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Sulfur Compound, Organic-carbon, Carbonate-carbon, Iron, and Mineral Composition Data on Samples from the Green River Formation, Wyoming, Colorado, and Utah

By

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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SULFUR COMPOUND, ORGANIC-CARBON, CARBONATE-CARBON, IRON, AND MINERAL COMPOSITION DATA ON SAMPLES FROM THE GREEN RIVER FORMATION, WYOMING, COLORADO, AND UTAH

By Michele L. Tuttle

INTRODUCTION

The geology and geochemistry of the Green River Formation are of interest because of the unique lithologic and geochemical characteristics of the rock. The Green River Formation is an enormous resource of oil shale, and also hosts evaporative minerals. These potentially-economical commodities were deposited in two large, saline lake systems (ancient lakes Uinta and Gosiute) starting in the early Eocene and spanning an estimated 14 million years. These lakes collectively covered nearly 62,150 km^2 (24,000 mi^2; Bradley, 1929) in what is now the Uinta basin, Utah; the Piceance basin, Colorado; and the Green River and Washakie basins, Wyoming (fig. 1). Previous work has enriched our understanding of the deposition and subsequent diagenesis of these rocks, yet the overall theories regarding the geochemical evolution of these oil-shale basins are often vague and conflicting.

An investigation is underway using a new approach toward understanding the origin of this unusual rock. This approach involves reconstruction and interpretation of the cycling of sulfur within the ancient lakes and is based on the premise that sulfur geochemistry of a lake, as recorded in the abundances and isotopic compositions of various forms of sulfur incorporated in the sediments, is dependent on the biogeochemistry, oxidation state, and pH of a lake system. Because sulfur cycling within a lacustrine system is linked to other aspects of the lake geochemistry, it is anticipated that information gained on sulfur will have implications for other geochemical processes as well.

Most existing sulfur data on the Green River Formation are for the rocks within the Uinta and Piceance basins. A review of the literature yields little information on concentrations and forms of sulfur in rocks from the Green River basin. Reported concentrations of total sulfur in the Green River Formation range from undetectable in algal carbonates in the Uinta basin, Utah (Boyer and Cole, 1983) to 5 wt. % in organic matter-rich shale from the saline zone in the Piceance basin, Colorado (Dyni, 1983). The sulfur is known to occur as sulfate, monosulfide, disulfide, and sulfur bound to organics. The abundance of sulfate is low in the oil shale (less than 4 % of the total sulfur; Stanfield and others, 1951; Smith and others, 1964) and sulfate minerals have not been identified in the formation (Milton and Eugster, 1959). Occurrences of monosulfides (pyrrhotite and ZnS) and disulfides (pyrite and marcasite) have been reported by Milton and Eugster (1959), Pabst (1970), Cole and others (1978), Cole and Picard (1981), and Melchior and others (1982). Monosulfides have not been previously quantified, but are considered to be a minor sulfur phase. According to Stanfield and others (1951) and Smith and Young (1983), 50-90 % of the sulfur in most Green River oil shales resides in pyrite with the remaining 10-50 % occurring as organically-bound sulfur. Sulfur-containing organic compounds in the Green River oil shales include thiophenes, benzothiophenes, and polycyclic thiols (Ingram and others, 1983).

The purpose of this report is to provide the results of analyses on 115 Green River Formation samples. Each sample was described and analyzed for whole-rock mineralogy, total sulfur, sulfate (S_{SO4}), monosulfide sulfur (S_{av}, av represents acid-volatile), disulfide sulfur (S_{di}), organically-bound sulfur (S_{org}), organic and carbonate carbon, and reactive iron.

SAMPLING METHODS

Samples were collected from three cores: the E.R.D.A. Black Forks core #1, Wyoming; the U.S. Bureau of Mines core 01A, Colorado; and the U.S. Geological Survey Coyote Wash #1 core, Utah. Each drill hole was located within the depositional center(s) of the lakes resulting in one core from the Green River basin, Wyoming; one from the Uinta basin, Utah; and one from the Piceance basin, Colorado (fig. 1). The Black Forks core #1 is stored at the Western Research Institute, Laramie, Wyoming (formerly the Laramie Energy Technology Center). An unpublished description of the core was kindly provided by Laurence Trudell, Western Research Institute. The 01A core and the Coyote Wash core are stored at the U.S. Geological Survey core library, Denver, Colorado. The 01A core is described in Snyder and Terry (1977) and the Coyote Wash core in Scott and Pantea (1982). Geologic sections of the three cores are illustrated in Figure 2.

Thirty-five samples were collected from the Black Forks core, 41 from the 01A core, and 39 for the Coyote Wash core. Total sulfur, carbonate carbon, and organic carbon were determined on all samples. Various forms of sulfur were determined in 20 01A samples and 25 Coyote Wash samples; forms of sulfur were determined in all 35 samples from the Green River basin (Black Forks core) because of the scarcity of literature sulfur data for the rocks within this basin. Macroscopic descriptions of the samples are given in Table 1.

ANALYTICAL METHODS

Whole-rock mineralogy.--Whole-rock mineral composition was determined on randomly-oriented powder mounts using an X-ray diffractometer with Ni-filtered, Cu K_{α} radiation. The minerals identified from the diffractograms are given in Table 1.

Total sulfur, carbonate carbon, and organic carbon.--Total sulfur and carbon concentrations were determined using an induction furnace coupled to an infrared-detection system. Another split of the sample was then placed in an analysis crucible, treated with small amounts of 6 N HCl, and thoroughly dried. Total carbon was determined as above on this acid-treated sample and represents the organic-carbon concentration. Carbonate-carbon concentrations were determined by difference. All sample concentrations were above the limit of determination and are reported in Table 2. Results were reproducible within 10 %.

Reactive iron.--Reactive iron (6N HCl-soluble iron plus iron contained in disulfides) is operationally defined as that iron available for sulfidization by H_2S. Six N HCl-soluble iron was determined by analyzing the HCl solution for the procedure decribed below by flame atomic absorption spectroscopy. The iron in disulfides was calculated from the disulfide sulfur concentrations as analyzed by the procedure outlined below. All sample concentrations were above the limit of determination and are reported in Table 2. Results were reproducible within 10 %.

Forms of sulfur.--The method designed to sequentially collect and gravimetrically analyze forms of sulfur (Tuttle and others, 1986) is shown diagrammatically in Figure 3. A brief description of the method follows.

Apparatus and Reagents

Jones reductor.--Preparation of a Jones reductor is described in Skogg and West (1976). The reductor contains amalgamated zinc which reduces Cr^{3+} to Cr^{2+}.

