Geochemistry of Two Interbeds in the Pennsylvanian Paradox Formation, Utah and Colorado—A Record of Deposition and Diagenesis of Repetitive Cycles in a Marine Basin

U.S. GEOLOGICAL SURVEY BULLETIN 2000-N

Cover. View south toward the La Sal Mountains along the Colorado River between Cisco and Moab, Utah. Fisher Towers in center is composed of Permian Cutler Formation and capped by Triassic Moenkopi Formation. The prominent meas at left center is capped by Jurassic Kayenta Formation and Wingate Sandstone and underlain by slope-forming Triassic Chinle and Moenkopi Formations. The Chinle-Moenkopi contact is marked by a thin, white, ledge-forming gritstone. The valley between Fisher Towers and Fisher Mesa in the background is part of Richardson Mesa, part of Professor Valley. Photograph by Omer B. Raup.

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EVOLUTION OF SEDIMENTARY BASINS—PARADOX BASIN
A.C. Huffman, Jr., Project Coordinator

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By Michele L. Tuttle,[1] Timothy R. Klett,[1] Mark Richardson,[2] *and* George N. Breit[1]

ABSTRACT

During the Pennsylvanian Period, repetitive cycles of marine evaporite, carbonate, and siliciclastic rocks were deposited in the Paradox Basin of Utah and Colorado. The carbonate (dolostone and limestone) and siliciclastic (siltstone and shale) rocks comprise interbeds bounded above and below by anhydrite and halite. The interbeds host petroleum source rocks, and shallow-marine carbonate rocks within the interbeds on the southwestern platform of the basin are reservoirs for generated hydrocarbons. The variability in the geochemistry of sulfur, carbon, and metals in the shale, carbonate rocks, siltstone, and anhydrite is related to areal and temporal changes in processes related to a distinct set of conditions that controlled the source of the organic matter and clastic material, seawater circulation, sedimentation rate, and water-column/sediment redox conditions.

At the onset of transgression, circulation was good in the upper part of the water column, but a bottom brine was present in the deeper parts of the basin due to dissolution of evaporite minerals. Primary productivity in the upper part of the water column was not high, and a large part of the organic matter in the sediment was terrestrial in origin. The anoxic nature of the brine promoted sulfide mineral formation at the sediment-water interface and retention in the sediment of metals such as chromium and nickel. Plagioclase was diagenetically altered to potassium feldspar as a result of high potassium content in the brine. As transgression proceeded, the water column mixed, diluting the brine and partially oxygenating the bottom water. Productivity increased, and reworking of organic matter at the sediment-water interface released phosphorous, now available for apatite formation, and some of the adsorbed metals. The redox front moved into the sediment where sulfide minerals formed. The best petroleum source rocks were deposited during this later phase.

INTRODUCTION

The Middle Pennsylvanian Paradox Formation of the Hermosa Group in southeastern Utah and southwestern Colorado (fig. 1) comprises repetitive sequences, each composed of evaporite, carbonate, and siliciclastic units; these sequences are referred to hereafter as cycles (Hite, 1970). The areal and vertical distribution of rock types within these cycles (figs. 2 and 3) reflects the interaction of eustasy, tectonics, and local climate. Interbeds of carbonate and shale with minor siltstone and sandstone are bounded above and below by anhydrite and halite. Many of the shale units of the interbeds are petroleum source rocks that can be stratigraphically correlated throughout the basin (fig. 3) and, in the past, have been interpreted as time-correlative units (Hite and Buckner, 1981). Production of hydrocarbons generated from these shales exceeds 54 million metric tons of oil and 28 billion m^3 of gas (Baars and Stevenson, 1982).

In this report, we present chemical, sulfur isotopic, and mineralogical data for 159 samples for 13 cores from laterally persistent interbeds within two cycles in the upper part of the Paradox Formation—cycle 3, in the Ismay oil-producing interval, and cycle 5, in the Desert Creek oil-producing interval. Oil-producing intervals are described in Hite and Buckner (1981). Lateral and vertical changes in geochemistry of the interbeds within and between the two cycles are

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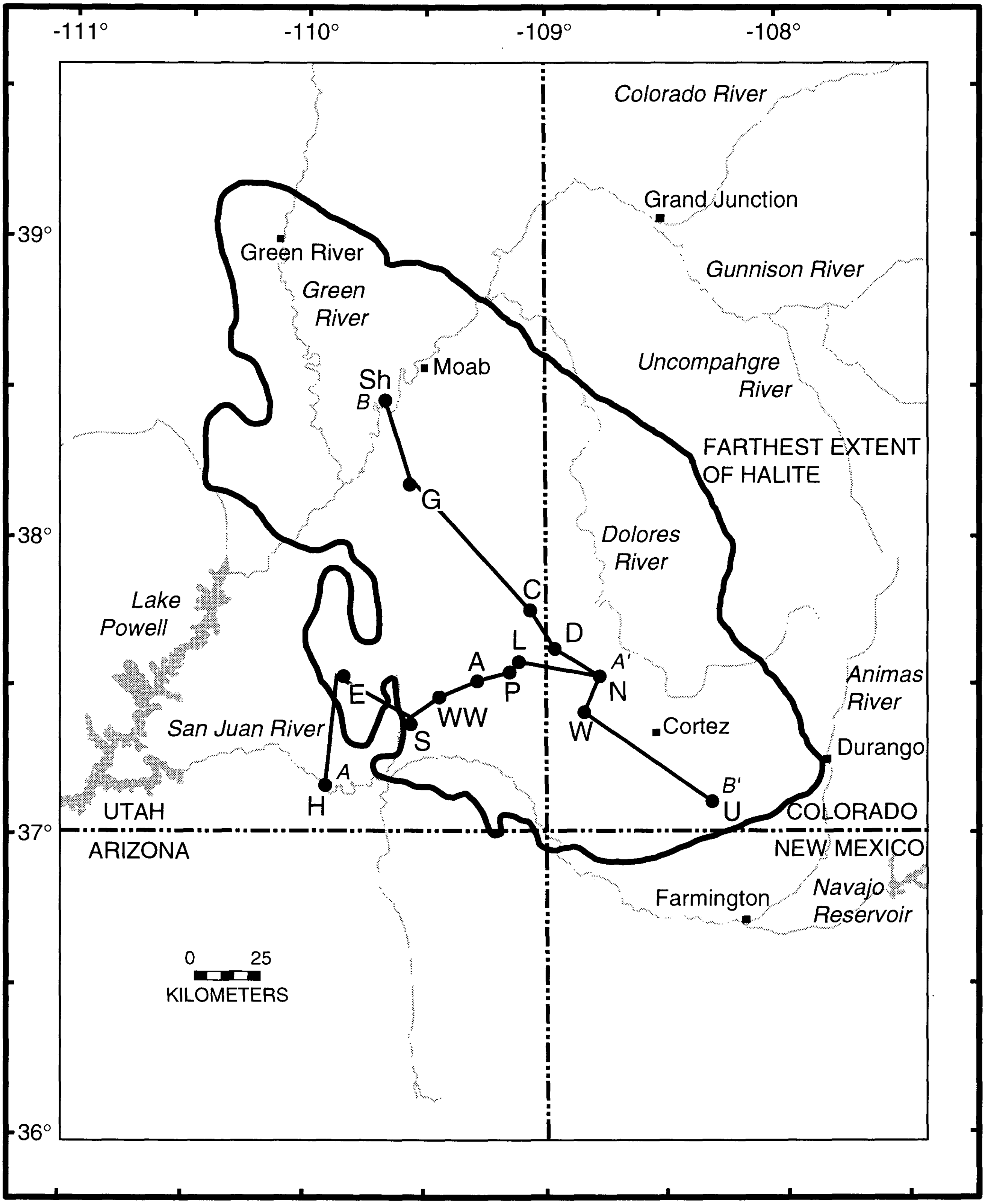

Figure 1. Location of core holes and outcrops (solid circles) used in study, and transects *A-A′* and *B-B′*, Paradox Basin. Sampling information is given in table 1. Heavy line delineates boundary of Paradox Basin as defined by approximate limit of the halite facies in the Pennsylvanian Paradox Formation. Sh, Shafer No. 1; G, Gibson Dome No. 1; C, Crowley Ranch No. 1; D, Duncan Tevault No. 1; N, Norton-Federal No. 1-4; W, Woods Unit No. 1-S; U, Ute Mountain No. 44-34; L, Lake Canyon Prospect Federal No. 1-27; P, Pickett Federal No. 1-33; A, Aztec Federal No. 1; WW, West Water Creek No. 1; S, State No. 1-16; E, Elk Ridge No. 1; H, Honaker Trail outcrop. Modified from Raup and Hite (1992).

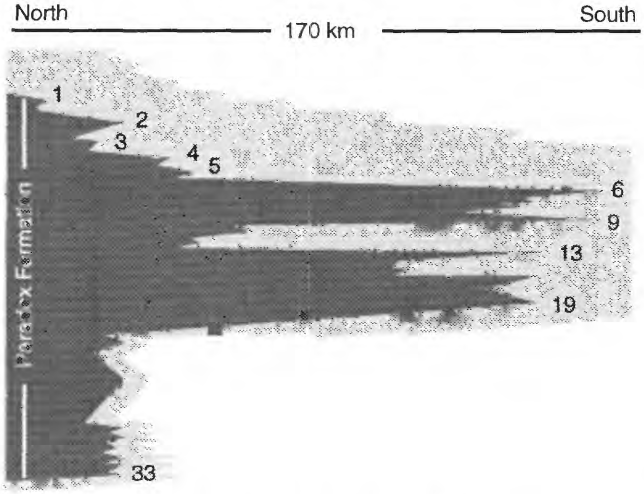

Figure 2. North-south cross section in the Paradox Basin of the Pennsylvanian Paradox Formation showing the extent of halite (dark shading) and carbonate (light shading) units. Selected cycles are numbered. Modified from Hite (1970).

used to identify geochemical processes during formation of the interbeds. A comparison of these processes with the detailed geochemical variability within a basin-center core helps to place the processes into a stratigraphic framework. The results of these two exercises are used to infer conditions of deposition and diagenesis of the shales within the interbeds to help understand formation of the source rocks of the Paradox Formation.

Acknowledgments.—EXXON Production Research provided the organic pyrolysis analyses, and Robert Rye of the U.S. Geological Survey (USGS) provided access to his isotope laboratory. Paradox Basin researchers of the USGS and outside organizations are acknowledged for sharing their observations and insights regarding the stratigraphy and geochemistry of the evaporites and their interbeds. This report has greatly benefited from the constructive reviews of Joseph Hatch and Robert Zielinski. The work on which this report is based was funded by the U.S. Geological Survey Evolution of Sedimentary Basins Program.

MIDDLE PENNSYLVANIAN PARADOX FORMATION

The Paradox Basin is a northwest-trending structural depression that formed as a result of continent-continent collisions along the southern and southeastern margins of North America (Huffman and Condon, 1993). During the Middle Pennsylvanian, alternation of seawater incursions into the basin and periods of evaporitic conditions resulted in deposition of 33 evaporite-carbonate-siliciclastic cycles (Hite, 1960; Hite and Buckner, 1981; Huffman and Condon, 1993; Williams-Stroud, 1994). Circulation into the basin from the open ocean was restricted by surrounding uplifts (Peterson and Hite, 1969; Mallory, 1975) and by the large Four Corners carbonate platform to the south. The dominant ocean accessways were the Cabezon seaway to the southeast (Wengerd, 1962) and a seaway between the Emery and Uncompahgre uplifts to the north (Szabo and Wengerd, 1975); minor accessways may have been present to the west. Circulation through these seaways was controlled by tectonics and (or) eustasy (Huffman and Condon, 1993).

During periods when ocean circulation was shut off, beds of evaporites formed, first anhydrite, then halite, and finally sylvite and carnallite. These minerals previously were thought to have formed through the evaporation of seawater; however, recent work shows that chemical paragenesis of the Paradox Formation evaporites is inconsistent with a simple seawater origin and may reflect a large meteoric water contribution during evaporitic periods (see Williams-Stroud, 1994, for discussion of the origin of the Paradox Formation evaporites).

For any one Paradox Formation cycle, the extent of rock types in the cycle varies from basin center to basin margin (fig. 3). In the deeper parts of the basin, halite (plus or minus potash salts) is present and is the most saline mineral assemblage observed (Hite, 1983). Removal of halite by dissolution has occurred intermittently throughout the basin (Hite and Buckner, 1981; Kendall, 1987) and, in part, may be responsible for the present-day distribution of halite. In this report, as in many others, the farthest extent of preserved bedded halite (fig. 2) (salt cycle 6 of Hite, 1961) is used to define the extent of the Paradox Basin (fig. 1). The areal distribution of anhydrite in any given cycle extends past the boundary of the halite but, for the two cycles studied, is within the cycle-6 halite boundary (fig. 1). Carbonate-siliciclastic interbeds between the halite and anhydrite comprise siltstone; dolostone; limestone; and argillaceous, dolomitic, and calcareous shale. Near the basin margins, no evaporites were deposited, and the sequence is dominantly a limestone succession with argillaceous and calcareous shale. The basin margin was a carbonate shelf that was exposed subaerially and eroded to varying degrees during evaporite deposition within the deeper parts of the basin. Arkose in the northern end of the basin formed from siliciclastic detritus shed off the ancestral Uncompahgre highland.

The areal distribution of arkose, halite, anhydrite, and carbonate in cycles 3 and 5 as shown in figure 4 is based on core data (Reid and Berghorn, 1981). The maps of figure 4 show the extent of lithofacies preserved from the regressive part of the cycle. The preserved halite facies of cycle 5 (fig. 4*A*) is less areally extensive than the maximum extent of preserved halite in the basin (heavy line, fig. 4). The anhydrite facies of cycle 5 is present throughout most of the basin. The areal extent of the halite and anhydrite facies of cycle 3 (fig. 4*B*) is much smaller than that of cycle 5.

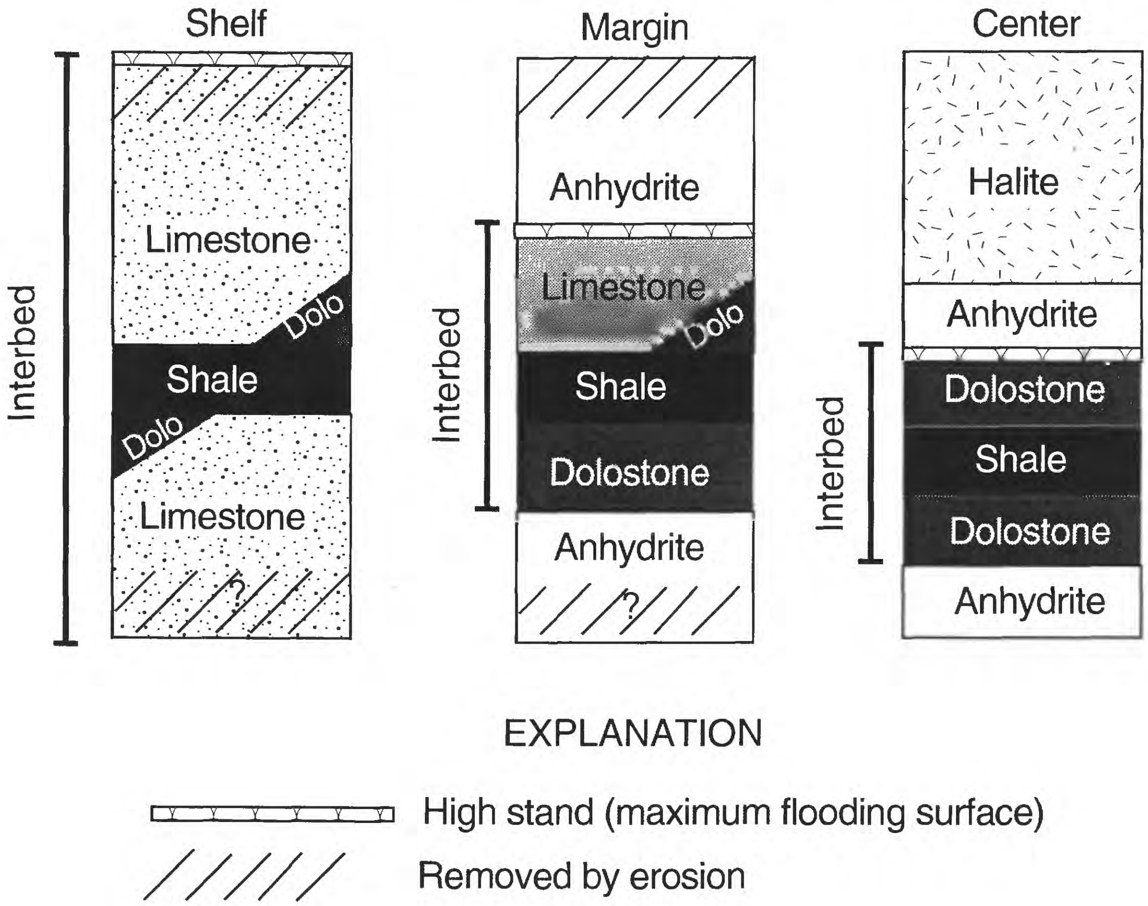

Figure 3. Generalized rock types in idealized cycles from the basin center, basin margins, and shelf. Dolo, dolostone.

The thickness of the interbeds of cycles 3 and 5 vary as shown in the isopach maps of figure 5. The interbed of cycle 5 (fig. 5*A*) thickens to 9 m (30-ft contour) in the southwestern part of the basin, and slightly thicker areas (as thick as 12 m, 40-ft contour) of small extent are present in the eastern part of the basin. The interbed of cycle 3 (fig. 5*B*) is generally much thicker (as thick as 61 m, 200-ft contour) than that of cycle 5 and is thickest near the Uncompahgre highland.

METHODS

SAMPLING METHODS

We collected 151 samples from interbeds of cycles 3 and 5 in 13 cores and 1 sample from an outcrop location that represents the southwesternmost part of the Paradox Formation accessible for sampling. Seven anhydrite samples from above and below the interbeds were collected in cores containing the evaporite facies. Well locations, API numbers, sampled intervals, and number of samples collected are summarized in table 1, and well locations are shown in figures 1, 4, and 5. All of the wells are within the boundary of the basin as defined by the farthest extent of halite (fig. 1). The wells are distributed along two intersecting transects that form a sideways "T" within the basin (fig. 1). The transects for each cycle are slightly different (compare figs. 4*A* and 4*B*); however, areal coverage for each cycle is believed to characterize the nature of basinwide variation in measured geochemical parameters. The southwest-to-northeast transect (*A-A′*, fig. 1) is perpendicular to the Uncompahgre trough (a structural depression along the northeastern margin of the basin that parallels the ancestral Uncompahgre uplift) (Hite, 1968). This transect extends from the carbonate shelf, across the anhydrite facies, to the halite facies near the trough (fig. 4). The northwest-to-southeast transect (*B-B′*, fig. 1) parallels the trough and extends from the halite facies, across the anhydrite facies, to the shelf (fig. 4). Samples in the latter transect were not collected from within or northeast of the trough because sequences have been severely disrupted by salt diapirism.

Gamma-ray logs, lithofacies descriptions, and sample distribution within the 13 sampled core intervals are presented in Appendix 1. Sampling density was based on the thickness of the interbed in the core and on the thickness and

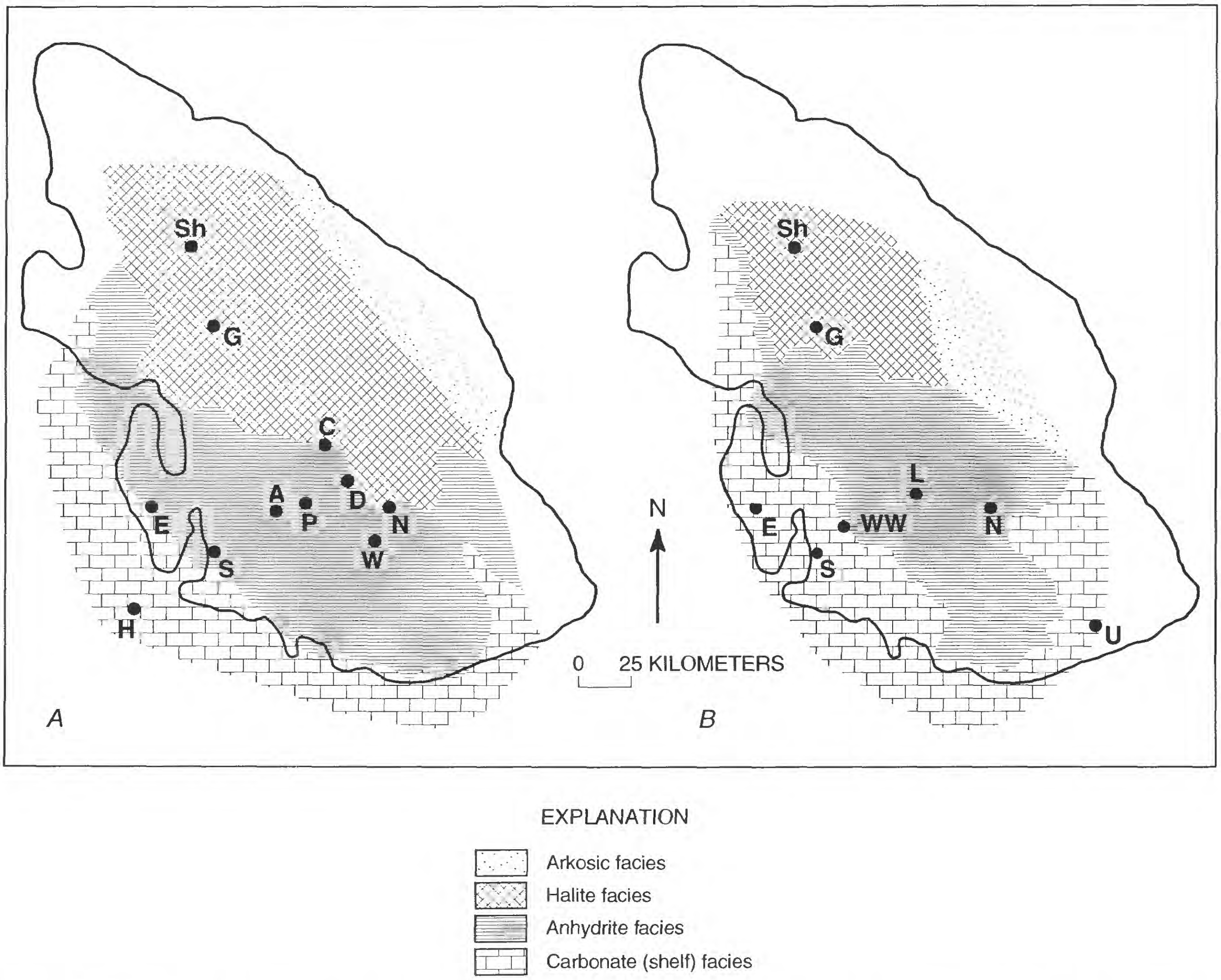

Figure 4. Distribution of environments during deposition of cycles 5 and 3 of the Pennsylvanian Paradox Formation. Abbreviations of core (solid circles) names are given in table 1. Heavy line delineates boundary of Paradox Basin as defined by approximate limit of the halite facies in the Pennsylvanian Paradox Formation. Modified from Reid and Berghorn (1981). *A*, cycle 5. *B*, cycle 3.

heterogeneity of each lithologic unit as identified in the core description. In some cases, the entire interbed was not available for sampling. The extent of interbed coverage by the core was determined by comparing the sampled interval with gamma-ray logs and, if available, with the location of evaporite beds in the core (see Appendix 1). The number of samples represented by each rock type in cycles 3 and 5 is given in table 2; rock types in this table were redefined from those in the core descriptions using mineralogical and chemical data as presented in the beginning of the Results and Discussion section of this report.

Each sample was cut to about 5 cm long and then split lengthwise with a diamond saw cooled with tap water. After cutting, the excess water on the samples was removed promptly by blotting with paper towels, and the samples were air dried at room temperature (25°C). Two splits, one approximately 2 g and one approximately 5 g, were reserved for polished thin section preparation and Rock-Eval pyrolysis, respectively. The remaining sample (as much as 50 g) was crushed by mortar and pestle and then ground in a ceramic ball mill to a <125-µm powder.

ANALYTICAL METHODS

Epoxy-impregnated, polished thin sections were commercially prepared for representative intervals in each core and examined under both transmitted and reflected light to determine sulfide-mineral morphology. Packed-powder mounts were analyzed for whole-rock mineralogy by X-ray diffractometry using nickel-filtered, copper K-alpha radiation. Diffractograms were from 4° to 64° two-theta.

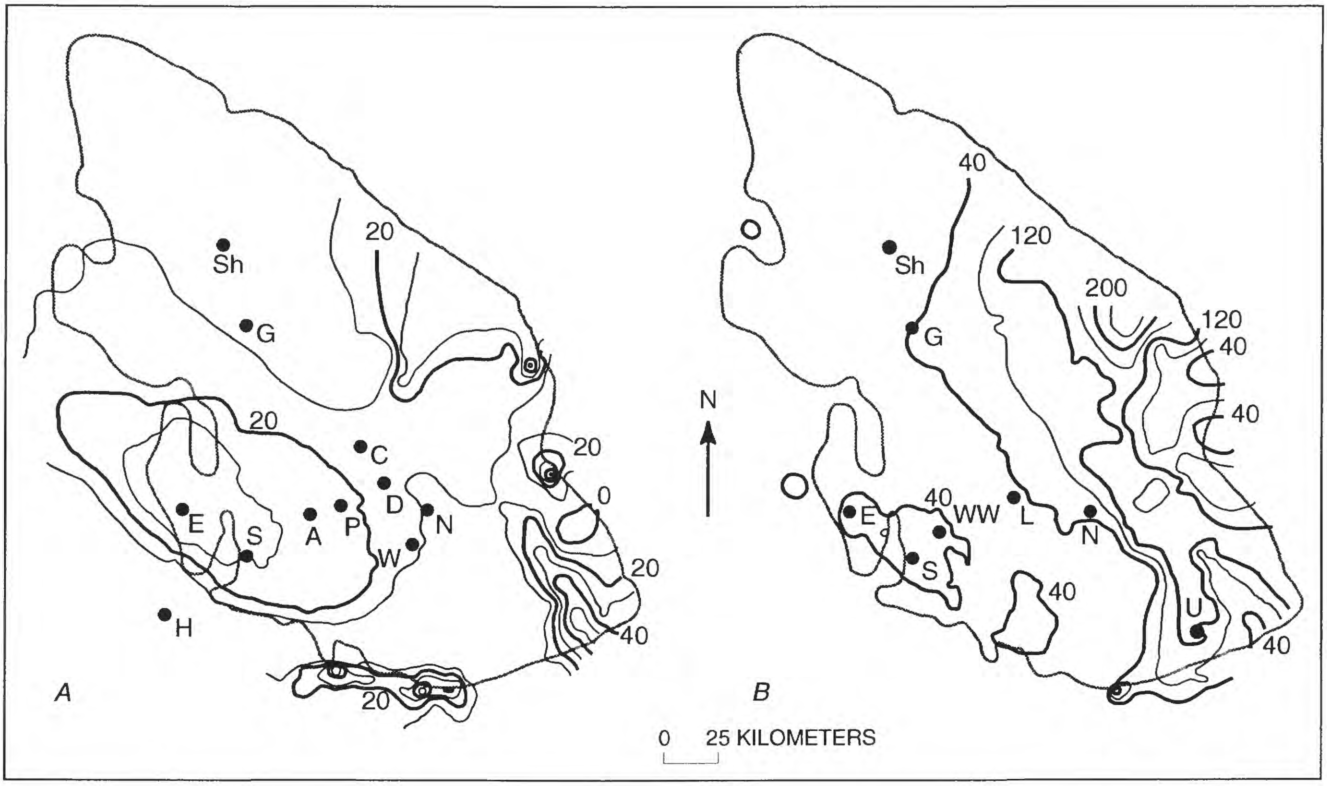

Figure 5. Isopach maps (in feet) of interbeds in cycles 5 and 3 of the Pennsylvanian Paradox Formation. Abbreviations of core (solid circles) names are listed in table 1. Approximate limit of halite facies in the Pennsylvanian Paradox Formation is shown as in figure 4. *A*, cycle 5. *B*, cycle 3.

Relative mineral contents were determined using relative intensities (units of 0.1 inch) of a selected diffraction peak chosen to represent each mineral. The values of degrees two-theta for the characteristic peaks of each mineral are listed in table 3.

Total carbon and organic carbon (C_{Org}) were measured on a commercial apparatus using an induction furnace and a thermal conductivity cell (reproducibility ±10 percent). The carbon measured on samples treated with 6 *M* HCl is assumed to be organic carbon. Carbonate carbon (C_{CO_3}) is the calculated difference between organic carbon and total carbon.

The type of organic matter (terrestrial or algal), as well as the maturity of the organic matter, is related to results from Rock-Eval pyrolysis. Rock-Eval analyses were performed by Exxon Production Research Company in Houston, Texas. Rock-Eval pyrolysis measures the amount of hydrocarbons (HC) and CO_2 generated from the sample as a function of temperature (Tissot and Welte, 1984). The characteristic S_1 and S_2 peak areas relate to milligrams of HC generated per gram of rock over specific temperature ranges, and the S_3 peak relates to the amount of CO_2 (in milligrams) generated per gram of rock. These values convert to hydrogen and oxygen indices (HI and OI) as follows:

$$HI = S_2 \text{ mg HC/g } C_{Org}, \text{ and}$$

$$OI = S_3 \text{ mg } CO_3\text{/g } C_{Org}$$

The T_{max} value is the temperature at which the S_2 peak intensity is greatest and is commonly used to assess the thermal maturity of organic matter in source rocks.

Total sulfur content was determined by two methods: (1) a commercial apparatus using an induction furnace and an infrared detection system (reproducibility ±10 percent), and (2) the summation of sulfur-species concentrations obtained by chemical separation (fig. 6). Details of the sulfur species separation technique and its development are described in Tuttle and others (1986). In this technique, a powdered sample is reacted with hot 6 *M* HCl, then with hot, acidified 1 *M* Cr^{2+} solution to sequentially extract acid-volatile sulfide, disulfide, and sulfate species. The residue is fused with an Eschka mixture to extract organically bound sulfur. Acid-volatile and disulfide sulfur are recovered as silver sulfide. Sulfate and organically bound sulfur are precipitated as barium sulfate. The precipitates are weighed and the weight percent of each sulfur species in the original sample calculated. Results were reproducible to within ±10 percent except near the detection limit (0.01 weight percent) where reproducibility approached ±20 percent.

The precipitates from the separation procedure (silver sulfide and barium sulfate) are converted to SO_2 in a vacuum line by combusting with vanadium oxide or elemental copper, respectively. Both combustions take place in the

Table 1. Sampling information, Pennsylvanian Paradox Formation, Utah and Colorado.

[Abbreviations for well names shown in parentheses are as shown in figure 1. Locations are listed in the order: Township, Range, and section]

Well name	Location	API number	Cycle[1]	Shale interval		Cored interval		Total no. of samples
				Top (m)	Bottom (m)	Top (m)	Bottom (m)	
91 PCH 1 HT	41S-18E-SW 29	--	5			Outcrop	Outcrop	1
Honaker Trail outcrop (H)	San Juan Co., Utah							
U.S. Department of Energy	37S-19E-30	4303790625	3	774	789	777[3]	791[3]	6
Elk Ridge No. 1 (E)	San Juan Co., Utah		5	815	824	797[3]	826[3]	9
Carbonit Exploration Inc.	39S-21E-SENW16	4303730603	3	1,689	1,709	1,682	1,692	6
State No. 1-16 (S)	San Juan Co., Utah		5	1,738	1,753[2]	1,735	1,741	6
Southland Royalty Co.	38S-22E-SWSE4	4303730713	3	1,922	1,937	1,921	1,927	4
West Water Creek No. 1 (WW)	San Juan Co., Utah							
E.L. and B.R. Cox	37S-23E-24	4303730724	5	1,945	1,953	1,943	1,949	6
Aztec Federal No. 1 (A)	San Juan Co., Utah							
McCulloch Oil and Gas Corp.	36S-25E-NESW33	4303730539	5	1,721[2]	1,727	1,720	1,729	14
Pickett Federal No. 1-33 (P)	San Juan Co., Utah							
Santa Fe Energy Co.	36S-25E-NWNW27	4303730692	3	1,750	1,758	1,751	1,760	9
Lake Canyon Prospect Federal No. 1-27 (L)	San Juan Co., Utah							
Davis Oil Company	40N-20W-SWSE35	503306047	5	1,940	1,945	1,940	1,942	4
Duncan Tevault No. 1 (D)	Dolores Co., Colorado							
Delhi-Taylor Oil Company	27S-20E-15	Not known	3	773[2]	783[2]	765[3]	786[3]	30
Shafer No. 1 (Sh)	San Juan Co., Utah		5	876[2]	899[2]	875[3]	902[3]	4
U.S. Department of Energy	30S-21E-21	4303796006	3	871[2]	884[2]	868[3]	891[3]	17
Gibson Dome No. 1 (G)	San Juan Co., Utah		5	934[2]		934[3]	948[3]	9
Transco Exploration	34S-25E-25	4303730978	5	1,800	1,804	1,798	1,803	2
TXPOC Crowley Ranch No. 1-25 (C)	San Juan Co., Utah							
McCulloch Oil and Gas Corp.	38N-18W-SENE4	508306260	3	1,804	1,824	1,804	1,807	4
Norton Federal No 1-4 (N)	Montzuma Co., Colorado		5	1,851	1,853	1,842	1,850	11
Celsius Energy	37N-18W-SENW20	508306359	5	1,802	1,805	1,802	1,808	8
Woods Unit No. 1-S (W)	Montzuma Co., Colorado							
Houston Oil and Mineral Corp.	34N-14W-SESE34	508306172	3	2,650	2,687[2]	2,649	2,652	1
Ute Mountain No. 44-34 (U)	Montzuma Co., Colorado					2,656	2,674	8

[1] Hite (1970).

[2] Depths from well logs.

[3] Entire well was cored. Depth refers to sampled intervals.

Table 2. Number of samples of each rock type sampled in cycles 3 and 5, Pennsylvanian Paradox Formation, Utah and Colorado.

Rock type	Total	Cycle 3	Cycle 5
Anhydrite	7	3	4
Dolostone	22	11	11
Limestone	19	10	9
Siltstone	14	3	11
Dolomitic shale	11	8	3
Calcareous shale	51	33	18
Argillaceous shale	35	18	17

Table 3. Characteristic peaks measured on X-ray diffractograms.

[Alternative peaks were used when interference was present for primary 2θ peak; alternative peak units were adjusted to those for 2θ peak using intensity factors]

Mineralogy	Degrees 2θ	Alternative peaks × intensity factors
Gypsum	11.70	
Clay	19.45–19.89	
Quartz	20.83	
Anhydrite	25.5	31.37 × 2.86 or 38.64 × 5.00
Potassium feldspar	27.51	
Sodium feldspar	27.77–27.89	
Calcite	29.40	43.14 × 5.56
Dolomite	30.96	41.15 × 3.33 or 37.36 × 10.00
Halite	31.69	56.48 × 1.43
Fluorapatite	31.93	
Pyrite	33.04	

presence of quartz glass to equilibrate the oxygen isotopic composition of the SO_2. Isotopic analysis of the SO_2 was performed using a high-resolution, 6-inch, 60°-sector mass spectrometer. All isotope results are reported in $\delta^{34}S$ notation[3] relative to the Cañon Diablo troilite standard (CDT). $\delta^{34}S$ values were reproducible to within ±0.1‰.

An aliquot of 6 *M* HCl filtrate from the speciation procedure was collected and analyzed by atomic absorption spectrophotometry for iron (reproducibility ±10 percent). The HCl-soluble iron was used to calculate reactive iron (Fe_{rct}) concentrations. Fe_{rct} is operationally defined as iron that is available for sulfidization by reduced sulfur species (Berner, 1984) and is calculated as

$$Fe_{rct} = Fe_{HCl} + Fe_{Di}$$

where

Fe_{HCl} is HCl-extractable iron (iron in carbonate, oxide, acid-volatile sulfide, and possibly clay mineral phases), and

Fe_{Di} is the iron in disulfide minerals and is calculated using the sulfur speciation value for disulfide and assuming stoichiometric FeS_2.

Berner (1970) defined degree of pyritization of the reactive iron (DOP_r) as the measure of the fraction of reactive iron available for sulfidization to form pyrite. Degree of pyritization traditionally has been used to examine iron and sulfur limitation on pyrite formation during sediment diagenesis. Recently, Canfield and others (1992) showed that DOP_r values are a crude measure of the amount of iron potentially reactive and that their use for determining controls on pyrite formation is limited. DOP_r is calculated as

$$DOP_r = Fe_{Di}/Fe_{rct}$$

and, in this report, will be used according to Canfield's definition.

Inductively coupled plasma–atomic emission spectrometry (ICP-AES) (Briggs, 1990) was used to determine major, minor, and trace elements in core samples. Estimated precision for most reported elements is ±10 percent (relative standard deviation). Other trace elements sought, but consistently below their detection limits, are listed in table 4.

Arsenic and selenium were determined for 27 selected shale samples using continuous-flow hydride-generation atomic absorption spectrophotometry (HG-AAS) (Crock and Sanzolone, 1990). The method has a reproducibility of better than ±10 percent.

RESULTS AND DISCUSSION

PRESENTATION OF DATA

Qualitative petrographic data are summarized in Appendix 1, and chemical, isotopic, and calculated data (Fe_{rct} and DOP_r) are tabulated in Appendix 2. Although all chemical data are included in Appendix 2, not all results are discussed in this report. Means for the various rock types and means for core that include all rock types except anhydrite were calculated using whole-rock data. In this report, means and deviations are either arithmetic or geometric, depending on the statistical distribution of the data (tables 5 and 6).

Within any one core, an interbed generally includes several rock types that reflect temporal facies changes. The means for a given cycle in each core were calculated to investigate compositional variations in the interbeds across the basin. These variations can then be related to geochemical processes. Comparison of means to examine these processes on a basinwide scale is restricted to those cores that completely penetrate the interbed and for which samples represent the lithologic distribution within the core. Cores that meet these criteria are shown in bold in tables 5 and 6 and are shown by the solid part of location dots in subsequent maps of geochemical means. Means for cores that do not meet the criteria (shown as open circles in figures) are

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[3] $\delta^{34}S_X = [(R_X - R_{CDT})/R_{CDT}] \times 1000$ ‰, where R is $^{34}S/^{32}S$.

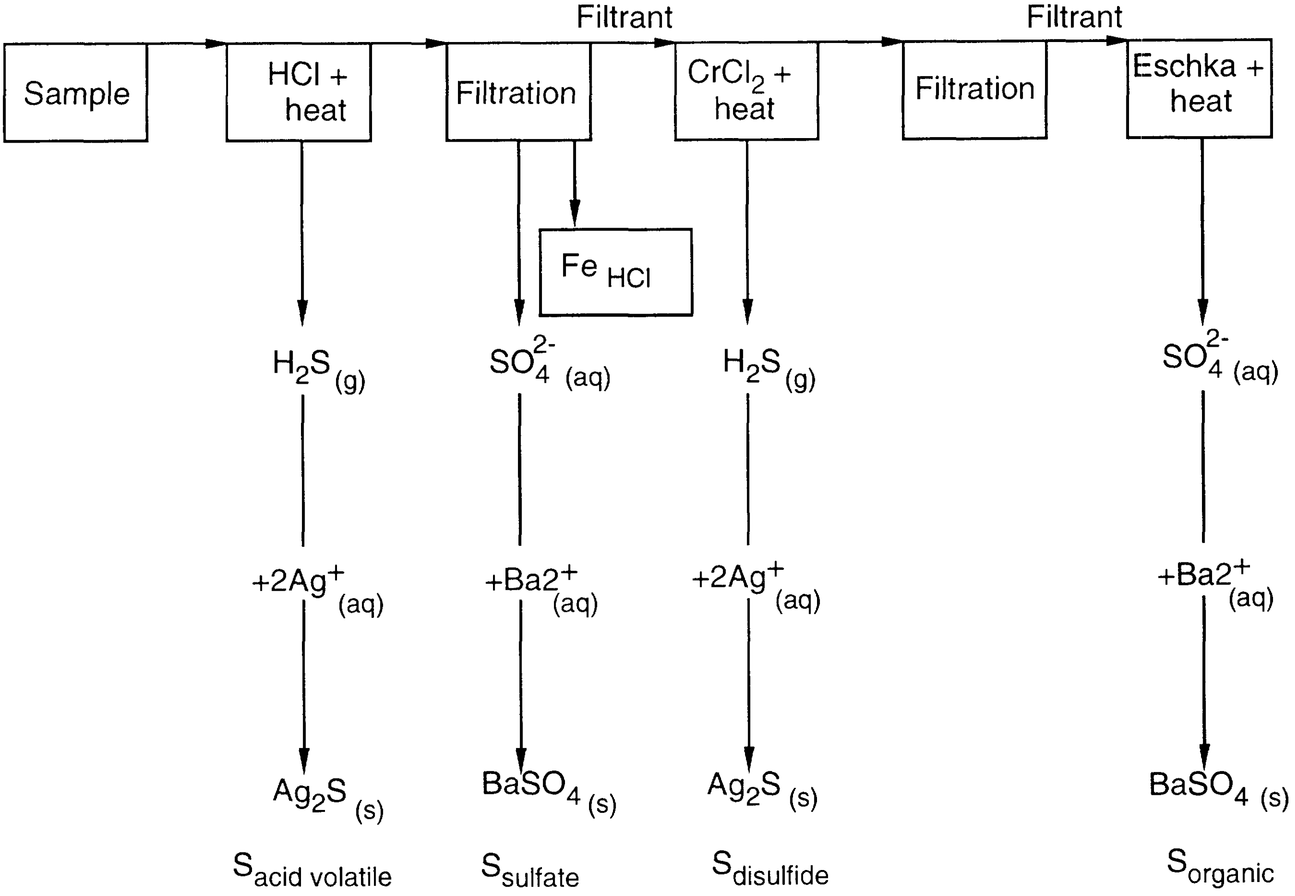

Figure 6. Analytical scheme to separate forms of sulfur contained in rock samples from the Paradox Formation. See text for explanation.

Table 4. Trace elements that were censored (concentrations below detection limits) and their detection limits.

Trace element	Detection limit (ppm)
Au	8
Bi	10
Cd	2
Eu	2
Ho	4
Sn	5
Ta	40
Th	4
U	100
Yb	1

presented on the maps for comparison but are considered less reliable.

LITHOFACIES AND SEDIMENTATION

LITHOLOGIC CLASSIFICATION

A crossplot of the relative amount of clay versus concentration of carbonate carbon (C_{CO_3}) was used to define fields for classifying samples with respect to their rock type (fig. 7). The field for shale is defined as having an X-ray diffraction (XRD) relative peak height for clay >5 chart units (0.5 inches) and C_{CO_3} concentrations <3 weight percent. These samples are commonly fissile and fissile bedded. Samples having clay peak heights >5 chart units and with C_{CO_3} concentrations between 3 weight percent (25 percent calcite equivalence) and 6 weight percent (25–50 percent calcite equivalence) are classified as calcareous or dolomitic shale. Calcareous and dolomitic shales are defined by the predominance of calcite or dolomite in the sample as determined by X-ray diffraction and transmitted-light petrography. If dolomite is greater than calcite, the upper limit for C_{CO_3} concentrations is increased to 6.5 weight percent (50 percent dolomite equivalence). Calcareous samples that have clay intensities >5 chart units and C_{CO_3} concentrations >6 weight percent are classified as shaly to silty limestone, and dolomitic samples with >6.5 weight percent C_{CO_3} are classified as shaly to silty dolostone. Samples with clay intensities <5 chart units and C_{CO_3} concentrations >6 weight percent are classified either as limestone or dolostone, depending on the dominant carbonate mineral. The remaining samples were classified as

Table 5. Arithmetic means of characteristic X-ray diffraction peak heights by rock type and by core and cycle, Pennsylvanian Paradox Formation, Utah and Colorado.

