chemical compositions, because of small between-family variability. Topsoil from a reclaimed area of the San Juan mine (area 3) most closely resembles the chemical composition of natural C horizons of soil from area 1. Spoil material that has not been topsoiled is likely to cause sodic- and saline-related problems in revegetation and may cause boron toxicity in plants. Topsoiling has apparently ameliorated these potential problems for plant growth on mine spoil.

Total and extractable concentrations for elements and other parameters for each area of the San Juan Basin provide background information for the evaluation of the chemical quality of soils in each area.

INTRODUCTION

A reconnaissance geochemical survey of soil in the part of the San Juan Basin of New Mexico that is most likely to be affected by energy-related developments was conducted in the summer of 1977. The survey consisted of three parts: (1) an evaluation of soil variability over the broad region, (2) an appraisal of chemical variability in the Sheppard, Shiprock, and Doak soil association, which is considered likely to be used in topsoiling the reclaimed areas, and (3) an

evaluation of variability in topsoil and spoil in a reclaimed area of the San Juan mine. In addition to assessing spatial variability for element composition of soils, basic background information on the element composition of soil and spoil is provided for the materials in the San Juan Basin, which may be used to derive compositional background levels for elements in the taxonomically distinct soils.

A substantial amount of published information on soil and vegetation in the San Juan Basin is available. The statewide soil survey (Maker, Dregne, Link, and Anderson, 1974), as well as individual county surveys (San Juan County — Maker, Keetch, and Anderson, 1973; Rio Arriba County — Maker, Folks, Anderson, and Link, 1973; McKinley County — Maker, Bullock, and Anderson, 1974; and Sandoval County — Maker, Folks, Anderson and Gallman, 1971), provided data on quantity and quality of soil material present and its areal distribution. Researchers from New Mexico State University have provided much information on the vegetation and soil character of areas to be strip mined (Gould, Howard, and Buchanan, 1972, 1977; Gould, Howard, and Valentine, 1972), chemical and physical properties of soil samples from a coal-lease area (Rai and others, 1975), and chemical and physical properties of core samples of rock from coal-lease areas (Rai and others, 1974; Gould, Miyamoto, and Rai 1977). Maps showing surficial and bedrock geology of the area where surface mining is expected to be concentrated are also available (O'Sullivan, Scott, and Heller, 1979a, 1979b; Scott, O'Sullivan, and Heller, 1979a, 1979b; and Scott, O'Sullivan, and Mytton, 1979). These studies and maps provide much of the information necessary to assess the quality of site-specific soil and spoil material and the plant-growth potential.

Background data for the total content of nearly 40 elements and the extractable content of 15 elements are presented for soils in the region likely to be altered by mining activities, for soils considered to be the best

available material for stockpiling to be used later as topsoil for reclaimed areas, and for mine soil (topsoil and spoil material). These data fill a void in the present information on the chemical composition of soil in the region. Power (1978) stated that chemical data add a new dimension to reclamation research by providing a basis for defining the nature and properties of the soil and spoil resource being utilized in reclamation, and by helping to determine soil quality in relation to plant-growth potential.

Throughout this report, the part of the work dealing with soils in the region that are likely to be altered by energy-related developments is referred to as Study 1; the work on soil material of the Sheppard, Shiprock, and Doak soil association is labeled Study 2; and the work on topsoil and mine spoil chemistry is designated Study 3.

ACKNOWLEDGMENTS

All analyses were done in the laboratories of the U.S. Geological Survey in Denver, Colo. by J. W. Baker, A. J. Bartel, P. H. Briggs, J. G. Crock, C. M. Ellis, Carol Gent, K. E. Horan, R. G. Havens, Claude Huffman, Jr., Fred Lichte, J. G. McDade, C. McFee, H. T. Millard, Jr., Violet Merrit, Harriet Neiman, F. D. Perez, S. E. Prelipp, George Riddle, V. E. Shaw, A. L. Sutton, Jr., J. A. Thomas, M. L. Tuttle, R. E. Van Loenen, J. S. Wahlberg, and W. J. Walz. Voucher specimens of each soil sampled in Study 1 and Study 2 were identified taxonomically by J. E. Ruiz and Leroy Hacker, soil scientists with the U.S. Department of Agriculture, Soil Conservation Service in Aztec and Albuquerque, N. Mex., respectively. We are grateful for the cooperation of R. W. Allen of the Western Coal Company in granting permission to sample soil and spoil material at the San Juan coal mine, and to the Navajo Tribal Council for granting permission to sample soils on their land. Monte McClendon, of the U.S. Bureau of Land Management at Farmington, N. Mex., and C. W. Keetch, of the Soil Conservation Service at Aztec, provided much valuable information about the local area.

METHODS

SAMPLING

At each sampling location, a pit was dug and specimens of each soil horizon were collected so that each soil sampled could, at a later date, be identified taxonomically. The actual samples for chemical analyses were collected with a barrel-type auger adjacent to the soil pit. About 2 kg (kilograms) of material were collected from the A and C horizon of

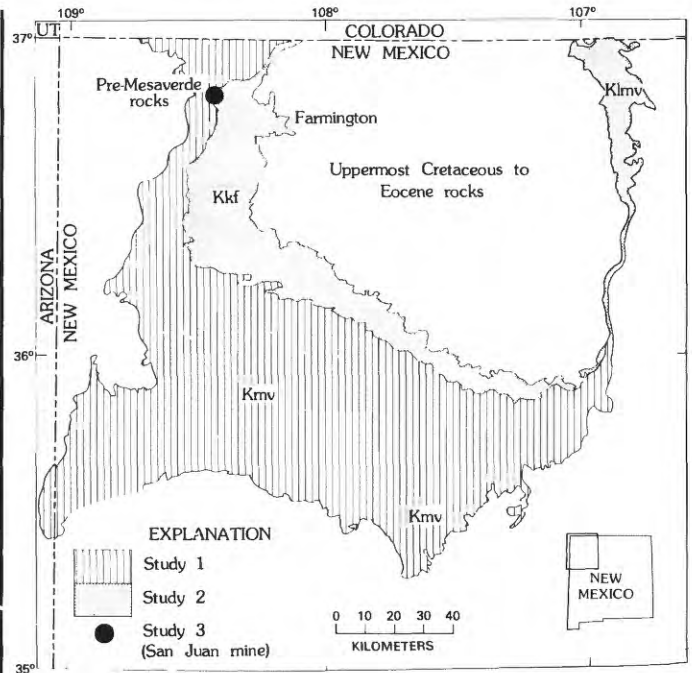


FIGURE 1.—Map showing geology and location of the three study areas within the San Juan Basin. Geology modified from Dane and Bachman (1965). Kkf, Kirtland Shale and Fruitland Formation; Klmv, Lewis Shale and Mesaverde Group; all of Late Cretaceous age. Units listed in order of increasing age.



FIGURE 2.—Landscape typical of the San Juan Basin. Sheppard and Shiprock soils are developed on stabilized dunes (background and foreground) and Doak soils are developed in the area between the stabilized dunes (middle ground). Photographed August 15, 1977.

the soil. This material was placed in paper envelopes for transportation to the laboratories.

Samples of A and C horizons of soils for Study 1 were collected at 47 locations in the coal region of northwest New Mexico (fig. 1). A typical landscape in the San Juan Basin is shown in figure 2. This area is underlain

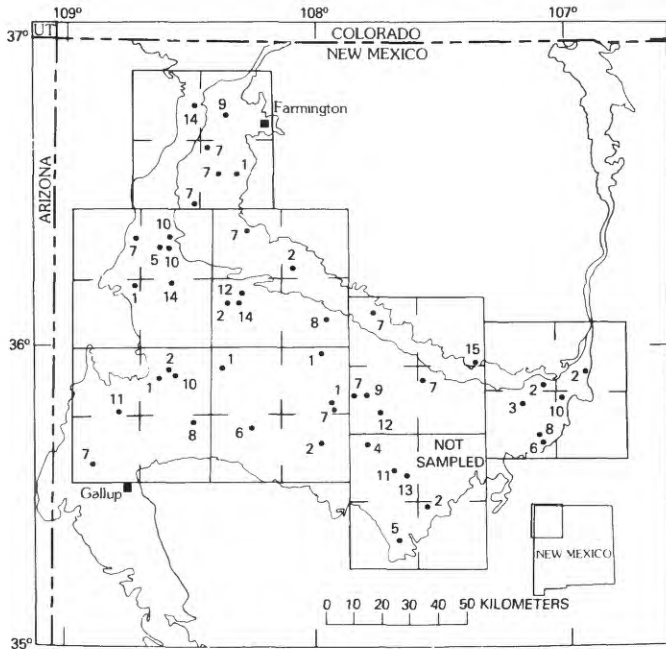


FIGURE 3.—Soil-sampling locations in the area likely to be affected by energy-related development in the San Juan Basin. Large squares (solid lines) are 50 km on a side; smaller squares (dashed lines) are 25 km on a side. Dots are sampling sites. Number adjacent to each dot indicates the soil taxonomy at the sampling site (table 7).

by the Kirtland Shale, Fruitland Formation, and the undifferentiated Mesaverde Group, all of Cretaceous age (Dane and Bachman, 1965). Sampling locations were selected randomly for a five-level, unbalanced, nested analysis-of-variance design (Leone and others, 1968). Within the irregular boundaries of the coal region, cells 50 km on a side were arranged to provide maximum coverage (fig. 3). Each of the eight 50-km (kilometers) cells was divided into areas of decreasing size, as follows: four 25-km cells, each of which was divided into 25 5-km cells. The cells sampled were randomly selected, as follows: all four 25-km cells; two 5-km cells in one 25-km cell and one 5-km cell in each of the three other 25-km cells; two 1-km cells in one 5-km cell and one 1-km cell in each of the four other 5-km cells. This nested arrangement of cells sampled resulted in the selection of 48 sampling locations as shown in figure 3; however, only 47 locations were actually sampled because one location was inaccessible. One sample each of A and C horizons of soil was collected from each location. Eight of the 47 samples of each horizon were split and analyzed in duplicate.

Samples of A and C horizons of soil for Study 2 were collected at 30 localities in northwest New Mexico. The localities were confined within the boundaries of

the mapped occurrence (Dane and Bachman, 1965) of the coal-bearing Fruitland Shale and Kirtland Formation of Cretaceous age (fig. 1), and also within the boundaries of the mapped occurrence of the Sheppard, Shiprock, and Doak soils (Maker, Keetch, and Anderson, 1973). The actual sampling locations were selected randomly, based on an unbalanced, nested analysis-of-variance design (Leone and others, 1968) of the barbell type (Tidball and Ebens, 1976). Three barbells were oriented in the area by selecting compass directions at random. The major axis of each barbell was 10 km long, and the sequentially smaller axes were 5, 1, and 0.1 km. The general location of each barbell is shown in figure 4. Ten localities were sampled in each barbell, resulting in a total of 30 samples each of A and C horizons of soils. Ten of the 30 samples from each horizon were split and analyzed in duplicate.

Samples of topsoil and mine spoil for Study 3 were collected at six locations at the San Juan mine (fig. 1) from an area that had been reclaimed (graded, topsoiled, and revegetated) in 1974 (fig. 5). Sample locations were selected randomly, based on a four-level, nested analysis-of-variance design (Leone and others, 1968). Within about a 4 ha (hectare) area, the axes of a barbell were oriented by selecting a compass direction at random. The major axis of the barbell was 100 m long, and the sequentially smaller axes were 25 and 5 m. Each of the six topsoil and mine spoil samples were split and analyzed twice, yielding a total of 24 samples. The topsoil consisted of a uniform layer of

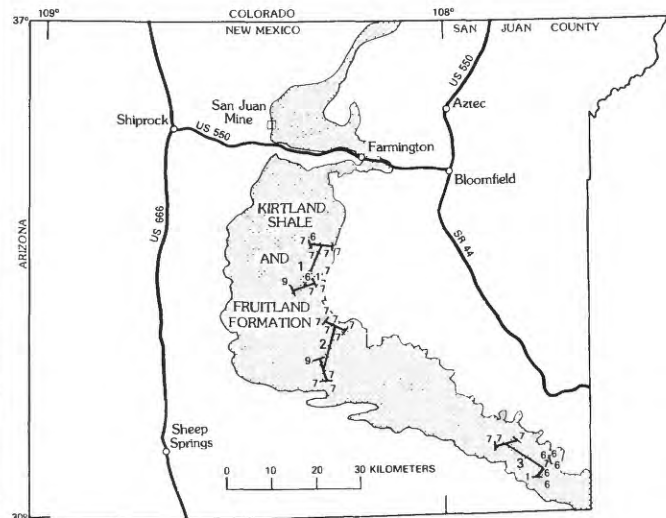


FIGURE 4.—Map showing generalized sample locations in the area containing soils considered to have potential for use as topsoil in mined-land reclamation. Numbers adjacent to barbells indicate approximate sampling locality and indicate the taxonomy of the soil sampled (table 7).



FIGURE 5.—Area of the San Juan Mine from which topsoil and spoil were collected in Study 3. The area was reclaimed (regraded, topsoiled, and seeded) in 1974. Photographed August 15, 1977.

about 20 cm (centimeters) of soil that had been stockpiled prior to mining. This 20 cm of topsoil, and underlying mine spoil to a depth of 50 cm, were sampled.

ANALYSIS

All samples were dried at ambient temperature and then were disaggregated in a motor-driven ceramic mortar and pestle, and the portion passing a 2-mm (millimeter) stainless-steel sieve was saved. Splits of the less-than-2-mm material was further ground to minus-100 mesh in a ceramic mill, and this material was used for all total-element determinations. The disaggregated but unground less-than-2-mm material was used for the extractable-element determinations. After disaggregating, greater than 95 percent of the material from the A and C horizons and of topsoil used in reclamation passed the 2-mm sieve. The amount of mine spoil material passing the sieve varied from sample to sample depending on the lithology and cementation of the rock. The effects of such fractionation, resulting from sample preparation, are unknown. Some guidelines should be established for preparation of sedimentary rocks differing in lithology and cementation in order to standardize the results of chemical analysis from laboratory to laboratory.

Concentrations of some elements in some samples were below the limit of determination (censored) by a given analytical method. When more than one-third of the determinations for an element were below this limit the element was omitted from the analysis of variance. For elements having less than one-third the censoring, the censored values were replaced by a value equal to 0.7 times the lower limit of determina-

tion. Because of their generally small number, the use of replacement values is thought to not substantially affect the geochemical interpretation of the data. Baseline summary statistics of such censored data were estimated by using the technique of Cohen (1959).

Variation due to all laboratory procedures was estimated separately in each study from a replicate analysis of samples selected randomly from the total suite of samples. These analytical splits were randomly placed among the total suite of samples. This procedure insured that any systematic error in analysis would effectively be converted to random error.

The analytical methods used for total-element determinations are described in U.S. Geological Survey (1975) by J. S. Wahlberg (p. 69), Claude Huffman, Jr. (p. 71), and H. T. Millard, Jr. (p. 79); and in U.S. Geological Survey (1976) by A. L. Sutton, Jr. (p. 131). Methods used for extractable element determinations are described in Crock and Severson (1980).

Determinations of exchangeable cations tend to be too high when the pH of the natural soil is greater than about 8.0. These high values reflect, in part, the fact that the exchanging solution was buffered at pH 7.0. When the natural soil pH is above about 8.0, salts and carbonates of calcium, magnesium, potassium, and sodium, which are stable at this high soil pH, begin to dissolve at the lower extraction solution pH and greater dilution, and, therefore, give values which are much too high. The values for exchangeable calcium, magnesium, potassium, and sodium reported here have been corrected for their water-soluble fractions.

USE OF VARIANCE COMPONENTS

Sampling was designed to measure the variation in soil-element content over increments of distance, expressed by cell size for Study 1 and by ranges in distance for Study 2 and Study 3. Total variation was, therefore, subdivided into distance-related geographical components.

A principal interest in variance components is in their use for calculating the minimum number of samples (n_p) required to estimate a mean with a specified degree of reliability, and to determine the presence and magnitude of regional variation as a basis for constructing maps. The conventional F -test at the 0.05 probability level is used to test each variance component to determine if variation between cells (or ranges in distance) is significantly different from variations within cells (or ranges in distance) at each level of the sampling design. If a component fails to be significant, it is not practical to attempt to map variation at the

interval associated with that component because of the high probability that the variation within units masks the variation between units. Analytical-error variance components in excess of 50 percent are considered to be excessive, and interpretation of the data for these elements must be made with caution.

A variance ratio (v) is computed to determine the feasibility of preparing geochemical maps from the data already collected, or for determining the magnitude of the sampling effort necessary to prepare maps based on various sampling intervals. The general expression for the variance ratio is:

$$v = \frac{\text{Estimated variance among sampling units}}{\text{Estimated total variance within sampling units}}$$

This ratio was defined by Miesch (1976, p. 8) as a "relative measure of the compositional heterogeneity among, and the compositional homogeneity within, mapped units of the population being studied." A value of v equal to 1.0 is chosen as the value below which a reliable map could not be prepared. If v is greater than 1.0, then there is some basis for preparing a map that will reliably depict the true geochemical pattern because of the relatively large variation among sampling units as compared to the smaller variation within units.

In addition to using v to indicate reliability of data for presentation in the form of a map, v can also be used to estimate the minimum number of samples that would need to be collected at random, from an area represented by some given distance increment, in order to prepare a reliable map (Miesch 1976, p. 9).

RESULTS AND DISCUSSION

SOIL VARIABILITY

STUDY 1

The assessment of spatial variation of soil parameters in Study 1 shows that two levels of the sampling design (between 25-km cells¹ and between 1-km cells) account for the largest portion of the measured variation for most parameters (table 1). Variation measured between 50-km cells is very small or nonexistent for most parameters in both A and C horizons of soils (table 1). Total arsenic and mercury and extractable potassium, manganese, and zinc in the A horizon, and organic carbon and pH in the C horizon are the only parameters that show significant variation between 50-km cells. For variation between 5-km cells, no gen-

eral statement can be made for either A or C horizons of soil because for a few parameters the measured variation is significant, for other parameters it is substantial but not significant, and yet for other parameters it is nonexistent.

A practical aspect of variance components is their usefulness for testing the feasibility of preparing maps based on the parameter means of a sampling-unit size. This feasibility can be calculated only for 50-km and 25-km cells if the intent is to provide maps of parameter values based on the present sampling design and data. For most parameters, variation measured for 50-km cells is nonexistent; therefore, attempting to map at this interval would be impractical. Mapping parameter-value distributions at an interval of 25 km may be practical using the present data because much of the total variation was measured for many parameters at this interval. It would not be possible to map at an interval of 5 km or 1 km using the present data because not all 5-km or 1-km cells were sampled.

The feasibility of presenting the data in map form, based on 25-km cells, was evaluated by the variance ratio described previously. The ratio for 25-km cells is computed as follows:

$$v = \frac{P_{(50)} + P_{(25)}}{P_{(5)} + P_{(1)} + P_{(e)}}$$

where P represents the percent of total variance between cells of the size indicated by the subscript, and $P_{(e)}$ indicates the percentage of the total variance between the analysis of duplicate samples.

These calculated variance ratios are presented in table 1. Elements having a ratio greater than 1.0 are total arsenic, potassium, lithium, molybdenum, and strontium in the A horizon, and total aluminum, arsenic, barium, beryllium, carbon, calcium, mercury, magnesium, sodium, nickel, silicon and strontium; carbonate carbon; DTPA (diethylenetriamine pentaacetic acid) extractable lead; and exchangeable calcium in the C horizon. Data for these elements are presented on maps (fig. 6) as geometric means for 25-km cells. The cell means are not contoured because there are no apparent regional trends (variance at the 50-km level is nonsignificant). Only for total arsenic in the A horizon (fig. 6A) are such trends suggested by the maps and by the analysis of variance. Four classes are represented by shading in figures 6A-6S. The determination of these classes is based on the assumption that the data for an element follows a log-normal distribution. The highest and lowest classes represent

¹For brevity, we refer to cell sizes of X-km on a side as X-km cells.

values that either exceed or are below the computed baseline (expected 95 percent range). The two intermediate classes represent values that are either above or below the geometric mean but within the limits of the baseline value.

Several other parameters show significant variation between 25-km cells but have a variance ratio less than 1.0. This ratio indicates that map patterns prepared from the present data may not be reproducible — within-cell variation is greater than be-

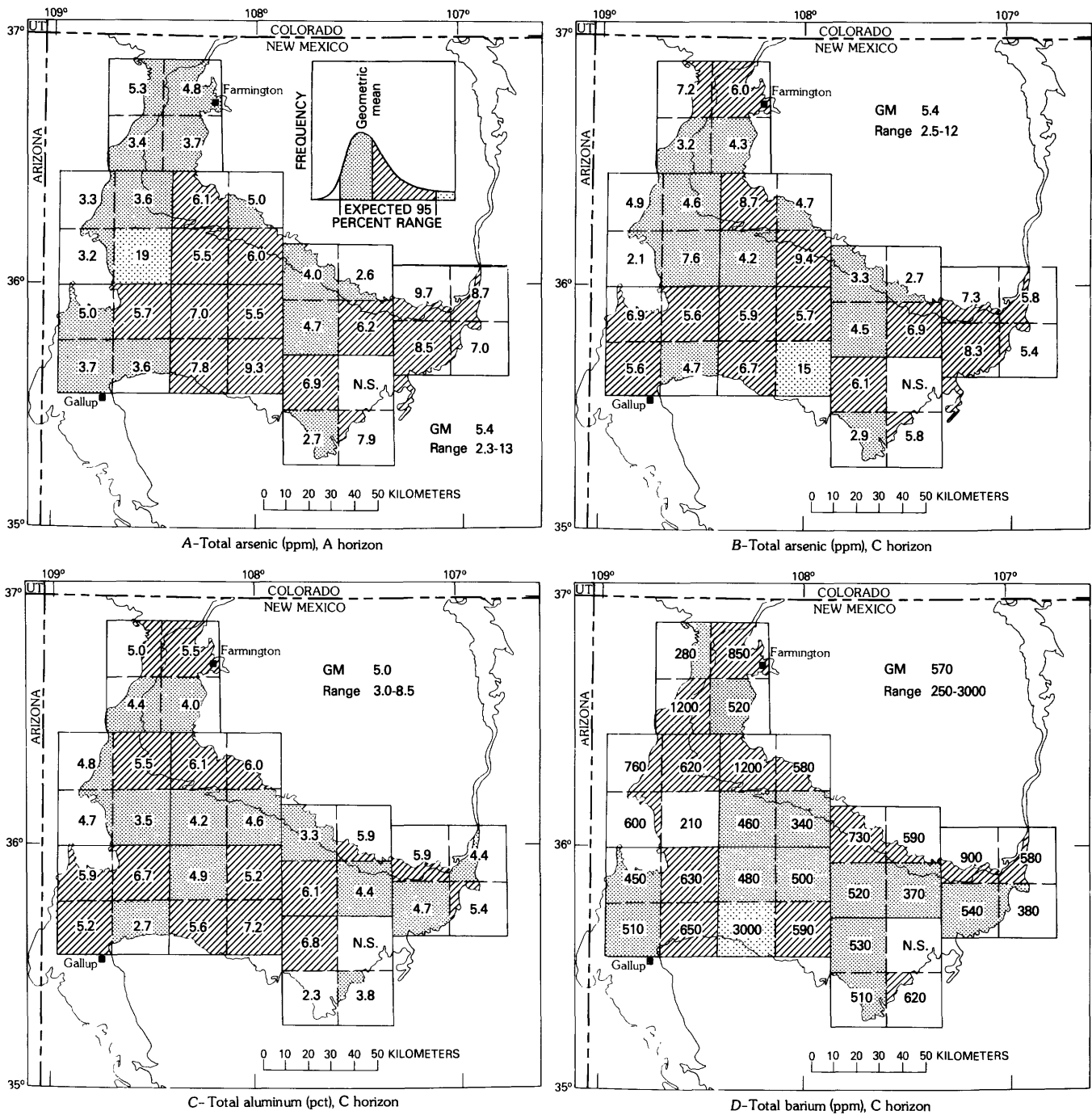


FIGURE 6.—Regional trends in soil parameters in the area likely to be affected by energy-related development. Values are means of cells 25-km on a side. Different shadings are based on the geometric mean (GM) and the upper or lower expected 95-percent values. N.S., not sampled.

