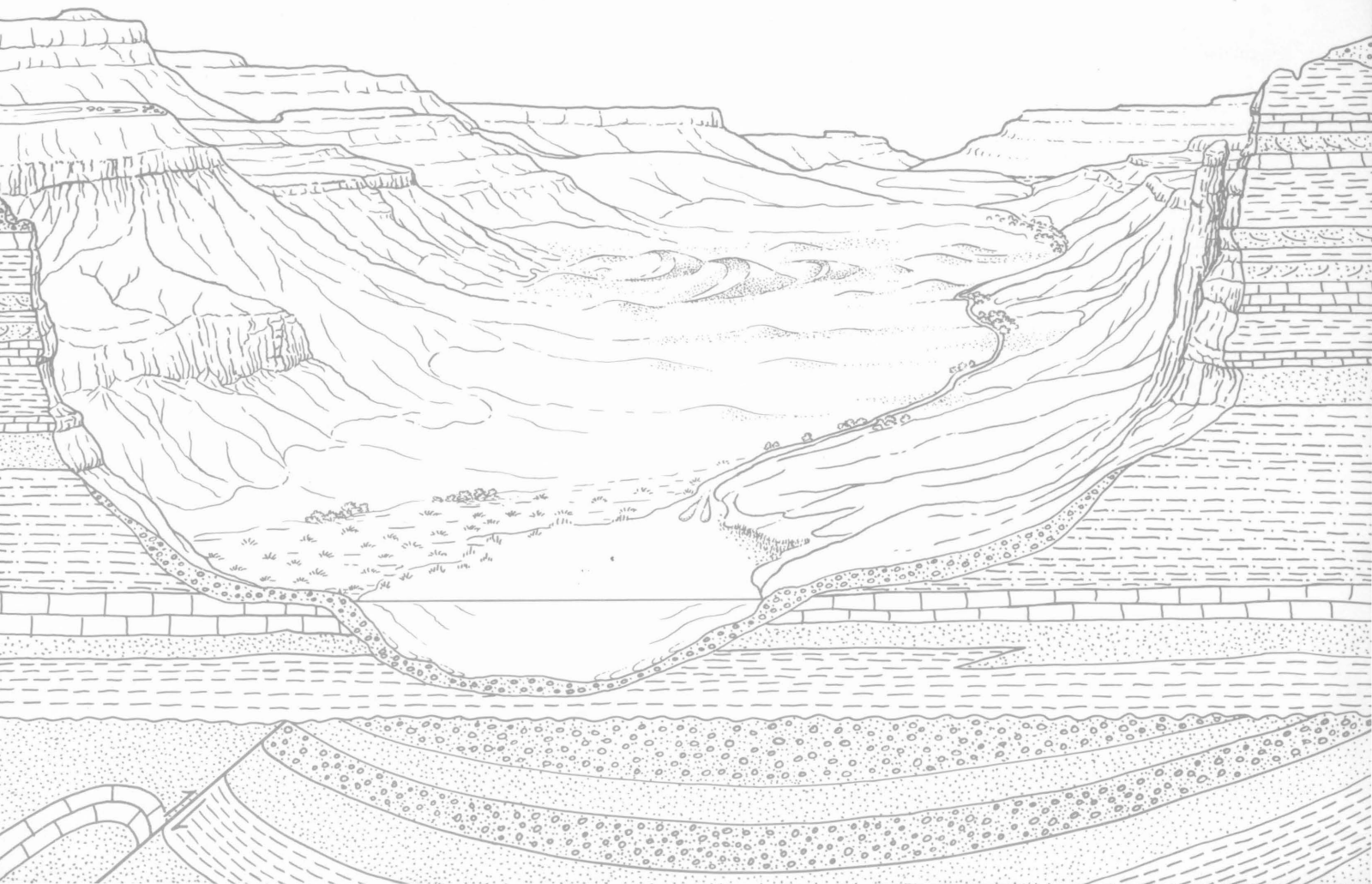


Geochemistry of Mariano Lake-Lake Valley Cores, McKinley County, New Mexico

U.S. GEOLOGICAL SURVEY BULLETIN 1808-I



Chapter I

Geochemistry of Mariano Lake-Lake Valley Cores, McKinley County, New Mexico

By JOEL S. LEVENTHAL

With an appendix on CHEMICAL ANALYSES AND PRECISION
By J. S. Leventhal, C. A. Gent, and F. E. Lichte

A multidisciplinary approach to research studies of sedimentary
rocks and their constituents and the evolution of sedimentary
basin, both ancient and modern

U.S. GEOLOGICAL SURVEY BULLETIN 1808-I

EVOLUTION OF SEDIMENTARY BASINS—SAN JUAN BASIN

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary



U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

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[Plate is in pocket]

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CONVERSION FACTORS FOR SOME SI METRIC AND U.S. UNITS OF MEASURE

To convert from	To	Multiply by
Feet (ft)	Meters (m)	0.3048
Miles (mi)	Kilometers (km)	1.609
Pounds (lb)	Kilograms (kg)	0.4536
Degrees Fahrenheit (°F)	Degrees Celsius (°C)	$\text{Temp } ^\circ\text{C} = (\text{temp } ^\circ\text{F} - 32) / 1.8$

Geochemistry of Mariano Lake-Lake Valley Cores, McKinley County, New Mexico

By Joel S. Leventhal

Abstract

The primary goal of the U.S. Geological Survey-Bureau of Indian Affairs drilling project in the Upper Jurassic Morrison Formation in McKinley County, New Mexico, was to better understand the relationship between host-rock stratigraphy and uranium mineralization. As part of this project, geochemical studies of approximately 280 samples from 8 cores and 1 outcrop were undertaken; samples from 4 of the cores show uranium enrichment. Geochemical relationships between samples of weathered outcrop, oxidized core, reduced (unmineralized) core, and ore-bearing core were contrasted by comparison of element abundances.

The uranium ores are mainly secondary or redistributed; the highest ore grade is 0.24 percent U. Ore in two of the ore-bearing cores is a dark-gray, roll-type ore, whereas ore in the other two ore-bearing cores occurs as black clots in interstitial positions between quartz and pink feldspar grains.

All of the samples, including ore-bearing samples, contain very low (< 0.03 percent) amounts of organic carbon. The ore-bearing samples have lower vanadium contents than most ores of the Grants uranium region. Although there are no obvious trace element anomalies above or below the mineralized zones, the ore zones are erratically enriched in vanadium and selenium. Molybdenum and arsenic are not enriched in or near the ores. One core has a clay layer at the base of the ore zone that probably localized the ore. The geochemistry of this layer indicates that the uranium-bearing solution originated above the clay layer.

Special comparative studies of sandstone and clay chemistry were made using results from X-ray diffraction, optical petrography, and chemical analysis.

INTRODUCTION

In 1980–81, the U.S. Geological Survey (USGS) and Bureau of Indian Affairs (BIA) conducted a drilling program, referred to as the Mariano Lake-Lake Valley drilling project, in the western part of the Grants uranium region in northwestern New Mexico (Rautman and others, 1980) (fig. 1), the largest uranium district in the United States. Eight cores were obtained; reports of the drilling, including electric and gamma-ray logs and core descriptions, are summarized in Kirk and others (1986) and presented in Kirk, Aubrey, and others (1981), Kirk, Gunderson, and others (1981), Kirk, Huffman, and others (1981), Huffman, Kirk, and others (1981), Huffman, Santos, and others (1981), Zech, Hammond, and others (1981), and Zech, Kirk, and others (1981).

One outcrop location of the Upper Jurassic Morrison Formation was also studied, and the series of drill holes trends basinward in a northeasterly direction from the outcrop for approximately 40 km (figs. 1, 2, table 1). Although the holes were drilled primarily to better understand the stratigraphy of the area, they were sited near two uranium deposits. Uranium ore in four of the holes probably represents extensions of known orebodies. Cores 3 and 4 are near the Crownpoint uranium deposits of Conoco (Section 29 and Crownpoint deposits) and the Mobil-TVA (Monument) uranium deposit, and cores 7 and 7a are near the Phillips (Nose Rock) uranium deposit (Chenoweth and Holen, 1980). In addition to the uranium, coal was present in the Upper Cretaceous Dakota Formation in all holes and flowing oil was encountered in hole 9 during drilling. Hole 9 was plugged before reaching the Morrison Formation.

The purpose of this report is to summarize the geochemistry of the core material obtained in the Mariano Lake-Lake Valley drilling project and to compare the chemistry of different lithologies and samples.

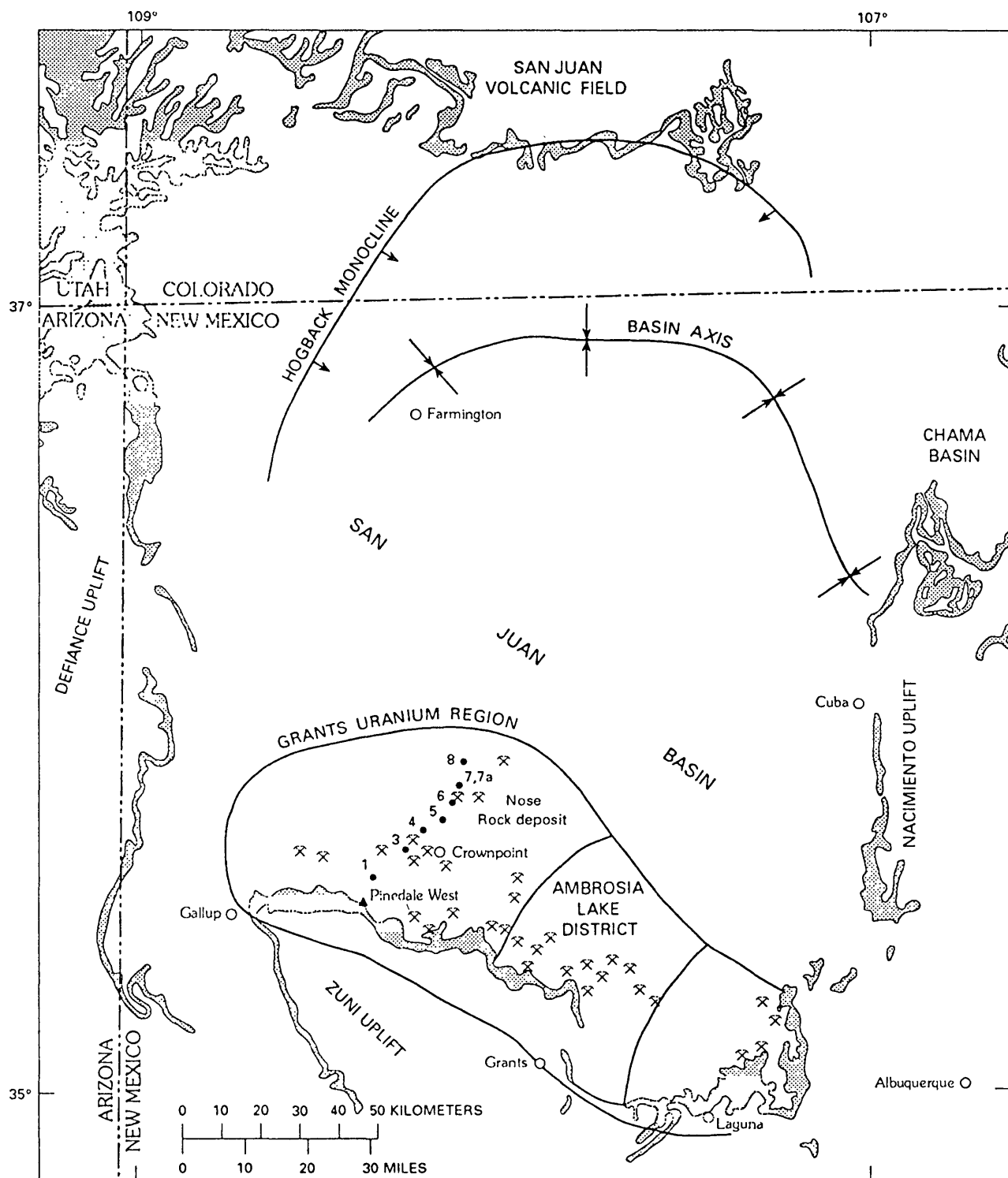


Figure 1. Location of cored drill holes (circles), Pinedale West measured section (triangle), major uranium deposits (pick and hammer), and outcrops of Morrison Formation (screen) in the San Juan basin of New Mexico. Modified from Hansley (in press).

Acknowledgments.—I thank Curt Huffman, Alan Kirk, Brenda Steele, Neil Fishman, Paula Hansley and other geologists of the USGS for discussions at the time

of sample selection and on data presentation. I thank Gene Whitney for X-ray diffraction analysis of samples (table 16). I thank personnel of the Branch of Analytical

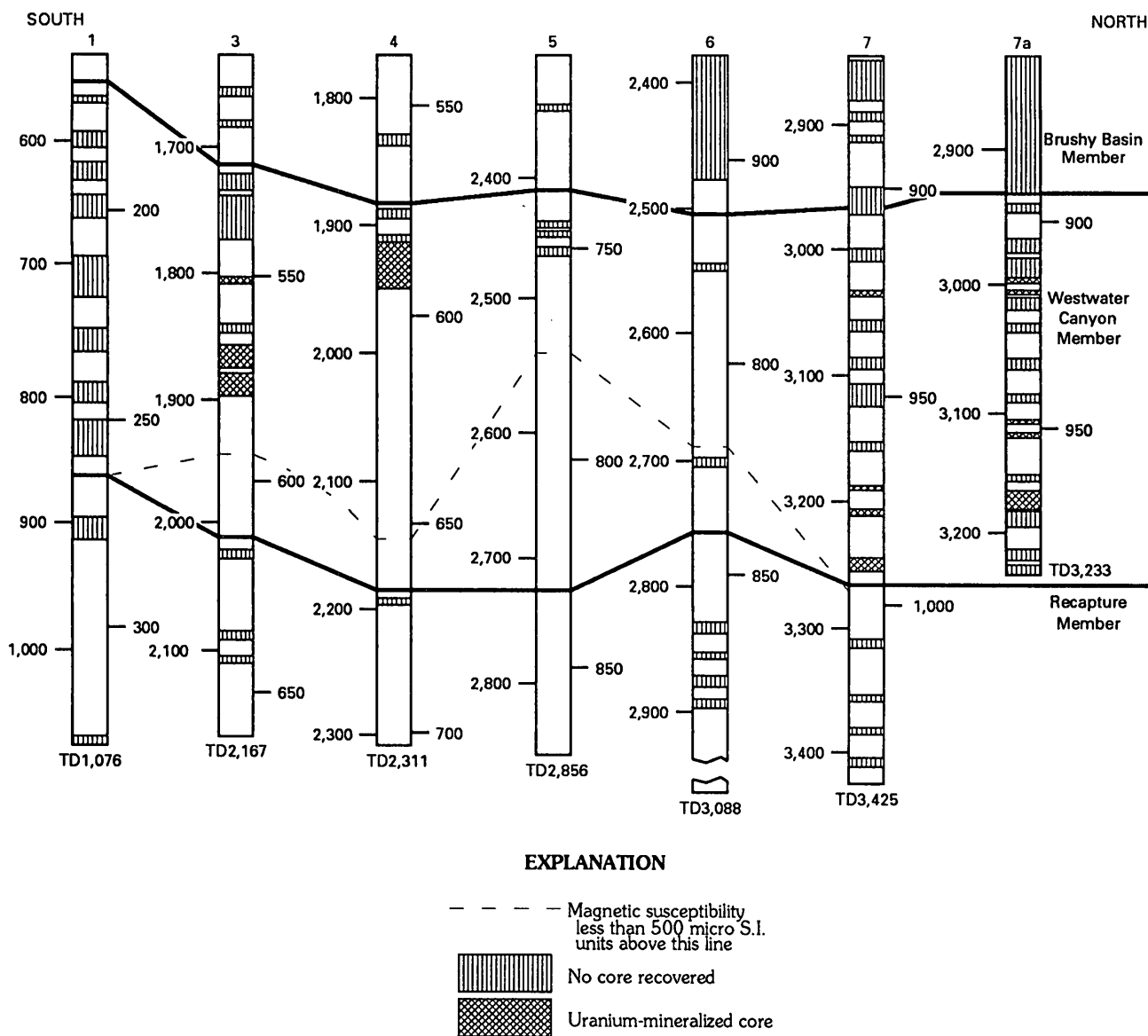


Figure 2. Stratigraphy, uranium-mineralized zones, magnetic susceptibility, and core recovery for core holes in Mariano Lake-Lake Valley drilling project. Depth of holes in feet (left) and meters (right); total depth (TD) in feet; horizontal distance not to scale. Datum is top of Morrison Formation. Modified from Steele (1984); magnetic susceptibility line from Hansley (1986).

