Geochemical Geodatabase of Sedimentary Strata (Coal, Coal-adjacent Rocks, Tuffaceous Oil Shale, Phosphate-rich Rocks) and Produced Water in the Uinta Region, Utah and Colorado

by

Ryan D. Gall[1], Lauren P. Birgenheier[2], Peyton D. Fausett[2], Haley H. Coe[2], Emma A. Morris[3], Diego P. Fernandez[2], Laura Wilcock[2], Michael D. Vanden Berg[1], Andrew L. Masterson[4], Aaron M. Jubb[4], Justin E. Birdwell[5], Logan M. Ashurst-McGee[2], Nicholas J. Bailey[2], Andrew R. Giebel[6], Amanda Herzberg[4], Jessica Chenault[4], Brittney M. Hoskins[2]

[1]Utah Geological Survey, Salt Lake City, Utah
[2]University of Utah, Salt Lake City, Utah
[3]University of North Carolina Wilmington, Wilmington, North Carolina
[4]U.S. Geological Survey, Reston, Virginia
[5]U.S. Geological Survey, Denver, Colorado
[6]Colorado Geological Survey, Golden, Colorado

Suggested citation:

Gall, R.D., Birgenheier, L.P., Fausett, P.D., Coe, H.H., Morris, E.A., Fernandez, D.P., Wilcock, L., Vanden Berg, M.D., Masterson, A.L., Jubb, A.M., Birdwell, J.E., Ashurst-McGee, L.M., Bailey, N.J., Giebel, A.R., Herzberg, A., Chenault, J., Hoskins, B.M., 2026, Geochemical geodatabase of sedimentary strata (coal, coal-adjacent rocks, tuffaceous oil shale, phosphate-rich rocks) and produced water in the Uinta region, Utah and Colorado: Utah Geological Survey Data Series 6, 9 p., 3 appendices, http://doi.org/10.34191/DS-6.

Disclaimer

This Data Series release makes datasets, databases, and their accompanying documents available to the public. The data may not conform to Utah Geological Survey technical, editorial, or policy standards. Although this product represents the work of professional scientists, the Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use, and does not guarantee accuracy or completeness of the data. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

DATA SERIES 6
UTAH GEOLOGICAL SURVEY
UTAH DEPARTMENT OF NATURAL RESOURCES
2026

CONTENTS

INTRODUCTION 1
IMPORTANT CONSIDERATIONS 3
Data Comparability 3
Detection Capability and Detection Limits 3
METHODS 3
GEODATABASE FEATURE CLASSES 3
EXPLANATION OF DATABASE FIELDS 4
StudyLocation_CORECM 4
StudyLocation_UGSarchive 4
Geochemical_pXRF & Geochemical_ICP-MS_ICP-OES 6
Reference_CoalFields 8
ADDITIONAL RESOURCES 9
ACKNOWLEDGEMENTS 9
REFERENCES 9
APPENDICES 10
APPENDIX A— Archived coal sample data 11
APPENDIX B— Detection limits for Vanta pXRF, ICP-MS, and ICP-OES analyses 12
APPENDIX C— Abandoned coal mines of Utah data 13

FIGURE

Figure 1. Overview of geodatabase 2

TABLES

Table 1. CORE-CM geochemical dataset 1
Table 2. List of feature classes included in geodatabase 3

GEODATABASE

Database— https://ugspub.nr.utah.gov/publications/data_series/ds-6/ds-6.zip
CSV files—https://ugspub.nr.utah.gov/publications/data_series/ds-6/ds-6x.zip

INTRODUCTION

The Geochemical Geodatabase of Sedimentary Strata (Coal, Coal-adjacent Rocks, Tuffaceous Oil Shale, Phosphate-rich Rocks) and Produced Water in the Uinta Region, Utah and Colorado, consists of compiled datasets acquired as part of the Carbon Ore, Rare Earth, and Critical Mineral (CORE-CM) Uinta Region assessment funded by the U.S. Department of Energy (DE-FE0032046, 2021–2024; Birgenheier et al., 2024). The CORE-CM assessment focused on providing comprehensive geological and geochemical characterization of current and prospective sedimentary-hosted resources including coal, oil shale, phosphatic limestone, and produced water from oil and gas targets present in eastern Utah and northwestern Colorado (Figure 1).