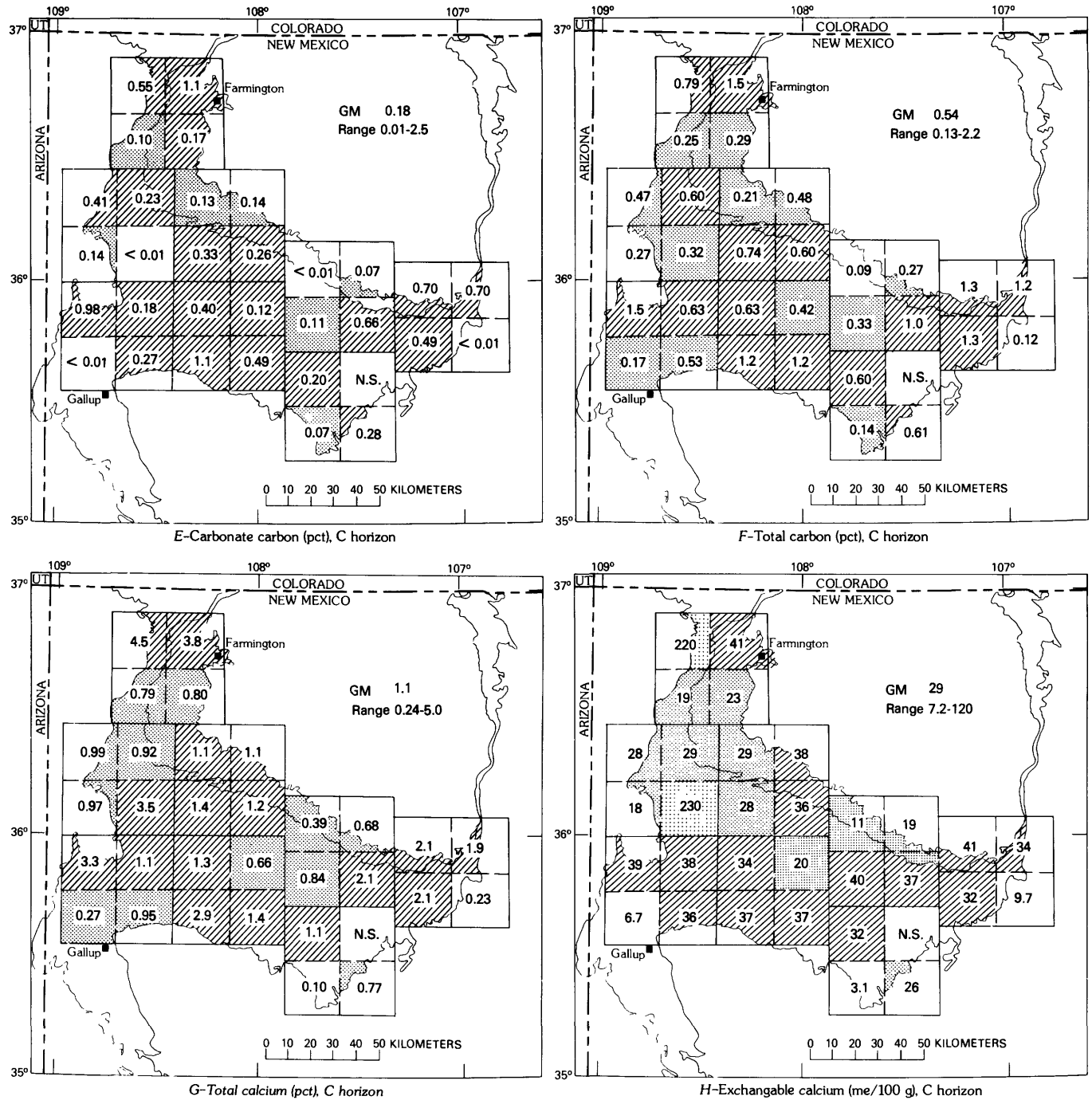


FIGURE 6—Continued

tween-cell variation, and additional sampling and analyses to produce a stable map may result in somewhat different patterns of parameter values in this area. However, variation between 25-km cells is statistically significant, and, therefore, average parameter values for each cell are displayed on maps in figure 7. Classes in parameter values are not distinguished, as in figure 6, because the patterns of parameter values may not be reproducible.

Many of the remaining elements or properties in either A or C horizons of soil could be represented by a map if only three or four samples (n_r values in table 1) were collected randomly from each 25-km cell. However, the maps thus generated would most likely show only poorly developed regional patterns because of the small variation measured for the larger 50-km cells (table 1). For these elements or properties, for which reliable maps could not be prepared because of exces-

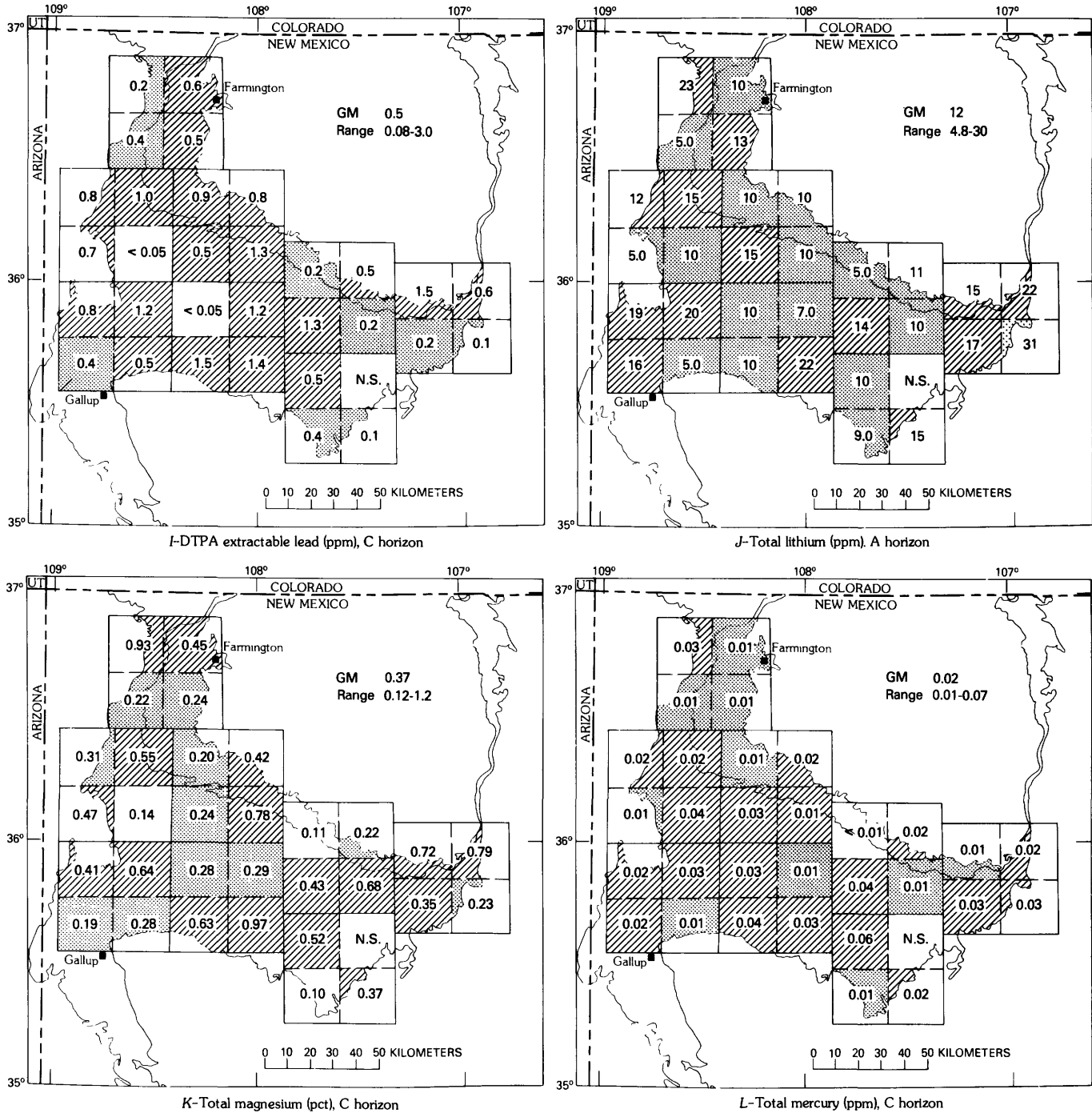


FIGURE 6—Continued

sive within-cell variability, and for those elements displayed on maps, the average composition and a measure of variability is expressed by a baseline value (table 2). The baseline represents an expected range in parameter values in soil that can be used in making extrapolations — new data may be compared to the baseline value to identify individual samples of extreme composition.

STUDY 2

Variation measured for parameters of the Shepard, Shiprock, and Doak soil association, Study 2, are presented in table 3. Most of this variation occurred at distance intervals of less than 5 km. Eight elements or properties (organic and total carbon; total titanium and uranium; extractable copper, calcium, and mag-

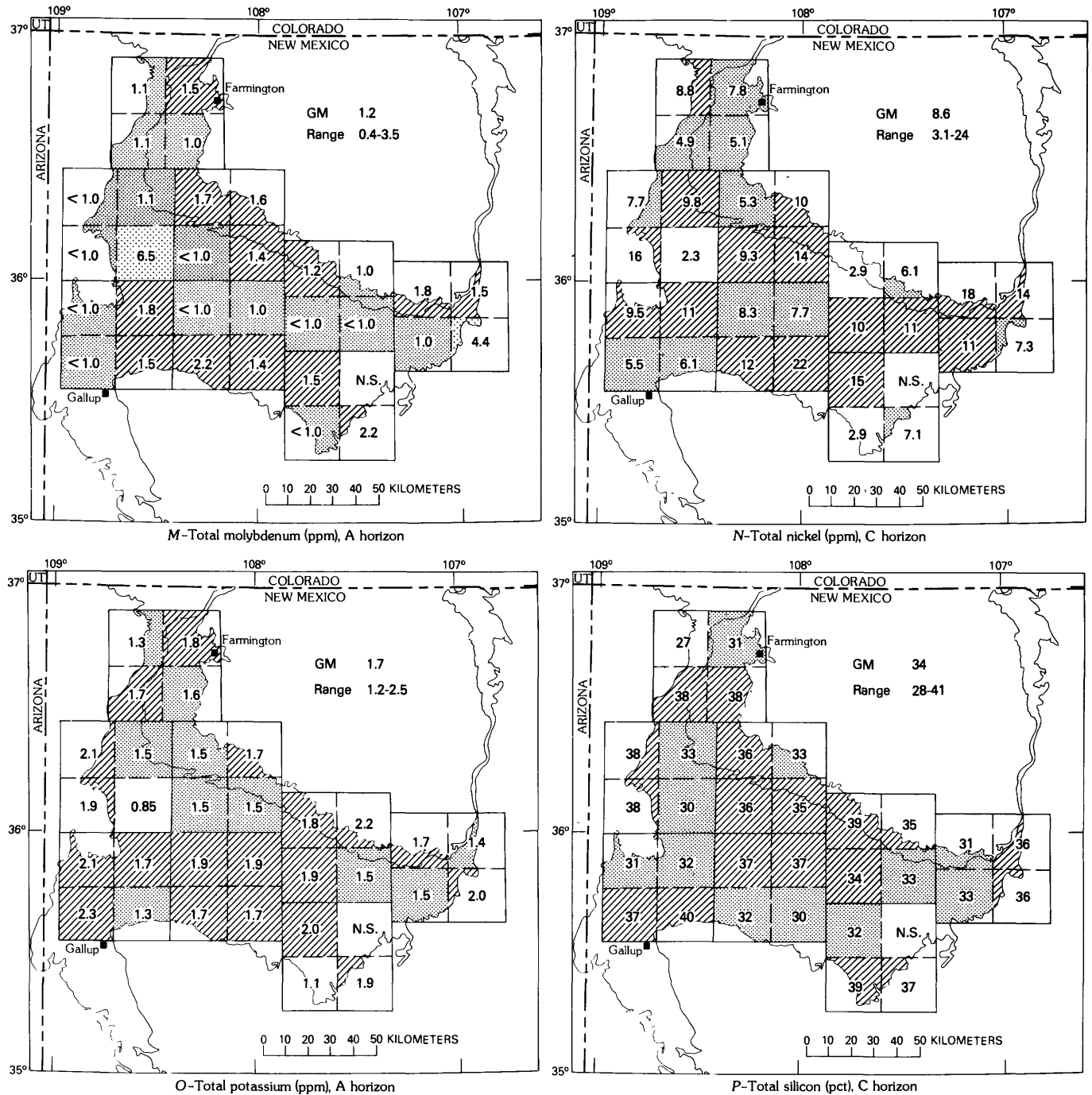


FIGURE 6—Continued

nesium; pH; and specific conductance) in the A horizon and four elements or properties (total lithium and magnesium; extractable magnesium; and cation-exchange capacity) in the C horizon have values greater than 50 percent of the total variation in these parameters that were measured at distance increments of greater than 5 km. Only with additional sam-

pling at 5-km intervals could these parameters be reliably mapped. A few additional parameters (table 3) show significant regional variation (between bar-bells, approximately 25-km distant), and therefore, could be reliably mapped in this area using the same cell size (25 km) as used in Study 1. Samples from the southernmost barbell (fig. 4) tend to be the highest

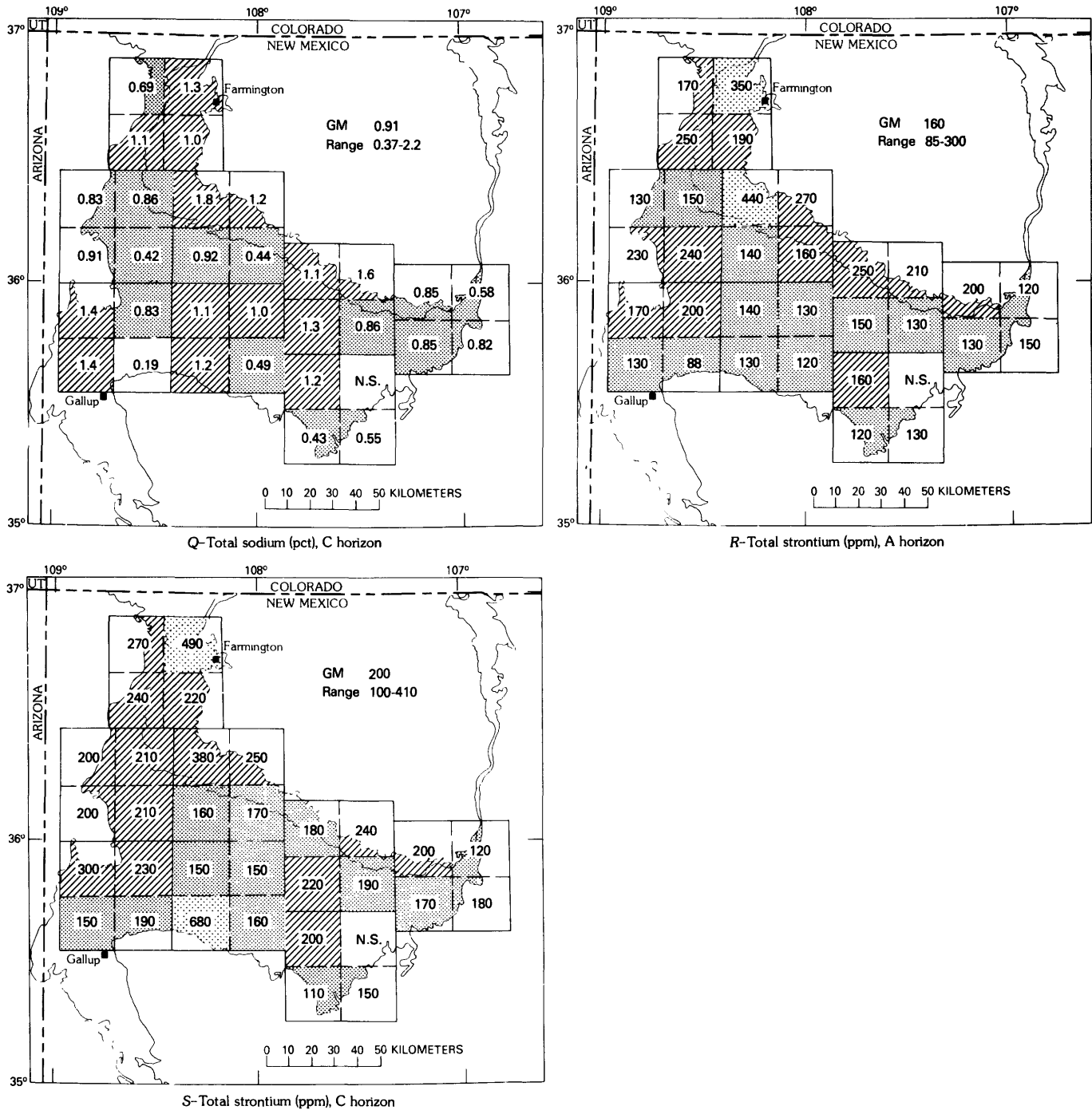


FIGURE 6—Continued

from the three areas in concentration of these additional parameters, except pH, which is the lowest. Samples from the other two locations are about equal in values of these parameters; however, the samples from the northernmost barbell tend to be higher in some parameters and lower in pH than those of the centrally located barbell. Total variation in most para-

meters measured for Study 2 is low (table 3) compared to the data for Study 1 (table 1).

Variances found in parameters of Study 2 suggest that the soil sampled in the area mapped as containing the Sheppard, Shiprock, and Doak soils is more uniform in element composition than are the soils of Study 1. Because of this uniformity, attempts to map differ-

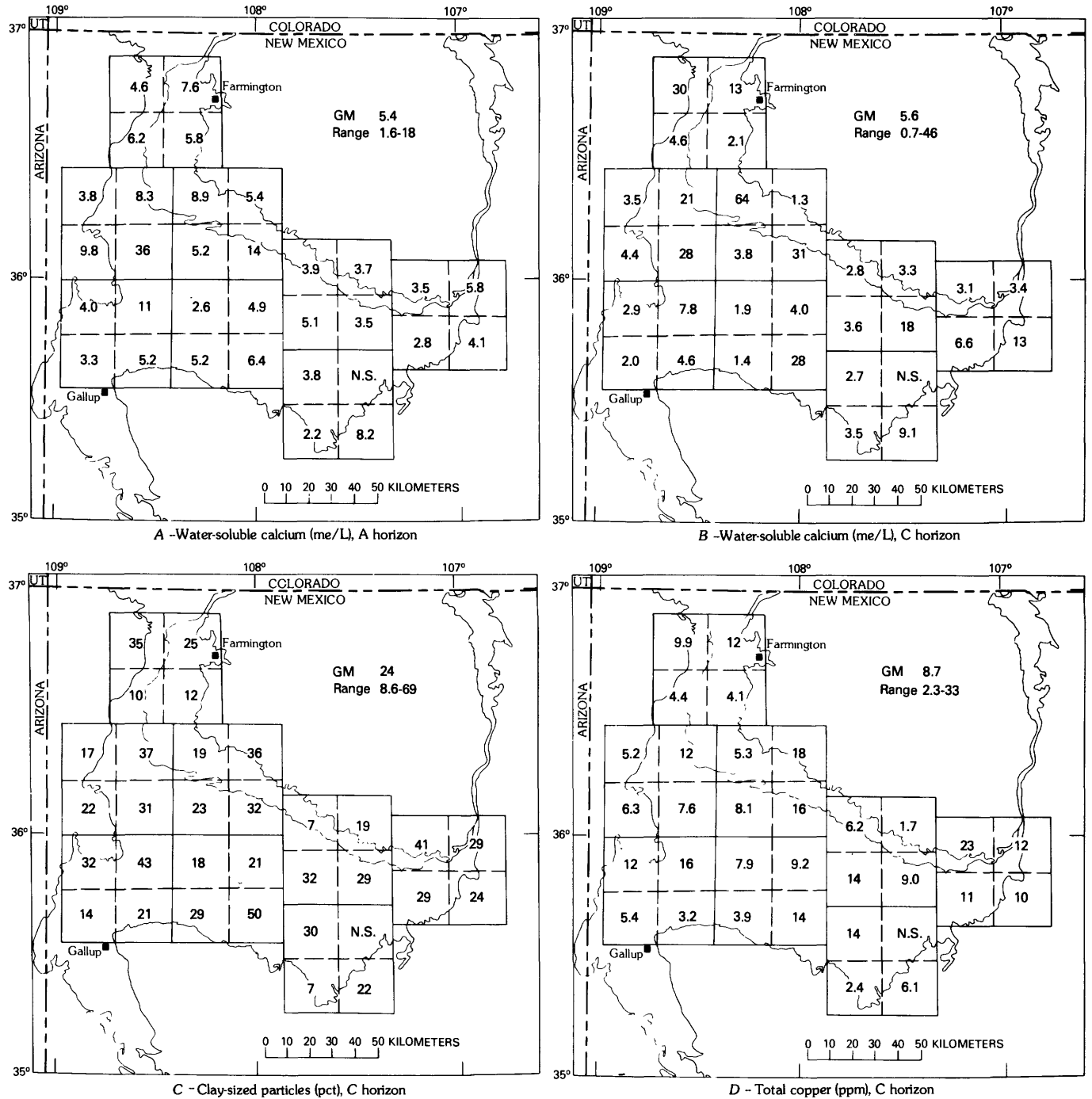


FIGURE 7.—Average values for soil parameters in cells 25 km on a side measured in the area likely to be affected by energy-related development. Values are geometric means (GM). Shading, as used in figure 6, is not used because the analysis of variance indicates that, although significant differences exist between 25-km cells, the patterns may tend not to be reproducible. N.S., not sampled.