[Units shown are 0.1-inch units; standard deviations are in parentheses. Bold type represents sampled cycle intervals that are representative of the entire interbed. n, number of samples]

Rock type	n	Quartz	Clay	Potassium feldspar	Sodium feldspar	Calcite	Dolomite	Apatite	Pyrite	Anhydrite[1]	Halite[2]
Dolostone	22	22 (17)	4 (3)	6 (6)	5 (6)	5 (7)	210 (71)	<1	4 (3)	15 (27)	4 (7)
Limestone	19	19 (8)	4 (3)	3 (4)	6 (4)	170 (59)	68 (34)	<1	4 (3)	9 (8)	0
Siltstone	14	51 (13)	6 (4)	26 (10)	6 (9)	54 (42)	87 (44)	<1	5 (3)	9 (21)	23 (37)
Argillaceous sh.	35	28 (10)	12 (4)	14 (10)	10 (10)	51 (27)	30 (23)	3 (6)	10 (4)	4 (5)	10 (21)
Dolomitic sh.	11	26 (8)	10 (2)	9 (5)	7 (5)	22 (32)	130 (54)	2 (3)	6 (3)	4 (5)	5 (8)
Calcareous sh.	51	26 (7)	10 (2)	6 (5)	9 (5)	110 (24)	34 (16)	3 (2)	9 (3)	3 (3)	0
All rock types	152	27 (13)	9 (4)	10 (9)	8 (7)	78 (60)	74 (73)	2 (4)	7 (4)	6 (13)	6 (17)

Core (cycle)	n	Quartz	Clay feldspar	Potassium feldspar	Sodium	Calcite	Dolomite	Apatite	Pyrite	Anhydrite[1]	Halite[2]
Shafer (3)	29	23 (9)	9 (4)	13 (6)	7 (5)	30 (29)	90 (78)	1 (3)	7 (4)	2 (3)	11 (8)
Shafer (5)	4	34 (22)	6 (4)	22 (15)	0	6 (11)	116 (128)	10 (14)	7 (4)	7 (9)	32 (47)
Gibson Dome (3)	15	27 (14)	9 (5)	6 (6)	14 (5)	90 (48)	77 (80)	3 (2)	8 (3)	2 (6)	0
Gibson Dome (5)	7	40 (20)	5 (3)	21 (17)	0	20 (24)	148 (64)	0	2 (1)	11 (27)	58 (40)
Crowley Ranch (5)	2	21	9	14	0	95	40	0	9	0	0
Duncan Tevault (5)	4	42 (27)	9 (7)	7 (5)	0	31 (41)	94 (101)	1 (3)	7 (2)	27 (47)	0
Norton Federal (3)	4	24 (3)	8 (1)	1 (3)	2 (2)	137 (10)	53 (15)	2 (2)	6 (1)	4 (1)	0
Norton Federal (5)	10	28 (21)	7 (4)	18 (14)	5 (14)	13 (21)	158 (121)	1 (3)	5 (3)	16 (20)	0
Woods (5)	8	21 (12)	9 (6)	10 (6)	8 (6)	143 (63)	45 (32)	1 (3)	7 (4)	8 (12)	0
Ute Mountain (3)	9	33 (7)	8 (1)	1 (2)	7 (2)	123 (42)	46 (9)	2 (1)	5 (2)	3 (1)	0
Lake Canyon (3)	9	20 (3)	10 (4)	2 (3)	13 (5)	125 (30)	43 (29)	3 (3)	9 (2)	6 (3)	0
Pickett Federal (5)	14	30 (11)	13 (4)	15 (9)	5 (5)	92 (32)	45 (35)	4 (4)	10 (3)	6 (4)	0
Aztec Federal (5)	6	23 (5)	10 (6)	8 (4)	10 (3)	102 (24)	51 (45)	3 (4)	8 (5)	2 (3)	0
West Water Ck. (3)	4	33 (4)	9 (3)	4 (5)	7 (2)	95 (28)	47 (12)	4 (1)	10 (3)	4 (1)	0
State(3)	6	33 (23)	4 (3)	3 (4)	5 (4)	168 (118)	34 (20)	1 (1)	3 (3)	1 (2)	0
State (5)	6	25 (6)	7 (5)	0	10 (3)	90 (43)	69 (56)	2 (3)	9 (6)	3 (2)	0
Elk Ridge (3)	7	25 (4)	8 (2)	8 (4)	7 (2)	103 (47)	70 (61)	3 (2)	9 (2)	0	0
Elk Ridge (5)	7	28 (12)	10 (6)	6 (7)	20 (7)	68 (34)	49 (80)	3 (3)	11 (5)	11 (29)	0
Honaker Trail[3] (5)	1	24	11	10	0	100	41	4	10	5	0

[1] Occurs as vein filling.

[2] Occurs as vein filling and also possible contamination during coring.

[3] Outcrop sample.

siltstone or sandstone, based on thin-section observation, quartz peak height, and hand-specimen examination. Samples composed mainly of halite and anhydrite were classified at the time of sampling, and the classification was verified using X-ray diffraction data. The total clay–carbonate carbon crossplot (fig. 7) shows the distribution of sample types. Shaly to silty limestone is combined with limestone and simply referred to as limestone hereafter. Similarly, shaly to silty dolomite is classified as dolostone. The rationale for combining these four rock types into two is based on the similar chemical characteristics of the two limestone and the two dolostone types.

MINERALOGY

A brief narrative of the mineralogy of cored intervals is given in the core summaries of Appendix 1. Mean peak heights of minerals (table 5) are useful for relative comparisons among rock types and among many of the cores. Quartz, as expected, and potassium feldspar are most abundant in siltstone. In cycle 5, the larger amounts of quartz (34–42 peak height) (fig. 8*A*) in the northern part of the basin and in the Norton core are the result of clastic silt-size grains whose sorting and rounded morphology suggest an eolian origin such as those grains observed in some of the halite beds. On the other hand, the larger amounts of quartz (33 peak height) in cycle 3 in the southern part of the basin are due to recrystallized sponge spicules. As expected, argillaceous shale contains the most clay and plagioclase. In cycle 5, clay (13 peak height) is most abundant in the south-central part of the basin, whereas in cycle 3, amounts of clay are relatively uniform across the basin (fig. 8*B*). In cycle 5, plagioclase is most abundant (20 peak height) in the southwestern part of the basin, whereas potassium feldspar is most abundant along transect *B-B′* (18–22 peak height). In cycle 3, plagioclase is most abundant (13–14 peak height) in

Table 6. Means of selected chemical parameters and sulfur isotopic compositions by rock type and by core and cycle, Pennsylvanian Paradox Formation, Utah and Colorado.

[Standard deviations in parentheses. n, number; C_{CO_3}, inorganic carbon; C_{Org}, organic carbon; HI, hydrogen index; S_{Di}, disulfide sulfur; Fe_{rct}, reactive iron; DOP_r, degree of pyritization. Bold type represents sampled cycle intervals that are representative of the entire interbed]

Rock type	C_{CO_3} (wt%)	C_{Org} (wt%[1])	n	HI	n	S_{Di} (wt%)	n	$\delta^{34}S_{Di}$ (‰)	n	Fe_{rct} (wt%)	n	DOP_r	n	Cr (ppm[1])	n	Ni (ppm[1])	n
Dolostone	8.0 (2.3)	0.62	22	210 (122)	14	0.70	12	−22.5 (11)	7	1.0 (.5)	13	0.47 (.28)	12	33	22	20	22
Limestone	8.3 (1.7)	0.38	19	76 (100)	14	1.2	9	−19.9 (7)	7	1.3 (1.6)	9	0.68 (.09)	9	40	19	17	19
Siltstone	3.9 (1.4)	0.18	14	113 (159)	5	0.52	10	−19.0 (12)	3	0.90 (.58)	10	0.52 (.16)	10	25	14	12	14
Argillaceous sh	2.2 (.79)	2.7	33	236 (146)	29	1.3	32	−24.6 (7)	27	2.3 (.67)	32	0.49 (.11)	32	280	35	98	35
Dolomitic sh	4.8 (1.0)	1.2	11	245 (174)	14	0.98	6	−27.2 (7)	4	1.8 (.39)	6	0.46 (.13)	6	150	11	61	11
Calcareous sh	4.4 (.91)	2.0	51	177 (147)	49	1.4	47	−19.2 (7)	34	2.0 (.50)	47	0.59 (.11)	47	230	51	74	51
All rock types	4.9 (2.5)	1.1	150	186 (148)	120	1.2	116	−21.7 (8)	82	1.8 (.81)	117	0.54 (.16)	116	120	152	45	152
Core (cycle)	C_{CO_3} (wt%)	C_{Org} (wt%[1])	n	HI	n	S_{Di} (wt%)	n	$\delta^{34}S_{Di}$ (‰)	n	Fe_{rct} (wt%)	n	DOP_r	n	Cr (ppm[1])	n	Ni (ppm[1])	n
Shafer (3)	4.2 (2.5)	1.5	29	301 (87)	25	1.1 (.5)	19	−25.5 (7)	19	2.2 (.7)	19	0.42 (.11)	19	150	29	59	29
Shafer (5)	6.0 (5.6)	2.6	4	340 (86)	3	0.28	2	−37.9	2	1.0	2	0.25	2	51	4	34	4
Gibson Dome (3)	4.9 (1.5)	1.3	15	382 (51)	12	1.1 (.4)	15	−17.8	2	1.8 (.8)	15	0.54 (.13)	15	110	15	44	15
Gibson Dome (5)	4.5 (1.9)	0.10	7		0	0.45 (.14)	6		0	0.91 (.28)	7	0.39 (.11)	6	27	7	13	7
Crowley Ranch (5)	4.0	1.9	2	22	2	2.0	2	−30.2	2	2.6	2	0.63	2	160	2	78	2
Duncan Tevault (5)	3.6 (2.7)	0.91	4	42 (8)	4	1.1 (.31)	3	−29.7 (4)	3	1.8 (.4)	3	0.52 (.05)	3	78	4	45	4
Norton Federal (3)	5.7 (.5)	1.3	4	51 (8)	4	1.0 (.1)	4	−14.3 (2)	4	1.4 (.1)	4	0.63 (.03)	4	160	4	48	4
Norton Federal (5)	5.6 (4.3)	0.91	10	28 (20)	5	0.58 (.42)	7	−28.1 (8)	7	1.2 (.6)	7	0.36 (.19)	7	43	10	26	10
Woods (5)	6.0 (3.4)	0.99	8	44 (21)	8	1.2 (.5)	3	−27.7	2	1.39 (.8)	3	0.56 (.02)	3	82	8	29	8
Ute Mountain (3)	5.5 (.9)	0.81	9	12 (5)	9	0.83 (.11)	7	−16.0 (4)	7	1.3 (.2)	7	0.57 (.04)	7	160	9	36	9
Lake Canyon (3)	5.9 (2.0)	1.3	8	72 (18)	8	1.7 (1.7)	6	−20.2 (4)	6	2.4 (1.4)	6	0.56 (.16)	6	180	9	59	9
Pickett Federal (5)	3.9 (2.1)	1.7	13	58 (21)	13	1.5 (.3)	11	−17.9 (5)	9	2.3 (.3)	11	0.57 (.03)	11	190	14	65	14
Aztec Federal (5)	5.1 (2.5)	1.4	6	80 (29)	6	2.0 (.1)	4	−16.4 (3)	4	2.6 (.1)	4	0.68 (.02)	4	150	6	63	6
West Water Ck. (3)	4.5 (.6)	2.0	4	212 (16)	4	1.9	2	−22.9	2	2.1	2	0.78	2	200	4	76	4
State(3)	6.6 (3.9)	0.16	6		0	0.54 (.43)	5	−23.5 (3)	5	0.76 (.57)	5	0.66 (.08)	5	33	6	16	6
State (5)	5.8 (3.0)	1.1	6	328 (40)	4	1.6 (1.0)	5	−8.3 (4)	5	1.7 (1.0)	5	0.81 (.06)	5	110	6	39	6
Elk Ridge (3)	5.3 (1.0)	1.8	7	319 (15)	6	1.2 (.2)	7	−18.7	2	1.7 (.3)	7	0.63 (.13)	7	200	7	67	7
Elk Ridge (5)	3.7 (1.7)	2.2	7	296 (26)	6	1.5 (.6)	7		0	2.2 (1.1)	7	0.61 (.14)	7	210	7	110	7
Honaker Trail[2] (5)	3.7	6.8	1	465	1	0.89	1	−21.4	1	0.61	1	0.61	1	470	1	170	1

[1] Geometric mean.

[2] Outcrop sample.

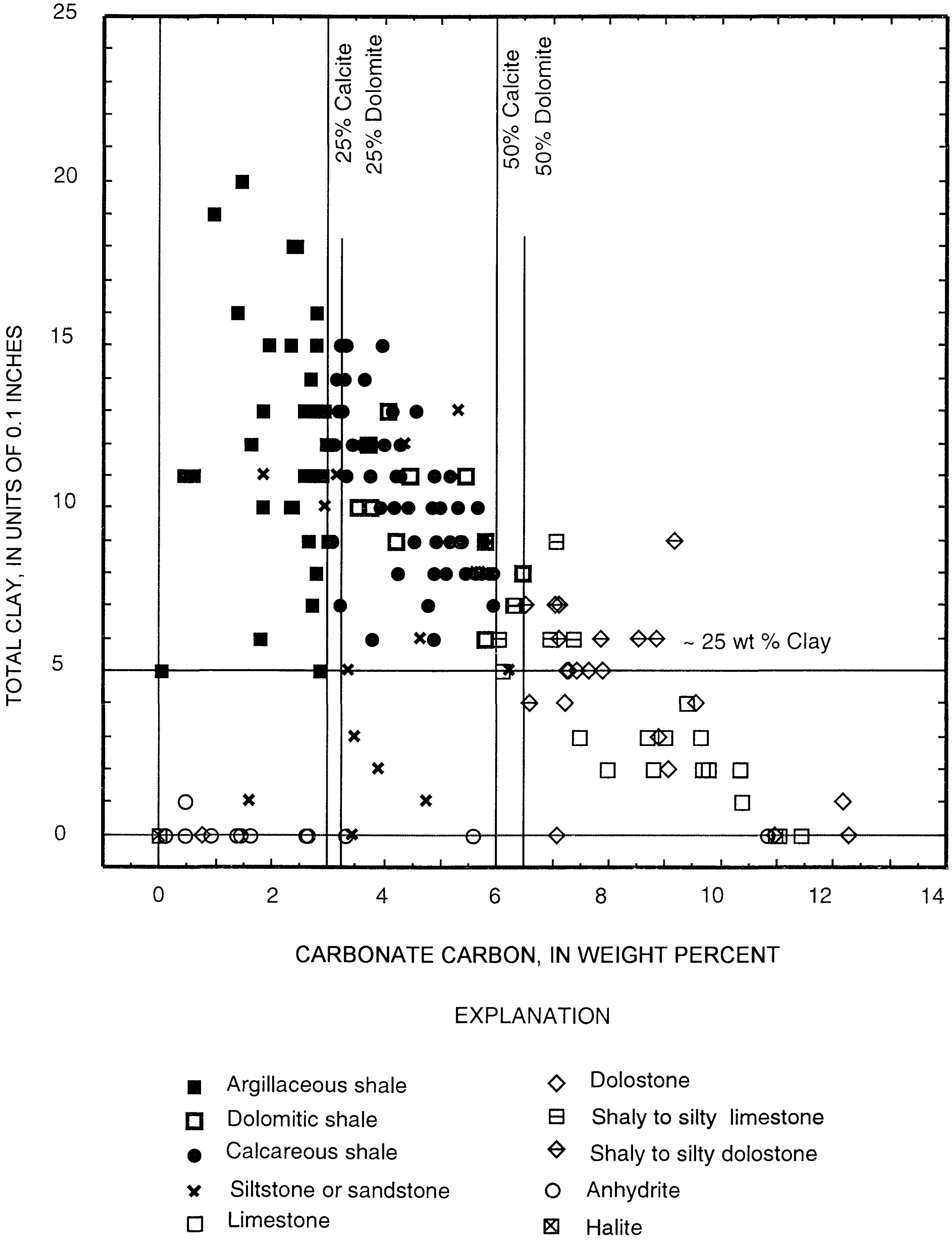
25% Calcite
25% Dolomite
50% Calcite
50% Dolomite
~ 25 wt % Clay
TOTAL CLAY, IN UNITS OF 0.1 INCHES
0
5
10
15
20
25
CARBONATE CARBON, IN WEIGHT PERCENT
0
2
4
6
8
10
12
14
EXPLANATION
■ Argillaceous shale
□ Dolomitic shale
● Calcareous shale
✖ Siltstone or sandstone
□ Limestone
◇ Dolostone
⊟ Shaly to silty limestone
◇ Shaly to silty dolostone
○ Anhydrite
⊠ Halite

Figure 7 (previous page). Crossplot of total clay (X-ray diffraction peak heights in units of 0.1 inch) versus carbonate carbon (C_{CO_3}) (weight percent) for cycles 5 and 3 of the Pennsylvanian Paradox Formation showing lithologic fields. See text for explanation.

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the central part of the basin, and potassium feldspar is most abundant (13 peak height) in the northern part of the basin (figs. 8*C*, 8*D*).

Calcite is generally most abundant in the southern part of the basin in shelf or near-shelf facies and in cores containing the smallest amounts of dolomite (figs. 8*E*, 8*F*). An exception is cycle 5 in the Elk Ridge core in which both amounts of calcite and dolomite are present in small amounts. In shale, calcite is generally micritic, although shell fragments are locally abundant. Limestone contains abundant shell fragments. In cycle 5, dolomite (115–160 peak height) is most abundant along transect *B-B′* (fig. 8*F*), and in cycle 3, dolomite is most abundant in the most northerly core (90 peak height). Dolostone comprises predominantly fine silt sized dolomite rhombs with some shell fragments.

CLASTIC SEDIMENTATION

Patterns of interbed thickness and sources of clastic sediment are significantly different for cycles 3 and 5, as shown in the isopach maps for the interbeds of the two cycles (fig. 5). The interbed of cycle 5 is much thinner than that of cycle 3, and three clastic sources are likely for cycle 5: a southwesterly source relatively rich in clay and plagioclase and poor in quartz, an easterly source relatively rich in quartz and potassium feldspar and poor in clay, and possibly a source of silt-sized quartz carried into the basin by winds from the north, the dominant wind direction in the basin during Middle Pennsylvanian time (Driese and Dott, 1984). These various clastic sources are proposed to explain the petrographic data and trends in the maps of relative mineral amounts (peak-height means, figs. 8*A*–8*D*). Note that the amount of plagioclase and, to some extent, potassium feldspar may be controlled in part by the salinity of pore water and diagenesis, an effect that is discussed later.

The interbeds of cycle 3 thicken dramatically to the northeast, where the basin was rapidly subsiding in response to uplift of the Uncompahgre highland (fig. 5*B*). The lack of variation in mineralogy throughout the basin in cycle 3 suggests that the single major source of clastic material during deposition of cycle 3 was the Uncompahgre highland.

AUTHIGENIC MINERAL PRECIPITATION

Chemical sediments in interbeds of the Paradox Formation include calcite, dolomite, anhydrite, and halite. Carbonate minerals are ubiquitous in the sampled cores and were detected in all rock types. The overall amount of carbonate carbon in the interbeds is independent of carbonate mineralogy (calcite or dolomite), except in areas within the basin dominated by argillaceous shale, which contains markedly less carbonate. The relative absence of carbonate in shale is attributed to either a decrease in carbonate supply during deposition or to a lack of carbonate formation during diagenesis. Thin-section observations show more calcareous bioclasts in calcareous shale relative to argillaceous shale, which supports the first hypothesis. The sulfur-isotope data, as discussed in the section Pyrite Formation, suggest that, in some parts of an interbed, sulfate reduction occurred after burial. Bicarbonate is produced during sulfate reduction and can react with available cations to form carbonates, one process consistent with the second hypothesis.

The amount of dolomite in interbeds across the basin may be related to the areal extent of the halite in each cycle. Large amounts of dolomite are restricted to cores in which the interbed is overlain by halite (as shown by superimposing figs. 4 and 8*F*). Therefore, we attribute the distribution of abundant dolomite to downward movement of brines during halite deposition. Halite-saturated brines have the large Mg:Ca ratio needed for dolomitization of calcite or aragonite (Bathurst, 1971). The cycle-3 interbed in the Gibson Dome core was deposited near the edge of halite distribution for that cycle (fig. 4*B*), and abundance of dolomite only in the upper two-thirds of the interval suggests that movement of the dolomitizing brine was limited to the upper part of the interbed.

The preceding hypothesis implies that much of the carbonate in the basin was originally deposited as calcite, in the form of shell fragments, micrite cement, and carbonate grains transported off the shelf at the onset of transgression, although some calcite formed during diagenesis. The pervasive dolomitization of some shale and dolostone probably occurred during very shallow burial. This hypothesis is consistent with the concentrically zoned dolomite rhombs observed in thin section. Large halite veins are present only in samples containing abundant dolomite, further evidence that a halite-saturated brine moved through the sediment after some compaction. On the other hand, small veinlets of halite are present in many of the argillaceous shale samples in which calcite is the dominant carbonate mineral. Dolomitization of the calcite within these shales may have been inhibited by organic films derived from their associated abundant organic matter. (For a discussion of this phenomenon see Bathurst, 1971.)

Small amounts of anhydrite are present in most interbed samples that are overlain by anhydrite. Some of the anhydrite is vein filling and some is present as disseminated crystals in the rock matrix. Vein-fill anhydrite is related to postdepositional movement of brines through the interbeds. One 5-m-thick interval of anhydrite was deposited in the

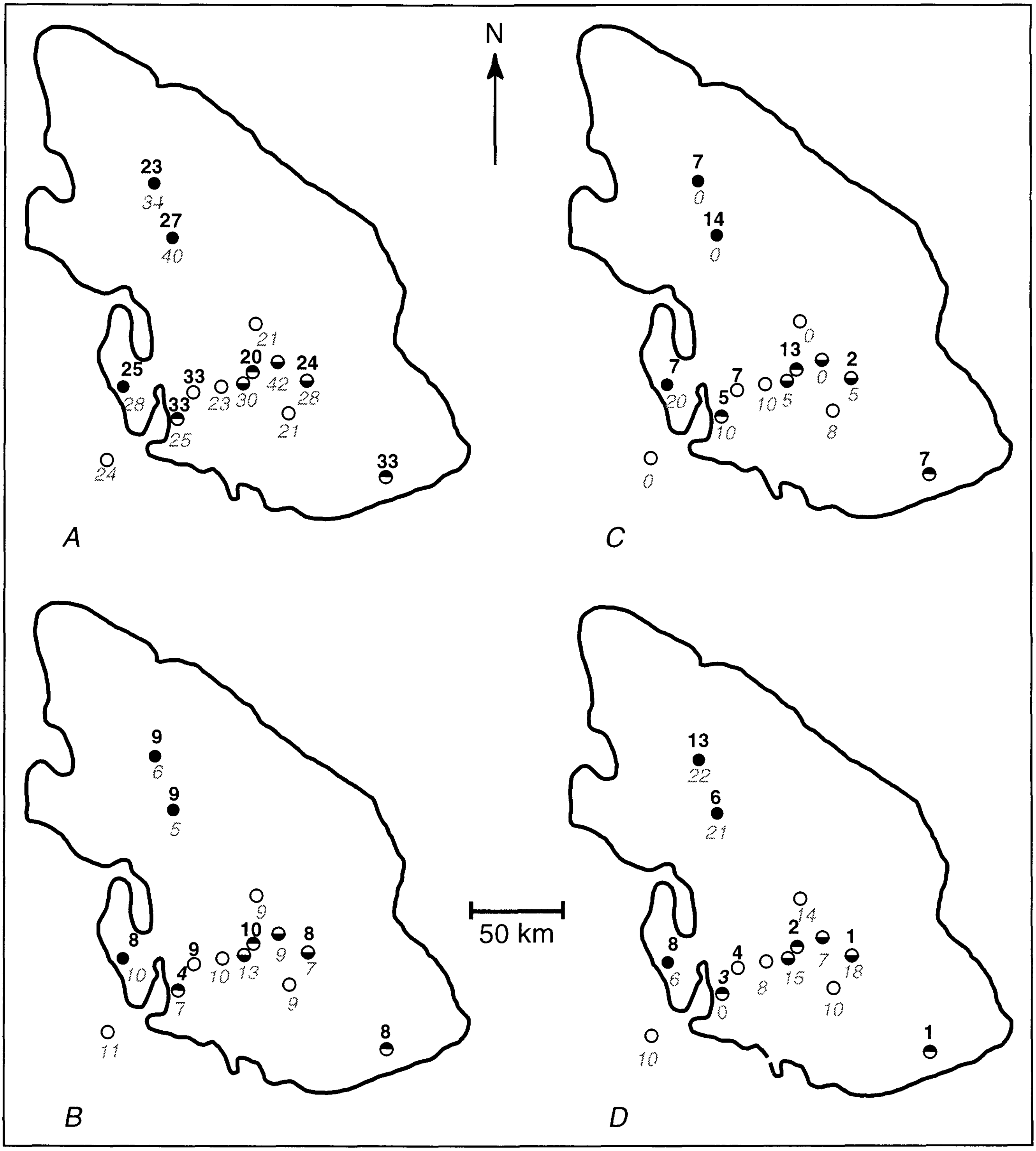
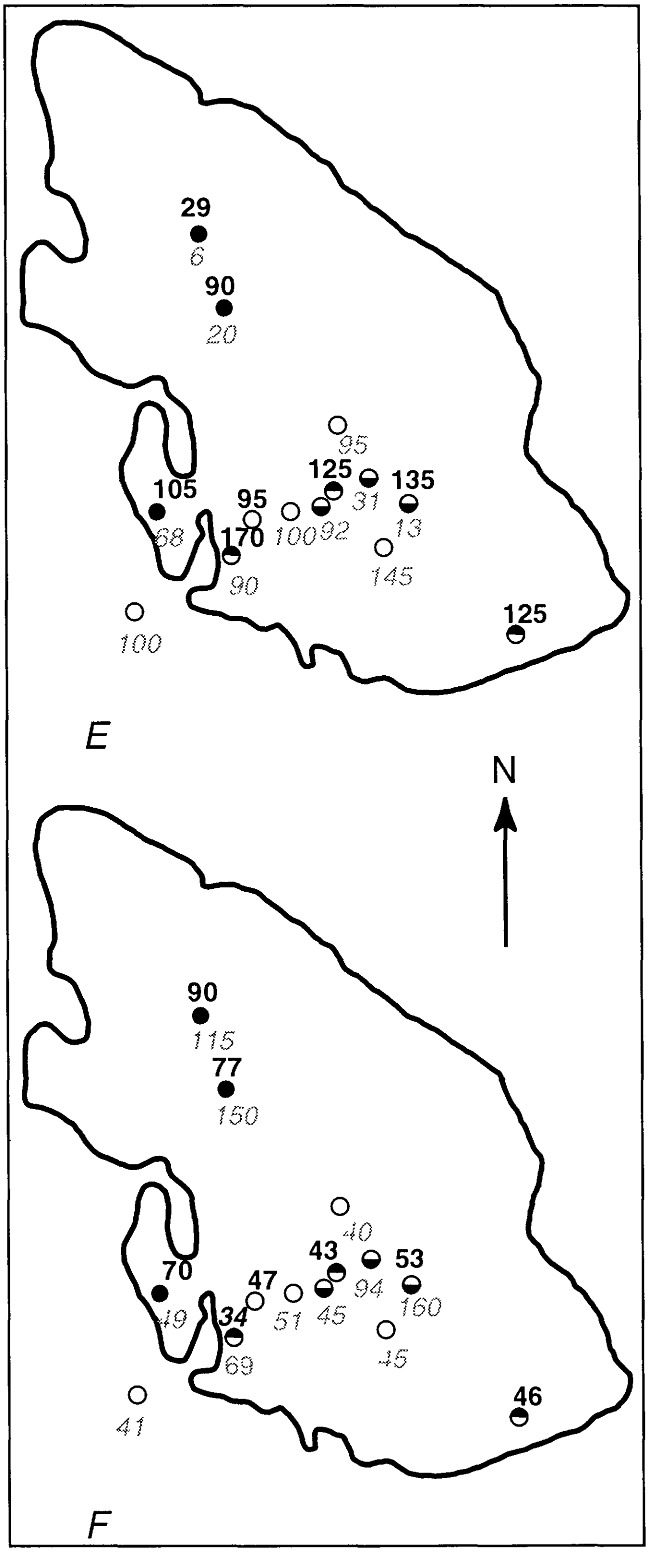


Figure 8 (above and facing page). Maps of means (X-ray diffraction peak heights in units of 0.1 inch) of minerals in individual cycles and cores. Circles with lower half filled indicate cycle 5 core samples representative of entire interbed; circles with upper half filled indicate cycle 3 core samples representative of entire interbed; filled circles indicate samples from cycles 5 and 3 representative of respective interbeds; open circles indicate samples from cycles 5 and 3 not representative of respective interbeds. Solid type represents data for cycle 3; screened italic type represents data for cycle 5. *A*, quartz. *B*, clay. *C*, sodium feldspar. *D*, potassium feldspar. *E*, calcite. *F*, dolomite.

middle of the cycle-5 interbed in the Shafer core, and thin beds (<1 m) of anhydrite also are present in the Gibson core. The accumulation of bedded anhydrite within the interbed of cycle 5 indicates that maximum salinity in the center of the basin was greater during deposition of the cycle-5 interbed than during deposition of the cycle-3 interbed.



ORGANIC GEOCHEMISTRY

ORGANIC-MATTER DATA

Mean values for organic carbon (C_{Org}, in weight percent) and hydrogen index (HI) for the various lithofacies and cores (by cycles) are given in table 6. The amounts of organic carbon in cycle 3 (mostly limestone) of State core ("S," fig. 1) and cycle 5 (mostly siltstone) of Gibson core ("G," fig. 1) are 0.16 and 0.10 weight percent, too small to determine a hydrogen index. Except for these two cores, organic carbon in both cycles decreases from the shelf facies into the basin along transect *A-A′* and increases from the shelf facies into the basin along transect *B-B′* (fig. 9*A*). Hydrogen indices in adjacent cores are similar between cycles and follow the same trends as organic carbon (fig. 9*B*). The dividing line between large (>200) and small (<100) hydrogen indices is about 30 km west of the Colorado-Utah State line between the Aztec and West Water Creek core holes ("A" and "WW," fig. 1).

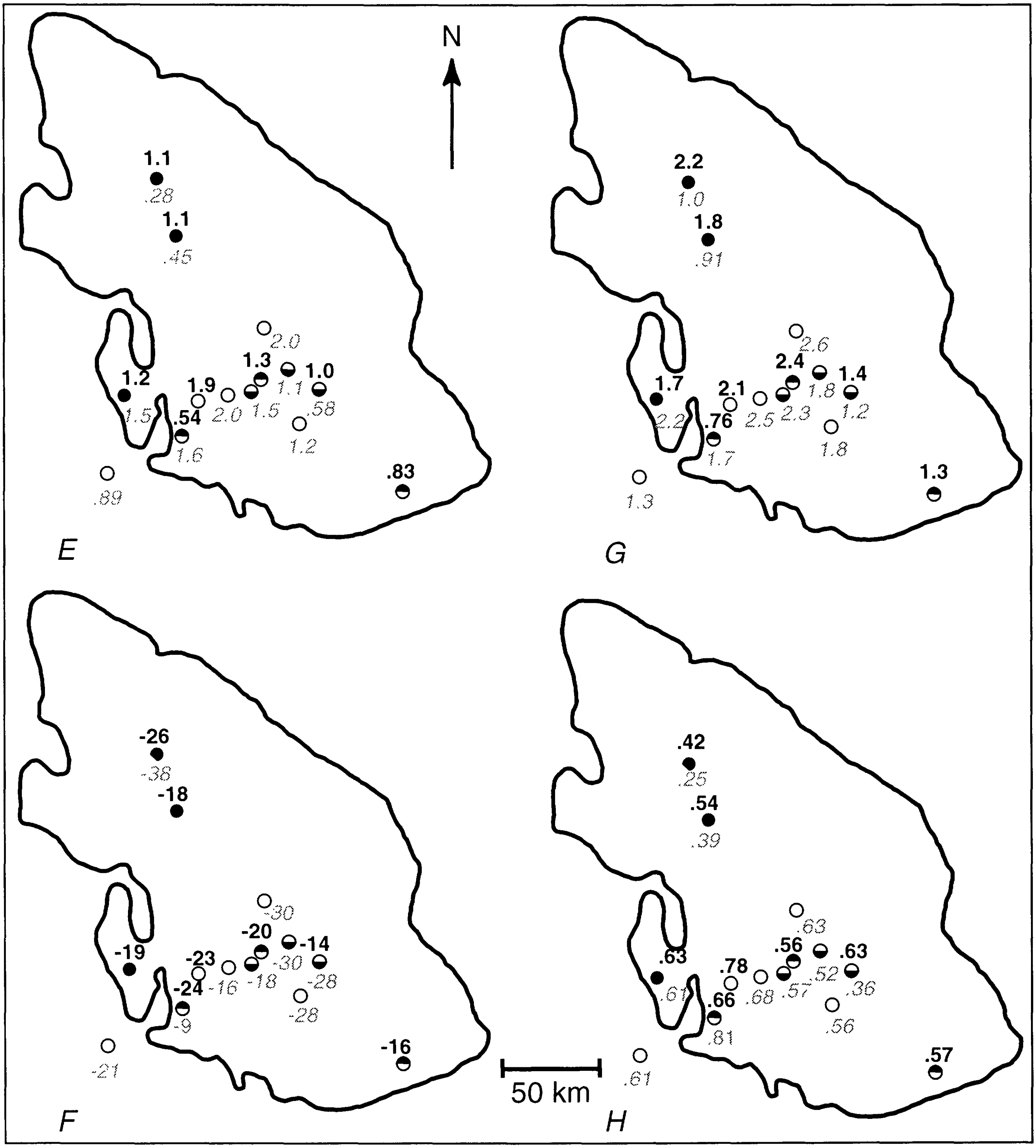
A map of core means of $T_{max}$is not presented because T_{max} values for some samples are suspiciously small compared to those in adjacent samples, and similar organic matter within narrow depth intervals should reflect similar maturation. Migrated bitumen can cause unusually low T_{max} values (Whelan and Thompson-Rizer, 1993), and oil staining was observed in some thin sections.

PRODUCTIVITY, PRESERVATION, AND MATURATION OF ORGANIC MATTER

An implicit assumption in the study of organic matter in sedimentary rocks is that the amount and type of organic matter analyzed is dependent on four variables: the transport of terrestrial organic matter into the depositional basin, primary productivity, preservation during sedimentation and early diagenesis, and maturation of hydrocarbons during burial to generate petroleum. (For a discussion of the role of these processes see Tissot and Welte, 1984, and Engel and Macko, 1993.) Hite and others (1984) and, to a lesser extent, Hite and Anders (1991) discussed a variety of organic-chemical results used to evaluate the effects of these variables on the organic geochemistry of Paradox Formation interbeds. Most of their samples were from cores along the western part of the basin where maturation for any one stratigraphic unit should be more or less constant. They proposed that the interbeds contain a mixture of marine and coaly (terrestrial) organic matter and that organic matter preservation was enhanced in a sulfidic (H_2S-bearing), saline depositional environment. They indicated that oil migration from shale sealed above and below by evaporites is negligible but that oil did migrate from shale where such seals are not present.

The east-to-west increase in hydrogen index values (fig. 9*B*) reflects differential organic matter maturation, migration of hydrocarbons, and (or) differences in the proportion of kerogen types. Burial reconstruction using vitrinite reflectance data (Nuccio and Condon, in press) and T_{max} values show that the sediments in the southeasternmost part of the basin are overmature with respect to petroleum generation and maturation decreases to the west. This

Figure 9 (above and facing page). Maps of means of selected chemical parameters in individual cycles and cores of cycles 5 and 3 of the Pennsylvanian Paradox Formation. Circles with lower half filled indicate cycle 5 core samples representative of entire interbed; circles with upper half filled indicate cycle 3 core samples representative of entire interbed; filled circles indicate samples from cycles 5 and 3 representative of respective interbeds; open circles indicate samples from cycles 5 and 3 not representative of respective interbeds. Solid type represents data for cycle 3; screened italic type represents data for cycle 5. *A*, organic carbon (C_{Org}) (weight percent). *B*, hydrogen index (HI) (mg HC/g C_{Org}). *C*, chromium (Cr) (parts per million). *D*, nickel (Ni) (parts per million). *E*, disulfide sulfur (S_{Di}) (weight percent). *F*, $\delta^{34}S_{Di}$ (per mil). *G*, reactive iron (Fe_{rct}) (weight percent). *H*, degree of pyritization (DOP_r).



pattern is consistent with maximum subsidence of the basin along the front of the Uncompahgre uplift (Stevenson and Baars, 1987; Huffman and Condon, 1993) and burial beneath a thick Permian section (Cater, 1970). The coincidence of small hydrogen index values in thermally overmature parts of the basin and large hydrogen index values in parts of the basin in, or just entering, the oil window suggests that thermal maturation plays a major role in the distribution of hydrogen index values across the basin.

Mixing of kerogen types also contributes to the variability in hydrogen index values; that is, hydrogen index values are low for terrestrial organics and high for algal-type organics. Mixing is evident from trends in hydrogen index values within the cycle-3 interval of the Shafer core. All samples in this interval have the same burial-thermal history and are just entering the oil-generating window (Hite and others, 1984; Nuccio and Condon, in press; T_{max} values, this study). Vertical variation in hydrogen index values in the Shafer interval are attributed to mixing of terrestrial organic matter with marine-algal organic matter. Because degradation of organic matter during deposition and early diagenesis decreases the hydrogen index value, especially that of the algal-type

Table 7. Means of trace metals in shales of Pennsylvanian Paradox Formation, Utah and Colorado.

[Average shale values from Wedepohl (1978); n, number of samples]

Metal	n	Range (ppm)	Arithmetic mean (ppm)	Standard deviation	Geometric mean (ppm)	Concentration in average shale (ppm)
As	23	4.2–23	8.8	4.1	8.1	13
Cr	97	24–580	270	120	240	83
Mo[1]	97	<2–77	5.0	8.7	3.2	2.6
Ni	97	10–950	96	95	80	53
Se	23	3–24	8.3	5.7	6.9	0.6
V	97	24–590	98	60	88	110

[1] Statistics calculated by substituting 1 ppm for the 15 samples containing < 2 ppm Mo.

organics, the vertical variations may also represent an increase in preservation of organic matter upward through the core. Variability in hydrogen index values was not observed within cores from the southeastern parts of the basin. If originally present, the variability may have been obliterated by degradation or thermal maturation of the organic matter.

TRACE-METAL GEOCHEMISTRY

TRACE-METAL DATA

The geometric means of chromium and nickel concentrations vary among rock types (table 6). All shale types have high mean concentrations (150–280 ppm Cr, 61–98 ppm Ni), whereas limestone, dolostone, and siltstone have lower mean concentrations (25–40 ppm Cr, 12–20 ppm Ni). Dolomitic shale (150 ppm Cr, 61 ppm Ni) has less chromium and nickel than calcareous or argillaceous shale (230 and 280 ppm Cr, 74 and 98 ppm Ni). No significant difference was detected in chromium and nickel contents between cycle-5 and cycle-3 interbeds, and variations among cores are not sufficiently systematic to identify trends within the basin (figs. 9*C*, 9*D*).

TRACE-METAL ENRICHMENT

Trace-element concentrations can be used to define geochemical conditions during carbonaceous rock deposition (Calvert and Pedersen, 1993). In table 7, average trace-element contents of Paradox Formation shale are compared to the mean abundance in average shale as defined in the compilation by Wedepohl (1978). The Paradox shales contain much more chromium, nickel, and selenium than average shale. Other elements commonly enriched in carbonaceous shale, such as arsenic, molybdenum, and vanadium (Vine and Tourtelot, 1971), have mean contents in Paradox Formation shale that are not significantly different from average shale (table 7). Concentrations much higher than the mean values for all these metals were measured in a few samples.

The amounts of chromium and nickel added to Paradox sediments by geochemical processes were estimated by subtracting the allochthonous component from the whole-rock concentration. These calculations of enriched values are subject to major assumptions, including a chemically homogeneous detritus and limited metal redistribution during diagenesis. Nonetheless, enriched values more directly reflect processes affecting interbed composition than do total concentrations.

Allochthonous detritus in Paradox interbeds is assumed to have originated from source areas that were chemically similar because variations in mineralogy across the basin are not evident in the abundances of most elements. For example, the constancy of the source areas is consistent with the similar Al:Ti ratios in limestone, dolostone, siltstone, dolomitic shale, and argillaceous shale. Ratios of Al:Ti range from 18 to 21 and have correlation coefficients greater than 0.92 for these rock types. Aluminum and titanium are mostly bound to phases that are relatively unreactive in marine environments; therefore, both of these elements provide a good estimate of the amount of allochthonous detritus.

The amounts of chromium and nickel attributed to the allochthonous detritus were estimated by plotting chromium and nickel concentrations as a function of aluminum content (figs. 10*A*, 10*B*). Samples that have the lowest chromium and nickel concentrations relative to aluminum are considered to be samples in which depositional and diagenetic enrichment of the metals was small. This subset of the data was used to define the expected background concentrations as a function of aluminum content. Note that the background lines define slopes similar to the ratio expected for average shale. The amount of metal expected to be in allochthonous detritus, based on the aluminum content, was then subtracted from the whole-rock concentration to estimate the amount of element enrichment for both chromium and nickel. Calculated maximum enrichments are almost 500 ppm chromium and 150 ppm nickel.

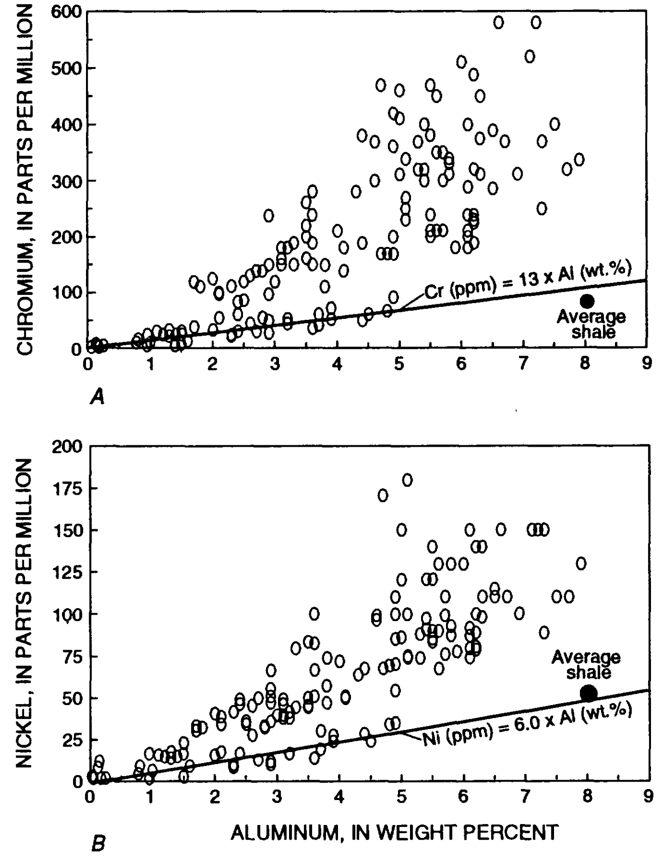


Figure 10. Crossplots of chromium (*A*) and nickel (*B*) versus aluminum for samples in study. See text for derivation of lines. Average shale values are from Wedepohl (1978).