Apparatus.--The decomposition of acid-volatile sulfides and disulfides is carried out in the apparatus shown in Figure 4. H_2S generated in the reaction flask passes through an aqueous wash solution buffered to a pH of 4.02, and is collected as Ag_2S in an aqueous solution of 0.1 F $AgNO_3$.

1 M Cr^{2+} solution.--Dissolve 133.2 g of reagent-grade $CrCl_3 \cdot 6 H_2O$ in 500 ml of 0.1 F HCl. Pass the solution through the Jones reductor. The color changes from bright green to bright blue as the Cr^{3+} is reduced to Cr^{2+}. The Cr^{2+} solution is unstable in air and should be prepared every few days.

Eschka flux.--This flux mixture can be obtained commercially or prepared by mixing three parts MgO to two parts Na_2CO_3 (wt/wt). The commercially prepared, reagent grade flux was used for these analyses.

Procedure.

Introduce a sample of known weight (about 5 g) into the round-bottom reaction flask (fig. 4). When the sample contains acid-soluble Fe^{3+}, add enough $SnCl_2$ (10-15 g) to the sample to result in a 15-20 wt % HCl solution. Connect the apparatus and flush for five minutes with high-purity grade N_2. Slowly introduce 80 ml 6 F, deoxygenated HCl through the dropping funnel. Deoxygenate the HCl by bubbling the acid with N_2. Allow the reaction to proceed at room temperature for 15 minutes. Heat slowly until the solution just begins to boil, reduce the heat and continue the reaction until the $AgNO_3$ solution clears and no H_2S is detected when paper wetted with $AgNO_3$ solution is held in the gas stream issuing from the buffer solution. Disconnect the apparatus, filter, wash (H_2O), and dry the residual solids saving the filtrate for sulfate analysis. Filter, wash (H_2O), and dry to constant weight the Ag_2S precipitate (S_{av}).

Return the dried residual solid to the round-bottom reaction flask and add 10 ml ethanol. Connect the apparatus and flush with N_2. Add a combined solution of 50 ml 1 M Cr^{2+} and 20 ml concentrated, deoxygenated HCl through the dropping funnel. Allow the reaction to proceed at room temperature for 15-30 minutes. Heat the sample to boiling and allow the solution to slowly boil until H_2S generation ceases. Filter, wash (H_2O), and dry the residual solids. Filter, wash (H_2O), and dry to constant weight the Ag_2S precipitate (S_{di}).

Mix the residual solids with Eschka flux (1:3 wt/wt) and place in a porcelain crucible. Cover the mixture with additional Eschka flux. Fuse the sample-flux mixture in a muffle furnace at 800 °C for two hours. Remove the crucible from the furnace, let it cool in air, and dissolve the solid in distilled water (10 ml for every 0.1 g of sample). Heat the solution for about 30 minutes, filter and discard the solid residue. Adjust the filtrate to pH <4.0 with HCl and add 10 ml bromine-saturated distilled water. Boil the solution until the bromine is expelled. Add 10 ml 10 wt % $BaCl_2$ solution and continue boiling for 15 minutes. Reduce the heat, cover the solution, and allow to digest overnight. Filter, wash (H_2O), and dry to constant weight the $BaSO_4$ precipitate (S_{org}). The HCl filtrate (S_{SO4}) from the acid-volatile sulfur step is treated the same as the solution from the Eschka fusion starting with the addition of the bromine-saturated water through the weighing of the $BaSO_4$. The limit of detection for these sulfur techniques (0.01 wt % S for a 5 g sample) is based on the uncertainty in weighing very small amounts of precipitate. Results of the analyses are given in Table 2. Most results were reproducible within 10 % except when concentrations were very near the limit of detection in which case the results were reproducible within 30 %.