ences in soil composition would require that a large number of samples be collected at close intervals for all parameters, except for those parameters showing regional variation that were mentioned above, in order to characterize the slight differences. The uni-

formity in composition indicates that a large area may be characterized by means of only a few samples. The element composition of the area containing mainly the Sheppard, Shiprock, and Doak soils can be effectively summarized by computing an average or baseline

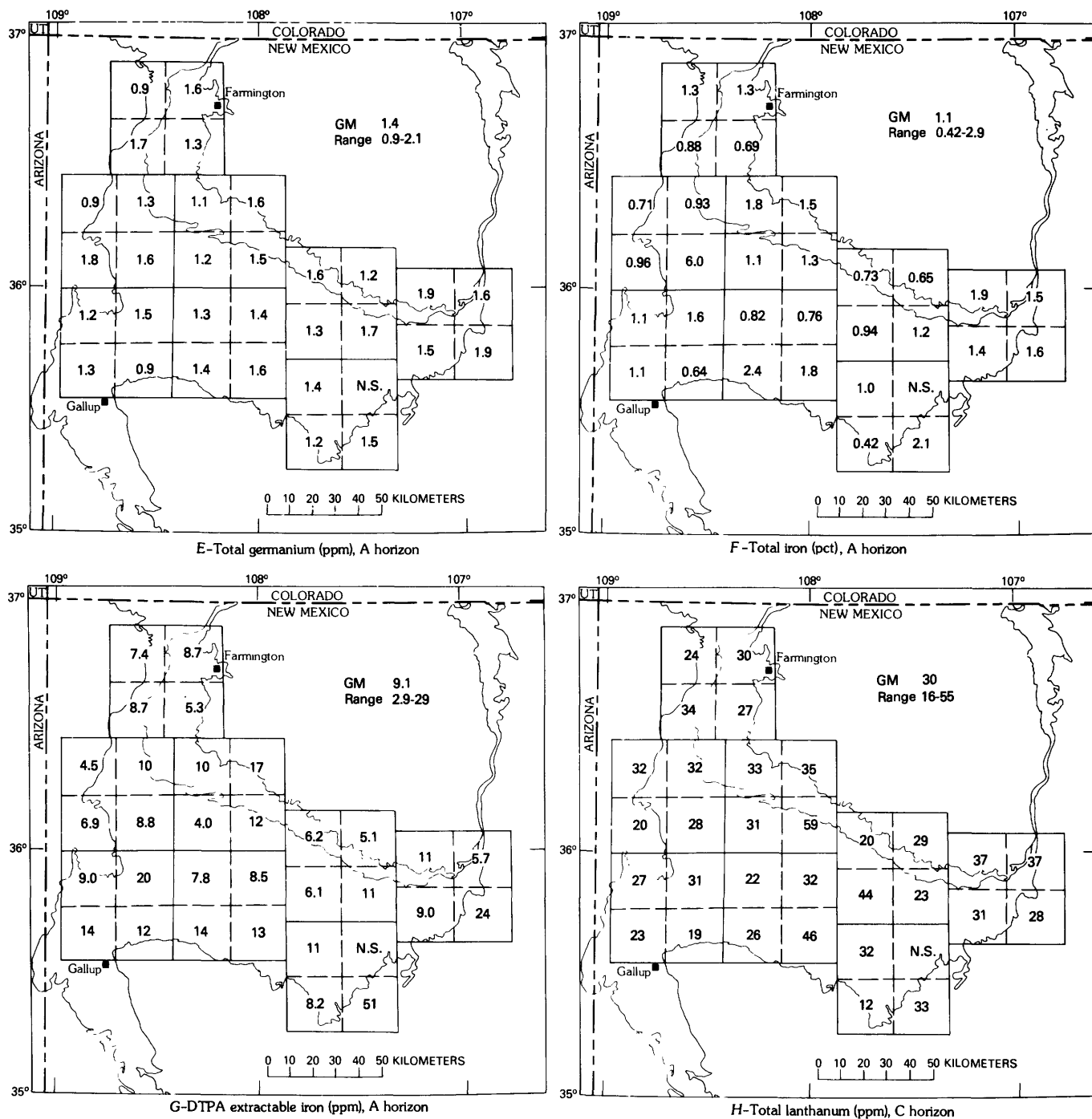


FIGURE 7—Continued

value (table 4), and this average value should be widely applicable for characterizing these soils. The baseline values can be used as described for Study 1.

STUDY 3

Variability in parameter values of topsoil and mine spoil, Study 3, from a limited sampling of a reclaimed

area of the San Juan mine, is presented in table 5. For most parameters in topsoil and mine spoil, greater than 50 percent of the total variation was measured at distance intervals of less than 5 m. Only values for total calcium and molybdenum, extractable calcium and potassium in topsoil, total sodium and strontium, extractable sodium and SO₄, and SAR (sodium adsorp-

GEOCHEMICAL SURVEY OF THE WESTERN ENERGY REGIONS

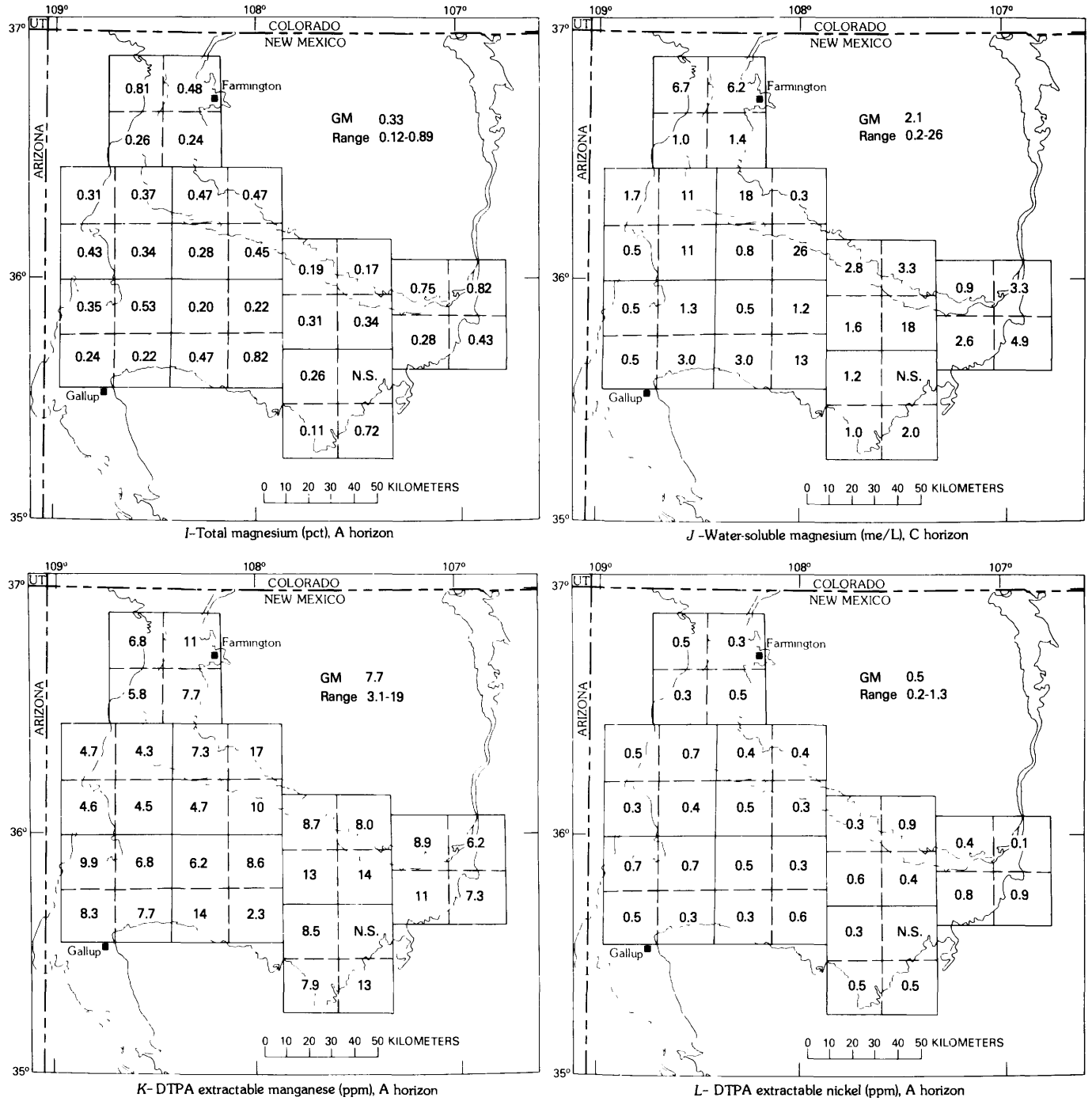


FIGURE 7—Continued

tion ratio) in mine spoil at distance intervals of 25 m is greater than 50 percent of the total variation measured. Total variation measured for total-element content of most elements was greater in mine spoil than in topsoil; however, the opposite relation was generally true for extractable elements (table 5).

The magnitude of the sampling effort needed to prepare a geochemical map of topsoil or mine spoil for

5-m and 25-m cells was estimated by using the variance components (table 5). The n_r values in this table indicate that, for most elements, more intensive sampling would be needed in mine spoil than in topsoil to prepare reliable maps of the chemical and physical composition of these soil materials. For many parameters, where most of the variation was measured at distance increments of less than 5 m, it would be

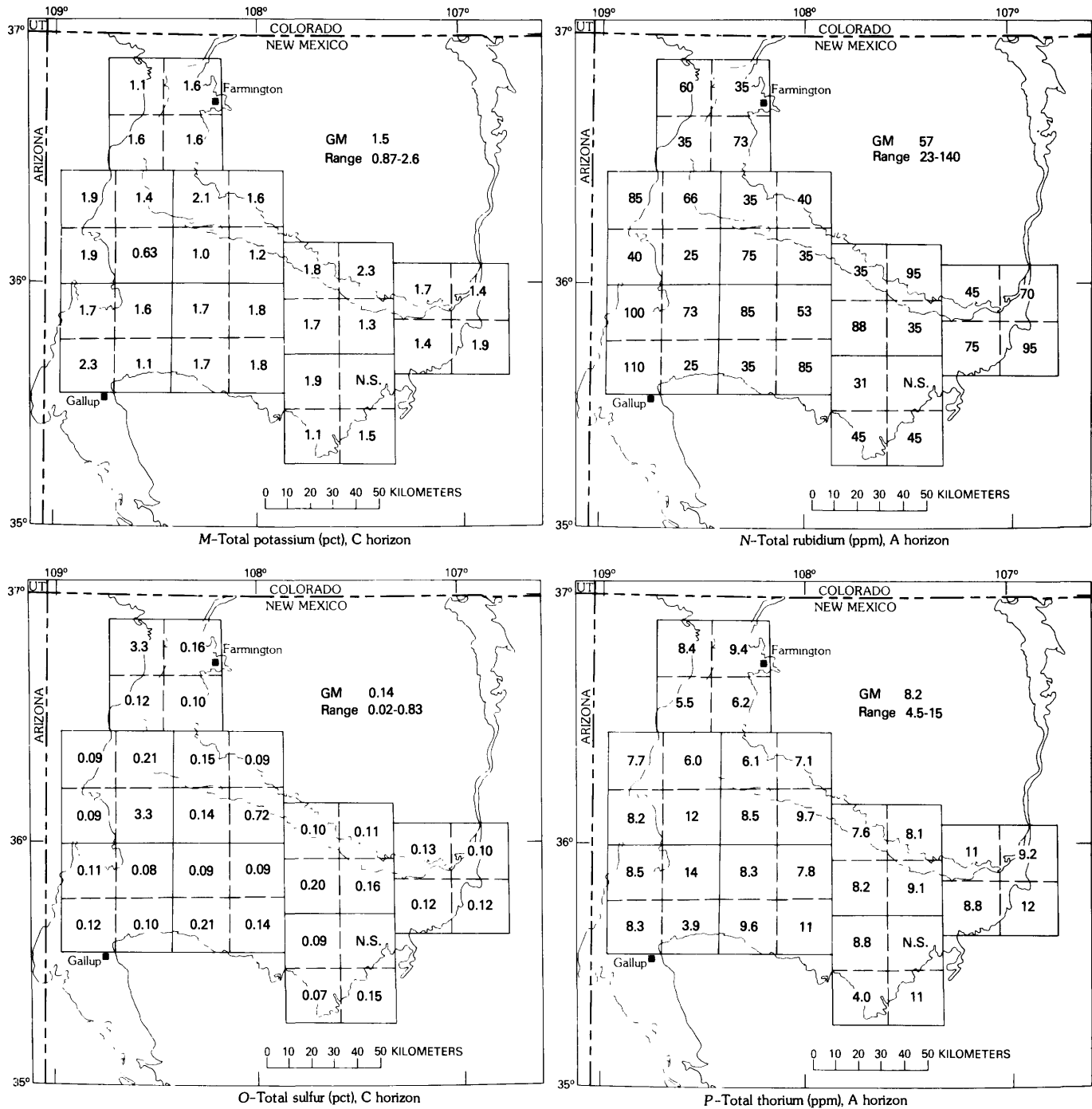


FIGURE 7—Continued

impractical to attempt a mapping program at any interval greater than 5 m. The average composition of topsoil and mine spoil from this small area at the San Juan mine is summarized by a baseline value in table 6.

SUMMARY

Variation was assessed at widely different distance increments in the three studies. Therefore, it is diffi-

cult to relate variation associated with a specific distance increment between the three studies. In Study 1 we used a nested-cell sampling design similar to that used by Severson and Tidball (1979) in the Northern Great Plains. In that study, as in the present study (figs. 6 and 7), parameter-value distributions in soil were based on a limited sampling of the entire area of interest and were presented in map form. The content

GEOCHEMICAL SURVEY OF THE WESTERN ENERGY REGIONS

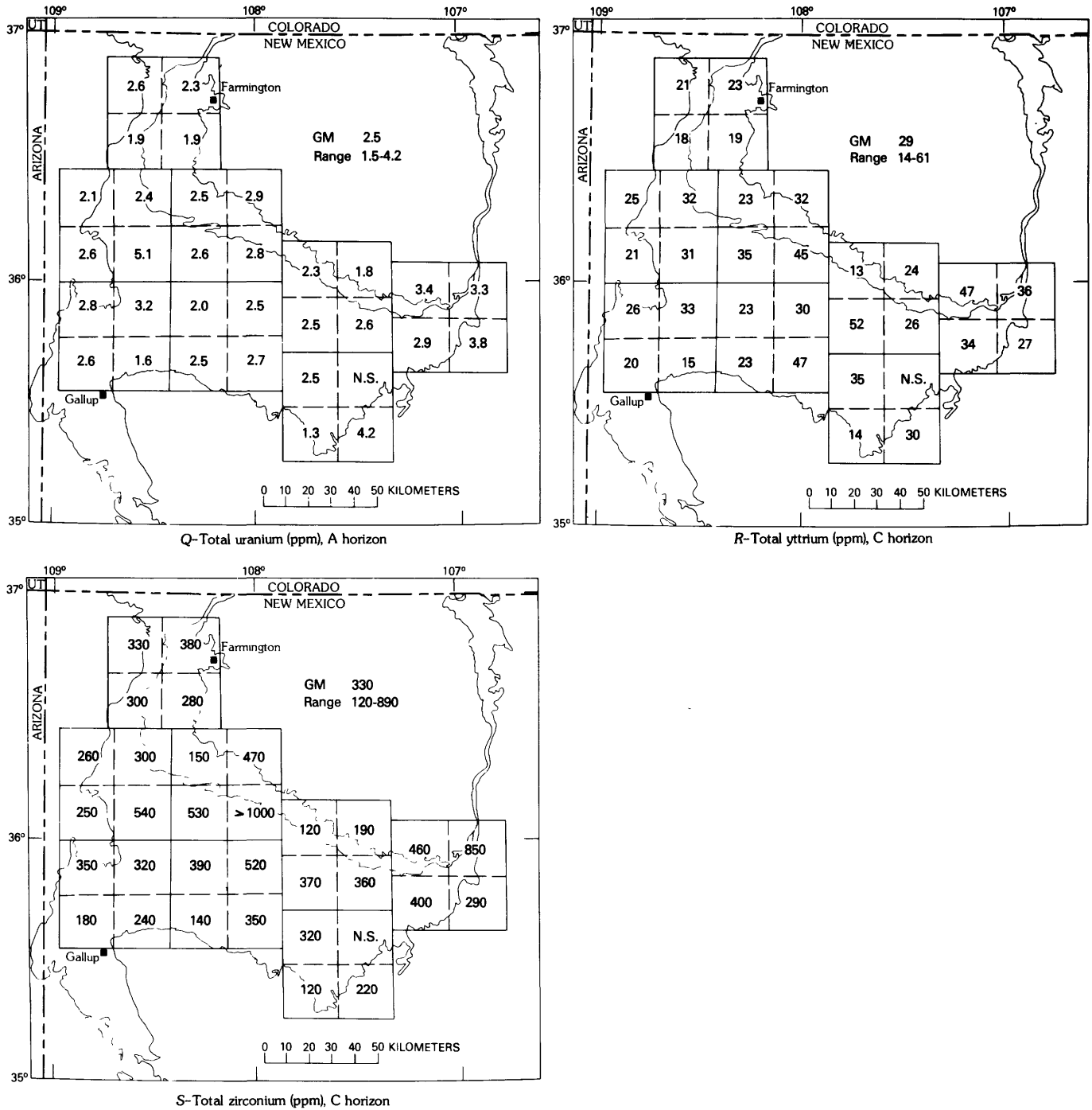


FIGURE 7—Continued

and variability of the remaining parameters in these soils of Study 1 are expressed as a baseline value (table 2). In Study 2 and Study 3 we used a barbell sampling design similar to that used by Severson (1979) in the Wind River and Bighorn Basins of Wyoming and Montana; that study and the present studies provide basic information on the variability of the material

sampled (without complete coverage of the area) and provide data on the average composition of the materials sampled. These data are represented by baseline values in table 4 for the soil material considered suitable for mined-land reclamation (Study 2), and in table 6 for soil and spoil from a reclaimed area of the San Juan mine (Study 3).

TABLE 2.— Summary statistics of parameters measured for two horizons of soils from the area likely to be affected by energy-related development in the San Juan Basin.

[Detection ratio, number of samples in which the parameter was found in measurable concentrations relative to the number of samples analyzed; geometric error (except as indicated) attributed to laboratory procedures; baseline, expected 95-percent range; leaders (---), no data available; <, less than, >, greater than; pct, percent; ppm, parts per million; me/L, milliequivalents per liter; mmhos/cm, reciprocal milliohms per centimeter; me/100g, milliequivalents per 100 grams]

Parameter	Soil horizon	Detection ratio	Geometric mean	Geometric deviation	Geometric error	Observed range		Baseline			
Based on total concentration											
Al, pct-----	A	47:47	4.7	1.27	1.04	2.4	-	7.7	2.9	-	7.6
	C	47:47	5.0	1.30	1.04	2.3	-	8.0	3.0	-	8.5
As, ppm-----	A	47:47	5.4	1.52	1.20	2.5	-	19	2.3	-	13
	C	47:47	5.4	1.46	1.14	2.1	-	15	2.5	-	12
B, ppm-----	A	39:47	16	2.20	1.81	<5	-	41	3.3	-	77
	C	36:47	15	2.59	2.29	<5	-	43	2.2	-	100
Ba, ppm-----	A	47:47	570	1.41	1.13	230	-	1,800	290	-	1,100
	C	47:47	570	1.52	1.16	300	-	3,000	250	-	1,300
Be, ppm-----	A	47:47	1.5	1.20	1.17	1.0	-	2.3	1.0	-	2.2
	C	47:47	1.5	1.24	1.18	1.1	-	2.8	1.0	-	2.3
C, carbonate, pct---	A	30:47	.040	9.37	---	<.010	-	1.6	---	-	---
	C	43:47	.18	3.71	1.37	<.010	-	1.1	.01	-	2.5
C, organic, pct-----	A	47:47	.37	1.86	1.35	.060	-	1.6	.11	-	1.3
	C	47:47	.27	2.24	1.46	.010	-	1.1	.05	-	1.4
C, total, pct-----	A	47:47	.51	1.80	1.02	.11	-	2.1	.16	-	1.7
	C	47:47	.54	2.01	1.01	.090	-	1.5	.13	-	2.2
Ca, pct-----	A	47:47	.55	2.12	1.05	.15	-	4.5	.12	-	2.5
	C	47:47	1.1	2.13	1.03	.097	-	4.5	.24	-	5.0
Co, ppm-----	A	47:47	5.7	1.44	1.14	2.1	-	11	2.7	-	12
	C	47:47	5.7	1.62	1.09	1.3	-	15	2.2	-	15
Cr, ppm-----	A	47:47	18	1.45	1.51	7.6	-	42	8.6	-	38
	C	47:47	18	1.51	1.32	6.3	-	47	7.9	-	41
Cu, ppm-----	A	47:47	8.9	1.90	1.14	2.1	-	30	2.5	-	32
	C	47:47	8.7	1.94	1.42	1.7	-	28	2.3	-	33
Er, ppm-----	A	42:47	6.1	1.21	1.28	<4.6	-	9.1	4.2	-	8.9
	C	45:47	6.5	1.21	1.21	<4.6	-	10	4.4	-	9.5
Fe, pct-----	A	47:47	1.1	1.62	1.03	.42	-	6.0	.42	-	2.9
	C	47:47	1.2	1.58	1.04	.41	-	2.5	.48	-	3.0
Ge, ppm-----	A	47:47	1.4	1.22	1.24	.8	-	1.9	.9	-	2.1
	C	47:47	1.3	1.20	1.20	.9	-	1.9	.9	-	1.9
Hg, ppm-----	A	47:47	.02	1.49	1.56	.01	-	.06	.01	-	.04
	C	46:47	.02	1.85	1.35	<.01	-	.06	.01	-	.07
K, pct-----	A	47:47	1.7	1.21	1.02	.85	-	2.3	1.2	-	2.5
	C	47:47	1.5	1.31	1.03	.56	-	2.3	.87	-	2.6
La, ppm-----	A	47:47	27	1.38	1.28	6.9	-	43	14	-	51
	C	47:47	30	1.35	1.21	12	-	61	16	-	55
Li, ppm-----	A	47:47	12	1.58	1.21	5.0	-	31	4.8	-	30
	C	47:47	13	1.70	1.29	5.0	-	32	4.5	-	38
Mg, pct-----	A	47:47	.33	1.64	1.03	.11	-	.82	.12	-	.89
	C	47:47	.37	1.77	1.04	.10	-	.97	.12	-	1.2
Mn, ppm-----	A	47:47	230	1.76	1.20	73	-	1,700	74	-	710
	C	47:47	180	1.76	1.25	33	-	510	58	-	560
Mo, ppm-----	A	31:47	1.2	1.71	1.37	<1.0	-	6.5	.4	-	3.5
	C	47:47	1.4	1.57	1.36	1.0	-	3.6	.6	-	3.5
Na, pct-----	A	47:47	.84	1.67	1.87	.10	-	2.1	.30	-	2.3
	C	47:47	.91	1.56	1.06	.19	-	2.0	.37	-	2.2
Nb, ppm-----	A	47:47	13	1.27	1.32	6.4	-	22	8.1	-	21
	C	47:47	12	1.32	1.18	5.0	-	21	6.9	-	21