The amounts of enriched chromium (Cr_{enrich}) and enriched nickel (Ni_{enrich}) are shown as a function of organic carbon in figures 11*A* and 11*B*. The linear distribution of the data indicates that organic matter accumulation and preservation and accumulation of the metals are related. A few dolostone and siltstone samples that contain moderate to large amounts of organic carbon are notable for their lack of metal enrichment. One of these samples contains migrated bitumen. The low chromium content of this sample is consistent with the small concentrations of chromium in petroleum (Barwise and Whitehead, 1983; Curiale, 1987). Other samples that have low metal contents relative to the amount of organic matter may also contain migrated hydrocarbons. Correlation coefficients of organic carbon versus enriched chromium and enriched nickel are 0.91 and 0.92, respectively, if the samples having low metals content and high organic-carbon content are excluded. Scatter away from a simple linear trend is attributed to spatial and temporal variations in the depositional environment and to organic-matter loss during oil and gas generation.

Trace elements originally dissolved in seawater accumulate in marine sediments through a range of possible processes (Breit and Wanty, 1991). Retention of these elements in the sediment requires geochemical conditions that inhibit cycling of the metals from the sediments back into the overlying water column (Shaw and others, 1990). The chemical conditions during deposition of the Paradox interbeds can therefore be estimated based on the metals that are most strongly enriched in carbonaceous rocks (Shaw and others, 1990; Emerson and Huested, 1991). Chromium, nickel, and selenium, the elements most enriched in the Paradox interbeds, accumulate in moderately to strongly reducing environments (Shaw and others, 1990). In contrast, arsenic, molybdenum, and vanadium, which are not enriched in the Paradox interbeds, are most enriched in strongly reducing sulfidic environments. The moderately reducing environment is envisioned to be capable of preserving organic matter but is devoid of H_2S until some depth below the sediment-water interface.

The weight ratio of enriched metal to organic matter in the Paradox interbeds is two to four orders of magnitude greater than the ratio found in modern organisms (Breit and Tuttle, 1994). Therefore, the ratio in the sediment requires either additional abiogenic mechanisms of chromium and nickel accumulation or the loss of more than 99.9 percent of the deposited organic matter. Alternative mechanisms of metal accumulation include diffusion into the sediment (Brumsack and Gieskes, 1983) and adsorption of metals onto organic and inorganic particles settling through the water column (Balistrieri and others, 1981). To account for chromium enrichments of more than 200 ppm in the Paradox interbeds, considering the small chromium concentrations of seawater (0.3 μg/kg; Quinby-Hunt and Turekian, 1983), a column of seawater several hundred meters high would have to pass through the sediment. Such a volume is inconsistent with both the preservation of organic matter and the sulfur isotope systematics of the chromium-enriched rocks. Accumulation by settling particles is a more reasonable explanation.

Ratios of enriched chromium to enriched nickel in the interbeds are variable and range from 0.3 to 25. For the shale samples, the ratio ranges from 0.35 to 7.7, and mean values are from 3.1 to 4.2. These ranges are attributed to variations in chemical conditions during deposition. Previous studies of modern and ancient sediments indicate that chromium is likely to accumulate and be retained in sediments in which organic matter is preserved (Shaw and others, 1990); however, nickel tends to accumulate in oxic sediments containing manganese oxides (Shaw and others, 1990) or is predicted to accumulate in sediments in which H_2S favors incorporation of nickel into sulfide minerals (Lewan, 1984). In moderately reducing sediments, nickel is cycled from the sediments into the overlying water because sulfide and manganese oxides are absent. Therefore, we interpret high ratios of enriched chromium to enriched nickel to indicate moderately reducing conditions near the sediment-water interface, whereas low ratios indicate more reducing conditions that favor sulfate reduction. Detailed analysis of the temporal variations in this ratio for cycle 3 of the Shafer core is presented in a later section.

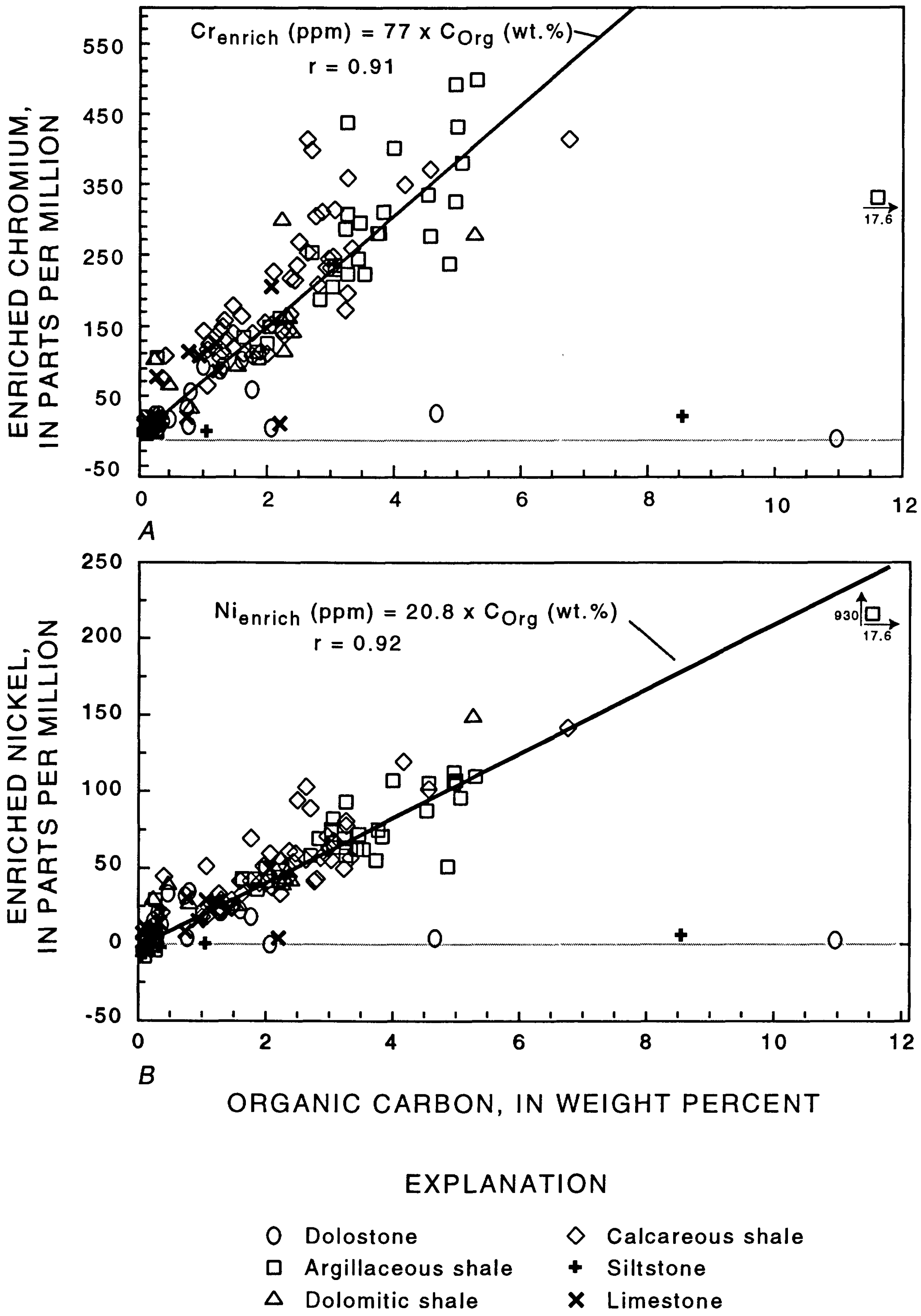


Figure 11. Crossplots of enriched chromium (*A*) and enriched nickel (*B*) versus organic carbon for samples in study by rock type.

SULFUR AND IRON GEOCHEMISTRY

SULFUR PHASES AND THEIR ISOTOPIC COMPOSITION

Disulfide sulfur (S_{Di}; sulfur in FeS_2) makes up 78 percent of the total sulfur in all but the anhydrite samples. The means of disulfide sulfur (weight percent) and its isotopic composition ($\delta^{34}S_{Di}$ ‰) for the different rock types and the different cores (by cycles) are presented in table 6. Argillaceous and calcareous shale have the largest means for disulfide sulfur. In cycle 5, the smallest means (0.28–0.58 weight percent) are in the northern part of the basin and in the Norton core (fig. 9*E*). In cycle 3, means are relatively similar among cores (0.83–1.3 weight percent), except for the high value (1.9 weight percent) in the West Water Creek core and the low value (0.54 weight percent) in the State core. The dominant disulfide mineral is pyrite, which is present as framboids, infilled framboids, anhedral and euhedral grains, and replacement of shells and sponge spicules (fig. 12).

$\delta^{34}S_{Di}$ values among the rock types are similar (–19.0 ‰ to –24.6 ‰), except that for dolomitic shale, which has a very negative $\delta^{34}S_{Di}$ mean (–30.4 ‰). Cores along the cycle-5 transect *B-B′* have similarly negative values (–28 ‰ to –38 ‰; fig. 9*F*). These very negative values reflect either slow bacterial sulfate-reduction rates (large isotopic fractionation factor) or a large, continuous supply of sulfate during sulfate reduction. Relative to many of the mean $\delta^{34}S_{Di}$ values in cycle 5, mean values for cores of cycle 3 are less negative (–14 ‰ to –26 ‰), indicating either faster reduction rates or smaller sulfate reservoirs during reduction.

Sulfate was detected in almost all samples (Appendix 2). $\delta^{34}S_{SO4}$ values of <0 ‰ suggest oxidation of a sulfide phase as the sulfate source. Pyrite could have oxidized during sample handling. Alternatively, sulfate could be the result of oxidation of H_2S during diagenesis. Sulfate that has a $\delta^{34}S_{SO4}$ value similar to that of bedded anhydrite (+12 ‰ to +17 ‰) probably was derived from sulfate in the water column or from migrating brines.

IRON AND ITS DEGREE OF PYRITIZATION

Reactive iron (iron soluble in hot 6 *M* HCl plus iron in FeS_2) makes up more than 86 percent of the total iron in all but the anhydrite samples (Appendix 2). The means for reactive iron (weight percent) and its degree of pyritization (DOP_r) for the various rock types and cores are given in table 6. Similar to means for disulfide sulfur, the highest means for reactive iron are for argillaceous and calcareous shales. In cycle 5, the highest means are for the west half of transect *A-A′* (fig. 9*G*). In the northern part of the basin, mean reactive iron values for cycle 5 are half those for cycle 3. Mean values for cycle 3 increase from the shelf into the basin along transect *B-B′* (1.3–2.2 weight percent). The highest mean for cycle 3 (2.4 weight percent) is in the middle of the southern part of the basin along transect *A-A′*.

Mean values for degree of pyritization are generally comparable among rock types, with the exception of a somewhat higher mean value (0.68) for limestone. In the northern part of the basin and in the Norton core (fig. 9*H*), mean values are the smallest (0.25–0.39). In the remainder of the southern cores, means are generally comparable between cycles and among cores (0.52–0.68), except for means for two of the shelf cores, which are larger (0.78 and 0.81).

PYRITE FORMATION

In the interbeds, the content of sulfur in disulfide minerals such as pyrite (S_{Di}) is proportional to amounts of reactive iron (S_{Di} and Fe_{rct} correlate with $r = 0.86$; fig. 13). If the amount of reactive iron sulfidized is considered (degree of pyritization, DOP_r), the amount of disulfide sulfur in the interbed can be expressed from this stepwise regression equation

$$S_{Di}\,(\mathrm{wt\%}) = -1.1 + 0.68 \times Fe_{rct}\,(\mathrm{wt\%}) + 1.9 \times DOP_r$$
$$(r = 0.96)$$

The amount of reactive iron parallels that of clay ($r = 0.84$), indicating that a primary reactive iron source to the sediment was probably iron-oxyhydroxide coatings on fine-grained particles. Such oxides are generally quite reactive to H_2S (Schoonen and Barnes, 1991). Because the amount and reactivity of iron ultimately controlled the amount of pyrite in the Paradox Formation interbeds, disulfide sulfur concentrations are not proportional to organic-carbon concentrations, as is the case for normal marine sediments (Sweeney, 1972).

Much of the data shown in figure 13 clusters near the stoichiometric FeS line. The predominant morphology of the sulfides in a given sample is predictable from where the sample plots relative to the FeS line. Samples that plot below the FeS line have DOP_r values <0.50 and contain predominantly framboidal pyrite, whereas those between the stoichiometric FeS and FeS_2 lines (DOP_r = 0.50–1.0) contain dominantly infilled framboids, euhedral or anhedral grains, or pyrite masses that replace shell fragments, sponge spicules, and tests.

Framboids are generally thought to be one of the first pyrite morphologies to form in sediment. They form by reaction of H_2S with reactive iron-oxyhydroxides to produce an unstable FeS phase that eventually converts to pyrite (Sweeney and Kaplan, 1972; Raiswell, 1982). Infilling of pyrite framboids (described in Love and Amstutz, 1966); growth of euhedral pyrite grains; and pyrite replacement of shells, spicules, and tests are thought

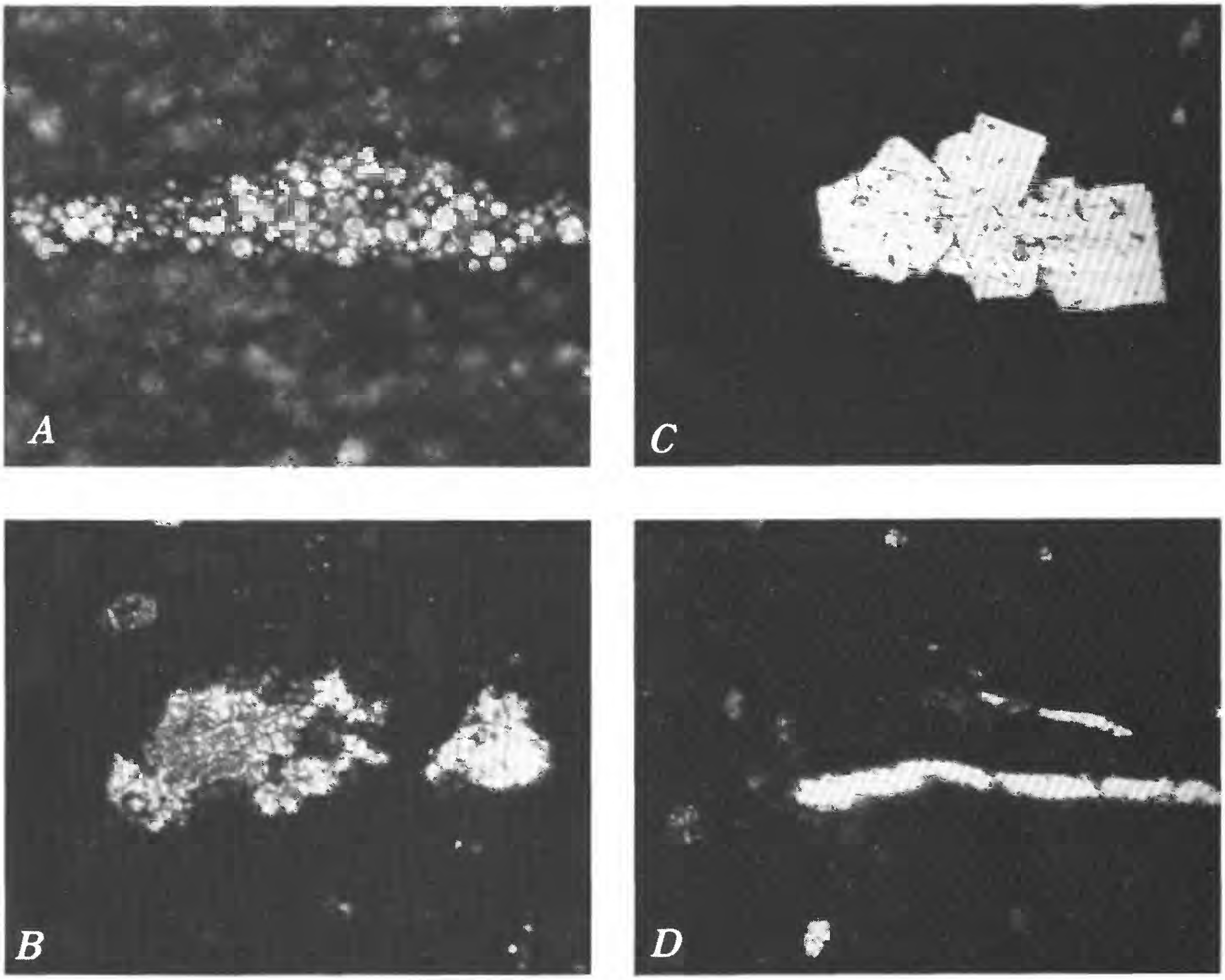


Figure 12. Photomicrographs of pyrite morphologies, reflected light in oil. Field of view 0.27 mm. *A*, framboids, Shafer core, 780.9-m depth. *B*, infilled framboids, Pickett Federal core, 1,726.4-m depth. *C*, euhedral, Crowley Ranch core, 1,802.9-m depth. *D*, replacement within shell, Pickett Federal core, 1,726.4-m depth.

to occur during deeper burial and may depend on the slow release of iron from more recalcitrant mineral phases (Raiswell, 1982; Canfield and others, 1992). The sulfur isotopic composition of pyrite can indicate conditions of pyrite formation and also help constrain the paragenesis of pyrite generations.

If seawater is the source of sulfate, the isotopic composition of sedimentary pyrite is controlled by three factors. First, the isotopic composition of the H_2S that ultimately forms pyrite is dependent on the fractionation factor associated with bacterial sulfate reduction. The size of the fractionation factor is inversely proportional to the rate of reduction (Kaplan and Rittenberg, 1964), which, in turn, is a function of organic matter preservation and sedimentation rate (Goldhaber and Kaplan, 1975). As rates of sedimentation increase, so do rates of sulfate reduction (because of enhanced organic-matter preservation), causing a decrease in the fractionation factor. The second factor is the size of the reservoir of available dissolved sulfate. The sulfate reservoir can decrease due to dilution, expulsion of pore water, or progressive sulfate reduction within a limited sulfate reservoir. As the sulfate reservoir decreases, a greater proportion of the sulfate is reduced, increasing the $\delta^{34}S$ of the H_2S produced (limited sulfate supply, as described by Nakai and Jensen, 1964). The third factor is the relative flux of sulfate input and sulfate removal. For example, dissolved sulfate in isolated bottom water of a stratified water column will become progressively enriched in ^{34}S because ^{32}S is preferentially reduced in the water column by bacteria and removed to the sediment as pyrite (Holser and Kaplan, 1966). This condition can be sustained only if the sulfate input rate into the system is similar to the sulfate

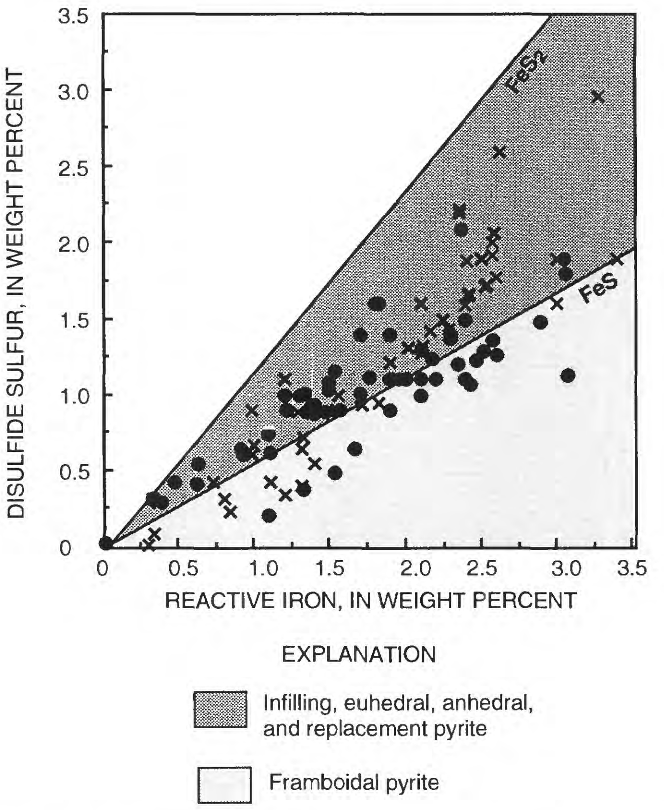


Figure 13. Crossplot of disulfide versus reactive iron for samples from cycle 5 (circles) and cycle 3 (x's) of the Pennsylvanian Paradox Formation showing fields of dominant pyrite morphology. Stoichiometric lines for pyrite (FeS_2) and monosulfides (FeS) are included for reference.

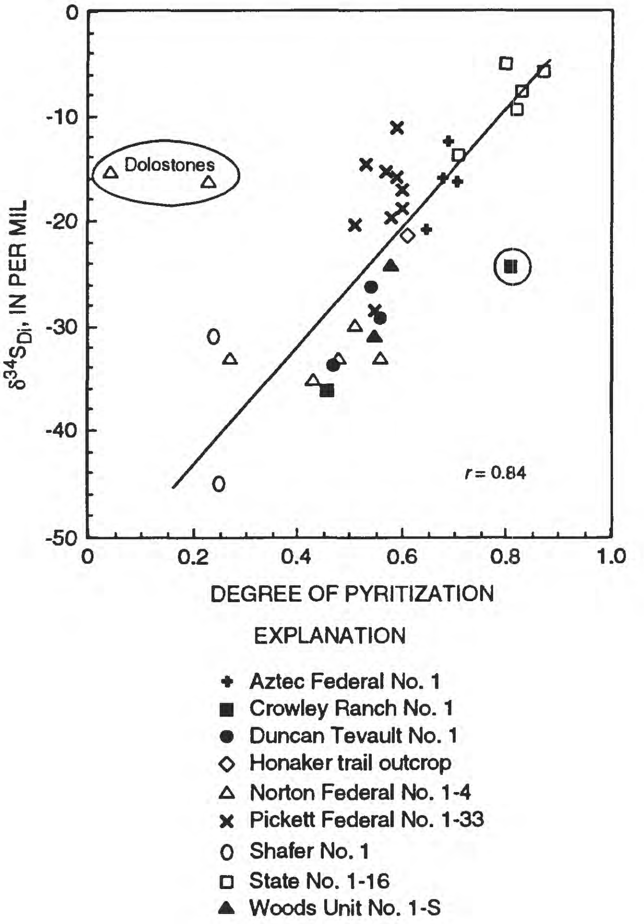


Figure 14. Crossplot of $\delta^{34}S_{Di}$ versus degree of pyritization (DOP_r) for samples from cycle 5 of the Pennsylvanian Paradox Formation. Circled points are excluded from the regression analysis.

removal rate. If a significant proportion of sulfate is reduced continually, the isotopic composition of the H_2S, hence pyrite, produced can evolve to $\delta^{34}S$ values much greater than those of the original dissolved sulfate (Tuttle and Goldhaber, 1993). This process can also produce pyrite of varying $\delta^{34}S_{Di}$ values, depending on the depth at which it forms in the water column (Tuttle and others, 1990; Sælen and others, 1993). The relative importance of these three controlling factors varies between cycles 3 and 5, among cores within a cycle, and within a single cycle, as indicated by cycle 3 of the Shafer core.

Interbeds from cycle 5 have a range of $\delta^{34}S_{Di}$ and degree of pyritization values because of variations in the conditions of sulfide formation. Both $\delta^{34}S_{Di}$ and degree of pyritization increase systematically to the southwest along transect *A-A'* (fig. 14). At the northeast end of the transect, at Duncan Tevault, $\delta^{34}S_{Di}$ values range from –33 ‰ to –23 ‰, whereas at the southwest end, the State samples have values from –15 ‰ to –5 ‰. Degree of pyritization values increase from 0.5–0.6 in the north to 0.7 and 0.9 in the south. Cores from this cycle that underlie the halite (Shafer core) and anhydrite (Crowley Ranch, Duncan Tevault, and Norton cores) from the northern end of the transect have $\delta^{34}S_{Di}$ values from –27 ‰ to –40 ‰ and degree of pyritization values <0.55. These large negative $\delta^{34}S_{Di}$ values and relatively low degree of pyritization values are typical of sulfides that form near the sediment-water interface in anoxic sediments if rates of sedimentation are slow and an infinite sulfate reservoir is available (Goldhaber and Kaplan, 1974, 1975). The change in both parameters to the south is consistent with reduction of sulfate in buried sediment. Under conditions of burial, the sulfate reservoir is isolated from sulfate in the overlying water column, and the H_2S generated becomes progressively enriched in ^{34}S as the proportion of the sulfate reservoir reduced increases. In addition, iron is released from less reactive phases during burial and reacts with available sulfide to produce a higher degree of pyritization. Increased depth of burial from north to south is consistent with the increasing thickness of the interbeds along transect *A-A'* (fig. 5*A*).

Cycle-3 shales from the southeastern part of the basin have $\delta^{34}S_{Di}$ values of about –15 ‰. These values are attributed to isolation of the sulfate reservoir by rapid sedimentation. Higher sedimentation rates in this area are inferred from the greater thickness of the interbed (fig. 5*B*). Intermediate negative $\delta^{34}S_{Di}$ values (–18 ‰ to –26 ‰) in other parts of the basin indicate that bacterial activity during cycle-3 deposition was similar (on the average) to that in open-marine sediment, although $\delta^{34}S_{Di}$ versus depth plots in the Shafer core show distinct isotopic evolution during cycle 3; this evolution is discussed in the next section.

VARIABILITY WITHIN A BASIN-CENTER CORE

Profound temporal changes in basin depositional conditions are best recorded in cores from basin centers, where the effects of more local and rapidly fluctuating basin-margin conditions are minimized. In order to examine the effects of changes in basin-center depositional and early diagenetic conditions on geochemical parameters, the cycle-3 interbed between bedded anhydrite (originally deposited as gypsum) in the Shafer core that is close to the depositional center of the basin (fig. 1) was sampled at a smaller interval than interbeds in other cores. Twenty-nine samples were collected from this 18-m-thick interval. The interbed lithology varies from bottom to top—from dolostone (possibly deposited as calcite) and siltstone, to argillaceous shale with thin beds of shaly dolostone, then back to dolostone (Appendix 1). Selected element concentrations, sulfur isotopic data, and other geochemical parameters are profiled in figure 15. The trends within these profiles indicate that conditions throughout deposition and diagenesis of the cycle-3 interbed were dynamic and that change occurred on several different time scales.

In general, organic-carbon concentration and hydrogen index (figs. 15*A*, 15*B*) increase systematically upward through the interval to a maxima at 774-m depth (5 weight percent and 430 mg/g, respectively), then decrease in the upper 4 m of the profile, which is composed of dolostone; values for dolostone are always less than those for adjacent shale. Because the thermal maturity is the same throughout this interval, the variability in hydrogen index probably results from either a change in the source of the organic matter or a change in preservation during deposition. The proportion of terrestrial and algal organic matter probably plays a greater role than preservation for reasons discussed in the following section.

No systematic change of disulfide sulfur values with depth is evident in the profiles (fig. 15*C*); however, values for shale are higher than those for adjacent dolostones and are higher in the upper part of the interval. Samples of shale having higher disulfide sulfur values also contain more reactive iron and higher degrees of pyritization (figs. 15*D*, 15*E*). $\delta^{34}S_{Di}$ values increase systematically from 782-m to 775-m depth (–35 ‰ to –17 ‰), then decrease systematically to the top of the profile (–38 ‰) (fig. 15*F*). This trend reflects a progressive change from sulfate reduction very near the sediment-water interface, to reduction in sediment isolated from the overlying water column during burial, then back to reduction at the sediment-water interface. More disulfide sulfur (higher reactive iron and degree of pyritization values) formed in sediments in which sulfate was reduced during burial when the release of iron during diagenesis would have occurred at the same time as generation of the H_2S.

Enriched chromium and enriched nickel values mimic the systematic increase in organic carbon above 782-m depth to maximum values of 380 ppm and 100 ppm, respectively (figs. 15*G*, 15*H*). Samples below 782-m depth are not enriched in either metal. The ratio of enriched chromium to enriched nickel does not vary systematically, and the dolostone within shale has ratios very similar to adjacent shale (fig. 15*I*). Similar to the $\delta^{34}S_{Di}$ data, the variations are attributed to changes in the depth at which H_2S is generated. Ratios of less than 3 indicate depositional periods during which H_2S was being generated very near the sediment-water interface and both chromium and nickel were retained in the sediment. Ratios of more than 3 indicate periods during which nickel, but not chromium, was recycled at the sediment-water interface because the redox front had moved deeper into the sediment.

Data for cycle 3 of Shafer core show that some geochemical parameters (C_{Org}, HI, S_{Di}, Fe_{rct}, DOP_r, Cr_{enrich}, and Ni_{enrich}) are dependent on rock type, whereas others ($\delta^{34}S_{Di}$ and Cr_{enrich}:Ni_{enrich} ratios) are not. The variability of parameters within the core indicates that processes during deposition and early diagenesis of the interbeds slowly and systematically changed within the basin (fig. 15).

GEOCHEMICAL PROCESSES DURING DEPOSITION AND DIAGENESIS OF SHALES OF THE PARADOX FORMATION

Shale within interbeds of the Paradox Formation is of special interest because it is a good petroleum source rock (high organic carbon and hydrogen index) and deserves special mention. Earlier in this report, we proposed that argillaceous, calcareous, and dolomitic shales have similar gross sedimentary characteristics. Calcareous shale has added bioclast carbonate material, and dolomitic shale is the result of postdepositional alteration of calcium carbonates during brine migration. On this basis, we can infer conditions of deposition and early diagenesis of identified shale populations using diagnostic geochemical parameters in a stratigraphic context.

The 35 samples of argillaceous shale that were analyzed for sulfur isotopic composition can be divided into two populations with respect to $\delta^{34}S_{Di}$ values: 10 samples

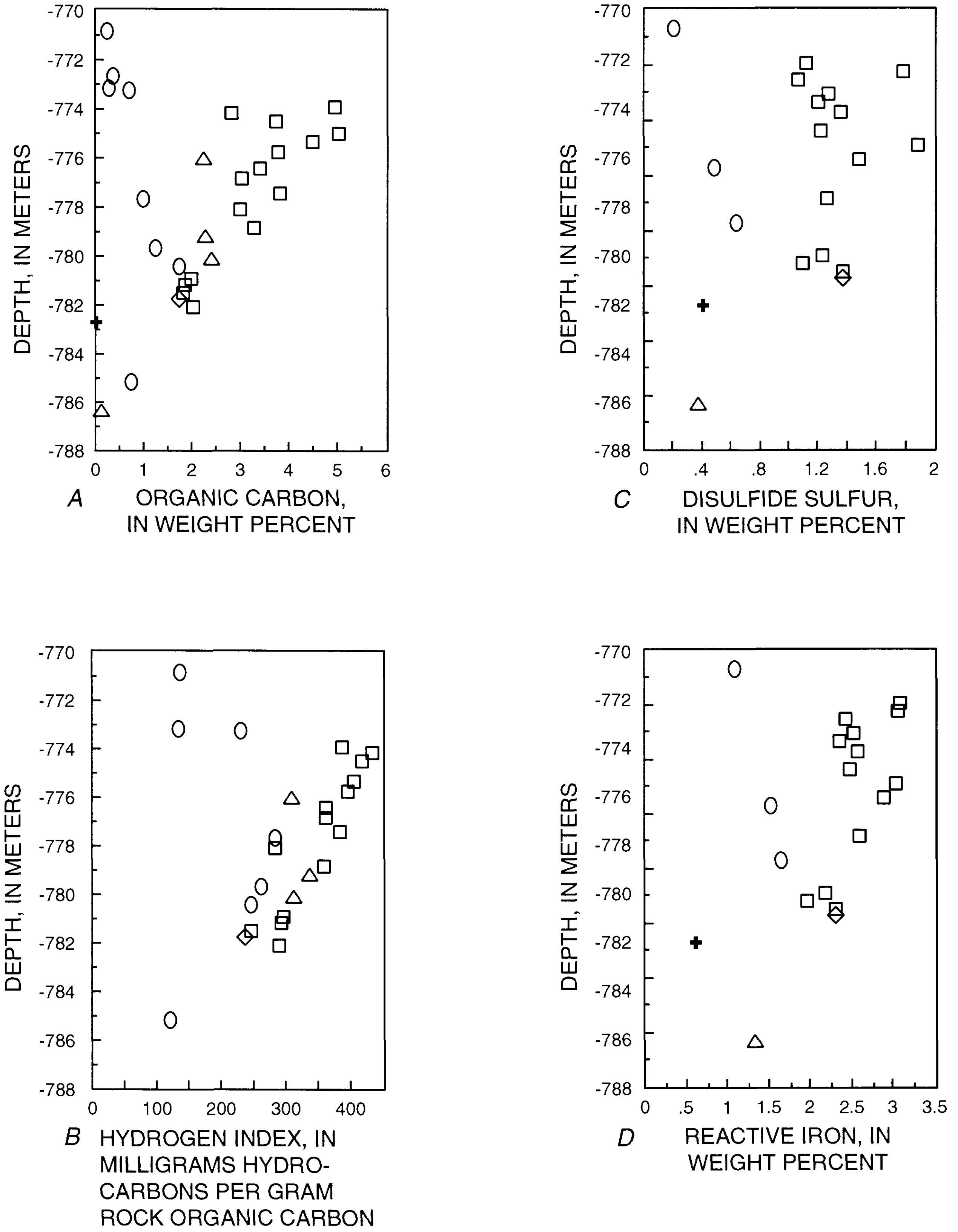
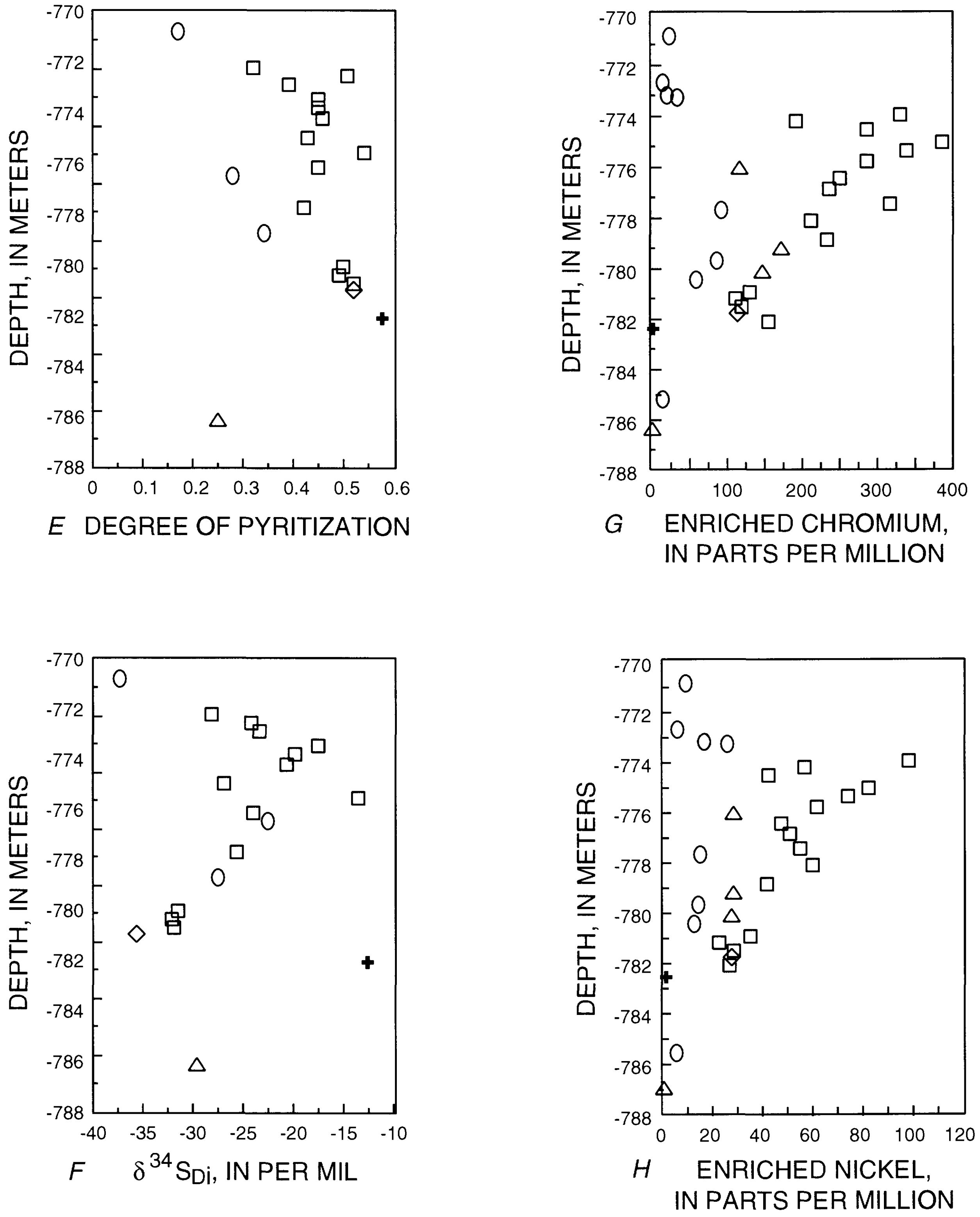
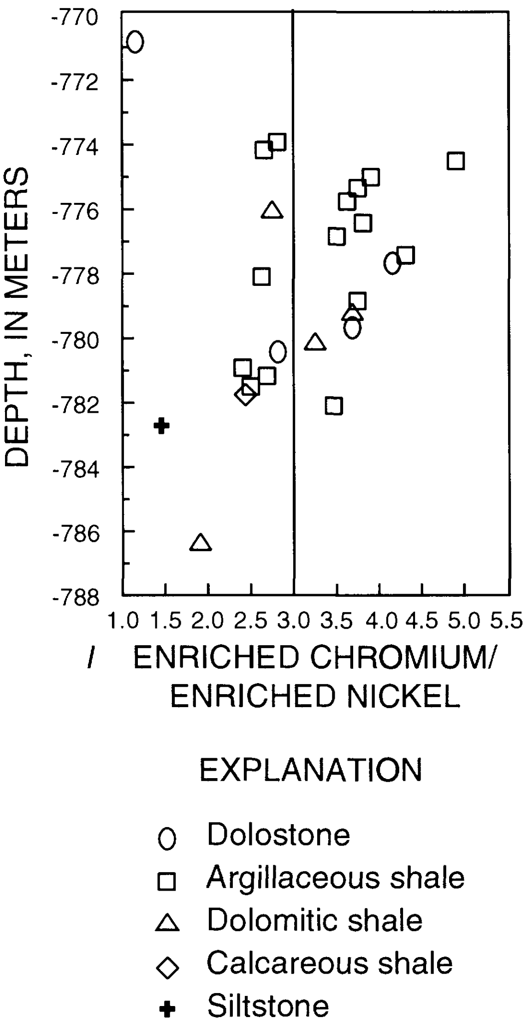


Figure 15 (above and following pages). Depth profiles of selected chemical parameters in cycle 3 in the Shafer core by rock type. *A*, Organic carbon (C_{Org}) (weight percent). *B*, hydrogen index (HI) (mg HC/g C_{Org}). *C*, disulfide sulfur (S_{Di}) (weight percent). *D*, reactive iron (Fe_{rct}) (weight percent). *E*, degree of pyritiztion (DOP_r). *F*, $\delta^{34}S_{Di}$ (per mil). *G*, enriched chromium (Cr_{enrich}) (parts per million). *H*, enriched nickel (Ni_{enrich}) (weight percent). *I*, enriched chromium to enriched nickel ratio (Cr_{enrich}:Ni_{enrich}) for interbed dolostones and shales.



have values <–27 ‰ (shale group 1) and 25 samples have values ≥–27 ‰ (shale group 2). Only one argillaceous sample in the shale group 1 contains sodium feldspar and apatite; all contain relatively large amounts of potassium feldspar; eight have Cr_{enrich}:Ni_{enrich} ratios ≤3.0; and all have DOP_r ≤0.56. Many samples in shale group 2 contain plagioclase and apatite, have relatively small contents of potassium feldspar, and generally have Cr_{enrich}:Ni_{enrich} ratios > 3.0 and DOP_r > 0.56. Argillaceous shale samples of group 1 are from cycle 5 and from the lower half of cycle 3 in the Shafer core. Argillaceous shale samples of group 2 are in all cores in both



cycles except that they are not in cycle 5 of the Shafer core.

With respect to geochemical parameters discussed in the preceding paragraph, of the 32 calcareous shales analyzed for $\delta^{34}S_{Di}$, 28 are similar to the argillaceous shale of group 2. The three dolomitic shales for which isotopic compositions were determined are more variable and do not fit neatly into either the shale group 1 or 2, possibly because of postdepositional alteration.

Proposed conditions of shale deposition and diagenesis consistent with geochemical characteristics of the two shale groups are summarized in figure 16.

Shale group 1.—As sea level rose at the onset of transgression, seawater entered the basin and a brine formed at the basin bottom through the dissolution of evaporites. The higher salinity of the brine created a pycnocline that separated the brine from the overlying seawater, and a stratified water column developed. Much of the organic matter accumulating in the sediment was terrestrial in origin, and the contribution from primary productivity was minor. Aided by the low oxygen content characteristic of brines (oxygen solubility decreases as salinity increases; Weiss, 1970) and by restricted circulation from stratification, settling organic matter quickly established anoxic conditions at the sediment-water interface. Bacterial reduction of sulfate occurred at or directly below the sediment-water interface where sulfate was readily available from the overlying water column (infinite reservoir). Only the very reactive iron oxyhydroxides were available to form pyrite by reaction with the H_2S being generated. The rate of sedimentation probably was slow, facilitating the diffusion of sulfate from the brine into the sediment. These conditions produced very ^{34}S depleted iron sulfides. Sulfate reduction ceased once the sediments were isolated from the overlying water column, possibly because of the refractory nature of terrestrial organic matter. In the upper water column, seawater circulation continued to provide fluxes of particulate organic matter and metals to the sediment; however, metals in the bottom brine were quickly depleted due to restricted circulation in the brine. Most of the chromium and nickel were retained in the anoxic sediment where organic-matter degradation was inhibited. The high potassium feldspar and low plagioclase contents in shale of group 1 relative to other shale may reflect the alteration of plagioclase to authigenic potassium feldspar, which has been described in the shale (D. Tromp and G. Whitney, 1992, unpub. data). High potassium concentrations enhance the alteration process and are a characteristic of brines derived from dissolution of the potassium-bearing evaporites or residual brines such as those in the Paradox Basin (Rice and others, 1994).

Shale group 2.—As the basin filled, the pycnocline weakened and the brine mixed with seawater, becoming less saline throughout the basin and only mildly reducing. Argillaceous shale accumulated in the basin center, whereas calcareous shale formed nearer to and on the shelf. Detrital sodium feldspar was stable in the more dilute bottom waters. Reworking of organic matter at the sediment-water interface was sufficient to release the phosphate needed to form apatite present in many samples of shale group 2 but not sufficient to destroy all the organic matter. Partial recycling of phosphate and other nutrients to the surface waters stimulated primary productivity. Chromium and nickel were supplied continually by good circulation of seawater throughout the entire water column. Chromium was preferentially retained in the sediment relative to nickel because once-reduced chromium is relatively immobile, even during reworking of organic matter in the sediment, whereas nickel may diffuse out of the sediment (Shaw and others, 1990). As circulation of bottom water increased, the redox front moved down into the sediments and sulfate reduction did not begin until the sediments were partially isolated from the infinite sulfate reservoir in the bottom waters. More pyrite formed in these sediments than during formation of shales of group 1 because release of iron from diagenetic processes was now time correlative with H_2S generation.