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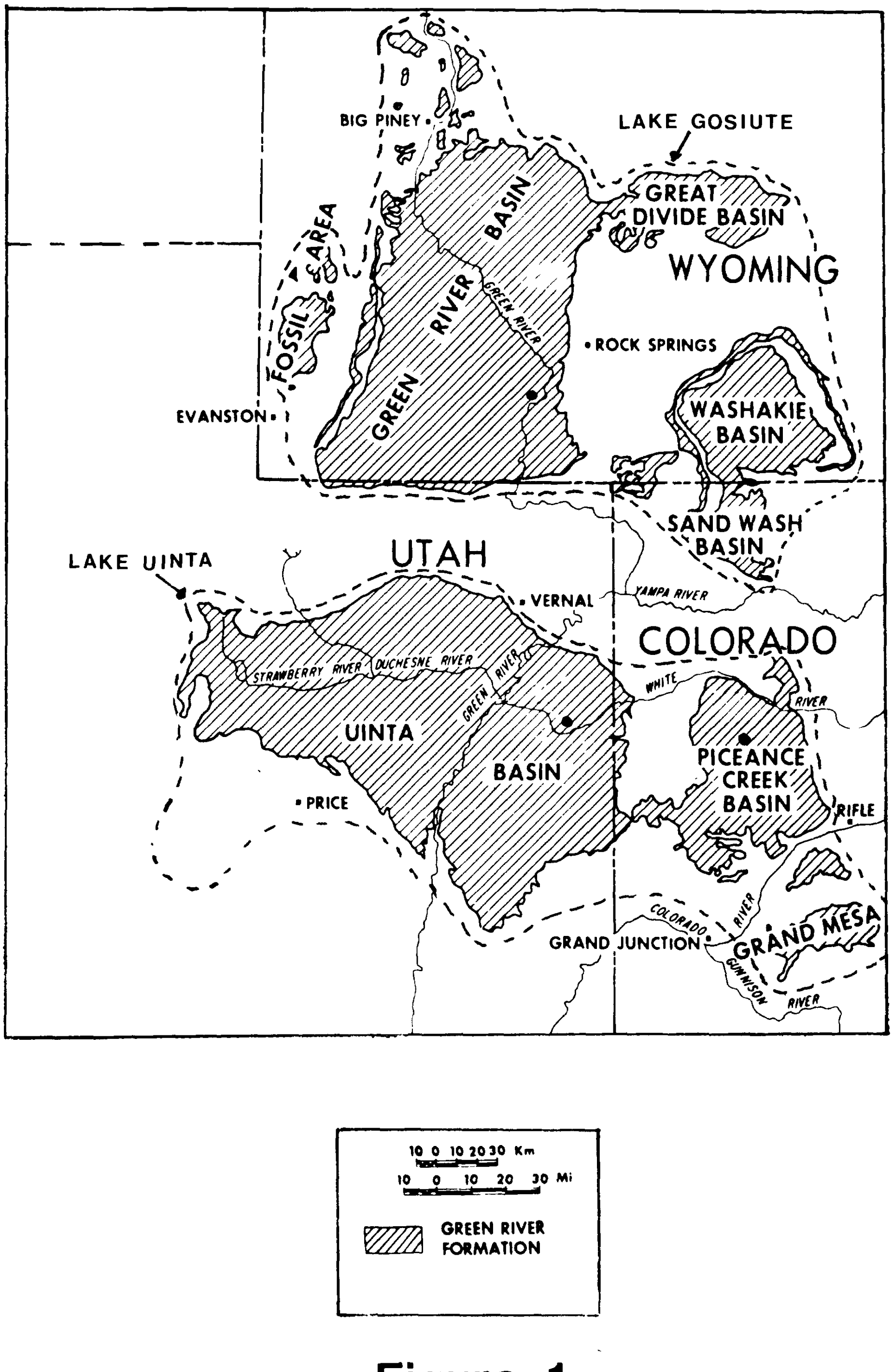
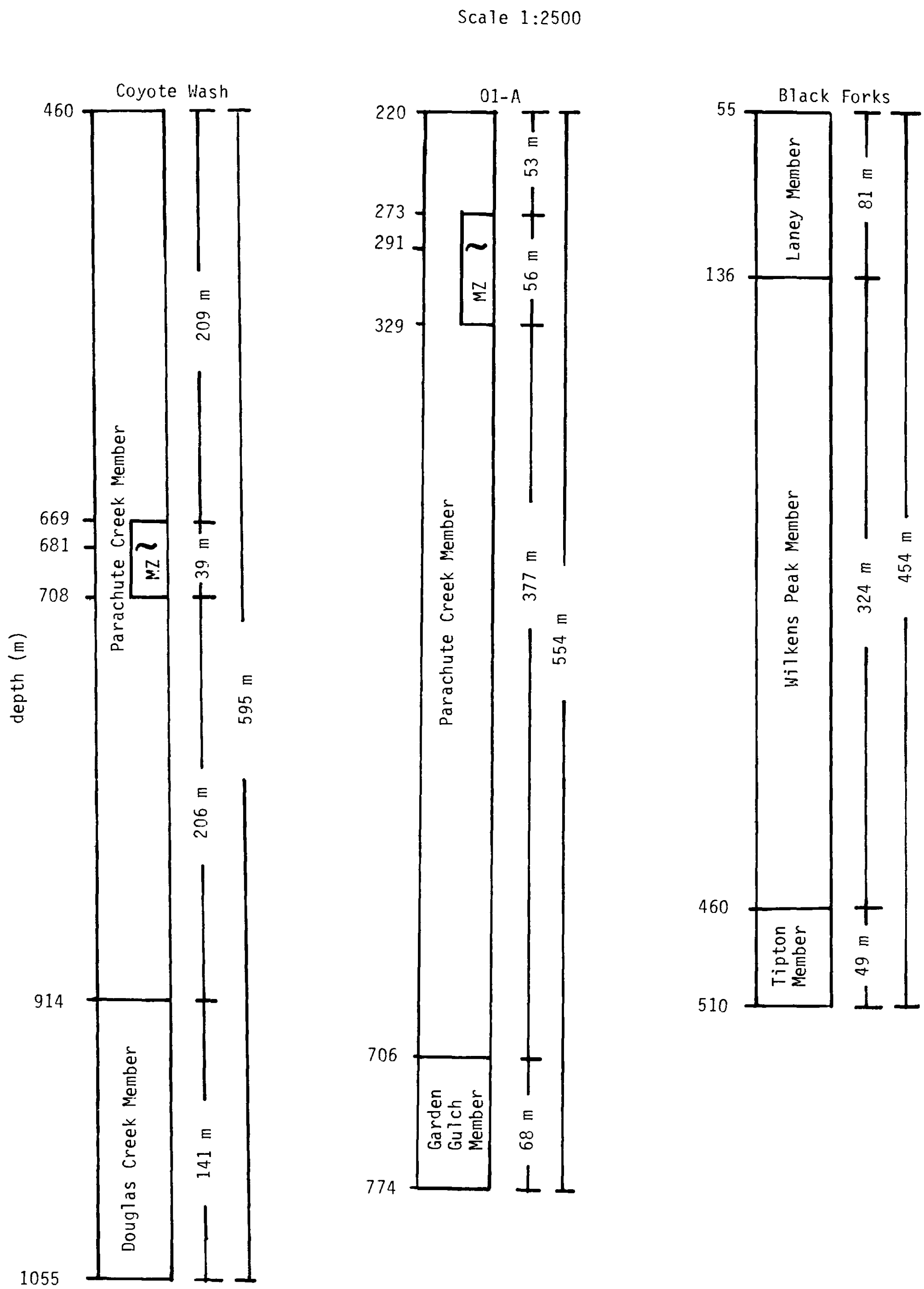
Figures



