



Mineral Resources Program

Results of Chemical Analyses of Soil, Shale, and Soil/Shale Extract from the Mancos Shale Formation in the Gunnison Gorge National Conservation Area, Southwestern Colorado, and at Hanksville, Utah

By Michele L.W. Tuttle, Juli Fahy, Richard I. Grauch, Bridget A. Ball, Geneva W. Chong, John G. Elliott, John J. Kosovich, Keith E. Livo, and Lisa L. Stillings



Mancos Shale near Hanksville



Upper Elephant Skin Wash, GGNCA

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Cover Photograph of the Mancos Shale Landscape in Elephant Skin Wash, Gunnison Gorge National Conservation Area, Southwestern Colorado (right) and the Mancos Shale Landscape at near Hanksville, Utah (left)

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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)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
Area		
square kilometer (km ²)	247.1	acre
square kilometer (km ²)	0.3861	square mile (mi ²)
Volume		
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
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:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32.$$

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88.)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25°C).

Concentrations of chemical constituents in solids are given either in weight percent (%) or parts per million (ppm).

Concentrations of chemical constituents in extracts are given either in milligrams per liter (mg/L) or micrograms per liter ($\mu\text{g}/\text{L}$).

Grain size abundances are listed in volume percent (v%). Stable isotope ratios are reported relative to internationally agreed upon standards.

Isotope data are given as per mil relative to VCDT (Vienna Cañon Diablo Troilite) or VSMOW (Vienna Standard Mean Ocean Water).

Abbreviated Chemical Symbols

Abbreviation	Chemical Species
Ag	silver
Al	aluminum
As	arsenic
B	boron
Ba	barium
Be	beryllium
Bi	bismuth
Br	bromine
C	total carbon
C CO ₃	carbonate carbon
C org	organic carbon
Ca	calcium
Cd	cadmium
Ce	cerium
Cl	chlorine
Co	cobalt
Cr	chromium
Cs	cesium
Cu	copper
DOC	dissolved organic carbon
Dy	dysprosium
Er	erbium
Eu	europium
Fe	iron
Ga	gallium
Gd	gadolinium
Ge	germanium
HCO ₃	Bicarbonate
Hg	mercury
Ho	holmium
In	indium
K	potassium
La	lanthanum
Li	lithium
Lu	lutetium
Mg	magnesium
Mn	manganese
Mo	molybdenum
N	nitrogen (as N)
Na	sodium
Nb	niobium
Nd	neodymium
Ni	nickel
NO ₃	nitrate
O _{SO₄}	sulfate oxygen
P	phosphorous
Pb	lead
Pr	praseodmium
Rb	rubidium
S	sulfur

Abbreviation	Chemical Species
S (av)	acid-volatile sulfur
S (di)	disulfide sulfur
S (elem)	elemental sulfur
S (H ₂ O)	water-soluble sulfur
S (HCl)	acid-soluble sulfur
S _{SO4}	sulfate sulfur
Sb	antimony
Sc	scandium
Se	selenium
Sm	samarium
Sn	tin
SO ₄	sulfate
Sr	strontium
Ta	tantalum
Tb	terbium
Te	tellurium
Th	thorium
Ti	titanium
Tl	thallium
Tm	thulium
Total C	total dissolved carbon (DOC + HCO ₃)
U	uranium
V	vanadium
W	tungsten
Y	yttrium
Yb	ytterbium
Zn	zinc
Zr	zirconium

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Results of Chemical Analyses of Soil, Shale and Soil/Shale Extract From the Mancos Shale Formation in the Gunnison Gorge National Conservation Area, Southwestern Colorado and at Hanksville, Utah

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Abstract

Results of chemical and some isotopic analyses of soil, shale, and water extracts collected from the surface, trenches, and pits in the Mancos Shale are presented in this report. Most data are for sites on the Gunnison Gorge National Conservation Area (GGNCA) in southwestern Colorado. For comparison, data from a few sites from the Mancos landscape near Hanksville, Utah, are included. Twelve trenches were dug on the GGNCA from which 258 samples for whole-rock (total) analyses and 187 samples for saturation paste extracts were collected. Sixteen of the extract samples were duplicated and subjected to a 1:5 water extraction for comparison. A regional soil survey across the Mancos landscape on the GGNCA generated 253 samples for whole-rock analyses and saturation paste extractions. Seventeen gypsum samples were collected on the GGNCA for sulfur and oxygen isotopic analysis. Sixteen samples were collected from shallow pits in the Mancos Shale near Hanksville, Utah.

Introduction

Responsible stewardship of lands is a primary goal of many federal and state agencies as well as non-government organizations and citizen groups. Many of the immediate issues regarding land-use management in the western United States are related to either specific naturally occurring toxicants such as selenium or to the general loading of water and soils by a large group of elements and compounds that may contribute to increased salinity. As the awareness of these issues

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increase, the science arms of the various federal agencies realize that the knowledge base is not always adequate to address all issues and in many cases pushes the limits of our understanding of some of the physical, chemical, and biologic processes involved. Because the marine Cretaceous Mancos Shale is a known contributor of toxicants and salt to the upper Colorado River Basin, the Mancos Shale Landscapes: Science and Management of Black Shale Terrains Regional Partnership Project was created in the U.S. Geological Survey (USGS) to provide the critical scientific data needed to expand our knowledge base of the various landscapes developed on the Mancos Shale and to showcase how this knowledge can be used to help land managers make sound, unbiased land-management decisions. Scientists from all five USGS disciplines (Biology, Geology, Geography, Water, and Geospatial Information) have partnered with scientists and land managers from the Bureau of Land Management (BLM) and the Bureau of Reclamation (BOR) in an effort to provide and synthesize these scientific data.

This report summarizes data about the pedogenic landscape of the Mancos Shale on the Gunnison Gorge National Conservation Area (GGNCA) in western Colorado and near Hanksville, Utah. Tables include chemical data for 1) soil, shale, and soil/shale saturation paste extracts from 12 trenches in the Mancos shale on the GGNCA; 2) soil and soil saturation paste extracts from three depths at 85 sites on Mancos Shale across the GGNCA; 3) sulfate isotopes in gypsum collected across the GGNCA; and 4) soil and shale from four pits in Mancos Shale near Hanksville, Utah. Interpretation of these data are not included in this report, and will be released in subsequent publications. An index map of the sampled areas is in figure 1.