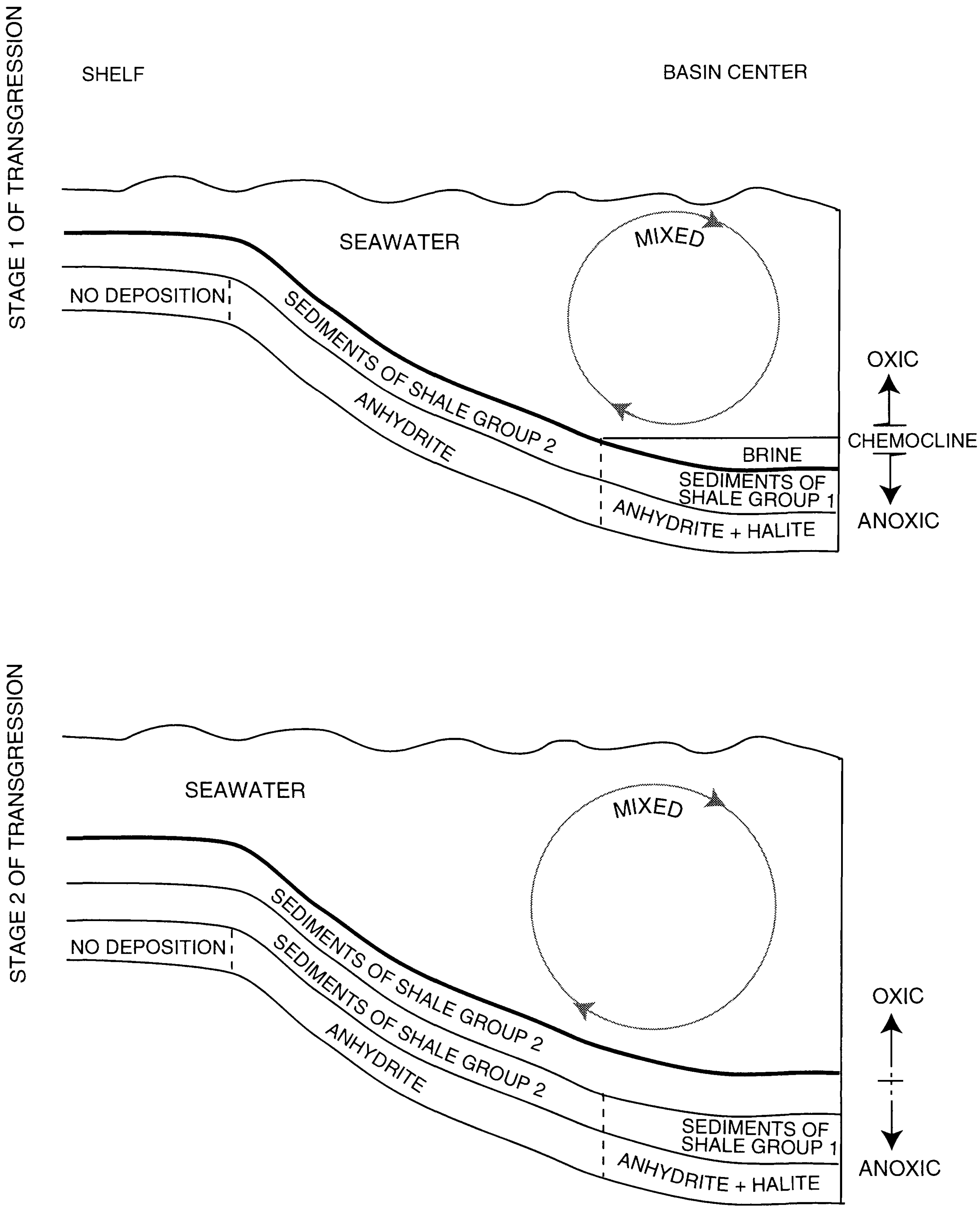


Figure 16. Conditions during deposition of shales of groups 1 and 2. See text for explanation of groups.

CONCLUSIONS

During the Pennsylvanian Period, 33 repetitive cycles of marine evaporite-carbonate-siliciclastic rocks were deposited in the Paradox Basin of Utah and Colorado. The similarity in the repetitive lithologic sequences of these 33 cycles was controlled primarily by eustasy (transgressive and regressive events). The vertical and aerial variability within and between interbeds of cycles 3 and 5 suggests that somewhat unique physical and chemical conditions existed during deposition of each cycle.

1. Variability in the mineralogy of silicates across the basin suggests that, during cycle 5, clastic material was derived from separate source areas to the southwest, the east, and the north. Mineralogical uniformity of clastics in cycle 3 suggests either one source or effective mixing of multiple sources.
2. Hydrogen indices vary both across the basin and vertically in cores because of changes in the proportions of terrestrial- and algal-derived organic matter deposited and preserved and because of differential maturation of the organic matter across the basin.
3. Sulfur and iron geochemistry suggests that, at the onset of transgression, the water column became stratified, possibly because of salt dissolution, and anoxic conditions persisted at the sediment-water interface. As transgression proceeded, seawater circulation mixed the water column and anoxic conditions moved deeper into the sediment.
4. Trace-metal concentrations in carbonaceous rocks suggest that circulation was good throughout the basin and indicate that H_2S was not an important component of water in the basin.
5. Shale in the interbeds was deposited under two sets of conditions. Shale of group 1 was not enriched in metals, contains terrestrially derived organic matter, and was deposited during early transgressive phases when circulation was restricted. Shale of group 2 was enriched in chromium, nickel, and algal matter; was deposited when seawater circulated throughout the basin, and is the notable petroleum source rock in the basin.

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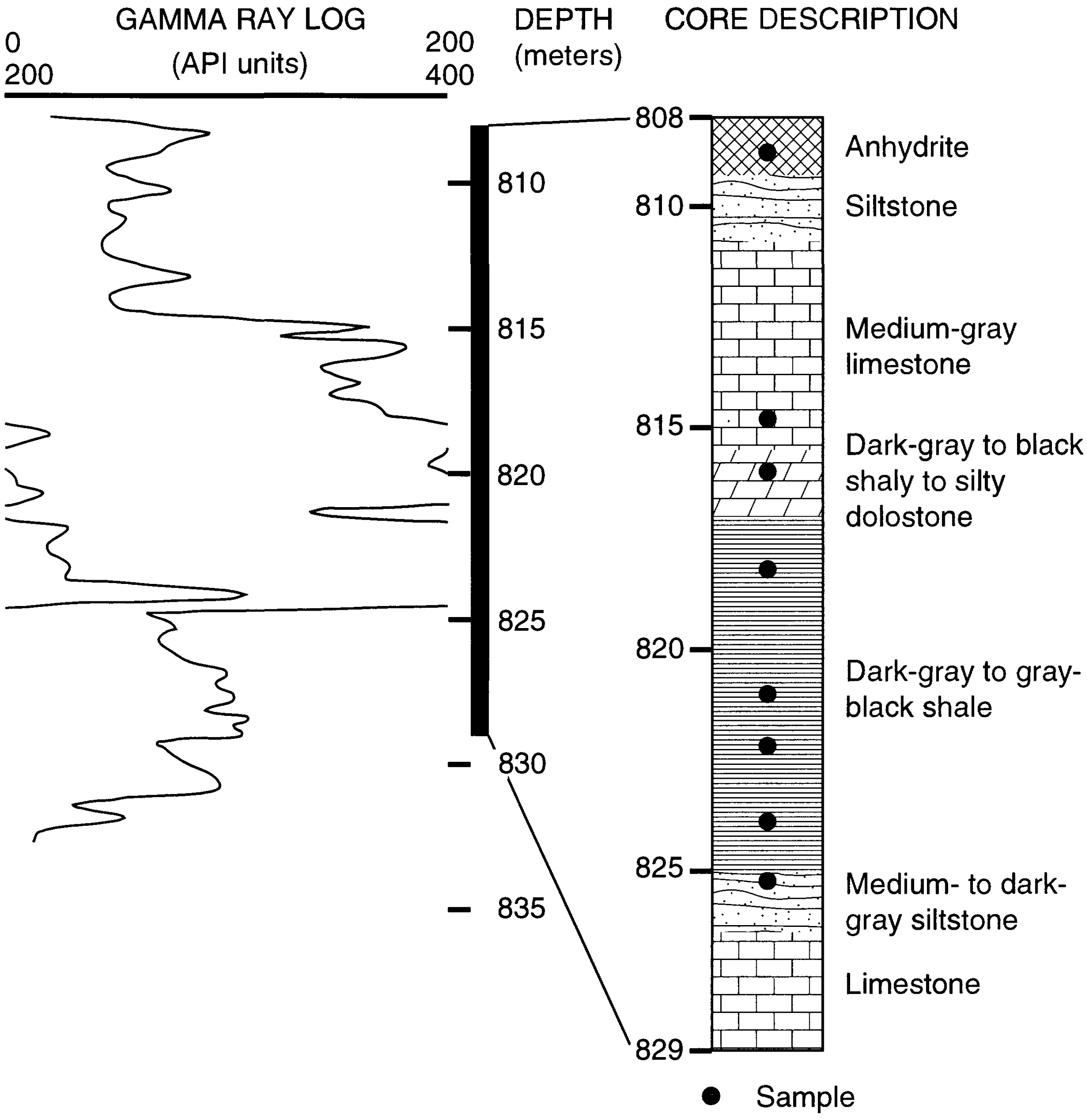
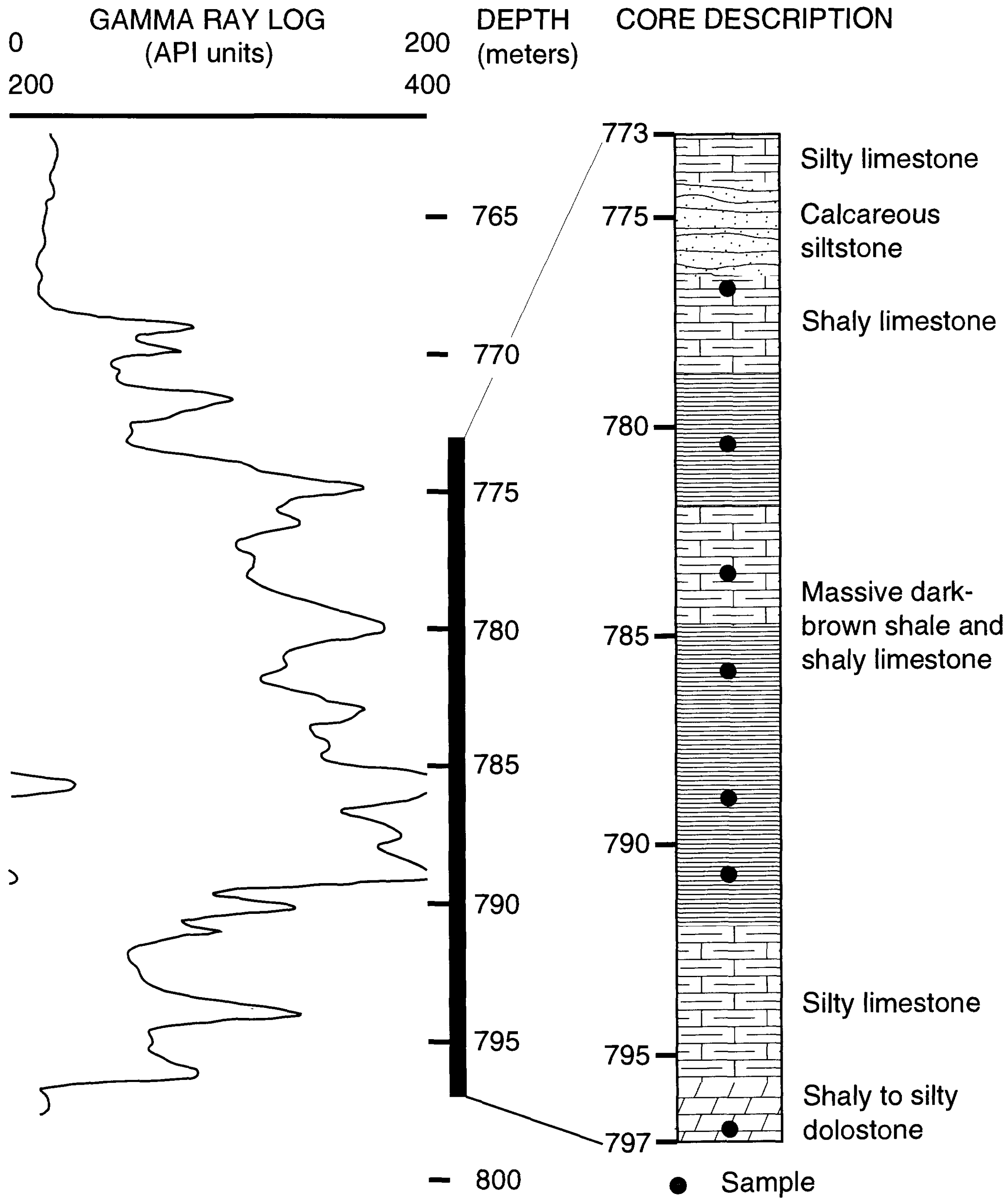
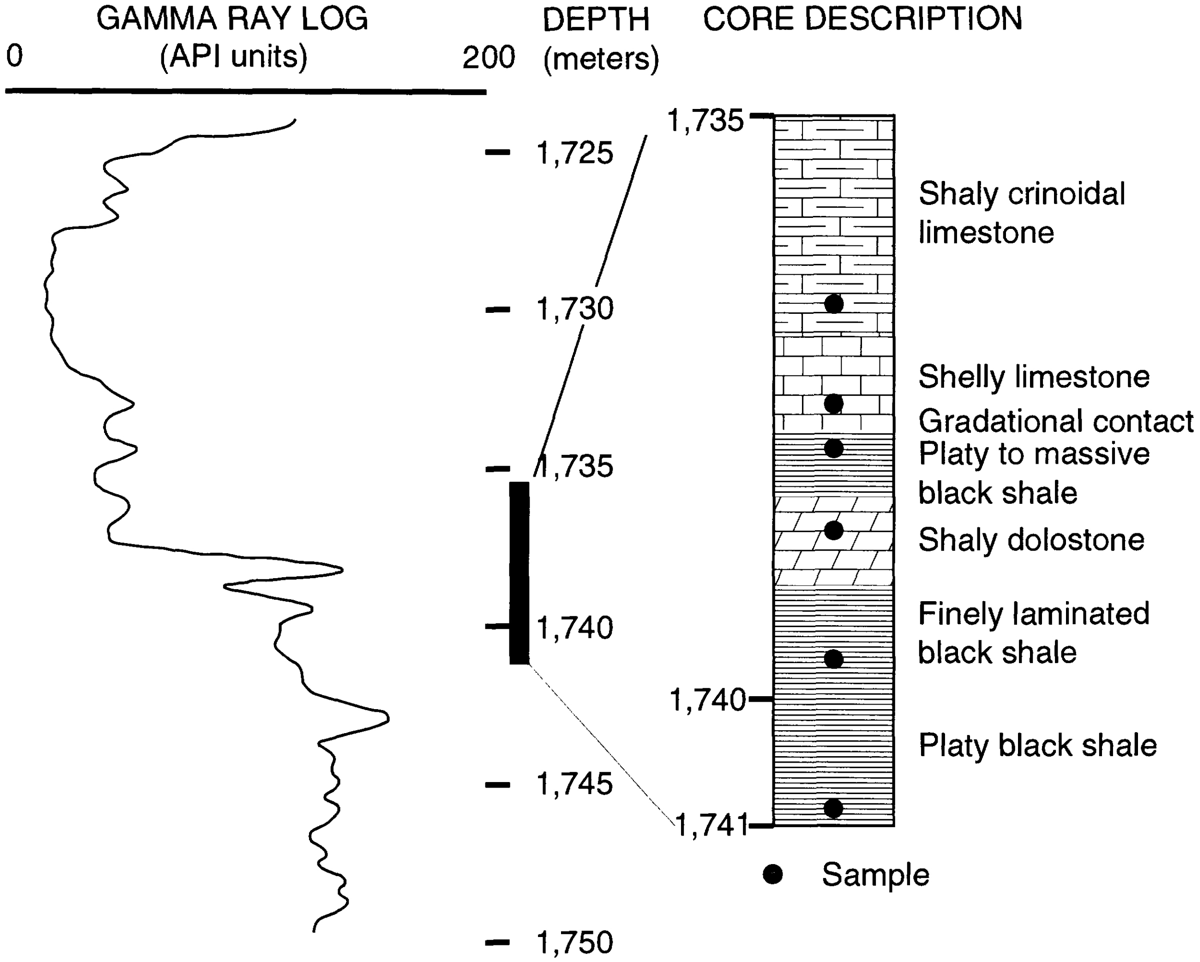
APPENDIX 1—CORE DESCRIPTIONS AND SAMPLING INFORMATION



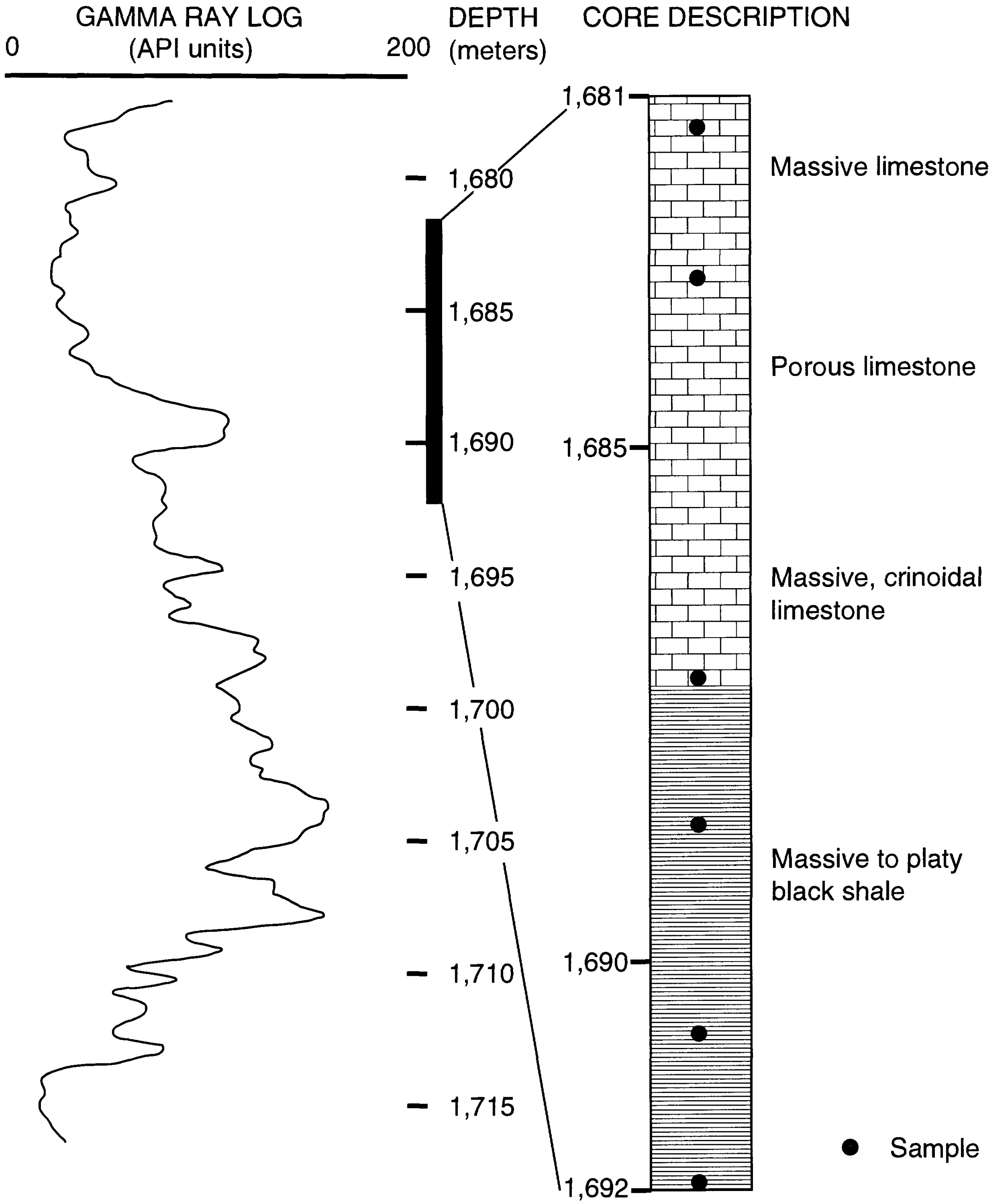
U.S. Department of Energy Elk Ridge No. 1, sec. 30, T. 37 S., R. 13 E., San Juan County, Utah. API 4303790625. Cycle 5. Twenty-one meters of cycle 5 was examined and sampled. The lower portion of the sampled interval is 3 m of limestone, overlain by 1.5 m medium- to dark-gray siltstone and 8 m of dark-gray to gray-black shale. The shale is laminated and contains abundant reddish organic matter, silt-size quartz and dolomite, well-oriented muscovite, and large pyrite grains elongated along laminae. Above the shale are 1.5 m of dark-gray to black dolostone, almost 5 m of gray limestone, 1.5 m of siltstone, and 1.5 m of anhydrite at the top of the interval. The dolostone is silty and weakly laminated and contains dolomite rhombs in a clay-carbonate matrix. Some shell fragments and possible echinoderm tests have been replaced by chalcedony and (or) micritic calcite. Pyrite is present as euhedral cubes, disseminated anhedral grains, and cement.



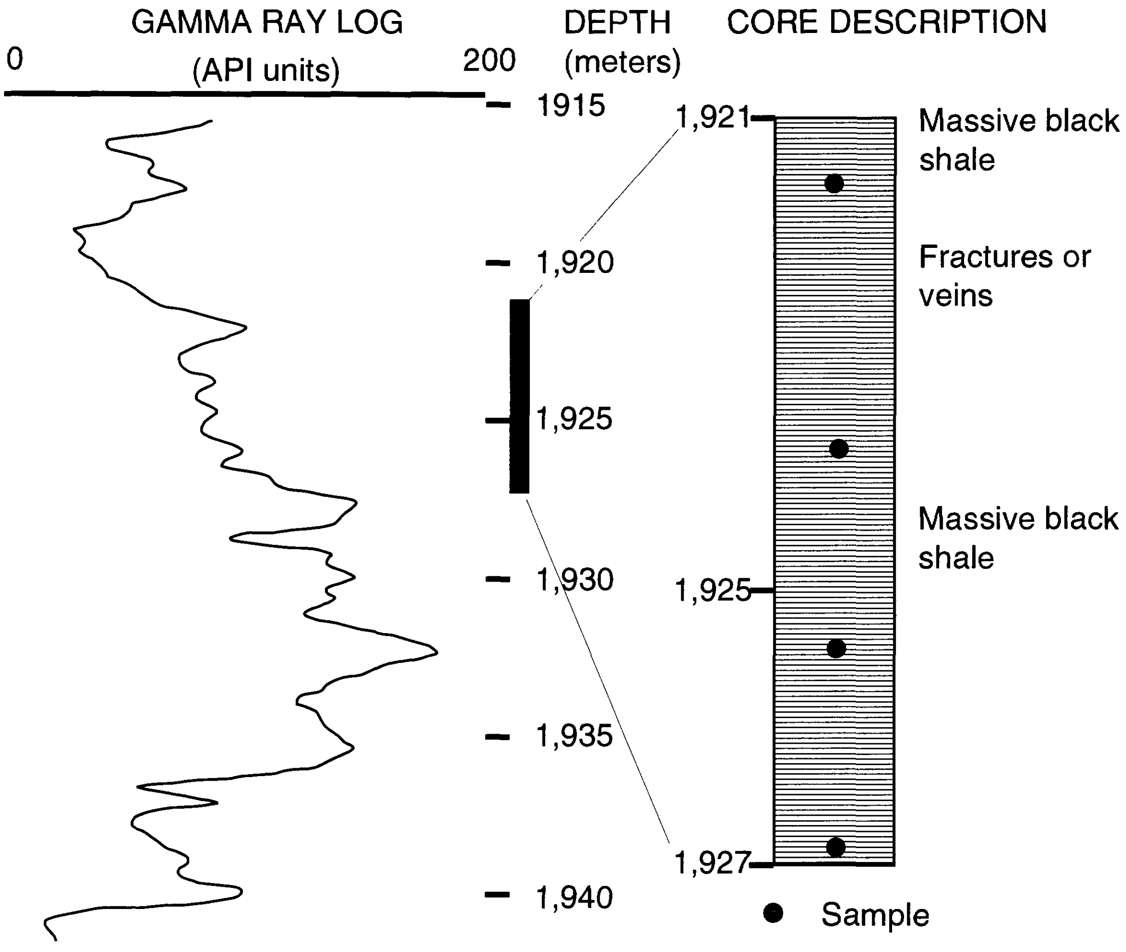
U.S. Department of Energy Elk Ridge No. 1, sec. 30, T. 37 S., R. 13 E., San Juan County, Utah. API 4303790625. Cycle 3. Approximately 24 m of cycle 3 was examined and sampled in this core. The lower part of the sampled interval is represented by shaly to silty, laminated dolostone. In some areas, the laminae are disrupted as if bioturbated. One area rich in organic matter contains a vein of pyrite cement. The dolostone contains minor to trace glauconite, anhydrite, and muscovite. About 16 m of alternating silty to shaly limestone and massive dark-brown calcareous shale beds overlies the dolostone. The shale contains some fine-sand-size quartz and carbonate grains, well-oriented muscovite grains, micritic carbonates, disseminated anhedral pyrite, and minor pyrite cement. The silty limestone has disrupted laminae, sparry calcite replacing shell fragments, and fine-sand-size quartz. Pyrite is present as anhedral grains and ragged-appearing framboids and framboid aggregates. A calcareous siltstone (2.5 m thick) overlies the alternating bed interval and is overlain by more silty limestone.



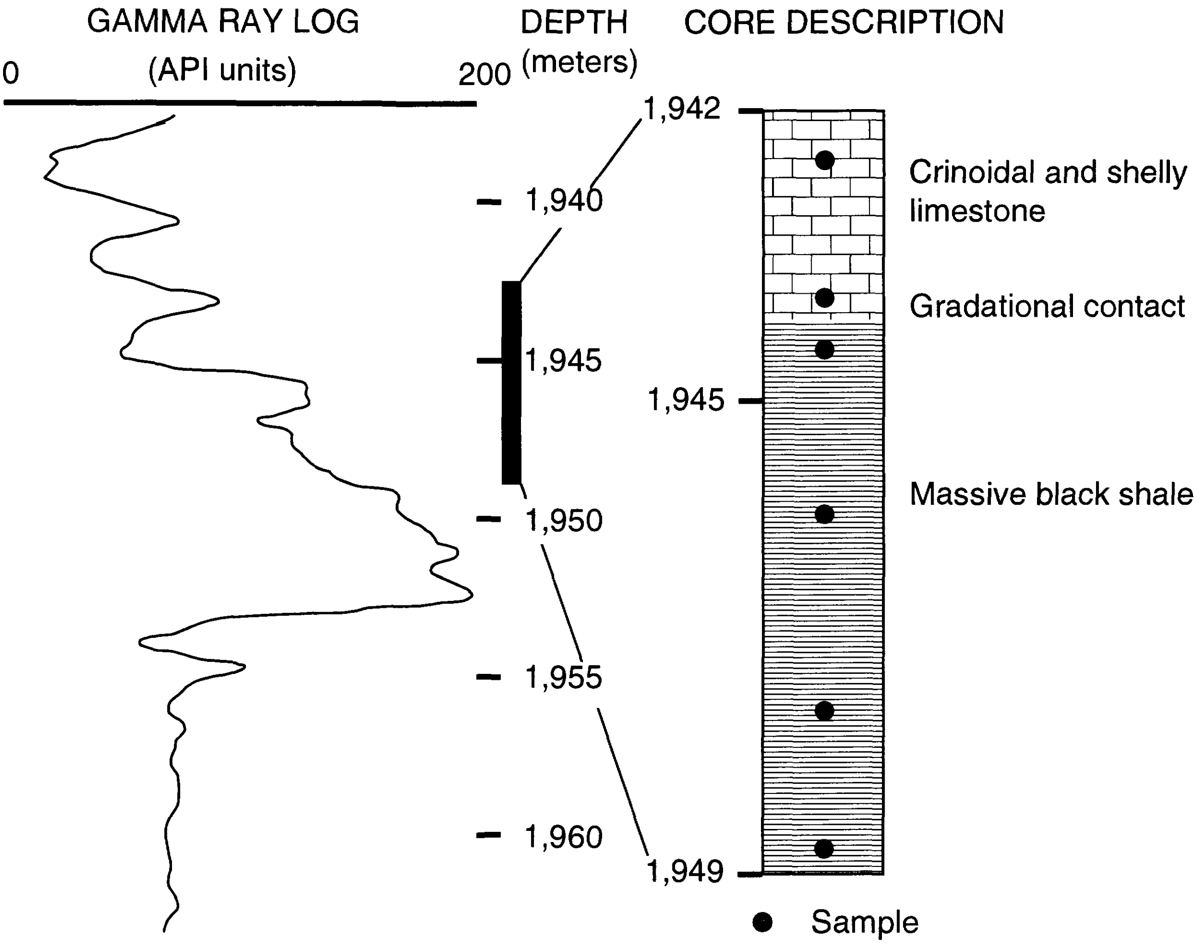
Carbonit Exploration State No. 1-16, SE¼NW¼ sec. 16, T. 39 S., R. 21 E., San Juan County, Utah. API 4303730603. Cycle 5. Approximately 6 m of cycle 5 core was examined and sampled. A platy, dark-gray to black shale in the lower 3.4 m of the interval grades upward into a massive, medium-gray, fossiliferous limestone. The shale appears to be less organic rich upward. Detrital grains in the shale are mostly silt-size quartz and calcite. Shell fragments are rare to common. Dolomite rhombs are the major authigenic component and can make up a major part of the shale. Pyrite is abundant as framboids and shell replacement. Some larger (silt-size) euhedral crystals of pyrite were observed in one sample (a dolomitic shale, 1,738.6 m). Marcasite may also be present.



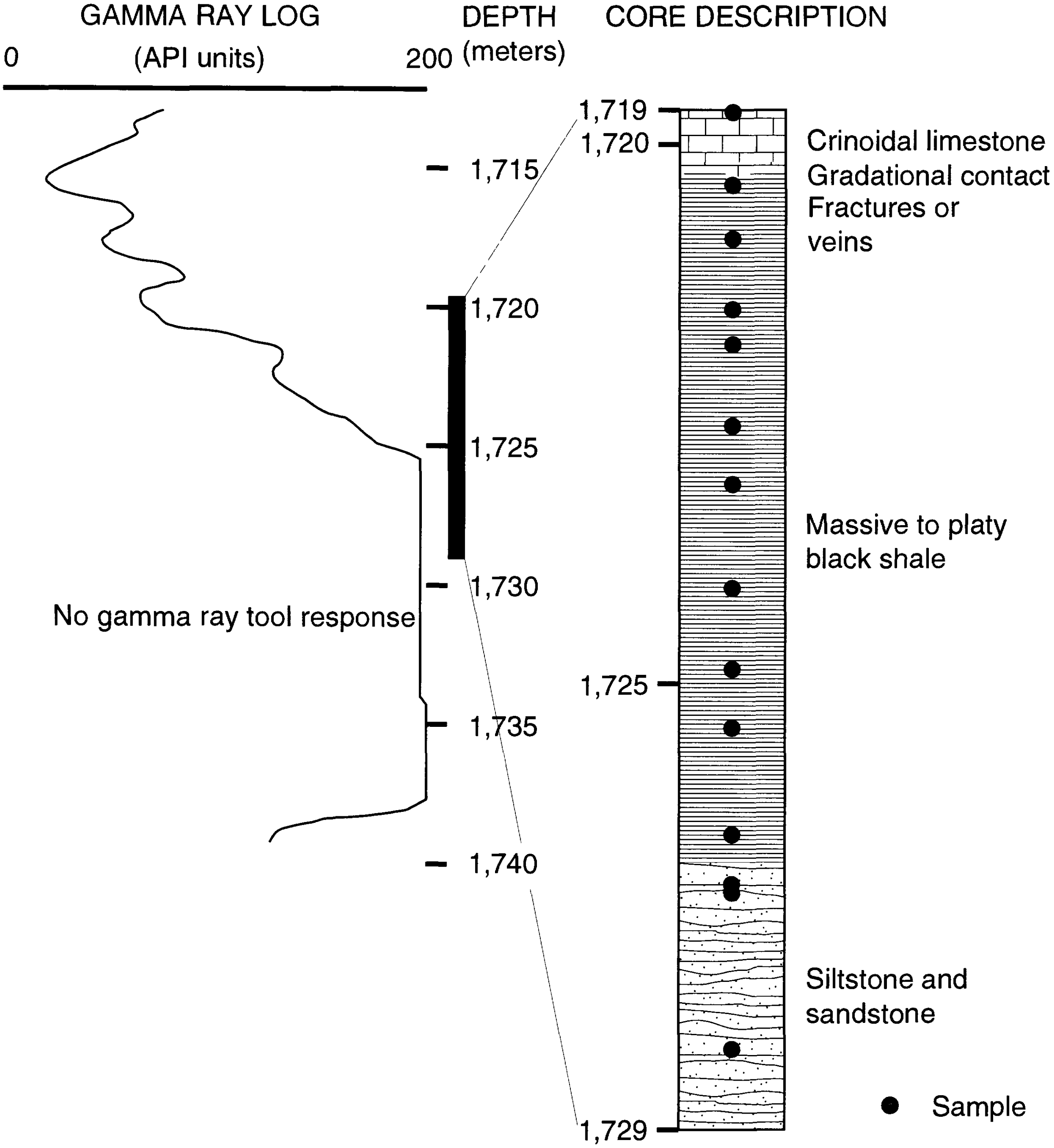
Carbonit Exploration State No. 1-16, SE¼NW¼ sec. 16, T. 39 S., R. 21 E., San Juan County, Utah. API 4303730603. Cycle 3. During cycle 3 time, the location of this well was on or close to a shallow marine shelf that bounded the western margin of the basin (text fig. 4*B*). The interval examined is approximately 10.7 m thick and contains, in ascending order, a massive to platy, dark-gray to black shale in the lowest part (4.9 m thick); a massive, medium-gray, crinoidal limestone (2 m thick); a vuggy, light-gray, fossiliferous limestone (3 m thick); and a massive, light-gray, crinoidal limestone at the top. The lowermost dark shale contains common to abundant, silt-size quartz, feldspar, and muscovite. Some shell fragments, and lenticular concentrations of sponge spicules as long as a few millimeters, are present. Authigenic minerals include sparse patches of microcrystalline calcite cement; common, well-developed, silt-size dolomite rhombs; abundant pyrite; and possibly some marcasite. The pyrite is present mostly as small (silt-size), disseminated crystals; however, larger (silt-size), anhedral, "hairy" crystals are common. Only a few framboids and pyrite replacements of shell fragments were observed.



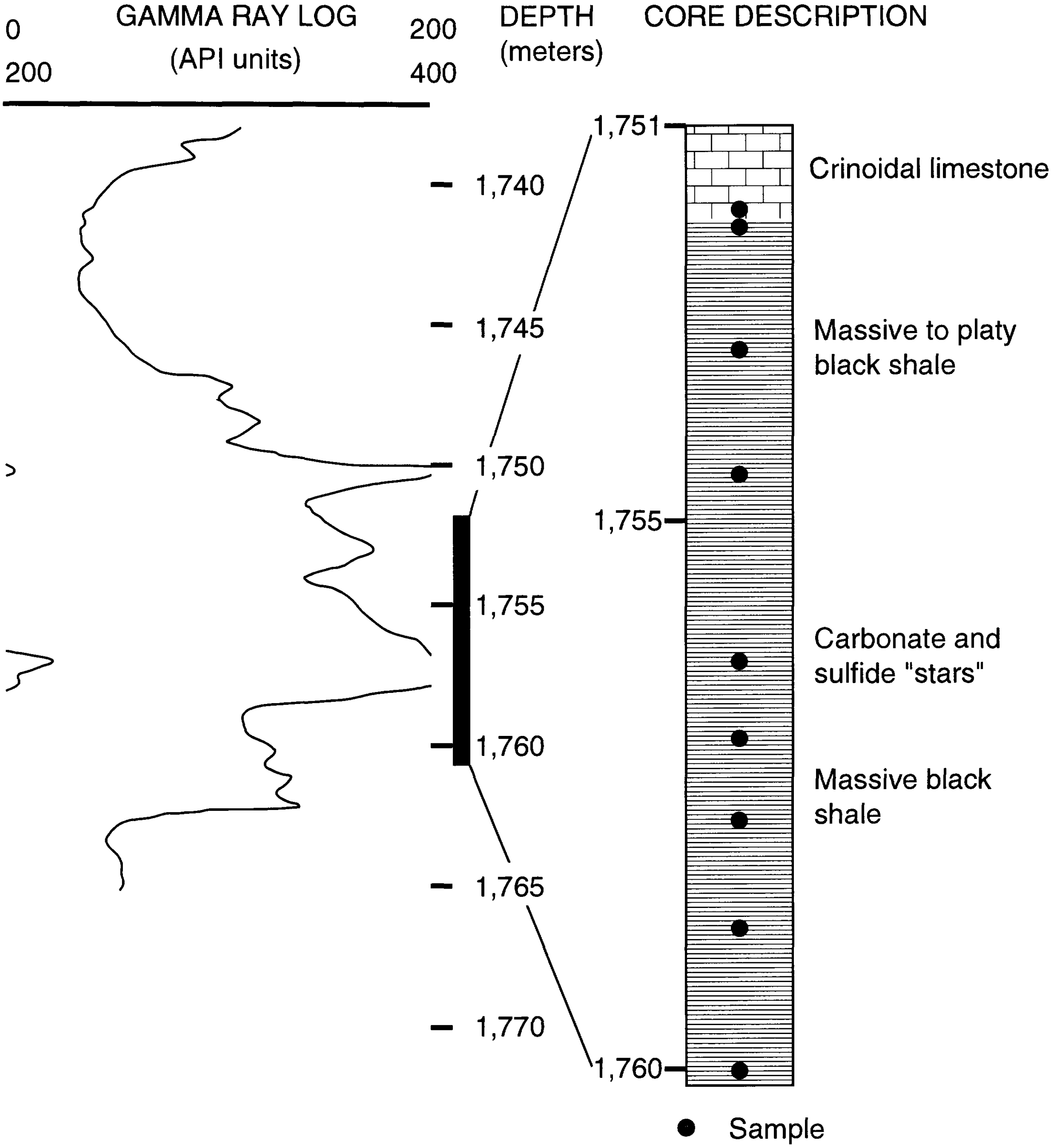
Southland Royalty West Water Creek No. 1, SW¼SE¼ sec. 4, T. 38 S., R. 22 E., San Juan County, Utah. API 4303730713. Cycle 3. Cycle 3 in this core is approximately 6 m thick and is predominantly a massive to platy, dark-gray to black shale. Within the upper 2 m, massive fractures or veins are filled with sulfides and sulfate minerals. The shale is more organic rich in its upper part, and both organic matter and the amount of clastic detritus increase upward. The uppermost sample contains abundant, silt-size quartz, feldspar, and muscovite, whereas the lowermost sample contains only rare silt-size quartz and muscovite grains. In all of the samples, carbonate grains (possibly abraded shell fragments), shell fragments, and sponge spicules were common. Some lenticular concentrations of sponge spicules are observed. Among the authigenic minerals are sparse to common, well-developed, occasionally zoned dolomite rhombs; pyrite; and, in the uppermost sample, chalcedony (partially replacing shell fragments) and patches of microcrystalline calcite cement in the spicule-rich lenses. Pyrite is common and is present mostly as framboids and disseminated, silt-size crystals. The framboids are most common in the lower part of the sampled interval. In the lower part, pyrite partially replaces sponge spicules and shell fragments.



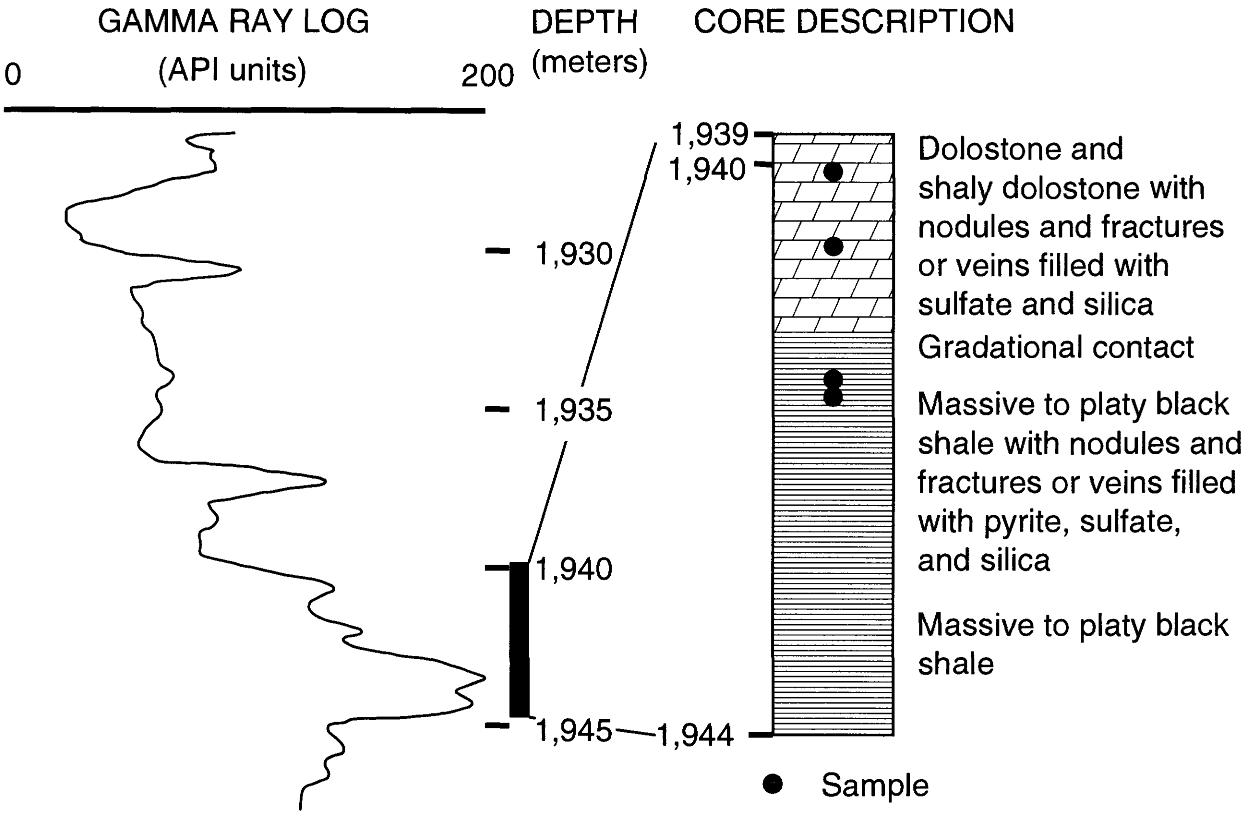
E.L. and B.R. Cox Aztec Federal No. 1, sec. 24, T. 37 S., R. 23 E., San Juan County, Utah. API 4303730724. Cycle 5. Approximately 6.3 m of core was sampled and examined. The lower 4.5 m is a massive, dark-gray to black, very organic rich shale that grades upward into a massive, medium-gray, fossiliferous, limestone. In the shale, silt-size quartz and muscovite grains are rare to common and decrease upward in amount. Unlike the dolostone, no shell fragments are observed in the shale. Pyrite was the only observed authigenic mineral. Pyrite is common to abundant and is present mostly as dispersed, single, silt-size crystals. A few framboids are present, and some may be overgrown or infilled.