This Data Series includes a geodatabase that consists of analytical geochemical data collected September 2021 through December 2024 via portable X-ray fluorescence (pXRF), and laboratory measured analyses produced by inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma optical emission spectroscopy (ICP-OES). The coal-related geochemical data are derived primarily from the Cretaceous Blackhawk Formation and Ferron Sandstone of Utah, and the Mesaverde Group of Colorado. Additional non-coal resources assessed include oil shale-bearing strata of the Eocene upper Green River Formation (Utah and Colorado), phosphate-rich limestone of the Permian Park City Formation (Utah) and produced water from oil and gas-bearing strata of the Eocene Green River and Wasatch Formations (Uinta Basin) and the Pennsylvanian Paradox Formation (Paradox Basin) (Table 1). The CORE-CM assessment included a wide range of lithologies present in the coal, oil shale, and phosphate geologic resource systems whether or not the specific lithology has current economic value. Geochemical analyses of produced water from oil and gas wells focused on current and emerging hydrocarbon targets in the central Uinta Basin and northern Paradox Basin. A total of 13,092 geochemical analyses from these geologic systems is provided in the included geodatabase. A series of coal quality data (e.g., composition and maceral analyses) is also included in the database and was digitized from archived coal samples from the Utah Geological Survey (Appendix A).

***Table 1**. CORE-CM geochemical dataset.*

Primary Resource	Age	Formation/Unit	*pXRF sample analyses	*ICP-MS analyses	*ICP-OES analyses
Coal	Cretaceous	Blackhawk	2473	133	0
Coal	Cretaceous	Dakota Sandstone	42	0	0
Coal	Cretaceous	Ferron Sandstone	7141	148	0
Coal	Cretaceous	Mesaverde Group	1022	44	0
Coal	Cretaceous	Mixed run of mine	493	15	0
Coal	Cretaceous	Other or undefined	27	0	0
Oil shale	Eocene	Green River	822	32	0
Phosphate	Permian	Park City	651	0	15
Oil and gas produced water	Eocene	Green River	0	7	7
Oil and gas produced water	Eocene	Wasatch	0	3	3
Oil and gas produced water	Pennsylvanian	Paradox	0	7	7
Total number of analyses:			**12671**	**389**	**32**