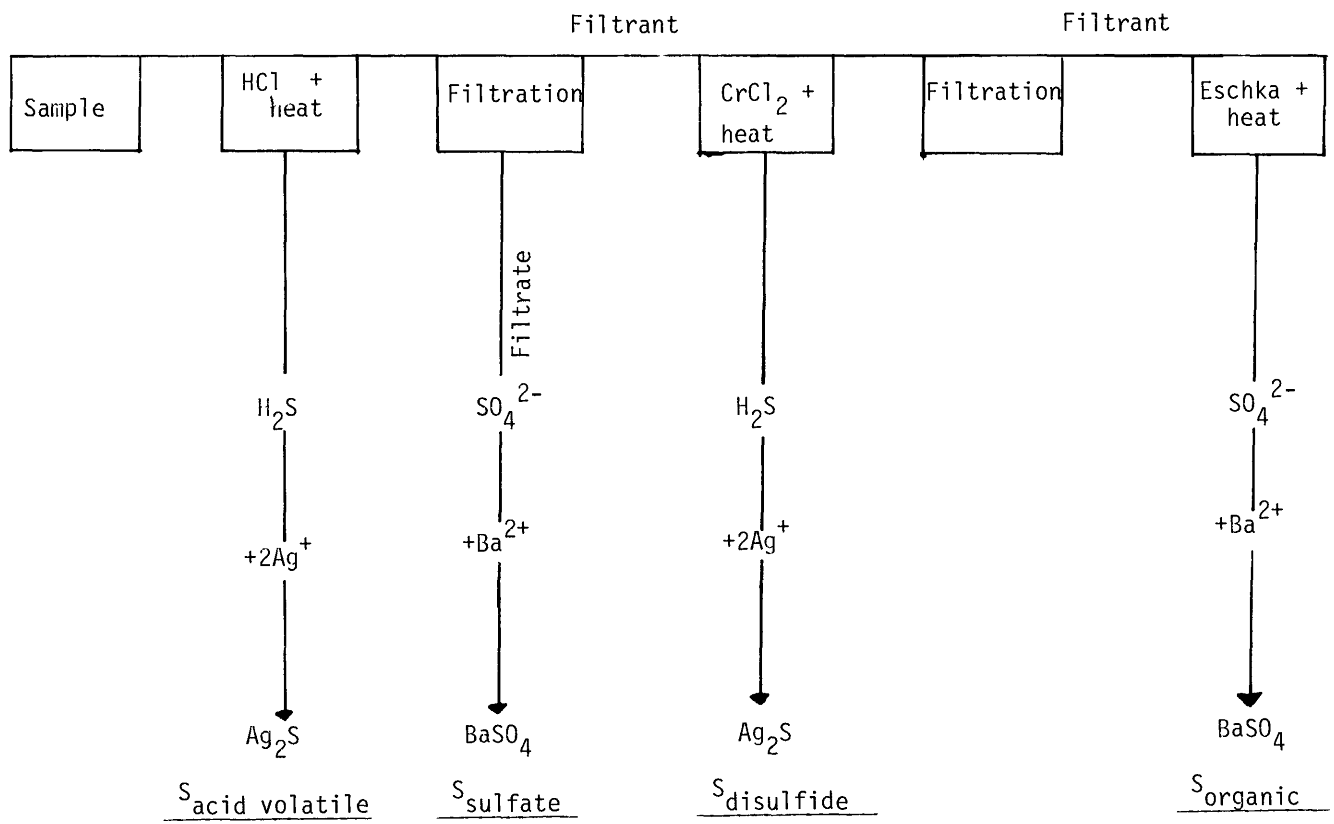
LAKE GOSIUTE
BIG PINEY
GREAT DIVIDE BASIN
WYOMING
FOSSIL AREA
GREEN RIVER BASIN
GREEN RIVER
ROCK SPRINGS
EVANSTON
WASHAKIE BASIN
SAND WASH BASIN
LAKE UINTA
UTAH
VERNAL
YAMPA RIVER
COLORADO
STRAWBERRY RIVER
DUCHESNE RIVER
GREEN RIVER
WHITE RIVER
UINTA
BASIN
PICEANCE CREEK BASIN
PRICE
RIFLE
COLORADO RIVER
GRAND JUNCTION
GRAND MESA
GUNNISON RIVER
10 0 10 20 30 Km
10 0 10 20 30 Mi
GREEN RIVER FORMATION

Figure 1

Figure 2



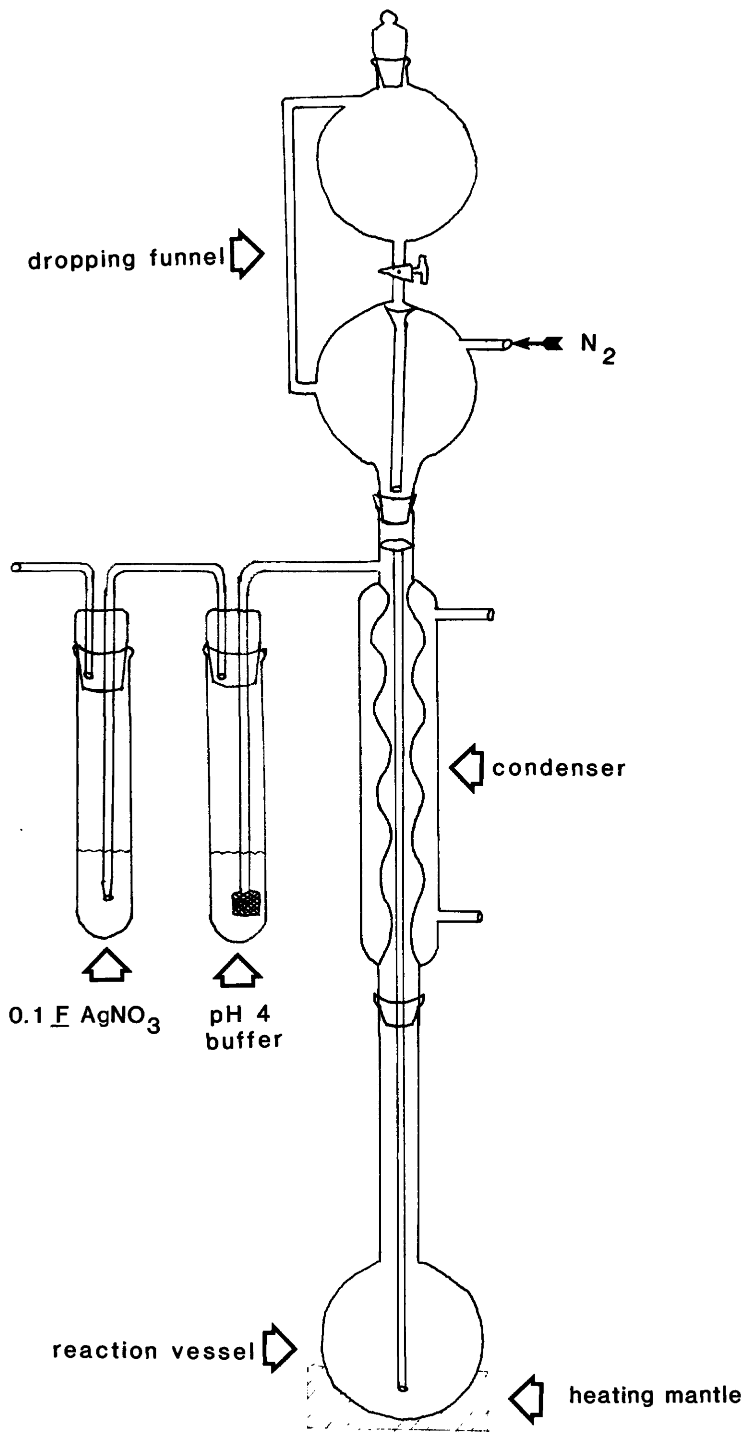
Scale 1:2500
depth (m)
Coyote Wash
460
669
681
708
914
1055
Parachute Creek Member
MZ
Douglas Creek Member
209 m
39 m
206 m
141 m
595 m
01-A
220
273
291
329
706
774
53 m
56 m
377 m
68 m
554 m
Garden Gulch Member
Black Forks
55
136
460
510
Laney Member
Wilkens Peak Member
Tipton Member
81 m
324 m
49 m
454 m



Filtrant
Filtrant
Sample
HCl + heat
Filtration
CrCl2 + heat
Filtration
Eschka + heat
Filtrate
H2S
SO4 2-
H2S
SO4 2-
+2Ag+
+Ba2+
+2Ag+
+Ba2+
Ag2S
BaSO4
Ag2S
BaSO4
S acid volatile
S sulfate
S disulfide
S organic

Figure 3

Figure 4



dropping funnel
N2
condenser
0.1 F AgNO3
pH 4
buffer
reaction vessel
heating mantle

TABLE 1

Macroscopic descriptions and X-ray diffraction mineralogy for: A. 35 samples from the Black Forks core #1 (BF), Wyoming; B. 41 samples from the 01A core (01), Colorado: and C. 39 samples from the Coyote Wash #1 core (CW) Utah. Abbreviations used in the appendix are explained below.