Gunnison Gorge National Conservation Area Overview Map Highlighting Soil Trench Locations

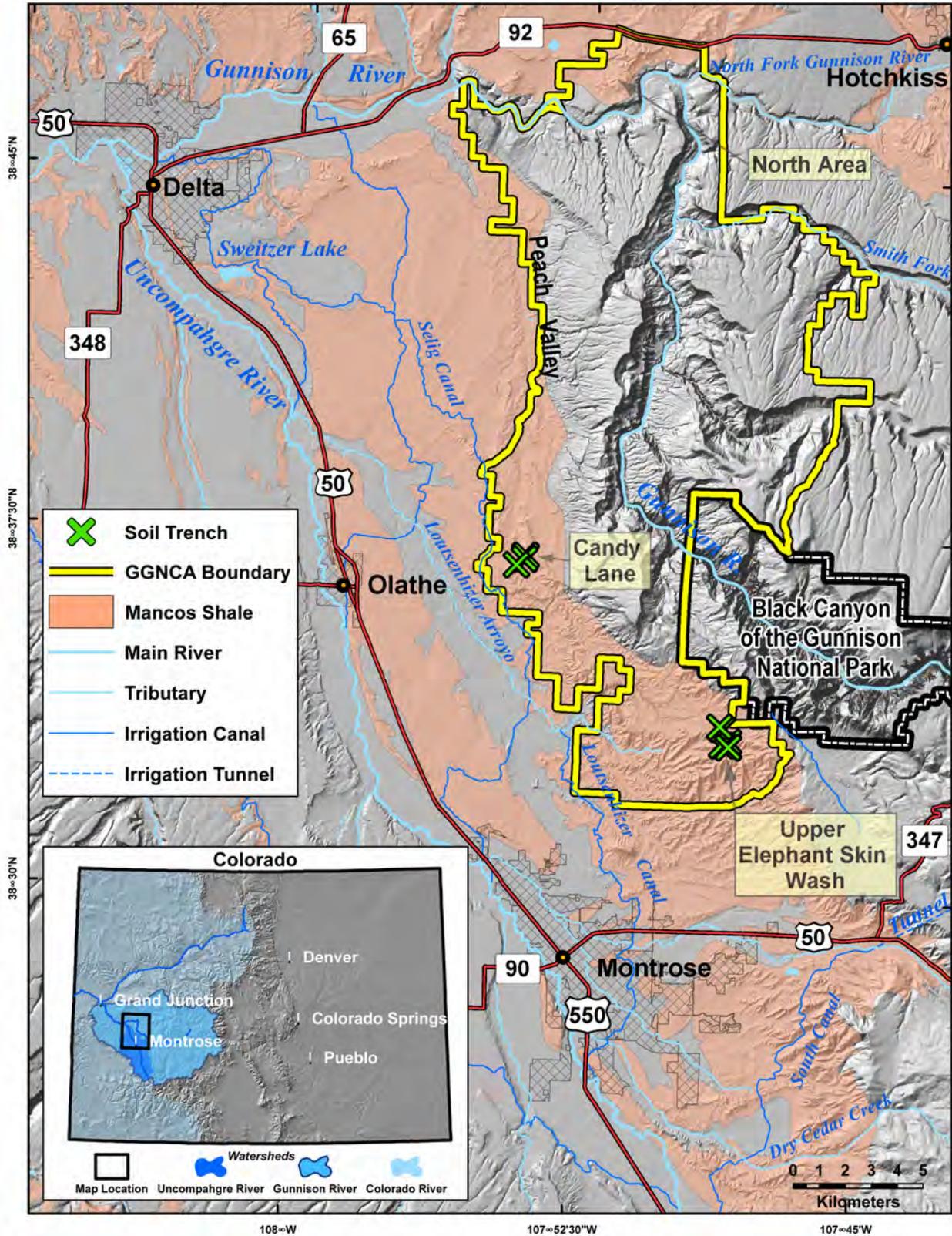


Figure 1. Map of the GGNCA, areas where Mancos crops out, showing trenches in Elephant Skin Wash and Candy Lane areas.

Sampling

GGNCA Trench Sampling

Sampling of GGNCA trenches occurred in 2003-2004. Table 1 summarizes the trench locations, their aspect, and number of samples taken. A detailed description of these trenches and their respective sample positions are included in Ball and others (unpub. data, 2006). Eight trenches were sampled in the Elephant Skin Wash (ESW) area: four into the toe of slope, two on ridge top pediment surfaces, and two in the valley floor. Four trenches were sampled in the Candy Lane (CL) area; all trenches were at the toe of the slope. Each trench except those in the valley floor penetrated shale, and petrographic examination of the shale showed varying degrees of weathering. In addition, large amounts of sulfate salts (predominately gypsum) on bedding planes of the shale and in fractures indicate that fluids had moved through the shale sometime in the past, possibly when the water table was much higher than it is today (greater than 150 meters depth in the CL area).

Soil samples for total chemistry are composites of varying depths. Some shale samples are composites as well (designated as “composite”); however, a single sample in the middle of the shale composite interval (designated as “bulk”) was taken for detailed mineralogic and petrographic examination. These bulk samples were also chemically analyzed. Soil and shale samples for extracts were taken across a much smaller interval in one ESW toe slope trench (T40A), and across similar intervals in all four CL trenches and the two ESW valley floor trenches.

Trench samples were described in the field (Ball and others, unpub. data, 2006). Whole-rock and saturation paste chemistry, including major elements and trace elements, were analyzed and are reported here. Quantitative mineralogy, bulk densities and particle densities were also done on the same sample intervals. At most of the trench sites, rainfall simulations on disturbed and undisturbed paired plots, as well as vegetation studies, were completed. Mineralogical, rainfall-simulation, and vegetation results will be released in separate reports.

Table 1. Location of each trench or pit, aspect of slope, and number of samples taken.