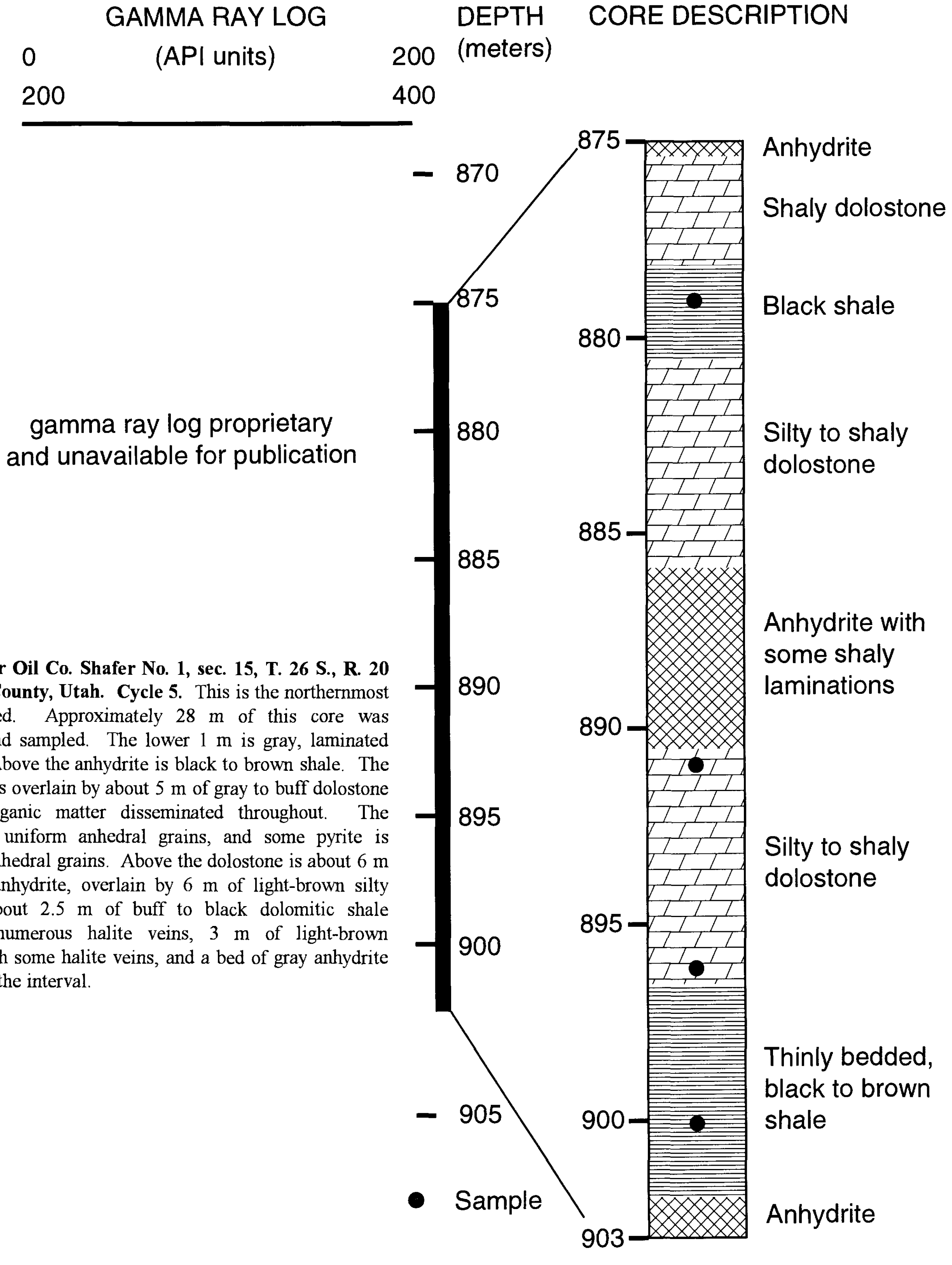
McCulloch Oil and Gas Corp. Pickett Federal No. 1-33, SE¼NE¼SW¼ sec. 33, T. 36 S., R. 25 E., San Juan County, Utah. API 43037330539. Cycle 5. Of the 9.5 m of core examined, the lower 3 m is sandstone and siltstone. These are overlain by platy to massive, dark-gray to black, fossiliferous, organic-rich shale approximately 3 m thick. This shale grades upward into a dark gray to black shale that is very organic-rich and devoid of fossils. This upper shale is approximately 3.5 m thick and grades upward into a massive, medium-gray, fossiliferous (crinoidal) limestone. Sulfate- or carbonate-filled fractures or veins are present in the shale close to the limestone contact. The sandstone (and siltstone) is generally silt size to very fine grained, sublitharenite to quartzarenite. Clay matrix content ranges from trace to common and probably decreases upward. The sandstone is almost completely cemented by pore-filling calcite and, in some samples, dolomite. The lower shale interval contains abundant silt-size quartz and muscovite, shell fragments, deformed phosphatic(?) pelloids, and elongate agglomerates. The amount of shell fragments and pelloids appears to decrease upward. The upper shale is very similar to the lower shale, except, as mentioned before, it is more organic-rich and is devoid of fossils. In both the upper and lower shale intervals, dolomite and pyrite are the major authigenic minerals. Dolomite is generally present as silt-size rhombs. Pyrite is present as framboids or single crystals. The framboids are sometimes clustered. In the lowermost shale interval, some shell fragments are replaced by pyrite.



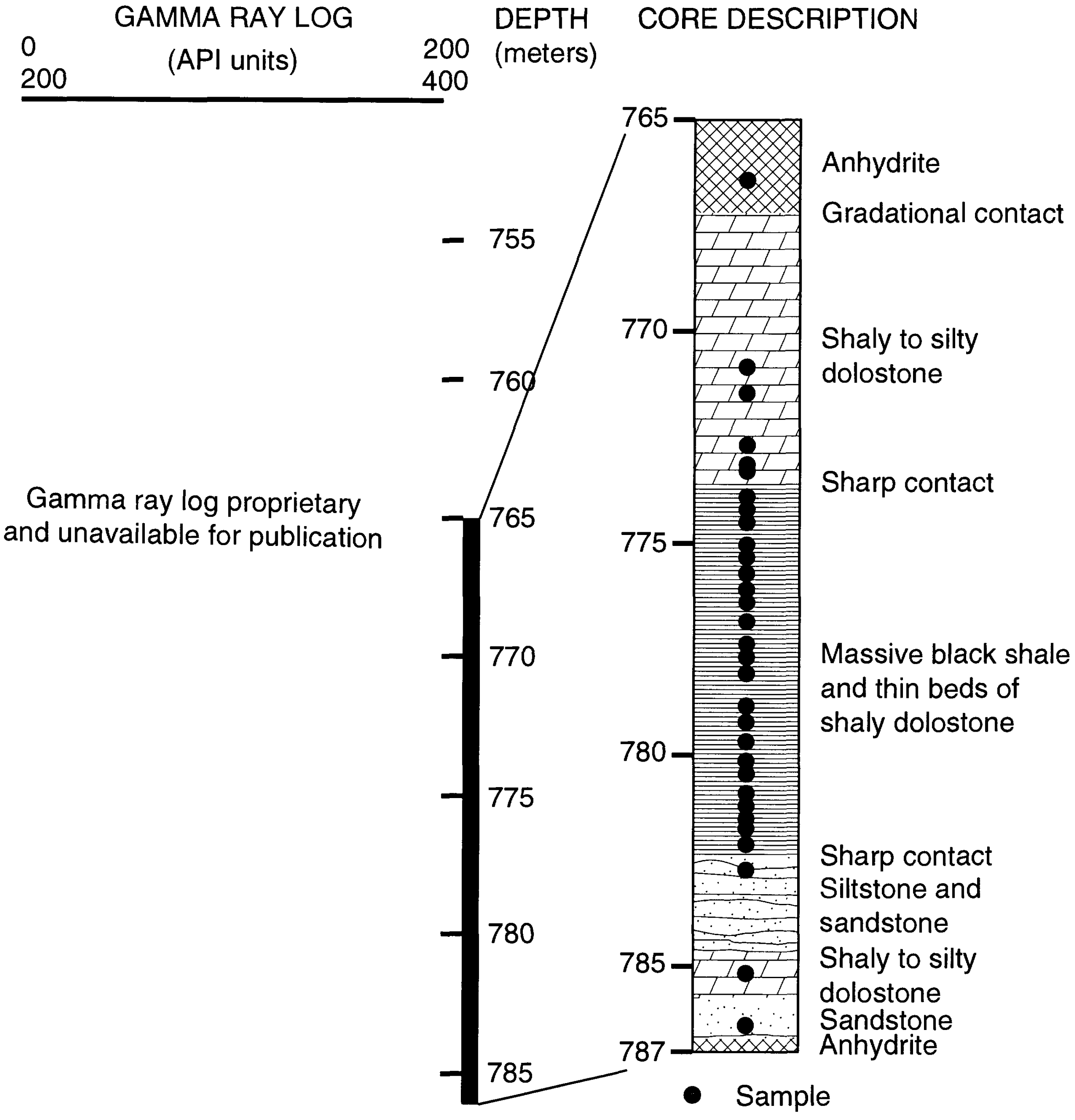
Santa Fe Energy Lake Canyon Prospect Federal No. 1-27, NW¼NW¼ sec. 27, T. 36 S., R. 25 E., San Juan County, Utah. API 4303730692. Cycle 3. Approximately 9 m of this core was examined and sampled. The lower 8 m is a massive, dark-gray to black, organic-rich shale and is capped by a massive, medium-gray, crinoidal limestone. In roughly the center of the shale interval are "star-shaped" sulfate-sulfide nodules and possibly some halite crystals. Silt-size quartz, muscovite, and carbonate grains are common to abundant in all the shale samples. Some shell fragments are present in the lowermost sample. Elongate patches (approximately 0.1 mm long) of agglomerated carbonate and silica grains, some hollow, are present in the shale and are most abundant in the uppermost shale sample. The agglomerates are assumed to have biological affinities and may be either compacted tests of agglutinated foraminifera or algal spore cases. The major authigenic minerals are silt-size dolomite rhombs (only in the upper part of the shale), calcite, and pyrite. Pyrite is common to abundant and is present mostly as dispersed single crystals in the upper part of the shale and framboids in the lower part. Within the sulfate-sulfide nodular interval, large patches of calcite laths are present. These laths commonly contain anhydrite, large euhedral pyrite crystals, and chalcedony. In addition, layers of microcrystalline calcite-cemented shale are present in the nodular interval.



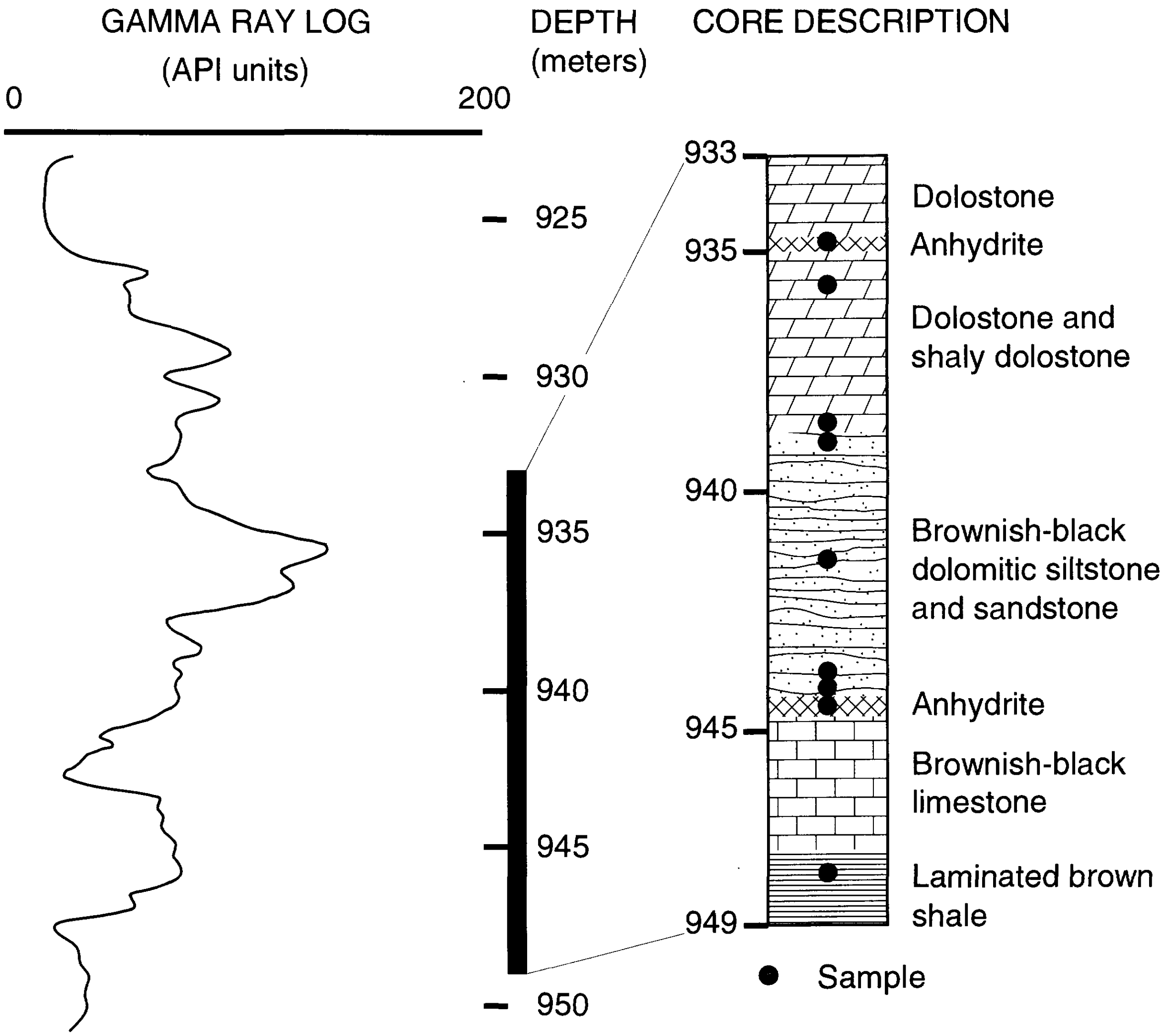
Davis Oil Company Duncan Tevault No. 1, SW¼SE¼ sec. 35, T. 40 N., R. 20 W., Dolores County, Colorado. API 0503306047. Cycle 5. Approximately 2.7 m of this core was examined and sampled. The lower 1.8 m is a massive to platy, organic-rich, dark-gray to black shale. This shale grades upward into a dolomitic shale or clay-rich dolostone. The organic-rich shale contains common silt-size quartz, carbonate, and muscovite grains, and elongate phosphatic(?) agglomerates. Pyrite, mostly as single crystals and framboids, is common in the dolostone and shale. Framboids are sometimes clustered, and their abundance appears to decrease upward. Both the dolostone and shale contain fractures or veins filled with chalcedony, pyrite, and anhydrite and sparsely distributed calcite and sphalerite. Generally, these fractures or veins are zoned as host, euhedral pyrite crystals, euhedral sphalerite crystals and (or) calcite, anhydrite, and chalcedony. In one sample (1,940-m depth), the chalcedony may have undergone repeated fracturing and filling. Some euhedral marcasite crystals were observed near or in these veins.



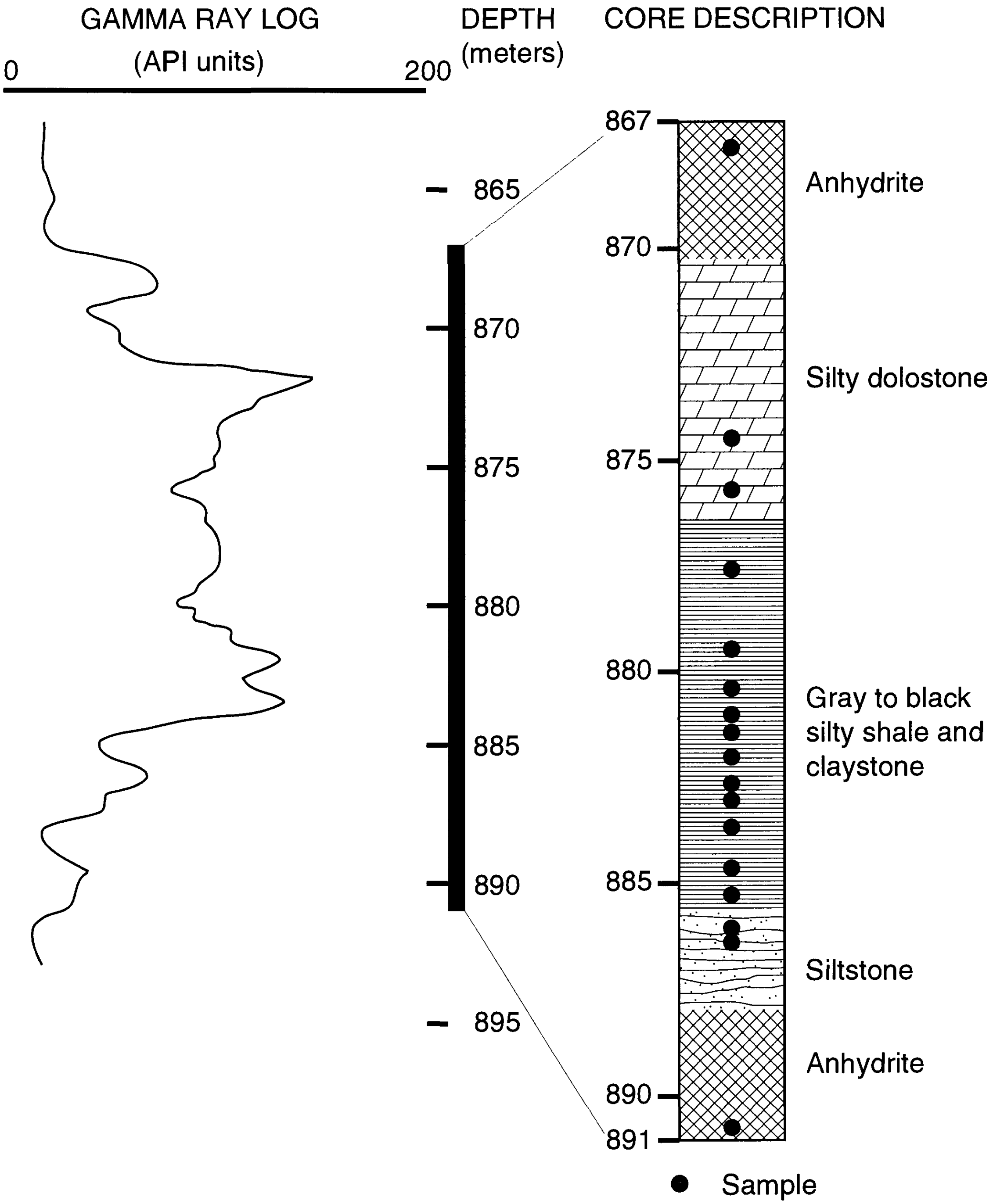
Delhi-Taylor Oil Co. Shafer No. 1, sec. 15, T. 26 S., R. 20 E., Grand County, Utah. Cycle 5. This is the northernmost well sampled. Approximately 28 m of this core was examined and sampled. The lower 1 m is gray, laminated anhydrite. Above the anhydrite is black to brown shale. The black shale is overlain by about 5 m of gray to buff dolostone that has organic matter disseminated throughout. The dolomite is uniform anhedral grains, and some pyrite is present as anhedral grains. Above the dolostone is about 6 m of nodular anhydrite, overlain by 6 m of light-brown silty dolomite, about 2.5 m of buff to black dolomitic shale containing numerous halite veins, 3 m of light-brown dolomite with some halite veins, and a bed of gray anhydrite at the top of the interval.



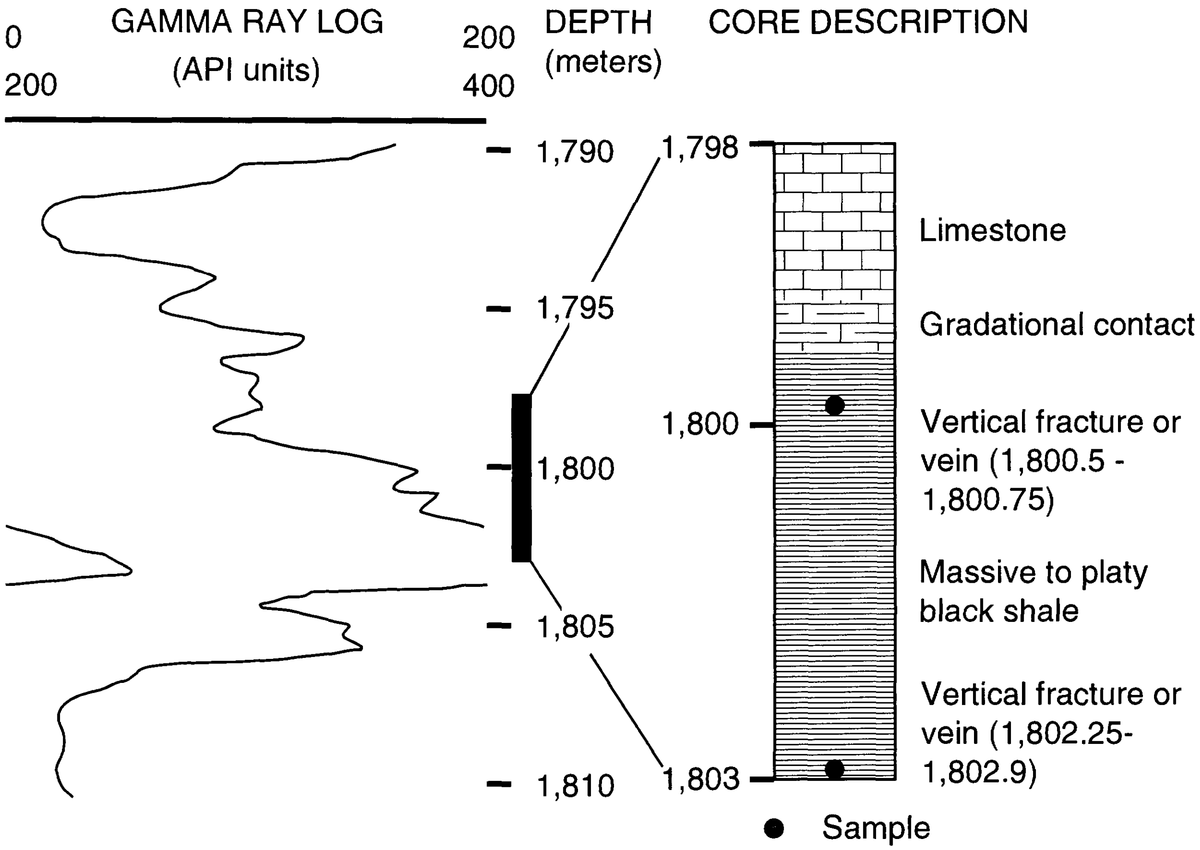
Delhi-Taylor Oil Co. Shafer No. 1, sec. 15, T. 26 S., R. 20 E., Grand County, Utah. Cycle 3. Approximately 32 m of this core was examined, and 33 samples were collected. It is the most sampled of all the wells. The deepest part of the interval contains a medium-gray anhydrite, above which is medium-gray to brown, sometimes dolomitic or calcareous, shale; siltstone; sandstone; and dolostone (total about 7.5 m thick). The siltstone and sandstone decrease upward. These medium-gray to brown beds grade upward into darker gray to black, organic-rich shale about 4.5 m thick. The shale is overlain by dolostone 2 m thick and the interval is capped by anhydrite. Fractures filled with anhydrite, pyrite, and halite are common throughout the interval but are most abundant in the upper shale and dolostone. Generally, both the medium-gray to brown shale and the dark-gray to black shale contain common to abundant, silt-size quartz, feldspar, and muscovite. Some foraminfera tests and elongate agglomerates of carbonate and silica grains are present in the upper, organic-rich shale. Sporadic patches of microcrystalline calcite are present. Dolomite rhombs were observed only in the uppermost shale. In one sample (775.3 m), a veinlet of individual and coalesced sphalerite crystals was observed, as well as calcium phosphate-rich patches. Pyrite is rare to abundant in the interval and is present mostly as single, dispersed, silt-size crystals or as framboids. Some possible euhedral to subhedral marcasite is present. The black shale and shaly dolostone contain veins of halite, one of which (771.5 m) was examined in thin section. The vein contains chalcedony, dolomite, halite, and iron sulfide minerals. The iron sulfides are very fine grained to coarse-grained anhedral grains, some of which may be marcasite



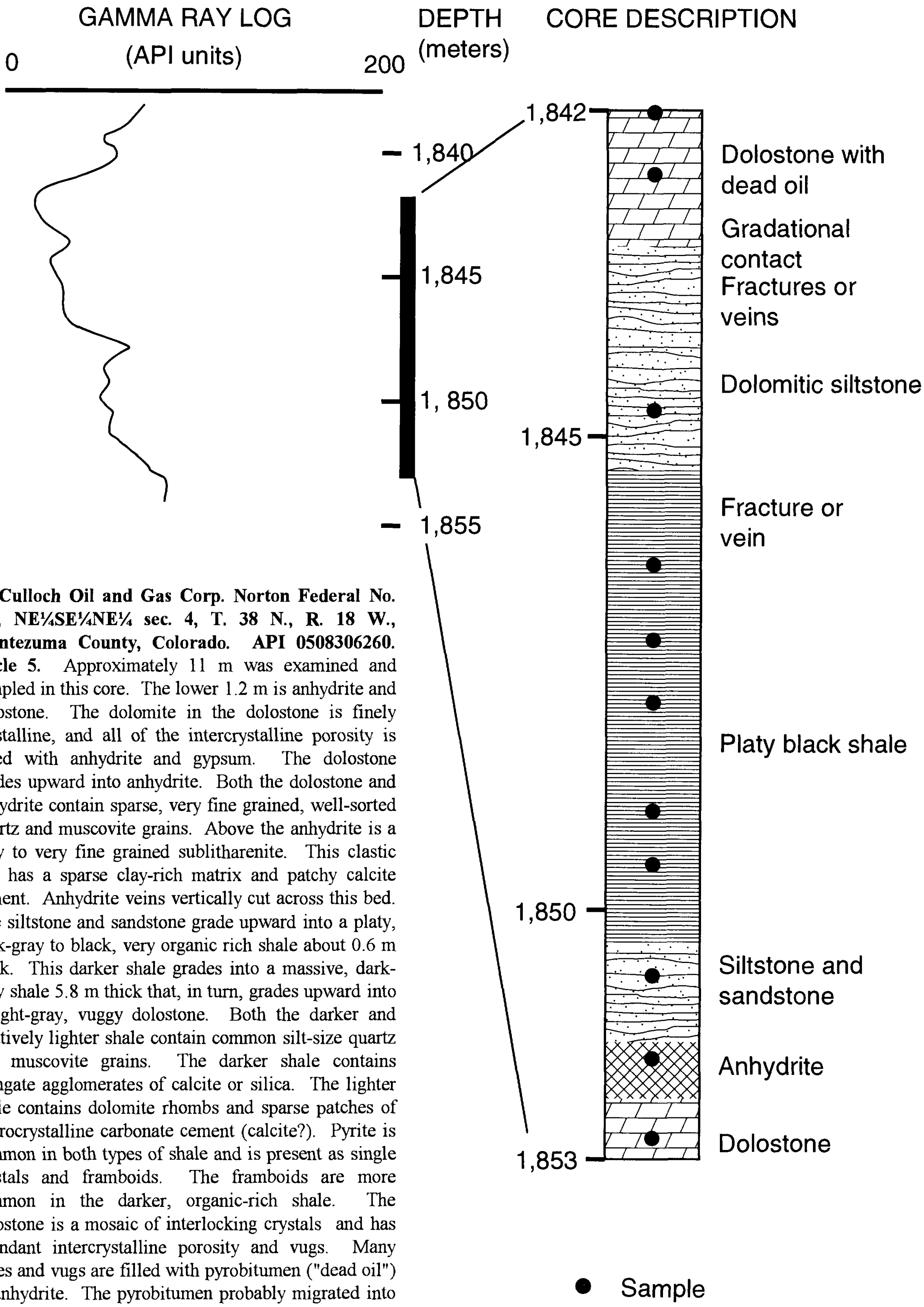
U.S. Department of Energy Gibson Dome No. 1, sec. 21, T. 30 S., R. 21 E., San Juan County, Utah. Cycle 5. Approximately 16 m was examined and sampled in this core. The lowest part of the interval is about 1.5 m of laminated brown shale, the upper part of which contains more silt and is grayer. Anhydrite, silt-size carbonates, and disseminated anhedral pyrite grains are present in minor or trace amounts. The shale is overlain by 3.5 m of brownish-black limestone, 0.4 m of anhydrite, and some 5 m of brownish-black dolomitic siltstone and sandstone. The siltstone is quite porous. The dolomite is mostly rounded grains, but some rhombs are present; minor amounts of muscovite, biotite, anhydrite, and potassium feldspar were observed in thin section. Approximately 6 m of dolostone to shaly dolostone overlies the siltstone. The dolostone unit contains a small bed of anhydrite.



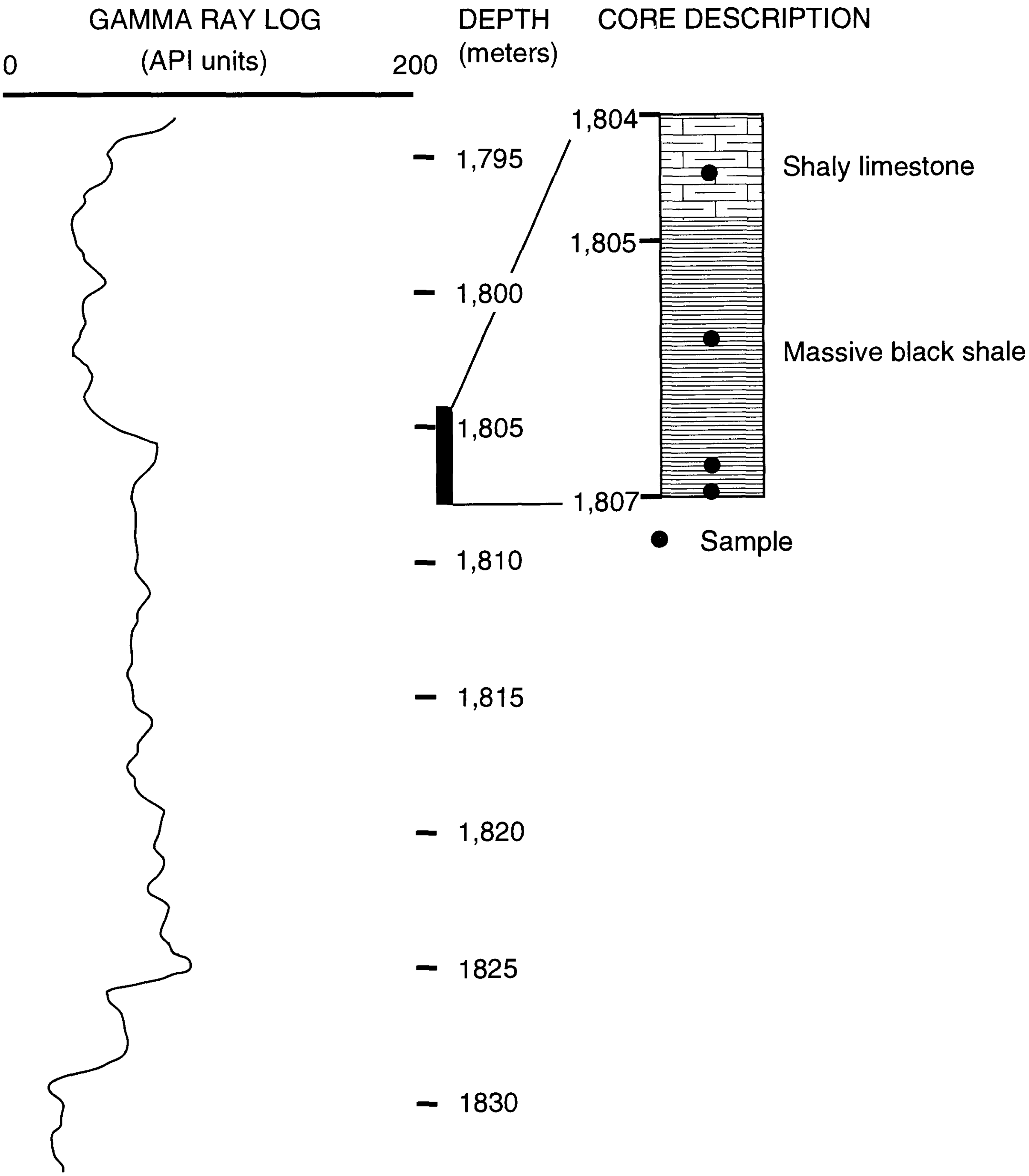
U.S. Department of Energy Gibson Dome No. 1, sec. 21, T. 30 S., R. 21 E., San Juan County, Utah. Cycle 3. Approximately 24 m was examined and sampled. The lowest part of the sampled interval is anhydrite overlain by 2 m of siltstone. The siltstone contains very abundant shell fragments. Pyrite is present as small anhedral grains and infilled framboids. The siltstone is overlain by 9.5 m of gray to black silty shale and claystone. This unit is calcareous, and thin dolomite beds are present throughout. The shale contains variable amounts of shell fragments, micritic calcite, well-oriented muscovite, and abundant pyrite framboids. Above the shale is about 6 m of silty dolostone overlain by anhydrite.



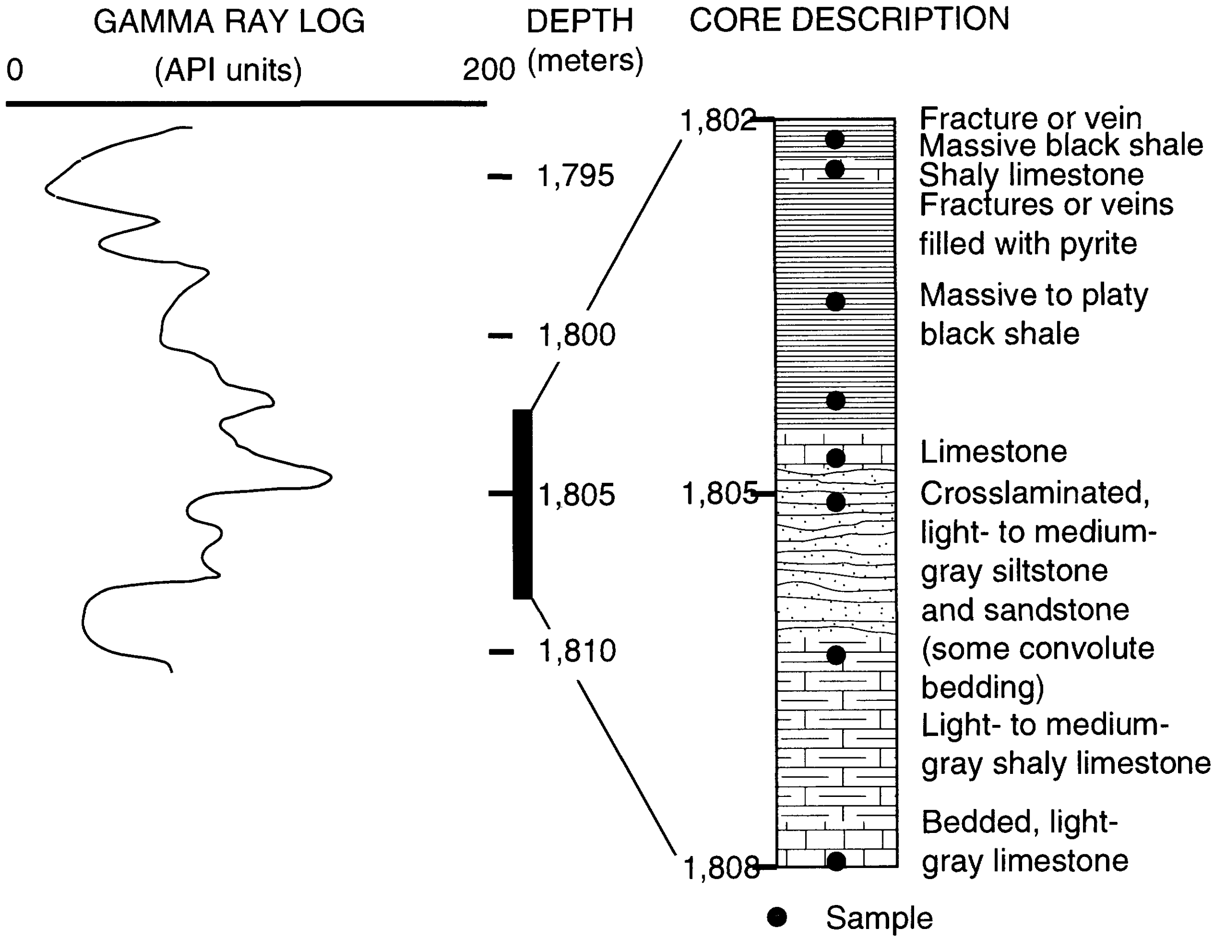
Transco Exploration TXPOC Crowley Ranch No. 1-25, sec. 25, T. 34 S., R. 25 E., San Juan County, Utah. API 4303730978. Cycle 5. Out of the approximately 5 m of core examined and sampled, the lower 3.7 m is a dark-gray to black, organic-rich shale. The shale grades upward into a limestone or dolostone that makes up the remainder of the core. Two prominent veins filled with anhydrite and calcite are present within the shale. One of the veins (1,802.8 m), examined in thin section, is filled with calcite. Incorporated within the calcite are large crystals of anhydrite and pyrite, and inclusions of the host rock. Pyrite crystals generally line the vein. The shale contains sparse silt-size quartz and muscovite grains, rare shell fragments, and, in the lowermost sample (1,802.8 m), abundant elongate agglomerates of calcite or silica. Dolomite rhombs are common in the upper sample. Pyrite is common and present as framboids and single crystals.



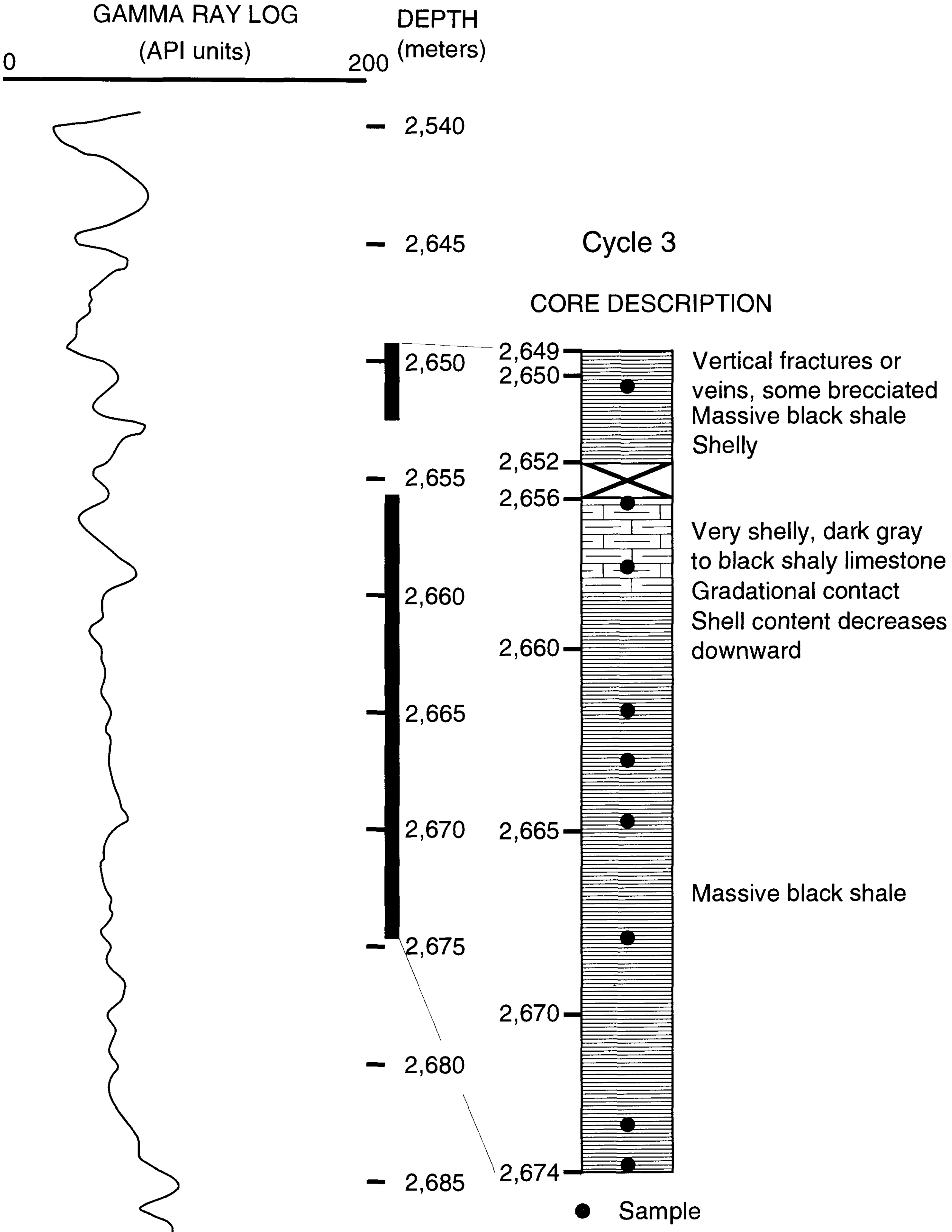
McCulloch Oil and Gas Corp. Norton Federal No. 1-4, NE¼SE¼NE¼ sec. 4, T. 38 N., R. 18 W., Montezuma County, Colorado. API 0508306260. Cycle 5. Approximately 11 m was examined and sampled in this core. The lower 1.2 m is anhydrite and dolostone. The dolomite in the dolostone is finely crystalline, and all of the intercrystalline porosity is filled with anhydrite and gypsum. The dolostone grades upward into anhydrite. Both the dolostone and anhydrite contain sparse, very fine grained, well-sorted quartz and muscovite grains. Above the anhydrite is a silty to very fine grained sublitharenite. This clastic bed has a sparse clay-rich matrix and patchy calcite cement. Anhydrite veins vertically cut across this bed. The siltstone and sandstone grade upward into a platy, dark-gray to black, very organic rich shale about 0.6 m thick. This darker shale grades into a massive, dark-gray shale 5.8 m thick that, in turn, grades upward into a light-gray, vuggy dolostone. Both the darker and relatively lighter shale contain common silt-size quartz and muscovite grains. The darker shale contains elongate agglomerates of calcite or silica. The lighter shale contains dolomite rhombs and sparse patches of microcrystalline carbonate cement (calcite?). Pyrite is common in both types of shale and is present as single crystals and framboids. The framboids are more common in the darker, organic-rich shale. The dolostone is a mosaic of interlocking crystals and has abundant intercrystalline porosity and vugs. Many pores and vugs are filled with pyrobitumen ("dead oil") or anhydrite. The pyrobitumen probably migrated into the rock after anhydrite cementation.