Laboratories for the careful and timely analysis of the samples, especially Fred Lichte for analysis of the handpicked ore (table 10). I thank Lincoln Materna, Petroleum Information Corporation, for the computerized listing of the data, statistical summary (table 14), and plots of the data. I acknowledge Jim Herring and Jennie Ridgley for technical review of the manuscript and thank Charlie Pierson for help with the computer program for the t-test on table 14 that was suggested by Ridgley.

METHODS OF SAMPLING AND ANALYSIS

After the cores were described and logged in the field, they were brought to the USGS core library in Denver, Colo., washed, and cut in half. Half of the core was archived for stratigraphic studies (A.C. Huffman, unpublished data). The other half was examined and samples were collected for several types of petrographic (Steele, 1984; Fishman and Reynolds, 1986; Hansley,

Table 1. Test holes drilled in Mariano Lake-Lake Valley area

[Data from Kirk and others, 1986. API is American Petroleum Institute. Drill-hole locations shown in fig. 1]

Hole number	API number	Location	Latitude, longitude	Cored interval (depth, in ft)	Mineralized zone (depth, in feet)
1	30-031-8001	NE/4 sec. 29, T. 16 N., R. 14 W.	35°30'30"N., 108°22'12"W.	4,77-1,076	None
3	30-031-8003	SE/4 sec. 29, T. 17 N., R. 13 W.	35°40'17"N., 108°14'36"W.	1,560-2,158	1,860-1,868*
4	30-031-8004	SE/4 sec. 15, T. 17 N., R. 13 W.	35°41'55"N., 108°12'00"W.	1,722-2,310	1,909-1,935
5	30-031-8006	NE/4 sec. 4, T. 17 N., R. 12 W.	35°44'15"N., 108°08'48"W.	2,250-2,850	None
6	30-031-8007	NE/4 sec. 19, T. 18 N., R. 12 W.	35°46'18"N., 108°08'54"W.	2,475-3,075	None
7	30-031-8008	SE/4 sec. 31, T. 19 N., R. 12 W.	35°49'45"N., 108°09'00"W.	2,833-3,440	3,179 3,227 3,257-3,264
7a	30-031-8009	SE/4 sec. 31, T. 19 N., R. 12 W.	35°49'43"N., 108°08'49"W.	2,930-3,231	3,133-3,139 3,160-3,169
8	30-031-8010	S/2 sec. 5, T. 19 N., R. 12 W.	35°53'10"N., 108°08'12"W.	3,060-3,520	None

*May differ from Kirk and others (1986) due to chemical criteria for ore designation.

1986), clay (Whitney, 1986; Whitney and Northrop, 1987), and geochemical studies.

The geochemical sampling was designed to obtain: (1) a representative suite of samples from each stratigraphic unit, (2) a representative suite of samples from each lithology, and (3) samples of comparable rock type and stratigraphic interval from each core. Further considerations included collecting samples from and near ore zones and from stratigraphically equivalent barren rock in order to examine the chemical transition (if present) from ore to protore to non-ore in each core, to examine the distribution of reductants (sulfides and organic matter), and to study non-ore samples that are stratigraphically equivalent to ore-bearing samples in other cores.

The sampling was not statistical in the sense that a sample was taken every 10 or 50 ft¹; however, each stratigraphic unit (member) was sampled and individual beds that appeared to be similar in hand specimen were sampled in detail to determine if their chemistry was also similar. In addition, unusual or subordinate lithologies were sampled in order to understand their genesis. Thus, using the stratigraphy and visual methods, I hoped to obtain more knowledge than could be achieved from a purely statistical sampling plan. This sampling approach is especially appropriate because the samples are unweathered (subsurface) and geologically well documented.

The samples were not submitted for chemical analysis either in order of their depth or randomly but instead were separated into three groups: barren sand-

stones, ore-bearing sandstones, and clays. The ores were submitted in order of increasing scintillometer response such that low-uranium samples were prepared (crushed, ground, and analyzed) first to avoid inadvertent uranium contamination. Usually, at least 1 sample in 25 was a replicate. The analytical methods and precision of results are described in the appendix.

The geochemical results reported for these samples are directed toward understanding the distribution of uranium. I was originally most interested in these samples because of the opportunity to study primary ore containing the usual amorphous (structureless) organic matter (Leventhal, 1980). Unfortunately, except for two samples in cores 7 and 7a, the ores were not the usual organic-rich type.

RESULTS AND DISCUSSION

Pinedale West

Samples from the Pinedale West measured section were collected by A.R. Kirk prior to the coring operation so that outcrop samples could be compared to core samples. The measured section is approximately 10 km south of core 1 (fig. 1) and comprises a vertical section through the Westwater Canyon Member of the Morrison Formation, similar to that encountered in the cores, and a horizontal section along one bed to check for lateral continuity. Results for the vertical section are listed in the appendix (table A13), and only certain results and a statistical summary are given here.

The SiO₂ content of the horizontal section (single bed) varies from 81.8 to 87.5 weight percent, and the SiO₂ content of most samples (7 of 12) is 84.1–85.4 percent. Al₂O₃ varies from 5.62 to 7.51 percent; the

¹All sampling intervals and core depths are given in feet because feet are the original measure unit base with which the drilling, geophysical logs, and sample collection was made.

content of most samples (5 of 12) is 6.24–6.80 percent. Iron content ranges from 1.03 to 2.93 percent; the content of most samples (7 of 12) is 1.29–1.99 percent. The other major elements (Na, Ca, K, Mg) are within ± 0.1 percent for the various samples. These samples show values similar to the sample 45 ft above the contact (table A13). Trace elements contents are within a factor of two for lowest and highest contents.

Large chemical variations exist between the samples from the vertical section that comprises the lower part of the Westwater Canyon Member mainly because of the presence of calcite in five samples; these samples have unusually low iron contents. In the non-calcite-bearing samples, SiO_2 varies from 80 to 87 percent, Al_2O_3 from 3.4 to 10.3 percent, and Fe_2O_3 from 0.4 to 2.2 percent. The samples containing the most Al_2O_3 also contain the most K_2O because of the presence of these constituents in potassium feldspar. These samples also show high values of zinc and manganese that may be due in part to surficial weathering processes.

These analytical results show that variable weathering (and oxidation) has affected even the one lateral bed. The sandstones generally have higher quartz contents (as measured by SiO_2) and lower feldspar contents than average sandstones (Pettijohn, 1963), in part because of the selective destruction of minerals other than quartz. Some samples contain large amounts of carbonate, clay, or iron oxide/hydroxide minerals as a result of weathering and redistribution of elements.

Core 1

For the most part, samples from this core are oxidized relative to iron (as indicated by red color) and are not mineralized; however, the uppermost Westwater Canyon Member claystone at 588 ft depth is from an 8-ft-thick, green-gray claystone layer. The sample at 594 ft contains both gray and red mudstone clasts. Oxidation of the core was not total as indicated by the red-gray claystone clasts in the sample at 636 ft, the gray mudstone at 740 ft, the mottled red-green sample at 810 ft, and the fine-grained gray sandstone from the Recapture Member at 881 ft. All of the other samples from the core are red sandstone. A complete description of the core is in Kirk, Aubrey, and others (1981), and a complete listing of the analytical results is given in the appendix (table A6).

A series of closely spaced samples was collected at 674 ft to determine the uranium homogeneity in an unmineralized section of uniform appearance. Samples at 674.0, -0.2 , -0.4 , -0.6 , and -0.8 ft have uranium contents of 5.3, 3.9, 4.3, 4.2, and 4.4 ppm, respectively. The analytical error is approximately ± 0.2 ppm; thus, there is a small, but real, variation in adjacent samples. These uranium contents are higher than those of most

sandstones reported herein, which average 1–2 ppm. The thorium contents of these samples are 4 ± 1 ppm. The uranium content of average sandstones is approximately 0.5 ppm and the thorium content approximately 2 ppm (Turekian and Wedepohl, 1961). The Th/U ratio of the samples from core 1 is about 1; most sandstones and other common rock types have ratios of approximately 3. Based on Th/U ratios and uranium contents, it seems likely that the uranium contents of these samples are higher than normal rather than the thorium contents lower than normal. Another point in favor of excess uranium is that thorium is not easily mobilized in low-temperature sandstone environments, whereas enrichment of uranium by mobility is quite possible. This enhancement by mobile uranium could be the result of higher than normal uranium contents of possible source rocks or the passage of uranium-containing solutions that left behind a small amount of the uranium that perhaps was adsorbed on amorphous iron oxides.

Core 3

Core 3 contains a mineralized zone 6 ft thick. All of the samples from core 3 are unoxidized (gray) with respect to iron, except for a red fine-grained sandstone at 1,939 ft, a brown sandstone at 2,005 ft, and a red claystone (Recapture) at 2,076 ft (table 2). A complete description of the core is in Huffman, Santos, and others (1981). In many samples, sulfide minerals are visible in hand specimen, and there is a mineralized zone from 1,863 to 1,868 ft. Several other protore (considerably above background, but not economic) samples are at 1,808, 1,882, and 1,892 ft. As will be discussed later, samples containing more than 100 ppm U are considered mineralized (uranium ore).

Several samples were collected from core 3 for particular reasons. The sample at 1,783 ft has the same hand-specimen appearance as the ore sample at 1,866 ft. A sample of drilling mud was collected at 1,833 ft, by scraping the surface of a highly coated section, to determine if the drilling mud had an unusual chemical composition that might affect or contaminate the samples (see appendix).

Table 2 gives selected chemical data for ore and non-ore samples from core 3 and includes results of selected organic carbon and selenium and arsenic analyses, which were not routinely done on non-ore samples. A complete listing of the analytical results is given in the appendix (table A7).

The sample at 1,796 ft is a mudstone, and the samples at 1,713 and 1,784 ft are sandstones that have a clay matrix visible in hand specimen. These three samples have the highest aluminum and rare-earth element contents (La, Ce, Yb) (table 2), not surprising because the rare-earth elements are associated with clays.

Table 2. Selected data for samples of the Westwater Canyon Member of the Morrison Formation from core 3

[Depth in feet. In parts per million unless indicated as percent (%). Lithology: ss, sandstone; clay, claystone; mudst, mudstone. Underline indicates high value for Fe, Ti, Al, Cr, and La; leader (-) indicates not analyzed; leaders (--) indicate no visual organic carbon. Average sandstone from Turekian and Wedepohl (1961). All elements by inductively coupled plasma analysis except for U by delayed neutron analysis and organic carbon (OrgC) by combustion. Analysts: C. Gent, F. Lichte, and M. Stanton]

Depth	Lithology	U	V	Mo	Pb	Se	S%	Fe%	Ti%	Cr	Zn	As	Al%	La	Ce	Y	Yb	OrgC%
1,713 ¹	ss+clay	4	48	<2	27	0.2	2.4	<u>3.8</u>	<u>0.25</u>	<u>18</u>	56	4.8	<u>6.7</u>	33	52	29	3	0.13
1,783	ss	52	14	2	62	.8	.14	.86	.11	6	48	7.3	3.8	16	23	10	1	--
1,784	ss+clay	8	40	31	34	6.7	.93	<u>5.8</u>	<u>.22</u>	<u>12</u>	93	5.5	<u>6.4</u>	27	36	21	3	--
1,796	mudst	5	72	<2	187	.4	.05	<u>3.0</u>	<u>.33</u>	<u>17</u>	48	2.5	<u>8.5</u>	68	94	51	5	.07
1,798	ss	8	14	<2	21	1.4	.07	.62	.09	4	21	2.0	3.7	11	17	7	<1	--
1,808	ss+ore	199	31	<2	22	1.6	.12	.67	.07	8	15	2.2	4.7	20	30	7	<1	--
1,833	ss	4	14	<2	15	1.1	.10	.55	.04	3	14	2.0	3.7	13	19	7	<1	--
1,833*	ss	2	14	<2	14	1.0	.08	.55	.04	4	13	1.6	3.8	14	21	--	<1	--
1,855	ss	3	15	<2	16	.9	.06	.54	.04	3	14	1.2	3.2	11	15	5	<1	--
1,863	ss+ore	390	66	<2	16	1.0	.10	.65	.06	7	14	2.8	4.6	18	25	8	<1	.12
1,864	ss+ore	670	100	<2	13	1.3	.13	1.1	.09	8	26	3.3	3.6	12	20	6	<1	<.03
1,866	ss+ore	1,410	168	<2	35	2.5	.60	1.3	.24	11	27	5.3	3.8	26	44	10	2	.24
1,868	ss+ore	830	102	<2	13	1.6	.26	.98	.13	7	22	3.7	3.9	20	28	7	<1	<.04
1,874	ss	44	31	<2	16	1.1	.10	.87	.07	4	19	1.6	4.1	13	20	8	1	--
1,882	ss+ore	201	51	<2	18	1.7	.20	.88	.15	6	18	2.4	3.5	16	28	7	<1	--
1,892	ss+ore	156	31	<2	16	.8	.12	.55	.06	6	13	2.3	3.7	18	25	8	<1	.28
1,905	ss	3	16	<2	15	<.1	.17	.63	.08	4	12	3.0	4.5	21	27	8	<1	--
1,916	ss	6	25	<2	21	<.1	.06	.85	.15	7	21	1.6	3.2	17	23	6	<1	--
1,939	red ss	2	56	<2	20	-	-	3.8	.26	13	51	-	5.3	45	64	20	2	--
2,005	ss	2	25	<2	16	-	-	.84	.15	10	18	-	3.2	14	21	7	1	--
2,076 ²	red clay	3	68	<2	42	-	-	5.9	.32	18	98	-	8.1	66	91	29	3	--
Average sandstone		0.5	35	<1	7	0.05	0.024	0.98	0.15	X0	16	1	2.5	19	32	15	<2	0.05

¹Brushy Basin Member.

²Recapture Member.

They also have the highest iron, titanium, and chromium contents. The former two elements are probably in minerals such as magnetite or ilmenite, the latter element may be associated with iron-titanium oxides or clays (Fishman and others, 1985). Two of these samples have high sulfur contents; presumably the sulfur is combined with iron as pyrite.