[ESW, Elephant Skin Wash in the GGNCA; CL, Candy Lane in the GGNCA; HV, Hanksville, UT. BG, Blue Gate Member; LT, Lower Tunuk Member; UT, Upper Tunuk Member. Total, whole-rock analyses; extract, 1:5 or saturation paste extract analyses]

Area, Trench	Latitude (degrees)	Longitude (degrees)	Slope Aspect	No. samples
TableSpanner				
ESW, T-9A	38.555033	-107.807916	Northwest	16 total
ESW, T-9B	38.555083	-107.808067	Southeast	11 total
ESW, T-40A	38.553783	-107.810467	Northwest	11 total, 16 extract
ESW, T-40B	38.553883	-107.810900	Southeast	12 total
ESW, TR-1	38.559450	-107.810983	na	10 total
ESW, TR-2	38.560333	-107.811950	na	7 total
ESW, V-1	38.553367	-107.807750	na	75 total, 72 extract
ESW, V-2	38.553150	-107.808050	na	19 total, 19 extract
CL, TS	38.617733	-107.900300	South	26 total, 11 extract
CL, TW	38.617750	-107.899817	West	23 total, 21 extract
CL, TN	38.616500	-107.900467	North	29 total, 23 extract
CL, TE	38.614383	-107.903983	East	19 total, 25 extract
HV, BG	38.365750	-110.935233	na	5 total
HV, LT	38.388400	-110.824583	na	6 total
HV, UT	38.388400	-110.826683	na	5 total

GGNCA Regional Soil Sampling

In 2005, a regional soil survey on Mancos Shale in the GGNCA was undertaken. Over a two-week period, 253 samples were collected from 85 0.65 kilometer square cells (one-quarter square mile grid) across the GGNCA (fig. 2). Latitudes and longitudes are given in Appendix Table A12. Each site was characterized with respect to vegetation (% cover included, with detailed vegetation data to be published in a separate report), electromagnetic data (included here), soil depth (included here, with the penetrometer data to be published in separate report), and visual disturbance (included here). At each site, three soil depths were sampled (0-5 cm, 5-25 cm, and 25-45 cm), and samples were analyzed for color, particle size distribution, total chemistry, and saturation-paste extract chemistry (all data included). Samples also were collected for mineralogy and bulk density, and these data will be published in separate reports.

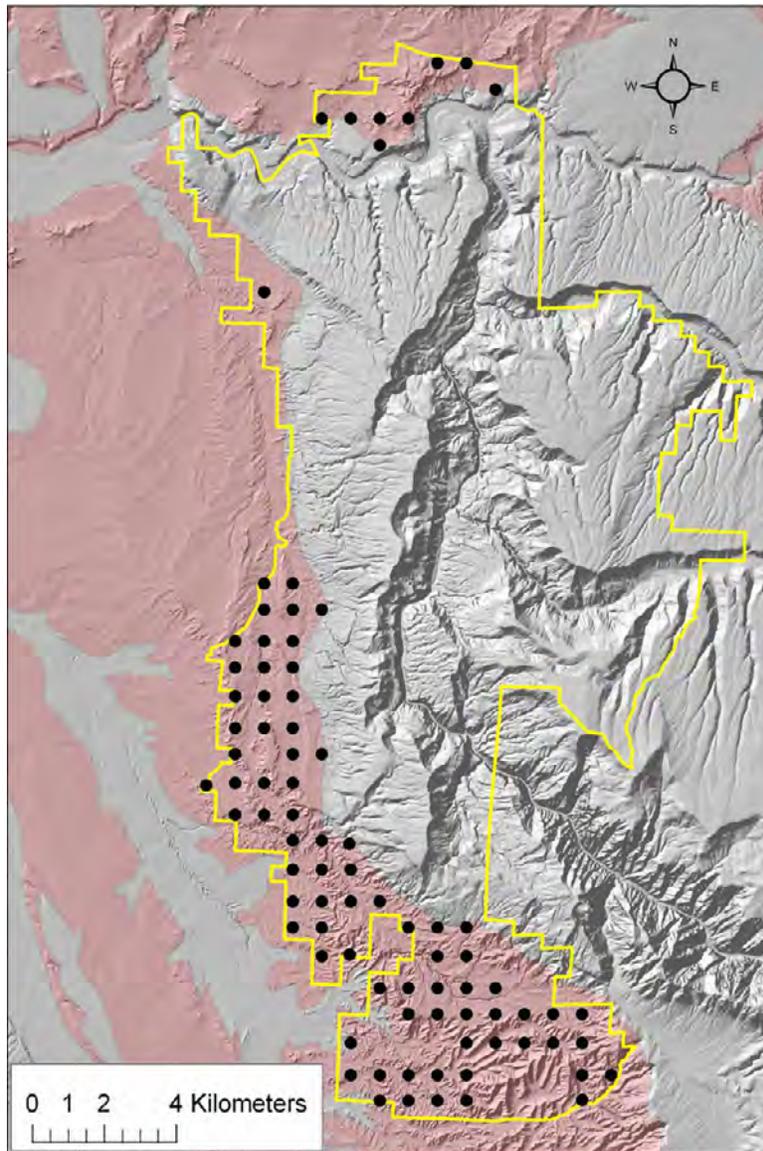


Figure 2. Map for the regional soil sampling of the GGNCA (boundary designated with yellow line). Pink shaded area is where the Mancos Shale crops out; round dot, sampling point within the sample grid.

GGNCA Gypsum Sampling

Gypsum is a prevalent salt across the GGNCA. It is found on the surface as it physically weathers from shale outcrop. It occurs in the soil in various depth horizons (maybe as remnants from shale disaggregation) and, in some localities, forms gypcretes. It is ubiquitous along bedding planes and as fracture fill in shale in the trenches, which were 6 m deep or less. It probably does not extend much deeper, as it was not observed in core material below 6 m depth (core location is in Candy Lane near trench TS; Bridget Ball, personal commun.). Gypsum samples are grab samples from the surface and within trenches.

The isotopic composition of gypsum (sulfur and oxygen of the sulfate) is used to fingerprint salt sources. Therefore, isotopically characterizing the gypsum on the GGNCA may help constrain its origin and provide a signature for assessing Mancos Shale contributions to salinization of nearby streams and rivers.

Hanksville Pit Sampling

In May 2003, several hand-dug pits were sampled from the Blue Gate and Lower and Upper Tununk Members of the Mancos Shale near Hanksville, Utah. One pit in each member was dug, and soil and shale samples were composites over homogeneous intervals determined by field observations. Samples were analyzed for whole-rock chemistry (data included in this report), and mineralogy (to be published in a separate report). The Hanksville samples were not extracted.

