



Geochemical Data for Colorado Soils: Results from the 2006 State-Scale Geochemical Survey

By David B. Smith, Karl J. Ellefsen, and James E. Kilburn

Data Series 520

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia 2010

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Suggested citation:
Smith, D.B., Ellefsen, K.J., and Kilburn, J.E., 2010, Geochemical data for Colorado soils—
Results from the 2006 state-scale geochemical survey: U.S. Geological Survey, Data Series
520, 9 p.

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in)
millimeter (mm)	0.03937	inch (in)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square kilometer (km ²)	247.1	acre
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound, avoirdupois (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
 $^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$

Geochemical Data for Colorado Soils: Results from the 2006 State-Scale Geochemical Survey

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Abstract

In 2006, soil samples were collected at 960 sites (1 site per 280 square kilometers) throughout the state of Colorado. These samples were collected from a depth of 0–15 centimeters and, following a near-total multi-acid digestion, were analyzed for a suite of more than 40 major and trace elements. The resulting data set provides a baseline for the natural variation in soil geochemistry for Colorado and forms the basis for detecting changes in soil composition that might result from natural processes or anthropogenic activities. This report describes the sampling and analytical protocols used and makes available all the soil geochemical data generated in the study.

Introduction

Understanding the natural variation in the concentration of major and trace elements in soil—particularly potentially harmful elements such as lead, arsenic, mercury, and cadmium—is essential to a proper assessment of soil contamination caused by human activities. Such background data are necessary for environmental monitoring, remediation of contaminated sites, land-use planning, and ecological evaluations. Reliable, comprehensive information about background levels of elements in Colorado soils will facilitate scientifically defensible decisions by industries and policy makers.

In 2006, the U.S Geological Survey (USGS) carried out a soil-sampling program in the state of Colorado to establish a geochemical database containing the information described above. The purpose of this report is to provide information on the protocols for the sampling and chemical analysis of soils and to make available the soil geochemical data generated in the study.

Sample-Collection and Sample-Preparation Protocols

To select sites for soil sampling, the state of Colorado was first divided into 966 equal-area polygons. A target site was then selected at random from within each of the polygons. This represented a density of approximately 1 site per 280 square kilometers (km^2). The actual site from which a sample was collected was chosen within the polygon's most representative landscape as near as possible to the target site while also taking into consideration the following guidelines:

1. No sample should be collected from within 200 meters (m) of a major highway.
2. No sample should be collected closer than 50 m to a rural road.

3. No sample should be collected closer than 100 m to a building or structure.

Because of problems in gaining access to sample sites in 6 of the polygons, 960 sites were sampled during this study (fig. 1). This small reduction in the number of sites sampled had a negligible effect on the sample density.