TABLE 2—Continued

Parameter	Soil horizon	Detection ratio	Geometric mean	Geometric deviation	Geometric error	Observed range			Baseline		
Based on total concentration											
Ni, ppm-----	A	47:47	8.4	1.59	1.10	2.8	-	19	3.3	-	21
	C	47:47	8.6	1.67	1.10	2.3	-	22	3.1	-	24
Pb, ppm-----	A	47:47	13	1.28	1.14	7.8	-	21	7.9	-	21
	C	47:47	12	1.36	1.18	5.1	-	24	6.5	-	22
Rb, ppm-----	A	47:47	57	1.56	1.64	15	-	110	23	-	140
	C	47:47	62	1.47	1.30	25	-	110	29	-	130
S, pct-----	A	47:47	.10	1.45	1.24	.05	-	.42	.05	-	.21
	C	47:47	.14	2.44	1.10	.06	-	3.3	.02	-	.83
Sc, ppm-----	A	47:47	3.6	1.59	1.12	1.5	-	11	1.4	-	9.1
	C	47:47	4.0	1.61	1.15	1.5	-	11	1.5	-	10
Si, pct-----	A	47:47	36	1.09	1.02	30	-	42	30	-	43
	C	47:47	34	1.10	1.03	27	-	40	28	-	41
Sn, ppm-----	A	34:47	.4	2.68	2.04	<.2	-	.8	.06	-	3.1
	C	39:47	.6	2.55	1.66	<.2	-	2.7	.1	-	4.0
Sr, ppm-----	A	47:47	160	1.37	1.09	90	-	440	85	-	300
	C	47:47	200	1.42	1.10	110	-	680	100	-	410
Th, ppm-----	A	47:47	8.2	1.35	1.18	39	-	15	45	-	15
	C	47:47	8.3	1.38	1.12	39	-	16	4.4	-	16
Ti, pct-----	A	47:47	.21	1.38	1.06	.09	-	.40	.11	-	.40
	C	47:47	.22	1.41	1.05	.09	-	.38	.11	-	.44
U, ppm-----	A	47:47	2.5	1.30	1.06	1.3	-	5.1	1.5	-	4.2
	C	47:47	2.7	1.40	1.06	1.1	-	4.9	1.4	-	5.3
V, ppm-----	A	47:47	41	1.49	1.09	15	-	94	18	-	91
	C	47:47	44	1.55	1.14	15	-	97	18	-	110
Y, ppm-----	A	47:47	28	1.34	1.18	15	-	46	16	-	50
	C	47:47	29	1.45	1.19	13	-	57	14	-	61
Yb, ppm-----	A	47:47	1.6	1.28	1.24	.8	-	2.6	1.0	-	2.6
	C	47:47	1.6	1.45	1.13	.7	-	5.8	.8	-	3.4
Zn, ppm-----	A	47:47	39	1.49	1.14	18	-	84	18	-	87
	C	47:47	37	1.66	1.03	12	-	91	13	-	100
Zr, ppm-----	A	46:47	430	1.65	1.57	130	-	>1,000	160	-	1,200
	C	46:47	330	1.64	1.33	120	-	>1,000	120	-	890
Based on DTPA extraction (ppm)											
Cd-----	A	19:47	0.05	1.14	---	<0.05	-	0.08	0.04	-	0.07
	C	7:47	.05	---	---	<.05	-	.05	---	-	---
Co-----	A	46:47	.4	1.49	1.59	<.1	-	.8	.2	-	.9
	C	43:47	.3	1.90	2.00	<.1	-	.7	.1	-	1.1
Cu-----	A	47:47	.7	1.67	1.20	.3	-	2.8	.3	-	2.0
	C	47:47	.6	1.89	1.14	.2	-	3.3	.2	-	2.1
Fe-----	A	47:47	9.1	1.77	1.39	2.8	-	51	2.9	-	29
	C	47:47	9.9	2.17	1.67	1.5	-	48	2.1	-	47
Mn-----	A	47:47	7.7	1.57	1.24	2.3	-	20	3.1	-	19
	C	47:47	4.5	1.94	1.17	.6	-	15	1.2	-	17
Ni-----	A	47:47	.5	1.61	1.32	.1	-	1.2	.2	-	1.3
	C	47:47	.4	1.78	1.53	.1	-	.9	.1	-	1.3
Pb-----	A	47:47	.8	2.17	2.42	.05	-	2.2	.2	-	3.8
	C	45:47	.5	2.45	2.27	<.05	-	2.5	.08	-	3.0
Zn-----	A	47:47	.4	1.60	1.37	.2	-	1.9	.2	-	1.0
	C	47:47	.3	1.70	1.35	.1	-	2.1	.1	-	.9
Based on sodium acetate extraction (me/100g)											
Ca-----	A	47:47	12	2.14	1.09	2.6	-	42	2.6	-	54
	C	47:47	30	2.03	1.06	3.1	-	230	7.3	-	120
K-----	A	47:47	1.1	2.21	2.16	.2	-	4.1	.8	-	1.6
	C	47:47	.6	3.14	2.43	.1	-	3.6	.1	-	2.5

TABLE 2—Continued

Parameter	Soil horizon	Detection ratio	Geometric mean	Geometric deviation	Geometric error	Observed range			Baseline		
Based on sodium acetate extraction (me/100g)--Continued											
Mg-----	A	47:47	1.3	1.71	1.05	.5	-	4.2	.4	-	4.0
	C	47:47	2.3	2.02	1.03	.4	-	8.5	.6	-	9.4
Na-----	A	47:47	.2	2.97	1.79	.1	-	18	.03	-	1.3
	C	47:47	.6	3.41	1.30	.1	-	26	.06	-	6.6
Based on water-saturation extraction											
Ca, me/L-----	A	47:47	5.4	1.84	1.14	1.6	-	36	1.6	-	18
	C	47:47	5.6	2.92	1.06	.6	-	64	.7	-	46
Cl, me/L-----	A	27:47	.5	4.05	1.97	<.5	-	75	.03	-	8.2
	C	32:47	1.4	7.92	3.04	<.5	-	75	.02	-	88
K, me/L-----	A	47:47	1.2	1.66	2.42	.2	-	3.2	.4	-	3.3
	C	47:47	.7	1.72	1.48	.1	-	3.1	.2	-	2.1
Mg, me/L-----	A	47:47	1.1	1.63	1.18	.3	-	5.1	.4	-	2.9
	C	47:47	2.1	3.53	1.28	.3	-	40	.2	-	26
Na, me/L-----	A	47:47	1.7	3.51	1.48	.2	-	680	.1	-	21
	C	47:47	8.2	4.16	1.22	.5	-	440	.5	-	140
SO ₄ , me/L-----	A	25:47	.2	24.5	1.36	<1	-	510	<.01	-	120
	C	32:47	1.3	30.2	1.44	<1	-	450	<.01	-	1200
Specific conductance, mhos/cm.	A	47:47	.9	2.38	1.05	.3	-	66	.2	-	5.1
	C	47:47	1.3	3.00	1.10	.3	-	47	.1	-	12
Based on hot-water extraction (ppm)											
B-----	A	15:47	0.3	1.99	2.56	<0.5	-	4.0	0.08	-	1.2
	C	27:47	.5	1.95	3.16	<.5	-	3.5	.1	-	1.9
Measured by specific ion electrode											
pH ¹ -----	A	47:47	8.1	0.30	0.061	7.3	-	8.6	7.5	-	8.7
	C	47:47	8.3	.81	.14	7.4	-	9.2	6.7	-	9.9
Based on replacement with sodium (me/100g)											
Cation-exchange capacity-----	A	47:47	10.2	2.40	1.20	0.2	-	37.3	1.8	-	59
	C	47:47	13.0	1.71	1.13	4.2	-	40.8	4.4	-	38
Based on calculated parameters											
ESP, ² pct-----	A	47:47	1.3	2.46	1.90	0.2	-	35	0.4	-	4.6
	C	47:47	1.7	2.82	1.24	.3	-	37	.2	-	13
Saturation index,--- pct.	A	47:47	1.0	3.02	1.45	.1	-	155	.1	-	9.1
	C	47:47	4.1	3.22	1.26	.3	-	97	.4	-	43
	A	47:47	27.1	1.24	1.04	18.8	-	53.9	17.8	-	41.4
	C	47:47	31.6	1.38	1.05	20.5	-	79.3	16.7	-	59.7
Based on physical properties (percent)											
Sand-----	A	47:47	62	1.51	1.06	14	-	89	27	-	100
	C	47:47	50	1.86	1.02	5.1	-	92	14	-	103
Silt-----	A	47:47	9.3	2.22	1.28	10	-	46	1.9	-	46
	C	47:47	10	2.82	1.63	10	-	71	1.3	-	80
Clay-----	A	47:47	19	1.73	1.42	5.7	-	59	6.3	-	57
	C	47:47	24	1.68	1.17	7.0	-	70	8.6	-	69

¹Variation is arithmetic.²Exchangeable sodium percentage.³Sodium absorption ratio.

TABLE 3.—Variance components expressed as a percentage of total variance of two horizons of soils from the area containing soils considered to have potential for use as topsoil in mined-land reclamation in the San Juan Basin

[*, variance component significantly different from zero at the 0.05 probability level]

Parameter	Soil horizon	Variance						
		Total log ₁₀ variance	Percent of total variance				n _r	
			Between barrells	5-10 km	1-5 km	0.1-1 km		
						0-0.1 km	Duplicate analyses	
Based on total concentration								
Al-----	A	0.0036	0	16.1	5.2	*45.1	0	33.6
	C	.0081	0	19.1	*42.1	6.5	0	32.3
As-----	A	.0111	0	0	30.1	.5	0	69.4
	C	.0239	0	0	22.6	*35.7	0	41.7
B-----	A	.0327	0	10.1	10.9	0	0	79.0
	C	.1013	*17.4	4.7	0	0	*56.5	21.4
Ba-----	A	.0257	.8	0	0	*58.4	0	44.4
	C	.0244	0	*19.4	0	9.4	*52.3	18.9
Be-----	A	.0040	.6	0	8.4	6.9	0	84.1
	C	.0041	.8	6.2	0	10.9	17.4	64.7
C, carbonate--	C	.3678	4.4	0	12.1	0	*75.0	8.5
C, organic----	A	.0294	1.2	*54.6	0	*14.6	14.1	15.5
	C	.2590	25.7	0	*26.0	12.6	0	35.7
C, total-----	A	.0225	0	*61.2	0	9.2	*26.5	3.1
	C	.1123	10.6	0	*39.9	0	*49.1	.4
Ca-----	A	.0237	0	11.7	0	*32.8	0	55.5
	C	.1040	12.9	0	*40.0	0	*43.3	3.8
Co-----	A	.0133	0	9.0	0	*38.8	0	52.2
	C	.0204	6.7	8.5	*37.3	2.6	*37.9	7.0
Cr-----	A	.0489	0	*29.3	7.2	0	8.8	54.7
	C	.0501	15.5	0	*27.9	2.7	0	53.9
Cu-----	A	.0244	0	*21.1	30.2	0	*31.0	17.7
	C	.0769	10.8	*29.0	7.2	0	22.7	30.3
Fe-----	A	.0085	0	.7	*51.1	13.6	*28.6	6.0
	C	.0282	4.6	3.3	*50.7	0	*25.5	15.9
Ge-----	A	.0050	2.4	0	16.7	0	*52.3	28.6
	C	.0203	*10.6	9.1	9.2	4.5	0	66.6
Hg-----	A	.0485	0	0	0	23.3	21.2	55.5
	C	.0940	3.2	0	0	12.8	0	84.0
K-----	A	.0020	*10.8	0	3.9	9.8	0	75.6
	C	.0045	3.8	35.2	*32.7	0	.1	28.2
La-----	A	.0099	0	22.9	23.6	0	7.3	46.2
	C	.0153	0	4.3	*47.4	8.5	14.2	25.6
Li-----	A	.0038	15.5	0	*35.8	0	28.3	20.4
	C	.0213	14.2	*44.0	7.0	*21.9	.8	12.1
Mg-----	A	.0171	*43.1	0	*33.5	2.2	*19.0	2.2
	C	.0502	26.2	*35.3	13.6	0	*24.7	.2
Mn-----	A	.0336	0	10.2	*34.5	0	20.5	34.8
	C	.0504	0	*35.7	3.4	0	21.6	39.3
Na-----	A	.0055	2.1	34.2	9.3	*46.1	*5.7	2.6
	C	.0105	0	0	*68.9	*21.6	3.2	6.3
Nb-----	A	.0145	1.1	0	*27.9	0	*45.6	25.4
	C	.0378	*26.3	0	0	*43.3	3.0	27.4
Ni-----	A	.0124	0	6.7	*28.0	23.3	0	42.0
	C	.0400	22.6	*23.3	19.1	4.1	*27.0	3.9
Pb-----	A	.0071	*11.2	0	19.3	6.4	0	63.1
	C	.0119	9.7	2.9	20.2	0	5.5	61.7
Rb-----	A	.0042	0	0	20.8	12.8	*42.1	24.3
	C	.0096	10.8	12.9	*23.0	8.5	0	44.8
Sc-----	A	.0086	0	16.1	*33.2	.6	0	50.1
	C	.0214	6.0	29.6	*23.3	0	24.4	16.7
Si-----	A	.0009	0	6.4	4.0	*27.4	0	62.2
	C	.0010	0	0	*34.1	0	39.7	26.2
Sn-----	A	.2857	16.8	0	0	*35.8	13.0	34.4
	C	.7026	4.9	0	0	0	0	95.1
Sr-----	A	.0118	5.4	*32.0	0	*48.5	7.6	6.5
	C	.0180	*40.7	7.2	5.8	3.3	0	43.0
Th-----	A	.0129	*18.9	0	*29.1	8.6	7.4	36.0
	C	.0202	0	42.2	*24.9	.6	14.6	17.7
Ti-----	A	.0108	*49.4	9.4	*22.5	0	*12.2	6.5
	C	.0163	23.3	0	*21.8	.7	18.9	35.3
U-----	A	.0085	*50.7	10.7	*14.4	0	10.9	13.3
	C	.0179	*30.3	0	28.7	*23.3	*14.5	3.2
V-----	A	.0077	0	0	*54.1	5.0	22.8	18.1
	C	.0266	5.5	6.7	*47.8	0	*34.6	5.4
Y-----	A	.0205	0	6.4	21.5	0	*56.5	15.5
	C	.0248	0	0	*39.1	9.5	2.4	49.0

TABLE 3—Continued

Parameter	Soil horizon	Variance						
		Total log ₁₀ variance	Percent of total variance				n _r	
			Between barrells	5-10 km	1-5 km	0.1-1 km		
						0-0.1 km	Duplicate analyses	
Based on total concentration								
Yb-----	A	.0252	3.2	0	0	0	23.6	73.2
	C	.0779	0	11.8	7.5	0	0	80.7
Zn-----	A	.0057	0	0	*56.1	4.7	*24.3	14.9
	C	.0204	4.1	10.5	*56.4	0	*26.5	2.5
Zr-----	A	.0389	*28.8	0	0	13.3	0	57.9
	C	.0736	*33.3	6.8	1.2	10.5	13.6	34.6
Based on DTPA extraction								
Cu-----	A	0.0203	5.4	*49.9	*13.7	2.2	10.9	17.9
	C	.4319	0	6.8	0	4.7	0	88.5
Fe-----	A	.0129	16.5	*32.7	0	13.1	*25.9	11.8
	C	.0070	0	*32.5	6.5	19.8	*28.0	13.2
Mn-----	A	.0288	5.9	*42.5	.7	18.0	*21.2	11.7
	C	.0341	12.9	*10.0	*27.0	0	*40.6	9.5
Ni-----	A	.0982	0	6.2	0	25.5	0	68.3
	C	.0835	0	17.7	0	0	21.0	61.3
Pb-----	A	.0483	0	0	0	33.4	0	66.6
	C	.0344	0	*32.2	0	0	*49.0	18.8
Zn-----	A	.0122	0	*19.3	0	0	20.6	60.1
Based on sodium acetate extraction								
Ca-----	A	0.0139	27.8	0	*40.8	10.8	*18.0	2.6
	C	.0516	15.4	0	16.1	3.3	*64.1	1.1
K-----	A	.0146	4.3	0	0	*56.3	0	39.4
	C	.0815	*17.5	0	7.7	0	26.7	48.1
Mg-----	A	.0144	0	24.5	*31.0	0	*40.5	4.0
	C	.0558	0	*62.8	0	18.1	*18.7	.4
Na-----	A	.0698	5.5	0	0	*39.8	0	54.7
	C	.0890	*29.4	2.4	0	*43.1	4.1	21.0
Based on water-saturation extraction								
Ca-----	A	0.0319	69.8	*11.5	4.0	*8.1	2.3	4.3
	C	.2799	2.2	0	31.4	16.2	*49.5	.7
Cl-----	A	.5839	16.5	0	7.9	10.9	*56.3	8.4
	C	.0521	13.3	*22.0	0	0	39.5	25.2
Mg-----	A	.0926	14.8	0	4.4	21.5	8.4	50.9
	C	.0230	0	*51.2	0	*30.8	2.4	15.6
	C	.3044	1.0	0	*39.1	11.5	*47.5	.9
Na-----	A	.1267	*27.3	1.3	0	4.6	17.1	49.7
	C	.2728	9.5	0	0	*56.5	*33.6	.4
SO ₄ -----	A	.6002	.2	0	36.0	6.5	*55.0	2.3
Specific conductance.	C	.0150	55.0	*19.1	.2	5.3	*14.1	6.3
	C	.1832	8.5	0	20.6	19.8	*50.6	.5
Measured by specific ion electrode								
pH ¹ -----	A	0.2089	*42.4	*21.5	0	*29.4	*5.2	1.5
	C	.1029	0	0	0	3.9	*94.6	1.5
Based on replacement with sodium								
Cation-exchange capacity.	A	0.0068	0	0	*38.8	0	32.0	29.2
	C	.0321	*40.4	10.4	*28.1	1.9	0	19.2
Based on calculated parameters								
ESP ² -----	A	0.0713	19.0	0	*24.6	8.6	7.6	40.2
	C	.0935	15.1	0	0	39.0	*29.4	16.5
SAR ³ -----	A	.1599	*39.2	.1	2.6	1.6	17.8	38.7
	C	.1786	10.9	0	0	*64.1	*24.4	.6
Saturation index.	A	.0032	0	*29.7	15.2	18.4	*25.6	11.1
	C	.0115	6.9	*29.5	*18.0	0	*31.8	7.5
Based on physical properties								
Sand-----	A	0.0031	21.2	1.1	*48.7	2.2	*25.4	1.4
	C	.0086	23.4	*25.9	5.3	0	*43.6	1.8
Silt-----	A	.0843	22.7	31.1	*15.2	10.6	*14.7	5.7
	C	.8128	*61.2	0	*32.1	0	*5.6	6.1
Clay-----	A	.0087	.4	0	*55.3	0	*37.6	6.7
	C	.0277	*31.6	23.5	*16.8	7.0	*17.3	3.8

¹Variance is arithmetic.

²Exchangeable sodium percentage.

³Sodium adsorption ratio.

TABLE 4.—Summary statistics of parameters measured for two horizons of soil from the area containing soils considered to have potential for use as topsoil in mined-land reclamation in the San Juan Basin

[Detection ratio, number of samples in which the parameter was found in measurable concentrations relative to the number of samples analyzed; geometric error (except as indicated) attributed to laboratory procedures; baseline, expected 95-percent range; leaders(---), no data available; <, less than, >, greater than; ppm, parts per million; me/L, milliequivalents per liter; mmhos/cm, reciprocal milliohms per centimeter; me/100g, milliequivalents per 100 grams; pct, percent]

Parameter	Soil horizon	Detection ratio	Geometric mean	Geometric deviation	Geometric error	Observed range		Baseline			
Based on total concentration											
Al, pct-----	A	30:30	4.4	1.12	1.08	3.4	-	5.7	3.5	-	5.5
	C	30:30	4.4	1.21	1.12	2.9	-	6.1	3.0	-	6.4
As, ppm-----	A	30:30	3.3	1.22	1.22	2.1	-	4.8	2.2	-	4.9
	C	30:30	3.7	1.39	1.26	1.7	-	7.6	1.9	-	7.1
B, ppm-----	A	30:30	16	1.42	1.45	6.4	-	27	7.9	-	32
	C	26:30	11	1.83	1.40	<5.0	-	25	3.3	-	37
Ba, ppm-----	A	30:30	620	1.24	1.28	330	-	970	400	-	950
	C	30:30	690	1.34	1.17	330	-	1,200	380	-	1,200
Be, ppm-----	A	30:30	1.3	1.13	1.14	1.1	-	1.7	1.0	-	1.7
	C	30:30	1.3	1.16	1.13	1.0	-	1.8	1.0	-	1.7
C, carbonate, pct--	A	3:30	<.01	53.4	---	<.01	-	.14	---	-	---
	C	26:30	.10	3.91	1.50	<.01	-	.82	.01	-	1.5
C, organic, pct----	A	30:30	.35	1.39	1.17	.19	-	.64	.18	-	.68
	C	29:30	.10	2.65	2.02	<.01	-	.40	.01	-	.70
C, total, pct-----	A	30:30	.36	1.36	1.06	.20	-	.64	.20	-	.67
	C	30:30	.27	1.95	1.05	.08	-	1.1	.07	-	1.0
Ca, pct-----	A	30:30	.64	1.26	1.30	.45	-	1.1	.40	-	1.0
	C	30:30	1.0	1.77	1.16	.40	-	3.4	.33	-	3.2
Co, ppm-----	A	30:30	4.9	1.28	1.21	3.1	-	11	3.0	-	8.0
	C	30:30	4.4	1.37	1.09	2.6	-	8.9	2.3	-	8.3
Cr, ppm-----	A	30:30	20	1.54	1.46	9.8	-	40	8.4	-	47
	C	30:30	13	1.50	1.46	5.5	-	40	5.8	-	29
Cu, ppm-----	A	30:30	8.8	1.41	1.16	4.9	-	19	4.4	-	17
	C	30:30	6.3	1.73	1.42	1.6	-	17	2.1	-	19
Er, ppm-----	A	17:30	4.9	1.31	---	<4.6	-	8.1	2.9	-	8.4
	C	13:30	4.5	1.37	---	<4.6	-	7.3	2.4	-	8.4
Fe, pct-----	A	30:30	.91	1.23	1.05	.58	-	1.2	.60	-	1.4
	C	30:30	.83	1.41	1.17	.44	-	1.5	.42	-	1.7
Ge, ppm-----	A	30:30	1.3	1.17	1.09	.9	-	1.7	1.0	-	1.8
	C	30:30	1.2	1.20	1.31	.9	-	1.6	.8	-	1.7
Hg, ppm-----	A	29:30	.02	1.55	1.46	<.01	-	.03	.01	-	.05
	C	25:30	.02	1.72	1.91	<.01	-	.04	.01	-	.06
K, pct-----	A	30:30	2.1	1.05	1.09	1.8	-	2.4	1.9	-	2.3
	C	30:30	2.1	1.17	1.09	1.7	-	3.1	1.5	-	2.9
La, ppm-----	A	30:30	28	1.24	1.17	18	-	43	18	-	43
	C	30:30	27	1.33	1.16	16	-	46	15	-	48
Li, ppm-----	A	30:30	13	1.13	1.07	11	-	18	10	-	17
	C	30:30	12	1.37	1.12	5.0	-	25	6.4	-	23
Mg, pct-----	A	30:30	.25	1.29	1.05	.17	-	.44	.15	-	.42
	C	30:30	.23	1.58	1.02	.11	-	.72	.09	-	.57
Mn, ppm-----	A	30:30	240	1.42	1.28	120	-	470	120	-	480
	C	30:30	220	1.63	1.37	81	-	1100	83	-	580
Mo, ppm-----	A	13:30	1.0	1.21	---	<1.0	-	1.4	.7	-	1.4
	C	12:30	.9	1.81	---	<1.0	-	3.4	.3	-	2.8
Na, pct-----	A	30:30	1.1	1.17	1.03	.85	-	1.7	.82	-	1.5
	C	30:30	1.1	1.23	1.06	.70	-	1.6	.73	-	1.7
Nb, ppm-----	A	30:30	10	1.26	1.15	5.6	-	15	6.3	-	16
	C	28:30	9.2	1.43	1.26	<4.6	-	15	4.5	-	19