Extract Preparation

In 2003, samples from one trench (T40A) were extracted using two methods for comparison: 1:5 water extracts and saturation paste extracts. Results from this comparison showed that, for the most part, the spatial trends in the 1:5 extracts mirrored those of the saturation paste extracts except that their element concentrations were smaller. We decided to continue to use only saturation paste extracts, even though in some saline soils, gypsum saturation controls the concentration of calcium and sulfate. Because high saturation indices in natural soil waters and runoff likely are similarly controlled, we concluded that saturation paste extracts more accurately represented natural conditions in our study areas, which receive very low annual precipitation (generally <20 cm). All extracts were prepared in the Bureau of Reclamation Soil Laboratory, Denver, Colorado.

1:5 Water Extracts

The 1:5 extracts (wt/wt basis) in the comparison study were prepared by adding five parts water to one part soil or shale (dried & ground portion of <2 mm material). The mixtures were shaken for 16 hours and filtered using vacuum filtration. The extract was collected for pH and conductivity measurements and split for chemical analyses.

Saturation Paste Extracts

Saturated paste extracts were prepared by mixing the soil or disaggregated shale sample (dried & ground portion of < 2mm material) into a smooth paste with a consistency comparative to that of pudding. The definition of the paste is “a particular mixture of soil and water such that the soil glistens as it reflects light, flows slightly when the container is tipped, and slides freely & cleanly from a spatula” (U.S. Department of Agriculture, 1996). There should be no free water on top of the sample. Each sample requires a different amount of water to be added to achieve the proper mixture, and the amount of water added is reflected in the percent saturation. That number is the amount of water added relative to the dry weight of the soil. For example, if a 200 g soil sample has a saturation of 50%, it requires 100 ml of water to make a saturated paste. After the appropriate amount of water is added, the samples are allowed to sit overnight. The pH is measured in the paste. Then the extract is removed by means of vacuum filtration. Extracts are collected and analyzed for conductivity, and then split for further chemical analyses. Percent saturation can be used to calculate extract concentrations to a dry-weight basis for a common comparison of samples: ((element concentration in extract) x (%saturation/100)).

Analytical Methods

Color and Moisture of Soil and Shale

Color of soil and shale was determined by comparing the sample to a Munsell Soil Color Chart. Colors were determined in the field for the regional study and in the laboratory for all samples. The laboratory colors allow comparison among samples that were collected at different

times of the year under different moisture conditions. Moisture was measured in most samples by weight loss after drying.

Particle Size Distribution of Soil

Grain-size data for regional soil samples were obtained using a Coulter LS 100 Particle Size Analyzer, a laser diffraction system capable of measuring particles between 0.4 μm (microns) and 900 μm that are suspended in liquid. This instrument is located in the Bureau of Reclamation Soil laboratory, Denver Colorado. For this study, dry samples were physically disaggregated by hand as much as possible without causing grain size reduction. They were then placed in a slurry consisting of sample, water, and sodium hexametaphosphate (to aid in clay dispersal), initially well-mixed, stirred occasionally thereafter, and left for a minimum of 24 hours. Individual samples were poured through a #35 sieve (0.5 mm) to remove larger pieces such as fossil and gypsum fragments to avoid scratching the lenses. Very little material was removed from any sample by this process.

Electromagnetics

The EM38 meter measures soil conductance by the use of a magnetic field. The primary field is emitted from one side of the meter and a receiver at the opposite end measures the relative strength of the secondary magnetic field as it passes through a block of soil. The relative strength of the secondary magnetic field is directly proportional to conductivity of the soil in the pathway. The dual output version of the meter has a vertical (deeper) and horizontal (near-surface) dipole mode that allows an estimate of whether the near-surface is more or less conductive than the material at depth. Generally, the horizontal dipole effectively measures a block of soil several inches wide and approximately 0.5 m deep. The vertical dipole is effective to about 1.5 m. If the horizontal reading is greater than the vertical reading, the near-surface material is more conductive and vice versa. If both readings are essentially the same, the conductivity is essentially uniform to about 1.5 meters, the effective depth of the EM38. Field readings were adjusted for soil temperature and moisture.

Chemical Analyses of Solid Samples and Extracts

XRAL Laboratories, Canada performed most analyses of solid samples. Specialized analyses on solids such as sulfur speciation, isotope analyses, and combustion sulfur analyses were performed in the USGS laboratories. Extracts were analyzed in USGS laboratories located in Denver, Colorado. Table 2 summarizes the methods of analyses.

Table 2. Summary of analytical methods used to analyze Mancos Shale soil and shale samples (total), and extracts (extract).

[abbreviations used in Appendix tables; references in table footnotes]

Analysis	Method	Abbreviation	Reference
Anions (extracts)	Ion chromatography	IC	¹
As, Se (solids)	Hydride generation-atomic absorption spectrometry	HYDR	²
Bicarb. (extracts), C _{org} (solids)	Difference (C _{total} - C _{org}) or (C _{total} - C _{CO3})	Diff	¹
C _{CO3} (solids), C _{org} (extracts)	Coulometric titration	CT	¹
C _(total) (solids), S _{total} (solids)	Combustion	COMB	¹
Cl & F (solids)	Ion selective electrode	ISE	³
Hg (solids)	Cold vapor atomic adsorption spectrometry	CVAA	⁴
Majors, some traces (solids)	Energy dispersive X-ray fluorescence	EDX	¹
Majors some traces (solids & extracts)	Inductive coupled plasma atomic emission spectrometry	ICP	¹ extracts ⁵ solids
Majors and traces (solids & extracts)	Inductive coupled plasma mass spectrometry	ICPMS	¹ extracts ⁶ solids
Moisture (solids)	Weight loss upon drying	GRAV	
N (solids)	Carbon, hydrogen, nitrogen analyzer	CHN	
Sulfur speciation (some solids)	Separation of sulfate, monosulfides, and disulfides	S _{H2O} , S _{HCL} , S _{AV} , S _{DI}	⁷
Tl (solids)	Graphite furnace atomic absorption spectrometry	GF	⁸

¹Taggert (ed.) and others, 2002

²As, sodium peroxide fusion dissolved in HCl and KI; Se, HF, nitric and HCL digestion.

³Cl, potassium hydroxide and ammonium nitrate fusion dissolved in ammonium citrate buffer; F, sodium hydroxide potassium nitrate dissolved in dilute nitric acid.