*Number of individual sample analyses

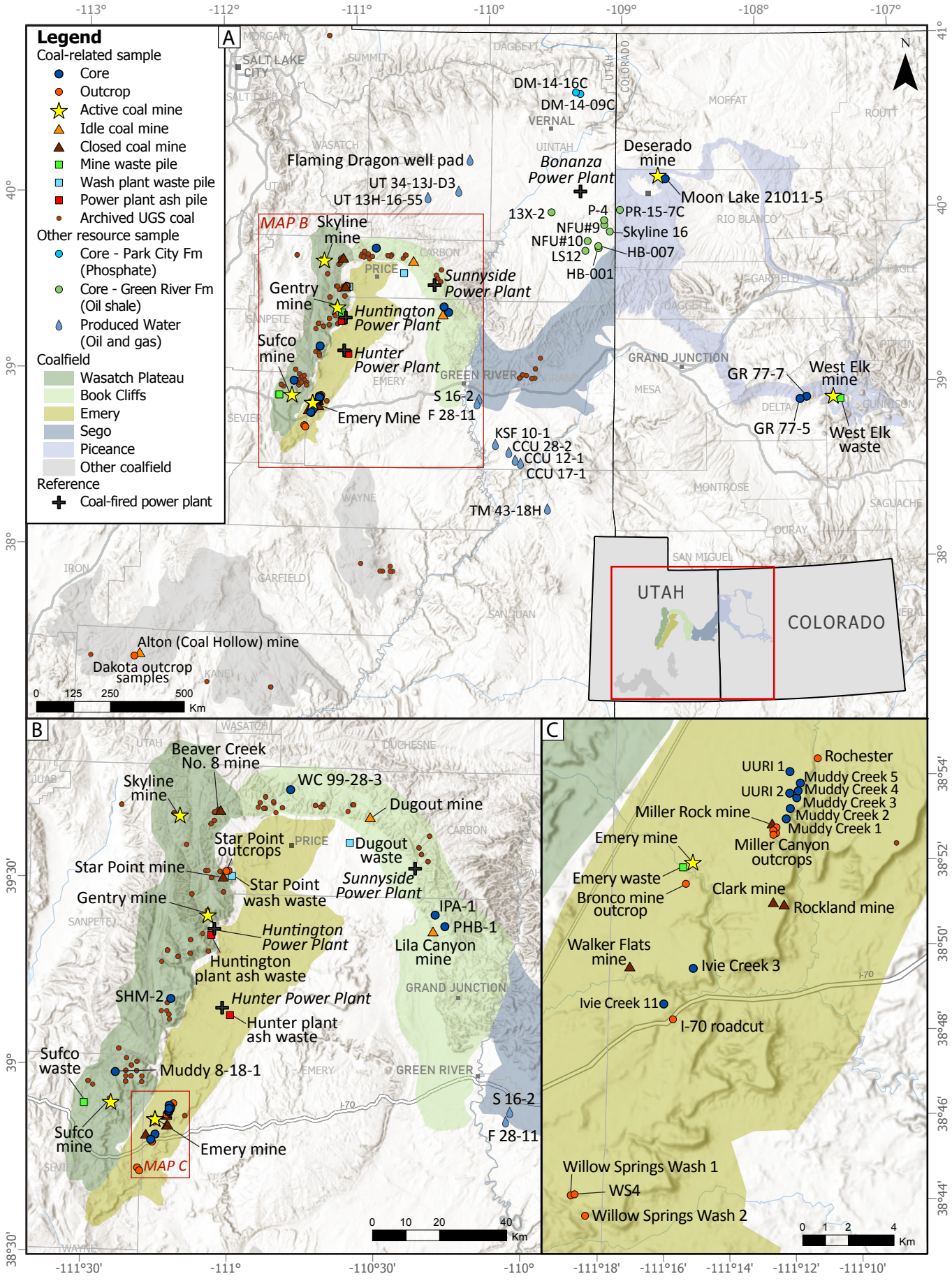

Figure 1. *Overview of geodatabase.*

IMPORTANT CONSIDERATIONS

Data Comparability

This dataset contains geochemical data acquired from multiple analytical methods (pXRF, ICP-MS, ICP-OES), which inherently vary in sample preparation method, detection method, sensitivity, and capability as described in Birgenheier et al. (2024). Variation in geochemical results between methods is expected and must be considered if comparing geochemical datasets. For example, pXRF does not analyze all elements, such as heavy rare earth elements, whereas ICP-MS and ICP-OES can capture full elemental suites. Coe et al. (2024) provided visual representations of results obtained by pXRF and ICP-MS from a subset of the data included herein, highlighting the variation between these analytic methods. Additional methodology comparisons can be found in Birgenheier et al. (2024).

Detection Capability and Detection Limits

The detection limit for any analyzed element varies by instrument (Appendix B). A "<" value in this dataset indicates that the elemental concentration is lower than the detection limit of the instrument used to analyze the sample. A null geochemical value in this dataset indicates that the analytical tool (pXRF, ICP-MS, ICP-OES) used does not analyze the particular element, or the specific method used did not assess that element.

METHODS

Datasets were compiled within ArcGIS Pro 3.0.2 and all geographic coordinates were normalized to the World Geodetic System 1984 (WGS84). All pXRF samples were analyzed using an Olympus Vanta M series pXRF at the Utah Core Research Center in Salt Lake City, Utah, or at onsite mine locations. ICP-MS analyses were performed at the University of Utah Earth Core Facility in Salt Lake City, Utah. ICP-OES analyses of rock samples were completed at the U.S. Geological Survey Central Energy Resources Science Center in Lakewood, Colorado. Produced water ICP-OES analyses were completed at the U.S. Geological Survey Brine Research Instrumentation and Experimental (BRInE) Laboratory in Reston, Virginia. Laboratory procedures used in each analytical method and sample type (e.g., core, outcrop, mine waste, produced water) are described in Birgenheier et al. (2024) and Jubb et al. (2020). Appendix B contains detection limits for pXRF and ICP-MS methods and complete ICP-OES data packages.