TABLE 4--Continued

Parameter	Soil horizon	Detection ratio	Geometric mean	Geometric deviation	Geometric error	Observed range		Baseline	
Based on total concentration --Continued									
Ni, ppm-----	A	30:30	6.2	1.29	1.18	3.8	-	12	3.7 - 10
	C	30:30	5.4	1.53	1.09	2.2	-	12	2.3 - 13
Pb, ppm-----	A	30:30	11	1.20	1.17	8.4	-	19	7.6 - 16
	C	30:30	9.7	1.29	1.22	6.0	-	18	5.8 - 16
Rb, ppm-----	A	30:30	83	1.15	1.08	65	-	110	63 - 110
	C	30:30	86	1.22	1.16	65	-	140	58 - 130
S, pct-----	A	18:30	.04	1.42	---	<.03	-	.07	.02 - .08
	C	18:30	.04	1.69	---	<.03	-	.13	.01 - .11
Sc, ppm-----	A	30:30	2.9	1.22	1.16	2.0	-	4.3	1.9 - 4.3
	C	30:30	2.5	1.32	1.15	1.7	-	4.4	1.4 - 4.4
Si, pct-----	A	30:30	34	1.05	1.06	30	-	37	31 - 37
	C	30:30	34	1.06	1.04	31	-	38	30 - 38
Sn, ppm-----	A	24:30	.8	3.33	2.06	<.2	-	2.7	.07 - 8.4
	C	22:30	.8	4.92	6.57	<.2	-	5.4	.03 - 18
Sr, ppm-----	A	30:30	220	1.21	1.07	160	-	340	150 - 320
	C	30:30	210	1.25	1.22	130	-	340	130 - 330
Th, ppm-----	A	30:30	7.7	1.25	1.17	4.9	-	11	4.9 - 12
	C	30:30	7.0	1.31	1.15	3.9	-	11	4.1 - 12
Ti, pct-----	A	30:30	.22	1.23	1.06	.15	-	.30	.15 - .33
	C	30:30	.18	1.31	1.19	.10	-	.30	.11 - .31
U, ppm-----	A	30:30	2.2	1.22	1.08	1.5	-	3.2	1.5 - 3.3
	C	30:30	1.9	1.28	---	1.1	-	3.0	1.2 - 3.1
V, ppm-----	A	30:30	28	1.21	1.09	20	-	42	19 - 41
	C	30:30	28	1.40	1.09	14	-	53	14 - 55
Y, ppm-----	A	30:30	30	1.33	1.14	18	-	71	17 - 53
	C	30:30	25	1.38	1.29	11	-	51	13 - 48
Yb, ppm-----	A	30:30	2.0	1.41	1.37	1.1	-	4.4	1.0 - 4.0
	C	30:30	1.6	1.48	1.78	.6	-	3.3	.7 - 3.5
Zn, ppm-----	A	30:30	31	1.18	1.07	23	-	44	22 - 43
	C	30:30	26	1.36	1.05	14	-	41	14 - 48
Zr, ppm-----	A	30:30	390	1.45	1.41	210	-	970	190 - 820
	C	29:30	270	1.82	44	97	-	>1,000	82 - 890
Based on DTPA extraction (ppm)									
Cd-----	A	3:30	---	---	---	<0.05	-	0.08	---
Co-----	A	3:30	---	---	---	<.2	-	.3	---
	C	6:30	0.2	1.37	---	<.2	-	.3	0.1 - 0.4
Cu-----	A	30:30	.6	1.36	1.15	.3	-	1.0	.3 - 1.1
	C	30:30	.4	2.45	4.15	.1	-	8.8	.07 - 2.4
Fe-----	A	30:30	7.6	1.25	1.09	4.4	-	12	4.9 - 12
	C	30:30	7.7	1.20	1.07	5.6	-	11	5.3 - 11
M-----	A	30:30	11	1.47	1.14	5.8	-	23	5.1 - 24
	C	30:30	6.2	1.43	1.14	1.8	-	12	3.0 - 13
N-----	A	20:30	.2	1.70	1.82	<.2	-	.7	.07 - .6
	C	23:30	.3	1.81	1.68	<.2	-	.9	.09 - 1.0
Pb-----	A	26:30	.7	1.41	1.51	<.5	-	1.2	.4 - 1.4
	C	16:30	.6	1.27	---	<.5	-	.8	.4 - 1.0
Zn-----	A	30:30	.5	1.38	1.20	.3	-	1.1	.3 - 1.0
	C	30:30	.2	1.23	1.22	.2	-	.3	.1 - .3
Based on sodium acetate extraction (me/100 g)									
Ca-----	A	30:30	7.0	1.25	1.05	5.0	-	12	4.5 - 11
	C	30:30	24	1.61	1.06	7.8	-	43	9.3 - 62
K-----	A	30:30	.7	1.32	1.19	.5	-	1.8	.5 - 1.0
	C	30:30	.4	1.95	1.61	.1	-	1.3	.2 - 1.0

TABLE 4—Continued

Parameter	Soil horizon	Detection ratio	Geometric mean	Geometric deviation	Geometric error	Observed range		Baseline			
Based on sodium acetate extraction (me/100g)--Continued											
Mg-----	A	30:30	1.5	1.28	1.06	.9	-	2.5	.9	-	2.4
	C	30:30	2.5	1.56	1.03	1.1	-	6.8	1.0	-	6.1
Na-----	A	30:30	.7	1.70	1.58	.2	-	4.1	.4	-	1.2
	C	30:30	1.1	1.65	1.48	.5	-	3.3	.6	-	2.1
Based on water-saturation extraction											
Ca, me/L-----	A	30:30	4.1	1.39	1.09	2.0	-	6.4	2.1	-	7.9
	C	30:30	4.9	2.65	1.11	1.5	-	32	.7	-	34
Cl, me/L-----	A	30:30	---	---	---	<.5	-	10	---	-	---
	C	25:30	2.7	6.70	1.66	<1.0	-	49	.06	-	120
K, me/L-----	A	30:30	.7	1.57	1.30	.2	-	1.5	.3	-	1.7
	C	26:30	.2	1.95	1.65	<.1	-	.6	.05	-	.8
Mg, me/L-----	A	30:30	1.2	1.32	1.15	.7	-	2.1	.7	-	2.1
	C	30:30	2.1	2.69	1.13	.6	-	23	.3	-	15
Na, me/L-----	A	30:30	.6	2.09	1.78	.2	-	2.8	.2	-	2.6
	C	30:30	8.0	2.74	1.08	.7	-	61	1.1	-	60
SO ₄ , me/L-----	A	15:30	1.0	1.56	---	<1.0	-	2.0	.4	-	2.4
	C	26:30	3.2	4.55	1.32	<1.0	-	65	.2	-	66
Specific conductance, mmhos/cm.	A	30:30	.5	1.29	1.07	.3	-	.8	.3	-	.8
	C	30:30	1.2	2.24	1.07	.5	-	7.0	.2	-	6.0
Based on hot-water extraction (ppm)											
B-----	A	1:30	---	---	---	<0.5	-	0.5	---	-	---
	C	10:30	0.4	2.00	---	<.5	-	2.0	0.1	-	1.6
Measured by specific ion electrode											
pH ¹ -----	A	30:30	7.9	0.38	0.055	7.0	-	8.4	7.1	-	8.7
	C	30:30	8.6	.29	.039	7.8	-	9.2	8.0	-	9.2
Based on replacement with sodium (me/100g)											
Cation-exchange----- capacity.	A	30:30	11	1.18	1.11	7.3	-	14	7.5	-	14
	C	30:30	12	1.42	1.20	6.0	-	21	5.8	-	23
Based on calculated parameters											
ESP ² , pct-----	A	30:30	6.7	1.68	1.48	2.2	-	29	3.4	-	13
	C	30:30	3.9	1.72	1.44	1.2	-	11	1.7	-	8.7
SAR ³ -----	A	30:30	.4	2.25	1.35	.1	-	2.2	.08	-	2.0
	C	30:30	4.2	2.25	1.08	.4	-	20	.8	-	21
Saturation index,--- pct.	A	30:30	22.9	1.12	1.04	18.7	-	27.4	18.5	-	28.3
	C	30:30	25.0	1.22	1.07	18.1	-	38.1	17.2	-	36.3
Based on physical properties (percent)											
Sand-----	A	30:30	70	1.14	1.02	51	-	87	54	-	91
	C	30:30	75	1.24	1.03	49	-	91	49	-	100
Silt-----	A	30:30	11	1.95	1.17	1.9	-	33	2.9	-	42
	C	30:30	27	7.97	1.24	.1	-	24	.4	-	100
Clay-----	A	30:30	16	1.24	1.06	11	-	21	10	-	25
	C	30:30	17	1.47	1.08	8.9	-	32	7.9	-	37

¹Variance is arithmetic.²Exchangeable sodium percentage.³Sodium adsorption ratio.

TABLE 6.—Summary statistics for parameters measured for topsoil and mine spoil from a reclaimed area of the San Juan mine in northwestern New Mexico

[Detection ratio, number of samples in which the parameter was found in measurable concentrations relative to the number of samples analyzed; geometric error (except as indicated) attributed to laboratory procedures; baseline, expected 95-percent range; leaders (---), no data available; <, less than, >, greater than; ppm, parts per million; me/L, milliequivalents per liter; mmhos/cm, reciprocal milliohms per centimeter; me/100 g, milliequivalents per 100 g; pct, percent]

Parameter	Soil horizon	Detection ratio	Geometric mean	Geometric deviation	Geometric error	Observed range		Baseline			
Based on total concentration											
Al, pct-----	Topsoil	12:12	4.9	1.06	1.03	4.5	-	5.5	4.4	-	5.5
	Spoil	12:12	6.1	1.11	1.03	5.1	-	6.9	5.0	-	7.5
As, pct-----	Topsoil	12:12	2.9	1.53	1.37	1.0	-	4.7	1.2	-	6.8
	Spoil	12:12	4.3	1.22	1.10	3.0	-	6.1	2.9	-	6.4
B, ppm-----	Topsoil	8:12	6.9	1.84	1.59	<5.0	-	23	2.0	-	23
	Spoil	12:12	13	1.52	1.41	7.3	-	25	5.6	-	30
Ba, ppm-----	Topsoil	12:12	450	1.37	1.36	330	-	1,000	240	-	840
	Spoil	12:12	590	1.46	1.61	310	-	1,100	280	-	1,300
Be, ppm-----	Topsoil	12:12	2.4	1.10	1.08	2.1	-	2.7	2.0	-	2.9
	Spoil	12:12	2.7	1.11	1.10	2.2	-	3.2	2.2	-	3.3
C, carbonate, pct----	Topsoil	12:12	.28	1.39	1.20	.19	-	.47	.15	-	.54
	Spoil	12:12	.23	1.63	1.43	.07	-	.42	.09	-	.61
C, organic, pct-----	Topsoil	12:12	.44	2.91	1.17	.19	-	4.1	.05	-	3.7
	Spoil	12:12	2.3	2.59	1.05	.89	-	14	.34	-	15
C, total, pct-----	Topsoil	12:12	.78	2.29	1.02	.40	-	4.5	.15	-	4.1
	Spoil	12:12	2.6	2.45	1.03	1.1	-	14	.43	-	16
Ca, pct-----	Topsoil	12:12	1.3	1.26	1.03	.96	-	1.9	.82	-	2.1
	Spoil	12:12	1.4	1.16	1.03	1.1	-	1.8	1.0	-	1.9
Co, ppm-----	Topsoil	12:12	6.0	1.14	1.11	4.9	-	7.4	4.6	-	7.8
	Spoil	12:12	8.5	1.22	1.10	5.8	-	12	5.7	-	13
Cr, ppm-----	Topsoil	12:12	22	1.41	1.41	10	-	29	11	-	44
	Spoil	12:12	14	1.26	1.14	10	-	22	8.8	-	22
Cu, ppm-----	Topsoil	12:12	10	1.48	1.15	6.6	-	24	4.6	-	22
	Spoil	12:12	18	1.58	1.50	6.0	-	28	7.2	-	45
Er, ppm-----	Topsoil	12:12	6.5	1.10	1.07	5.2	-	7.5	5.4	-	7.9
	Spoil	12:12	7.1	1.15	1.10	5.2	-	9.1	5.4	-	9.4
Fe, pct-----	Topsoil	12:12	1.4	1.09	1.07	1.3	-	1.6	1.2	-	1.7
	Spoil	12:12	1.7	1.17	1.08	1.3	-	2.1	1.2	-	2.3
Ge, ppm-----	Topsoil	12:12	1.3	1.31	1.31	.7	-	1.9	.8	-	2.2
	Spoil	12:12	1.4	1.59	1.17	.5	-	2.3	.6	-	3.5
Hg, ppm-----	Topsoil	12:12	.01	2.01	1.22	.01	-	.06	<.01	-	.04
	Spoil	12:12	.03	1.80	1.16	.02	-	.09	.01	-	.10
K, pct-----	Topsoil	12:12	1.5	1.05	1.01	1.4	-	1.6	1.4	-	1.7
	Spoil	12:12	1.4	1.12	1.01	1.1	-	1.6	1.1	-	1.8
La, ppm-----	Topsoil	12:12	25	1.36	1.26	18	-	51	14	-	46
	Spoil	12:12	32	1.21	1.21	21	-	40	22	-	47
Li, ppm-----	Topsoil	12:12	17	1.11	1.03	16	-	22	14	-	21
	Spoil	12:12	22	1.10	1.03	19	-	26	18	-	27
Mg, pct-----	Topsoil	12:12	.42	1.05	1.01	.40	-	.46	.38	-	.46
	Spoil	12:12	.56	1.13	1.01	.45	-	.67	.44	-	.72
Mn, ppm-----	Topsoil	12:12	260	1.36	1.26	190	-	430	140	-	480
	Spoil	12:12	340	1.32	1.12	190	-	430	200	-	590
Mo, ppm-----	Topsoil	12:12	1.8	1.29	1.12	1.3	-	2.8	1.1	-	3.0
	Spoil	12:12	2.7	1.13	1.11	2.1	-	3.2	2.1	-	3.4
Na, pct-----	Topsoil	12:12	1.2	1.04	1.02	1.1	-	1.3	1.1	-	1.3
	Spoil	12:12	1.7	1.22	1.02	1.2	-	2.0	1.1	-	2.5
Nb, ppm-----	Topsoil	12:12	11	1.26	1.20	7.5	-	16	6.9	-	17
	Spoil	12:12	9.2	1.41	1.26	5.1	-	15	4.6	-	18
Ni, ppm-----	Topsoil	12:12	8.6	1.14	1.06	7.1	-	11	6.6	-	11
	Spoil	12:12	12	1.18	1.06	9.4	-	16	8.6	-	17
Pb, ppm-----	Topsoil	12:12	11	1.15	1.18	8.2	-	13	8.3	-	15
	Spoil	12:12	11	1.33	1.11	6.6	-	17	6.2	-	19

TABLE 6—Continued

Parameter	Soil horizon	Detection ratio	Geometric mean	Geometric deviation	Geometric error	Observed range		Baseline			
Based on total concentration											
Rb, ppm-----	Topsoil	12:12	70	1.05	1.04	65	-	75	63	-	77
	Spoil	12:12	71	1.14	1.06	55	-	80	55	-	92
S, pct-----	Topsoil	12:12	.10	1.55	1.13	.06	-	.24	.04	-	.24
	Spoil	12:12	.26	1.63	1.30	.10	-	.52	.10	-	.69
Sc, ppm-----	Topsoil	12:12	3.9	1.14	1.10	3.1	-	5.2	3.0	-	5.1
	Spoil	12:12	5.4	1.33	1.09	3.6	-	9.0	3.1	-	9.6
Si, pct-----	Topsoil	12:12	35	1.06	1.01	31	-	36	31	-	39
	Spoil	12:12	30	1.11	1.01	23	-	32	24	-	37
Sn, ppm-----	Topsoil	11:12	1.1	2.24	1.60	<.2	-	2.6	.2	-	5.5
	Spoil	12:12	1.9	1.27	1.29	1.4	-	2.8	1.2	-	3.1
Sr, ppm-----	Topsoil	12:12	190	1.55	1.57	48	-	260	79	-	460
	Spoil	12:12	270	1.14	1.05	220	-	330	210	-	350
Th, ppm-----	Topsoil	12:12	7.7	1.19	1.16	6.0	-	11	5.4	-	11
	Spoil	12:12	9.8	1.14	1.14	7.9	-	12	7.5	-	13
Ti, pct-----	Topsoil	12:12	.23	1.05	1.04	.21	-	.25	.21	-	.25
	Spoil	12:12	.27	1.14	1.04	.21	-	.32	.21	-	.35
U, ppm-----	Topsoil	12:12	2.9	1.16	1.05	2.4	-	4.0	2.2	-	3.9
	Spoil	12:12	4.1	1.17	1.03	3.4	-	5.6	3.0	-	5.6
V, ppm-----	Topsoil	12:12	45	1.08	1.09	40	-	50	39	-	52
	Spoil	12:12	56	1.26	1.06	38	-	78	35	-	89
Y, ppm-----	Topsoil	12:12	27	1.11	1.08	22	-	32	22	-	33
	Spoil	12:12	32	1.23	1.11	22	-	41	21	-	48
Yb, ppm-----	Topsoil	12:12	1.6	1.10	1.10	1.3	-	1.8	1.3	-	1.9
	Spoil	12:12	1.6	1.25	1.15	1.1	-	2.5	1.0	-	2.5
Zn, ppm-----	Topsoil	12:12	41	1.08	1.02	39	-	49	35	-	48
	Spoil	12:12	56	1.14	1.04	47	-	66	43	-	73
Zr, ppm-----	Topsoil	11:12	420	1.51	1.51	260	-	>1000	180	-	960
	Spoil	12:12	300	1.35	1.37	190	-	600	160	-	550
Based on DTPA extraction (ppm)											
Cd-----	Topsoil	3:12	---	---	---	<0.05	-	0.05	---	-	---
	Spoil	11:12	0.05	1.00	1.11	<.05	-	.05	0.05	-	0.05
Co-----	Topsoil	2:12	---	---	---	<.1	-	.1	---	-	---
	Spoil	2:12	---	---	---	<.1	-	1.4	---	-	---
Cu-----	Topsoil	12:12	.7	1.68	1.08	.5	-	2.2	.2	-	2.0
	Spoil	12:12	2.0	1.18	1.04	1.5	-	2.4	1.4	-	2.8
Fe-----	Topsoil	12:12	13	2.93	1.32	6.4	-	130	1.5	-	110
	Spoil	12:12	61	1.98	1.13	30	-	210	16	-	240
Mn-----	Topsoil	12:12	8.1	1.78	1.09	5.6	-	32	2.6	-	26
	Spoil	12:12	12	2.32	1.06	5.4	-	55	2.2	-	65
Ni-----	Topsoil	5:12	---	---	---	<.05	-	.4	---	-	---
	Spoil	12:12	.2	2.23	1.22	.1	-	.9	.04	-	1.0
Pb-----	Topsoil	7:12	.1	4.13	---	<.1	-	1.5	.006	-	1.7
	Spoil	10:12	.5	2.74	1.45	<.1	-	1.4	.07	-	3.8
Zn-----	Topsoil	12:12	.4	2.25	1.43	.2	-	2.2	.08	-	2.0
	Spoil	12:12	1.5	1.89	1.05	.8	-	5.2	.4	-	5.4
Based on sodium acetate extraction (me/100 g)											
Ca-----	Topsoil	12:12	29	1.25	1.07	21	-	46	19	-	44
	Spoil	12:12	32	1.13	1.06	28	-	42	26	-	40
K-----	Topsoil	12:12	.2	1.22	1.13	.2	-	.3	.2	-	.3
	Spoil	12:12	.3	1.18	1.00	.3	-	.4	.2	-	.4
Mg-----	Topsoil	12:12	3.4	1.22	1.02	2.9	-	5.2	2.3	-	5.1
	Spoil	12:12	5.9	1.48	1.06	3.8	-	12	2.7	-	13
Na-----	Topsoil	12:12	1.0	2.63	1.26	.3	-	6.6	.2	-	6.5
	Spoil	12:12	6.0	4.42	3.39	.1	-	18	.8	-	44

TABLE 6—Continued

Parameter	Soil horizon	Detection ratio	Geometric mean	Geometric deviation	Geometric error	Observed range		Baseline			
Based on water saturation extraction											
Ca, me/L-----	Topsoil	12:12	11	1.96	1.13	5.9	-	30	2.9	-	42
	Spoil	12:12	26	1.13	1.05	23	-	33	20	-	33
Cl, me/L-----	Topsoil	12:12	7.2	1.62	1.19	3	-	15	2.7	-	19
	Spoil	12:12	19	1.50	1.13	9	-	31	8.4	-	43
K, me/L-----	Topsoil	12:12	.4	1.46	1.20	.2	-	.7	.2	-	.9
	Spoil	12:12	.6	1.17	1.06	.5	-	.8	.4	-	.8
Mg, me/L-----	Topsoil	12:12	4.9	2.11	1.15	2.4	-	15	1.1	-	22
	Spoil	12:12	27	1.68	1.11	15	-	71	9.6	-	76
Na, me/L-----	Topsoil	12:12	21	3.15	1.10	6.5	-	120	2.1	-	210
	Spoil	12:12	260	1.69	1.10	97	-	500	91	-	740
SO ₄ , me/L-----	Topsoil	12:12	18	3.12	1.14	5	-	95	1.8	-	180
	Spoil	12:12	230	1.79	1.13	75	-	480	72	-	740
Specific conductance, mmhos/cm.	Topsoil	12:12	2.8	2.37	1.14	1.3	-	11	.5	-	16
	Spoil	12:12	9.6	1.70	1.45	4.0	-	17	3.3	-	28
Based on hot-water extraction (ppm)											
B-----	Topsoil	8:12	0.6	2.56	1.10	<0.5	-	3.5	0.09	-	3.9
	Spoil	11:12	1.8	2.91	1.46	.5	-	11	.2	-	15
Measured by specific ion electrode											
pH ¹ -----	Topsoil	12:12	8.0	0.67	0.076	6.6	-	8.4	6.7	-	9.3
	Spoil	12:12	7.6	.87	.12	6.3	-	8.4	5.9	-	9.3
Based on replacement with sodium (me/100 g)											
Cation-exchange----- capacity.	Topsoil	12:12	17	1.62	1.08	12	-	46	6.5	-	45
	Spoil	12:12	36	1.41	1.08	22	-	68	18	-	72
Based on calculated parameters											
ESP ² , pct-----	Topsoil	12:12	3.1	2.28	1.28	1.0	-	13	0.6	-	15
	Spoil	12:12	13	4.12	3.14	.2	-	32	2.4	-	69
SAR ³ -----	Topsoil	12:12	7.6	2.26	1.11	2.7	-	25	1.5	-	39
	Spoil	12:12	51	1.56	1.06	20	-	78	21	-	120
Saturation index, pct.	Topsoil	12:12	28.2	1.15	1.07	24.4	-	38.7	22.1	-	36.0
	Spoil	12:12	50.2	1.23	1.07	33.0	-	61.9	33.9	-	74.2
Based on physical properties (percent)											
Sand-----	Topsoil	12:12	67	1.10	1.02	54	-	71	55	-	81
	Spoil	12:12	42	1.22	1.01	30	-	52	28	-	63
Silt-----	Topsoil	12:12	12	1.23	1.23	7.4	-	18	7.9	-	18
	Spoil	12:12	19	1.23	1.06	14	-	27	13	-	29
Clay-----	Topsoil	12:12	21	1.21	1.08	17	-	32	14	-	31
	Spoil	12:12	37	1.14	1.02	30	-	45	28	-	48

¹Variance is arithmetic.²Exchangeable sodium percentage.³Sodium adsorption ratio.