The gray sandstone at 1,783 ft (table 2), just above the mudstone at 1,784 ft, was selected for analysis because it has the same hand specimen appearance as the ore-bearing samples; however, it has no anomalous radioactivity or other unusual features and is not near a known ore zone. In fact, the geochemistry of this sample is similar to ore and the uranium content is enriched—52 ppm. This uranium content is much higher than that of the normal adjacent sandstone, although it is not possible to see that amount of uranium in hand specimen. The appearance of this sandstone sample is related to its chemistry and may be useful in identifying other suitable host rocks. The sample is also enriched in molybdenum, lead, zinc, and arsenic relative to other samples. Its enrichment in these trace elements may be related to its proximity to the mudstone, or the sample may be a protore (anomalous but not economic), or it may be from a leached (but not oxidized) zone that once had a higher uranium content. The higher sulfur, iron, and titanium contents of the sample are similar to those of sandstones from the ore zone.

The ore samples (1,863–1,868 ft) and adjacent protore samples (1,808, 1,882, 1,892 ft) have higher vanadium contents than the unmineralized sandstones. Some of these samples also have higher iron, sulfur, and selenium contents, and one sample has a higher lead content. Two of the ore samples have higher organic carbon contents than the unmineralized sandstones, and two of the sandstone ores have low (<0.04 percent) or no organic carbon (table 2).

The sample sequence from 1,808 to 1,892 ft contains sulfur, as sulfide, in amounts from 0.06 to 0.60 percent in sandstones and from 0.93 to 2.4 percent in claystones. Although these amounts may seem minor, their presence suggests that in the sandstones conditions are still nonoxidizing and that sulfides can be an important reductant for uranium (Granger and Warren, 1969). For example, 0.1 percent of sulfide sulfur is capable of reducing approximately 2.5 percent U because oxidation of sulfide to sulfate involves seven electrons, whereas reduction of uranium from +6 to +4 involves two electrons. In addition, the atomic weight of sulfur of 32, as compared to the much larger weight of 238 for uranium, gives the larger reducing power for a smaller weight. This chemical reaction requires complete oxidation of sulfide and its reaction exclusively with uranium without loss, which is unlikely in fluids in porous sandstones, but the reducing power of sulfide is still

considerable. If the above process is only 4 percent effective, it will result in reduction of 1,000 ppm of uranium by 0.1 percent sulfide.

Excluding the claystone sample at 1,784 ft, selenium values are higher in the ore zone and protore samples and lower in samples above and below the ore zone. Arsenic does not show the same pattern as selenium; this is not easily explained because they are both chalcophile elements and should show similar chemistries. The lack of arsenic enrichment in roll-type deposits has been noted previously by Harshman (1974).

A series of nine closely spaced samples (1,872A–I, table 3) was taken from an unmineralized, slightly laminated, unoxidized length of core of uniform appearance. These samples are below the ore zone as defined by detailed scintillometer and (or) geiger counter readings taken at the time of sample selection. Although they were collected only 4 ft below ore (at 1,868 ft), their uranium contents are lower by a factor of approximately 50. Two samples (1,882 and 1,892 ft) of protore 10 ft below the closely spaced samples have approximately eight times the uranium content of the closely spaced samples.

Table 3. Uranium content of nine closely spaced samples and fourteen adjacent samples from core 3

[By delayed neutron analysis. Analyst: D. McKown]

Depth (in feet)		Uranium (in ppm)
1,798		8.1
1,808		199
1,833		4.3 ^a
1,855		3.0
1,863		731
1,864		1,320
1,866		2,790
1,868		1,630
1,872.0	A	31.1
	B	27.8
	C	26.1
	D	24.5
	E	21.3
	F	22.2
	G	20.5
	H	20.7
(1,873.0)	I	19.6
1,874		43.7
1,882		201
1,892		156
1,905		2.6
1,916		6.1
1,939 ^b		1.6

^aSplit contains 1.8 ppm U.

^bRed sand.

The closely spaced samples have much higher uranium contents than normal sandstones (approximately 20 times) and reflect either an incompletely formed low-grade ore or a partly destroyed (leached or oxidized) ore. The lack of oxidation favors the former explanation, as does the lack of sufficient reductant. That is, the ore zone samples still contain visible pyrite, which means the reductant (sulfide) has not been consumed, in contrast to the adjacent low-grade samples, which do not contain visible pyrite.

Core 4

Core 4 is unoxidized and contains a mineralized interval of approximately 25 ft (1,909–1,934 ft, table 4) that was extensively sampled in order to document chemical indicators of the ore and to interpret the geochemical genesis of the ore. The sample at the base of the ore zone (1,935 ft) consists of a clay matrix and larger pebbles and probably was deposited in the bottom of a stream channel. A complete description of the core can be found in Huffman, Santos, and others (1981), and a complete listing of the analytical results is given in the appendix (table A8).

Visual inspection at the time of sampling showed that all of the samples were gray (that is, no oxidized iron was visible), and that pyrite was visible both directly above (1,878, 1,900 ft) and below the ore zone (2,006, 2,010, 2,027, 2,030 ft). In the ore zone, however, only 3 of 16 samples contain visible pyrite (1,909, 1,917, 1,928 ft). The total sulfur data are in agreement with these observations: pyrite was not observed in samples containing less than 0.06 percent sulfur (except for the sample at 1,900 ft).

Core 4 samples from the Westwater Canyon and Recapture Members of the Morrison Formation contain no visible organic carbon except for black specks in ore samples that may represent organic carbon. Subsequent total carbon analysis of the ore samples shows 0.05 percent or less. Several samples in the ore zone (1,933, 1,933.5, 1,934, 1,935 ft) initially had higher carbon contents; however, upon detailed analysis (by direct carbon analysis and by difference (total minus organic)), this carbon was determined to be carbonate carbon. The presence of calcite in these samples is confirmed by their higher calcium and manganese contents. Calcium, manganese, and strontium are covariant if calcium is above approximately 0.1 percent, and all three elements presumably reside mainly in calcite.

The major feature in the ore zone is the calcite cement in the lowest three sandstone samples of the ore zone (1,933, 1,933.5, 1,934 ft) and in the clay sample at 1,935 ft. These samples have markedly higher uranium contents and higher vanadium, iron, titanium, manganese, and calcium contents. Interestingly, the organic

carbon and sulfur contents of the three samples are not higher than those of the overlying, leaner ore samples. Thus, even the higher grade ore, which was not subsequently leached because it was protected by carbonate, does not show evidence of originally having the amount of organic matter of typical Grants primary ore (Leventhal, 1980). The vanadium content of the ore samples of core 4 is not high, as compared to that of both core 3 ores and most other New Mexico ores for which the U/V ratio is near 3 for primary ores and 0.8 for secondary ores (Spirakis and others, 1981). The ores of cores 3 and 4 are secondary because they lack organic carbon and because the U/V ratios for the low-grade (approximately 500 ppm) ores are about 3 and for the high-grade (2,000 ppm) ores about 10. These are higher than normal U/V ratios and indicate that the samples either are relatively enriched in uranium or depleted in vanadium relative to other San Juan basin ores (Spirakis and others, 1981); the ratios are similar to ores of the Church Rock deposit (Spirakis and Pierson, 1983). These high U/V ratios may be typical for secondary ores in the northwestern part of the San Juan basin. The claystone ore sample at 1,935 ft has high contents of Se, Pb, V, Mo, Cu, Al, and rare-earth elements, which are probably related to high clay-mineral contents.

Elements associated with uranium mineralization are not uniformly distributed. Selenium contents (table 4) are high in the ore zone, but the highest selenium content is not associated with the highest uranium content. The variation in selenium is great even over the 6- to 12-in. intervals sampled: it varies from 1.3 to 57 ppm (greatest extreme) to a factor of two for many adjacent samples. Harshman (1974) showed that in roll-type uranium deposits the highest selenium contents are just updip (toward the oxidizing environment) from the highest uranium contents. He interpreted this data using equilibrium thermodynamic information (Eh-pH) to show that selenium was reduced prior to uranium (and vanadium) and that molybdenum, which appears down-dip, was reduced after uranium by more reducing (lower Eh) conditions. Following the same line of reasoning as Harshman, the highest selenium contents (1,916.5, 1,917 ft) and the highest uranium content (around 1,933.5 ft) seem to imply a vertical Eh gradient that decreases downward. The samples having the highest selenium contents also have sulfur contents of 0.20–0.26 percent, considerably above the more common 0.05-percent value. Spirakis and others (1981) reported a mean value for selenium of 60 ppm for primary uranium deposits and 15 ppm for secondary deposits. The mean value for selenium for all sandstone ore samples in core 4 is 11.4 ppm; however, if the two high samples are excluded, the mean value is 3.2 ppm, below the value for primary deposits but overall perhaps compatible with the value

Table 4. Selected data for samples from core 4

[Depth in feet. Samples are from the Westwater Canyon Member of the Morrison Formation except 1,739.1, 1,739.2, 1,739.3, and 1,759 are from the Dakota Sandstone, 1,867 is from the Brushy Basin Member of the Morrison Formation, and 2,204 is from the Recapture Member of the Morrison Formation. All samples are sandstones except claystone or ash is indicated by asterisk (*); plus (+) indicates ore bearing. Data in parts per million unless indicated as percent (%). All elements by inductively coupled plasma analysis except U by delayed neutron analysis; total C, organic C (OrgC), and S by combustion, and Se by hydride atomic absorption. Leaders (—) indicate not analyzed; checkmark (✓) indicates optical spectroscopy conducted. Analysts: C. Gent, F. Lichte, and M. Stanton]

Depth	U	OrgC%	Total C%	Se	S%	Pb	V	Mo	Ca%	Mn	Sr	Fe%	Ti%	Cr	Cu	Al%	La	Ce	Y	Yb
1,739.1*	26	3.6	4.0	--	0.07	77	42	<4	2.0	490	510	1.9	0.54	4	12	15	77	130	39	4
1,739.2*	14	.03	4.4	--	.07	52	23	<4	13.0	3,100	500	1.2	.31	<2	6	11	43	72	24	2
1,739.3*	12	35.8	37.1	--	.35	51	31	<4	.15	70	130	1.0	.24	8	10	8.1	100	160	43	5
1,759*	8	3.5	3.6	--	.30	52	89	<4	.32	170	310	2.5	.51	54	24	12	54	91	40	4
1,867*	1	--	--	--	.04	25	29	✓	.40	560	270	5.9	.18	11	<2	5.2	34	62	37	5
1,878	9	<.04	.04	<.1	2.4	9	43	✓	.11	130	78	2.7	.08	8	4	3.4	12	24	9	<.1
1,900	11	<.02	.02	0.9	.05	6	63	✓	.09	73	59	.46	.11	4	5	2.7	16	28	6	<.1
1,909+	277	<.02	.02	1.3	.34	6	92	✓	.10	100	87	.67	.05	2	10	4.0	18	33	7	<.1
1,911.5+	153	<.01	.01	0.8✓	.45	8	68	✓	.10	69	110	.73	.05	3	4	4.5	26	50	7	<.1
1,913.5+	428	<.03	.03	1.9✓	.15	32	67	✓	.09	110	100	.54	.05	3	3	3.9	22	45	9	<.1
1,914.5+	566	<.01	.01	5.7✓	.25	15	87	✓	.09	120	110	.70	.06	5	5	4.6	33	66	12	1
1,915.5+	650	<.01	<.01	1.3✓	.13	8	66	✓	.06	110	70	.50	.10	4	2	2.8	17	39	8	<.1
1,916.5+	534	<.01	<.01	57	.20	10	60	✓	.07	140	80	.69	.09	4	15	3.6	20	40	10	1
1,917+	462	<.04	.04	90	.26	11	76	✓	.10	160	83	.81	.08	6	9	4.2	22	38	9	<.1
1,917.5+	474	<.04	.04	8.7✓	.25	9	49	✓	.08	110	81	.59	.04	3	17	3.4	17	35	9	<.1
1,919.8+	367	<.05	.05	14 ✓	.15	11	49	✓	.05	97	78	.45	.04	1	16	3.3	16	35	9	<.1
1,921+	632	.05	.05	1.3✓	.03	9	69	✓	.04	160	58	.66	.15	5	5	2.3	15	32	8	1
1,923+	455	<.02	.02	2.0✓	.07	6	60	✓	.06	120	83	.64	.11	4	2	3.4	24	52	10	<.1
1,925+	431	<.02	.02	1.5✓	.06	10	60	✓	.08	110	83	.45	.11	4	3	3.3	24	48	11	1
1,928+	352	<.02	.02	1.1	.04	<5	64	✓	.07	100	60	.49	.08	3	8	2.8	14	24	6	<.1
1,930+	626	.05	.05	--	<.01	11	89	✓	.10	130	80	.65	.10	8	4	3.5	16	26	8	<.1
1,931+	589	<.05	.05	1.3	.07	<4	74	✓	.07	95	77	.53	.07	4	2	3.2	13	28	7	<.1
1,933+	1,560	.02	1.02	1.1	.04	10	110	✓	3.3	1,100	110	.93	.16	5	7	3.3	19	32	10	1
1,933.5+	1,990	.11	.56	3.8	.04	11	100	✓	1.9	700	99	.74	.11	5	9	3.6	19	30	9	1
1,934+	2,430	.02	.42	3.5	.04	11	120	✓	1.3	600	93	.76	.11	7	10	3.6	18	28	7	<.1
1,935*+	911	.13	.20	12	.15	37	430	4	.62	430	140	1.5	.23	15	24	7.1	43	74	29	3
1,936	9	<.07	.07	3.3	<.01	5	45	✓	.17	270	78	1.7	.13	4	8	4.1	14	25	5	<.1
1,939	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1,960	3	<.05	.05	<.1	<.01	<5	33	✓	.11	120	93	.89	.19	5	6	4.4	14	26	8	<.1
2,006	6	<.03	.03	1.1	.11	<5	17	✓	.06	42	57	.46	.07	3	4	2.7	9	16	4	<.1
2,010	17	<.04	.04	1.2	.13	5	51	✓	.08	75	60	.82	.14	7	6	3.2	14	26	6	<.1
2,027	2	<.06	.06	.6	.16	<5	16	✓	.16	55	90	.51	.07	3	3	4.3	17	29	5	<.1
2,030	4	.04	.04	<.1	.62	8	28	✓	.10	130	63	1.2	.32	10	5	2.8	14	25	6	<.1
2,041	2	--	--	--	.35	19	28	✓	.15	76	77	1.1	.09	3	8	4.4	11	18	5	<.2
2,097	1	--	--	--	.08	16	24	✓	.09	61	63	.80	.16	6	3	3.5	14	27	6	<.2
2,105	1	--	--	--	.07	20	13	✓	.76	120	89	.47	.05	<2	5	3.9	17	28	6	<.2
2,137	1	.05	.06	--	<.01	14	24	✓	.13	58	76	.86	.12	5	4	4.3	13	22	7	<.2
2,156	1	--	--	--	<.01	19	18	✓	.31	86	76	.84	.09	4	4	4.4	16	28	7	<.2
2,204	1	--	--	--	.05	14	19	✓	.37	110	170	.62	.09	7	5	3.9	12	17	5	<.2

for secondary deposits. The value of 12 ppm for the mineralized mudstone sample (1,935 ft) is much less than the mean of 80 ppm reported by Spirakis and others (1981) for mineralized mudstones.

Rare-earth element contents for samples from core 4 are probably mainly controlled by the clay content (proportional to the aluminum content above 3.5 percent) and probably not related to uranium ores. For example, the claystone at 1,867 ft, which is not in the ore zone, has rare-earth element and yttrium contents similar to the mineralized clay-bearing sample at 1,935 ft.