GEODATABASE FEATURE CLASSES

Feature class items are broadly divided into three categories as identified by the feature class prefix: 1) Study location; 2) Geochemical data; or 3) Reference data. Feature class coordinates from study locations and geochemical data overlap, although are intentionally divided into distinct feature classes to provide relevant information and aid usability of the dataset. Each feature class is summarized in Table 2 and attributes are described in the following section.

Table 2. *List of feature classes included in geodatabase.*

Feature Class Name	Feature Type	Description
StudyLocation_CORECM	Point	CORE-CM specific study location
StudyLocation_Coal_UGSArchive	Point	CORE-CM study location of archived coal samples from the Utah Geological Survey repository. Includes newly digitized coal quality data from the Utah Geological Survey library.
Geochemical_pXRF	Point	All pXRF geochemical data generated in CORE-CM
Geochemical_ICPMS_ICPOES	Point	All ICP-MS and ICP-OES geochemical data generated in CORE-CM
Reference_CoalFields	Polygon	Coalfields of the Uinta region and other assessed areas in CORE-CM

EXPLANATION OF DATABASE FIELDS

StudyLocation_CORECM

Primary Resource	Primary economic resource for stratigraphic interval at sampling location (coal, oil shale, oil and gas, phosphate)
Resource Qualifier	Sample locality type (mine site, waste site, production well, core, outcrop)
Sample Type	Type of sample derived from locality (core, handsample, produced water)
Unique site ID	Sample locality name (name of core, mine, waste site, oil and gas well, outcrop location). A suffix of ".
Short ID	Short sample locality name
Unique ID_API	American Petroleum Institute (API) number or repository ID number; N/A = not applicable.
Basin or Geologic Province	General geologic province or specific basin name
Coalfield or oil field	Name of coalfield or oil and gas field
Formation	Name of sampled formation or group
Subunit or coal seam	Name of sampled subunit, member, or coal seam
Coal seam thickness	Measured thickness of coal seam
Core storage location	Location of core as of 12/31/2024
Core top depth (ft)	Depth at which core begins, in feet
Core bottom depth (ft)	Depth at which core ends, in feet
Cored interval thickness (ft)	Total thickness of core interval, in feet
Ground level (ft)	Ground surface elevation relative to mean sea level, in feet
Latitude	WGS84
Longitude	WGS84
Notes	Additional notes on sample locality

StudyLocation_UGSarchive

Primary Resource	Primary economic resource for stratigraphic interval at sampling location (coal)
Resource Qualifier	Sample locality type (archived sample)
Sample Type	Type of sample derived from locality (handsample)
UGS ID	Identification number in Utah Geological Survey repository. ".#" suffixes on duplicated UGS ID's indicate different stratigraphic intervals sampled from the same coal seam (see stratigraphic context).
Sample ID	CORE-CM Sample ID. Duplicated sample IDs with ".#" suffix indicates an additional study point on the same sample.
Basin or Geologic Province	General geologic province or specific basin name
Coalfield	Name of coalfield
Formation	Name of target formation or group
Archived coal seam	Name of coal seam as archived
Revised coal seam	Revised coal seam name by CORE-CM
Stratigraphic Context	Stratigraphic notes of sample location, as recorded in archive
Lithology	Lithology of sample