Study 1 assessed the variation of soil for the broad area likely to be affected by energy-related development in the San Juan Basin. Maps were prepared for some elements (figures 6A-S), but for other parameters, reliable maps showing parameter-value distributions in soil could not be prepared from the present data. For these latter parameters, the feasibility of preparing such maps was estimated and is shown in table 1. However, it is likely that if additional samples were analyzed in order to prepare maps for the addi-

tions in soil could not be prepared from the present data. For these latter parameters, the feasibility of preparing such maps was estimated and is shown in table 1. However, it is likely that if additional samples were analyzed in order to prepare maps for the addi-

tional parameters, they would show no gradational regional patterns because of the small variation that had already been found at the 50-km cell level. From the maps that were prepared (figs. 6A-S), it is apparent that any consistent gradational trends in element content of soil across the region is lacking. In general, the maps of element concentrations do not reflect geologic units (compare figs. 1 and 6), nor do they reflect mapped soil units (see Maker, Dregne, Link, and Anderson, 1974 and compare with fig. 6). Many more maps were possible for total-element content than for extractable-element content. This difference may indicate that total-element content reflects types of surficial materials, whereas extractable-element content reflects pedogenic processes; surficial materials tend to be uniform throughout larger areas, but the effects of pedogenic processes on surficial materials do not. These processes probably reflect site-specific microclimate and vegetation. Of special interest is the single sample of the A horizon from the 25-km cell in which the Huerfano soil series (Typic Natrargid) was sampled, and in which arsenic (fig. 6A) and molybdenum (fig. 6M) both exceed the baseline value. High molybdenum and arsenic were observed in a similar study in the Northern Great Plains (Severson and Tidball, 1979), where potential problems associated with high molybdenum in forage, leading to molybdenosis in cattle, are suspected and are currently being investigated (J. A. Erdman, oral communication, 1979). A similar molybdenosis potential may exist for the far-western part of the area of Study 1 because of very high levels of molybdenum in galleta grass (Gough and Severson, 1981).

Study 2 was designed to assess the soil variation in the area containing the Sheppard, Shiprock, and Doak soil association. These soils provide the best available topsoil material for mined-land reclamation. The feasibility of mapping composition at distance intervals of greater than 1 km is slight because, for most parameters in both A and C horizons of soils, the variation measured at distances of greater than 1 km is less than 50 percent of the total variation (table 3). Moreover, the total variation measured for many parameters is small, indicating a rather uniform composition of the soil sampled within the mapped occurrence of these soils. Because of this inferred uniformity, the number of samples required to map the slight variations in composition of these soils would be large for most parameters. Also, as was expected, the total variation measured for the parameters of these soils is smaller than the variation measured in soils covering the larger area of Study 1 (table 3). For more information on the use of analysis-of-variance data to determine minimum sampling requirements, which may be app-

lied to the present study, see the discussion in Severson (1979) where a similar sampling design was used, and see Miesch (1976), who gave a more basic comprehensive discussion.

Study 3 was designed to assess variation in parameters of a reclaimed area within the San Juan mine and to provide data on the composition of topsoil and mine spoil. Again, the analysis-of-variance data can be used to assess the feasibility of preparing maps of composition at various distance intervals. The distance increments used in this study were much smaller than those used in the previous studies. Smaller increments were used because much of the variability was expected at very small distance increments due to the heterogeneous mixing of soil and spoil materials associated with mining operations. Generally, only a small area, a few hectares in size, is reclaimed at any one time. The analysis-of-variance data (table 5) show that topsoil tends to be less variable in its total-element composition than does mine spoil; however, the opposite relation is true for extractable elements. This result seems reasonable for total-element composition of mine spoil, because it consists of rock fragments that have not undergone pedogenic processes such as addition, removal, transfer, or transformation of various soil constituents that tend to make one soil different from another. The greater variation in extractable elements is probably because the topsoil reflects chemical differentiation due to pedogenic processes, even though it is physically homogenized by stockpiling and respreading. Variation at distance intervals of less than 5 m tends to account for most of the variation for both total- and extractable-element content in mine spoil. Variation in topsoil is also large at distance increments of less than 5 m but does not totally dominate variation at greater distances. In both topsoil and mine spoil, it would generally be necessary to sample at distance intervals of less than 5 m in order to describe more than 50 percent of the total variation measured for many elements or properties. The preparation of maps explaining a reasonable portion of the total variation would be expensive even for a moderate-size area.

Schafer (1979), in comparing the variation in soil physical and morphological properties between mine-reclaimed land and adjacent undisturbed areas in Montana, has stated that the variation is mainly at two increments of distance in the mine-reclaimed land — major variation at 0.1–1 m (local) and minor variation at greater than 500 m (landscape). However, natural soils were more variable than mine-reclaimed soils at the landscape scale (greater than 500 m) but less variable at the local scale (0.1–1 m). The data obtained in the present study show variance components for

natural soils to be large for some parameters at distance increments of more than 25 km (regional), whereas for most parameters the largest variance component was measured at less than 1 km (table 1). Also, mine-reclaimed soils show most of their variability at distance increments of less than 5 m (table 5). The present study does not assess variability of mine-reclaimed soils at any increment that could be considered regional, nor does it assess variability of natural soils at distance increments of a few meters. Comparisons between the two studies would be purely speculative because they were conducted in different areas, different soil properties were measured, and different distance increments were used to express variance components. However, further work on assessing chemical variability, in addition to physical and morphological properties, at similar increments for natural and mine-reclaimed soils would provide basic information useful to persons charged with evaluating mine-reclaimed areas whose main experience has been gained in mapping natural soils.

SOIL COMPOSITION

STUDY 1

Baseline values for the soils in the area likely to be affected by energy development are shown in table 2. Similar geometric means and observed and expected ranges for total content in A and C horizons are shown for most elements (calcium in the C horizon, however, is about double the amount in the A horizon). This similarity indicates that similar variability was measured for both soil horizons. Means and ranges for extractable concentrations of boron, calcium, chlorine, magnesium, sodium, and SO_4 , and SAR are two or more times greater in the C horizon than the A horizon, whereas extractable potassium and manganese are higher in the A horizon than in the C horizon. These contrasts between total and extractable levels in the two soil horizons suggest that total-element content indicates gross mineralogy, whereas extractable-element content indicates pedogenic processes — in this case, movement of readily solubilized constituents from the A horizon to the C horizon. Those extractable elements that tend to be higher in the A horizon than in the C horizon either are not as easily mobilized under the present soil conditions (manganese, for example) or are readily recycled by vegetation (potassium, for example).

Total content of many trace metals in these soils in the area likely to be affected by mining operations is from one-half to one-fifth the total content of these metals in soils of the northern part of the Great Plains

(Severson, 1979, table 8). In addition, total calcium and magnesium contents are about one-half of those measured in the Great Plains. However, DTPA extractable levels of trace metals in soils in this area are similar to those reported for the Northern Great Plains (Severson and others, 1977, table 19; Gough and others, 1979). This similarity indicates that the trace-metal reservoir in soil is greater in the Northern Great Plains than in this area of the San Juan Basin; however, the extractable or plant-available amounts are similar.

Three soil orders were identified (Entisol, Aridisol, and Mollisol). The series names and taxonomic classification at the great-group level are shown in table 7 for the 47 soils sampled. The sampling locations and taxonomic classifications at the great-group level are shown in figure 3. From figure 3, it is apparent that the great groups are dispersed throughout the area in a haphazard fashion and do not correspond to mapped geologic units (fig. 1). Soils are classified into like groups based on selected properties, generally those which define diagnostic horizons. These horizons may be identified by properties of either or both the A or B horizon of the soil. Because only A and C horizons of soils were sampled and analyzed, the presentation of chemical data based on taxonomic criteria may be of limited significance.

A horizons of soil were analyzed because they are presumed to be the most biologically active and most closely related to element uptake by plants. C horizons of soil were sampled because they represent the largest volume of soil material and should most closely reflect the chemical character of surficial deposits or, where surficial deposits are thin or absent, they should reflect the chemical character of the underlying geo-

TABLE 7.—*Taxonomy of soils sampled in the San Juan Basin*

[Index numbers are keyed to figs. 3 and 4]

Index Number	Subgroup	Family	Series
1	Typic Torriorthent-	Coarse loamy, mixed (calcareous), mesic.	Fruitland.
2	Typic Torriorthent-	Fine loamy mixed (calcareous), mesic.	Turley.
3	Typic Torriorthent-	Shallow, loamy, mixed (calcareous), mesic.	Persayo.
4	Lithic Torriorthent	Loamy, mixed (calcareous), mesic.	Unknown.
5	Typic Torripsamment	Mixed, mesic-----	Sheppard.
6	Typic Haplargid---	Fine loamy, mixed, mesic---	Doak.
7	Typic Haplargid---	Coarse loamy, mixed, mesic---	Shiprock, Mayqueen.
8	Lithic Haplargid---	Fine loamy, mixed, mesic---	Monicero.
9	Typic Calciorthid---	---do-----	Avalon.
10	Typic Camborthid---	Fine, mixed, mesic-----	Notal.
11	Typic Camborthid---	Fine loamy, mixed, mesic---	Kinnear.
12	Typic Camborthid---	Coarse loamy, mixed, mesic---	Koyen.
13	Ustollic Camborthid---	Fine loamy, mixed, mesic---	LaFonda.
14	Typic Natrargid---	Shallow, loamy, mixed, mesic---	Huerfano.
15	Cumulic Haplustoll-	Fine loamy, mixed, mesic---	Manzano.

logic units. B horizons of soil were not sampled because in some soils they are absent and because when present they generally make up only a small part of the total soil volume.

It may be of general interest to compare the average composition of all soils (table 2) to the average composition of soils in each great group (table 8). Total and extractable concentrations for most of the elements are similar for all seven great groups. Only the Torripsamment and Natrargid great groups show noticeable deviations in some parameters from the average composition of groups. The Torripsamment great group is low in total aluminum in both A and C horizons, total thorium and titanium in the A horizon, extractable lead in the A horizon, and cation-exchange capacity in the A horizon. The Natrargid great group is high in total calcium, sulfur, and extractable calcium and sodium in the C horizon. It is also low in total potassium, in both A and C horizons. The geometric deviations for carbonate carbon; total boron, carbon, calcium, copper, sulfur, and tin; DTPA extractable iron and lead; exchangeable potassium and sodium; most of the water-soluble constituents; ESP (exchangeable sodium percentage) and SAR (sodium adsorption ratio) are greater than 2.00 for the other great groups. These high deviations indicate that, within a single great group, the range in values for these elements and properties is quite large — the great groups are certainly neither chemically distinct from one another nor very homogeneous within themselves. For the remaining elements or properties, each great group is more uniform; however, as stated above, the differences between great groups, based on chemical composition, are small. It is difficult to distinguish one great group from another based on these chemical parameters, except possibly for the properties of the Torripsamment and Natrargid great groups mentioned above.

Water-soluble boron greater than 2.0 parts per million, specific conductance greater than 4 millimhos/cm, SAR greater than 11, and ESP greater than 15 are generally accepted as being restrictive to plant growth. All of these values are exceeded by some samples of both A and C horizons of natural soils in the area of Study 1 (table 2, Observed range). In table 8, geometric means for C-horizon samples from the Calciorthids and Natrargids indicate that these two are the least favorable for plant growth. Also, if the DTPA extractable levels of copper, iron, manganese, and zinc, considered by Lindsay and Norvell (1978) as being deficient for growing corn and sorghum in Colorado soils, are at all applicable to native and mine-reclaimed soils in the San Juan Basin, then copper, manganese, and iron are adequate for plant growth, and zinc may be

generally deficient. Although the low zinc values were observed to have no effect on the native plants growing on these soils, they may affect introduced plants growing on reclaimed mine spoil. Such an effect has been noted by Safaya (1980) to be minimal on mine land in the Northern Great Plains.

STUDY 2

Baseline parameter values of the A and C horizons for the area containing the Sheppard, Shiprock, and Doak soil association are presented in table 4. Similar geometric means for the total content of most elements are reported for both soil horizons. However, the expected range is wider for the C horizon than for the A horizon because the C horizon shows greater variability. The geometric means and observed ranges for extractable elements are comparable for many elements or properties between the A and C horizons; however, the C horizon is noticeably higher in boron, chlorine, magnesium, sodium, SO_4 , pH, and SAR than the A horizon. Measures of the total content tend to reflect gross mineralogy, whereas measures of the extractable content reflect pedogenic processes, as described for Study 1. The baseline values used to characterize the composition of these soils may be extrapolated to other parts of the region where these soils occur.

The total content of many trace elements tends to be less in these soils by factors of from two to five than was reported for areas in the northern part of the Great Plains (Severson, 1979, table 8); however, the content of trace metals extracted by DTPA is similar in the two areas (Severson and others, 1977, table 19). This general observation indicates, as for Study 1, that the DTPA-extractable trace-element levels are similar for the two regions, but the reserves of these elements in soils are greater in the Northern Great Plains than they are in the Sheppard, Shiprock, and Doak soils.

The average composition of the five soil families sampled is presented in table 9; differences between the average composition of samples of these families is small. Moreover, the geometric deviations for most parameters within each soil family are also small. These facts indicate that the composition of these soils, when they are grouped at the family level, is rather uniform. The uniformity in composition of these soils was emphasized in the previous section on variability and is also shown by the small deviations for composition of all soils (table 4). It is difficult to distinguish between most of these soil families on a compositional basis because of this uniformity. However, the Typic Torripsamment, mixed, mesic family shows relatively low concentrations of total arsenic in the C horizon, and total iron, titanium, and uranium in the A horizon.

TABLE 8.—Parameter values measured for seven soil great groups in the area likely to be affected by energy-related developments in the San Juan Basin
 [Ratio, number of samples in which the parameter was found in measurable units relative to the number of samples analyzed; means not given for the Haplustoll great group because it is represented by a single sampler; *, value is an estimate, based on Cohen's (1959) technique, for censored data; leaders (---), no data available; <---, less than; pct, percent; ppm, parts per million; me/L, milliequivalents per liter; mmhos/cm, reciprocal milliohm per centimeter; me/100 g, milliequivalents per 100 grams]

Parameter	Soil horizon	Soil great group														
		Calcicorthid		Camborthid		Torriorthent		Natrorthid		Haplargid		Torripsamment		Haplustoll		
		Ratio	Geometric mean	Ratio	Geometric mean	Ratio	Geometric mean	Ratio	Geometric mean	Ratio	Geometric mean	Ratio	Geometric mean	Ratio	Geometric mean	
Based on total concentration																
Al, pct	A	2:2	5.1	1.20	9:9	5:9	5.20	1.68	9:9	5:9	5.20	1.68	9:9	5:9	5.20	1.68
	C	2:2	6.1	1.16	9:9	5:9	5.40	1.65	9:9	5:9	5.40	1.65	9:9	5:9	5.40	1.65
As, ppm	A	2:2	5.1	1.09	9:9	5:4	6.0	1.46	9:9	5:4	6.0	1.46	9:9	5:4	6.0	1.46
	C	2:2	4.6	1.46	9:9	6:0	1.30	1.54	9:9	5:4	1.40	1.72	9:9	5:4	1.40	1.72
B, ppm	A	2:2	17	1.40	6:9	*12	*3.06	13:15	*18	*2.23	3:3	23	*1.76	0:2	<5.0	---
	C	1:2	<5.0	---	7:9	*16	*2.43	13:15	*19	*2.15	3:3	27	1.44	1:2	<5.0	---
Ba, ppm	A	2:2	480	1.68	9:9	5:9	5.20	1.68	9:9	5:9	5.20	1.68	9:9	5:9	5.20	1.68
	C	2:2	600	1.65	9:9	5:9	5.40	1.65	9:9	5:9	5.40	1.65	9:9	5:9	5.40	1.65
Be, ppm	A	2:2	1.3	1.12	9:9	1:6	1.16	1.30	9:9	1:7	1.26	1.45	9:9	1:7	1.26	1.45
	C	2:2	1.5	1.26	9:9	1:7	1.30	1.30	9:9	1:7	1.30	1.30	9:9	1:7	1.30	1.30
C, carbonate, pct	A	2:2	2.1	1.79	3:9	*.02	*6.84	14:15	*.14	*3.06	3:3	4.1	1.13	1:2	1.20	1.06
	C	2:2	.39	4.21	8:9	*.16	*4.50	15:15	*.16	*3.06	2:2	*.09	*13.8	1:2	<.01	3.37
C, organic, pct	A	2:2	.43	1.34	9:9	.39	2.34	15:15	.37	2.28	3:3	.37	1.56	2:2	.41	1.02
	C	2:2	.28	1.63	9:9	.43	1.61	15:15	.35	1.70	3:3	.32	1.31	2:2	.15	2.93
C, total, pct	A	2:2	.65	1.48	9:9	.46	2.29	15:15	.59	1.90	3:3	.86	2.23	2:2	.38	1.62
	C	2:2	.71	2.82	9:9	.73	1.64	15:15	.59	1.75	3:3	.64	1.84	2:2	.32	3.15
Ca, pct	A	2:2	1.3	1.12	9:9	.42	2.05	15:15	.75	1.71	3:3	1.5	2.73	2:2	.43	4.26
	C	2:2	2.5	1.85	9:9	1.0	2.19	15:15	1.1	1.50	3:3	3.0	1.63	2:2	.34	5.76
Co, ppm	A	2:2	5.4	1.49	9:9	6.1	1.47	15:15	6.5	1.41	7:1	7.1	1.46	2:2	2.9	1.58
	C	2:2	6.4	1.01	9:9	7.7	1.58	15:15	6.6	1.33	3:3	4.5	1.40	2:2	3.1	1.34
Cr, ppm	A	2:2	23	1.53	9:9	18	1.56	15:15	18	1.38	3:3	20	1.25	2:2	12	1.81
	C	2:2	16	1.09	9:9	19	1.33	15:15	18	1.41	3:3	19	1.68	2:2	13	2.27
Cu, ppm	A	2:2	10	2.04	9:9	8.8	2.20	15:15	11	1.81	3:3	13	2.12	2:2	3.1	1.77
	C	2:2	15	1.33	9:9	12	1.65	15:15	12	1.79	3:3	8.0	1.22	2:2	3.3	1.58
Er, ppm	A	2:2	6.3	1.03	9:9	*5.9	*1.23	15:15	6.7	1.13	2:3	*5.2	*1.17	1:2	<4.6	---
	C	2:2	6.6	1.10	9:9	7.1	1.18	15:15	6.8	1.19	3:3	6.4	1.23	1:2	<4.6	---
Fe, pct	A	2:2	1.1	1.34	9:9	1.1	1.51	15:15	1.3	1.49	3:3	2.2	2.35	2:2	.57	1.51
	C	2:2	1.4	1.20	9:9	1.5	1.49	15:15	1.4	1.47	3:3	1.1	1.68	2:2	.57	1.60
Ce, ppm	A	2:2	1.5	1.05	9:9	1.4	1.19	15:15	1.6	1.11	3:3	1.2	1.45	2:2	1.2	1.00
	C	2:2	1.1	1.37	9:9	1.4	1.21	15:15	1.3	1.22	3:3	1.3	1.27	2:2	1.3	1.17
Hg, ppm	A	2:2	.02	1.00	9:9	.02	1.81	15:15	.02	1.46	3:3	.02	1.49	2:2	.02	1.00
	C	2:2	.02	3.12	9:9	.03	1.56	15:15	.02	1.71	3:3	.04	1.42	2:2	.01	1.00
K, pct	A	2:2	1.8	1.00	9:9	1.8	1.21	15:15	1.7	1.12	3:3	1.2	1.31	2:2	1.4	1.33
	C	2:2	1.6	1.01	9:9	1.6	1.15	15:15	1.6	1.11	3:3	.74	1.45	2:2	1.3	1.31
La, ppm	A	2:2	31	1.20	9:9	31	1.23	15:15	30	1.23	3:3	26	1.27	2:2	11	1.89
	C	2:2	43	1.65	9:9	34	1.28	15:15	31	1.27	3:3	27	1.12	2:2	16	1.49
Li, ppm	A	2:2	12	1.27	9:9	16	1.49	15:15	13	1.75	3:3	15	1.52	2:2	11	1.37
	C	2:2	10	1.40	9:9	17	1.43	15:15	16	1.57	3:3	14	2.60	2:2	6.7	1.52
Mg, pct	A	2:2	.38	1.40	9:9	.31	1.69	15:15	.42	1.67	3:3	.44	1.72	2:2	.21	2.61
	C	2:2	.44	1.03	9:9	.44	1.51	15:15	.45	1.54	3:3	.27	2.94	2:2	.21	2.95
Mn, ppm	A	2:2	380	1.34	9:9	230	1.81	15:15	260	1.59	3:3	560	2.71	1.39	1.89	2.00
	C	2:2	180	1.31	9:9	190	2.09	15:15	240	1.49	3:3	62	1.75	2:2	130	1.60
Ko, ppm	A	1:2	<1.0	---	6:9	*1.4	*1.97	11:15	*1.3	*1.39	2:3	*1.3	*4.50	1:2	<1.0	---
	C	2:2	2.2	1.87	9:9	*1.7	*1.56	13:15	*1.5	*1.44	1:3	<1.0	---	<1.0	---	---
Na, pct	A	2:2	1.2	1.11	9:9	.75	2.35	15:15	.86	1.29	3:3	.59	1.64	2:2	.56	1.35
	C	2:2	1.4	1.02	9:9	1.0	1.52	15:15	.86	1.34	3:3	.69	1.67	2:2	.51	1.06
Nb, ppm	A	2:2	14	1.00	9:9	14	1.18	15:15	12	1.24	3:3	11	1.60	2:2	11	1.06
	C	2:2	12	1.13	9:9	12	1.31	15:15	13	1.24	3:3	13	1.54	2:2	13	1.00
Ni, ppm	A	2:2	8.3	1.50	9:9	11	1.54	15:15	10	1.66	3:3	11	1.52	2:2	3.8	1.55
	C	2:2	8.8	1.19	9:9	11	1.45	15:15	10	1.56	3:3	6.2	2.40	2:2	4.1	1.65
Pb, ppm	A	2:2	14	1.23	9:9	13	1.27	15:15	15	1.25	3:3	15	1.45	2:2	7.9	1.01
	C	2:2	12	1.34	9:9	14	1.26	15:15	13	1.29	3:3	6.2	1.23	2:2	8.9	1.35
Rb, ppm	A	2:2	55	1.87	9:9	59	1.81	15:15	60	1.43	3:3	47	1.74	2:2	56	1.37
	C	2:2	35	1.23	9:9	72	1.39	15:15	69	1.33	3:3	49	1.23	2:2	42	1.59