At the time of sample selection, two 1-in.-thick black samples of "coal" (1,739.1 and 1,739.3 ft) separated by a 1-in.-thick white ash layer (1,739.2 ft) were noted in the Dakota Sandstone near the top of core 4. Another coal is lower in the core (1,759 ft). Despite the coaly appearance of these samples, they contain considerably less organic carbon than is required to be classified as a coal (table 4). The loss on ignition at 900 °C shows that the coaly samples contain less than 50 percent carbon and thus are not coals but carbonaceous shales. They do contain more than 3 percent organic matter, which accounts for their dark color; it has been shown that above approximately 6 percent organic carbon content samples get no darker in color (Stanton and others, 1983). Therefore, the samples are mixtures of fine-grained mineral matter and organic matter. The SiO₂ content of the samples was not directly measured but can be calculated. If kaolinite is the clay, then silicon and aluminum are approximately the same weight percent and the silicon not in clay can be estimated (table 5). The coaly samples contain approximately 10 and 7 percent quartz and the ash 27 percent quartz; the bulk of each sample is clay. The ash sample contains 13 percent Ca present as calcite, which accounts for 32.5 percent by weight of the sample. The organic carbon, carbonate, and sulfur contents of these samples are given in table 4. The organic-carbon-rich samples at 1,739 ft are actually carbonaceous shales.

The carbonaceous shale samples at 1,739 ft are also unusual in their high uranium and thorium contents. The Th/U ratios of these samples are 2.3–4.8, normal for crustal materials; thus, the uranium is not due to secondary enrichment. The carbonate-rich ash bed quite

possibly is a well-preserved example of the type of ash beds that were the source rock for some of the uranium; however, the presence of carbonate or anhydrite indicates that uranium was not leached from this particular bed at this locality. These carbonaceous shale and ash layers also are enriched in vanadium and zinc as compared to average sandstones (Turekian and Wedepohl, 1961).

In two places, a continuous series of 1- to 1.5-in.-thick samples was taken to determine if the visual similarity (continuity) of the samples is reflected in their uranium contents. Table 6 shows that samples both close to ore samples in the Westwater Canyon Member and far from ore samples in the Brushy Basin Member have fairly constant uranium contents that show only slight variation from the ±0.2 ppm precision. It is particularly interesting to note that, in contrast to the core 3 series of samples near ore, these samples near ore (1,939–40 ft) contain only twice as much uranium as samples far from ore. Presumably the claystone at 1,935 ft was effective in containing the mineralizing fluids above it. This background uranium value of 2–3 ppm near ore has two further and significant implications: (1) the claystone at 1,935 ft was fairly continuous laterally, and (2) uranium-bearing fluids originated above 1,935 ft.

Th/U ratios of these samples are 1–2 for samples near ore and 3–6 for most of the samples far from ore. These ratios indicate no significant addition of uranium to samples far from ore, although these sandstones contain more uranium than the average sandstone of Turekian and Wedepohl (0.45 ppm) (1961). The ratios are in contrast to those for core 3, in which the near-ore samples have Th/U ratios of approximately 1 that probably reflect a slight enrichment in uranium resulting from the passage of uranium-bearing solutions and adsorption of uranium on mineral oxides.

Core 6

Core 6 is unoxidized, but although many samples contain sulfides, they are not mineralized. Pyrite was visible in 11 of 36 samples. A complete description of the core is in Kirk, Gunderson, and others (1981), and a

Table 5. Additional data for core 4 ash and coaly samples
[Zr, U, and Th in ppm; all others in percent. See text for discussion of sample types. Organic carbon, CO₃-C, and LOI by combustion; Zn by ICP; SiO₂ by XRF; U and Th by delayed neutron]

Depth (in feet)	Sample type	Zn	U	Th	Th/U	LOI	Organic carbon	CO ₃ -C	SiO ₂	Quartz ¹
1,739.1	Coal	53	26	61	2.3	19.6	3.56	0.44	42.4	10
1,739.2	Ash	40	14	46	3.3	24.6	.03	4.40	29.2	5.6
1,739.3	Coal	58	12	58	4.8	54.3	35.8	1.3	24.4	7.0
1,759	Coal	83	8	27	3.4	13.7	3.46	.12	53.3	27.4

¹Quartz=(Si-Al)×2.

Table 6. Analysis of sequential sandstone samples from core 4

[In parts per million; by delayed neutron analysis. Leaders (--) indicate interference. Analyst: D. McKown]

Depth (ft)	Thorium	Uranium
Far from ore		
1,807-1	12	1.2
1,807-2	11	3.1
1,807-3	9	2.4
1,807-4	9	1.8
1,807-5	7	1.5
1,807-6	8	1.5
1,807-7	6	1.6
1,808-8	8	1.3
1,808-9	7	1.4
1,808-10	8	1.4
Near ore		
1,939-1	5	2.7
1,939-2	4	1.9
1,939-3	4	1.9
1,939-4	4	2.1
1,939-5	6.5	2.9
1,939-6	4	2.3
1,939-7	3	3.0
1,939-8	3	2.2
1,939-9	3	2.1
1,940-10	3	2.7
1,940-11	4	2.6
1,940-12	5	2.9
1,940-13	--	3.0
1,940-14	9	7.3

complete listing of the analytical data is given in the appendix (table A10). Sulfur contents range from <0.01 to 6.7 percent. The sulfur content for a well-cemented sample at 2,508 ft is 6.7 percent, but the sample's low calcium (0.13 percent) and carbonate-carbon (0.02 percent) contents indicate that the cement is silica rather than carbonate. Most of the samples that have visible pyrite contain only 0.4–0.8 percent S.

Four samples in core 6 (2,580 and 2,751 ft, Westwater Canyon Member; 2,808 and 2,826 ft, Recapture Member) have black matrix laminations visible in hand specimen that are composed of either opaque minerals or organic matter. The samples at 2,751, 2,808, and 2,826 ft contain 2.0, 1.3, and 0.68 percent Fe and 3,800, 2,100, and 600 ppm Ti, respectively. The samples at 2,751 and 2,808 ft have among the highest iron and titanium contents in the core (excluding clay samples), and the black laminations are probably heavy mineral segregations. This interpretation is supported by the very low organic carbon contents of 0.09 and 0.07 percent for the samples at 2,808 and 2,826 ft. The sample at 2,826 ft does not have unusual iron and titanium chemistry, but pyrite is visible in hand specimen and fine-grained pyrite may account for the sample's dark laminations. The sandstone at 2,580 ft has a black matrix and an organic

carbon content of 0.14 percent, considerably higher than most samples. Unfortunately, it was not analyzed for iron and titanium and so the cause of its black matrix is not known.

The sample at 2,808 ft has visible black laminations in hand specimen. Its organic carbon content is relatively low (0.09 percent) and its iron (about 1.5 percent) and titanium (2,400 ppm) contents high. Opaque heavy minerals such as magnetite or ilmenite probably are responsible for the black color.

The sample at 2,657.5 ft has a high iron content (2.2 percent) but contains sufficient aluminum (7.9 percent) to be classified as a clayey sandstone. Its iron and titanium contents are similar to the other high-aluminum (claystone) samples.

Grain size

Four unrelated samples in core 6 were chosen to examine chemical element contents as a function of grain size (table 7). Sample 2,641 is a medium- to fine-grained, gray, well-cemented sandstone. Sample 2,657.5 is a fine-grained sandstone with a gray clay matrix. Sample 2,702 is a coarse-grained, brown sandstone. Sample 2,808 is a medium-grained sandstone with dark (black) laminations. These samples were specially prepared and analyzed; the samples were carefully disaggregated (rather than fine ground), then passed through 60- and 100-mesh (0.25- and 0.15-mm), depending on the amount of material. For two samples (2,641, 2,657.5 ft), the 60-mesh and 100-mesh fractions were combined in order to obtain enough material so that the fine fraction weighed at least 20 g, sufficient for inductively coupled plasma (ICP), X-ray fluorescence (XRF), and delayed neutron (DN) analyses. This fine fraction is 5 to 37 percent of the total sample.

All of the samples contain low amounts of sulfur and total carbon (table 8). Two samples (2,641, 2,702 ft) give markedly different results for the chemistry of the coarse and fine fraction, whereas results for the other two show very little significant difference. The fine fraction of the sample at 2,641 ft is enriched in elements not associated with quartz; these elements may reside in clay, feldspar, or iron oxide phases or minerals. The ratio of element concentrations in the fine fraction as compared to the coarse fraction varies from 0.89 for SiO₂ to 2.6–3.4 for zinc, phosphorus, and copper (table 9). The ratios fit expected mineralogical-geochemical patterns: Ba, Sr, and Li for barite and (or) feldspar; Mn, Sr, and Ca for calcite; Al, Ce, and La for clays; Cr and V for clays; and Fe and U for adsorption of U on iron oxide/hydroxide minerals.

The fine fraction of the sample at 2,702 ft is also enriched in elements not associated with quartz. This is not surprising because the sample is a coarse sandstone,

Table 7. Chemical and petrographic data, core 6 size fractions

[Depth in feet. All samples from the Westwater Canyon Member of the Morrison Formation except for 2,808, which is from the Recapture Member. Optical data in volume percent (Steele (1984); chemical data in weight percent. Analysts: J. Baker and M. Stanton]

Depth	Description	Sieving		Optical data					XRF				Combustion		
		Weight percent	Passes (mesh)	Quartz	Si cement	Feldspar	Matrix	Porosity	SiO ₂	Al ₂ O ₃	LOI	Fe ₂ O ₃	OrgC%	CO ₃ -C%	S%
2,641	Medium to fine sandstone, gray, cement	--	--	51.7	15.7	16.6	0.7	10.3	--	--	--	--	0.04	0.02	<0.01
	Coarse	87	--	--	--	--	--	--	91.3	4.8	0.68	0.54	--	--	--
	Fine	13	100	--	--	--	--	--	82.6	8.15	1.54	1.19	--	--	--
2,657.5	Fine-grained sandstone w/clay, some organic material	--	--	Not determined					--	--	--	--	.11	.02	<.01
	Coarse	73	--	--	--	--	--	--	72.7	13.2	3.6	2.8	--	--	--
	Fine	27	100	--	--	--	--	--	73.4	13.1	3.5	2.8	--	--	--
2,702	Coarse sandstone, brown	--	--	41.6	0.7	26.0	1.7	13.7	--	--	--	--	.11	.07	<.01
	Coarse	95	--	--	--	--	--	--	82.9	8.98	1.16	0.62	--	--	--
	Fine	5	60	--	--	--	--	--	74.5	11.6	2.54	1.4	--	--	--
2,808	Black laminations	--	--	59.9	0.01	8.0	3.7	23.7	--	--	--	--	.09	.13	.06
	Coarse	63	--	--	--	--	--	--	86.0	5.76	1.5	1.8	--	--	--
	Fine	37	60	--	--	--	--	--	85.4	5.76	1.6	2.7	--	--	--

Table 8. Chemical analysis of coarse and fine fractions of samples from core 6

[Depth in feet. In parts per million except Al, Fe, Mg, Ca, Na, and K₂O in percent.. Leaders indicate not analyzed. Parentheses indicate possible site contamination. Analyses by inductively coupled plasma analysis except U and Th by delayed neutron analysis and K₂O by XRF. Analysts: C. Gent and D. McKown]

Depth	Fraction	U	Th	Al	Fe	Mg	Ca	Na	K ₂ O	Ti	Mn	Ba	Cr	Cu	La	Ce	Y	Yb	Pb	Sr	V	Zn	P	Li
2,641	Coarse	3.26	--	2.4	0.44	0.13	0.17	0.74	2.3	0.06	0.54	314	4	17	11	14	4	<1	<10	35	18	10	0.01	12
	Fine	7.07	--	4.4	.91	.25	.24	1.4	4.1	.12	175	401	7	57	18	21	8	1	(35)	48	33	26	.03	16
2,657.5	Coarse	5.67	13	7.9	2.2	.92	.36	.74	4.5	.34	158	532	22	22	32	41	28	3	22	203	49	48	.05	23
	Fine	5.71	17	7.9	2.2	.91	.39	.76	4.5	.34	179	559	20	(190)	31	52	29	4	20	203	49	88	.06	22
2,702	Coarse	1.18	3	5.0	0.54	.15	.45	1.3	4.6	.05	97	634	6	21	18	28	7	<1	(24)	86	18	20	.02	9
	Fine	2.08	3	6.9	1.2	.28	1.1	1.6	6.2	.13	247	571	8	46	20	29	8	1	(150)	104	38	27	.02	13
2,808	Coarse	1.27	6	3.1	1.3	.20	.64	.80	1.9	.21	191	539	12	10	22	27	7	1	13	129	38	25	.02	9
	Fine	1.58	6	3.1	1.9	.26	.42	.69	2.0	.31	247	471	11	49	18	26	7	<1	11	98	56	40	.02	13

and only 5 percent of the sample passed 60-mesh. The ratio of elements in the fine to coarse fraction varies from 0.90 for SiO₂ and barium to 2.6 for titanium (table 9). The enrichment factors in the fine fraction are similar to those for the sample at 2,641 ft, but the geochemical groupings are not as clear, perhaps because the fine fraction comprises only 5 percent of the sample.

The ratio of 6.2 for lead in sample 2,702 probably reflects contamination because a lead content of 150 ppm is unexpectedly high and even 24 ppm is high for these sandstones. Another evidence of contamination and its source is the tin content. Tin was not detected in any other samples except for the fine fraction of two of the samples that were sieved, and contamination from the sieve may be the source. The detection limit of tin is 10 ppm and the normal value for sandstone is 0.X ppm (Turekian and Wedepohl, 1961). Tin contents for sample 2,702 are <10 ppm for the coarse fraction and 260 ppm for the fine fractions. For the sample at 2,641 ft, tin contents are <10 ppm for the coarse fraction and 27 ppm for the fine fraction. In the process of sieving these samples, a very small piece of solder holding the brass screen to the sieve could have come off and been included with the fine fraction. This might have occurred during the pounding action of the "Ro-Tap" device. The fine fraction weighs approximately 20 g; thus, for a density of 8, 100 ppm is 2 mg. This is a speck of material 0.2 mm in diameter, a size that would pass through the screen of the sieve into the fine fraction. The contamination thus could have come from the bottom of the coarse sieve or from the 100- or 150-mesh sieve.

Another possible instance of contamination is in the sample at 2,657.5 ft, for which the fine-fraction and coarse-fraction chemistry are almost the same for all constituents except copper and zinc, which show ratios of 8.6 and 1.8, respectively. Again these anomalous results could be due to a small piece of the brass sieve or sieve screen depositing in the fine fraction. This process may also be the cause of a five-times increase in copper in the sample at 2,808 ft; this sample has the same element contents for the coarse and fine fractions, except for copper, which is different by a factor of 5, and a few other

elements: zinc by 1.6, vanadium by 1.5, and iron by 1.5. Despite care in inspection and cleaning the sieves, it appears that brass sieves with solder should be used only if very careful attention is paid to their condition. Stainless steel sieves with silver solder would be preferable. It is also suggested that the harsh treatment by the "Ro-Tap" device should preclude its use. A final point of confirmation is that the other samples (240) were not sieved, and none show any evidence of tin, lead, copper, or zinc contamination.