McCulloch Oil and Gas Corp. Norton Federal No. 1-4, NE¼SE¼NE¼ sec. 4, T. 38 N., R. 18 W., Montezuma County, Colorado. API 0508306260. Cycle 3. Only about 3.6 m was examined and sampled. The cored interval is represented by a massive, dark-gray to black, organic-rich shale that contains common silt-size quartz and muscovite. The uppermost sample (1,804 m) is calcareous and contains sparse shell fragments. Well-developed zoned dolomite rhombs are present in many of the samples. The lowermost sample contains patches of microcrystalline calcite. Pyrite is common to abundant and is present as disseminated, silt-size crystals and as framboids. Shell fragments partially replaced by pyrite are present in the uppermost sample. Some anhedral to subhedral marcasite is present in many of the samples.



Celsius Energy Woods Unit No. 1-S, NW¼SE¼NW¼ sec. 20, T. 37 N., R. 18 W., Montezuma County, Colorado. API508306359. Cycle 5. Approximately 6 m was examined and sampled. The lowest 0.6 m is a light-gray limestone. Sharply overlying the limestone is 7 m of light- to medium-gray shale intercalated with dark-gray shale. The shale grades upward into 2.8 m of laminated and ripple-cross-laminated siltstone and sandstone. Some convolute bedding is observed. The siltstone and sandstone grade upward into a thin limestone, that is overlain by a dark-gray to black, organic-rich shale. Some veinlets filled with pyrite, calcite, and chalcedony are present near the top of the core (1,802–1,803 m). The intercalated light and dark shale exhibits organic-rich and organic-poor laminae and cross laminae and contains common silt-size quartz, muscovite, and calcite grains. A few pyritized foraminifera tests were observed. Pyrite is common as single crystals and infilled framboids. The siltstone and sandstone are a sublitharenite or subarkose. Coarser grained intervals are generally cemented with patchy or micritic calcite cement and zoned dolomite rhombs. Finer grained intervals are clay and mica rich. Pyrite is present as crystals or infilled framboids. The overlying organic-rich shale generally contains common silt-size quartz, muscovite, and calcite grains, and the amount of siliciclastics inceases upward. In addition, this shale contains abundant shell fragments, rare to abundant dolomite rhombs (many zoned), and some elongate agglomerates. In one sample (1,802.4 m), some pelloids (possibly phosphatic) are present. Pyrite is common as framboids, single grains, and shell replacement. In the uppermost sample (1,802.4 m), one of the veinlets showed zonation similar to that observed in other wells; that is, host rock, pyrite, calcite, and chalcedony. Pyrite is present as relatively large euhedral crystals within the vein.



See caption for above figure on following page.

Houston Oil and Mineral Corp. Ute Mountain No. 44-34, SE¼SE¼ sec. 24, T. 34 N., R. 14 W., Montezuma County, Colorado. API 508306172. Cycle 3 (preceding page). This is the southernmost well sampled. Only 23 m was available for examination and sampling. No core material was retrieved from 2,674.3-m to 2,854.5-m depth. Below 2,854.5 m are anhydrite and dolostone that are not discussed herein because they may belong to cycle 4. The upper 21.5 m (above 2,674.3 m) is predominantly a massive, dark-gray to black shale. The shale is fossiliferous (shell fragments and sponge spicules) near the top, but the fossil abundance decreases with depth. No shell fragments were observed below 10 m from the top of the core. Near the top of the sampled interval, vertical veins of anhydrite, pyrite, calcite, and (or) chalcedony, and brecciated shale are present. The shale is organic poor in the upper part of the interval but becomes more organic rich with depth. Silt-size quartz, calcite, and muscovite grains are generally common to abundant throughout. However, in the uppermost sample, clastic detritus is rare. The large amount of quartz indicated by XRD (appendix 2) may be due to siliceous sponge spicules. Dolomite rhombs, some zoned, are present in the upper samples but become sparse with depth. Pyrite is generally sparse in the shale and is present as disseminated silt-size crystals.

APPENDIX 2—LITHOLOGIC, CHEMICAL, ISOTOPIC, AND MINERALOGIC DATA FOR CORE SAMPLES IN STUDY

Appendix 2, table 1. Lithologic, chemical, isotopic, and mineralogic data for core samples in study.

[Lithology of samples is from core descriptions and rock type is the classification used in this Bulletin—in most cases they are the same. S_{Di}, disulfide sulfur; S_{SO_4}, sulfate sulfur; S_{Org}, organic sulfur; S_{tot}, total sulfur; C_{CO_3}, carbonate carbon; C_{Org}, organic carbon; Fe_{rct}, reactive iron. Rock Eval data: S_1, volatile hydrocarbons (in mg/g of rock); S_2, generated hydrocarbons (in mg/g of rock); S_3, generated CO_2 (in mg/g of rock); T_{max} in °C (see text for description); HI, hydrogen index, and OI, oxygen index (see text for description). Isotope data are in per mil relative to Cañon Diablo troilite standard. DOP_T is degree of pyritization (see text for explanation). Mineralogical data for quartz, potassium feldspar, sodium feldspar, apatite, calcite, dolomite, anhydrite, halite, pyrite, and total clay are XRD peak heights in units of 0.1 inch. Inductively coupled plasma spectral data: major elements (Al, Ca, Fe, K, Mg, Na, P, Ti) are reported in weight percent; minor and trace elements are reported in parts per million. Cr* and Ni* are enriched concentrations as calculated using formulas shown in the text. na, data not available; insuf, insufficient data; sh., shale; siltst., siltstone; sandst., sandstone. <, below detection limit]

Well name	Depth (ft)	Depth (m)	Cycle	Lithology of sample	Rock type for statistics	S_{Di} (weight percent)	S_{SO_4} (weight percent)
Aztec Federal No. 1	6374.8	1943.0	Cycle 5	Limestone	Limestone	na	na
Aztec Federal No. 1	6378.5	1944.2	Cycle 5	Limestone	Limestone	na	na
Aztec Federal No. 1	6379.8	1944.6	Cycle 5	Calcareous sh.	Calcareous sh.	1.9	0.02
Aztec Federal No. 1	6384.3	1945.9	Cycle 5	Calcareous sh.	Calcareous sh.	1.9	0.03
Aztec Federal No. 1	6389.5	1947.5	Cycle 5	Calcareous sh.	Calcareous sh.	2.0	0.06
Aztec Federal No. 1	6393.3	1948.7	Cycle 5	Calcareous sh.	Calcareous sh.	2.1	0.04
Crowley Ranch No. 1-25	5905.0	1799.8	Cycle 5	Calcareous sh.	Calcareous sh.	0.95	0.04
Crowley Ranch No. 1-25	5915.0	1802.9	Cycle 5	Calcareous sh.	Calcareous sh.	3.0	0.17
Duncan Tevault No. 1	6365.0	1940.1	Cycle 5	Dolostone	Dolostone	na	na
Duncan Tevault No. 1	6367.0	1940.7	Cycle 5	Shaly dolomite	Dolostone	0.72	0.03
Duncan Tevault No. 1	6370.5	1941.7	Cycle 5	Dolomitic sh.	Dolomitic sh.	1.3	0.06
Duncan Tevault No. 1	6371.0	1941.9	Cycle 5	Argillaceous sh.	Argillaceous sh.	1.2	0.03
Elk Ridge No. 1	2548.4	776.8	Cycle 3	Limestone	Limestone	1.0	na
Elk Ridge No. 1	2560.4	780.4	Cycle 3	Calcareous sh.	Calcareous sh.	1.4	na
Elk Ridge No. 1	2570.5	783.5	Cycle 3	Limestone	Limestone	1.0	na
Elk Ridge No. 1	2578.5	785.9	Cycle 3	Calcareous sh.	Calcareous sh.	1.1	na
Elk Ridge No. 1	2588.5	789.0	Cycle 3	Calcareous sh.	Calcareous sh.	1.1	na
Elk Ridge No. 1	2594.7	790.9	Cycle 3	Calcareous sh.	Calcareous sh.	1.6	na
Elk Ridge No. 1	2614.4	796.9	Cycle 3	Shaly dolomite	Dolostone	1.4	na
Elk Ridge No. 1	2653.6	808.8	Cycle 5	Anhydrite	Anhydrite	na	na
Elk Ridge No. 1	2676.8	815.9	Cycle 5	Shaly dolomite	Dolostone	1.1	na
Elk Ridge No. 1	2680.7	817.1	Cycle 5	Calcareous sh.	Calcareous sh.	1.6	na
Elk Ridge No. 1	2687.9	819.3	Cycle 5	Argillaceous sh.	Argillaceous sh.	1.9	na
Elk Ridge No. 1	2693.8	821.1	Cycle 5	Argillaceous sh.	Argillaceous sh.	1.9	na
Elk Ridge No. 1	2701.0	823.3	Cycle 5	Argillaceous sh.	Argillaceous sh.	1.6	na
Elk Ridge No. 1	2706.7	825.0	Cycle 5	Calcareous sh.	Calcareous sh.	1.9	na
Elk Ridge No. 1	2711.1	826.3	Cycle 5	Calcareous siltst.	Siltstone	0.31	na
Gibson Dome No. 1	2846.6	867.6	Cycle 3	Anhydrite	Anhydrite	na	na
Gibson Dome No. 1	2869.0	874.5	Cycle 3	Dolostone	Dolostone	1.7	na
Gibson Dome No. 1	2873.0	875.7	Cycle 3	Dolostone	Dolostone	0.55	na
Gibson Dome No. 1	2879.0	877.5	Cycle 3	Dolomitic sh.	Dolomitic sh.	1.1	na
Gibson Dome No. 1	2885.6	879.5	Cycle 3	Calcareous sh.	Calcareous sh.	1.1	na
Gibson Dome No. 1	2888.5	880.4	Cycle 3	Calcareous sh.	Calcareous sh.	1.1	na
Gibson Dome No. 1	2890.5	881.0	Cycle 3	Calcareous sh.	Calcareous sh.	1.0	na

Appendix 2, table 1. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Depth (m)	Cycle	Lithology of sample	Rock type for statistics	S_{DI} (weight percent)	$S_{\mathrm{SO_4}}$ (weight percent)
Gibson Dome No. 1	2892.0	881.5	Cycle 3	Calcareous sh.	Calcareous sh.	1.0	na
Gibson Dome No. 1	2893.9	882.1	Cycle 3	Dolomitic sh.	Dolomitic sh.	1.4	na
Gibson Dome No. 1	2895.9	882.7	Cycle 3	Calcareous sh.	Calcareous sh.	1.3	na
Gibson Dome No. 1	2897.2	883.1	Cycle 3	Dolomitic sh.	Dolomitic sh.	1.1	na
Gibson Dome No. 1	2898.6	883.5	Cycle 3	Calcareous sh.	Calcareous sh.	1.5	na
Gibson Dome No. 1	2902.7	884.7	Cycle 3	Calcareous sh.	Calcareous sh.	1.4	na
Gibson Dome No. 1	2904.6	885.3	Cycle 3	Calcareous sh.	Calcareous sh.	1.4	na
Gibson Dome No. 1	2907.5	886.2	Cycle 3	Calcareous siltst.	Siltstone	0.43	na
Gibson Dome No. 1	2908.3	886.4	Cycle 3	Calcareous siltst.	Siltstone	0.31	na
Gibson Dome No. 1	2922.5	890.8	Cycle 3	Anhydrite	Anhydrite	na	na
Gibson Dome No. 1	3066.9	934.8	Cycle 5	Anhydrite	Anhydrite	na	na
Gibson Dome No. 1	3069.6	935.6	Cycle 5	Dolostone	Dolostone	nan	na
Gibson Dome No. 1	3079.2	938.5	Cycle 5	Shaly dolomite	Dolostone	0.55	na
Gibson Dome No. 1	3080.8	939.0	Cycle 5	Dolomitic siltst.	Siltstone	0.43	na
Gibson Dome No. 1	3089.0	941.5	Cycle 5	Dolomitic siltst.	Siltstone	0.31	na
Gibson Dome No. 1	3096.3	943.8	Cycle 5	Dolomitic siltst.	Siltstone	0.67	na
Gibson Dome No. 1	3098.2	944.3	Cycle 5	Dolomitic siltst.	Siltstone	0.43	na
Gibson Dome No. 1	3098.6	944.5	Cycle 5	Anhydrite	Anhydrite	na	na
Gibson Dome No. 1	3110.2	948.0	Cycle 5	Argillaceous sh.	Argillaceous sh.	0.31	na
Honaker Trail outcrop	0.0	0.0	Cycle 5	Calcareous sh.	Calcareous sh.	0.89	0.19
Lake Canyon No. 1-27	5748.5	1752.1	Cycle 3	Limestone	Limestone	na	na
Lake Canyon No. 1-27	5749.0	1752.3	Cycle 3	Argillaceous sh.	Argillaceous sh.	0.90	0.07
Lake Canyon No. 1-27	5752.8	1753.5	Cycle 3	Calcareous sh.	Calcareous sh.	1.1	0.03
Lake Canyon No. 1-27	5756.5	1754.6	Cycle 3	Calcareous sh.	Calcareous sh.	0.90	0.02
Lake Canyon No. 1-27	5762.3	1756.3	Cycle 3	Limestone	Limestone	5.3	0.50
Lake Canyon No. 1-27	5764.5	1757.0	Cycle 3	Calcareous sh.	Calcareous sh.	na	na
Lake Canyon No. 1-27	5767.0	1757.8	Cycle 3	Calcareous sh.	Calcareous sh.	1.0	0.02
Lake Canyon No. 1-27	5770.3	1758.8	Cycle 3	Calcareous sh.	Calcareous sh.	na	na
Lake Canyon No. 1-27	5774.5	1760.1	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.1	0.02
Norton Federal No. 1-4	5919.8	1804.4	Cycle 3	Limestone	Limestone	1.0	<.01
Norton Federal No. 1-4	5925.0	1805.9	Cycle 3	Calcareous sh.	Calcareous sh.	1.1	0.02
Norton Federal No. 1-4	5929.0	1807.2	Cycle 3	Calcareous sh.	Calcareous sh.	1.0	0.01
Norton Federal No. 1-4	5929.8	1807.4	Cycle 3	Calcareous sh.	Calcareous sh.	0.94	0.04
Norton Federal No. 1-4	6042.0	1841.6	Cycle 5	Dolostone	Dolostone	0 01	0.61
Norton Federal No. 1-4	6044.3	1842.3	Cycle 5	Dolostone	Dolostone	na	na
Norton Federal No. 1-4	6052.3	1844.7	Cycle 5	Dolomitic siltst.	Siltstone	0.40	0.07
Norton Federal No. 1-4	6057.5	1846.3	Cycle 5	Dolomitic sh.	Dolomitic sh.	na	na
Norton Federal No. 1-4	6060.3	1847.2	Cycle 5	Dolomitic sh.	Dolomitic sh.	0.64	0.01
Norton Federal No. 1-4	6062.3	1847.8	Cycle 5	Argillaceous sh.	Argillaceous sh.	1.0	0.01
Norton Federal No. 1-4	6066.0	1848.9	Cycle 5	Argillaceous sh.	Argillaceous sh.	0.94	0.02

Appendix 2, table 1. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Depth (m)	Cycle	Lithology of sample	Rock type for statistics	S_{Di} (weight percent)	S_{SO_4} (weight percent)
Norton Federal No. 1-4	6067.8	1849.5	Cycle 5	Argillaceous sh.	Argillaceous sh.	1.0	0.03
Norton Federal No. 1-4	6071.5	1850.6	Cycle 5	Siltstone	Siltstone	na	na
Norton Federal No. 1-4	6074.5	1851.5	Cycle 5	Anhydrite	Anhydrite	na	na
Norton Federal No. 1-4	6077.3	1852.4	Cycle 5	Dolostone	Dolostone	0.08	2.74
Pickett Federal No. 1-33	5642.0	1719.7	Cycle 5	Limestone	Limestone	na	na
Pickett Federal No. 1-33	5644.3	1720.4	Cycle 5	Calcareous sh.	Calcareous sh.	1.3	0.07
Pickett Federal No. 1-33	5645.8	1720.8	Cycle 5	Calcareous sh.	Calcareous sh.	0.9	0.02
Pickett Federal No. 1-33	5648.0	1721.5	Cycle 5	Calcareous sh.	Calcareous sh.	1.3	0.03
Pickett Federal No. 1-33	5649.0	1721.8	Cycle 5	Calcareous sh.	Calcareous sh.	1.7	0.03
Pickett Federal No. 1-33	5651.2	1722.5	Cycle 5	Calcareous sh.	Calcareous sh.	1.7	0.02
Pickett Federal No. 1-33	5653.3	1723.1	Cycle 5	Argillaceous sh.	Argillaceous sh.	1.7	0.06
Pickett Federal No. 1-33	5656.5	1724.1	Cycle 5	Argillaceous sh.	Argillaceous sh.	1.6	0.03
Pickett Federal No. 1-33	5659.0	1724.9	Cycle 5	Argillaceous sh.	Argillaceous sh.	1.8	0.05
Pickett Federal No. 1-33	5660.8	1725.4	Cycle 5	Argillaceous sh.	Argillaceous sh.	1.7	0.04
Pickett Federal No. 1-33	5664.0	1726.4	Cycle 5	Argillaceous sh.	Argillaceous sh.	1.4	0.07
Pickett Federal No. 1-33	5665.5	1726.8	Cycle 5	Calcareous siltst.	Siltstone	na	na
Pickett Federal No. 1-33	5665.8	1726.9	Cycle 5	Dolomitic siltst.	Siltstone	1.5	0.12
Pickett Federal No. 1-33	5670.5	1728.4	Cycle 5	Calcareous siltst.	Siltstone	na	na
Shafer No. 1	2514.5	766.4	Cycle 3	Anhydrite	Anhydrite	0.05	13
Shafer No. 1	2529.0	770.8	Cycle 3	Shaly dolomite	Dolostone	na	na
Shafer No. 1	2535.0	772.7	Cycle 3	Shaly dolomite	Dolostone	0.21	0.06
Shafer No. 1	2536.5	773.1	Cycle 3	Dolomite	Dolostone	na	na
Shafer No. 1	2537.0	773.3	Cycle 3	Shaly dolomite	Dolostone	na	na
Shafer No. 1	2539.0	773.9	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.1	0.38
Shafer No. 1	2540.0	774.2	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.8	0.15
Shafer No. 1	2541.0	774.5	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.1	0.07
Shafer No. 1	2542.8	775.0	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.3	0.11
Shafer No. 1	2543.8	775.4	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.2	0.14
Shafer No. 1	2545.0	775.7	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.4	0.10
Shafer No. 1	2546.3	776.1	Cycle 3	Dolomitic sh.	Dolomitic sh.	na	na
Shafer No. 1	2547.3	776.4	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.2	0.16
Shafer No. 1	2548.8	776.9	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.9	0.07
Shafer No. 1	2550.5	777.4	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.5	0.19
Shafer No. 1	2551.5	777.7	Cycle 3	Shaly dolomite	Dolostone	0.49	0.13
Shafer No. 1	2552.8	778.1	Cycle 3	Argillaceous sh.	Argillaceous sh.	na	na
Shafer No. 1	2555.3	778.9	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.3	0.23
Shafer No. 1	2556.5	779.2	Cycle 3	Dolomitic sh.	Dolomitic sh.	na	na
Shafer No. 1	2558.0	779.7	Cycle 3	Shaly dolomite	Dolostone	0.64	0.12
Shafer No. 1	2559.5	780.1	Cycle 3	Dolomitic sh.	Dolomitic sh.	na	na
Shafer No. 1	2560.5	780.4	Cycle 3	Shaly dolomite	Dolomitic sh.	na	na

Appendix 2, table 1. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Depth (m)	Cycle	Lithology of sample	Rock type for statistics	S_{DI} (weight percent)	S_{SO_4} (weight percent)
Shafer No. 1	2562.0	780.9	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.2	0.11
Shafer No. 1	2563.0	781.2	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.1	0.13
Shafer No. 1	2564.0	781.5	Cycle 3	Argillaceous sh.	Argillaceous sh.	1.4	0.14
Shafer No. 1	2564.8	781.8	Cycle 3	Calcareous sh.	Calcareous sh.	1.4	0.15
Shafer No. 1	2566.0	782.1	Cycle 3	Argillaceous sh.	Argillaceous sh.	na	nan
Shafer No. 1	2568.0	782.7	Cycle 3	Siltst./sandst.	Siltstone	0.41	0.03
Shafer No. 1	2576.0	785.2	Cycle 3	Shaly dolomite	Dolostone	na	na
Shafer No. 1	2580.0	786.4	Cycle 3	Dolomitic sh.	Dolomitic sh.	0.38	0.11
Shafer No. 1	2884.0	879.0	Cycle 5	Argillaceous sh.	Argillaceous sh.	0.34	1.0
Shafer No. 1	2923.0	890.9	Cycle 5	Shaly dolomite	Dolostone	na	na
Shafer No. 1	2940.0	896.1	Cycle 5	Dolostone	Dolostone	na	na
Shafer No. 1	2953.0	900.1	Cycle 5	Argillaceous sh.	Argillaceous sh.	0.23	0.09
State No. 1-16	5518.3	1682.0	Cycle 3	Limestone	Limestone	0.02	0.06
State No. 1-16	5521.3	1682.9	Cycle 3	Limestone	Limestone	na	na
State No. 1-16	5537.0	1687.7	Cycle 3	Limestone	Limestone	0.29	0.03
State No. 1-16	5542.0	1689.2	Cycle 3	Calcareous sh.	Calcareous sh.	1.2	0.02
State No. 1-16	5546.8	1690.7	Cycle 3	Argillaceous sh.	Argillaceous sh.	0.64	0.04
State No. 1-16	5552.0	1692.2	Cycle 3	Calcareous sh.	Calcareous sh.	0.6	0.03
State No. 1-16	5698.0	1736.8	Cycle 5	Limestone	Limestone	0.29	0.01
State No. 1-16	5700.5	1737.5	Cycle 5	Limestone	Limestone	na	na
State No. 1-16	5701.8	1737.9	Cycle 5	Argillaceous sh.	Argillaceous sh.	2.2	0.02
State No. 1-16	5704.0	1738.6	Cycle 5	Shaly dolomite	Dolostone	0.90	0.02
State No. 1-16	5707.7	1739.7	Cycle 5	Calcareous sh.	Calcareous sh.	2.2	<.01
State No. 1-16	5711.5	1740.9	Cycle 5	Calcareous sh.	Calcareous sh.	2.6	0.01
Ute Mountain No. 44-34	8695.0	2650.2	Cycle 3	Dolomitic sh.	Dolomitic sh.	na	na
Ute Mountain No. 44-34	8714.0	2656.0	Cycle 3	Limestone	Limestone	na	na
Ute Mountain No. 44-34	8720.0	2657.9	Cycle 3	Limestone	Limestone	0.90	0.01
Ute Mountain No. 44-34	8732.5	2661.7	Cycle 3	Calcareous sh.	Calcareous sh.	0.74	0.02
Ute Mountain No. 44-34	8737.0	2663.0	Cycle 3	Calcareous sh.	Calcareous sh.	0.89	0.02
Ute Mountain No. 44-34	8742.5	2664.7	Cycle 3	Calcareous sh.	Calcareous sh.	0.92	0.03
Ute Mountain No. 44-34	8753.0	2667.9	Cycle 3	Calcareous sh.	Calcareous sh.	0.62	0.03
Ute Mountain No. 44-34	8769.8	2673.0	Cycle 3	Calcareous sh.	Calcareous sh.	0.88	0.03
Ute Mountain No. 44-34	8773.0	2674.0	Cycle 3	Calcareous sh.	Calcareous sh.	0.89	0.02
West Water Creek No. 1	6304.8	1921.7	Cycle 3	Calcareous sh.	Calcareous sh.	2.1	0.03
West Water Creek No. 1	6311.8	1923.8	Cycle 3	Calcareous sh.	Calcareous sh.	na	na
West Water Creek No. 1	6317.3	1925.5	Cycle 3	Calcareous sh.	Calcareous sh.	na	na
West Water Creek No. 1	6322.5	1927.1	Cycle 3	Calcareous sh.	Calcareous sh.	1.6	0.03
Woods Unit No. 1-S	5912.5	1802.1	Cycle 5	Calcareous sh.	Calcareous sh.	1.4	0.03
Woods Unit No. 1-S	5913.3	1802.4	Cycle 5	Limestone	Limestone	na	na
Woods Unit No. 1-S	5916.7	1803.4	Cycle 5	Calcareous sh.	Calcareous sh.	1.4	0.03

Appendix 2, table 1. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Depth (m)	Cycle	Lithology of sample	Rock type for statistics	S_{Di} (weight percent)	S_{SO_4} (weight percent)
Woods Unit No. 1-S	5919.5	1804.3	Cycle 5	Argillaceous sh.	Argillaceous sh.	na	na
Woods Unit No. 1-S	5921.0	1804.7	Cycle 5	Limestone	Limestone	0.61	0.05
Woods Unit No. 1-S	5922.2	1805.1	Cycle 5	Calcareous siltst.	Siltstone	na	na
Woods Unit No. 1-S	5926.3	1806.3	Cycle 5	Limestone	Limestone	na	na
Woods Unit No. 1-S	5932.0	1808.1	Cycle 5	Limestone	Limestone	na	na

Appendix 2, table 2. Lithologic, chemical, isotopic, and mineralogic data for core samples in study.

Well name	Depth (ft)	S_{Org} (weight percent)	S_{tot} (weight percent)	C_{CO_3} (weight percent)	C_{Org} (weight percent)	S_1	S_2	S_3	HI
Aztec Federal No. 1	6374.8	na	0.33	8.7	0.26	0.15	0.16	0.42	61
Aztec Federal No. 1	6378.5	na	0.42	8.0	0.32	0.11	0.13	0.46	40
Aztec Federal No. 1	6379.8	0.04	2.2	4.6	2.5	1.2	1.6	0.80	64
Aztec Federal No. 1	6384.3	0.04	2.1	3.2	3.0	1.5	3.1	0.81	104
Aztec Federal No. 1	6389.5	0.03	2.1	3.3	2.9	1.6	3.1	0.80	106
Aztec Federal No. 1	6393.3	0.4	2.7	3.2	4.6	2.6	4.9	0.61	105
Crowley Ranch No. 1-25	5905.0	<0.01	1.0	4.8	1.1	0.27	0.25	0.93	23
Crowley Ranch No. 1-25	5915.0	<0.01	3.5	3.3	3.2	0.7	0.67	0.53	20
Duncan Tevault No. 1	6365.0	na	6.0	0.75	0.23	0.09	0.11	0.35	47
Duncan Tevault No. 1	6367.0	<0.01	0.77	7.1	0.81	0.22	0.25	0.61	30
Duncan Tevault No. 1	6370.5	<0.01	1.4	3.7	2.2	0.65	1.1	0.48	47
Duncan Tevault No. 1	6371.0	<0.01	1.3	2.8	1.6	0.4	0.70	0.77	42
Elk Ridge No. 1	2548.4	na	1.1	6.1	1.2	1.1	3.3	0.27	292
Elk Ridge No. 1	2560.4	na	1.7	5.1	2.4	1.9	7.6	0.38	335
Elk Ridge No. 1	2570.5	na	1.2	6.3	2.1	2.0	6.8	0.35	322
Elk Ridge No. 1	2578.5	na	1.6	4.2	3.0	2.1	9.8	0.44	328
Elk Ridge No. 1	2588.5	na	1.9	4.4	3.3	2.2	11	0.64	316
Elk Ridge No. 1	2594.7	na	1.5	4.8	3.3	2.5	11	0.53	320
Elk Ridge No. 1	2614.4	na	1.5	6.5	0.29	na	na	na	na
Elk Ridge No. 1	2653.6	na	20	0.46	0.04	na	na	na	na
Elk Ridge No. 1	2676.8	na	1.2	7.3	1.6	2.7	5.2	0.48	312
Elk Ridge No. 1	2680.7	na	2.1	3.1	3.0	3.8	11	0.77	335
Elk Ridge No. 1	2687.9	na	3.2	2.7	5.3	3.3	18	1.1	308
Elk Ridge No. 1	2693.8	na	3.5	2.3	5.0	3.3	15	1.1	276
Elk Ridge No. 1	2701.0	na	2.9	2.6	5.0	3.2	14	0.95	273
Elk Ridge No. 1	2706.7	na	2.5	4.3	4.2	2.7	12	0.90	274
Elk Ridge No. 1	2711.1	na	4.5	3.4	0.09	na	na	na	na
Gibson Dome No. 1	2846.6	na	21	0.92	0.03	na	na	na	na

Appendix 2, table 2. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	S_{Org} (weight percent)	S_{tot} (weight percent)	C_{CO_3} (weight percent)	C_{Org} (weight percent)	S_1	S_2	S_3	HI
Gibson Dome No. 1	2869.0	na	0.67	7.2	0.11	na	na	na	na
Gibson Dome No. 1	2873.0	na	0.44	8.9	0.21	na	na	na	na
Gibson Dome No. 1	2879.0	na	1.5	4.1	5.3	1.9	27	1.0	491
Gibson Dome No. 1	2885.6	na	1.8	4.0	2.3	1.2	8.7	1.0	366
Gibson Dome No. 1	2888.5	na	1.7	4.3	2.0	1.3	7.4	0.88	366
Gibson Dome No. 1	2890.5	na	1.6	4.9	2.3	1.4	8.9	0.92	400
Gibson Dome No. 1	2892.0	na	1.6	4.5	1.9	1.1	6.2	0.88	328
Gibson Dome No. 1	2893.9	na	1.3	5.8	1.5	0.72	4.0	0.78	286
Gibson Dome No. 1	2895.9	na	1.7	4.2	2.8	1.6	11	0.93	398
Gibson Dome No. 1	2897.2	na	1.4	5.4	2.3	1.7	9.2	0.87	392
Gibson Dome No. 1	2898.6	na	2.0	4.1	2.8	1.7	11	0.94	410
Gibson Dome No. 1	2902.7	na	1.7	3.9	2.2	1.1	7.2	0.85	344
Gibson Dome No. 1	2904.6	na	1.7	3.3	3.3	1.6	13	0.97	412
Gibson Dome No. 1	2907.5	na	0.43	3.9	1.1	0.19	4.1	0.29	393
Gibson Dome No. 1	2908.3	na	1.2	4.7	0.12	na	na	na	na
Gibson Dome No. 1	2922.5	na	23	0.43	0.04	na	na	na	na
Gibson Dome No. 1	3066.9	na	14	1.6	0.08	na	na	na	na
Gibson Dome No. 1	3069.6	na	2.5	7.1	0.11	na	na	na	na
Gibson Dome No. 1	3079.2	na	0.49	7.1	0.46	na	na	na	na
Gibson Dome No. 1	3080.8	na	0.34	3.5	0.06	na	na	na	na
Gibson Dome No. 1	3089.0	na	0.25	3.4	0.06	na	na	na	na
Gibson Dome No. 1	3096.3	na	0.52	4.7	0.05	na	na	na	na
Gibson Dome No. 1	3098.2	na	0.31	3.0	0.08	na	na	na	na
Gibson Dome No. 1	3098.6	na	22	2.6	0.05	na	na	na	na
Gibson Dome No. 1	3110.2	na	0.26	2.7	0.1	na	na	na	na
Honaker Trail outcrop	0.0	0.74	1.9	3.7	6.8	2.1	32	0.48	465
Lake Canyon No. 1-27	5748.5	na	0.77	9.0	0.27	0.16	0.12	0.31	44
Lake Canyon No. 1-27	5749.0	0.66	1.7	na	na	na	na	na	na
Lake Canyon No. 1-27	5752.8	0.05	1.3	5.7	1.3	0.46	0.71	0.69	56
Lake Canyon No. 1-27	5756.5	0.01	1.3	5.9	1.3	0.79	0.89	0.57	70
Lake Canyon No. 1-27	5762.3	0.01	5.4	7.8	0.75	0.51	0.48	0.35	64
Lake Canyon No. 1-27	5764.5	na	1.4	5.7	1.4	0.88	1.0	0.61	73
Lake Canyon No. 1-27	5767.0	0.07	1.2	5.3	2.1	1.4	1.8	0.63	83
Lake Canyon No. 1-27	5770.3	na	1.4	5.0	1.5	0.91	1.1	0.57	78
Lake Canyon No. 1-27	5774.5	0.08	1.5	2.4	4.6	2.3	4.7	0.69	104
Norton Federal No. 1-4	5919.8	<0.01	1.1	6.3	1.2	0.50	0.73	0.76	60
Norton Federal No. 1-4	5925.0	0.02	1.2	5.4	1.3	0.57	0.72	0.77	55
Norton Federal No. 1-4	5929.0	0.01	1.1	5.9	1.3	0.51	0.58	0.76	44
Norton Federal No. 1-4	5929.8	0.02	1.1	5.3	1.5	0.62	0.66	0.68	44
Norton Federal No. 1-4	6042.0	<0.01	0.37	12	11	1.5	7.0	0.60	64

Appendix 2, table 2. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	S_{Org} (weight percent)	S_{tot} (weight percent)	C_{CO_3} (weight percent)	C_{Org} (weight percent)	S_1	S_2	S_3	HI
Norton Federal No. 1-4	6044.3	na	0.93	9.5	0.30	na	na	na	na
Norton Federal No. 1-4	6052.3	<0.01	0.56	5.7	0.37	na	na	na	na
Norton Federal No. 1-4	6057.5	na	1.1	5.8	0.80	0.16	0.16	0.61	20
Norton Federal No. 1-4	6060.3	<0.01	0.78	6.5	0.47	na	na	na	na
Norton Federal No. 1-4	6062.3	0.04	1.2	2.4	2.7	0.35	0.52	0.78	19
Norton Federal No. 1-4	6066.0	0.02	1.1	0.60	2.2	0.31	0.42	0.49	19
Norton Federal No. 1-4	6067.8	0.08	1.1	0.40	3.1	0.50	0.61	0.42	19
Norton Federal No. 1-4	6071.5	na	1.3	1.9	0.20	na	na	na	na
Norton Federal No. 1-4	6074.5	na	19	3.3	0.25	na	na	na	na
Norton Federal No. 1-4	6077.3	<0.01	2.4	11	0.23	na	na	na	na
Pickett Federal No. 1-33	5642.0	na	0.36	9.4	0.19	0.08	0.06	0.46	31
Pickett Federal No. 1-33	5644.3	0.06	1.5	5.1	2.7	1.2	1.7	0.79	64
Pickett Federal No. 1-33	5645.8	0.72	1.7	3.2	2.0	0.68	1.5	0.78	73
Pickett Federal No. 1-33	5648.0	0.19	1.7	3.6	2.9	1.1	2.2	0.83	77
Pickett Federal No. 1-33	5649.0	0.04	1.8	3.2	2.4	1.0	1.7	0.71	69
Pickett Federal No. 1-33	5651.2	<0.01	1.8	3.3	2.6	1.0	1.6	0.80	60
Pickett Federal No. 1-33	5653.3	0.35	2.1	2.8	4.9	1.8	3.3	0.83	67
Pickett Federal No. 1-33	5656.5	0.03	2.1	2.8	3.5	1.5	2.0	0.61	58
Pickett Federal No. 1-33	5659.0	0.04	1.9	2.4	3.2	1.4	1.8	0.66	56
Pickett Federal No. 1-33	5660.8	0.06	1.9	1.4	3.3	1.2	2.0	0.40	61
Pickett Federal No. 1-33	5664.0	0.02	1.6	na	na	na	na	na	na
Pickett Federal No. 1-33	5665.5	na	0.74	6.3	0.09	0	0	0.53	0
Pickett Federal No. 1-33	5665.8	0.08	1.6	4.4	8.6	3.6	5.9	0.91	69
Pickett Federal No. 1-33	5670.5	na	1.2	3.2	0.26	0.13	0.17	0.39	65
Shafer No. 1	2514.5	0.12	20	1.4	0.05	0	0.08	0.24	160
Shafer No. 1	2529.0	na	0.26	7.0	0.24	0.18	0.33	0.59	137
Shafer No. 1	2535.0	na	0.34	7.7	0.36	na	na	na	na
Shafer No. 1	2536.5	na	0.32	9.1	0.31	0.12	0.42	0.83	135
Shafer No. 1	2537.0	na	0.48	7.3	0.72	0.23	1.7	3.6	230
Shafer No. 1	2539.0	<0.01	1.5	1.9	5.0	2.5	19	0.93	386
Shafer No. 1	2540.0	0.01	2.2	1.8	2.8	2.3	22	1.5	435
Shafer No. 1	2541.0	0.03	1.4	3.0	3.7	1.6	16	1.5	418
Shafer No. 1	2542.8	0.07	1.5	2.7	5.1	na	na	na	na
Shafer No. 1	2543.8	0.04	1.2	2.7	4.5	2.1	18	1.6	407
Shafer No. 1	2545.0	0.04	1.6	2.9	3.8	1.8	15	1.5	396
Shafer No. 1	2546.3	na	1.1	4.4	2.3	1.2	7.0	0.75	310
Shafer No. 1	2547.3	0.07	1.4	2.3	3.4	1.5	12	1.5	363
Shafer No. 1	2548.8	0.03	2.1	2.9	3.1	1.3	11	1.4	364
Shafer No. 1	2550.5	0.05	1.7	1.8	3.8	1.6	15	0.98	384
Shafer No. 1	2551.5	0.01	0.58	8.9	0.99	0.51	2.8	0.59	283

Appendix 2, table 2. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	S_{Org} (weight percent)	S_{tot} (weight percent)	C_{CO_3} (weight percent)	C_{Org} (weight percent)	S_1	S_2	S_3	HI
Shafer No. 1	2552.8	na	2.3	1.4	3.0	1.3	8.6	0.9	285
Shafer No. 1	2555.3	0.06	1.5	1.6	3.3	1.4	12	1.1	359
Shafer No. 1	2556.5	na	1.3	3.5	2.3	1.9	7.8	0.89	338
Shafer No. 1	2558.0	0.01	0.79	7.9	1.3	0.61	3.4	0.70	263
Shafer No. 1	2559.5	na	1.0	3.7	2.4	1.0	7.5	0.84	312
Shafer No. 1	2560.5	na	0.53	7.9	1.8	0.69	4.4	0.71	247
Shafer No. 1	2562.0	0.03	1.1	3	2.0	0.85	6.0	1.2	296
Shafer No. 1	2563.0	<0.01	1.3	2.8	1.9	0.79	5.5	1.2	294
Shafer No. 1	2564.0	0.03	1.6	2.7	1.8	0.69	4.5	1.5	247
Shafer No. 1	2564.8	0.02	1.5	3.1	1.8	0.64	4.2	1.4	238
Shafer No. 1	2566.0	<0.01	1.3	2.7	2.0	1.0	6.0	1.6	291
Shafer No. 1	2568.0	<0.01	0.5	1.6	0.05	na	na	na	na
Shafer No. 1	2576.0	na	0.29	7.4	0.76	0.28	0.94	1.2	123
Shafer No. 1	2580.0	<0.01	0.58	5.3	0.13	na	na	na	na
Shafer No. 1	2884.0	0.1	1.1	<0.01	17	8.5	50	0.86	288
Shafer No. 1	2923.0	na	0.25	9.2	4.7	1.4	14	0.59	294
Shafer No. 1	2940.0	na	0.18	12	2.1	1.3	9.0	1.1	439
Shafer No. 1	2953.0	<0.01	0.33	2.8	0.26	na	na	na	na
State No. 1-16	5518.3	<0.01	0.13	11	0.07	na	na	na	na
State No. 1-16	5521.3	na	0.13	11	0.07	na	na	na	na
State No. 1-16	5537.0	<0.01	0.39	7.5	0.11	na	na	na	na
State No. 1-16	5542.0	<0.01	1.4	3.2	0.41	na	na	na	na
State No. 1-16	5546.8	<0.01	0.79	2.8	0.25	na	na	na	na
State No. 1-16	5552.0	<0.01	0.74	3.8	0.36	na	na	na	na
State No. 1-16	5698.0	0.01	0.42	8.8	0.27	na	na	na	na
State No. 1-16	5700.5	na	0.34	9.7	0.19	na	na	na	na
State No. 1-16	5701.8	0.51	2.9	2.6	3.3	0.69	9.1	0.67	279
State No. 1-16	5704.0	0.06	1.2	6.6	1.3	0.55	4.3	0.64	329
State No. 1-16	5707.7	0.04	2.4	3.4	2.6	1.7	8.7	0.89	330
State No. 1-16	5711.5	0.03	2.8	3.6	2.4	1.7	9.0	0.76	376
Ute Mountain No. 44-34	8695.0	na	0.28	4.2	0.22	0	0	0.23	13
Ute Mountain No. 44-34	8714.0	na	0.54	7.4	0.25	0	0	0.22	0
Ute Mountain No. 44-34	8720.0	<0.01	0.97	6.0	0.93	0.13	0.11	0.53	11
Ute Mountain No. 44-34	8732.5	<0.01	0.98	4.9	1.0	0.15	0.15	0.36	14
Ute Mountain No. 44-34	8737.0	<0.01	0.95	4.9	1.1	0.15	0.12	0.31	10
Ute Mountain No. 44-34	8742.5	<0.01	1.0	5.9	1.1	0.16	0.15	0.29	14
Ute Mountain No. 44-34	8753.0	<0.01	1.0	5.4	1.5	0.21	0.22	0.31	14
Ute Mountain No. 44-34	8769.8	<0.01	0.98	5.7	1.3	0.21	0.18	0.30	14
Ute Mountain No. 44-34	8773.0	<0.01	1.0	5.6	1.3	0.21	0.20	0.44	15
West Water Creek No. 1	6304.8	<0.01	2.2	3.8	1.8	1.0	3.5	0.41	200

Appendix 2, table 2. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	S_{Org} (weight percent)	S_{tot} (weight percent)	C_{CO_3} (weight percent)	C_{Org} (weight percent)	S_1	S_2	S_3	HI
West Water Creek No. 1	6311.8	na	1.1	4.9	1.6	1.4	3.2	0.36	196
West Water Creek No. 1	6317.3	na	1.4	4.2	2.1	1.8	4.6	0.53	223
West Water Creek No. 1	6322.5	<0.01	1.7	5.2	2.5	1.9	5.6	0.41	227
Woods Unit No. 1-S	5912.5	<0.01	1.7	3.9	3.1	1.3	1.9	1.0	61
Woods Unit No. 1-S	5913.3	na	0.66	7.0	1.1	0.46	0.68	0.67	62
Woods Unit No. 1-S	5916.7	<0.01	1.4	3.1	1.6	0.54	1.0	0.94	60
Woods Unit No. 1-S	5919.5	na	1.7	0.94	3.5	1.3	1.8	0.60	50
Woods Unit No. 1-S	5921.0	0.02	0.65	9.6	2.2	0.83	1.1	0.43	50
Woods Unit No. 1-S	5922.2	na	1.5	5.7	0.35	0.12	0.13	0.64	37
Woods Unit No. 1-S	5926.3	na	0.86	7.0	0.74	0.25	0.24	0.67	32
Woods Unit No. 1-S	5932.0	na	1.7	11	0.09	0	0	0.16	0

Appendix 2, table 3. Lithologic, chemical, isotopic, and mineralogic data for core samples in study.