Coal type	Coal type of sample
County	County
Archived location	Public Land Survey System (PLSS) coordinates as recorded in archive
Latitude	Approximate latitude converted from PLSS, WGS84
Longitude	Approximate longitude converted from PLSS, WGS84
Vitrinite	Maceral analysis (mineral matter free), % vitrinite observed under white light
Pseudo_Vitrinite	Maceral analysis (mineral matter free), % pseudo vitrinite observed under white light
Resinite	Maceral analysis (mineral matter free), % resinite observed under white light
Sporinite	Maceral analysis (mineral matter free), % sporinite observed under white light
Cutinite	Maceral analysis (mineral matter free), % cutinite observed under white light
Micrinite	Maceral analysis (mineral matter free), volume % micrinite observed under white light
Semi_Fusinite	Maceral analysis (mineral matter free), volume % semifusinite observed under white light
Sclerotinite	Maceral analysis (mineral matter free), volume % sclerotinite observed under white light
Fusinite	Maceral analysis (mineral matter free), volume % fusinite observed under white light
Macrinite	Maceral analysis (mineral matter free), volume % macrinite observed under white light
Sporinite_1	Maceral analysis (mineral matter free), volume % sporinite observed under UV light
Cutinite_1	Maceral analysis (mineral matter free), volume % cutinite observed under UV light
Green	Maceral analysis (mineral matter free), volume % green resinite observed under UV light
Yellow	Maceral analysis (mineral matter free), volume % yellow resinite observed under UV light
Orange	Maceral analysis (mineral matter free), volume % orange resinite observed under UV light
Exsudatinite	Maceral analysis (mineral matter free), volume % exsudatinite observed under UV light
Alginite	Maceral analysis (mineral matter free), volume % alginite observed under UV light
Fluorinite	Maceral analysis (mineral matter free), volume % fluorinite observed under UV light
Bituminite	Maceral analysis (mineral matter free), volume % bituminite observed under UV light
Non_Fluorescing	Maceral analysis (mineral matter free), volume % non-fluorescing material observed under UV light
Vitrinite_Ro	Vitrinite reflectance (%)
STD_Dev	Standard deviation of Vitrinite Ro
Rank_by_Ro	Coal rank by vitrinite reflectance (e.g., high-volatile type A [hva] or high-volatile type B [hvb])
Rank_by_BTU	Coal rank by British thermal units(e.g., high-volatile type A [hva] or high-volatile type B [hvb])
Moisture	Weight % moisture
Ash	Weight % ash
Volatile_Matter	Weight % volatile matter
Fixed_Carbon	Weight % fixed carbon
Sulfur_TOTAL	Weight % total sulfur
Carbon	Weight % carbon
Hydrogen	Weight % hydrogen
Nitrogen	Weight % nitrogen
Oxygen	Weight % oxygen
Chlorine	Weight % chlorine
BTU	British thermal units

MMF_BTU	British thermal units on a moist, mineral-matter-free basis
Density	Grams per cubic centimeter
App__Porosity	Apparent porosity (%)
Comments	Additional comments regarding sample
Data_Source	Scanned file name with sample information (Appendix A). Null values indicate that PDF format data is not available.

Geochemical_pXRF & Geochemical_ICP-MS_ICP-OES

Sample_ID	CORE-CM sample ID. Duplicated sample IDs with ".#" suffix indicates an additional study point on the same sample
Sample_Type	Type of sample
Unique_site_ID	Name of core, mine, power plant, well, or outcrop
API_number	American Petroleum Institute (API) identification number
Resource_Group	Primary resource (e.g., coal, oil shale)
Formation	Formation or group
Unit_or_Coal_Seam	Subunit or coal seam name
Lithology	Lithology
Age	Geologic age
Sample_status	Availability of sampled material
Sample_Notes	Additional sample notes
Coordinates_datum	Coordinate system
Latitude	Latitude, WGS84
Longitude	Longitude, WGS84
Depth_ft_	Sample depth in feet
County	County
State	State
Country	Country
Basin_or_Geologic_Province	Basin or geologic province
Name_of_company_owner_ or operator	Name of company owner or operator
Name_of_sample_collector	Name of person that collected the sample
Date_Collected__ MM_DD_YYYY	Date collected in month/day/year
Sample_ID_1	Same identification number
Laboratory_where_analyses_ completed	Laboratory that completed sample analyses
Analysis_technique	Analytical technique used for sample analysis
Sample_preparation_method	Sample preparation method
Digestion_method	Digestion method used in sample preparation
Material	Material assessed
Coal_rank_if_applicable	Coal rank