Core 7

Core 7 is made up of normal unmineralized sandstone, a coal at 2,857 ft from the Dakota Sandstone, gray claystone at 2,924 ft from the Brushy Basin Member and at 3,023 and 3,049 ft from the Westwater Canyon Member, and red claystone near the bottom of the core at 3,314 and 3,397 ft from the Recapture Member. A complete description of the core is in Kirk, Huffman, and others (1981), and a complete listing of the analytical results is given in the appendix (table A11). Sandstone collected from the ore zones (3,248, 3,259, 3,260, 3,264, 3,268, 3,272 ft; see fig. 2) contains abundant pink feldspar, and the uranium ore occurs as small black clots at grain boundaries. Two other uranium-rich samples (3,179, 3,227 ft) are dark gray or black, similar to normal Grants primary ore.

Because of the unusual mineral appearance of the ore samples relative to normal primary or secondary ore, it was not clear if the high scintillometer readings were due to redistributed daughter elements rather than to uranium. Therefore, a portion of the sample at 3,259 ft was high graded; that is, the black clots (aggregates of friable crystals) were handpicked while the sample was carefully disaggregated (sample weight 0.069 g). This black material was highly alpha radioactive: the handpicked sample was approximately 50 times background and thus contains the radioactivity. The sample was analyzed by ICP spectroscopy and found to contain

Table 9. Ratios of elements in fine to coarse fraction and geochemical associations for two samples from core 6

Sample 2,641 ft							
[1]	0.89	1.3-1.4	1.5-1.7	1.8	1.9-2.0	2.0-2.3	2.6-3.4
[2]	SiO ₂	Ba, Li, Sr, Mn, Ca	Ce, La, Al	Cr, V	K, Mg	Y, Na ₂ O, Fe, U, LOI	Zn, Pb, Cu
[3]	Quartz	Barite, calcite	Clay	Clay	Feldspars	Iron oxides	Heavy minerals
Sample 2,702 ft							
[1]	0.90	1.0-1.1	1.2-1.4	1.8	2.1-2.5	>2.6	
[2]	SiO ₂ , Ba	P, Ce, La, Y	Sr, Na, Cr, Al, Zn, K, Li	Mg, U	V, Cu, LOI, Fe, Ce, Mn	Ti	
[3]	Quartz, feldspar	Clay	Feldspars	Clay	Clay, iron oxides	Oxides	

[1] Ratio of element concentration (for the elements listed) in the fine fraction to the coarse fraction.

[2] Elements having that ratio.

[3] Mineralogical association.

1.7 percent U (table 10); thus, the black clots are indeed uranium ore.

Chemical analyses of selected samples from core 7 are in table 11. The sample at 3,179 ft is 5 cm thick and contains 1.0 percent organic carbon and 1,450 ppm U. In hand specimen, it appears to be typical Grants primary ore; it does not contain visible clots of mineralized material (as do samples from 3,248–3,272 ft), and the uranium is apparently distributed throughout the matrix. This sample also contains more V, Mo, Se, Pb, Zn, Y, and Yb than ores deeper in the core (3,258–3,263 ft). The sample at 3,227 ft is a lower grade (830 ppm U) version of the sample at 3,179 ft; it contains proportionately less U, organic carbon, Zn, Y, and Yb.

The sample at 3,178 ft (within 1 ft of ore) was analyzed for remnants of uranium-mineralized rock from the primary ore at 3,179 ft. Based on hand specimen examination and aluminum content (table 11), it contains some clay. It also contains 18 ppm U, 50 ppm Se, 50 ppm Pb, and 5 ppm As, amounts all higher than is normal for unmineralized samples. The sample has higher aluminum and iron contents, common to claystones, and contains the accompanying trace elements La, Ce, Y, Yb, Ti, Cr, and Zn. Because the sample contains negligible organic carbon or sulfur, it may not have had the necessary reductants to concentrate higher amounts of uranium.

Although indicated as such, the samples at 3,302 ft are *not* analytical splits; they are closely spaced samples that both contain visible pyrite. The first sample has a discrete zone, approximately 0.5-in. thick, in which pyrite is concentrated, whereas the second sample contains scattered pyrite. Analytical results (table A11) indicate that these adjacent samples are quite different in their content of certain elements.

Based on chemical analysis and mineral analysis of the samples from core 7, several geochemical patterns emerge. Samples containing stoichiometric amounts of

Ca, carbonate-carbon, and associated Mn contain calcite (3,190, 3,223, 3,229, 3,258 ft). Samples that do not contain carbonate but have similar amounts of Ca, Sr, and SO₃ or S contain anhydrite (CaSO₄) (3,133.5, 3,272, 3,272.5 ft). The sample at 3,282 ft contains both calcite and anhydrite. It is possible that the carbonate contains oxidized organic carbon and the anhydrite contains oxidized sulfide; thus, these elements could be related to ore-forming or remobilization events.

Other Cores

Complete results for unmineralized core 5, ore-bearing core 7a, and unmineralized core 8 are given in the appendix (tables A9, A12), and statistical summaries for comparison to other cores are presented later.

DATA DISPLAY

Downhole Plots

Initially, analytical results were entered (except for C, S and other elements such as Se, As, and Hg that were measured only on a limited number of samples) into a Digital Equipment Corporation VAX computer in a modified EGSP-NPRA format (Dyman and Wilcox, 1983; Wilcox and others, 1988). The results were plotted as a function of depth for each hole (plate 1); elements showing similar downhole patterns were grouped together. The similarity of the patterns is related mainly to the claystone and clay-bearing samples that have higher major element (except SiO₂) and trace element contents. The ore samples that have higher uranium and vanadium contents are also easily recognized. Presumably, samples that have similar element patterns are related in that they contain the same mineral (for example, Al and K in feldspar or Mn in calcite) or have been subjected to the same geochemical processes (for example, U and V enrichment). Note that some of the trace elements (V, U, Mn, Sr) show much greater variation and are plotted on a logarithmic scale on the downhole plots.

These downhole plots are of considerable use in verifying known trace element geochemical relationships; for example, clays contain aluminum and rare-earth elements, and carbonate minerals contain manganese and sometimes strontium. The downhole plots also show that the mineralized zones are enriched in uranium and vanadium. They can be used to see other element associations that sometimes occur, such as magnesium in calcite and titanium in iron oxides.

Sandstones are chemically similar; thus, the samples showing the greatest chemical variations in the

Table 10. ICP analysis of highly radioactive, handpicked sample at 3,259 ft depth from core 7

Percent					
Al	4.1	Ca	1.3	Fe	1.1
K	4.0	Na	1.1	Mg	0.29
P	0.15	Ti	0.1	U	1.7
Parts per million					
Ba	450	Ni	12	La	230
Be	4	Pb	150	Ce	450
Co	15	Se	14	Pr	35
Cr	26	Sr	80	Nd	160
Cu	26	V	150	Sm	40
Li	15	Zn	110	Eu	8
Mn	450	Zr	50*	Er	4
Mo	10			Yb	13
				Y	110

*May be low due to incomplete dissolution.

Table 11. Selected chemical data for samples from core 7

[Depth in feet. Samples from Morrison Formation: samples 3,133.0-3,263 from Westwater Canyon Member; samples 3,267-3,302.5 from Recapture Member. All samples are sandstone except for 3,178 (claystone), 3,302 (pyrite layer), and 3,302.5 (pyrite). Samples 3,179, 3,258, 3,259, and 3,263 are ore bearing. In parts per million unless indicated as percent (%). Leaders -- indicate not analyzed; asterisk (*) indicates replicate of previous sample. All elements by inductively coupled plasma analysis except U by delayed neutron analysis, organic carbon (OrgC), S, and CO₃-C by combustion, and SO₃ by XRF. Analysts: F. Lichte, C. Gent, and M. Stanton]

Depth	U	OrgC%	S%	SO ₃ %	V	Mo	Se	Pb	As	CO ₃ -C%	Ca%	Mn	Sr	Fe%	Ti%	Cr	Zn	Al%	Y	La	Ce	Yb
3,133	2	<0.01	<0.01	--	37	<2	--	11	--	0.04	0.14	41	49	0.50	0.06	<10	8	4.0	6	14	17	<1
3,133*	2	.02	.01	--	37	<2	--	11	--	.07	.18	40	1,700	.50	.06	<10	8	3.9	6	13	16	<1
3,178	18	--	<.01	--	43	<2	50	50	5	--	.32	90	190	1.3	.25	20	37	5.9	16	36	67	2
3,179	1,450	1.0	.05	--	110	6	70	87	5	--	.20	110	120	1.5	.18	11	309	4.4	146	19	44	8
3,190	1	.07	<.02	--	17	<2	--	15	--	.16	.51	143	91	.62	.04	<10	8	4.6	6	17	22	<1
3,213	1	--	--	--	21	4	--	<10	--	--	2.7	639	57	.55	.06	<10	6	3.2	6	13	20	<1
3,223	1	.23	--	--	45	<2	--	13	--	3.1	8.6	2,940	110	1.9	.05	<10	72	2.9	7	14	17	<1
3,227	830	.18	.02	--	93	<2	>5	21	<5	<.03	0.15	230	61	4.7	.13	6	83	3.9	51	12	28	3
3,229	4	.09	--	<.1	82	<2	--	21	--	.04	.45	235	77	1.7	.31	<10	22	3.6	4	24	38	<1
3,247	3	--	--	<.1	47	<2	--	17	--	--	.20	111	65	1.5	.26	<10	17	4.1	6	25	38	<1
3,258	940	.22	.03	<.1	137	7	>5	37	5	.40	1.6	520	84	.76	.07	4	43	4.4	7	20	44	<1
3,259	460	.11	.01	<.1	55	6	>5	30	2	.04	.34	130	58	.78	.09	7	20	3.1	7	11	20	1
3,263	390	.11	.14	.31	54	8	>5	16	7	.03	.41	110	81	1.1	.09	4	30	4.1	6	14	23	1
3,267	10	.02	0.92	1.7	17	5	--	12	--	.04	1.0	61	259	.66	.09	<10	13	3.1	3	11	17	1
3,272	5	<.01	5.3	12.	15	5	--	12	--	.01	5.4	39	1,730	.45	.07	<10	10	2.8	3	11	15	<1
3,272*	5	<.01	5.5	11.1	15	4	--	--	--	<.01	5.6	36	1,690	.46	.07	<10	13	2.7	3	12	<10	<1
3,282	3	<.01	1.1	2.4	14	<2	--	10	--	2.75	8.8	2,100	1,410	.20	.11	<10	9	2.4	14	15	27	1
3,296	2	--	--	.8	50	<2	--	14	--	--	.98	310	143	1.5	.25	<10	22	3.7	6	17	22	<1
3,300	2	--	--	.57	49	<2	>5	19	1	--	.48	120	150	1.2	.24	10	24	3.7	8	23	45	1
3,302	3	--	1.3	.64	36	<2	>5	28	15	--	.60	93	140	1.6	.13	7	23	4.1	8	25	45	1
3,302*	1.6	<.01	.47	--	51	<2	>5	17	--	.03	.45	81	27	.83	.17	40	16	3.9	6	16	14	<1

downhole plots are claystones, ores, and carbonates. Sandstones consist mainly of quartz, which has low abundances of trace elements, that dilutes the other elements and shows low chemical variability. In general, the higher the quartz content, the lower the major (except Si), minor, and trace element content. Elements below detection limits (Eu, Yb, As, Ag, Ga, and Co) could not be compared, and detection limits partially interfered with comparison of other elements. Molybdenum was detected in some claystones and ores but was less than 2 ppm in normal sandstones. Thorium by DN was detected in unmineralized sandstones, but because U^{238} interferes in ores, no comparison of ores and non-ores could be made. Thorium by ICP was too close to the limit of detection (8 ppm) to allow meaningful comparisons.

Covariance between Elements

The geochemistry and mineralogy of sandstones gives a regularity to certain element relations in many samples; however, in ore and claystone samples certain different relationships are observed. Because of the large number of possible element associations and large number of samples, only the strongest and most important of these will be mentioned. Examples from individual cores will be given because of the crowding of data points that would occur if results for all cores were plotted on the same diagram.

Figures 3 and 4 show the relationship between sodium and barium for cores 4 and 6. This relationship is also seen in cores 1, 7a, 3, and 5 and is presumably due to the presence of barium in feldspars. Figure 5 shows the relationship between calcium and manganese in core 6, a relationship also seen in the other cores. This relationship reflects the substitution of manganese into calcite. Figure 6 shows the covariance between magnesium and iron in core 4, probably due to their presence in illite and chlorite; this relationship is also seen in cores 4, 6, 7a, and 7. Figure 7 shows the lack of correlation between aluminum and titanium in core 4 that would be observed if the aluminum is mostly in clay rather than feldspar.

Figure 8 shows the expected covariance in core 1 between lanthanum and cerium, both light rare-earth elements having very similar geochemical behavior. This relationship is also observed in the other cores. Figure 9 shows that samples in core 6 having enhanced amounts of zinc and yttrium are claystones or samples that have a clay component. One sample that contains coarse feldspar grains also has higher zinc and yttrium contents. Figure 10 shows the lack of relationship between uranium and vanadium in core 4 at normal levels

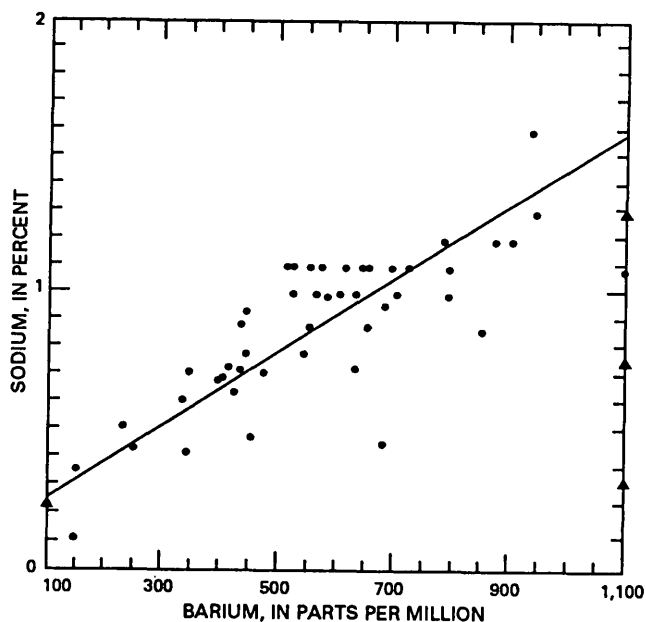


Figure 3. Covariance between sodium and barium in core 4. Triangle indicates sample off scale.

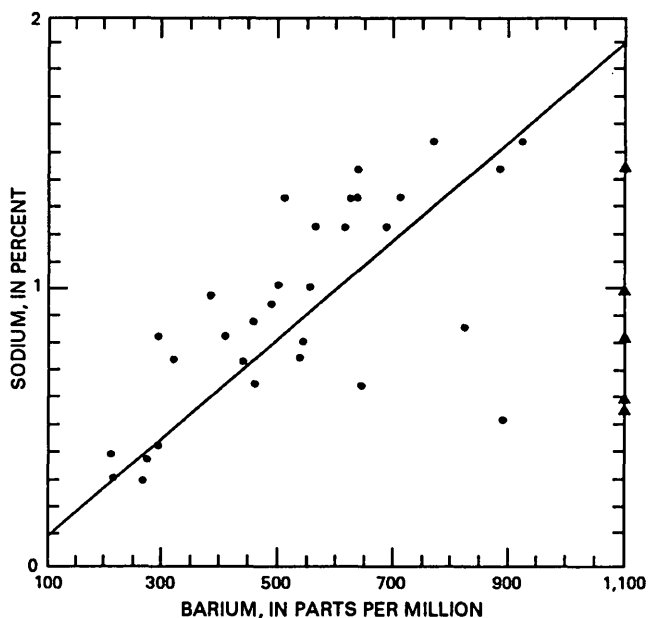


Figure 4. Covariance between sodium and barium in core 6. Triangle indicates sample off scale.