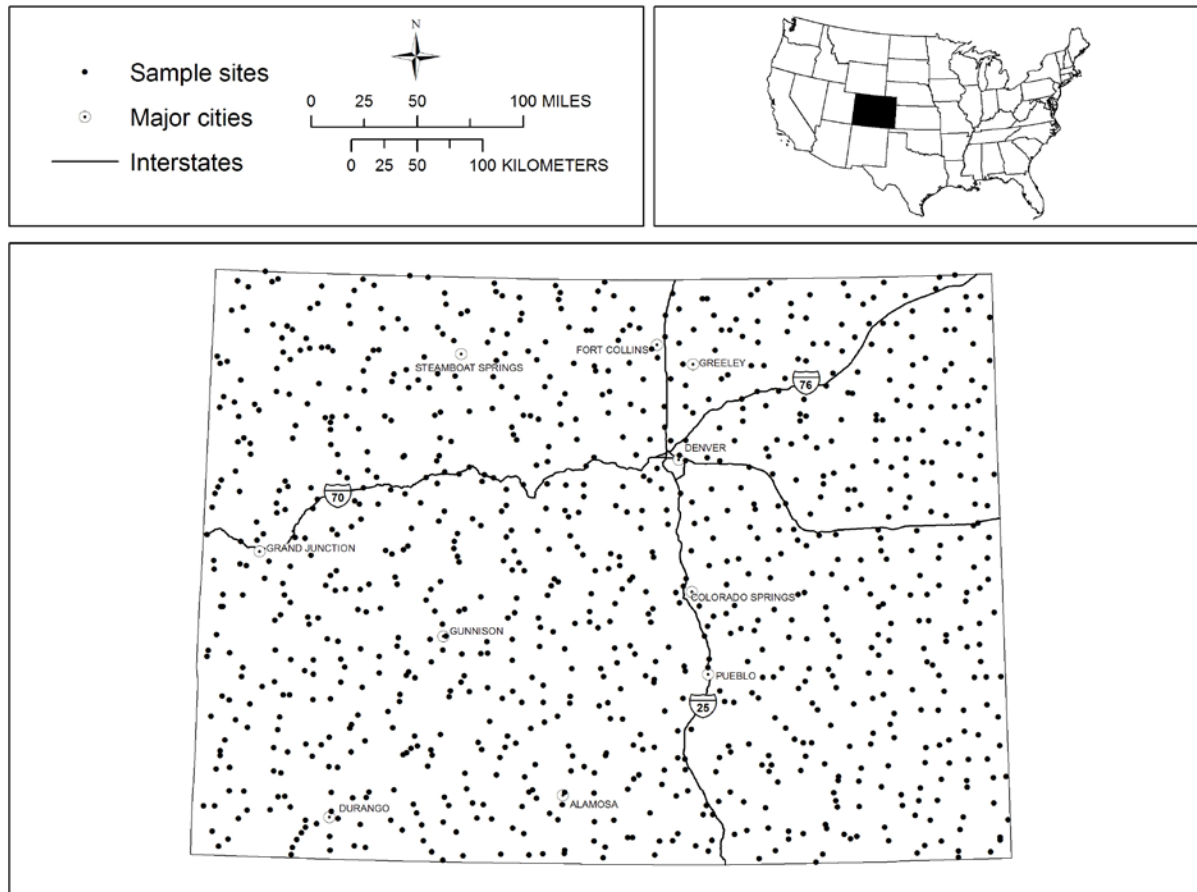


Figure 1. Map of Colorado showing the locations of 960 soil samples collected for chemical analysis.

At each site, a sample of soil was collected from a depth of 0 to 15 centimeters (cm) after removing loose plant debris (if any) from the ground surface. This particular sample medium was selected to be consistent with published soil geochemical data sets for the Front Range Urban Corridor (Severson and Tourtelot, 1994) and the Denver metropolitan area (Kilburn and others, 2007). The samples were air dried at ambient temperature, disaggregated, and sieved through a 2-millimeter (mm) stainless steel screen. Material less than 2 mm in size was crushed to less than 150 micrometers (μm) in a ceramic mill and thoroughly mixed to ensure homogeneity. The crushed samples were randomized prior to chemical analysis to avoid confusing spatial variation with any possible systematic bias within a given analytical technique. This randomization does not eliminate a systematic error, but the error is effectively transformed into one that is random with respect to geographic location (Tidball, 1984).

Analytical Protocols

The prepared samples were sent to a USGS contract geochemical laboratory for major and trace element analysis. The concentrations of the elements aluminum (Al), calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), sulfur (S), titanium (Ti), silver (Ag), arsenic (As), barium (Ba), beryllium (Be), bismuth (Bi), cadmium (Cd), cerium (Ce), cobalt (Co), chromium (Cr), cesium (Cs), copper (Cu), gallium (Ga), indium (In), lanthanum (La), lithium (Li), manganese (Mn), molybdenum (Mo), niobium (Nb), nickel (Ni), phosphorus (P), lead (Pb), rubidium (Rb), antimony (Sb), scandium (Sc), tin (Sn), strontium (Sr), tellurium (Te), thorium (Th), thallium (Tl), uranium (U), vanadium (V), tungsten (W), yttrium (Y), and zinc (Zn) were determined by inductively coupled plasma–atomic emission spectrometry (ICP-AES) by a method similar to Briggs (2002) and by inductively coupled plasma–mass spectrometry (ICP-MS) by a method similar to Briggs and Meier (2002). A soil sample of 0.25 grams (g) was digested using a mixture of concentrated hydrochloric, nitric, perchloric, and hydrofluoric acids at temperatures between 110 and 160°C.

The four-acid digestion results in a nearly total dissolution of most mineral constituents in soil. However, it does not fully dissolve some of the more refractory or resistant minerals. Some examples of such incomplete dissolution include Ba in barite, Cr in chromite, Ti in rutile, Sn in cassiterite, Al in corundum, and rare earth elements in monazite (Briggs, 2002). An aliquot of the digested sample was aspirated into the ICP-AES and ICP-MS instruments and the concentrations of the optimal elements were determined. The ICP-AES method is best for the major elements, sulfur, and elements with relatively high concentrations not requiring a low detection limit, and the ICP-MS method is optimal for trace elements requiring lower limits of determination near or below their crustal abundance and for elements not determined by ICP-AES. The lower limits of determination (LLD) are listed in table 1.

Table 1. Elements determined by ICP-MS and ICP-AES.