⁴Hg, Nitric and hydrochloric acid digestion, followed by the addition of potassium permanganate, sulfuric acid, and a NaCl-hydroxylamine solution.

⁵Major and some trace elements (solids)—lithium metaborate fusion dissolved in dilute nitric acid.

⁶Major and trace elements (solids), hydrofluoric-, nitric-, perchloric- and hydrochloric-acid digestion.

⁷Tuttle and others, 1986.

⁸Tl-sodium peroxide fusion followed by DIBK extraction that is introduced in to a graphite furnace.

Sulfur and Oxygen Isotopes of Gypsum Sulfate

Gypsum samples from the GGNCA were placed in water and shaken for 30 minutes and then filtered. The filtrate was saved. The solid collected on the filter was placed in 6 N HCl, warmed slightly and then quickly filtered. The water filtrate was acidified to a pH less than 4. Barium chloride was added to each filtrate and the solutions were allowed to stand overnight. The precipitated barite was filtered and dried. The sulfur and oxygen isotopic composition in delta format of the barite was determined using procedures (MS abbreviation in appendix tables) in Kester and others (2001).⁵ Oxygen compositions of the sulfate were analyzed on samples extracted with water because of exchange of oxygen between sulfate and water in acid extractions.

Results

Tabulated results are in the Appendix tables. The data are provided in Excel worksheets and in PDF tabular form. The appendix also provides a table for each data set that includes the elements and their method of analyses that were excluded because all values were less than the lower limit of determination (5 times the standard deviation of the blank; Taggart, 2002). In the same table, elements with some censored values are also included along with the method of analysis, the lower limit of determination, percent of censored values and replacement values (1/2 the lower limit of determination) for those elements with less than 20 percent of their values censored. The authors recommend that these replacement values (red fonts) are valid for statistics on elements only when the percentage of censored values is less than 20 percent of reported values.

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⁵ Delta value format is $\delta (\text{‰}) = (R_{\text{sample}} - R_{\text{standard}}) / (R_{\text{standard}}) \times 1000$, where R is the ratio of ³⁴S:³²S or ¹⁸O:¹⁶O. The standard for sulfur is troilite from Cañon Diablo Meteorite (VCDT) and for oxygen, Standard Mean Oceanic Water (VSMOW).

Appendix

Each data set is preceded by a table that lists elements with unreported values (all below the lower limit of determination) or with replaced censored values. Replacement values (1/2 the lower limit of determination) are those suggested by the authors and are for those elements with 20 percent or less of the samples censored. The authors do not suggest using elements for interpretative purposes when greater than 20 percent of their values in the sample suite are censored.

“Total” data are for samples that were collected in the field, ground, and analyzed—these analyses are reported on a whole-sample basis in percent (weight basis) or parts per million (ppm); isotope data are reported in per mil VCDT or VSMOW. Extract data are for 1:5 or saturation paste extracts and are reported on a solution basis in milligrams per liter (mg/L) or micrograms per liter ($\mu\text{g/L}$).

GGNCA Trench Soil and Shale Data

Most sample profiles within the trenches are vertical, and depths are adjusted to a common datum (the soil/transition soil interface). The transition soil in this study is defined as soil containing distinct shale fragments, generally between 0.5 and 2 cm in length. Positive depths from the datum are distances upward into soil, and negative depths are distances below this datum into transition soil and shale.

Elephant Skin Wash Slope and Pediment Trenches

Tables A1, A2, A3, and A4 tabulate total and extract data from six trenches—four on toe slopes (T9A, T9B, T40A, T40B) and two on ridge-top pediments (TR-1 and TR-2). Sample profiles within these trenches are vertical. Also included in the “total” data set are chemical data for five soil samples (high depth resolution) collected from a hand-dug pit (PN) where an endangered species of penstemon grows. This pit is immediately adjacent to TR-2 trench.

Table A1. Elements in solid samples (total) from Elephant Skin Wash Trenches, GGNCA whose values were all below the lower limit of determinations or with censored values (below the lower limit of determination).

[Replacement values are for elements with <20% of the samples are censored and are designated with a red font.]

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
Ag	ICPMS,EDX	1 ppm				
Bi	EDX	5 ppm				
Br			EDX	1 ppm	13	0.5 ppm
Cd	EDX	1 ppm				
Cl			ISE	50 ppm	6	25 ppm
Ge	EDX	2 ppm				
Nb	ICP	10 ppm				
Nd			EDX	10 ppm	1	5 ppm
Sb	EDX	2 ppm				
Se			EDX	1 ppm	4	0.5 ppm
Sn	EDX	2 ppm				
Te	ICPMS	0.1 ppm				
U	EDX	4 ppm				
W	EDX	5 ppm				

Table A2. Data for solid samples from Elephant Skin Wash slope and pediment trenches, GGNCA.

[Click here to open Table A2](#)

Table A3. Elements in extracts of samples from T-40A, Elephant Skin Wash, GGNCA, whose values were all below the lower limit of determinations or with censored values (below the lower limit of determination).

[Replacement values are for elements with <20% of the samples censored and are designated with a red font.]

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)	Comments
Ag	ICP,ICPMS	0.1 mg/L, <3 µg/L					
As	ICP	1 mg/L	ICPMS	1 mg/L	19	0.5 mg/L	
Be	ICP	0.05 mg/L					
Bi	ICPMS	0.2µg/L					
Cd	ICP	0.1 mg/L					
Cl			IC	1.6 to 4 mg/L	25		use SP data
Co	ICP	0.1 mg/L	ICPMS	0.02 µg/L	38	none	use SP data
Cr	ICP	0.1 mg/L	ICPMS	1 µg/L	47	0.5 µg/L	use SP data
Cu	ICP	0.1 mg/L					
Dy			ICPMS	0.005 µg/L	3	0.003 µg/L	
Er			ICPMS	0.005 µg/L	38	0.003 µg/L	use SP data
F			IC	0.8 to 8 mg/L	34	none	
Fe	ICP	0.2 mg/L					
Ga	ICPMS	0.05 µg/L					
Gd			ICPMS	0.005 µg/L	3	0.003 µg/L	
Ge			ICPMS	0.05 µg/L	16	0.03 µg/L	
Li			ICP	0.1 mg/L	19	0.05 mg/L	
Lu	ICPMS	0.1 µg/L					
Mn	ICP	0.1 mg/L					
Mo	ICP	0.2 mg/L					
Nb	ICPMS	0.2 µg/L					
Ni	ICP	0.1 mg/L	ICPMS	0.4 µg/L	34	none	use SP data
NO3			IC	1.6 to 8 mg/L	84	none	
P	ICP	1 mg/L	ICPMS	0.01 µg/L	16	0.005 µg/L	
Pb	ICP	1 mg/L	ICPMS	0.05 µg/L	3	0.03 µg/L	
Pr			ICPMS	0.01 µg/L	34	none	use SP data
Sb			ICPMS	0.3 µg/L	63	none	
Sm			ICPMS	0.01 µg/L	34	none	use SP data
Ta			ICPMS	0.02 µg/L	16	0.01 µg/L	