Key to Abbreviations

anal......analcime
aptt......apatite
arag......aragonite
b.........bladed
brec......brecciated
brn.......brown
c.........continuous
cal.......calcareous
calc......calcite
cly.......clay
cr-g......course grained
d.........disseminated
daw.......dawsonite
dk........dark
dol.......dolomitic
dolo......dolomite
ds........distinct
f.........faint
f-gr......fine grained
Fe-dol....iron-rich dolomite
fos.......fossiliferous
grn.......green
gy........gray
hlit......halite
horn......hornblende
ill.......illite
inter....interbedded
Kfld.....potassium feldspar
l........lense
lam......laminated
lt.......light
m........medium
mdst.....mudstone
musc.....muscovite
Nafld....sodium feldspar
Nahc.....nahcolite
nc.......noncontinuous
org......organic-matter rich
ost......ostracods
po.......pyrrhotite
py.......pyrite
qtz......quartz
rd.......red
sh.......shortite
sid......siderite
sltst....siltstone
slty.....silty
ss.......sandstone
sul......sulfides
tr.......trona
tuf......tuffaceous
v........vuggy

A. Black Forks core #1, Green River basin, Wyoming.

Sample	Depth (m)	sul	org	cal	dol	tuf	lam	Color, grain size	Mineralogy
		Sample description							
BF-1	63	d			X	X		lt gy sltst to f-gr ss	qtz,calc,dolo, Kfld,Nafld, anal,py,ill
BF-2	70	d	X	X		X	ds,c	dk brn mdst	qtz,calc,dolo, Kfld,anal,py, ill
BF-3	91	d,l	X	X		X	f,c	m brn mdst	qtz,calc,dolo, Kfld,anal,py, ill
BF-4	98		X		X	X	ds,nc	m grn-m brn mdst	qtz,calc,dolo, Kfld,anal,ill, cly
BF-5	107		X		X		f,c	lt brn mdst	qtz,calc,dolo, Kfld
BF-6	125	d				X	ds,nc	lt-m gy sltst	qtz,calc,Kfld, anal,py,cly
BF-7	135	d,l	X	X			ds,c	m-dk gy-brn mdst	qtz,calc,dolo, Nafld,anal,py
BF-8	144	d,b		X				dk grn mdst-sltst	qtz,dolo,Kfld, sh,po
BF-9	162	d	X		X			m-dk brn mdst	qtz,dolo,Nafld, sh,py
BF-10	180	d	X		X			dk brn mdst	qtz,dolo,sh,py
BF-11	189			X				m grn-gy mdst	qtz,dolo,Kfld, Nafld,sh,ill
BF-12	199	d		X				m grn-gy mdst	qtz,calc,dolo, Kfld,Nafld, sh,py,po,ill
BF-13	217	d		X				m grn mdst	qtz,dolo,Nafld, sh,py,ill,cly

Sample	Depth (m)	Sample description: sul	org	cal	dol	tuf	lam	Color, grain size	Mineralogy
BF-14	235		X	X				m-dk brn mdst	qtz,calc,dolo, Nafld,anal,sh, ill,cly
BF-15	244		X	X			d-c	lt-dk brn mdst	qtz,dolo,Nafld,sh
BF-16	254	d,l				X	d-nc	m grn mdst m br-grn sltst	qtz,calc,dolo, Kfld,Nafld,anal, ill,cly
BF-17	272			X				m grn mdst	qtz,calc,dolo,Kfld, Nafld,anal,ill,cly
BF-18	290			X				dk grn mdst	qtz,calv,dolo,Kfld, Nafld,anal,ill,cly
BF-19	299		X	X			f-c	m brn-grn mdst	qtz,calc,dolo,Nafld, ill
BF-20	3-9							grn slty mdst	qtz,calc,Nafld, anal,ill,cly
BF-21	333	d	X		X		d-c	m brn-grn mdst	qtz,dolo,Kfld, Nafld,sh,py,ill
BF-22	344			X				m grn-gy mdst	qtz,dolo,sh,tr
BF-23	353		X	X		X	f-c	m grn-brn mdst	qtz,dolo,Nafld, anal,cly
BF-24	363		X	X			d-c	dk brn mdst	qtz,dolo,Nafld, sh,ill
BF-25	381	d		X				m grn mdst to m gy slty mdst	qtz,dolo,Kfld, Nafld,sh,tr,py
BF-26	400			X				lt grn mdst	qtz,dolo,Nafld,sh, cly
BF-27	409			X				m grn-gy slty mdst	qtz,dolo,Kfld, Nafld,sh,ill,cly
BF-28	418			X				m grn-gy slty mdst	qtz,dolo,Kfld, Nafld,sh,ill,cly
BF-29	437	d,l		X				m grn mdst	qtz,dolo,Kfld, Nafld,sh,py,ill

Sample	Depth (m)	Sample description sul	org	cal	dol	tuf	lam	Color, grain size	Mineralogy
BF-30	454	d,b		X		X		lt grn-gy slty mdst	qtz,calc,dolo,kfld Nafld,anal,py,po, ill,cly
BF-31	464	d,l	X	X		X	f-nc	lt brn mdst	qtz,calc,Fe-dolo, Kfld,Nafld,anal, py,ill
BF-32	473	d,l	X		X	X	d-c	dk brn mdst	qtz,calc,dolo, Kfld,anal,py,ill
BF-33	491	d	X	X			d-c	dk gy-brn mdst	qtz,calc,dolo, Nafld,sid,py,ill, cly
BF-34	500	d,l	X		X	X	d-c	dk brn ost mdst	qtz,calc,dolo, Kfld,anal,py,ill, cly
BF-35	509	d	X	X				dk brn fos mdst	qtz,calc,arag, Nafld,py,cly