		Based on water-saturation extraction																	
Ca, me/L	A 2:2	7.1	1.10	9:9	5.7	2.23	15:15	6.0	1.58	3:3	8.8	3.41	15:15	4.6	1.67	2:2	3.7	2.10	3.7
	C 2:2	17	1.58	9:9	6.8	2.70	15:15	5.2	2.44	3:3	13	3.77	15:15	3.9	3.45	2:2	6.3	2.32	3.3
Cl, me/L	A 2:2	1.2	1.33	4:9	*3.0	*26.5	12:15	*1.0	*2.49	2:3	*5	*1.00	6:15	*4	*1.60	1:2	<5	---	<5
	C 2:2	13	1.39	7:9	*3.0	*10.5	12:15	*1.4	*3.28	1:3	<5	---	8:15	*6	*1.2.5	1:2	<5	---	<5
K, me/L	A 2:2	1.8	1.12	9:9	1.2	1.56	15:15	1.3	2.05	3:3	1.0	1.50	15:15	1.1	1.46	2:2	1.2	1.57	1.4
	C 2:2	.8	1.19	9:9	.7	1.47	15:15	.7	1.71	3:3	.7	1.66	15:15	.7	1.89	2:2	1.8	2.08	.9
Mg, me/L	A 2:2	1.4	1.42	9:9	1.2	2.05	15:15	.9	1.65	3:3	1.3	1.71	15:15	1.3	1.39	2:2	.9	1.46	1.3
	C 2:2	6.3	1.02	9:9	3.0	4.20	15:15	1.2	2.98	3:3	3.7	4.28	15:15	2.4	3.88	2:2	1.5	1.86	1.2
Na, me/L	A 2:2	1.3	1.39	9:9	3.0	9.52	15:15	2.5	2.62	3:3	2.2	2.67	15:15	1.0	1.90	2:2	.9	1.82	.9
	C 2:2	6.9	3.27	9:9	12	5.77	15:15	7.0	2.33	3:3	32	4.48	15:15	.6	4.19	2:2	2.1	2.49	2.5
SO ₄ , me/L	A 1:2	<1.0	---	4:9	*4.3	*65.6	9:15	*1.8	*2.64	2:3	*1.6	*19.0	8:15	*1.5	*7.09	1:2	<1.0	---	<1.0
	C 2:2	48	3.69	6:9	*4.2	*15.2	13:15	*3.7	*4.31	2:3	*1.6	*25.1	8:15	*2.7	*2.18	1:2	<1.0	---	<1.0
Specific conductance, umhos/cm.	A 2:2	.9	1.10	9:9	1.1	4.96	15:15	1.0	2.05	3:3	1.0	2.33	15:15	.6	1.49	2:2	.6	1.88	.6
	C 2:2	6.8	2.46	9:9	1.4	4.27	15:15	1.2	1.93	3:3	4.5	4.42	15:15	1.0	2.78	2:2	.9	2.44	.6

		Based on hot water-extraction (ppm)				
B-----	A 0:2	<0.5	---	4:9	*0.8	*2.83
	C 2:2	1.0	1.00	8:9	*.6	*1.46

		Measured by specific ion electrode				
pH-----	A 2:2	8.3	0	9:9	8.1	0.33
	C 2:2	8.3	.14	9:9	8.2	.32

		Based on replacement with sodium (me/100 g)				
Cation-exchange capacity.	A 2:2	14	1.05	9:9	7.8	4.83
	C 2:2	17	1.42	9:9	20	1.90

		Based on calculated parameters																	
ESP ² -----	A 2:2	0.4	1.54	9:9	1.8	3.88	15:15	1.3	2.32	3:3	0.8	2.35	15:15	1.2	1.73	2:2	2.6	2.41	1.3
	C 2:2	4.8	2.84	9:9	2.4	4.16	15:15	2.1	2.59	3:3	1.0	2.60	15:15	1.2	2.28	2:2	1.5	2.28	1.0
SAR ³ -----	A 2:2	.6	1.50	9:9	1.6	6.75	15:15	1.3	2.45	3:3	.9	2.37	15:15	.6	1.86	2:2	.6	1.30	.6
	C 2:2	20	2.75	9:9	5.3	3.95	15:15	3.8	2.44	3:3	11	3.58	15:15	3.2	3.11	2:2	1.1	1.67	1.7
Saturation index, pct.	A 2:2	23.1	1.08	9:9	29.6	1.29	15:15	29.9	1.29	3:3	23.6	1.03	15:15	24.7	1.13	2:2	25.9	2.41	24.1
	C 2:2	34.0	1.92	9:9	41.1	1.45	15:15	32.8	1.33	3:3	32.5	1.11	15:15	27.1	1.27	2:2	24.1	1.12	23.0

		Based on physical properties (percent)																	
Sand-----	A 2:2	69	1.11	9:9	5.7	1.66	15:15	52	1.75	3:3	63	1.10	15:15	72	1.16	2:2	85	1.06	72
	C 2:2	45	1.50	9:9	37	2.17	15:15	50	1.62	3:3	17	2.83	15:15	68	1.11	2:2	85	1.11	71
Silt-----	A 2:2	13	1.25	9:9	9.0	2.41	15:15	10	2.61	3:3	15	1.30	15:15	9.1	1.77	2:2	2.3	1.99	9.8
	C 2:2	18	1.22	9:9	15	1.64	15:15	11	2.69	3:3	46	1.49	15:15	6.0	2.96	2:2	2.6	1.94	18
Clay-----	A 2:2	18	1.23	9:9	19	2.12	15:15	24	1.80	3:3	22	1.16	15:15	15	1.47	2:2	10	1.76	18
	C 2:2	34	1.55	9:9	34	1.58	15:15	27	1.59	3:3	30	1.21	15:15	19	1.60	2:2	11	1.93	19

1-Variance is arithmetic.
 2-Exchangeable sodium percentage.
 3-Sodium adsorption ratio.

The Typic Torriorthent, coarse loamy, mixed calcareous, mesic family shows relatively high values for total calcium, sodium, and strontium in the A horizon.

Means and observed ranges (table 4) for water-soluble boron, and SAR, ESP, and specific conductance in both horizons of these samples of potential topsoil material indicate that very few samples have levels of these properties that can be considered restrictive to plant growth. Again, as for Study 1, using the Lindsay and Norvell (1978) critical levels for copper, iron, manganese, and zinc, only zinc appears to be at levels that are low enough in all soil families to limit plant growth, and copper in the C horizon of the Typic Calciorthid, fine loamy, mixed, mesic family (table 9) may also be at a deficiency level for plant growth. However, these low values do not appear to be affecting native plants growing on these soils, and there may be only a potential effect for introduced plants under reclamation conditions.

STUDY 3

Baseline values for topsoil and mine spoil from an area of the San Juan Mine that has been reclaimed (regraded, topsoiled, and revegetated in 1974) are given in table 6. The total content of only a few elements averaged two or more times as high in mine spoil as in topsoil (boron, organic and total carbon, mercury, and sulfur). However, extractable concentrations of many elements are from three to five times as great in mine spoil as in topsoil (DTPA-extractable copper, iron, lead, and zinc; water-soluble boron, calcium, chlorine, and magnesium; and specific conductance). ESP and SAR are about six times higher in mine spoil than in topsoil, and exchangeable sodium, water-soluble sodium, and SO_4 are an order of magnitude higher in mine spoil than in topsoil. The average composition of topsoil (table 6), however, is similar to that of the C-horizon soil from both Study 1 (table 2) and Study 2 (table 4) for many parameters. The topsoil values are within the baseline ranges for the Study 1 area for more parameters than for Study 2 because many varied soils were sampled in the former area, whereas the soils sampled in the latter area showed greater uniformity and, therefore, a narrower baseline range.

The upper and lower limits of the observed ranges in parameter values in mine spoil either exceed or are below the baseline ranges for many parameters in both A and C horizons of soils in both the Study 1 and Study 2 areas. Many more parameter values exceed these baselines than are below the baselines. The composition of mine spoil is much different from that of natural soils in this same area. Of special interest are

the high values of extractable boron and sodium, specific conductance, SAR, and ESP in mine spoil and their possible effects on the establishment and growth of vegetation. The element composition of plants grown both on and off mine spoil is reported in Gough and Severson (1980).

SUMMARY

Baseline ranges for total- and extractable-element composition and other properties of soils sampled in the area likely to be affected by energy-related development (Study 1) are shown in table 2. Baseline ranges for the area containing potential topsoil materials (Study 2) are shown in table 4, and baseline ranges for mine-reclaimed soils (Study 3) are shown in table 6. In tables 2 and 4 the geometric means for most elements are similar. Only a few soil properties (total sulfur in both horizons, water-soluble calcium and potassium in the C horizon, water-soluble sodium, and SAR in the A horizon) are two or more times higher in the Study 1 area (table 2) than in the Study 2 area (table 4). The baselines for the Study 1 area encompass a much wider range in concentration than do those for the Study 2 area.

Great groups of soil in the Study 1 area, or soil families in the Study 2 area, are difficult to distinguish on the basis of their composition. In the Study 1 area, only the Natrargid and Torripsamment great groups show high or low values in composition for a few elements. However, the range of values measured for many parameters within each great group is large, making it difficult to define a discrete range in composition that may be expected for any single great group. In the Study 2 area, the range in values measured for many parameters in each family is small; however, the average composition of each family is so similar that it is difficult to distinguish them based on composition alone. Only the Typic Torripsamment, mixed, mesic family shows low values in composition for a few elements. In the Study 1 area, Calciorthid and Natrargid great groups generally have high SAR, ESP, and specific conductance, which may restrict plant growth. The soils in the Study 2 area can be considered as suitable for plant growth with respect to these properties. Concentrations of cadmium, cobalt, copper, iron, manganese, lead, and zinc measured in the Study 1 and Study 2 areas were similar to those shown to be favorable for native plant growth in the Northern Great Plains (Gough, and others, 1979).

In Study 3, the total content of only a few elements was as much as two times higher in mine spoil than in topsoil. However, extractable concentrations of many elements in mine spoil were from three to 13 times

TABLE 9.—Parameter values measured for five soil families sampled in the area containing soils considered to have potential for use as topsoil in mined-land reclamation in the San Juan Basin

[Ratio, number of samples in which the parameter was found in measurable units relative to the number of samples analyzed; means not given for the Typic Torripsamment mixed, mesic family because it is represented by a single sample; *, value is an estimate, based on Cohen's (1959) technique, for censored data; leaders (---), no data available; <, less than; pct, percent; ppm, parts per million; me/L, milliequivalents per liter; mmhos/cm, reciprocal milliohms per centimeter; me/100 g, milliequivalents per 100 grams]

Parameter	Soil horizon	Soil family												
		Typic Haplargid, fine loamy, mixed, mesic			Typic Torriorthent, coarse loamy, mixed (calcareous), mesic			Typic Calciorthid, fine loamy mixed, mesic			Typic Haplargid, coarse loamy, mixed, mesic			Typic Torripsamment mixed mesic
		Ratio	Geometric mean	Geometric deviation	Ratio	Geometric mean	Geometric deviation	Ratio	Geometric mean	Geometric deviation	Ratio	Geometric mean	Geometric deviation	
Based on total concentration														
Al, pct-----	A	7:7	4.7	1.08	2:2	5.3	1.11	2:2	4.4	1.11	18:18	4.3	1.11	4.3
	C	7:7	4.9	1.16	2:2	5.1	1.25	2:2	3.8	1.01	18:18	4.1	1.21	4.6
As, ppm-----	A	7:7	3.4	1.18	2:2	3.5	1.30	2:2	3.1	1.23	18:18	3.3	1.24	2.3
	C	7:7	4.6	1.15	2:2	3.6	1.29	2:2	2.9	1.18	18:18	3.7	1.40	1.7
B, ppm-----	A	7:7	19	1.22	2:2	10	1.91	2:2	20	1.24	18:18	15	1.37	8.4
	C	7:7	*10	*2.61	2:2	12	1.19	2:2	4.4	1.39	18:18	*10	*1.82	<5.0
Ba, ppm-----	A	7:7	620	1.19	2:2	790	1.33	2:2	720	1.17	18:18	590	1.25	600
	C	7:7	670	1.45	2:2	760	1.16	2:2	730	1.06	18:18	690	1.36	740
Be, ppm-----	A	7:7	1.4	1.16	2:2	1.3	1.12	2:2	1.5	1.10	18:18	1.3	1.11	1.4
	C	7:7	1.4	1.15	2:2	1.3	1.05	2:2	1.2	1.06	18:18	1.3	1.18	1.2
C, carbonate, pct---	A	0:7	<.01	---	0:2	<.01	---	1:2	<.01	---	2:18	<.01	---	<.01
	C	6:7	*.11	*4.14	2:2	.12	2.10	2:2	.18	1.59	15:18	*.09	*4.34	.27
C, organic, pct-----	A	7:7	.44	1.45	2:2	.30	1.07	2:2	.28	1.03	18:18	.34	1.37	.22
	C	7:7	.19	1.52	2:2	.18	1.12	2:2	.02	4.57	18:18	.08	2.58	.16
C, total, pct-----	A	7:7	.44	1.45	2:2	.30	1.07	2:2	.31	1.20	18:18	.36	1.31	.22
	C	7:7	.35	1.89	2:2	.32	1.25	2:2	.22	1.21	18:18	.24	2.09	.43
Ca, pct-----	A	7:7	.67	1.15	2:2	1.1	1.04	2:2	.69	1.58	18:18	.59	1.18	.56
	C	7:7	1.2	1.86	2:2	1.3	1.35	2:2	1.0	1.08	18:18	.93	1.86	1.3
Co, ppm-----	A	7:7	6.3	1.32	2:2	5.4	1.18	2:2	4.8	1.00	18:18	4.5	1.19	3.1
	C	7:7	5.5	1.30	2:2	4.6	1.28	2:2	3.2	1.33	18:18	4.1	1.37	4.7
Cr, ppm-----	A	7:7	23	1.59	2:2	17	1.58	2:2	23	2.17	18:18	19	1.46	9.8
	C	7:7	17	1.57	2:2	11	1.06	2:2	13	1.17	18:18	11	1.48	14
Cu, ppm-----	A	7:7	12	1.41	2:2	8.5	1.09	2:2	8.0	1.29	18:18	8.0	1.33	5.4
	C	7:7	11	1.61	2:2	8.4	1.08	2:2	4.2	1.02	18:18	5.1	1.63	7.7
Er, ppm-----	A	5:7	*5.5	*1.24	1:2	<4.6	---	1:2	<4.6	---	9:18	*4.7	*1.37	<4.6
	C	4:7	*5.3	*1.39	0:2	<4.6	---	1:2	<4.6	---	9:18	*4.7	*1.25	<4.6
Fe, pct-----	A	7:7	1.0	1.15	2:2	1.0	1.06	2:2	.93	1.19	18:18	.87	1.22	.58
	C	7:7	1.1	1.39	2:2	1.0	1.30	2:2	.57	1.44	18:18	.74	1.30	1.2
Ge, ppm-----	A	7:7	1.4	1.14	2:2	1.1	1.14	2:2	1.4	1.16	18:18	1.3	1.18	1.4
	C	7:7	1.5	1.10	2:2	1.1	1.14	2:2	1.1	1.20	18:18	1.2	1.20	1.0
Hg, ppm-----	A	6:7	*.02	*1.57	2:2	.01	1.63	2:2	.02	1.33	18:18	.02	1.57	.02
	C	5:7	*.01	*1.79	2:2	.02	1.00	1:2	<.01	---	15:18	*.01	*1.79	<.01
K, ppm-----	A	7:7	2.1	1.04	2:2	1.9	1.05	2:2	2.0	1.07	18:18	2.1	1.06	2.0
	C	7:7	2.0	1.08	2:2	2.0	1.03	2:2	2.2	1.11	18:18	2.1	1.22	2.1
La, ppm-----	A	7:7	31	1.14	2:2	30	1.29	2:2	29	1.33	18:18	27	1.25	19
	C	7:7	30	1.20	2:2	25	1.09	2:2	40	1.04	18:18	25	1.35	21
Li, ppm-----	A	7:7	14	1.13	2:2	12	1.13	2:2	13	1.00	18:18	12	1.11	11
	C	7:7	17	1.24	2:2	14	1.11	2:2	9.5	1.08	18:18	11	1.32	13
Mg, pct-----	A	7:7	.26	1.33	2:2	.25	1.38	2:2	.31	1.15	18:18	.24	1.27	.17
	C	7:7	.39	1.51	2:2	.27	1.08	2:2	.15	1.16	18:18	.20	1.44	.25
Mn, ppm-----	A	7:7	290	1.37	2:2	210	1.07	2:2	330	1.14	18:18	230	1.44	140
	C	7:7	230	1.57	2:2	210	1.07	2:2	190	1.29	18:18	220	1.77	190
Mo, ppm-----	A	3:7	*1.0	*1.23	2:2	1.2	1.13	1:2	<1.0	---	6:18	*.9	*1.25	<1.0
	C	5:7	*1.2	*1.18	1:2	<1.0	---	1:2	<1.0	---	5:18	*.6	*2.68	<1.0
Na, pct-----	A	7:7	1.2	1.10	2:2	1.6	1.13	2:2	1.1	1.24	18:18	1.0	1.13	1.1
	C	7:7	1.2	1.14	2:2	1.4	1.20	2:2	1.1	1.03	18:18	1.0	1.26	1.3
Nb, ppm-----	A	7:7	11	1.18	2:2	8.4	1.03	2:2	8.9	1.10	18:18	10	1.32	9.9
	C	7:7	11	1.28	2:2	10	1.00	2:2	7.3	1.35	18:18	8.5	1.58	9.9
Ni, ppm-----	A	7:7	8.0	1.25	2:2	6.1	1.12	2:2	6.3	1.00	18:18	5.8	1.24	3.8
	C	7:7	8.5	1.42	2:2	5.2	1.39	2:2	3.1	1.61	18:18	4.9	1.39	5.0
Pb, ppm-----	A	7:7	14	1.20	2:2	11	1.21	2:2	12	1.13	18:18	11	1.16	8.8
	C	7:7	10	1.21	2:2	8.6	1.02	2:2	10	1.07	18:18	9.6	1.35	11
Rb, ppm-----	A	7:7	83	1.17	2:2	77	1.05	2:2	92	1.04	18:18	82	1.16	90
	C	7:7	87	1.11	2:2	85	1.09	2:2	92	1.21	18:18	86	1.26	65
S, pct-----	A	7:7	.04	1.33	2:2	.03	1.17	2:2	.03	1.00	18:18	.04	1.39	<.03
	C	7:7	.05	1.82	2:2	.03	1.00	2:2	.06	1.05	18:18	.03	1.30	.07
Sc, ppm-----	A	7:7	3.4	1.13	2:2	3.0	1.12	2:2	2.8	1.08	18:18	2.7	1.22	2.4
	C	7:7	3.5	1.31	2:2	2.5	1.12	2	1.44	140				
	C	7:7	230	1.57	2:2	210	1.07	2:2	190	1.29	18:18	220	1.77	190
Mo, ppm-----	A	3:7	*1.0	*1.23	2:2	1.2	1.13	1:2	<1.0	---	6:18	*.9	*1.25	<1.0
	C	5:7	*1.2	*1.18	1:2	<1.0	---	1:2	<1.0	---	5:18	*.6	*2.68	<1.0
Na, pct-----	A	7:7	1.2	1.10	2:2	1.6	1.13	2:2	1.1	1.24	18:18	1.0	1.13	1.1
	C	7:7	1.2	1.14	2:2	1.4	1.20	2:2	1.1	1.03	18:18	1.0	1.26	1.3
Nb, ppm-----	A	7:7	11	1.18	2:2	8.4	1.03	2:2	8.9	1.10	18:18	10	1.32	9.9
	C	7:7	11	1.28	2:2	10	1.00	2:2	7.3	1.35	18:18	8.5	1.58	9.9
Ni, ppm-----	A	7:7	8.0	1.25	2:2	6.1	1.12	2:2	6.3	1.00	18:18	5.8	1.24	3.8
	C	7:7	8.5	1.42	2:2	5.2	1.39	2:2	3.1	1.61	18:18	4.9	1.39	5.0
Pb, ppm-----	A	7:7	14	1.20	2:2	11	1.21	2:2	12	1.13	18:18	11	1.16	8.8
	C	7:7	10	1.21	2:2	8.6	1.02	2:2	10	1.07	18:18	9.6	1.35	11
Rb, ppm-----	A	7:7	83	1.17	2:2	77	1.05	2:2	92	1.04	18:18	82	1.16	90
	C	7:7	87	1.11	2:2	85	1.09	2:2	92	1.21	18:18	86	1.26	65