($U < 10$ ppm, $V < 100$ ppm) and the correlation between uranium and vanadium for the protore and ore samples.

Figure 11 shows the relationship between aluminum and uranium in core 7. Unmineralized sandstones contain less than 5.25 percent Al and less than 100 ppm U, whereas claystones contain more than 5.25 percent Al and sandstone ores more than 100 ppm U based on histograms (see later section). Figure 12 shows the

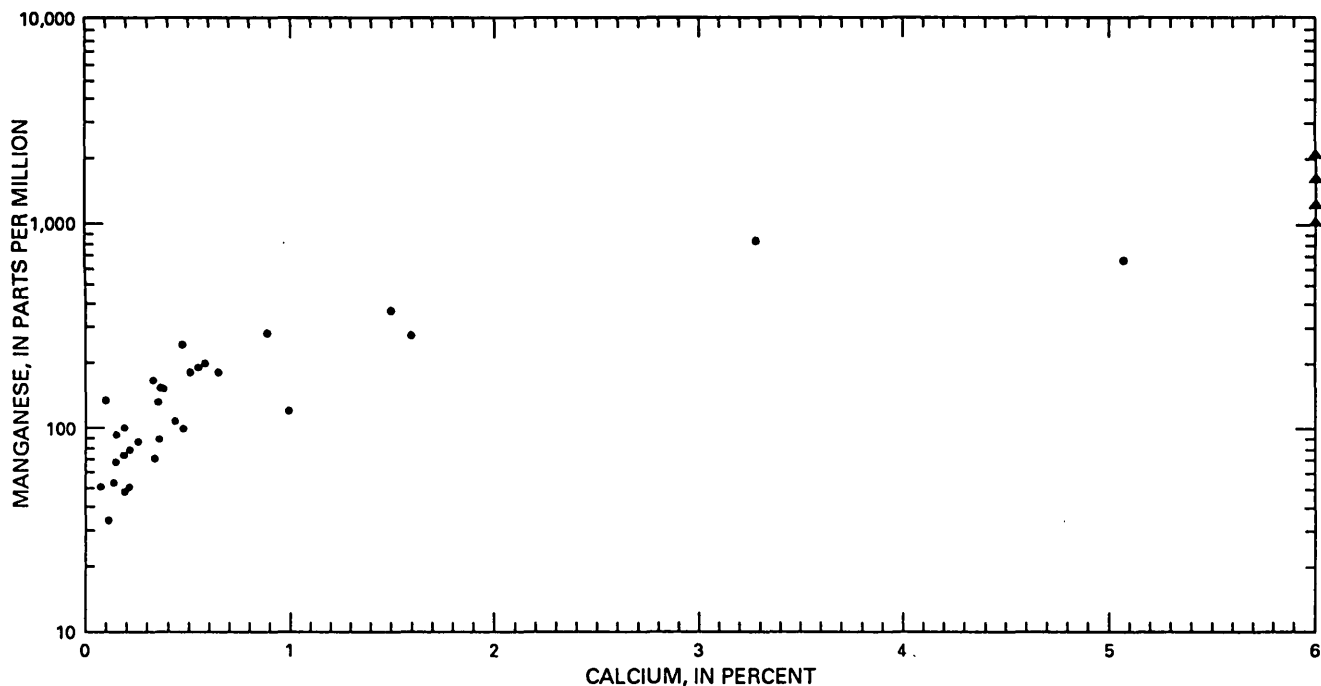


Figure 5. Covariance between calcium and manganese in core 6. Triangle indicates sample off scale.

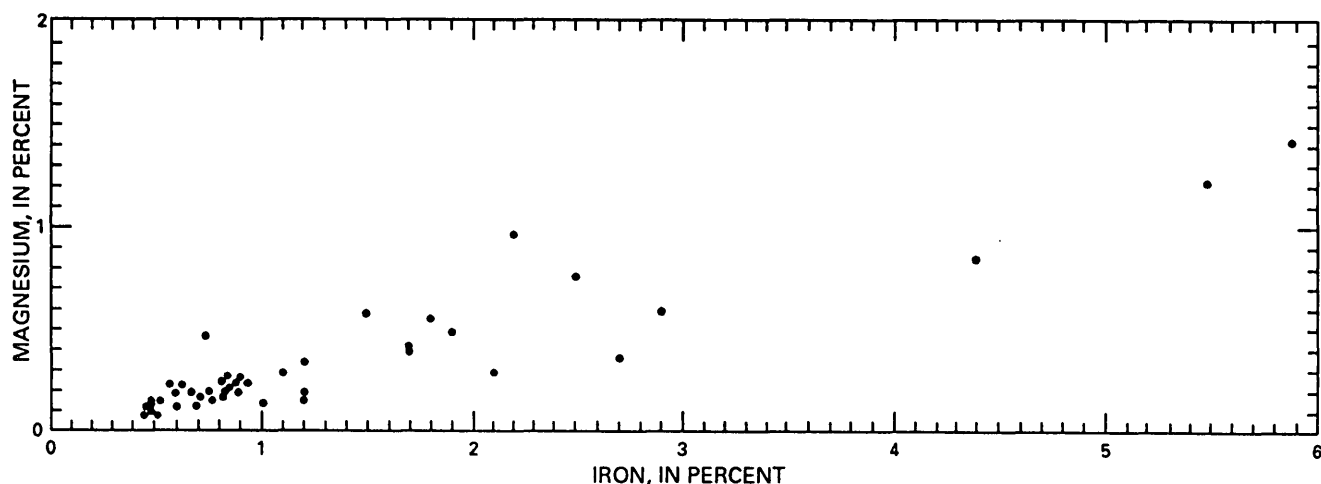


Figure 6. Covariance between magnesium and iron in core 4.

relationship between clay and sandstone in core 7 somewhat differently. Claystones can be differentiated from unmineralized sandstones by their lanthanum content and from ores by their uranium content (as above). Figure 13 shows that the claystones in core 4 contain more lead, which is related to their aluminum content, and that the uranium ores contain variable amounts of lead, unrelated to their uranium content. Thus, the geochemical syngenetic affinity of common lead and not epigenetic radiogenic lead dominates this plot.

STATISTICAL ANALYSIS

When large numbers of samples are used in a study, it is often helpful, and sometimes absolutely necessary, to use statistical analysis of the data. The use of statistical analysis should be done, however, with thought toward the geologic problem and not as just a computer number-crunching exercise.

For this study we had the assistance of Mr. Lincoln Materna, Petroleum Information Corporation, who used an input format modified from that used in a study of the

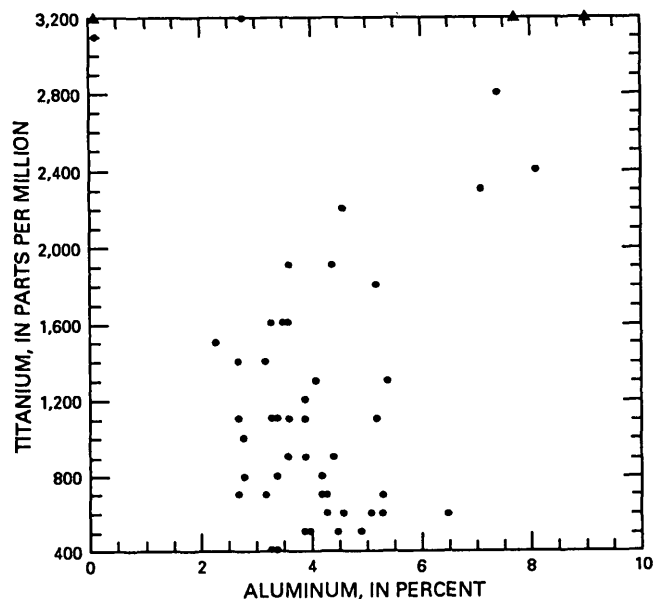


Figure 7. Covariance between aluminum and titanium in core 4. Triangle indicates sample off scale.

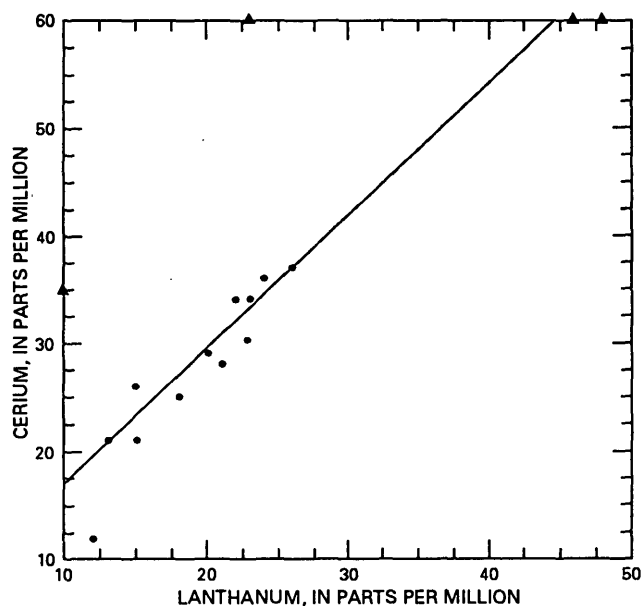


Figure 8. Covariance between cerium and lanthanum in core 1. Triangle indicates sample off scale.

Naval Petroleum Reserve in Alaska (Wilcox and others, 1988). This was done using a program called Geologic Analysis System (Wilcox and others, 1988) and programs modified from Davis (1973).

For this large sample set, a number of groupings and comparisons could be made: ore versus non-ore, claystone versus sandstone, oxidized versus reduced rock, and comparisons of stratigraphic units such as Westwater Canyon Member versus Brushy Basin Member. Because of the small number of samples

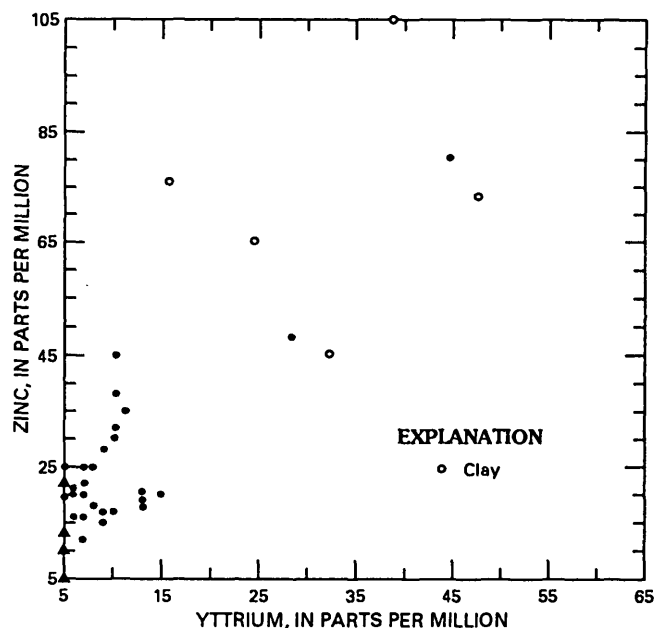


Figure 9. Covariance between zinc and yttrium in core 6. Triangle indicates sample off scale; open circle indicates claystone.

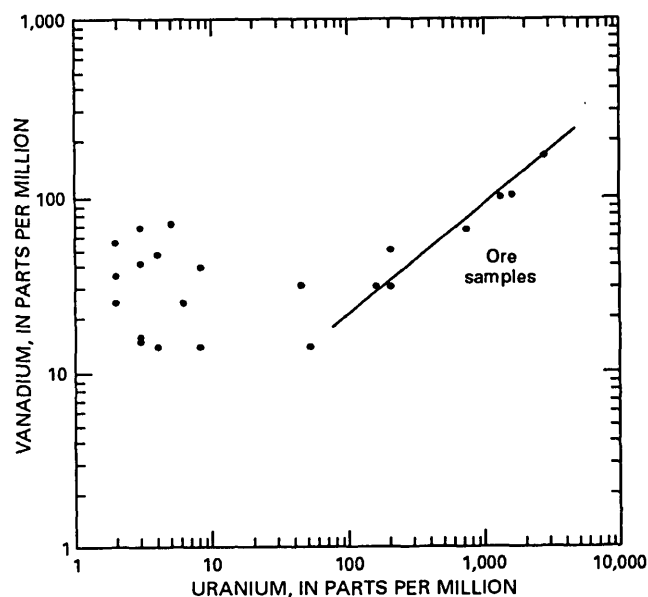


Figure 10. Covariance between uranium and vanadium in core 4. Line delineates ore and non-ore samples.

collected from some units, not all these comparisons can be made in a statistically meaningful way. In particular, after separating the samples into claystones and sandstones by unit, there are not enough sandstone samples in the Dakota Sandstone or the Brushy Basin Member to compare these units to the Westwater Canyon Member in any core. Sandstones of the

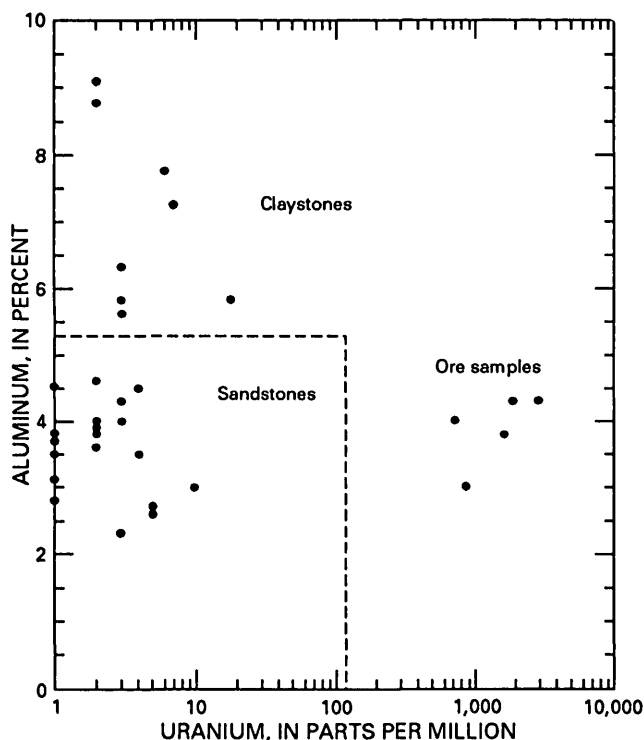


Figure 11. Lack of covariance between aluminum and uranium in core 7.

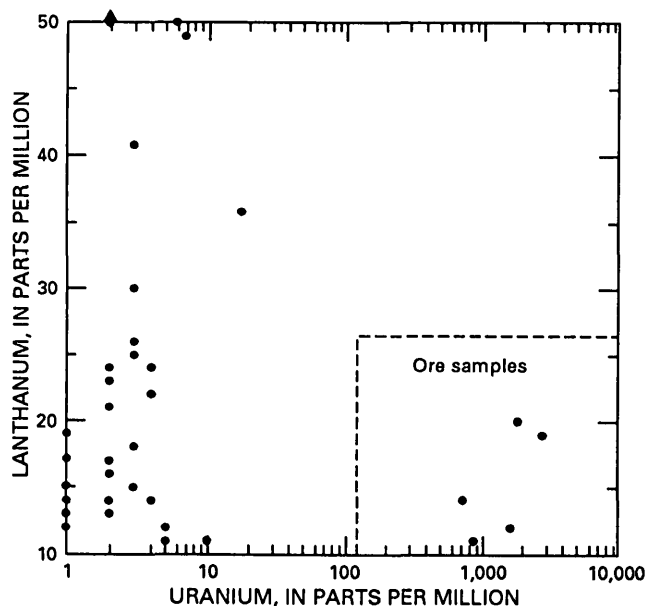


Figure 12. Lack of covariance between lanthanum and uranium in core 7.