Repeat_analyses	Number of repeated analyses
Li	Li ppm (mg/L for produced water samples)
Be	Be ppm (mg/L for produced water samples)
B	B ppm (mg/L for produced water samples)
F	F ppm (mg/L for produced water samples)
Na	Na ppm (mg/L for produced water samples)
Mg	Mg ppm (mg/L for produced water samples)
Al	Al ppm (mg/L for produced water samples)
Si	Si ppm (mg/L for produced water samples)
P	P ppm (mg/L for produced water samples)
Cl	Cl ppm (mg/L for produced water samples)
K	K ppm (mg/L for produced water samples)
Ca	Ca ppm (mg/L for produced water samples)
Sc	Sc ppm (mg/L for produced water samples)
Ti	Ti ppm (mg/L for produced water samples)
V	V ppm (mg/L for produced water samples)
Cr	Cr ppm (mg/L for produced water samples)
Fe	Fe ppm (mg/L for produced water samples)
Co	Co ppm (mg/L for produced water samples)
Ni	Ni ppm (mg/L for produced water samples)
Cu	Cu ppm (mg/L for produced water samples)
Zn	Zn ppm (mg/L for produced water samples)
Ga	Ga ppm (mg/L for produced water samples)
Ge	Ge ppm (mg/L for produced water samples)
As	As ppm (mg/L for produced water samples)
Se	Se ppm (mg/L for produced water samples)
Rb	Rb ppm (mg/L for produced water samples)
Sr	Sr ppm (mg/L for produced water samples)
Y	Y ppm (mg/L for produced water samples)
Zr	Zr ppm (mg/L for produced water samples)
Nb	Nb ppm (mg/L for produced water samples)
Mo	Mo ppm (mg/L for produced water samples)
Ag	Ag ppm (mg/L for produced water samples)
Cd	Cd ppm (mg/L for produced water samples)
In	In ppm (mg/L for produced water samples)
Sn	Sn ppm (mg/L for produced water samples)
Sb	Sb ppm (mg/L for produced water samples)
Cs	Cs ppm (mg/L for produced water samples)

Ba	Ba ppm (mg/L for produced water samples)
La	La ppm (mg/L for produced water samples)
Ce	Ce ppm (mg/L for produced water samples)
Pr	Pr ppm (mg/L for produced water samples)
Nd	Nd ppm (mg/L for produced water samples)
Sm	Sm ppm (mg/L for produced water samples)
Eu	Eu ppm (mg/L for produced water samples)
Gd	Gd ppm (mg/L for produced water samples)
Tb	Tb ppm (mg/L for produced water samples)
Dy	Dy ppm (mg/L for produced water samples)
Ho	Ho ppm (mg/L for produced water samples)
Er	Er ppm (mg/L for produced water samples)
Tm	Tm ppm (mg/L for produced water samples)
Yb	Yb ppm (mg/L for produced water samples)
Lu	Lu ppm (mg/L for produced water samples)
Hf	Hf ppm (mg/L for produced water samples)
Ta	Ta ppm (mg/L for produced water samples)
W	W ppm (mg/L for produced water samples)
Hg	Hg ppm (mg/L for produced water samples)
Tl	Tl ppm (mg/L for produced water samples)
Pb	Pb ppm (mg/L for produced water samples)
Bi	Bi ppm (mg/L for produced water samples)
Th	Th ppm (mg/L for produced water samples)
U	U ppm (mg/L for produced water samples)
Total_REE_whole_rock_ppm	Sum of rare earth elements (REE), excluding Y, ppm (mg/L for produced water samples)
Total_REE_Y_whole_rock_ppm	Sum of REE, including Y, ppm (mg/L for produced water samples)
Total_REE_ashed_ppm	Sum of ashed REE, excluding Y, ppm
Total_REE_Y_ashed_ppm	Sum of ashed REE, including Y, ppm

Reference_CoalFields

Field_Name	Name of coalfield
Economics	Economics of coalfield (economic; marginal; prospective)
Coordinate_datum	WGS84
Shape_Length	Length of polygon in degrees
Shape_Area	Area of polygon in square degrees