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)	Comments
Tb	ICPMS	0.005 µg/L					
Th	ICPMS	0.2 µg/L					
Ti	ICP	0.5 mg/L					
Tl	ICPMS	0.1 µg/L					
Tm	ICPMS	0.005 µg/L					
V	ICP	0.1 mg/L	ICPMS	0.5µg/L	3	0.3 µg/L	
W	ICPMS	0.5 µg/L					
Y							
Yb			ICPMS	0.005 µg/L	38	none	use SP data
Zn	ICP	0.1 mg/L					
Zr			ICPMS	0.2 µg/L	47	none	

Table A4. Data for extracts from Trench T40A, Elephant Skin Wash, GGNCA.

[Click here to open Table A4](#)

Elephant Skin Wash Valley Fill Trenches

Tables A5, A6, and A7 tabulate data from two trenches in the Elephant Skin Wash valley floor (V-1 and V-2). Only pH, conductivity, and % saturation are available on saturation paste extracts. Profiles sampled within trench V-1 include a horizontal profile that intersected the arroyo about one-half its maximum depth, a horizontal profile that was just below the arroyo, and three vertical profiles, one on either side of the arroyo and one beneath the arroyo. Only one vertical profile was sampled in V-2.

Table A5. Elements in solid samples from Elephant Skin Wash valley fill trenches, GGNCA, whose values were all below the lower limit of determinations or with censored values (below the lower limit of determination).

[Replacement values are for elements with <20% of the samples censored and are designated with a red font.]

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
Ag	ICPMS, EDX	1 ppm				
Bi	EDX	5 ppm				
Br			EDX	1 ppm	5	0.5 ppm
Cd	EDX	1 ppm				
Cr			ISE	5 ppm	2	3 ppm
Cs	EDX	5 ppm				
Ge	EDX	2 ppm				
Mo	EDX	2 ppm	EDX			
Nb				10 ppm	7	5 ppm
Sb	EDX	2 ppm	EDX			
Se	EDX	2 ppm				
Sn	EDX	2 ppm				
Te	ICPMS	0.1 ppm				
Th	EDX	4 ppm				
U	EDX	4 ppm				
W	EDX	5 ppm				

Table A6. Data for solid samples from valley fill trenches, Elephant Skin Wash, GGNCA.

[Click here to open Table A6](#)

Table A7. Data for extracts of samples from valley fill trenches, Elephant Skin Wash, GGNCA.

[Click here to open Table A7](#)

Candy Lane Slope Trenches

Tables A8, A9, A10, and A11 tabulate total and extract data from four slope trenches (TS, TW, TN, and TE). Most profiles are vertical except for the TN-horizontal sample sequence taken along one bedding plane from the mouth of the trench to the back wall. TS-lower are soil samples taken at the mouth of the trench about 4' from trench floor; TS-Trench face, soils taken just to the left of the trench wall; TE-W series, on the trench wall; TW-C and TW-0 series, soil taken just to the left of the trench wall.

Table A8. Elements in solid samples from trenches in Candy Lane, GGNCA, whose values were all below the lower limit of determinations or with censored values (below the lower limit of determination).

[Replacement values are for elements with <20% of the samples censored and are designated with a red font.]

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
Ag	ICPMS,EDX	1 ppm, 4 ppm				
As			ICPMS, EDX	1, 0.4 ppm	2, 5	0.5, 0.2 ppm
Ba			EDX	5 ppm	1	3 ppm
Bi	EDX	5 ppm				
Br			EDX	1 ppm	28	
Cd	EDX	1 ppm				
Cl			ISE	50 ppm	4	25 ppm
Cs	EDX	5 ppm				
Cu			EDX	2 ppm	1	1 ppm
Ga			EDX	0.6 ppm	1	0.3 ppm
Ge	EDX	2 ppm				
La			EDX	2 ppm	1	1 ppm
Mo			EDX	2 ppm	1	1 ppm
Nb	ICP	10 ppm				
Nd			EDX	10 ppm	14	5 ppm
Sb	EDX	2 ppm				
Se			EDX	1 ppm	31	0.5 ppm
Sn	EDX	2 ppm				
Te	ICPMS	0.1 ppm				
U			EDX	4 ppm	48	
W	EDX	5 ppm				

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
Y			EDX	0.6 ppm	1	0.3 ppm
Zr			EDX	1.6 ppm	1	0.8 ppm

Table A9. Data for solid samples from trenches in Candy Lane, GGNCA.

[Click here to open Table A9](#)

Table A10. Elements in extracts from trenches in Candy Lane, GGNCA whose values were all below the lower limit of determinations or with censored values (below the lower limit of determination).

[Replacement values are for elements with <20% of the samples censored and are designated with a red font.]