B. 01A core, Piceance basin, Colorado.

Sample	Depth (m)	sul	org	cal	dol	tuf	lam	Color, grain size	Mineralogy
01-6	268		X		X		ds,c	dk brn mdst	qtz,calc,arag,dolo Nafld,anal,cly
01-8	272		X		X		ds,c	lt brn mdst	qtz,dolo,kfld,daw, cly
01-12	285		X		X		ds,c	m brn mdst	qtz,dolo,Kfld,Nafld daw,py,cly
01-14	290		X		X	X	ds,c	dk brn mdst	qtz,calc,dolo,Kfld, Nafld,daw,py,cly
01-18	304		X	X			ds,c	dk brn mdst	qtz,calc,dolo,Kfld, Nafld,anal,py,cly
01-24	321	l,d	X	X			f,dc	m brn mdst, v	qtz,calc,dolo,Kfld, Nafld,anal,ill,cly
01-26	328	d	X	X			f,dc	lt-m brn mdst, v	qtz,calc,dolo,Kfld, Nafld,cly

Sample	Depth (m)	Sample description: sul	org	cal	dol	tuf	lam	Color, grain size	Mineralogy
01-30	340	d	X		X	X	ds,c	m brn mdst	qtz,calc,dolo,Kfld, Nafld,cly
01-36	358		X		X		ds,c	dk brn mdst	qtz,calc,dolo,Kfld, Nafld,ill
01-42	378	d	X		X		ds,c	m brn mdst	qtz,dolo,Kfld,Nafld, anal,ill,cly
01-48	395	d	X		X			brec lt brn mdst	qtz,dolo,Kfld,Nafld py,cly
01-54	415	d	X		X		f,c	dk brn mdst	qtz,dolo,Kfld,Nafld, anal,py,ill
01-59	429	d,b	X	X				inter m brn mdst nahc	qtz,dolo,Kfld,Nafld, anal,daw,nahc,py, ill,cly
01-62	437		X	X				inter dk brn mdst nahc,hlit	qtz,calc,dolo,Nafld,
01-65	448	d,l	X	X			ds,cd	lt brn mdst	qtz,dolo,Kfld,Nafld daw,nahc,py,cly
01-72	468	d	X	X			ds,dc	m brn mdst	qtz,calc,dolo,Kfld, Nafld,daw,nahc,py
01-74	474	l	X	X		X	dsdc	m brn mdst	qtz,calc,dolo,Kfld, Nafld,daw,nach,py, cly
01-78	486	d	X		X		ds,dc	dk brn mdst	qtz,dolo,Kfld,Nafld, daw,py,cly
01-84	504		X	X			ds,dc	dk brn mdst,bedded hlit & nahc	qtz,calc,dolo,Nafld, daw,nahc,hlit,cly
01-86	510	d	X	X				dk brn mdst	Qtz,dolo,Kfld,Nafld, daw,nahc,hlit,py,cly
01-89	521	d		X			ds,c	f-gr nahc,lt br mdst	qtz,dolo,Nafld,daw nahc,hlit,ill,cly
01-96	541		X		X		ds,c	dk brn mdst	qtz,dolo,Kfld,Nafld, daw,py,cly
01-98	547	l	X		X			dk brn mdst	qtz,dolo,Kfld,Nafld, daw,py,cly

Sample	Depth (m)	Sample description: sul	org	cal	dol	tuf	lam	Color, grain size	Mineralogy
01-102	559	d,l	X		X		ds,dc	dk brn mdst	qtz,dolo,Kfld,daw, py,cly
01-108	578		X	X			ds,dc	lt-m brn mdst	qtz,calc,dolo,Kfld, daw,py
01-110	583	d	X	X				cr-gr nahc,dk brn mdst	qtz,dolo,nahc,ill, cly
01-113	595	l	X		X			dk brn mdst	qtz,dolo,Kfld,Nafld, daw,py,cly
01-120	614		X	X				cr-gr nahc,dk brn mdst	qtz,dolo,Kfld,Nafld, daw,nahc,ill
01-123	625	d	X		X		ds,c	dk brn mdst	qtz,dolo,Kfld,Nafld daw,py
01-126	632			X				cr-gr nahc	qtz,daw,nahc,ill,cly
01-132	651		X	X			ds,c	inter nahc,m brn mdst	qtz,dolo,Kfld,Nafld daw,nahc,cly
01-134	657	d	X	X				dk brn mdst	qtz,calc,dolo,Kfld, Nafld,daw,nahc,py,cl
01-138	669		X		X			lt brn mdst	qtz,dolo,Kfld,Nafld, daw,py,cly
01-144	687	d	X	X				cr-gr nahc, m brn mdst	qtz,dolo,Kfld,Nafld, nahc,py,cly
01-150	705		X	X			ds,c	dk brn-gy mdst	qtz,calc,dolo,Nafld py,ill
01-154	717		X	X			ds,c	dk brn mdst	qtz,dolo,Nafld,py, ill
01-155	728	l	X	X			ds,c	dk brn-gy mdst	Qtz,dolo,Nafld,py, ill,aptt
01-162	743		X	X				dk gy-brn mdst	qtz,dolo,Kfld,Nafld, py,ill,cly,aptt
01-165	755	d	X		X		f,c	dk brn mdst	qtz,dolo,Nafld,py, ill,cly,aptt
01-168	760		X	X			ds,c	m gy-brn ost mdst	qtz,calc,dolo,py,ill
01-172	773		X		X		f,c	m gy-brn mdst	qtz,dolo,Nafld,py, ill,aptt

C. Coyote Wash #1 core, Uinta basin, Utah.

Sample	Depth (m)	Sample description sul	org	cal	dol	tuf	lam	Color, grain size	Mineralogy
CW-38	571	d	X		X		ds,c	lt-m brn mdst	qtz,calc,dolo,Nafld, sid
CW-37	587	d	X		X		ds,c	m brn mdst	qtz,calc,dolo,Nafld, ill
CW-36	597		X		X		ds,c	m-dk brn mdst	qtz,calc,dolo,Kfld, Nafld,sid,ill
CW-35	606	d	X	X		X	ds,c	m-dk brn mdst	qtz,calc,dolo,Nafld
CW-34	624	d	X		X		ds,c	dk brn mdst	qtz,calc,dolo,Nafld, daw,sid,py,ill
CW-33	642	d	X		X	X	ds,c	m rd, m brn mdst	qtz,calc,dolo,Kfld, Nafld,daw,py
CW-32	652	d	X		X	X	f,dc	m-dk brn mdst	qtz,calc,dolo,Nafld, daw,py,cly
CW-31	661	d	X	X			f,dc	m-dk brn mdst	qtz,calc,dolo, Kfld,Nafld,py
CW-30	670		X		X		ds,dc	m brn mdst	qtz,calc,dolo,Nafld, daw,sid
CW-29	681	l	X		X	X	ds,dc	dk brn mdst (Mahogany bed)	qtz,calc,dolo, Nafld,py
CW-28	697		X	X				lt brn mdst	qtz,calc,dolo, Kfld,Nafld,anal,ill
CW-27	706	d	X		X		ds,c	m-dk brn mdst	qtz,calc,dolo,Kfld, Nafld,anal,ill
CW-26	716		X		X		ds,c	lt-m brn mdst	qtz,calc,dolo, Nafld
CW-25	726	d	X		X		ds,dc	lt brn mdst	qtz,calc,dolo,Kfld, Nafld,anal,daw,ill
CW-24	734	d	X		X		ds,c	lt-m brn mdst	qtz,calc,dolo,Kfld, Nafld,daw
CW-23	752	d	X		X		ds,c	m brn mdst	qtz,calc,dolo,Kfld, Nafld,anal,sid,py, ill