Well name	Depth (ft)	OI	T_{max} (°C)	$\delta^{34}S_{Di}$	$\delta^{34}S_{SO_4}$	$\delta^{34}S_{Org}$	Fe_{rct} (weight percent)	DOP_r	Quartz
Aztec Federal No. 1	6374.8	161	393	na	na	na	na	na	22
Aztec Federal No. 1	6378.5	143	413	na	na	na	na	na	30
Aztec Federal No. 1	6379.8	32	446	-20.9	insuf	-7.3	2.6	0.65	15
Aztec Federal No. 1	6384.3	27	444	-12.5	insuf	insuf	2.4	0.69	27
Aztec Federal No. 1	6389.5	27	440	-15.9	insuf	insuf	2.6	0.68	19
Aztec Federal No. 1	6393.3	13	447	-16.4	insuf	-13.7	2.6	0.71	23
Crowley Ranch No. 1-25	5905.0	86	434	-36.1	-6.5	insuf	1.8	0.46	27
Crowley Ranch No. 1-25	5915.0	16	450	-24.3	14.1	insuf	3.3	0.81	14
Duncan Tevault No. 1	6365.0	152	349	insuf	16.2	insuf	na	na	83
Duncan Tevault No. 1	6367.0	75	423	-33.7	insuf	insuf	1.3	0.47	28
Duncan Tevault No. 1	6370.5	21	445	-26.3	11.5	insuf	2.1	0.54	31
Duncan Tevault No. 1	6371.0	46	437	-29.1	insuf	insuf	1.9	0.56	27
Elk Ridge No. 1	2548.4	23	443	-23.6	na	na	1.2	0.62	27
Elk Ridge No. 1	2560.4	16	444	na	na	na	1.7	0.72	25
Elk Ridge No. 1	2570.5	16	442	na	na	na	1.3	0.62	20
Elk Ridge No. 1	2578.5	14	442	na	na	na	1.9	0.52	28
Elk Ridge No. 1	2588.5	18	444	na	na	na	2.1	0.42	21
Elk Ridge No. 1	2594.7	15	444	-13.8	na	na	1.8	0.82	32
Elk Ridge No. 1	2614.4	na	na	na	na	na	1.7	0.72	23
Elk Ridge No. 1	2653.6	na	na	na	na	na	na	na	19
Elk Ridge No. 1	2676.8	28	441	na	na	na	1.2	0.77	38
Elk Ridge No. 1	2680.7	23	443	na	na	na	2.1	0.64	34

Appendix 2, table 3. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	OI	T_{max} (°C)	$\delta^{34}S_{Di}$	$\delta^{34}S_{SO_4}$	$\delta^{34}S_{Org}$	Fe_{rct} (weight percent)	DOP_r	Quartz
Elk Ridge No. 1	2687.9	19	446	na	na	na	3.0	0.53	18
Elk Ridge No. 1	2693.8	20	444	na	na	na	3.4	0.47	17
Elk Ridge No. 1	2701.0	18	444	na	na	na	3.0	0.45	18
Elk Ridge No. 1	2706.7	19	446	na	na	na	2.5	0.64	24
Elk Ridge No. 1	2711.1	na	na	na	na	na	0.33	0.79	47
Gibson Dome No. 1	2846.6	na	na	insuf	15.4	insuf	na	na	0
Gibson Dome No. 1	2869.0	na	na	na	na	na	0.81	0.92	29
Gibson Dome No. 1	2873.0	na	na	na	na	na	0.63	0.62	23
Gibson Dome No. 1	2879.0	18	442	-17.5	na	na	2.2	0.42	26
Gibson Dome No. 1	2885.6	42	442	na	na	na	2.4	0.42	21
Gibson Dome No. 1	2888.5	43	442	na	na	na	2.2	0.42	25
Gibson Dome No. 1	2890.5	41	441	-18.1	na	na	2.1	0.42	21
Gibson Dome No. 1	2892.0	46	442	na	na	na	2.1	0.42	21
Gibson Dome No. 1	2893.9	56	441	na	na	na	1.9	0.62	18
Gibson Dome No. 1	2895.9	34	440	na	na	na	2.1	0.52	20
Gibson Dome No. 1	2897.2	37	440	na	na	na	2.0	0.49	20
Gibson Dome No. 1	2898.6	35	442	na	na	na	2.4	0.52	21
Gibson Dome No. 1	2902.7	40	443	na	na	na	2.3	0.52	23
Gibson Dome No. 1	2904.6	31	440	na	na	na	2.3	0.52	26
Gibson Dome No. 1	2907.5	28	443	na	na	na	0.48	0.62	70
Gibson Dome No. 1	2908.3	na	na	na	na	na	0.33	0.62	47
Gibson Dome No. 1	2922.5	na	na	insuf	15.5	na	na	na	0
Gibson Dome No. 1	3066.9	na	na	insuf	13.8	na	na	na	2
Gibson Dome No. 1	3069.6	na	na	na	na	na	0.55	na	11
Gibson Dome No. 1	3079.2	na	na	na	na	na	1.4	0.33	16
Gibson Dome No. 1	3080.8	na	na	na	na	na	0.73	0.49	48
Gibson Dome No. 1	3089.0	na	na	na	na	na	0.8	0.32	39
Gibson Dome No. 1	3096.3	na	na	na	na	na	1.0	0.56	52
Gibson Dome No. 1	3098.2	na	na	insuf	14.5	na	1.1	0.33	59
Gibson Dome No. 1	3098.6	na	na	na	na	na	0.33	<	6
Gibson Dome No. 1	3110.2	na	na	na	na	na	0.8	0.32	58
Honaker Trail outcrop	0.0	7	440	-21.4	-13.2	-17.1	1.3	0.61	24
Lake Canyon No. 1-27	5748.5	114	420	na	na	na	na	na	19
Lake Canyon No. 1-27	5749.0	na	na	-22.6	9.8	insuf	1.9	0.42	17
Lake Canyon No. 1-27	5752.8	55	441	-25.5	insuf	-19.2	1.8	0.55	25
Lake Canyon No. 1-27	5756.5	44	442	-22.1	insuf	insuf	1.6	0.50	19
Lake Canyon No. 1-27	5762.3	46	371	-14.1	15.9	insuf	5.3	0.87	16
Lake Canyon No. 1-27	5764.5	44	441	na	na	na	na	na	20
Lake Canyon No. 1-27	5767.0	30	440	-16.0	insuf	-14.1	1.7	0.52	22
Lake Canyon No. 1-27	5770.3	39	438	na	na	na	na	na	22

Appendix 2, table 3. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	OI	T_{max} (°C)	$\delta^{34}S_{D1}$	$\delta^{34}S_{SO_4}$	$\delta^{34}S_{Org}$	Fe_{rct} (weight percent)	DOP_r	Quartz
Lake Canyon No. 1-27	5774.5	15	446	-20.9	insuf	-15.5	1.9	0.50	23
Norton Federal No. 1-4	5919.8	62	390	-11.8	insuf	insuf	1.3	0.67	20
Norton Federal No. 1-4	5925.0	59	368	-14.7	insuf	insuf	1.5	0.64	24
Norton Federal No. 1-4	5929.0	58	369	-15.0	insuf	insuf	1.5	0.61	25
Norton Federal No. 1-4	5929.8	46	371	-15.8	insuf	insuf	1.4	0.59	28
Norton Federal No. 1-4	6042.0	5	484	-15.4	12.8	insuf	0.30	0.04	0
Norton Federal No. 1-4	6044.3	na	na	na	na	na	na	na	14
Norton Federal No. 1-4	6052.3	na	na	-33.2	-17.0	insuf	1.3	0.27	39
Norton Federal No. 1-4	6057.5	76	400	na	na	na	na	na	30
Norton Federal No. 1-4	6060.3	na	na	-35.3	insuf	insuf	1.3	0.43	24
Norton Federal No. 1-4	6062.3	28	450	-30.0	insuf	-18.4	1.7	0.51	30
Norton Federal No. 1-4	6066.0	22	454	-33.2	insuf	insuf	1.7	0.48	30
Norton Federal No. 1-4	6067.8	13	458	-33.2	insuf	-24.4	1.6	0.56	32
Norton Federal No. 1-4	6071.5	na	na	na	na	na	na	na	75
Norton Federal No. 1-4	6074.5	na	na	insuf	14.8	insuf	na	na	4
Norton Federal No. 1-4	6077.3	na	na	-16.4	insuf	insuf	0.34	0.23	2
Pickett Federal No. 1-33	5642.0	242	347	na	na	na	na	na	19
Pickett Federal No. 1-33	5644.3	29	440	-28.4	6.0	insuf	2.1	0.55	15
Pickett Federal No. 1-33	5645.8	39	437	-20.3	insuf	-20.0	1.5	0.51	28
Pickett Federal No. 1-33	5648.0	28	447	-15.2	insuf	-10.5	2.0	0.57	26
Pickett Federal No. 1-33	5649.0	29	451	-18.7	insuf	insuf	2.4	0.60	25
Pickett Federal No. 1-33	5651.2	30	448	na	na	na	2.4	0.60	28
Pickett Federal No. 1-33	5653.3	17	459	-17.1	insuf	-11.3	2.5	0.60	25
Pickett Federal No. 1-33	5656.5	17	454	-19.7	insuf	insuf	2.4	0.58	35
Pickett Federal No. 1-33	5659.0	20	451	insuf	insuf	-13.5	2.6	0.59	30
Pickett Federal No. 1-33	5660.8	12	455	-15.8	insuf	-6.8	2.5	0.59	32
Pickett Federal No. 1-33	5664.0	na	na	-14.5	1.9	insuf	2.3	0.53	23
Pickett Federal No. 1-33	5665.5	588	na	na	na	na	na	na	45
Pickett Federal No. 1-33	5665.8	10	449	-11.1	-2.1	-2.9	2.3	0.59	26
Pickett Federal No. 1-33	5670.5	150	413	na	na	na	na	na	57
Shafer No. 1	2514.5	480	414	-19.2	13.1	insuf	0.52	0.08	1
Shafer No. 1	2529.0	245	432	na	na	na	na	na	23
Shafer No. 1	2535.0	na	na	-37.2	-1.5	na	1.1	0.17	21
Shafer No. 1	2536.5	267	436	na	na	na	na	na	12
Shafer No. 1	2537.0	504	432	na	na	na	na	na	22
Shafer No. 1	2539.0	18	435	-28.2	-15.3	-14.5	3.1	0.32	26
Shafer No. 1	2540.0	29	439	-24.1	-5.7	insuf	3.1	0.51	27
Shafer No. 1	2541.0	40	439	-23.3	-5.7	insuf	2.4	0.39	26
Shafer No. 1	2542.8	na	na	-17.4	-5.6	-11.4	2.5	0.45	25
Shafer No. 1	2543.8	34	438	-19.8	-3.2	na	2.4	0.45	26

Appendix 2, table 3. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	OI	T_{max} (°C)	$\delta^{34}S_{DI}$	$\delta^{34}S_{SO_4}$	$\delta^{34}S_{Org}$	Fe_{rct} (weight percent)	DOP_r	Quartz
Shafer No. 1	2545.0	38	439	-20.7	-3.6	na	2.6	0.46	22
Shafer No. 1	2546.3	33	435	na	na	na	na	na	23
Shafer No. 1	2547.3	44	436	-26.8	-4.2	insuf	2.5	0.43	23
Shafer No. 1	2548.8	45	440	-13.6	insuf	insuf	3.1	0.54	23
Shafer No. 1	2550.5	25	438	-24.0	0.4	-9.0	2.9	0.45	23
Shafer No. 1	2551.5	59	438	-22.5	6.3	insuf	1.5	0.28	12
Shafer No. 1	2552.8	29	433	na	na	na	na	na	28
Shafer No. 1	2555.3	32	437	-25.7	2.8	insuf	2.6	0.42	22
Shafer No. 1	2556.5	38	436	na	na	na	na	na	21
Shafer No. 1	2558.0	55	437	-27.4	-0.8	insuf	1.7	0.34	12
Shafer No. 1	2559.5	34	435	na	na	na	na	na	23
Shafer No. 1	2560.5	40	437	na	na	na	na	na	12
Shafer No. 1	2562.0	60	437	-31.5	-5.8	-15.8	2.2	0.50	25
Shafer No. 1	2563.0	65	435	-32.1	-5.5	insuf	2.0	0.49	21
Shafer No. 1	2564.0	81	436	-31.9	-5.0	insuf	2.3	0.52	21
Shafer No. 1	2564.8	80	437	-35.7	-6.2	insuf	2.3	0.52	20
Shafer No. 1	2566.0	78	436	na	na	na	na	na	18
Shafer No. 1	2568.0	na	na	-12.6	-5.0	insuf	0.62	0.58	65
Shafer No. 1	2576.0	152	436	na	na	na	na	na	21
Shafer No. 1	2580.0	na	na	-29.6	-4.3	na	1.3	0.25	22
Shafer No. 1	2884.0	4	434	-44.9	-24.8	-23.4	1.2	0.25	26
Shafer No. 1	2923.0	12	435	na	na	na	na	na	43
Shafer No. 1	2940.0	54	436	na	na	na	na	na	9
Shafer No. 1	2953.0	na	na	-30.9	insuf	insuf	0.84	0.24	59
State No. 1-16	5518.3	na	na	-23.8	12.9	na	<.05	0.78	12
State No. 1-16	5521.3	na	na	na	na	na	na	na	2
State No. 1-16	5537.0	na	na	-28.7	14.0	insuf	0.39	0.65	25
State No. 1-16	5542.0	na	na	-21.3	insuf	insuf	1.5	0.66	48
State No. 1-16	5546.8	na	na	-22.9	insuf	insuf	0.91	0.62	60
State No. 1-16	5552.0	na	na	-20.9	7.6	insuf	0.92	0.57	50
State No. 1-16	5698.0	na	na	-13.7	insuf	insuf	0.36	0.71	19
State No. 1-16	5700.5	na	na	na	na	na	na	na	17
State No. 1-16	5701.8	20	452	-9.4	insuf	-8.0	2.4	0.82	25
State No. 1-16	5704.0	49	444	-5.0	insuf	-1.1	1.0	0.80	33
State No. 1-16	5707.7	33	446	-7.7	insuf	-0.7	2.4	0.83	25
State No. 1-16	5711.5	31	445	-5.8	insuf	insuf	2.6	0.87	29
Ute Mountain No. 44-34	8695.0	104	415	na	na	na	na	na	45
Ute Mountain No. 44-34	8714.0	88	na	na	na	na	na	na	27
Ute Mountain No. 44-34	8720.0	56	462	-23.3	insuf	insuf	1.2	0.64	31
Ute Mountain No. 44-34	8732.5	35	469	-16.5	insuf	insuf	1.1	0.60	43

Appendix 2, table 3. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	OI	T_{max} (°C)	$\delta^{34}S_{Di}$	$\delta^{34}S_{SO_4}$	$\delta^{34}S_{Org}$	Fe_{rct} (weight percent)	DOP_r	Quartz
Ute Mountain No. 44-34	8737.0	28	470	-16.5	insuf	insuf	1.4	0.58	34
Ute Mountain No. 44-34	8742.5	27	480	-14.3	insuf	insuf	1.4	0.59	27
Ute Mountain No. 44-34	8753.0	21	477	-15.6	insuf	insuf	1.1	0.49	32
Ute Mountain No. 44-34	8769.8	23	482	-13.4	insuf	insuf	1.4	0.55	30
Ute Mountain No. 44-34	8773.0	21	482	-12.3	insuf	insuf	1.5	0.53	26
West Water Creek No. 1	6304.8	23	444	-22.7	insuf	insuf	2.4	0.77	31
West Water Creek No. 1	6311.8	21	446	na	na	na	na	na	36
West Water Creek No. 1	6317.3	25	445	na	na	na	na	na	36
West Water Creek No. 1	6322.5	16	446	-23.1	insuf	insuf	1.8	0.78	29
Woods Unit No. 1-S	5912.5	33	446	-24.3	insuf	insuf	2.2	0.58	21
Woods Unit No. 1-S	5913.3	62	437	na	na	na	na	na	20
Woods Unit No. 1-S	5916.7	58	435	-31.1	insuf	insuf	2.3	0.55	22
Woods Unit No. 1-S	5919.5	16	458	na	na	na	na	na	30
Woods Unit No. 1-S	5921.0	19	456	insuf	11.1	-1.6	1.0	0.56	6
Woods Unit No. 1-S	5922.2	182	397	na	na	na	na	na	42
Woods Unit No. 1-S	5926.3	90	434	na	na	na	na	na	21
Woods Unit No. 1-S	5932.0	177	na	na	na	na	na	na	4

Appendix 2, table 4. Lithologic, chemical, isotopic, and mineralogic data for core samples in study.

Well name	Depth (ft)	Potassium feldspar	Sodium feldspar	Apatite	Calcite	Dolomite	Anhydrite	Halite	Pyrite
Aztec Federal No. 1	6374.8	5	8	0	133	120	0	0	2
Aztec Federal No. 1	6378.5	4	5	0	133	90	0	0	1
Aztec Federal No. 1	6379.8	10	11	0	90	51	0	0	11
Aztec Federal No. 1	6384.3	9	9	10	90	20	0	0	14
Aztec Federal No. 1	6389.5	8	10	0	81	14	6	0	9
Aztec Federal No. 1	6393.3	14	15	6	84	13	7	0	12
Crowley Ranch No. 1-25	5905.0	9	0	0	79	69	0	0	7
Crowley Ranch No. 1-25	5915.0	19	0	0	111	10	0	0	11
Duncan Tevault No. 1	6365.0	0	0	0	17	10	97	0	4
Duncan Tevault No. 1	6367.0	6	0	0	8	223	4	0	6
Duncan Tevault No. 1	6370.5	10	0	5	6	127	0	0	7
Duncan Tevault No. 1	6371.0	12	0	0	91	17	7	0	9
Elk Ridge No. 1	2548.4	5	5	3	161	58	0	0	7
Elk Ridge No. 1	2560.4	5	5	4	111	46	0	0	10
Elk Ridge No. 1	2570.5	4	6	2	117	75	0	0	7

Appendix 2, table 4. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Potassium feldspar	Sodium feldspar	Apatite	Calcite	Dolomite	Anhydrite	Halite	Pyrite
Elk Ridge No. 1	2578.5	7	8	3	106	25	0	0	8
Elk Ridge No. 1	2588.5	17	10	4	122	22	0	0	8
Elk Ridge No. 1	2594.7	8	6	4	100	66	0	0	12
Elk Ridge No. 1	2614.4	10	10	0	6	200	0	0	10
Elk Ridge No. 1	2653.6	0	0	0	2	11	203	0	0
Elk Ridge No. 1	2676.8	0	8	0	4	230	0	0	8
Elk Ridge No. 1	2680.7	9	18	5	106	18	0	0	12
Elk Ridge No. 1	2687.9	7	25	5	57	15	0	0	14
Elk Ridge No. 1	2693.8	0	26	5	66	13	0	0	14
Elk Ridge No. 1	2701.0	11	25	5	66	15	0	0	12
Elk Ridge No. 1	2706.7	0	24	3	106	30	0	0	14
Elk Ridge No. 1	2711.1	18	17	0	70	20	76	0	1
Gibson Dome No. 1	2846.6	0	0	0	0	26	249	9	0
Gibson Dome No. 1	2869.0	11	27	0	0	220	0	0	13
Gibson Dome No. 1	2873.0	5	13	0	0	250	8	0	3
Gibson Dome No. 1	2879.0	9	14	5	5	160	0	0	8
Gibson Dome No. 1	2885.6	8	12	3	111	23	0	0	8
Gibson Dome No. 1	2888.5	0	16	3	133	20	0	0	8
Gibson Dome No. 1	2890.5	0	9	3	128	26	0	0	7
Gibson Dome No. 1	2892.0	0	12	3	128	41	0	0	7
Gibson Dome No. 1	2893.9	5	8	0	75	130	0	0	10
Gibson Dome No. 1	2895.9	0	12	4	122	21	0	0	9
Gibson Dome No. 1	2897.2	0	9	5	94	130	0	0	8
Gibson Dome No. 1	2898.6	0	14	4	128	21	0	0	11
Gibson Dome No. 1	2902.7	9	11	3	122	24	0	0	10
Gibson Dome No. 1	2904.6	12	14	5	106	24	0	0	10
Gibson Dome No. 1	2907.5	12	20	0	87	21	0	0	2
Gibson Dome No. 1	2908.3	17	21	0	106	51	24	0	1
Gibson Dome No. 1	2922.5	0	0	0	9	0	232	0	0
Gibson Dome No. 1	3066.9	0	0	0	0	62	68	29	0
Gibson Dome No. 1	3069.6	0	0	0	3	210	72	23	0
Gibson Dome No. 1	3079.2	12	0	0	7	250	0	8	3
Gibson Dome No. 1	3080.8	23	0	0	66	94	0	75	2
Gibson Dome No. 1	3089.0	43	0	0	43	80	0	94	1
Gibson Dome No. 1	3096.3	31	0	0	8	160	0	95	4
Gibson Dome No. 1	3098.2	37	0	0	9	140	0	19	2
Gibson Dome No. 1	3098.6	0	0	0	0	83	212	0	0
Gibson Dome No. 1	3110.2	0	0	0	5	100	7	95	1
Honaker Trail outcrop	0.0	10	0	4	100	41	5	0	10
Lake Canyon No. 1-27	5748.5	0	12	0	128	110	3	0	12

Appendix 2, table 4. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Potassium feldspar	Sodium feldspar	Apatite	Calcite	Dolomite	Anhydrite	Halite	Pyrite
Lake Canyon No. 1-27	5749.0	7	23	9	73	58	6	0	12
Lake Canyon No. 1-27	5752.8	0	11	3	145	36	5	0	8
Lake Canyon No. 1-27	5756.5	5	9	3	139	54	4	0	6
Lake Canyon No. 1-27	5762.3	0	8	0	117	28	12	0	10
Lake Canyon No. 1-27	5764.5	0	9	0	145	29	4	0	7
Lake Canyon No. 1-27	5767.0	6	9	3	150	33	5	0	9
Lake Canyon No. 1-27	5770.3	0	13	4	150	22	6	0	7
Lake Canyon No. 1-27	5774.5	0	20	5	81	13	9	0	9
Norton Federal No. 1-4	5919.8	5	3	3	128	75	3	0	7
Norton Federal No. 1-4	5925.0	0	0	0	145	50	4	0	5
Norton Federal No. 1-4	5929.0	0	3	3	128	48	3	0	6
Norton Federal No. 1-4	5929.8	0	3	0	145	39	4	0	4
Norton Federal No. 1-4	6042.0	0	0	0	0	290	35	0	0
Norton Federal No. 1-4	6044.3	12	0	0	0	303	13	0	4
Norton Federal No. 1-4	6052.3	23	0	6	0	157	10	4	6
Norton Federal No. 1-4	6057.5	10	0	0	5	230	18	0	4
Norton Federal No. 1-4	6060.3	11	0	6	7	186	5	0	5
Norton Federal No. 1-4	6062.3	21	0	0	67	39	0	0	6
Norton Federal No. 1-4	6066.0	35	0	0	25	0	0	0	7
Norton Federal No. 1-4	6067.8	40	45	0	13	0	0	0	7
Norton Federal No. 1-4	6071.5	30	0	0	12	86	15	0	6
Norton Federal No. 1-4	6074.5	5	0	0	0	46	215	0	0
Norton Federal No. 1-4	6077.3	0	0	0	2	290	65	0	0
Pickett Federal No. 1-33	5642.0	3	0	0	161	90	4	0	3
Pickett Federal No. 1-33	5644.3	8	6	10	111	69	7	0	11
Pickett Federal No. 1-33	5645.8	10	8	5	92	17	7	0	11
Pickett Federal No. 1-33	5648.0	7	7	5	128	19	7	0	9
Pickett Federal No. 1-33	5649.0	11	9	0	91	18	8	0	10
Pickett Federal No. 1-33	5651.2	12	8	5	111	17	7	0	10
Pickett Federal No. 1-33	5653.3	14	8	8	76	17	8	0	12
Pickett Federal No. 1-33	5656.5	15	11	6	77	14	8	0	13
Pickett Federal No. 1-33	5659.0	16	0	6	71	19	0	0	12
Pickett Federal No. 1-33	5660.8	18	10	0	44	17	12	0	13
Pickett Federal No. 1-33	5664.0	14	0	7	68	71	7	0	14
Pickett Federal No. 1-33	5665.5	27	0	0	128	110	0	0	6
Pickett Federal No. 1-33	5665.8	19	0	7	56	95	0	0	11
Pickett Federal No. 1-33	5670.5	37	0	0	70	54	0	0	7
Shafer No. 1	2514.5	0	0	0	0	39	200	0	0
Shafer No. 1	2529.0	8	9	0	0	213	0	10	3
Shafer No. 1	2535.0	8	6	0	0	246	4	0	0

Appendix 2, table 4. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Potassium feldspar	Sodium feldspar	Apatite	Calcite	Dolomite	Anhydrite	Halite	Pyrite
Shafer No. 1	2536.5	5	4	0	0	213	3	0	3
Shafer No. 1	2537.0	6	5	0	0	193	0	18	4
Shafer No. 1	2539.0	15	14	0	0	71	0	13	8
Shafer No. 1	2540.0	10	10	17	29	44	0	15	17
Shafer No. 1	2541.0	11	10	0	63	24	0	13	7
Shafer No. 1	2542.8	12	11	0	61	25	6	12	9
Shafer No. 1	2543.8	11	10	0	72	26	0	10	10
Shafer No. 1	2545.0	11	9	0	74	26	6	10	9
Shafer No. 1	2546.3	11	8	0	0	130	5	11	6
Shafer No. 1	2547.3	16	11	0	59	23	6	9	7
Shafer No. 1	2548.8	13	10	0	66	28	0	12	11
Shafer No. 1	2550.5	14	11	0	17	45	0	12	11
Shafer No. 1	2551.5	5	5	0	7	210	3	0	5
Shafer No. 1	2552.8	16	13	0	0	38	0	20	14
Shafer No. 1	2555.3	18	13	0	30	31	0	8	8
Shafer No. 1	2556.5	14	10	0	15	74	6	10	7
Shafer No. 1	2558.0	6	5	0	9	153	4	7	4
Shafer No. 1	2559.5	15	11	0	6	87	0	9	7
Shafer No. 1	2560.5	8	6	0	17	206	4	0	4
Shafer No. 1	2562.0	19	0	0	82	28	0	8	8
Shafer No. 1	2563.0	18	0	0	61	18	0	11	5
Shafer No. 1	2564.0	19	0	0	56	19	0	9	7
Shafer No. 1	2564.8	16	0	0	53	21	10	7	8
Shafer No. 1	2566.0	14	0	0	61	23	11	10	10
Shafer No. 1	2568.0	33	13	0	4	66	0	36	3
Shafer No. 1	2576.0	9	0	0	5	190	0	20	2
Shafer No. 1	2580.0	15	8	0	5	137	4	24	2
Shafer No. 1	2884.0	39	0	30	0	13	19	0	1
Shafer No. 1	2923.0	27	0	8	0	59	9	9	0
Shafer No. 1	2940.0	2	0	0	0	303	0	0	0
Shafer No. 1	2953.0	21	0	0	22	90	0	86	2
State No. 1-16	5518.3	0	3	0	245	0	0	0	0
State No. 1-16	5521.3	0	0	0	356	32	0	0	0
State No. 1-16	5537.0	4	4	0	189	50	0	0	2
State No. 1-16	5542.0	11	8	0	78	40	4	0	7
State No. 1-16	5546.8	0	6	3	63	29	4	0	6
State No. 1-16	5552.0	5	11	0	75	55	0	0	5
State No. 1-16	5698.0	0	13	0	122	103	0	0	3
State No. 1-16	5700.5	0	9	0	145	120	1	0	3
State No. 1-16	5701.8	0	13	7	67	15	6	0	14

Appendix 2, table 4. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Potassium feldspar	Sodium feldspar	Apatite	Calcite	Dolomite	Anhydrite	Halite	Pyrite
State No. 1-16	5704.0	0	4	0	24	140	3	0	4
State No. 1-16	5707.7	0	11	4	100	13	4	0	12
State No. 1-16	5711.5	0	12	0	83	21	5	0	16
Ute Mountain No. 44-34	8695.0	0	5	2	20	28	3	0	0
Ute Mountain No. 44-34	8714.0	0	5	0	161	52	0	0	4
Ute Mountain No. 44-34	8720.0	0	10	3	145	60	3	0	5
Ute Mountain No. 44-34	8732.5	0	9	3	128	51	4	0	7
Ute Mountain No. 44-34	8737.0	0	8	3	106	40	4	0	5
Ute Mountain No. 44-34	8742.5	0	6	2	139	46	3	0	6
Ute Mountain No. 44-34	8753.0	5	6	3	139	47	4	0	6
Ute Mountain No. 44-34	8769.8	0	7	3	150	45	4	0	8
Ute Mountain No. 44-34	8773.0	0	10	3	117	44	3	0	6
West Water Creek No. 1	6304.8	11	10	5	59	46	6	0	13
West Water Creek No. 1	6311.8	6	5	3	100	63	3	0	7
West Water Creek No. 1	6317.3	0	6	4	92	35	4	0	9
West Water Creek No. 1	6322.5	0	6	4	128	44	4	0	12
Woods Unit No. 1-S	5912.5	8	8	6	122	25	5	0	7
Woods Unit No. 1-S	5913.3	5	5	0	145	91	0	0	4
Woods Unit No. 1-S	5916.7	11	0	5	111	16	6	0	8
Woods Unit No. 1-S	5919.5	18	13	0	39	9	11	0	14
Woods Unit No. 1-S	5921.0	5	4	0	222	25	3	0	4
Woods Unit No. 1-S	5922.2	12	16	0	98	84	0	0	11
Woods Unit No. 1-S	5926.3	17	15	0	194	40	6	0	5
Woods Unit No. 1-S	5932.0	0	3	0	211	70	36	0	3

Appendix 2, table 5. Lithologic, chemical, isotopic, and mineralogic data for core samples in study.

Well name	Depth (ft)	Total clay	Al (wt. %)	Ca (wt. %)	Fe (wt. %)	K (wt. %)	Mg (wt. %)	Na (wt. %)	P (wt. %)	Ti (wt. %)
Aztec Federal No. 1	6374.8	3	1.4	25	0.73	0.63	6.7	0.32	0.04	0.06
Aztec Federal No. 1	6378.5	2	1.5	23	0.8	0.59	4.8	0.36	0.19	0.06
Aztec Federal No. 1	6379.8	13	5.8	13	2.9	2.6	3.7	0.57	0.23	0.23
Aztec Federal No. 1	6384.3	13	5.4	11	2.7	2.5	2.6	0.47	0.62	0.23
Aztec Federal No. 1	6389.5	15	6.3	9.9	3.0	2.8	2.5	0.53	0.19	0.26
Aztec Federal No. 1	6393.3	13	6.3	8.9	3.3	3.3	2.1	0.63	0.24	0.27
Crowley Ranch No. 1-25	5905.0	7	3.8	15	2.0	2.3	4.5	0.08	0.16	0.13
Crowley Ranch No. 1-25	5915.0	11	5.5	15	3.5	3.9	2.2	0.07	0.10	0.20
Duncan Tevault No. 1	6365.0	0	0.16	10	0.49	0.06	0.32	0.04	0.005	0.004

Appendix 2, table 5. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Total clay	Al (wt. %)	Ca (wt. %)	Fe (wt. %)	K (wt. %)	Mg (wt. %)	Na (wt. %)	P (wt. %)	Ti (wt. %)
Duncan Tevault No. 1	6367.0	6	2.4	15	1.4	1.3	11	0.13	0.12	0.09
Duncan Tevault No. 1	6370.5	12	4.9	8.7	2.5	2.7	7.4	0.22	0.19	0.20
Duncan Tevault No. 1	6371.0	16	6.1	9.8	2.3	3.4	3.0	0.26	0.14	0.25
Elk Ridge No. 1	2548.4	5	2.3	19	1.3	0.9	3.2	0.29	0.15	0.08
Elk Ridge No. 1	2560.4	8	3.5	15	2.0	1.5	2.9	0.34	0.20	0.13
Elk Ridge No. 1	2570.5	7	2.9	17	1.5	1.2	3.8	0.33	0.17	0.10
Elk Ridge No. 1	2578.5	10	4.6	12	2.2	2.0	2.2	0.53	0.19	0.18
Elk Ridge No. 1	2588.5	10	4.9	13	2.4	2.2	2.1	0.51	0.26	0.19
Elk Ridge No. 1	2594.7	10	3.6	13	2.1	1.8	2.9	0.33	0.20	0.13
Elk Ridge No. 1	2614.4	7	3.9	12	2.0	2.1	6.4	0.52	0.05	0.16
Elk Ridge No. 1	2653.6	1	0.12	24	0.06	0.04	0.42	0.06	<	0.01
Elk Ridge No. 1	2676.8	5	1.7	14	1.3	0.51	6.5	0.42	0.12	0.06
Elk Ridge No. 1	2680.7	12	5.0	9.1	2.5	1.6	1.5	0.84	0.21	0.20
Elk Ridge No. 1	2687.9	14	6.6	7.1	3.5	2.0	1.7	1.3	0.28	0.27
Elk Ridge No. 1	2693.8	15	7.1	6.7	4.0	2.1	1.7	1.2	0.25	0.28
Elk Ridge No. 1	2701.0	13	7.2	7.6	3.5	2.1	1.6	1.2	0.29	0.28
Elk Ridge No. 1	2706.7	11	5.0	12	2.9	1.4	1.7	1.2	0.20	0.19
Elk Ridge No. 1	2711.1	0	1.4	16	0.35	0.78	1.1	0.42	0.02	0.05
Gibson Dome No. 1	2846.6	0	0.05	27	0.03	0.03	1.3	0.05	<	<
Gibson Dome No. 1	2869.0	4	2.4	13	0.92	0.85	7.7	1.0	0.04	0.07
Gibson Dome No. 1	2873.0	3	1.5	16	0.71	0.55	9.4	0.48	0.04	0.06
Gibson Dome No. 1	2879.0	13	5.1	8	2.6	2.2	4.9	0.77	0.34	0.21
Gibson Dome No. 1	2885.6	12	5.5	12	2.8	2.0	2.9	0.79	0.17	0.24
Gibson Dome No. 1	2888.5	12	4.9	13	2.6	1.7	2.7	0.76	0.14	0.21
Gibson Dome No. 1	2890.5	11	4.4	15	2.4	1.5	3.0	0.66	0.19	0.18
Gibson Dome No. 1	2892.0	9	4.8	13	2.5	1.8	3.4	0.65	0.16	0.21
Gibson Dome No. 1	2893.9	9	4.1	14	2.2	1.4	5.1	0.61	0.12	0.17
Gibson Dome No. 1	2895.9	11	5.1	13	2.5	1.8	2.6	0.74	0.21	0.22
Gibson Dome No. 1	2897.2	11	4.0	15	2.3	1.4	4.2	0.59	0.38	0.16
Gibson Dome No. 1	2898.6	13	5.3	13	2.8	1.9	2.5	0.78	0.18	0.23
Gibson Dome No. 1	2902.7	15	5.6	12	2.7	2.1	2.8	0.78	0.15	0.25
Gibson Dome No. 1	2904.6	14	5.8	10	2.7	2.2	2.6	0.80	0.23	0.25
Gibson Dome No. 1	2907.5	2	1.6	13	0.53	0.55	1.2	0.76	0.06	0.06
Gibson Dome No. 1	2908.3	1	1.5	16	0.35	0.63	1.8	0.73	0.01	0.03
Gibson Dome No. 1	2922.5	0	0.08	28	0.03	0.06	0.12	0.09	<	<
Gibson Dome No. 1	3066.9	0	0.21	21	0.19	0.2	2.0	8.1	<	0.01
Gibson Dome No. 1	3069.6	0	1.0	16	0.61	1.0	7.7	6.3	0.02	0.03
Gibson Dome No. 1	3079.2	7	2.9	14	1.6	2.2	9.5	0.25	0.08	0.11
Gibson Dome No. 1	3080.8	3	2.3	9.4	0.82	2.1	3.3	3.6	0.03	0.1
Gibson Dome No. 1	3089.0	5	2.9	8.2	0.91	2.5	4.0	4.7	0.03	0.11

Appendix 2, table 5. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Total clay	Al (wt. %)	Ca (wt. %)	Fe (wt. %)	K (wt. %)	Mg (wt. %)	Na (wt. %)	P (wt. %)	Ti (wt. %)
Gibson Dome No. 1	3096.3	6	2.7	8.8	1.2	2.6	5.1	4.6	0.03	0.11
Gibson Dome No. 1	3098.2	10	3.6	6.1	1.3	2.6	6.3	1.1	0.03	0.13
Gibson Dome No. 1	3098.6	0	0.71	24	0.35	0.69	2.9	0.73	0.01	0.03
Gibson Dome No. 1	3110.2	7	2.9	5.7	0.91	2.4	4.5	3.9	0.04	0.12
Honaker Trail outcrop	0.0	11	4.7	14	2.5	2.7	2.6	0.24	0.30	0.19
Lake Canyon No. 1-27	5748.5	3	1.3	25	0.93	0.44	5.7	0.42	0.11	0.05
Lake Canyon No. 1-27	5749.0	12	5.5	11	2.7	2.3	3.7	0.96	0.78	0.23
Lake Canyon No. 1-27	5752.8	10	3.8	16	2.0	1.5	3.3	0.57	0.20	0.19
Lake Canyon No. 1-27	5756.5	8	3.8	17	2.0	1.4	3.8	0.58	0.16	0.19
Lake Canyon No. 1-27	5762.3	6	3.1	17	5.6	1.1	2.8	0.44	0.14	0.14
Lake Canyon No. 1-27	5764.5	9	4.1	17	2.1	1.6	3.1	0.55	0.17	0.20
Lake Canyon No. 1-27	5767.0	10	4.3	16	2.0	1.7	3.2	0.54	0.22	0.21
Lake Canyon No. 1-27	5770.3	10	4.9	15	2.3	1.8	3.0	0.69	0.18	0.25
Lake Canyon No. 1-27	5774.5	18	7.3	6.9	2.6	2.9	2.6	0.92	0.13	0.37
Norton Federal No. 1-4	5919.8	7	3.1	18	1.5	1.4	3.9	0.14	0.18	0.15
Norton Federal No. 1-4	5925.0	8	3.6	17	1.7	1.5	3.4	0.16	1.18	0.16
Norton Federal No. 1-4	5929.0	8	3.3	17	1.6	1.4	3.4	0.15	0.17	0.15
Norton Federal No. 1-4	5929.8	9	3.5	17	1.6	1.4	3.0	0.15	0.19	0.17
Norton Federal No. 1-4	6042.0	0	0.03	24	0.38	0.03	15	0.05	0.004	0.004
Norton Federal No. 1-4	6044.3	4	1.3	20	0.87	1.1	15	0.07	0.03	0.06
Norton Federal No. 1-4	6052.3	8	3.2	12	1.4	2.4	10	0.11	0.08	0.12
Norton Federal No. 1-4	6057.5	6	2.1	14	1.1	1.3	9.7	0.09	0.09	0.07
Norton Federal No. 1-4	6060.3	8	2.9	14	1.6	1.9	11	0.11	0.15	0.11
Norton Federal No. 1-4	6062.3	10	5.4	8.3	1.9	4.3	3.8	0.14	0.36	0.22
Norton Federal No. 1-4	6066.0	11	7.3	2.6	2.0	6.2	3.4	0.19	0.08	0.32
Norton Federal No. 1-4	6067.8	11	7.9	2.0	2.0	7.6	2.5	0.16	0.17	0.33
Norton Federal No. 1-4	6071.5	11	4.5	4.7	1.9	3.2	5.8	0.15	0.04	0.19
Norton Federal No. 1-4	6074.5	0	0.53	24	0.24	0.52	1.7	0.02	0.01	0.02
Norton Federal No. 1-4	6077.3	0	0.18	25	0.39	0.22	14	0.03	0.005	0.006
Pickett Federal No. 1-33	5642.0	4	1.1	29	0.67	0.56	4.1	0.09	0.1	0.04
Pickett Federal No. 1-33	5644.3	11	5.0	16	2.4	2.4	3.7	0.29	0.70	0.20
Pickett Federal No. 1-33	5645.8	13	6.2	10	2.5	3.0	2.5	0.35	0.16	0.27
Pickett Federal No. 1-33	5648.0	14	5.5	12	2.5	2.6	2.7	0.28	0.26	0.23
Pickett Federal No. 1-33	5649.0	15	6.1	9.9	2.7	2.9	2.7	0.34	0.19	0.26
Pickett Federal No. 1-33	5651.2	15	6.2	9.1	3.1	3.2	2.5	0.29	0.32	0.26
Pickett Federal No. 1-33	5653.3	15	5.8	11	2.7	2.7	2.7	0.30	0.20	0.24
Pickett Federal No. 1-33	5656.5	16	6.3	8.3	3.0	3.4	2.4	0.29	0.21	0.28
Pickett Federal No. 1-33	5659.0	18	6.7	7.5	2.9	3.7	2.4	0.27	0.16	0.30
Pickett Federal No. 1-33	5660.8	20	7.5	4.1	2.9	3.9	2.3	0.35	0.12	0.35
Pickett Federal No. 1-33	5664.0	13	5.5	12	2.7	3.3	3.7	0.19	0.37	0.22

Appendix 2, table 5. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Total clay	Al (wt. %)	Ca (wt. %)	Fe (wt. %)	K (wt. %)	Mg (wt. %)	Na (wt. %)	P (wt. %)	Ti (wt. %)
Pickett Federal No. 1-33	5665.5	5	2.3	18	1.2	1.7	3.5	0.09	0.03	0.09
Pickett Federal No. 1-33	5665.8	12	4.9	11	2.4	3.1	3.4	0.15	0.31	0.22
Pickett Federal No. 1-33	5670.5	11	4.4	9.0	2.0	3.0	2.5	0.17	0.04	0.17
Shafer No. 1	2514.5	0	0.14	24	0.12	0.06	1.7	0.71	0.004	0.007
Shafer No. 1	2529.0	7	2.8	14	1.4	1.6	9.7	0.61	0.07	0.11
Shafer No. 1	2535.0	5	2.6	15	1.3	1.5	7.6	0.43	0.06	0.10
Shafer No. 1	2536.5	2	1.7	18	1.5	0.95	14	0.35	0.06	0.08
Shafer No. 1	2537.0	5	2.4	14	1.7	1.4	10	1.1	0.06	0.09
Shafer No. 1	2539.0	15	6.1	4.5	3.6	3.1	5.5	0.96	0.10	0.28
Shafer No. 1	2540.0	10	5.1	7.6	3.7	2.5	4.2	1.1	1.2	0.21
Shafer No. 1	2541.0	12	5.6	8.8	2.7	2.9	3.8	0.99	0.28	0.23
Shafer No. 1	2542.8	13	5.6	8.1	2.9	2.9	3.6	0.9	0.28	0.24
Shafer No. 1	2543.8	13	5.4	9.7	2.8	2.8	3.6	0.69	0.57	0.22
Shafer No. 1	2545.0	11	5.7	9.5	3	2.9	3.8	0.84	0.32	0.24
Shafer No. 1	2546.3	11	4.7	9.5	2.7	2.5	9.0	0.72	0.17	0.19
Shafer No. 1	2547.3	10	6.2	7.9	2.9	3.7	3.5	0.79	0.33	0.26
Shafer No. 1	2548.8	13	5.7	8.7	3.4	3.2	3.7	0.98	0.26	0.24
Shafer No. 1	2550.5	13	6.5	5.1	3.3	3.5	4.3	0.84	0.34	0.29
Shafer No. 1	2551.5	6	2.5	17	1.8	1.3	12	0.38	0.09	0.10
Shafer No. 1	2552.8	16	6.5	3.6	4.0	3.8	3.9	1.2	0.24	0.30
Shafer No. 1	2555.3	12	6.9	5.4	3.2	4.1	3.8	0.80	0.20	0.31
Shafer No. 1	2556.5	10	6.1	6.7	2.8	3.6	4.6	0.83	0.19	0.28
Shafer No. 1	2558.0	6	3.0	16	1.9	1.7	11	0.46	0.11	0.12
Shafer No. 1	2559.5	10	5.7	7.8	2.7	3.5	7.2	0.71	0.19	0.25
Shafer No. 1	2560.5	5	2.5	17	1.7	1.6	12	0.38	0.08	0.11
Shafer No. 1	2562.0	9	6.1	9.7	2.6	4.2	3.1	0.76	0.16	0.27
Shafer No. 1	2563.0	8	6.1	9.4	2.4	4.4	2.7	0.66	0.14	0.27
Shafer No. 1	2564.0	9	6.2	8.9	2.7	4.4	2.8	0.94	0.16	0.27
Shafer No. 1	2564.8	9	5.9	10	2.7	4.0	3	0.82	0.31	0.27
Shafer No. 1	2566.0	11	6.2	9.9	2.6	3.9	3.5	0.92	0.15	0.25
Shafer No. 1	2568.0	1	0.94	1.9	0.44	0.84	1.0	4.4	0.01	0.04
Shafer No. 1	2576.0	5	4.8	28	2.9	3.2	18	2.3	0.1	0.22
Shafer No. 1	2580.0	13	3.7	10	1.6	2.3	7.2	1.4	0.05	0.15
Shafer No. 1	2884.0	5	4.4	6.6	1.7	5.0	1.8	0.25	2.2	0.14
Shafer No. 1	2923.0	9	3.9	4.2	1.4	2.8	4.1	0.32	0.39	0.25
Shafer No. 1	2940.0	1	0.78	19	0.82	0.39	14	0.09	0.06	0.03
Shafer No. 1	2953.0	8	2.3	6.6	0.95	1.6	4.2	4.0	0.03	0.09
State No. 1-16	5518.3	0	0.12	39	0.09	0.04	0.54	0.1	0.01	0.005
State No. 1-16	5521.3	0	0.06	40	0.03	0.01	0.74	0.18	0.006	0.004
State No. 1-16	5537.0	3	0.96	25	0.47	0.35	2.2	0.21	0.11	0.05

Appendix 2, table 5. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Total clay	Al (wt. %)	Ca (wt. %)	Fe (wt. %)	K (wt. %)	Mg (wt. %)	Na (wt. %)	P (wt. %)	Ti (wt. %)
State No. 1-16	5542.0	7	3.6	9.9	1.7	1.4	3.0	0.44	0.19	0.19
State No. 1-16	5546.8	5	2.0	8.9	1.1	0.66	2.2	0.34	0.14	0.12
State No. 1-16	5552.0	6	2.1	10	0.99	0.62	3.2	0.34	0.17	0.10
State No. 1-16	5698.0	2	1.2	23	0.44	0.29	5.1	0.36	0.07	0.05
State No. 1-16	5700.5	2	0.81	25	0.38	0.21	6.9	0.29	0.06	0.04
State No. 1-16	5701.8	11	6.0	7.6	3.0	2.2	2.0	0.68	0.54	0.28
State No. 1-16	5704.0	4	1.8	14	1.2	0.49	8.3	0.31	0.11	0.08
State No. 1-16	5707.7	12	5.3	10	2.6	1.8	1.8	0.68	0.26	0.24
State No. 1-16	5711.5	12	5.1	9.3	2.8	1.7	2.0	0.71	0.17	0.23
Ute Mountain No. 44-34	8695.0	9	2.6	13	1.1	0.64	3.5	0.28	0.18	0.12
Ute Mountain No. 44-34	8714.0	6	2.1	22	0.92	0.64	3.2	0.27	0.11	0.10
Ute Mountain No. 44-34	8720.0	6	2.8	18	1.4	0.95	3.1	0.31	0.17	0.14
Ute Mountain No. 44-34	8732.5	9	3.2	15	1.5	1.2	2.8	0.32	0.19	0.15
Ute Mountain No. 44-34	8737.0	8	3.1	15	1.5	1.0	2.8	0.33	0.20	0.15
Ute Mountain No. 44-34	8742.5	7	2.9	17	1.5	0.99	3.0	0.29	0.18	0.14
Ute Mountain No. 44-34	8753.0	9	3.5	16	1.6	1.3	2.8	0.31	0.25	0.17
Ute Mountain No. 44-34	8769.8	8	3.1	17	1.5	1.1	2.8	0.31	0.21	0.16
Ute Mountain No. 44-34	8773.0	8	3.5	17	1.7	1.2	3.0	0.33	0.21	0.19
West Water Creek No. 1	6304.8	12	4.9	8.7	2.6	2.1	3.2	0.44	0.26	0.24
West Water Creek No. 1	6311.8	6	2.7	14	1.4	0.98	3.1	0.30	0.15	0.12
West Water Creek No. 1	6317.3	8	3.3	12	1.7	1.3	2.6	0.32	0.25	0.15
West Water Creek No. 1	6322.5	9	3.6	14	2.0	1.4	2.8	0.33	0.30	0.17
Woods Unit No. 1-S	5912.5	10	4.6	14	2.7	2.2	3.5	0.39	0.34	0.17
Woods Unit No. 1-S	5913.3	6	2.9	21	1.5	1.2	4.7	0.29	0.19	0.12
Woods Unit No. 1-S	5916.7	14	6.2	11	2.7	3.1	3.5	0.46	0.17	0.26
Woods Unit No. 1-S	5919.5	19	7.7	3.7	2.9	3.9	3.1	0.46	0.11	0.35
Woods Unit No. 1-S	5921.0	3	2.0	31	1.1	1.1	2.3	0.26	0.21	0.06
Woods Unit No. 1-S	5922.2	8	3.2	15	2.2	1.9	3.5	0.60	0.05	0.16
Woods Unit No. 1-S	5926.3	9	3.7	21	1.7	2.0	2.9	0.49	0.10	0.23
Woods Unit No. 1-S	5932.0	0	0.24	36	0.25	0.13	3.6	0.17	0.006	0.007

Appendix 2, table 6. Lithologic, chemical, isotopic, and mineralogic data for core samples in study.