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
Ag	ICPMS	100, 3 µg/L				
Al	ICP	500 µg/L				
As	ICP	1 mg/L	ICPMS	1 mg/L	19	0.5 mg/L
Be	ICP	0.05 mg/L				
Bi			ICPMS	0.005 µg/L	8	0.003 µg/L
Cd	ICP	0.1 mg/L				
Co	ICP	0.1 mg/L				
Cr	ICP	0.1 mg/L				
Cs			ICPMS	.01 µg/L	5	0.005 µg/L
Cu			ICP	100 µg/L	2	50 µg/L
Dy			ICPMS	0.005 µg/L	3	0.003 µg/L
Er			ICPMS	0.005 µg/L	3	0.003 µg/L
F			IC	0.08 mg/L	10	0.04 mg/L
Fe	ICP	200 µg/L	ICPMS	50 µg/L	50	none

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
Gd			ICPMS	0.005 µg/L	1	0.003 µg/L
Ge			ICPMS	0.05 µg/L	37	none
Ho			ICPMS	0.005 µg/L	18	0.003 µg/L
Li			ICP	0.1 mg/L	24	none
Lu	ICPMS	0.1 µg/L				
Mn	ICP	0.1 mg/L				
Mo			ICP	200 µg/L	38	none
Nb			ICPMS	0.02 µg/L	4	0.01 µg/L
Ni			ICP	100 µg/L	43	none
P	ICP	1 mg/L				
Pb	ICP	1 mg/L				
Pr			ICPMS	0.01 µg/L	2	0.005 µg/L
Sb	ICP	1 mg/L				
Sm			ICPMS	0.01 µg/L	3	0.005 µg/L
Ta			ICPMS	0.02 µg/L	14	0.01 µg/L
Tb			ICPMS	0.005 µg/L	24	none
Th			ICPMS	0.005 µg/L	1	0.003 µg/L
Ti	ICP	0.5 mg/L				
Tl			ICPMS	0.05 µg/L	14	0.03 µg/L
Tm	ICPMS	0.005 µg/L	ICPMS	0.005 µg/L	30	none
V	ICP	0.1 mg/L				
W			ICPMS	0.02 µg/L	2	0.01 µg/L
Yb			ICPMS	0.005 µg/L	6	0.003 µg/L
Zn	ICP	0.1 mg/L				
Zr			ICPMS	0.05 µg/L	2	0.03 µg/L

Table A11. Data for extracts from trenches in Candy Lane, GGNCA.

[Click here to open Table A11](#)

GGNCA Regional Soil Data

Tables A12, A13, A14, A15, and A16 tabulate data for sites and samples collected during GGNCA regional sampling. Each sample is keyed to a horizontal (X) and vertical (Y) cell number (fig. 2).

Table A12. Locations and description of GGNCA regional sampling sites.

[Click here to open Table A12](#)

Table A13. Elements in solid samples from the GGNCA regional sampling whose values were all below the lower limit of determinations or with censored values (below the lower limit of determination).

[Replacement values are for elements with <20% of the samples censored and are designated with a red font.]

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
Ag	ICP-MS	1 ppm				
As			EDX	2 ppm	5	1 ppm
Br			EDX	1 ppm	25	na
Cl			ISE	50 ppm	2	25 ppm
Cr			EDX	5 ppm	1	3 ppm
Cu			EDX	2 ppm	1	1 ppm
Ga			EDX	2 ppm	3	1 ppm
HG			CVAA	0.02 ppm	21	na
In			ICP-MS	0.02 ppm	3	0.01 ppm
Cd			ICP-MS	0.1 ppm	3	0.05 ppm
Cr			ICP-MS	10 ppm	1	5 ppm
Cu			EDX	2 ppm	1	1 ppm
Ga			EDX	2 ppm	3	1 ppm
Mn			ICP-MS	100 ppm	3	50 ppm
Mo			EDX	2 ppm	37	na

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
Na			ICP-MS	0.01%	1	0.005 %
Nb			ICP-MS	10 ppm	33	na
Nb			EDX	2 ppm	2	1 ppm
Nd			EDX	10 ppm	9	5 ppm
P			ICP-MS	0.01%	0	0.005 %
Pb			EDX	4 ppm	1	2 ppm
S			COMB	0.05%	32	na
Te	ICP-MS	0.1 ppm				
Tl			ICP-MS	0.1 ppm	0	0.05 ppm
V			EDX	6 ppm	2	3 ppm
Y			ICP-MS	10 ppm	2	5 ppm

Table A14. Data for solid samples (total) from GGNCA regional sampling.

[Click here to open Table A14](#)

Table A15. Elements in saturation paste extracts from the GGNCA regional sampling whose values were all below the lower limit of determinations or with censored values (below the lower limit of determination).

[Replacement values are for elements with <20% of the samples censored and are designated with a red font.]

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
Ag	ICP, ICPMS	100.3 µg/L				
Al	ICP-AES	500 µg/L	ICP-MS	2.0 µg/L	2	1 µg/L
As	ICP-AES	1000 µg/L	ICP-MS	1 µg/L	4	0.5 µg/L
B			ICP-AES	100 µg/L	2	50 µg/L
Ba			ICP-MS	0.2 µg/L	1	0.1 µg/L

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
Be	ICP, ICPMS	50, 0.05 µg/L				
Bi	ICP-MS	0.2 µg/L				
Ca			ICP-MS	0.2 mg/L	1	0.1 mg/L
Cd	ICP-AES	100 µg/L	ICP-MS	0.02 µg/L	1	0.01 µg/L
Ce			ICP-MS	0.01 µg/L	2	0.005 µg/L
Co	ICP-AES	100 µg/L	ICP-MS	.02 µg/L	4	0.01 µg/L
Cr	ICP-AES	100 µg/L	ICP-MS	1 µg/L	29	na
Cs			ICP-MS	0.02 µg/L	11	0.01 µg/L
Cu			ICP-MS	0.5 µg/L	1	0.3 µg/L
Cu			ICP-AES	100 µg/L	50	na
Dy			ICP-MS	0.005 µg/L	1	0.003 µg/L
Er			ICP-MS	0.005 µg/L	2	0.003 µg/L
Eu			ICP-MS	0.005 µg/L	1	0.003 µg/L
F			IC	0.08 mg/L	14	0.04
Fe	ICP-AES	200 µg/L	ICP-MS	50 µg/L	27	na
Ga			ICP-MS	0.05 µg/L	40	na
Gd			ICP-MS	0.005 µg/L	2	0.003 µg/L
Ge			ICP-MS	0.05 µg/L	43	na
Ho			ICP-MS	.005 µg/L	5	0.003 µg/L
K			ICP-MS	0.03 mg/L	1	0.015 mg/L
K			ICP-AES	1 mg/L	1	0.5 mg/L
La			ICP-MS	0.01 µg/L	2	0.005 µg/L
Li	ICP-AES	100 µg/L	ICP-MS	0.1 µg/L	0	0.05 µg/L
Lu	ICP-MS	.1 µg/L				
Mg			ICP-MS	0.01 µg/L	1	0.005 µg/L
Mn	ICP-AES	100 µg/L	ICP-MS	0.2 µg/L	1	0.1 µg/L
Mo	ICP-AES	200 µg/L	ICP-MS	2 µg/L	10	1 µg/L
Nd	ICP-MS	.2 µg/L	ICP-MS	0.01 µg/L	1	0.005 µg/L
Ni	ICP-AES	100 µg/L	ICP-MS	0.4 µg/L	2	0.2 µg/L