[LLD, lower limit of determination; ICP-MS, inductively coupled plasma–mass spectrometry; ICP-AES, inductively coupled plasma–atomic emission spectrometry]

Element	Method	LLD
Aluminum	ICP-AES	0.01%
Calcium	ICP-AES	0.01%
Iron	ICP-AES	0.01%
Potassium	ICP-AES	0.01%
Magnesium	ICP-AES	0.01%
Sodium	ICP-AES	0.01%
Phosphorous	ICP-AES	50 mg/kg
Titanium	ICP-AES	0.01%
Silver	ICP-MS	1 mg/kg
Arsenic	ICP-MS	1 mg/kg
Barium	ICP-MS	5 mg/kg
Beryllium	ICP-MS	0.1 mg/kg
Bismuth	ICP-MS	0.04 mg/kg
Cadmium	ICP-MS	0.1 mg/kg
Cerium	ICP-MS	0.05 mg/kg
Cobalt	ICP-MS	0.1 mg/kg
Chromium	ICP-MS	1 mg/kg
Cesium	ICP-MS	0.05 mg/kg
Copper	ICP-MS	0.5 mg/kg
Gallium	ICP-MS	0.05 mg/kg
Indium	ICP-MS	0.02 mg/kg
Lanthanum	ICP-MS	0.5 mg/kg
Lithium	ICP-MS	1 mg/kg
Manganese	ICP-MS	5 mg/kg
Molybdenum	ICP-MS	0.05 mg/kg
Niobium	ICP-MS	0.1 mg/kg
Nickel	ICP-MS	0.5 mg/kg
Lead	ICP-MS	0.5 mg/kg
Rubidium	ICP-MS	0.2 mg/kg
Sulfur	ICP-MS	0.01%
Antimony	ICP-MS	0.05 mg/kg
Scandium	ICP-MS	0.1 mg/kg
Tin	ICP-MS	0.1 mg/kg
Strontium	ICP-MS	0.5 mg/kg
Tellurium	ICP-MS	0.1 mg/kg
Thallium	ICP-MS	0.1 mg/kg
Thorium	ICP-MS	0.2 mg/kg
Uranium	ICP-MS	0.1 mg/kg
Vanadium	ICP-MS	1 mg/kg
Tungsten	ICP-MS	0.1 mg/kg
Yttrium	ICP-MS	0.1 mg/kg
Zinc	ICP-MS	1 mg/kg

The concentration of Hg was determined by treating 0.1 g of sample with a mixture of nitric and hydrochloric acids and heating for 30 minutes (min). Once cooled, solutions of sulfuric acid, potassium permanganate, and potassium persulfate were added, followed by sodium chloride-hydroxylamine sulfate. The final solution was reduced by stannous chloride and analyzed by atomic absorption spectrometry. This method is a modification of that published by the U.S. Environmental Protection Agency (2007). The LLD is 0.02 milligrams per kilogram (mg/kg).

The concentration of Selenium (Se) was determined by digesting 0.25 g of sample using a multi-acid procedure. At the end of the digestion period, Se was reduced to the +4 oxidation state. Sodium borohydride was then added to form the gaseous Se hydride, which was then transported with inert gas to an atomic absorption spectrometer. The method is similar to that published by Hageman and Brown (2002). The LLD is 0.2 mg/kg.

Quality Assurance and Quality Control

Quality assurance (QA) is mainly the concern of the analytical laboratory. The various components of the QA plan include standard operating procedures, instrument logs, training records, data acceptance and rejection criteria, and laboratory audits. Unlike the unquantifiable QA element, the quality control (QC) element measures the bias and precision of the data produced by a specific analytical method. The bias and precision are established through the analysis of reference materials (RMs) and sample replicates, respectively.

The samples that passed through the analytical process in the USGS laboratories received QC checks on two separate levels. The first level involved QC assessment by the USGS contract laboratory. In the next level, quality was assessed by the USGS QC officer.

The USGS contract laboratory is accredited to the International Organization for Standardization/International Electrotechnical Commission 17025 standard, which includes both QA and QC protocols. The QC is monitored by analyzing an RM with every batch of 48 samples. The RM most often used is a syenite rock standard (SY-3) developed by the Canadian Centre for Mineral and Energy Technology (Govindaraju, 1989). Shewhart Control Charts (Taylor, 1987) are generated for the RM analyses and reviewed with every report as part of the internal quality audits.

The accuracy for elements determined by ICP-MS and ICP-AES was considered acceptable if recovery was within the range of 85–115 percent at five times the LLD. The accuracy for Hg and Se was considered acceptable if recovery was within 80–120 percent at five times the LLD.

At the second tier, the USGS QC officer assessed precision and accuracy on the basis of five RMs that were inserted between every batch of 50 samples. The soil RMs used in this study were SRM 2709 and SoNE-1. SRM 2709, a soil from the San Joaquin Valley of central California, is a certified RM available from the National Institute of Standards and Technology and is used to assess both bias and precision (National Institute of Standards and Technology, 2003). The acceptance criteria for accuracy are the same as those itemized earlier as used by the contract laboratory.