Sample	Depth (m)	Sample description sul	org	cal	dol	tuf	lam	Color, grain size	Mineralogy
CW-22	762		X	X				lt brn mdst	qtz,calc,dolo,Kfld, Nafld,daw
CW-21	771	d,b	X		X			m brn mdst	qtz,calc,dolo,Kfld, Nafld,anal,daw,sid, ill
CW-20	789	d	X		X		ds,c	m brn mdst	qtz,dol,Kfld, Nafld,anal,ill
CW-19	807	d	X		X		f,c	lt gr mdst	qtz,calc,dolo,Kfld, Nafld,daw,musc
CW-18	815	d,b	X		X		ds,c	lt m brn mdst	qtz,calc,dol, Kfld,Nafld,anal,ill
CW-17	825		X	X			ds,c	lt-m brn mdst	qtz,calc,dolo,Kfld, anal,ill,cly
CW-16	843	d	X		X		ds,dc	m-dk brn mdst	qtz,calc,dolo,Klfd, Nafld,anal,py,ill, cly
CW-15	862		X		X		ds,c	lt grn, gr mdst	qtz,calc,dolo,Kfld, Nafld,anal,horn,ill, cly
CW-14	871	d	X		X		ds,c	lt-m brn mdst	qtz,calc,dolo,Kfld, Nafld,anal,ill,cly
CW-13	880	d,l	X		X		f,dc	dk brn mdst	qtz,dolo,Kfld,anal, py,ill
CW-12	898		X		X		ds,dc	lt-m brn ost mdst	qtz,calc,dolo,Kfld, Nafld,anal,ill
CW-11	908		X		X		ds,c	m gr-brn mdst	qtz,calc,dolo, Kfld,Nafld,anal,ill
CW-10	917	d	X	X			ds,dc	m gr-m brn mdst	qtz,calc,dolo, Kfld,Nafld,anal, py,ill,cly
CW-9	926			X				m gr mdst	qtz,calc,dolo,Kfld, Nafld,anal,ill,cly

Sample	Depth (m)	Sample description						Color, grain size	Mineralogy
		sul	org	cal	dol	tuf	lam		
CW-8	935	d			X			dk grn gr slty mdst	qtz,calc,dolo,Kfld Nafld,anal,py,ill, cly
CW-7	953				X			m brn-gr mdst	qtz,calc,dolo,Kfld, Nafld,anal,ill,cly
CW-6	971	d		X			ds,c	m-lt gr slty mdst	qtz,calc,dolo, Kfld,Nafld,anal py,ill,cly
CW-5a	981			X				m gr slty mdst	qtz,calc,dolo,Kfld, Nafld,anal,sid,ill, cly
CW-5	990		X	X			ds,dc	m brn mdst	qtz,calc,dolo,Kfld, Nafld,anal,ill,cly
CW-4	1008			X				lt gr sltst	qtz,calc,dolo,Kfld, Nafld,anal,ill
CW-3	1026		X	X			ds,c	m brn mdst	qtz,calc,dolo,arag, Nafld,ill,cly
CW-2	1035			X		X		m gr brn mdst-sltst	qtz,calc,dolo,Kfld, Nafld,anal,sid,ill, cly
CW-1	1043	d	X		X		f,dc	dk-m brn mdst	qtz,dolo,Kfld, Nafld,anal,py,ill

TABLE 2

Chemical data for Green River Formation samples: A. 35 from the Black Forks core #1, Wyoming; B. 41 from the 01A core, Colorado; and C. 39 from the Coyote Wash #1 core, Utah. Abbreviations used in the table are explained below.

Key to Abbreviations

m........meters

S_{tot}.....total sulfur

S_{SO4}.....sulfate

S_{av}......acid-volatile sulfur

S_{di}......disulfide

S_{org}.....organically-bound sulfur

C_{CO3}.....carbonate carbon

C_{org}.....organic carbon

Fe_r......reactive iron

A. Black Forks core #1, Wyoming

Sample	depth(m)	$\%S_{tot}$	$\%S_{SO4}$	$\%S_{AV}$	$\%S_{PY}$	$\%S_{ORG}$	$\%C_{CO3}$	$\%C_{ORG}$	$\%Fe_r$
BF-1	63	1.8	0.15	0.02	1.4	0.02	2.1	0.39	2.9
BF-2	70	1.2	.05	<.01	.65	.26	5.6	6.5	.93
BF-3	91	1.5	.12	<.01	1.1	.15	5.1	4.9	2.0
BF-4	98	.56	.03	<.01	.36	.20	4.4	8.3	1.9
BF-5	107	.79	.16	.01	.27	.26	7.2	8.8	1.2
BF-6	125	1.2	.34	.01	.65	.14	.24	4.1	1.2
BF-7	135	1.1	.04	<.01	.87	.12	7.7	7.0	.93
BF-8	144	.61	<.01	.34	.17	.03	6.2	1.5	1.3
BF-9	162	.68	<.01	<.01	.38	.18	7.9	8.2	.67
BF-10	180	.75	<.01	<.01	.09	.02	6.9	9.7	.43
BF-11	189	.60	<.01	<.01	.51	.04	7.2	2.2	.90
BF-12	199	.75	<.01	.01	.61	.03	7.3	1.5	1.3
BF-13	217	1.2	<.01	<.01	1.0	.06	7.2	2.8	1.5
BF-14	235	.02	<.01	<.01	.01	.02	9.9	.99	.56
BF-15	244	.02	<.01	<.01	<.01	.01	11	.70	.39
BF-16	254	.32	.01	.07	.18	.01	1.2	.19	3.2
BF-17	272	.18	<.01	<.01	.17	.01	5.4	.15	1.7
BF-18	290	.02	<.01	<.01	<.01	<.01	5.7	.14	1.7
BF-19	299	.25	<.01	<.01	.19	.04	7.7	4.1	.87
BF-20	308	.02	<.01	<.01	.01	.01	1.1	.14	3.2
BF-21	333	.97	<.01	<.01	.83	.04	7.6	3.3	1.7
BF-22	344	.51	<.01	<.01	.39	.01	9.1	.58	.77
BF-23	353	.32	<.01	.01	.22	.10	7.1	8.3	1.2
BF-24	363	.02	.02	<.01	.01	.01	8.1	1.2	1.4
BF-25	381	.97	.08	<.01	.77	.01	2.3	.12	2.5