Recapture Member can be compared to sandstones of the Westwater Canyon Member in cores 1, 6, and 7.

Initially, all sample data were listed and certain elements were displayed as histograms. Figure 14 shows the distribution of uranium for the samples. The histo-

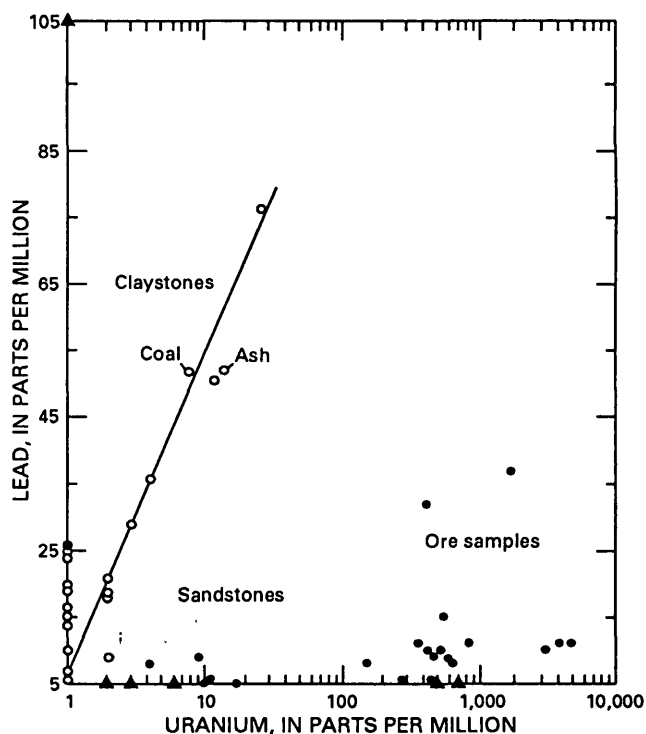


Figure 13. Covariance between lead and uranium in core 4. Triangle indicates sample off scale; solid circle indicates sandstone; open circle indicates claystone except as noted. Uranium by delayed neutron analysis.

gram shows two groups: unmineralized samples contain 2–4 ppm U, and the majority of the mineralized samples contain 512–1,024 ppm U. Based on this distribution, samples containing more than 100 ppm U are classified as ore. The bulk of the samples contain more than the 0.5 ppm U that is usually attributed to average sandstones, and these higher values presumably reflect the closeness to ore deposits and (or) to the epigenetic processes that increase uranium content. The higher uranium values are also due to the presence of clays and iron oxides in these arkosic sandstones because both of these components commonly contain more than 2 ppm U. Thus, we can define two groups of samples—ore and non-ore—based on uranium content.

A histogram of the aluminum content (0.5-percent interval) is shown in figure 15. The nearly symmetrical distribution about 3.5–4.0 percent Al can be used to infer that samples containing more than 5.5 percent Al have a much larger clay component than the normal distribution. Replotting the data at 0.25-percent intervals (fig. 16) establishes this separation at 5.25 percent: those samples containing less than 5.25 percent Al are designated sandstones, those containing 5.25 percent Al or more are claystones.

Four categories of samples were defined based on uranium and aluminum contents:

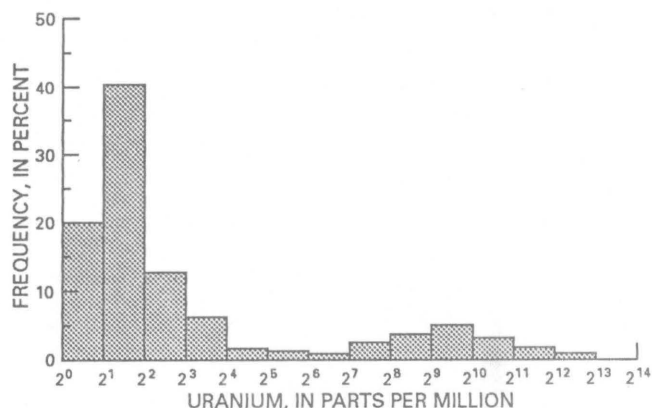


Figure 14. Histogram for uranium content of all core samples in study. Uranium values in powers of two.

I	U \geq 100 ppm, Al $<$ 5.25 percent	Sandstone ore
II	U $<$ 100 ppm, Al $<$ 5.25 percent	Unmineralized sandstone
III	U $<$ 100 ppm, Al \geq 5.25 percent	Unmineralized claystone
IV	U \geq 100 ppm, Al \geq 5.25 percent	Claystone ore

Group IV has only 1 sample in its population, whereas groups I, II, III have 35, 154 and 52 samples, respectively.

The reason for separating the samples into these groups before any statistical analysis is first to define element associations for normal (non-ore) sandstones (group II) and claystones (group III) and then to look for differences in these as compared to sandstone ores

(group I). The claystone sample element associations can be used to separate the clay-enriched elements from the elements associated with ore.

The samples were also separated by cores because core 1 is mainly chemically oxidized (relative to iron), cores 3 and 4 are ore bearing and chemically reduced (relative to iron), cores 5 and 6 are reduced non-ore, and cores 7 and 7a are ore bearing. Based on hand-specimen and microscope analysis, ore samples from core 7 and 7a are somewhat different from those from cores 3 and 4. In cores 7 and 7a, ore occurs as clots at the interstices of coarse to medium pink feldspar and quartz; whereas in cores 3 and 4, uranium is finely dispersed in medium- to fine-grained gray sandstone, similar to the occurrence of most secondary uranium deposits. Core 8 is unmineralized and reduced.

Element Contents of Stratigraphic Units

The chemical abundances of elements from samples in particular stratigraphic units can be compared between units and between cores where there are sufficient numbers of samples. Data for the Westwater Canyon Member in cores 1, 3, 5, 6, and 7 are sufficient to compare them, and data for the Westwater Canyon and Recapture Members in cores 1, 6, and 7 are sufficient to compare them. Mean values for most of the elements are very similar, as judged by the fact that the standard

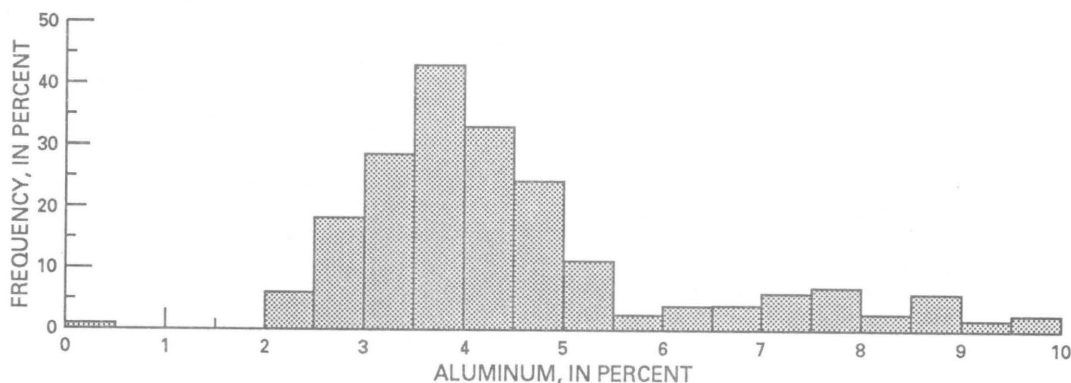


Figure 15. Histogram for aluminum content of all core samples in study. Interval 0.05 percent.

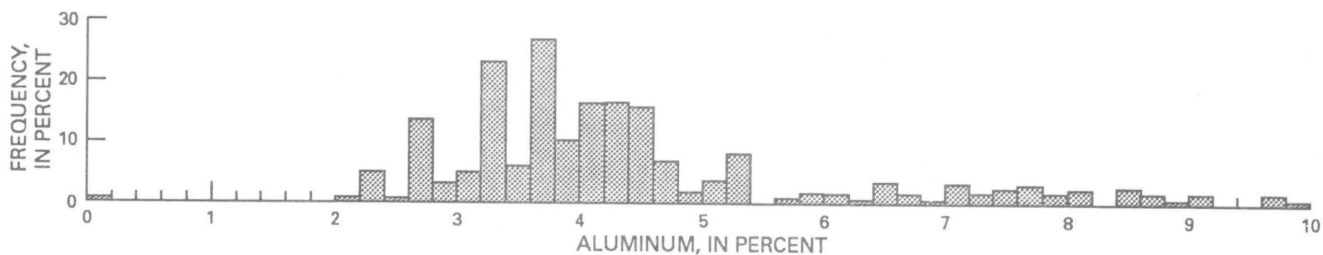


Figure 16. Histogram for aluminum content of all core samples in study. Interval 0.25 percent.

Table 12. Mean values for selected major elements in unmineralized sandstone samples from the Westwater Canyon and Recapture Members of the Morrison Formation

[WWC, Westwater Canyon Member (cores 1, 3, 5, 6, and 7); RC, Recapture Member (cores 1, 6, and 7). Asterisk (*) indicates high value not used; n.t. indicates not tested; pound sign (#) indicates K₂O data is missing and elemental K×1.2 was used for K₂O]

		Fe		Al		Na		K ₂ O		Ca	
		WWC	RC	WWC	RC	WWC	RC	WWC	RC	WWC	RC
Core 1	Mean	1.06	0.58	4.1	3.1	0.79	0.49	2.7	1.7#	0.30	1.6
	σ	0.34	0.25	0.59	0.43	0.17	0.18	0.42	0.67	0.10	0.8
	n	12	8*	12	9	12	10	12	9	12	10
Core 3	Mean	0.79		3.8		1.1		3.3		0.41	
	σ	0.21	n.t.	0.51	n.t.	0.21	n.t.	0.44	n.t.	0.34	n.t.
	n	16*		17		17		17		16*	
Core 5	Mean	1.33		3.8		0.92		3.6#		0.38	
	σ	0.59	n.t.	0.59	n.t.	0.20	n.t.	1.5	n.t.	0.25	n.t.
	n	10*		10*		11		11		10*	
Core 6 ¹	Mean	0.78	0.70	4.0	3.2	1.1	0.65	3.9	2.1	0.25	4.3
	σ	0.38	0.27	0.83	0.59	0.26	0.24	0.79	0.47	0.20	3.9
	n	17*	10	19	10	19	10	18	9	19	10
Core 7	Mean	0.89	0.88	4.1	3.5	1.1	0.78	3.26	2.7	0.46	
	σ	0.7	0.42	0.66	0.55	0.23	0.16	0.70	0.51	0.64	n.t.
	n	10	11	10	11	10	11	9	11	8	

¹Includes four samples from the Poison Canyon Formation.

Table 13. Mean values for selected minor and trace elements in unmineralized sandstone samples from the Westwater Canyon and Recapture Members of the Morrison Formation

[WWC, Westwater Canyon Member (cores 1, 3, 5, 6, and 7); RC, Recapture Member (cores 1, 6, and 7). Asterisk (*) indicates high value omitted; n.t. indicates not tested]

		U		Mn		Ti		La	
		WWC	RC	WWC	RC	WWC	RC	WWC	RC
Core 1	Mean	2.8	1.5	137	189	1,017	1,111	18.9	15.6
	σ	0.88	1.1	41	138	301	496	5.4	6.9
	n	12	10	12	10	12	9	12	10
Core 3	Mean			129		975		16.0	
	σ	n.t.	n.t.	71	n.t.	417	n.t.	3.4	n.t.
	n			15*		16		16	
Core 5	Mean	2.0		134		1,144		16.9	
	σ	0.63	n.t.	104	n.t.	450	n.t.	2.5	n.t.
	n	11		10*		9*		10*	
Core 6	Mean	2.03	1.5	87	613	1,016	1,560	19	16
	σ	0.68	0.51	39	560	544	638	6.1	5.4
	n	18	9*	18	10	18	10	19	10
Core 7	Mean			99		825	1,091	19.5	16.8
	σ	n.t.	n.t.	68	n.t.	341	540	4.8	4.8
	n			8*		8*	9	10	11

deviations of the mean are larger than the differences in the mean value for the two stratigraphic units. Data for selected elements of interest are given in tables 12 and 13. These values are somewhat different from those in the summary in table 14 because table 14 also includes the Brushy Basin sandstones and because tables 12 and 13 exclude anomalous (usually high) values (more than three standard deviations from the mean).

There are few obvious systematic trends in the chemistry of the Westwater Canyon Member in the core fence; however, sodium and potassium contents are

lower in updip oxidized core 1 and manganese contents are lower in cores 6 and 7. Thus, the mineralogical and chemical changes in the <1-μm fraction noted by Whitney and Northrop (1987) are reflected in bulk for potassium but not for iron.

In order to identify significant variations with respect to elemental abundances in each core and stratigraphic unit, the summary data on tables 12 and 13 for samples of the Westwater Canyon and Recapture Members in cores 1, 3, 5, 6, and 7 were treated by the technique summarized in Natrella (1963) and used by

Table 14. Statistically significant differences for elements in core samples from various drill holes and between stratigraphic members of the Morrison Formation [Double asterisk (**) indicates greater than 99 percent significance; asterisk (*) indicates between 99 and 95 percent significance. Core having greatest elemental content is listed first in comparisons]

	Westwater Canyon	Westwater Canyon-Recapture	Recapture
Fe	Cores 5 and 3** Cores 5 and 6** Cores 1 and 3* Cores 1 and 6*	Core 1**	Cores 7 and 1*
Al		Core 1** Core 6** Core 7**	
Na	Cores 3 and 5*	Core 1** Core 6** Core 7**	
K ₂ O	Cores 6 and 1** Cores 6 and 3** Cores 6 and 7* Cores 1 and 5*	Core 1** Core 6** Core 7*	Cores 1 and 6** Cores 1 and 7*
Ca	Cores 3 and 6*		Cores 1 and 6*
Ti		Core 6*	Cores 6 and 1* Cores 6 and 7*
Mn	Cores 6 and 1** Cores 6 and 3**	Core 6*	Cores 6 and 1*
U	Cores 1 and 5** Cores 1 and 6**	Core 1** Core 6**	
La		Cores 7 and 3* Cores 7 and 5* Cores 6 and 3*	

Spirakis and Pierson (1983). Data for the Westwater Canyon and Recapture from each core were tested, as were data for the Westwater Canyon and Recapture in the same core, for all elements on tables 12 and 13. Of the 145 comparisons, 20 are significantly different at the greater than 99-percent confidence level and 17 are significantly different at the greater than 95-percent but less than 99-percent levels (table 14).

Significant differences in major, minor, and trace elements in the sandstones are quite interesting because sandstones generally are so similar, particularly those in cores in a single basin or adjacent formations.

Iron shows the most significant differences. For the Westwater Canyon, both cores 1 and 5 contain more iron than cores 3 and 6; for the Recapture, core 7 contains more iron than core 1. Iron contents are greater in the Westwater Canyon relative to the Recapture in core 1. Thus, the fact that core 1 is oxidized is not reflected in a different iron content.