SoNE-1 is a USGS in-house, non-certified soil RM prepared specifically for the North American Soil Geochemical Landscapes Project (Smith and others, 2009). It was collected from the Sharpsburg Soil Series (Natural Resources Conservation Service, 2008) in Lancaster County, Nebr., and is used in this study to assess only precision. The precision

for elements determined by ICP-MS and ICP-AES was considered acceptable if the calculated relative standard deviation (RSD) of duplicate samples is no greater than 15 percent. The precision for Hg and Se was considered acceptable if the calculated RSD of duplicate samples was no greater than 20 percent.

Description of Data Tables

Table 2 shows a statistical summary of the major and trace element data generated from the Colorado soil samples. Table 3 presents the complete analytical results for the Colorado soils.

Table 2. Statistical summary for geochemical data on 0–15-cm soils from Colorado.

[N = 960; LLD, lower limit of determination; Min, minimum; Q1, first quartile; Q3, third quartile; Max, maximum; MAD, median absolute deviation; mg/kg, milligrams per kilogram]

Element	Concentration units	Number of samples below LLD	Min	Q1	Median	Q3	Max	MAD
Aluminum	%	0	1.12	4.66	5.54	6.35	9.98	1.26
Calcium	%	0	0.11	0.71	1.23	2.38	21.9	0.98
Iron	%	0	0.27	1.55	2.14	2.77	9.42	0.90
Potassium	%	0	0.38	1.93	2.29	2.65	5.86	0.53
Magnesium	%	0	0.03	0.37	0.57	0.79	3.77	0.31
Sodium	%	0	0.07	0.69	0.90	1.29	4.05	0.41
Sulfur	%	29	<0.01	0.02	0.03	0.04	9.54	0.015
Titanium	%	0	0.03	0.15	0.20	0.25	1.21	0.074
Arsenic	mg/kg	4	<1	3	5	7	126	3.0
Silver	mg/kg	941	<1	<1	<1	<1	35	0
Barium	mg/kg	0	155	606	719	814	4,660	153
Beryllium	mg/kg	0	0.4	1.3	1.6	1.9	6.4	0.44
Bismuth	mg/kg	11	<0.04	0.12	0.18	0.24	14.6	0.089
Cadmium	mg/kg	54	<0.1	0.2	0.3	0.4	20.2	0.15
Cerium	mg/kg	0	14.6	52.3	63.9	76.7	350	17.9
Cobalt	mg/kg	0	0.7	5.2	7.3	9.4	43.3	3.1
Chromium	mg/kg	0	3	20	29	39	141	14.8
Cesium	mg/kg	735	<5	<5	<5	5	22	0
Copper	mg/kg	0	1.7	10.7	15.6	20.8	464	7.6
Gallium	mg/kg	0	2.8	10.4	12.9	15.1	26.5	3.5
Mercury	mg/kg	662	<0.02	<0.02	<0.02	0.02	0.4	0
Indium	mg/kg	135	<0.02	0.03	0.04	0.05	13.8	0.015
Lanthanum	mg/kg	0	7.5	27.1	33.1	38.9	176	8.7
Lithium	mg/kg	0	4	16	21	28	259	8.9
Manganese	mg/kg	0	75	316	431	608	3,460	196
Molybdenum	mg/kg	0	0.15	0.64	0.97	1.44	23.4	0.56
Niobium	mg/kg	0	1.5	7.1	9.1	11.3	69.9	3.1
Nickel	mg/kg	0	2	9.3	13.8	19.1	149	7.3
Phosphorous	mg/kg	5	<50	450	650	860	2,840	296
Lead	mg/kg	0	5.5	18.8	21.7	26.5	3,600	5.3
Rubidium	mg/kg	0	22.1	77.3	91.6	105	312	20.8
Antimony	mg/kg	2	<0.05	0.34	0.5	0.72	66.7	0.27
Scandium	mg/kg	0	0.9	5	6.8	8.6	33.9	2.7
Selenium	mg/kg	435	<0.2	<0.2	0.2	0.4	11.3	0
Tin	mg/kg	0	0.2	1.1	1.4	1.7	125	0.44
Strontium	mg/kg	0	37.5	134	181	254	1,430	79
Tellurium	mg/kg	899	<0.1	<0.1	<0.1	<0.1	4.3	0
Thorium	mg/kg	0	2.2	8	10	12.6	82.6	3.4
Thallium	mg/kg	0	0.1	0.5	0.6	0.7	3.1	0.15
Uranium	mg/kg	0	0.6	1.9	2.4	3	18.6	0.74
Vanadium	mg/kg	0	4	40	59	80	373	29.6
Tungsten	mg/kg	0	0.2	0.6	0.8	1	14	0.3
Yttrium	mg/kg	0	3.8	12.8	16.2	19.3	169	4.8
Zinc	mg/kg	0	10	47	66	90	7,000	32.6

To view Table 3 as an Excel file: [CLICK HERE](#).

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