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
NO3			IC	0.08 mg/L	30	na
P	ICP-AES	1 mg/L	ICP-MS	0.01 µg/L	5	0.005 µg/L
Pb	ICP-AES	1000 µg/L	ICP-MS	0.05 µg/L	3	0.03 µg/L
Pr			ICP-MS	0.01 µg/L	2	0.005 µg/L
Rb			ICP-MS	0.01 µg/L	1	0.005 µg/L
Sb	ICP-AES	1000 µg/L	ICP-MS	0.3 µg/L	34	na
Sc			ICP-MS	0.6 µg/L	1	0.3 µg/L
Se			ICP-MS	1 µg/L	2	0.5 µg/L
Sm			ICP-MS	0.01 µg/L	2	0.005 µg/L
SO4			ICP-MS	2 mg/L	1	1 mg/L
Sr			ICP-MS	0.5 µg/L	0	0.3 µg/L
Ta	ICP-MS	0.02 µg/L				
Tb			ICP-MS	.005 µg/L	5	0.003 µg/L
Th	ICP-MS	0.2 µg/L				
Ti	ICP-AES	500 µg/L	ICP-MS	0.5 µg/L	1	0.3 µg/L
Tl	ICP-MS	0.1 µg/L				
Tm	ICP-MS	0.005 µg/L				
U			ICP-MS	0.1 µg/L	1	0.05 µg/L
V	ICP-AES	100 µg/L	ICP-MS	0.5 µg/L	1	0.3 µg/L
Y			ICP-MS	0.01 µg/L	1	0.005 µg/L
Yb			ICP-MS	0.005 µg/L	2	0.003 µg/L
W	ICP-MS	0.5 µg/L				
Zn	ICP-AES	100 µg/L	ICP-MS	0.5 µg/L	1	0.3 µg/L
Zr			ICP-MS	0.2 µg/L	14	0.1 µg/L

Table A16. Data for extracts from GGNCA regional sampling.

[Click here to open Table A16](#)

GGNCA Gypsum Isotope Data

Table A17. Location and sulfur- and oxygen-isotope data for gypsum collected throughout the GGNCA.

Field No.	Site	Latitude •	Longitude•	MSdelta 34S ‰	MS delta 34S ‰	MS delta 18O ‰
EV	Eagle Valley (east of Peach Valley Road)			-20.1	-19.9	1.9
QU	Quarry, North GGNCA			-21.2	-21.5	-2.4
04-CLTN-07	Candy Lane North Trench, fibrous salt on bedding plane	38.616500	-107.900467	-21.8	-19.6	-9.5
04-CLTN-07A	Candy Lane North Trench, matted salt on bedding plane	38.616500	-107.900467	-18.8	-16.7	-9.7
04-CLTN-08	Bed plane CL North Trench	38.616500	-107.900467	-21.3	-20.4	-9.8
04-CLTN-26A	Bed plane CL North Trench	38.616500	-107.900467	-19.5	-12.2	-8.8
04-CLTN-30G	Bed plane CL North Trench	38.616500	-107.900467	-20.3	-19.5	-9.1
04-CLTE-13G	Bed plane CL East Trench	38.614383	-107.903983	-22.6	-21.9	
04-CLTE-14G	Bed plane CL East Trench	38.614383	-107.903983	-22.6	-22.8	-8.8
04-CLTE-15G	Bed plane CL East Trench	38.614383	-107.903983	-25.9	-24.3	-6.5
04-CLTE-16G	Bed plane CL East Trench	38.614383	-107.903983	-26.0	-25.5	-9.1
4BG-G1	Gypcrete, Bobcat trail	38.632930	-107.888317	-18.6	-19.0	
4EXE-G-1	Gypcrete, Peach Valley Exclosure east	38.625950	-107.888267	-18.1	-17.4	
4EXM-G-1	Gypcrete, Peach Valley Exclosure west	38.625870	-107.891317	-19.1	-19.3	
4CL-G-1	Gypcrete on Ridge above South & West Candy Lane Trench	38.617750	-107.901490	-15.2	-15.3	
04-ESV-1-NW148	Elephant Skin Wash valley trench	38.553367	-106.192150	-22.5	-22.7	
4PV-F-2	Ferricrete deposit in upper Peach Valley	38.713100	-107.895883	0.6	0.6	

Hanksville Pit Data

Sites near Hanksville, Utah, were chosen to match those of Andrew Godfrey's long term erosion studies (Andrew Godfrey, personal commun.). Hand-dug pits were located near Godfrey's accumulation pits, and shale was sampled from waste piles excavated from these pits.

Table A18. Elements in solid samples from the Hanksville pits whose values were all below the lower limit of determinations or with censored values (below the lower limit of determination).

[Replacement values are for elements with <20% of the samples censored and are designated with a red font.]

Elements not reported or w/censored values	Methods not reported	Lower limit of determination for elements not reported	Methods with replaced censored values	Lower limit of determination of censored values	% of samples with censored values	Replacement value (1/2 DL)
Ag	ICPMS,EDX	1 ppm				
Bi	EDX	5 ppm				
Br			EDX	1 ppm	25	
Ca						
Cd	EDX	1 ppm	ICPMS	0.1 ppm	69	
Cs			EDX	5 ppm	38	
Ge	EDX	2 ppm				
Hg			CVAA	0.02 ppm	31	
Mn			ICP	100 ppm	19	50 ppm
Mo			EDX	2 ppm	63	
Sb	EDX	2 ppm				
Se			HYDR, EDX	0.2 ppm, 1 ppm	19, 69	0.1 ppm
Sn	EDX	2 ppm				
Te	ICPMS	0.1 ppm				
U	EDX	4 ppm	EDX	4 ppm	13	2 ppm
W	EDX	5 ppm				

Table A19. Data for solid samples from Hanksville pits, Utah.

[Click here to open Table A19](#)