Sample	depth(m)	%S_{tot}	%S_{SO4}	%S_{AV}	%S_{PY}	%S_{ORG}	%C_{CO3}	%C_{ORG}	%Fe
BF-26	400	.26	.02	<.01	.21	<.01	7.6	.49	1.2
BF-27	409	.13	<.01	<.01	.10	.03	4.7	2.9	1.5
BF-28	418	.86	.08	<.01	.56	.12	6.0	1.2	2.5
BF-29	437	8.5	.06	.01	7.4	<.01	2.7	1.3	8.4
BF-30	454	.97	.06	.80	<.01	.02	4.5	.47	3.9
BF-31	464	1.1	<.01	.02	.87	.16	2.3	12	2.7
BF-32	473	1.7	<.01	<.01	1.4	.13	3.2	7.3	2.2
BF-33	491	2.2	.06	<.01	1.9	.30	3.9	5.8	2.3
BF-34	500	1.5	<.01	<.01	1.1	.23	7.0	11	1.3
BF-35	509	2.8	.07	<.01	1.7	.15	7.4	2.5	1.9
B. 01A core, Colorado									
01-6	268	0.71	.04	<.01	.54	.18	6.0	9.6	1.6
01-8	272	.25	.03	<.01	.18	.03	4.3	1.3	2.7
01-12	285	.38	.01	<.01	.33	.07	5.6	5.4	2.4
01-14	290	2.0	.08	.01	1.4	.64	2.6	34	1.4
01-18	304	.83					7.2	13	
01-24	321	.55					6.4	10	
01-26	328	.59	<.01	<.01	.52	.08	7.5	7.5	1.3
01-30	340	1.5					5.3	14	
01-36	358	1.3					5.3	23	
01-42	378	.61	.03	.20	.32	.06	3.8	10	3.1
01-48	395	2.5					4.5	7.0	
01-54	415	5.0					2.2	5.6	
01-59	429	1.1	.04	<.01	.85	.22	12	5.6	1.6
01-62	437	.24					7.4	18	

Sample	depth(m)	$\%S_{tot}$	$\%S_{SO4}$	$\%S_{AV}$	$\%S_{PY}$	$\%S_{ORG}$	$\%C_{CO3}$	$\%C_{ORG}$	%Fe
01-65	448	.90	.13	.01	.69	.14	6.3	10	1.5
01-72	468	1.3					5.3	13	
01-74	474	.93					5.2	11	
01-78	486	1.4	.08	<.01	1.3	.27	4.9	11	2.4
01-84	504	.78					4.7	7.4	
01-86	510	2.4					4.7	14	
01-89	521	.42	.07	.01	.24	.03	7.4	1.2	.95
01-96	541	1.2	.06	<.01	.97	.12	6.7	6.8	2.4
01-98	547	1.6	.45	.03	.42	.28	4.5	12	1.8
01-102	559	1.4					5.8	15	
01-108	578	.94					5.2	17	
01-110	583	.38					13	.94	
01-113	595	1.8	.42	.08	.93	.23	5.6	14	2.3
01-120	614	1.2					8.9	11	
01-123	625	1.4					3.8	8.9	
01-126	632	.08	.01	<.01	.06	.01	14	.55	.07
01-132	651	.47					8.6	8.5	
01-134	657	1.2	.39	.02	.32	.47	4.9	13	1.7
01-138	669	.52					7.3	17	
01-144	687	11	4.6	.59	4.7	1.3	5.7	6.2	8.8
01-150	705	.93	.06	<.01	1.1	.18	5.0	22	1.5
01-154	717	1.5	.01	.02	.85	.15	1.5	12	1.9
01-155	728	1.7					1.3	12	
01-162	743	3.7					1.8	14	
01-165	755	2.5	.01	.01	1.9	.23	2.9	8.6	3.5
01-168	760	.83					6.2	3.2	

Sample	depth(m)	$\%S_{tot}$	$\%S_{SO4}$	$\%S_{AV}$	$\%S_{PY}$	$\%S_{ORG}$	$\%C_{CO3}$	$\%C_{ORG}$	%Fe
01-172	773	.73	<.01	<.01	.59	.07	6.5	3.7	2.1

C. Coyote Wash #1 core, Utah

CW-38	571	0.95	<.01	<.01	.66	.03	4.7	3.4	2.4
CW-37	587	.46					5.2	3.5	
CW-36	596	.08	<.01	<.01	.01	.05	7.3	6.6	1.6
CW-35	606	.07					6.3	6.2	
CW-34	624	.25	<.01	.05	.16	.08	5.2	11	1.6
CW-33	642	.63					3.8	7.2	
CW-32	652	.79	<.01	<.01	.70	.08	6.3	8.2	1.5
CW-31	661	0.36	<.01	0.03	0.30	0.08	6.5	5.2	.90
CW-30	670	.30					4.7	26	
CW-29	681	1.8	.23	<.01	.76	.69	7.0	26	2.3
CW-28	697	.04	<.01	<.01	<.01	.04	8.5	2.5	1.6
CW-27	706	.10					2.9	4.9	
CW-26	716	.02	<.01	<.01	.01	.03	4.6	2.1	3.5
CW-25	725	.50	.06	<.01	.39	.03	4.2	.92	1.8
CW-24	734	.35	<.01	<.01	.31	.04	8.0	3.2	1.4
CW-23	752	1.0	<.01	<.01	.93	.08	6.4	4.9	2.0
CW-22	762	.02					8.6	2.4	
CW-21	771	.25	<.01	.05	.17	.04	2.7	2.8	2.8
CW-20	789	1.8	<.01	1.0	.64	.10	2.5	7.4	3.6
CW-19	807	.89	.04	<.01	.72	.02	6.2	.74	1.4
CW-18	815	1.1	.02	.67	.29	.03	4.6	1.0	3.0
CW-17	825	.13	<.01	<.01	.01	.09	5.3	8.6	1.0