Well name	Depth (ft)	As (ppm)	Ba (ppm)	Ce (ppm)	Co (ppm)	Cr (ppm)	Cr* (ppm)	Cu (ppm)	Ga (ppm)
Aztec Federal No. 1	6374.8	na	72	18	3	25	9	4	3
Aztec Federal No. 1	6378.5	na	77	23	5	31	14	8	3
Aztec Federal No. 1	6379.8	na	160	30	10	340	275	42	13

Appendix 2, table 6. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	As (ppm)	Ba (ppm)	Ce (ppm)	Co (ppm)	Cr (ppm)	Cr* (ppm)	Cu (ppm)	Ga (ppm)
Aztec Federal No. 1	6384.3	na	130	58	9	300	239	32	12
Aztec Federal No. 1	6389.5	na	130	46	11	310	239	35	14
Aztec Federal No. 1	6393.3	na	140	46	10	450	379	43	14
Crowley Ranch No. 1-25	5905.0	na	160	29	10	110	67	24	8
Crowley Ranch No. 1-25	5915.0	na	77	93	11	240	178	39	13
Duncan Tevault No. 1	6365.0	na	23	28	5	6	4	8	3
Duncan Tevault No. 1	6367.0	na	89	25	7	82	55	18	3
Duncan Tevault No. 1	6370.5	na	145	36	8	360	305	29	10
Duncan Tevault No. 1	6371.0	na	150	35	11	210	141	29	14
Elk Ridge No. 1	2548.4	na	71	22	5	110	84	14	4
Elk Ridge No. 1	2560.4	na	110	28	6	260	221	24	8
Elk Ridge No. 1	2570.5	na	84	26	5	240	207	21	6
Elk Ridge No. 1	2578.5	na	160	36	8	300	248	34	11
Elk Ridge No. 1	2588.5	na	160	47	9	420	365	38	11
Elk Ridge No. 1	2594.7	na	140	34	9	240	200	37	7
Elk Ridge No. 1	2614.4	na	400	31	8	52	8	15	9
Elk Ridge No. 1	2653.6	na	8	<	2	2	1	1	<
Elk Ridge No. 1	2676.8	na	170	15	3	120	101	12	<
Elk Ridge No. 1	2680.7	na	130	48	8	310	254	34	11
Elk Ridge No. 1	2687.9	na	140	53	9	580	506	52	15
Elk Ridge No. 1	2693.8	na	140	58	10	520	440	51	17
Elk Ridge No. 1	2701.0	na	130	60	12	580	499	51	16
Elk Ridge No. 1	2706.7	na	110	56	8	410	354	36	9
Elk Ridge No. 1	2711.1	na	84	14	3	6	-10	5	<
Gibson Dome No. 1	2846.6	na	66	<	2	<	<	<	<
Gibson Dome No. 1	2869.0	na	280	23	5	30	3	5	6
Gibson Dome No. 1	2873.0	na	110	15	4	24	7	7	4
Gibson Dome No. 1	2879.0	na	230	42	12	340	283	46	13
Gibson Dome No. 1	2885.6	na	160	44	10	210	148	31	12
Gibson Dome No. 1	2888.5	na	190	41	10	170	115	24	11
Gibson Dome No. 1	2890.5	na	120	43	9	190	140	21	10
Gibson Dome No. 1	2892.0	na	150	36	9	170	116	20	11
Gibson Dome No. 1	2893.9	na	110	37	8	140	94	26	9
Gibson Dome No. 1	2895.9	na	170	45	9	270	213	25	12
Gibson Dome No. 1	2897.2	na	120	45	8	210	165	24	10
Gibson Dome No. 1	2898.6	na	140	44	9	370	310	27	12
Gibson Dome No. 1	2902.7	na	150	43	10	210	147	27	13
Gibson Dome No. 1	2904.6	na	190	42	9	330	265	31	13
Gibson Dome No. 1	2907.5	na	410	28	3	14	-4	11	o
Gibson Dome No. 1	2908.3	na	190	25	2	7	-10	2	o

Appendix 2, table 6. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	As (ppm)	Ba (ppm)	Ce (ppm)	Co (ppm)	Cr (ppm)	Cr* (ppm)	Cu (ppm)	Ga (ppm)
Gibson Dome No. 1	2922.5	na	17	<	1	1	0	1	o
Gibson Dome No. 1	3066.9	na	18	<	1	3	1	<	o
Gibson Dome No. 1	3069.6	na	93	4	2	11	0	2	o
Gibson Dome No. 1	3079.2	na	120	17	10	51	18	14	8
Gibson Dome No. 1	3080.8	na	380	18	4	22	-4	8	5
Gibson Dome No. 1	3089.0	na	290	19	4	27	-6	4	7
Gibson Dome No. 1	3096.3	na	350	14	6	30	0	8	6
Gibson Dome No. 1	3098.2	na	330	16	5	37	-4	8	8
Gibson Dome No. 1	3098.6	na	59	8	3	7	-1	3	o
Gibson Dome No. 1	3110.2	na	300	41	4	28	-5	7	6
Honaker Trail outcrop	0.0	na	155	48	9	470	417	52	11
Lake Canyon No. 1-27	5748.5	na	74	22	4	33	18	5	3
Lake Canyon No. 1-27	5749.0	5.8	250	52	10	470	408	41	14
Lake Canyon No. 1-27	5752.8	5.4	140	33	7	150	107	20	9
Lake Canyon No. 1-27	5756.5	5.9	100	31	7	150	107	19	9
Lake Canyon No. 1-27	5762.3	4.8	85	27	7	150	115	15	7
Lake Canyon No. 1-27	5764.5	6.4	120	34	8	180	134	18	10
Lake Canyon No. 1-27	5767.0	4.2	200	33	7	280	232	20	10
Lake Canyon No. 1-27	5770.3	8.1	140	41	10	200	145	22	12
Lake Canyon No. 1-27	5774.5	8.4	180	28	12	370	288	48	18
Norton Federal No. 1-4	5919.8	na	77	26	6	160	125	14	8
Norton Federal No. 1-4	5925.0	na	93	27	6	190	150	17	8
Norton Federal No. 1-4	5929.0	na	99	27	5	150	113	13	7
Norton Federal No. 1-4	5929.8	na	90	28	7	160	121	16	8
Norton Federal No. 1-4	6042.0	na	28	3	2	1	0	1	3
Norton Federal No. 1-4	6044.3	na	92	12	4	22	7	2	3
Norton Federal No. 1-4	6052.3	na	180	28	8	53	17	12	6
Norton Federal No. 1-4	6057.5	na	81	13	6	56	32	13	3
Norton Federal No. 1-4	6060.3	na	110	23	8	97	64	19	5
Norton Federal No. 1-4	6062.3	na	160	43	7	320	259	31	11
Norton Federal No. 1-4	6066.0	na	280	40	11	250	168	28	18
Norton Federal No. 1-4	6067.8	na	200	35	14	335	246	37	17
Norton Federal No. 1-4	6071.5	na	335	33	11	62	11	18	12
Norton Federal No. 1-4	6074.5	na	38	9	2	7	1	1	3
Norton Federal No. 1-4	6077.3	na	30	7	2	3	1	1	3
Pickett Federal No. 1-33	5642.0	na	52	22	4	30	18	4	3
Pickett Federal No. 1-33	5644.3	na	160	44	9	460	404	37	11
Pickett Federal No. 1-33	5645.8	na	150	32	11	230	160	33	14
Pickett Federal No. 1-33	5648.0	na	150	46	8	380	318	27	12
Pickett Federal No. 1-33	5649.0	na	160	44	11	290	221	34	13

Appendix 2, table 6. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	As (ppm)	Ba (ppm)	Ce (ppm)	Co (ppm)	Cr (ppm)	Cr* (ppm)	Cu (ppm)	Ga (ppm)
Pickett Federal No. 1-33	5651.2	na	150	47	9	490	420	44	14
Pickett Federal No. 1-33	5653.3	na	140	44	9	310	245	34	12
Pickett Federal No. 1-33	5656.5	na	220	51	10	375	304	41	15
Pickett Federal No. 1-33	5659.0	na	180	54	11	370	295	33	15
Pickett Federal No. 1-33	5660.8	na	170	65	13	400	316	36	18
Pickett Federal No. 1-33	5664.0	na	190	48	13	200	138	39	12
Pickett Federal No. 1-33	5665.5	na	190	33	4	24	-2	6	3
Pickett Federal No. 1-33	5665.8	na	220	40	17	93	38	75	12
Pickett Federal No. 1-33	5670.5	na	300	18	13	51	2	18	9
Shafer No. 1	2514.5	na	11	3	1	6	4	4	3
Shafer No. 1	2529.0	na	165	25	7	55	24	10	5
Shafer No. 1	2535.0	na	130	25	6	44	15	13	6
Shafer No. 1	2536.5	na	89	33	6	39	20	17	4
Shafer No. 1	2537.0	na	130	34	8	60	33	18	5
Shafer No. 1	2539.0	na	230	32	10	400	331	49	10
Shafer No. 1	2540.0	12	210	97	11	250	193	40	12
Shafer No. 1	2541.0	9.4	160	41	8	350	287	37	12
Shafer No. 1	2542.8	8.9	160	42	11	450	387	52	12
Shafer No. 1	2543.8	8.4	150	62	10	400	339	46	12
Shafer No. 1	2545.0	9	170	47	10	350	286	42	13
Shafer No. 1	2546.3	6.4	140	36	9	170	117	28	10
Shafer No. 1	2547.3	10	180	46	11	320	250	40	14
Shafer No. 1	2548.8	8.3	170	50	12	300	236	46	13
Shafer No. 1	2550.5	7.4	200	44	12	390	317	37	15
Shafer No. 1	2551.5	8.7	77	38	5	120	92	16	4
Shafer No. 1	2552.8	23	185	44	14	285	212	41	15
Shafer No. 1	2555.3	na	210	36	10	310	232	45	20
Shafer No. 1	2556.5	6.5	180	45	12	240	171	35	15
Shafer No. 1	2558.0	4.6	90	46	6	120	86	19	6
Shafer No. 1	2559.5	6	170	42	11	210	146	41	13
Shafer No. 1	2560.5	4	79	44	6	86	58	17	5
Shafer No. 1	2562.0	8.4	190	41	11	200	131	35	14
Shafer No. 1	2563.0	7.2	200	38	11	180	111	30	14
Shafer No. 1	2564.0	9.5	180	37	13	190	120	29	13
Shafer No. 1	2564.8	17	180	42	13	180	114	30	13
Shafer No. 1	2566.0	na	190	42	12	225	155	28	15
Shafer No. 1	2568.0	na	160	11	1	6	-5	15	3
Shafer No. 1	2576.0	na	270	64	10	67	13	41	10
Shafer No. 1	2580.0	na	270	27	8	42	0	12	8
Shafer No. 1	2884.0	na	140	16	12	380	330	30	5

Appendix 2, table 6. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	As (ppm)	Ba (ppm)	Ce (ppm)	Co (ppm)	Cr (ppm)	Cr* (ppm)	Cu (ppm)	Ga (ppm)
Shafer No. 1	2923.0	na	330	23	9	72	28	16	10
Shafer No. 1	2940.0	na	31	5	3	10	1	7	3
Shafer No. 1	2953.0	na	280	15	5	24	-2	10	6
State No. 1-16	5518.3	na	6	3	2	7	6	8	3
State No. 1-16	5521.3	na	10	3	2	4	3	1	3
State No. 1-16	5537.0	na	41	13	3	25	14	7	3
State No. 1-16	5542.0	na	110	31	7	150	110	19	8
State No. 1-16	5546.8	na	135	21	5	125	102	19	5
State No. 1-16	5552.0	na	71	25	5	97	73	15	4
State No. 1-16	5698.0	na	29	13	4	25	12	3	3
State No. 1-16	5700.5	na	23	13	3	17	8	3	3
State No. 1-16	5701.8	na	110	57	9	510	442	46	15
State No. 1-16	5704.0	na	130	16	4	110	90	12	5
State No. 1-16	5707.7	na	130	45	8	320	260	36	13
State No. 1-16	5711.5	na	120	40	9	230	173	28	12
Ute Mountain No. 44-34	8695.0	na	86	23	5	130	101	7	7
Ute Mountain No. 44-34	8714.0	na	86	17	4	99	75	6	5
Ute Mountain No. 44-34	8720.0	na	62	26	5	140	108	13	7
Ute Mountain No. 44-34	8732.5	na	95	27	5	180	144	9	8
Ute Mountain No. 44-34	8737.0	na	85	25	5	160	125	10	7
Ute Mountain No. 44-34	8742.5	na	64	25	5	150	117	10	7
Ute Mountain No. 44-34	8753.0	na	77	28	5	220	181	13	8
Ute Mountain No. 44-34	8769.8	na	71	27	4	180	145	11	8
Ute Mountain No. 44-34	8773.0	na	75	28	6	200	161	12	9
West Water Creek No. 1	6304.8	na	160	35	10	200	145	29	13
West Water Creek No. 1	6311.8	na	77	21	6	140	110	17	6
West Water Creek No. 1	6317.3	na	97	27	6	190	153	24	8
West Water Creek No. 1	6322.5	na	86	31	7	280	240	28	9
Woods Unit No. 1-S	5912.5	na	200	39	8	370	318	36	11
Woods Unit No. 1-S	5913.3	na	220	36	6	150	117	15	6
Woods Unit No. 1-S	5916.7	na	290	48	12	240	170	35	15
Woods Unit No. 1-S	5919.5	na	210	47	12	320	233	39	19
Woods Unit No. 1-S	5921.0	na	130	37	7	33	10	28	6
Woods Unit No. 1-S	5922.2	na	310	45	8	45	9	18	7
Woods Unit No. 1-S	5926.3	na	230	42	12	62	20	26	10
Woods Unit No. 1-S	5932.0	na	360	16	2	5	2	1	3

Appendix 2, table 7. Lithologic, chemical, isotopic, and mineralogic data for core samples in study.

Well name	Depth (ft)	La (ppm)	Li (ppm)	Mn (ppm)	Mo (ppm)	Nd (ppm)	Ni (ppm)	Ni* (ppm)
Aztec Federal No. 1	6374.8	13	50	240	<	15	15	3
Aztec Federal No. 1	6378.5	17	56	230	<	20	23	10
Aztec Federal No. 1	6379.8	21	120	260	14	22	130	81
Aztec Federal No. 1	6384.3	41	83	170	4	48	97	51
Aztec Federal No. 1	6389.5	33	72	190	3	32	98	44
Aztec Federal No. 1	6393.3	33	55	160	6	33	140	86
Crowley Ranch No. 1-25	5905.0	21	130	300	3	20	74	42
Crowley Ranch No. 1-25	5915.0	59	62	160	13	43	83	36
Duncan Tevault No. 1	6365.0	24	19	27	5	14	12	11
Duncan Tevault No. 1	6367.0	19	120	290	3	18	49	29
Duncan Tevault No. 1	6370.5	26	155	225	12	25	85	43
Duncan Tevault No. 1	6371.0	27	130	160	2	23	80	28
Elk Ridge No. 1	2548.4	27	53	110	16	21	42	22
Elk Ridge No. 1	2560.4	28	44	120	6	21	83	53
Elk Ridge No. 1	2570.5	27	38	120	4	23	67	42
Elk Ridge No. 1	2578.5	28	40	170	4	25	99	60
Elk Ridge No. 1	2588.5	37	38	190	3	33	110	68
Elk Ridge No. 1	2594.7	28	33	200	7	21	100	69
Elk Ridge No. 1	2614.4	18	28	320	14	17	24	0
Elk Ridge No. 1	2653.6	<2	6	14	79		3	1
Elk Ridge No. 1	2676.8	13	39	120	2	9	33	19
Elk Ridge No. 1	2680.7	37	73	150	<	30	86	44
Elk Ridge No. 1	2687.9	42	80	160	3	39	150	94
Elk Ridge No. 1	2693.8	40	62	170	4	41	150	90
Elk Ridge No. 1	2701.0	40	53	190	3	40	150	89
Elk Ridge No. 1	2706.7	37	40	160	77	33	150	108
Elk Ridge No. 1	2711.1	9	6	140	<	7	<	<
Gibson Dome No. 1	2846.6	<	<	17	<	<	<	<
Gibson Dome No. 1	2869.0	15	26	260	8	19	17	0
Gibson Dome No. 1	2873.0	11	21	240	2	8	17	4
Gibson Dome No. 1	2879.0	27	85	290	10	27	180	137
Gibson Dome No. 1	2885.6	36	68	200	3	30	85	38
Gibson Dome No. 1	2888.5	36	64	200	3	29	70	28
Gibson Dome No. 1	2890.5	41	61	190	<	30	68	31
Gibson Dome No. 1	2892.0	33	66	200	<	27	69	28
Gibson Dome No. 1	2893.9	31	65	240	2	25	50	15
Gibson Dome No. 1	2895.9	39	60	210	<	33	74	31
Gibson Dome No. 1	2897.2	38	59	180	2	35	72	38
Gibson Dome No. 1	2898.6	37	57	170	3	31	74	29
Gibson Dome No. 1	2902.7	35	59	190	4	27	68	20

Appendix 2, table 7. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	La (ppm)	Li (ppm)	Mn (ppm)	Mo (ppm)	Nd (ppm)	Ni (ppm)	Ni* (ppm)
Gibson Dome No. 1	2904.6	32	56	200	4	27	93	44
Gibson Dome No. 1	2907.5	23	24	180	2	15	10	0
Gibson Dome No. 1	2908.3	17	8	150	<	14	2	0
Gibson Dome No. 1	2922.5	<	2	11	<	<	<	<
Gibson Dome No. 1	3066.9	3	7	71	5	<	<	<
Gibson Dome No. 1	3069.6	4	16	310	<	<	7	0
Gibson Dome No. 1	3079.2	10	92	510	<	9	51	26
Gibson Dome No. 1	3080.8	14	40	170	<	10	8	0
Gibson Dome No. 1	3089.0	13	46	190	<	11	12	0
Gibson Dome No. 1	3096.3	9	28	260	5	9	13	0
Gibson Dome No. 1	3098.2	9	82	210	<	8	14	0
Gibson Dome No. 1	3098.6	4	9	140	3	7	4	0
Gibson Dome No. 1	3110.2	23	48	210	<	18	10	0
Honaker Trail outcrop	0.0	38	80	175	<	33	170	130
Lake Canyon No. 1-27	5748.5	17	25	205	<	22	18	7
Lake Canyon No. 1-27	5749.0	46	75	220	5	44	140	93
Lake Canyon No. 1-27	5752.8	31	69	200	4	29	57	25
Lake Canyon No. 1-27	5756.5	31	66	200	2	28	47	15
Lake Canyon No. 1-27	5762.3	26	51	150	3	24	49	23
Lake Canyon No. 1-27	5764.5	31	60	180	1	28	51	16
Lake Canyon No. 1-27	5767.0	32	60	160	2	30	64	27
Lake Canyon No. 1-27	5770.3	32	57	190	3	33	55	13
Lake Canyon No. 1-27	5774.5	20	64	210	4	19	150	88
Norton Federal No. 1-4	5919.8	28	42	140	<	26	46	20
Norton Federal No. 1-4	5925.0	29	46	140	3	29	51	20
Norton Federal No. 1-4	5929.0	28	43	140	2	27	44	16
Norton Federal No. 1-4	5929.8	29	43	140	<	28	50	20
Norton Federal No. 1-4	6042.0	1	1	290	<	5	3	3
Norton Federal No. 1-4	6044.3	8	38	250	<	10	14	3
Norton Federal No. 1-4	6052.3	20	150	270	2	17	42	15
Norton Federal No. 1-4	6057.5	9	120	300	3	10	39	21
Norton Federal No. 1-4	6060.3	17	170	350	3	18	56	31
Norton Federal No. 1-4	6062.3	31	190	160	9	32	91	45
Norton Federal No. 1-4	6066.0	27	180	120	3	20	89	27
Norton Federal No. 1-4	6067.8	22	110	125	2	20	130	63
Norton Federal No. 1-4	6071.5	19	105	230	3	17	24	0
Norton Federal No. 1-4	6074.5	3	7	64	<	7	3	0
Norton Federal No. 1-4	6077.3	5	2	300	2	10	1	0
Pickett Federal No. 1-33	5642.0	16	34	270	<	17	16	7
Pickett Federal No. 1-33	5644.3	29	94	250	12	38	120	78

Appendix 2, table 7. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	La (ppm)	Li (ppm)	Mn (ppm)	Mo (ppm)	Nd (ppm)	Ni (ppm)	Ni* (ppm)
Pickett Federal No. 1-33	5645.8	22	85	270	2	23	89	36
Pickett Federal No. 1-33	5648.0	34	89	150	3	33	90	43
Pickett Federal No. 1-33	5649.0	30	85	190	3	31	92	40
Pickett Federal No. 1-33	5651.2	34	79	150	6	36	140	87
Pickett Federal No. 1-33	5653.3	32	82	160	3	33	87	38
Pickett Federal No. 1-33	5656.5	31	68	165	5	35	110	56
Pickett Federal No. 1-33	5659.0	30	64	180	5	35	110	53
Pickett Federal No. 1-33	5660.8	36	68	180	4	37	110	46
Pickett Federal No. 1-33	5664.0	26	58	290	3	34	120	73
Pickett Federal No. 1-33	5665.5	18	20	240	<	20	9	0
Pickett Federal No. 1-33	5665.8	18	46	360	26	28	35	0
Pickett Federal No. 1-33	5670.5	10	39	220	3	12	29	0
Shafer No. 1	2514.5	2	9	34	3	3	1	0
Shafer No. 1	2529.0	16	71	300	3	12	33	9
Shafer No. 1	2535.0	16	69	310	11	11	28	6
Shafer No. 1	2536.5	29	49	370	2	10	31	17
Shafer No. 1	2537.0	29	69	330	4	12	46	26
Shafer No. 1	2539.0	22	150	280	6	20	150	98
Shafer No. 1	2540.0	67	140	220	4	75	100	57
Shafer No. 1	2541.0	35	140	170	3	28	90	42
Shafer No. 1	2542.8	34	130	150	5	26	130	82
Shafer No. 1	2543.8	46	130	150	4	45	120	74
Shafer No. 1	2545.0	39	130	170	3	31	110	62
Shafer No. 1	2546.3	30	110	260	2	20	68	28
Shafer No. 1	2547.3	38	120	200	7	34	100	47
Shafer No. 1	2548.8	40	120	180	4	32	99	51
Shafer No. 1	2550.5	34	130	190	3	32	110	55
Shafer No. 1	2551.5	35	57	280	<	19	36	15
Shafer No. 1	2552.8	35	115	200	23	30	115	60
Shafer No. 1	2555.3	29	110	190	5	21	100	41
Shafer No. 1	2556.5	35	100	220	6	29	80	28
Shafer No. 1	2558.0	41	59	270	3	25	40	14
Shafer No. 1	2559.5	31	93	250	<	23	76	28
Shafer No. 1	2560.5	40	43	280	2	20	34	13
Shafer No. 1	2562.0	32	90	200	5	23	87	35
Shafer No. 1	2563.0	30	80	210	3	22	74	22
Shafer No. 1	2564.0	30	88	210	4	23	81	28
Shafer No. 1	2564.8	30	89	220	5	30	78	28
Shafer No. 1	2566.0	33	100	210	3	25	79	26
Shafer No. 1	2568.0	8	7	51	<	3	1	0

Appendix 2, table 7. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	La (ppm)	Li (ppm)	Mn (ppm)	Mo (ppm)	Nd (ppm)	Ni (ppm)	Ni* (ppm)
Shafer No. 1	2576.0	40	82	690	<	34	34	0
Shafer No. 1	2580.0	16	65	270	6	9	19	0
Shafer No. 1	2884.0	8	51	120	3	11	950	913
Shafer No. 1	2923.0	10	79	170	<	10	28	0
Shafer No. 1	2940.0	2	34	480	2	3	5	0
Shafer No. 1	2953.0	8	57	170	<	3	10	0
State No. 1-16	5518.3	3	2	35	<	3	8	7
State No. 1-16	5521.3	3	1	35	<	3	1	1
State No. 1-16	5537.0	13	21	97	<	8	17	9
State No. 1-16	5542.0	29	84	120	<	26	67	36
State No. 1-16	5546.8	20	54	96	<	18	41	24
State No. 1-16	5552.0	24	72	93	<	20	34	16
State No. 1-16	5698.0	9	18	140	<	15	15	5
State No. 1-16	5700.5	10	14	150	<	17	9	2
State No. 1-16	5701.8	50	130	190	5	46	130	79
State No. 1-16	5704.0	14	91	75	<	16	32	17
State No. 1-16	5707.7	38	87	150	2	33	88	43
State No. 1-16	5711.5	31	73	160	2	31	75	32
Ute Mountain No. 44-34	8695.0	27	56	94	1	24	45	23
Ute Mountain No. 44-34	8714.0	20	24	110	<	25	18	0
Ute Mountain No. 44-34	8720.0	25	24	110	2	24	32	8
Ute Mountain No. 44-34	8732.5	23	23	115	2	23	38	11
Ute Mountain No. 44-34	8737.0	22	27	120	<	23	38	12
Ute Mountain No. 44-34	8742.5	24	23	140	2	23	36	11
Ute Mountain No. 44-34	8753.0	26	22	120	2	27	45	15
Ute Mountain No. 44-34	8769.8	25	22	130	<	27	40	14
Ute Mountain No. 44-34	8773.0	26	24	130	<	27	44	14
West Water Creek No. 1	6304.8	29	77	230	19	27	100	58
West Water Creek No. 1	6311.8	21	50	120	3	21	50	27
West Water Creek No. 1	6317.3	25	48	120	2	25	80	52
West Water Creek No. 1	6322.5	32	43	130	7	29	82	51
Woods Unit No. 1-S	5912.5	32	90	160	3	31	96	57
Woods Unit No. 1-S	5913.3	32	79	200	<	29	47	22
Woods Unit No. 1-S	5916.7	32	79	285	<	33	79	26
Woods Unit No. 1-S	5919.5	26	75	140	33	27	110	45
Woods Unit No. 1-S	5921.0	26	30	320	7	25	16	0
Woods Unit No. 1-S	5922.2	23	31	260	7	24	17	0
Woods Unit No. 1-S	5926.3	22	43	260	17	28	31	0
Woods Unit No. 1-S	5932.0	11	2	190	4	17	1	0

Appendix 2, table 8. Lithologic, chemical, isotopic, and mineralogic data for core samples in study.

Well name	Depth (ft)	Sc (ppm)	Se (ppm)	Sr (ppm)	V (ppm)	Y (ppm)	Zn (ppm)
Aztec Federal No. 1	6374.8	3	na	260	23	10	43
Aztec Federal No. 1	6378.5	3	na	270	24	16	41
Aztec Federal No. 1	6379.8	12	na	250	120	26	81
Aztec Federal No. 1	6384.3	11	na	230	95	47	64
Aztec Federal No. 1	6389.5	13	na	200	98	32	92
Aztec Federal No. 1	6393.3	13	na	200	110	36	190
Crowley Ranch No. 1-25	5905.0	7	na	410	63	21	28
Crowley Ranch No. 1-25	5915.0	11	na	380	110	28	10000
Duncan Tevault No. 1	6365.0	1	na	710	3	6	3400
Duncan Tevault No. 1	6367.0	5	na	130	44	19	25
Duncan Tevault No. 1	6370.5	10	na	135	98	26	25
Duncan Tevault No. 1	6371.0	12	na	220	110	24	32
Elk Ridge No. 1	2548.4	5	na	240	47	18	53
Elk Ridge No. 1	2560.4	7	na	280	63	25	190
Elk Ridge No. 1	2570.5	6	na	320	61	24	200
Elk Ridge No. 1	2578.5	10	na	290	80	27	260
Elk Ridge No. 1	2588.5	10	na	320	100	34	250
Elk Ridge No. 1	2594.7	8	na	240	130	22	200
Elk Ridge No. 1	2614.4	6	na	2500	48	12	45
Elk Ridge No. 1	2653.6	<	na	1400	10	<	110
Elk Ridge No. 1	2676.8	3	na	440	35	11	170
Elk Ridge No. 1	2680.7	11	na	250	78	32	180
Elk Ridge No. 1	2687.9	14	na	230	110	44	380
Elk Ridge No. 1	2693.8	15	na	250	120	39	350
Elk Ridge No. 1	2701.0	15	na	210	140	42	370
Elk Ridge No. 1	2706.7	10	na	280	590	33	510
Elk Ridge No. 1	2711.1	<	na	1300	11	6	7
Gibson Dome No. 1	2846.6	<	na	2300	<	<	<
Gibson Dome No. 1	2869.0	3	na	1000	26	9	9
Gibson Dome No. 1	2873.0	3	na	410	21	8	7
Gibson Dome No. 1	2879.0	10	na	140	150	28	200
Gibson Dome No. 1	2885.6	12	na	290	82	30	100
Gibson Dome No. 1	2888.5	10	na	570	78	27	800
Gibson Dome No. 1	2890.5	10	na	350	75	31	50
Gibson Dome No. 1	2892.0	10	na	330	77	26	63
Gibson Dome No. 1	2893.9	9	na	280	70	24	56
Gibson Dome No. 1	2895.9	11	na	520	100	32	160
Gibson Dome No. 1	2897.2	9	na	300	72	33	100
Gibson Dome No. 1	2898.6	12	na	320	85	31	160
Gibson Dome No. 1	2902.7	12	na	300	96	28	85

Appendix 2, table 8. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Sc (ppm)	Se (ppm)	Sr (ppm)	V (ppm)	Y (ppm)	Zn (ppm)
Gibson Dome No. 1	2904.6	12	na	290	94	29	79
Gibson Dome No. 1	2907.5	<	na	2000	28	13	4
Gibson Dome No. 1	2908.3	<	na	580	7	11	<
Gibson Dome No. 1	2922.5	<	na	1700	2	<	<
Gibson Dome No. 1	3066.9	<	na	930	4	<	<
Gibson Dome No. 1	3069.6	<	na	380	11	4	3
Gibson Dome No. 1	3079.2	6	na	290	47	11	19
Gibson Dome No. 1	3080.8	3	na	170	20	10	8
Gibson Dome No. 1	3089.0	4	na	190	25	10	11
Gibson Dome No. 1	3096.3	4	na	180	26	9	11
Gibson Dome No. 1	3098.2	6	na	250	32	10	17
Gibson Dome No. 1	3098.6	1	na	1000	7	3	2
Gibson Dome No. 1	3110.2	4	na	190	26	15	190
Honaker Trail outcrop	0.0	11	na	245	235	37	375
Lake Canyon No. 1-27	5748.5	3	na	305	20	15	165
Lake Canyon No. 1-27	5749.0	11	18	230	120	43	230
Lake Canyon No. 1-27	5752.8	8	3.7	350	69	26	130
Lake Canyon No. 1-27	5756.5	8	3	320	71	25	67
Lake Canyon No. 1-27	5762.3	7	4.1	350	57	22	410
Lake Canyon No. 1-27	5764.5	9	3.2	360	86	26	100
Lake Canyon No. 1-27	5767.0	9	6.5	350	91	28	100
Lake Canyon No. 1-27	5770.3	10	4.3	320	89	27	86
Lake Canyon No. 1-27	5774.5	15	24	190	140	21	150
Norton Federal No. 1-4	5919.8	7	na	340	60	25	90
Norton Federal No. 1-4	5925.0	7	na	365	66	25	130
Norton Federal No. 1-4	5929.0	7	na	370	61	25	130
Norton Federal No. 1-4	5929.8	7	na	370	65	26	130
Norton Federal No. 1-4	6042.0	1	na	170	1	1	2
Norton Federal No. 1-4	6044.3	2	na	170	19	6	7
Norton Federal No. 1-4	6052.3	5	na	170	43	11	17
Norton Federal No. 1-4	6057.5	4	na	220	46	10	1300
Norton Federal No. 1-4	6060.3	5	na	180	55	19	19
Norton Federal No. 1-4	6062.3	10	na	260	100	29	23
Norton Federal No. 1-4	6066.0	15	na	240	120	18	27
Norton Federal No. 1-4	6067.8	14	na	215	93	19	29
Norton Federal No. 1-4	6071.5	7	na	260	49	8	23
Norton Federal No. 1-4	6074.5	1	na	2000	6	2	1
Norton Federal No. 1-4	6077.3	1	na	600	5	3	1
Pickett Federal No. 1-33	5642.0	2	na	330	25	13	7
Pickett Federal No. 1-33	5644.3	10	na	280	110	39	170

Appendix 2, table 8. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Sc (ppm)	Se (ppm)	Sr (ppm)	V (ppm)	Y (ppm)	Zn (ppm)
Pickett Federal No. 1-33	5645.8	13	na	230	100	24	53
Pickett Federal No. 1-33	5648.0	11	na	250	100	32	86
Pickett Federal No. 1-33	5649.0	12	na	210	90	29	380
Pickett Federal No. 1-33	5651.2	13	na	200	130	40	96
Pickett Federal No. 1-33	5653.3	12	na	220	87	30	47
Pickett Federal No. 1-33	5656.5	13	na	205	99	31	290
Pickett Federal No. 1-33	5659.0	13	na	190	110	33	37
Pickett Federal No. 1-33	5660.8	15	na	150	140	24	140
Pickett Federal No. 1-33	5664.0	11	na	200	88	33	34
Pickett Federal No. 1-33	5665.5	3	na	200	22	14	7
Pickett Federal No. 1-33	5665.8	9	na	260	160	26	27
Pickett Federal No. 1-33	5670.5	7	na	150	48	10	19
Shafer No. 1	2514.5	1	na	1500	4	1	38
Shafer No. 1	2529.0	5	na	160	40	12	19
Shafer No. 1	2535.0	5	na	140	39	12	19
Shafer No. 1	2536.5	3	na	130	26	18	12
Shafer No. 1	2537.0	5	na	140	44	17	17
Shafer No. 1	2539.0	10	na	180	150	20	49
Shafer No. 1	2540.0	11	11	200	92	59	39
Shafer No. 1	2541.0	13	9	260	99	30	41
Shafer No. 1	2542.8	12	18	240	120	29	63
Shafer No. 1	2543.8	12	14	260	110	43	120
Shafer No. 1	2545.0	12	11	260	120	33	67
Shafer No. 1	2546.3	10	4.7	150	77	27	54
Shafer No. 1	2547.3	13	9	240	110	35	65
Shafer No. 1	2548.8	13	12	250	100	30	140
Shafer No. 1	2550.5	13	7.7	190	120	34	160
Shafer No. 1	2551.5	6	2.8	150	43	23	22
Shafer No. 1	2552.8	13	7.9	195	110	33	55
Shafer No. 1	2555.3	10	na	210	130	27	54
Shafer No. 1	2556.5	14	4.2	180	99	30	45
Shafer No. 1	2558.0	8	2.8	160	47	27	24
Shafer No. 1	2559.5	12	4.3	170	89	28	45
Shafer No. 1	2560.5	7	1.9	140	40	25	26
Shafer No. 1	2562.0	13	4.4	270	94	25	61
Shafer No. 1	2563.0	13	3.4	270	95	22	42
Shafer No. 1	2564.0	13	4.5	270	100	24	45
Shafer No. 1	2564.8	13	4.1	290	99	27	52
Shafer No. 1	2566.0	13	na	285	105	23	51
Shafer No. 1	2568.0	1	na	100	5	3	1

Appendix 2, table 8. Lithologic, chemical, isotopic, and mineralogic data for core samples in study—*Continued.*

Well name	Depth (ft)	Sc (ppm)	Se (ppm)	Sr (ppm)	V (ppm)	Y (ppm)	Zn (ppm)
Shafer No. 1	2576.0	10	na	350	69	30	58
Shafer No. 1	2580.0	6	na	240	42	11	35
Shafer No. 1	2884.0	3	na	530	73	21	110
Shafer No. 1	2923.0	4	na	480	110	22	79
Shafer No. 1	2940.0	1	na	160	29	6	420
Shafer No. 1	2953.0	4	na	1500	24	7	170
State No. 1-16	5518.3	1	na	960	5	1	5
State No. 1-16	5521.3	1	na	1200	1	1	1
State No. 1-16	5537.0	2	na	450	14	10	24
State No. 1-16	5542.0	8	na	220	83	25	59
State No. 1-16	5546.8	4	na	420	44	19	28
State No. 1-16	5552.0	4	na	410	40	21	48
State No. 1-16	5698.0	2	na	220	15	8	13
State No. 1-16	5700.5	1	na	220	11	9	8
State No. 1-16	5701.8	13	na	210	110	54	310
State No. 1-16	5704.0	4	na	520	33	12	78
State No. 1-16	5707.7	11	na	320	82	35	250
State No. 1-16	5711.5	10	na	340	82	27	220
Ute Mountain No. 44-34	8695.0	6	na	390	48	23	82
Ute Mountain No. 44-34	8714.0	4	na	530	36	16	38
Ute Mountain No. 44-34	8720.0	6	na	450	55	22	71
Ute Mountain No. 44-34	8732.5	6	na	430	58	23	82
Ute Mountain No. 44-34	8737.0	6	na	430	56	23	81
Ute Mountain No. 44-34	8742.5	6	na	450	51	23	81
Ute Mountain No. 44-34	8753.0	7	na	460	63	27	95
Ute Mountain No. 44-34	8769.8	6	na	480	54	24	80
Ute Mountain No. 44-34	8773.0	7	na	480	59	25	95
West Water Creek No. 1	6304.8	11	na	270	93	29	190
West Water Creek No. 1	6311.8	6	na	240	47	18	130
West Water Creek No. 1	6317.3	7	na	290	67	25	180
West Water Creek No. 1	6322.5	8	na	280	74	30	230
Woods Unit No. 1-S	5912.5	10	na	270	90	34	190
Woods Unit No. 1-S	5913.3	6	na	270	56	27	28
Woods Unit No. 1-S	5916.7	13	na	275	110	28	33
Woods Unit No. 1-S	5919.5	15	na	180	210	22	110
Woods Unit No. 1-S	5921.0	4	na	700	80	12	12
Woods Unit No. 1-S	5922.2	6	na	240	44	16	17
Woods Unit No. 1-S	5926.3	6	na	300	72	16	23
Woods Unit No. 1-S	5932.0	1	na	5900	3	4	1

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