ADDITIONAL RESOURCES

A subset of the coal data included herein is included in Coe et al. (2024) and Wilcock et al. (2025), both of which provide additional interpretation of rare earth element enrichment observed in some samples. Other published datasets complement this information. The U.S. Geological Survey COALQUAL database contains geochemical data from coal fields across the United States, including the Uinta region (https://ncrdspublic.er.usgs.gov/coalqual/; Palmer et al., 2015). Simmons (2017) contains additional produced water analyses from the Uinta and Paradox Basins. Abandoned mine information can be found at the Utah Geological Survey abandoned coal mine database of Utah (https://geology.utah.gov/map-pub/maps/interactive-maps/abandoned-coal-mines/; also included as Appendix C) and the Historic Mines of Colorado publication (Carroll and Bauer, 2001).

ACKNOWLEDGEMENTS

This work was funded by the U.S. Department of Energy Federal Grant DE-FE0032046. ALM, AMJ, AH, and JC were funded by the USGS Energy Resources Program. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. This work thanks various geoscientists who have contributed to the Utah Geological Survey repository and library over many decades, and assistance from Ammon McDonald at the Utah Core Research Center.

REFERENCES

Birgenheier, L.P., Coe, H., Morris, E., Gall, R., Fausett, P., Wilcock, L., Bailey, N., Vanden Berg, M.D., Giebel, A., Fernandez, D., 2024, Basinal assessment of Carbon Ore, Rare Earth, and Critical Minerals (CORE-CM) Resources, *in* Free, M., editor, CORE-CM: Transforming Uinta Basin earth materials into advanced products, final report: Department of Energy project DE-FE0032046, p. 21–168, https://doi.org/10.2172/2565707.

Carroll, C.J., Bauer., M.A., 2001, Historic coal mines of Colorado: Colorado Geological Survey Information Series 64 [dataset], https://coloradogeologicalsurvey.org/publications/historic-coal-mines-colorado.

Coe, H.H., Birgenheier, L.P., Fernandez, D.P., Gall, R.D., Vanden Berg, M.D., Giebel, A., 2024, Rare earth element enrichment in coal and coal-adjacent strata of the Uinta region, Utah and Colorado: Frontiers, v. 12, 17 p., https://doi.org/10.3389/feart.2024.1381152.

Jubb, A.M., Engle, M.A., Chenault, J.M., Blondes, M.S., Danforth, C.G., Doolan, C., Gallegos, T.J., Mueller, D., and Shelton, J.L., 2020, Direct trace element determination in oil and gas produced waters with inductively coupled plasma-optical emission spectrometry—Advantages of high-salinity tolerance: Geostandards and Geoanalytical Research, v. 44, no. 2, p. 385–397, https://doi.org/10.1111/ggr.12316.

Palmer, C.A., Oman, C.L., Park, A.J., Luppens, J.A., 2015, The U.S. Geological Survey coal quality (COALQUAL) database version 3.0: U.S. Geological Survey Data Series 975, 43 p. with appendices, http://dx.doi.org/10.3133/ds975.

Simmons, S., 2017, Critical elements in produced fluids from Nevada and Utah: Energy and Geoscience Institute at the University of Utah, Geothermal Data Repository, https://doi.org/10.15121/1452708.

Wilcock, L., Birgenheier, L.P., Morris, E.A., Fausett, P.D., Coe, H.H., Fernandez, D.P., Gall, R.D., Vanden Berg, M.D., 2025, REY spatial distribution and mineral association in coal, carbonaceous shale and siltstone: Implications for REE Enrichment Mechanisms, Minerals, v. 15, no. 8, 22 p., https://doi.org/10.3390/min15080869.

APPENDICES

APPENDIX A

Archived coal sample data

https://ugspub.nr.utah.gov/publications/data_series/ds-6/ds-6a.zip

APPENDIX B

Detection limits for Vanta pXRF, ICP-MS, and ICP-OES analyses

https://ugspub.nr.utah.gov/publications/data_series/ds-6/ds-6b.zip

APPENDIX C

Abandoned coal mines of Utah data

https://ugspub.nr.utah.gov/publications/data_series/ds-6/ds-6c.zip