TABLE 9 — Continued

Parameter	Soil horizon	Soil family												
		Typic Haplargid, fine loamy, mixed, mesic			Typic Torriorthent, coarse loamy, mixed (calcareous), mesic			Typic Calciorthid, fine loamy mixed, mesic			Typic Haplargid, coarse loamy, mixed, mesic			Typic Torrripsament mixed mesic
		Ratio	Geometric mean	Geometric deviation	Ratio	Geometric mean	Geometric deviation	Ratio	Geometric mean	Geometric deviation	Ratio	Geometric mean	Geometric deviation	
Based on total concentration—Continued														
S, pct	A	7:7	.04	1.33	2:2	.03	1.17	2:2	.03	1.00	18:18	.04	1.39	<.03
	C	7:7	.05	1.82	2:2	.03	1.00	2:2	.06	1.05	18:18	.03	1.30	.07
Sc, ppm	A	7:7	3.4	1.13	2:2	3.0	1.12	2:2	2.8	1.08	18:18	2.7	1.22	2.4
	C	7:7	3.5	1.31	2:2	2.5	1.12	2:2	2.0	1.24	18:18	2.3	1.21	2.2
Si, pct	A	7:7	34	1.06	2:2	33	1.04	2:2	33	1.09	18:18	35	1.04	36
	C	7:7	33	1.06	2:2	34	1.05	2:2	35	1.01	18:18	34	1.06	33
Sn, ppm	A	5:7	*.5	*4.01	2:2	.9	4.73	2:2	2.3	1.20	14:18	*.7	*3.53	1.9
	C	3:7	*.1	*12.4	2:2	2.4	1.30	2:2	.5	6.32	13:18	*.7	*4.89	<.2
Sr, ppm	A	7:7	240	1.13	2:2	340	1.02	2:2	210	1.49	18:18	200	1.13	200
	C	7:7	250	1.13	2:2	220	1.14	2:2	210	1.49	18:18	200	1.21	340
Th, ppm	A	7:7	8.7	1.17	2:2	6.7	1.08	2:2	8.0	1.24	18:18	7.5	1.29	5.6
	C	7:7	8.5	1.22	2:2	5.9	1.02	2:2	5.9	1.00	18:18	6.9	1.33	5.3
Ti, pct	A	7:7	.27	1.16	2:2	.25	1.26	2:2	.21	1.07	18:18	.21	1.21	.15
	C	7:7	.24	1.30	2:2	.18	1.21	2:2	.14	1.04	18:18	.16	1.23	.22
U, ppm	A	7:7	2.7	1.22	2:2	2.4	1.27	2:2	2.0	1.12	18:18	2.2	1.15	1.5
	C	7:7	2.5	1.20	2:2	1.9	1.16	2:2	1.4	1.01	18:18	1.8	1.24	2.1
V, ppm	A	7:7	33	1.15	2:2	32	1.09	2:2	28	1.19	18:18	27	1.20	20
	C	7:7	39	1.33	2:2	29	1.16	2:2	18	1.42	18:18	26	1.33	26
Y, ppm	A	7:7	34	1.15	2:2	28	1.25	2:2	29	1.07	18:18	30	1.39	19
	C	7:7	30	1.36	2:2	24	1.06	2:2	19	1.04	18:18	24	1.40	18
Yb, ppm	A	7:7	2.3	1.26	2:2	1.9	1.72	2:2	2.4	1.03	18:18	1.9	1.46	1.6
	C	7:7	2.0	1.41	2:2	1.8	1.04	2:2	1.2	1.19	18:18	1.5	1.52	.9
Zn, ppm	A	7:7	34	1.15	2:2	32	1.12	2:2	33	1.24	18:18	30	1.17	23
	C	7:7	35	1.21	2:2	30	1.21	2:2	17	1.29	18:18	24	1.32	29
Zr, ppm	A	7:7	560	1.34	2:2	370	1.21	2:2	500	1.22	18:18	340	1.38	210
	C	6:7	*510	*1.68	2:2	180	1.08	2:2	150	1.10	18:18	250	1.68	300
Based on DTPA extraction (ppm)														
Cd	A	1:7	<0.05	---	0:2	<0.05	---	0:2	<0.05	---	2:18	*0.02	*1.88	<0.05
	C	0:7	<0.05	---	0:2	<0.05	---	0:2	<0.05	---	0:18	<0.05	---	<0.05
Co	A	1:7	<.2	---	1:2	<.2	---	0:2	<.2	---	1:18	<.2	---	<.2
	C	3:7	*.2	*1.34	0:2	<.2	---	0:2	<.2	---	3:18	*.2	*1.26	<.2
Cu	A	7:7	.7	1.29	2:2	.5	1.41	2:2	.5	1.07	18:18	.5	1.37	.4
	C	7:7	.6	1.32	2:2	.6	1.77	2:2	.1	1.63	18:18	.3	2.79	.3
Fe	A	7:7	8.9	1.23	2:2	8.4	1.01	2:2	7.0	1.04	18:18	7.1	1.26	8.1
	C	7:7	8.5	1.15	2:2	9.4	1.23	2:2	6.6	1.23	18:18	7.4	1.20	7.1
Mn	A	7:7	14	1.64	2:2	8.3	1.03	2:2	8.2	1.25	18:18	11	1.38	6.9
	C	7:7	7.8	1.26	2:2	6.6	1.33	2:2	4.6	1.04	18:18	5.8	1.49	6.2
Ni	A	6:7	*.3	*1.54	2:2	.4	2.43	2:2	.3	1.23	9:18	*.2	*1.52	.3
	C	6:7	*.4	*1.67	2:2	.5	1.14	1:2	<.2	---	13:18	*.3	*1.83	<.2
Pb	A	7:7	.6	1.40	1:2	<.5	---	2:2	.9	1.17	16:18	*.7	*1.37	1.0
	C	6:7	*.5	*1.32	0:2	<.5	---	1:2	<.5	---	9:18	*.5	*1.22	.4
Zn	A	7:7	.5	1.36	2:2	.4	1.00	2:2	.3	1.23	18:18	.5	1.42	.4
	C	7:7	.2	1.21	2:2	.2	1.63	2:2	.2	1.23	18:18	.2	1.20	.2
Based on sodium acetate extraction (me/100 g)														
Ca	A	7:7	6.9	1.27	2:2	7.5	1.43	2:2	9.9	1.38	18:18	7.0	1.19	5.3
	C	7:7	27	1.49	2:2	30	1.14	2:2	25	1.26	18:18	21	1.71	39
K	A	7:7	.7	1.35	2:2	.8	1.31	2:2	.7	1.05	18:18	.8	1.34	.7
	C	7:7	.4	1.28	2:2	.3	1.14	2:2	.3	1.00	18:18	.3	1.73	.3
Mg	A	7:7	1.8	1.24	2:2	1.2	1.41	2:2	1.5	1.10	18:18	1.5	1.24	.9
	C	7:7	4.1	1.47	2:2	2.5	1.22	2:2	1.5	1.18	18:18	2.2	1.37	1.1
Na	A	7:7	.6	1.34	2:2	.8	1.31	2:2	.5	1.41	18:18	.7	1.89	.8
	C	7:7	1.6	1.42	2:2	1.5	3.21	2:2	.9	1.47	18:18	.9	1.53	.9
Based on water-saturation extraction														
Ca, me/L	A	7:7	3.2	1.44	2:2	3.5	2.17	2:2	5.6	1.14	18:18	4.4	1.26	4.0
	C	7:7	6.5	3.07	2:2	2.0	1.28	2:2	26	1.19	18:18	4.0	2.28	4.3
Cl, me/L	A	0:7	<1.0	---	0:2	<1.0	---	0:2	<1.0	---	3:18	*.2	*2.97	<1.0
	C	7:7	12	4.08	1:2	<1.0	---	2:2	13	1.22	14:18	*1.4	*5.98	1.0
K, me/L	A	7:7	.6	1.96	2:2	.4	1.44	2:2	.8	1.44	18:18	.8	1.37	.6
	C	7:7	.3	2.14	2:2	.2	1.33	2:2	.3	1.00	14:18	*.2	*2.06	.2
Mg, me/L	A	7:7	1.2	1.32	2:2	1.0	1.55	2:2	1.2	1.06	18:18	1.3	1.31	.9
	C	7:7	3.9	3.44	2:2	.7	1.23	2:2	9.8	1.15	18:18	1.7	1.93	.7
Na, me/L	A	7:7	.8	2.26	2:2	2.2	1.17	2:2	.4	1.63	18:18	.5	1.81	.3
	C	7:7	17	2.26	2:2	8.2	3.97	2:2	24	1.12	18:18	5.5	2.48	3.8
SO ₄ , me/L	A	3:7	*.9	*1.93	2:2	<1.0	---	2:2	1.2	1.33	8:18	*.9	*1.47	1.0
	C	5:7	*3.2	*5.86	2:2	2.7	4.16	2:2	46	1.01	16:18	*2.4	*3.52	<1.0
Specific conductance, mmhos/cm.	A	7:7	.5	1.32	2:2	.5	1.33	2:2	.6	1.12	18:18	.5	1.28	.5
	C	7:7	2.2	2.42	2:2	.9	2.38	2:2	4.2	1.11	18:18	.9	1.73	.7
Based on hot-water extraction (ppm)														
B	A	0:7	<0.5	---	0:2	<0.5	---	0:2	<0.5	---	1:18	<0.5	---	<0.5
	C	4:7	*.5	*1.68	1:2	<.5	---	1:2	<.5	---	4:18	*.5	*1.00	<.5

TABLE 9 — Continued

Parameter	Soil horizon	Soil family												
		Typic Haplargid, fine loamy, mixed, mesic			Typic Torriorthent, coarse loamy, mixed (calcareous), mesic			Typic Calciorthid, fine loamy mixed, mesic			Typic Haplargid, coarse loamy, mixed, mesic			Typic Torripsamment mixed mesic
		Ratio	Geometric mean	Geometric deviation	Ratio	Geometric mean	Geometric deviation	Ratio	Geometric mean	Geometric deviation	Ratio	Geometric mean	Geometric deviation	
Measured by specific ion electrode														
pH ¹ -----	A	7:7	7.5	0.47	2:2	8.1	0.35	2:2	8.3	0.14	18:18	7.9	0.26	7.9
	C	7:7	8.5	.30	2:2	8.8	.28	2:2	8.4	.14	18:18	8.7	.30	8.5
Based on replacement with sodium (me/100 g)														
Cation-exchange capacity.-----	A	7:7	11	1.14	2:2	11	1.03	2:2	11	1.07	18:18	10	1.18	7.3
	C	7:7	17	1.15	2:2	14	1.22	2:2	6.8	1.20	18:18	10	1.32	15.4
Based on calculated parameters														
ESP ² , pct-----	A	7:7	6.4	1.45	2:2	7.4	1.09	2:2	3.6	1.08	18:18	7.2	1.80	9.9
	C	7:7	4.9	1.71	2:2	4.2	2.69	2:2	3.0	1.80	18:18	3.8	1.69	2.2
SAR ³ -----	A	7:7	.6	2.59	2:2	1.5	1.66	2:2	.2	1.56	18:18	.3	1.82	.2
	C	7:7	7.5	1.55	2:2	7.1	4.46	2:2	5.6	1.08	18:18	3.2	2.25	2.4
Saturation index,--- pct.	A	7:7	24.2	1.11	2:2	23.8	1.12	2:2	20.0	1.10	18:18	22.5	1.11	26.6
	C	7:7	30.3	1.21	2:2	30.7	1.24	2:2	19.8	1.07	18:18	23.3	1.15	27.8
Based on physical properties (percent)														
Sand-----	A	7:7	61	1.14	2:2	7.5	1.00	2:2	73	1.02	18:18	72	1.10	87
	C	7:7	59	1.21	2:2	70	1.07	2:2	89	1.00	18:18	81	1.09	78
Silt-----	A	7:7	18	1.85	2:2	9.0	1.18	2:2	9.0	1.55	18:18	11	1.73	1.9
	C	7:7	13	1.92	2:2	9.5	1.13	2:2	9.5	1.91	18:18	1.4	5.73	5.4
Clay-----	A	7:7	18	1.17	2:2	16	1.09	2:2	17	1.13	18:18	15	1.19	11
	C	7:7	25	1.21	2:2	20	1.32	2:2	10	1.09	18:18	15	1.37	16

¹Variance is arithmetic.
²Exchangeable sodium percentage.
³Sodium adsorption ratio.

higher. Exchangeable sodium, water-soluble boron, specific conductance, ESP, and SAR values were measured at levels considered to be detrimental to plant growth (Sandoval and Gould, 1978). The values reported by Gould, Howard, and Buchanan (1977) and by Gould, Miyamoto, and Rai (1977) for water-extractable cations and anions, pH, and SAR from soils in southern San Juan County are within the expected range of those reported for the Study 2 area (table 4). However, when the soil properties measured in the present study (tables 8 and 9) are compared to the same properties of taxonomically similar soils as reported by Gould, Howard, and Buchanan (1977, table 4) and Gould, Miyamoto, and Rai (1977, table 3), both similarities and discrepancies are noted. In general, values for soils of the Torripsamment great group, as determined in this study and the other studies, are similar. Many of the values reported by Gould, Miyamoto, and Rai (1977, table 3) for the Haplargid great group are somewhat higher, and for the Calciorthid great group somewhat lower, than those reported for the same great groups in the present study (tables 8 and 9). Judged from these studies, as stated previously, named taxonomic soil groups show wide ranges in chemical properties.

Rai, Wierenga, and Gould (1974, table 3) reported values for water-soluble cations and anions, pH, and SAR in core samples of rock from the Fruitland Formation in the southern part of San Juan County. The

values for most elements in these rock samples are much higher than are those for mine spoil from the San Juan mine of this report (table 6). However, similar ranges are reported in both studies for water-extractable boron, and potassium, pH, and SAR. Perhaps the chemical composition of the Fruitland Formation changes appreciably between these two locations, or perhaps some process in the mining and mined-land reclamation operation is responsible for these disparities.

CONCLUSIONS

1. Maps of element content in soils in the broad area likely to be affected by energy-related development (Study 1), show no gradational pattern across the area. Such geochemical maps do not show patterns that resemble geologic or soils maps, indicating that named geologic or soil units are poor indicators of the element composition of soils.
2. In Study 1, many more maps resulted from studies of total-element content than from extractable-element content. This result indicates that total-element content of soil is variable at a regional scale, whereas extractable element content is variable at a smaller, or local, scale. This difference suggests that total-element composition may reflect distribution of differing sur-

- ficial deposits, whereas extractable element composition may reflect the more site-specific pedogenic processes acting on these surficial deposits.
3. In the Study 2 area, containing materials considered suitable for use as topsoil in mined-land reclamation, most of the variability in soil composition was confined to small distance increments. The soils are uniform in composition and, as a group, can adequately be characterized by a baseline range.
 4. Topsoil and spoil material (Study 3) had a large portion of the total variability measured, for most parameters, at distance intervals of less than 5 m. In order to prepare reliable maps of composition of topsoil or spoil, it would be necessary to sample at this interval. Such maps, even for a moderate-size area, would be very expensive to prepare.
 5. When the composition of soils of Study 1 are summarized according to their taxonomic great groups, it is difficult to distinguish between these groups based on composition alone. This difficulty indicates that soil taxonomy cannot be used to characterize the composition of soil groups very effectively.
 6. It is also difficult to distinguish between the soils of Study 2, when grouped at the family taxonomic level, on the basis of their compositions alone. Taxonomic family groupings of soil in this area cannot be used very effectively to characterize composition.
 7. In Study 1, many of the samples of C horizons of soils (and a few samples of A horizons) had values for SAR and ESP that would limit their desirability for use as topsoil in mined-land reclamation. In general, soils classified as Haplargids and Torriorthents are superior to those classified as Calciorthids and Natrargids as potential sources of topsoil material for mined-land reclamation. The latter two great groups have water-soluble boron, SAR and ESP values that may be restrictive to plant growth.
 8. Most of the soils sampled in Study 2 were identified as the Shiprock or Doak soil series. These soils appear to be suitable for use as topsoil in mined-land reclamation because they have few, if any, undesirable chemical properties.
 9. High values for total arsenic and molybdenum in soil were measured in the western part of the Study 1 area. The potential for molybdenosis problems in livestock needs further investigation in this area.
 10. The chemical composition of the topsoil material (Study 3) is similar to that of natural C horizons of soils from the Study 1 and Study 2 areas. However, mine spoil is much different in composition from natural soils. For example, high values for extractable boron and sodium, SAR, and ESP indicate that, without topsoil, the establishment and growth of vegetation on mine spoil may be difficult. In addition, extractable levels of copper, iron, lead, and zinc are three to five times higher in spoil than in topsoil. Topsoiling of reclaimed spoil material has ameliorated these undesirable chemical properties.
 11. Total content of many trace elements in the soils sampled in Study 1 and Study 2 is from one-half to one-fifth that measured in soils in the northern part of the Great Plains; however, DTPA extractable levels are similar for all these areas. Therefore, although the trace-element reservoir is greater in soil in the Northern Great Plains, the extractable or plant available amounts are similar.

REFERENCES CITED

- Cohen, A. C., Jr., 1959, Simplified estimators for the normal distribution when samples are singly censored or truncated: *Technometrics*, v. 1, p. 217-237.
- Crock, J. G. and Severson, R. C., 1980, Four reference soil and rock samples for measuring element availability in the Western energy regions: U.S. Geological Survey Circular, 841, 16 p.
- Dane, C. H. and Bachman, G. O., 1965, Geologic map of New Mexico: U.S. Geological Survey, scale 1:500,000, 2 sheets.
- Gough, L. P., and Severson, R. C., 1981, Biogeochemical variability of plants at native and altered sites, San Juan Basin, New Mexico: U.S. Geological Survey Professional Paper 1134-D.
- Gough, L. P., Severson, R. C., and McNeal, J. M., 1979, Extractable and total-soil element concentrations favorable for native plant growth in the northern Great Plains, *in* Wali, M. K., ed., *Ecology and coal resource development*: New York, Pergamon Press, p. 859-869.
- Gould, W. L., Howard, V. W., Jr., and Buchanan, B. A., 1972, Biotic composition and soil characteristics of an area to be strip-mined in San Juan county by El Paso Natural Gas Company: New

- Mexico State University Agricultural Experiment Station Special Report 24, 47 p.
- 1977, Biotic composition and soil properties on a Fruitland Formation exposure in northwestern New Mexico: New Mexico State University Agricultural Experiment Station Special Report 33, 62 p.
- Gould, W. L., Howard, V. W., Jr., and Valentine, K. A., 1972, Soil characteristics, biotic composition, and vegetative production of areas leased by Western Coal Company for strip mining near Fruitland, New Mexico: New Mexico State University Agricultural Experiment Station Special Report 20, 49 p.
- Gould, W. L., Miyamoto, S., and Rai, Dhanpat, 1977, Reclamation potential of overburden materials in the Fruitland Formation in the San Juan Basin: New Mexico State University Agricultural Experiment Station Bulletin 657, 39 p.
- Leone, F. C., Nelson, L. S., Johnson, N. L., and Eisenstat, Stanley, 1968, Sampling distributions of variance components. II. Empirical studies of unbalanced nested designs: *Technometrics*, v. 10, no. 4, p. 719-737.
- Lindsay, W. L., and Norvell, W. A., 1978, Development of a DTPA soil test for zinc, iron, manganese, and copper: *Soil Science Society of America Journal*, v. 42, no. 3, p. 421-428.
- Maker, H. J., Bullock, H. E., Jr., and Anderson, J. U., 1974, Soil associations and land classification for irrigation, McKinley County: New Mexico State University Agricultural Experiment Station Research Report 262, 68 p.
- Maker, H. J., Dregne, H. E., Link, V. G., and Anderson, J. U., 1974, Soils of New Mexico: New Mexico State University Agricultural Experiment Station Research Report 285, 132 p.
- Maker, H. J., Folks, J. J., Anderson, J. U., and Gallman, W. B., 1971, Soil associations and land classification for irrigation, Sandoval and Los Alamos Counties: New Mexico State University Agricultural Experiment Station Research Report 188, 45 p.
- Maker, H. J., Folks, J. J., Anderson, J. U., and Link, V. G., 1973, Soil associations and land classification for irrigation, Rio Arriba County: New Mexico State University Agricultural Experiment Station Research Report 254, 69 p.
- Maker, H. J., Keetch, C. W., and Anderson, J. U., 1973, Soil associations and land classification for irrigation, San Juan County: New Mexico State University Agricultural Experiment Station Research Report 257, 44 p.
- Miesch, A. T., 1976, Geochemical survey of Missouri — methods of sampling, laboratory analysis, and statistical reduction of data in a geochemical survey of Missouri, *with sections on Laboratory methods*: U.S. Geological Survey Professional Paper 954-A, 39 p.
- O'Sullivan, R. B., Scott, G. R., and Heller, J. S., 1979a, Preliminary geologic map of the Bisti Trading Post quadrangle, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1075, scale 1:24,000.
- 1979b, Preliminary geologic map of the Kirkland SW quadrangle, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1080, scale 1:24,000.
- Power, J. F., 1978, Reclamation research on strip-mined lands in dry regions, *in* Reclamation of drastically disturbed lands: Madison, Wis., American Society of Agronomy and others, p. 521-535.
- Rai, Dhanpat, Wierenga, P. J., and Gould, W. L., 1974, Chemical and physical properties of core samples from a coal-bearing formation in San Juan County, New Mexico: New Mexico State University Agricultural Experiment Station Research Report 287, 13 p.
- 1975, Chemical and physical properties of soil samples from a coal-bearing formation in San Juan County, New Mexico: New Mexico State University Agricultural Experiment Station Research Report 294, 24 p.
- Safaya, N. M., 1980, Delineation of mineral stresses in mine spoils and screening plants for adaptability, *in* Wali, M. K., ed., *Ecology and coal resource development*: New York, Pergamon Press, p. 830-849.
- Sandoval, F. M., and Gould, W. L., 1978, Improvement of saline- and sodium-affected disturbed lands, *in* Reclamation of drastically disturbed land: Madison, Wis., American Society of Agronomy, p. 485-504.
- Schafer, W. M., 1979, Variability of mine soils and natural soils in southeastern Montana: *Soil Science Society of America Journal*, v. 43, no. 6, p. 1207-1212.
- Scott, G. R., O'Sullivan, R. B., and Heller, J. S., 1979a, Preliminary geologic map of the Burnam Trading Post quadrangle, San Juan County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1076, scale 1:24,000.
- 1979b, Preliminary geologic map of the Pillar NW quadrangle, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1077, scale 1:24,000.
- Scott, G. R., O'Sullivan, R. B., and Mytton, J. W., 1979, Reconnaissance geologic map of the Almo West quadrangle, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1074, scale 1:24,000.
- Severson, R. C., 1979, Regional soil chemistry in the Bighorn and Wind River Basins, Wyoming and Montana: U.S. Geological Survey Professional Paper 1134-B, 9 p.
- Severson, R. C., Gough, L. P., and McNeal, J. M., 1977, Availability of elements in soils to native plants. Northern Great Plains: U.S. Geological Survey Open-File Report 77-847, 90 p.
- Severson, R. C., and Tidball, R. R., 1979, Spatial variation in total element concentration in soil within the Northern Great Plains coal region: U.S. Geological Survey Professional Paper 1134-A, 18 p.
- Tidball, R. R., and Ebens, R. J., 1976, Regional geochemical baselines in soils of the Powder River Basin, Montana-Wyoming, *in* Laudon, R. B., ed., *Geology and energy resources of the Powder River Basin*: Wyoming Geological Association 28th Annual Field Conference, Casper, Wyo., Guidebook, p. 299-310.
- U.S. Geological Survey, 1975, Geochemical survey of the western energy regions, 2nd annual progress report: U.S. Geological Survey Open-File Report 75-436, 132 p.
- 1976, Geochemical survey of the western energy regions, 3rd annual progress report: U.S. Geological Survey Open-File Report 76-729, 138 p.