Aluminum, potassium, and sodium behave as a group and show similar relationships. The Westwater Canyon contains more aluminum, potassium, and sodium than the Recapture in cores 1, 6, and 7 (that is, all those where data were tested). The similar weight percent difference is probably due to a mineral such as feldspar that contains these elements. This chemical difference is reflected in figure 17 (adapted from Steele, 1984), in which the Westwater Canyon plots mainly in the arkose and lithic arkose fields and the Recapture plots mostly in the subarkose field. In addition, cores farther into the basin (cores 6 and 7) contain more potassium than core 1 for both the Westwater Canyon and Recapture, and core 6 contains more potassium than core 3 for the Westwater Canyon.

Similar relationships can be seen for the major element calcium and the minor element manganese, both of which are commonly geochemically associated in the mineral calcite, which in this environment is epigenetic. The Westwater Canyon contains more calcium and manganese in core 3 than core 6, and the Recapture contains more calcium and manganese in core 6 than core 1.

The Westwater Canyon contains more titanium than the Recapture. The Recapture contains more titanium in core 6 than cores 1 and 7.

The Westwater Canyon contains more uranium in core 1 than cores 5 and 6, perhaps because of epigenetic adsorption on iron oxyhydroxides. More significantly, both core 1 and 6 contain more uranium in the Westwater Canyon than in the Recapture; this is not simply due to uranium adsorption on iron oxyhydroxides because although the iron content is different in core 1, it is not significantly different in core 6. Thus, the higher uranium content of the Westwater Canyon relative to the Recapture may be because that unit originally contained more uranium or because uranium-bearing solutions passed through the Westwater Canyon but not the Recapture.

Although iron and iron-titanium oxide minerals are important in petrographic and genetic studies, they only show significant statistical differences for the Westwater Canyon and Recapture in core 1 for iron and in core 6 for titanium. Iron shows a difference in abundance between the Westwater Canyon and Recapture only in core 1, where it is greater in the Westwater Canyon (tables 12, 14). If the two high-iron samples from the Recapture are included in the tabulation, however, there is no difference between these units in core 1. Titanium commonly occurs in the same mineral phase as iron and was also examined statistically. In general, the Recapture has a higher titanium content than the Westwater Canyon. This relationship is most marked for core 6, the only core to show a statistically significant difference.

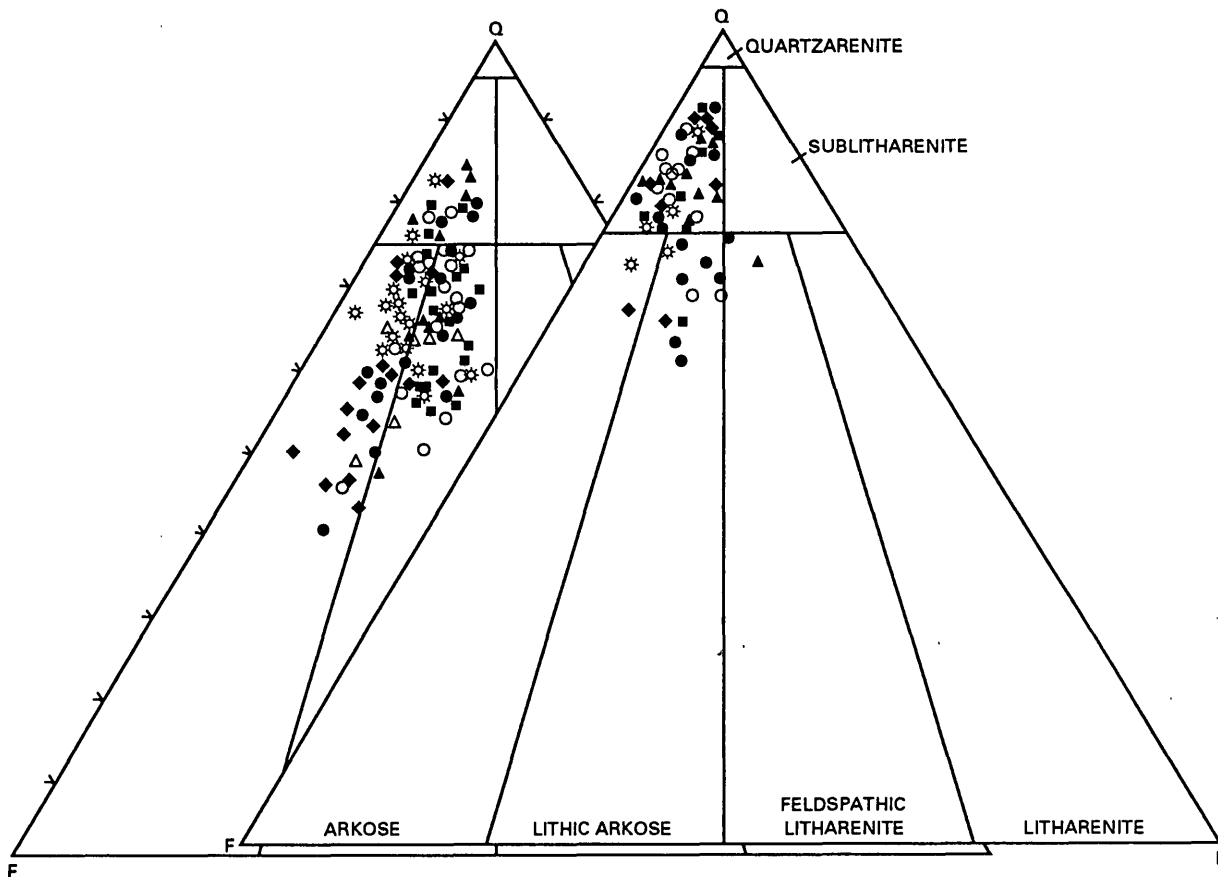


Figure 17. Quartz(Q)-feldspar(F)-lithic fragments (L) ternary diagrams for samples from the Recapture (right triangle) and Westwater Canyon (left triangle) Members of the Morrison Formation. Modified from Steele (1984).

Figure 18 shows that for cores 1 and 7 the samples highest in iron are also highest in titanium; however, these samples are mainly shales. Among the sandstones, the highest iron and titanium contents commonly are in the same sample but not in a regular way. The ore samples are indicated separately on figure 18, but these ores are *not* unique in their iron and titanium contents.

Reynolds and others (1986) showed that magnetic properties of iron minerals change as the result of destruction by chemically active solution or groundwater. Magnetic susceptibility data presented in their report show that the magnetic iron-titanium oxide minerals (magnetite and ilmenite) in the upper part of the Westwater Canyon have been destroyed. These data include petrographic observations and field borehole and laboratory magnetic susceptibility measurements. In cores 1 and 7, the magnetic susceptibility changes near the Westwater Canyon-Recapture boundary (fig. 2). As noted above, the iron content for the Westwater Canyon and Recapture is not statistically different in core 7, whereas it is statistically different in core 1 (if the two high-iron samples are omitted) (tables 12, 14). Thus, it is not clear if stratigraphic or magnetic properties are responsible for any observed iron change. The lack of correlation between total iron content and magnetic

susceptibility may be due to the presence of nonmagnetic iron minerals. In core 6, the magnetic susceptibility changes near the middle of the Westwater Canyon; the mean value for iron is 0.65 ± 0.23 ($n = 6$) in the upper part of the core where iron-titanium oxide minerals have been destroyed, and 0.86 ± 0.34 (or 1.15 ± 0.58) for the lower five (or seven) samples of the Westwater Canyon in the zone where iron-titanium oxide minerals are preserved. Thus, destruction of the iron-titanium oxide minerals may mobilize as much as 30–45 percent of the iron; however, the standard deviation for the mean is sufficiently large to account for most of the difference in these mean values. Titanium values for core 6 show no statistical difference between the magnetic and nonmagnetic parts of the Westwater Canyon.

Element Contents of Ore-Bearing Sandstones

The ore zones encountered in the drilling project were generally thin (a few feet) and of rather low grade. As a result, many samples chosen as ores contain less uranium than “normal” ore. Recall that for statistical purposes samples containing more than 100 ppm U are

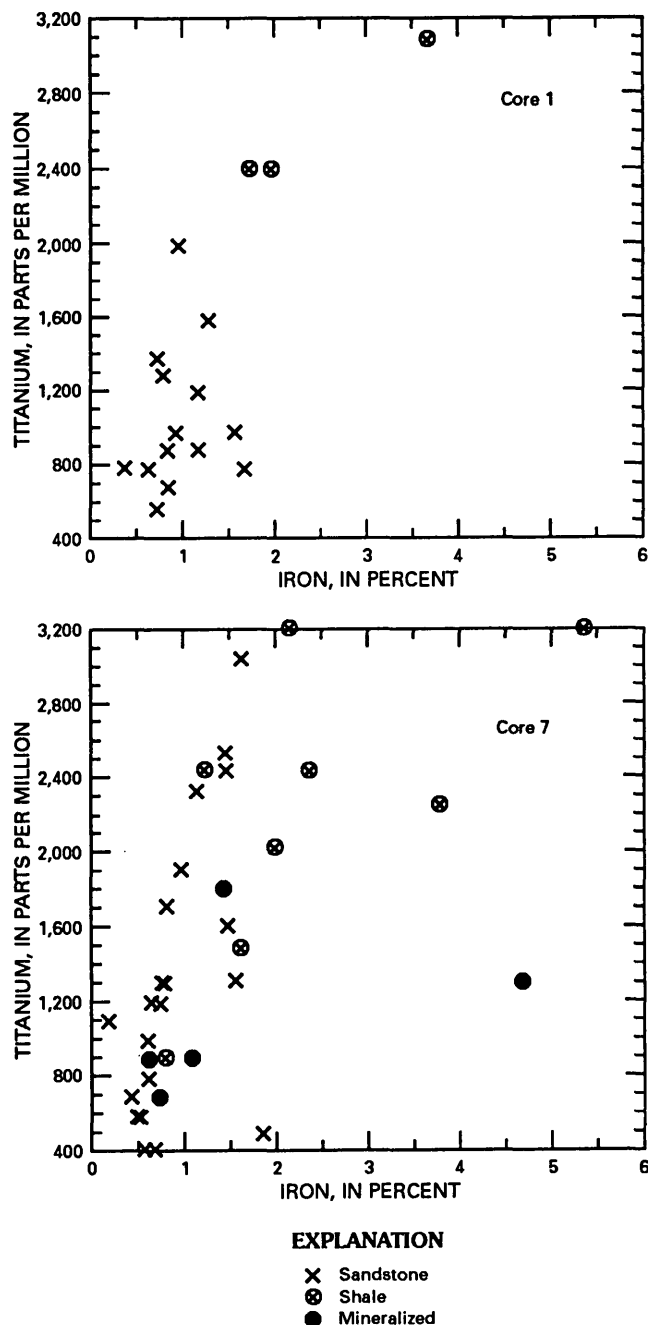


Figure 18. Covariance between iron and titanium in cores 1 and 7 for sandstone, shale, and ore samples.

“ores”. In core 3, three of the seven ore samples, by this criterion, contain less than 202 ppm U. Likewise in core 7a, three of five ore samples contain less than 182 ppm U. On the other hand, in core 4 only two (of 19) samples contain less than 278 ppm U; in core 7, the lowest uranium content of the five ores is 390 ppm.

The 100-ppm division point was chosen because it is 100–200 times the uranium content of average sandstones and also is the “graphical valley” between the

two populations in the histogram (fig. 14). For geochemical (but not economic) studies, this choice should be perfectly adequate. Because of the small number of samples (except core 4), one or two anomalous (high or low) samples can markedly affect the average. Each core and its samples are discussed separately in order to point out these effects. Mean values (table 15) for ore and non-ore sandstones are compared, and then, in light of the small number of ore samples (cores 3, 7, and 7a), mean values for the individual cores are examined.

Overall, the uranium-ore samples contain more uranium, vanadium, and yttrium and perhaps zinc, cerium, and lead than non-ore samples. Mean values of the latter three elements are heavily influenced by the results for cores 7 and 7a. The ores in cores 7 and 7a also contain more iron, which possibly may account for the zinc and lead contents, either adsorbed on iron oxide minerals or in the sulfide minerals.

The ore samples contain less calcium, strontium, and phosphorus and perhaps chromium, manganese, and titanium. The former three elements are all present in calcite and may have been depleted in ores as a result of leaching that mobilized or partially destroyed the ores. Despite the fact that ores are lower in calcium, the calcite-bearing (cemented?) ores in core 4 (1,933, 1,933.5, 1,934 ft) are the highest grade uranium ores. Two generations of calcite may be present in these samples: an early generation that filled porosity and prevented mineralization and a later one that cemented ores and protected them from later mobilization. This example shows that interpretation of mean values should be done with caution and should be related to non-geochemical information, such as petrography, wherever possible.

The chemical element contents of the samples in this study can be compared to other compilations for sandstones, sandstones in New Mexico, and sandstone uranium ores. Because these data were obtained within a 2-year period using the same analytical methods, it is believed that they represent a consistent data set; however, they are not necessarily comparable to recent compilations of data by Spirakis and others (1981), Spirakis and Pierson 1983), and Spirakis and others (1983), who used older data and 6-step emission spectroscopy data. The statistical techniques used in these studies are not the same as those used in other studies; mean and standard deviation values were used to determine that ores are more than one standard deviation from non-ores rather than the statistical t-test.

The analytical methods used for study of the Church Rock deposit (Spirakis and others, 1983), however, are the same as those used in the present study and comparison should be valid. The Church Rock samples and our core samples contain approximately 10 times less vanadium than other Grants mineral-belt deposits. The

Table 15. Summary of chemical data for core samples from Mariano Lake-Lake Valley drilling project
[In parts per million unless indicated as percent (%). n, number of samples. Average sandstone and shale from Turekian and Wedepohl (1961)]

	n	Fe%	Zn	Mg%	Ti	Cr	La	Ce	Al%	Y	P	V	U	Na%	Ba	K%	Ca%	Mn	Sr	Cu	Li	Pb
Ore-bearing sandstones (n=35)																						
Core 3	7	0.88	19	0.17	1,143	7.6	19	25	3.7	7.6	186	79	551	1.2	651	2.5	0.55	165	103	8.0	14	19
4	18	.64	14	.15	867	4.2	20	38	3.5	8.8	91	76	716	1.0	655	2.5	.43	230	86	7.3	7	10
7	5	1.8	109	.4	1,120	6.4	15	32	4.0	43	109	90	1,120	.70	456	2.3	.54	220	147	6.6	16	38
7a	5	1.2	69	.3	860	3.6	12	28	3.8	16	90	91	555	.89	630	2.8	.26	132	65	2.6	9	20
Mean		.93	36	.21	957	5.1	18	34	3.7	14	117	80	674	.98	622	2.5	.44	201	83	6.7	10	18
Std. dev.		.73	75	.14	430	2.3	5	11	.6	25	60	34	547	.25	155	.5	.71	217	20	4.3	6	15
Unmineralized sandstones (n=156)																						
Core 1	21	0.93	26	0.31	1,057	8.1	17	30	3.7	7.6	198	30	2.3	.78	648	1.8	.9	158	150	14	13	14
3	14	.86	22	.24	1,202	6.3	16	22	3.7	7.4	140	26	9.5	.90	687	2.1	1.2	290	143	8.1	12	18
4	33	1.3	27	.28	1,261	6.8	15	27	3.9	7.9	209	33	3.8	.86	619	2.7	.37	148	95	4.8	14	12
5	16	1.4	21	.30	1,369	9.4	17	26	3.9	8.3	174	27	1.8	.83	454	2.7	1.7	294	81	6.0	12	10
6	27	1.0	24	.23	1,385	7.9	18	23	3.7	8.6	207	28	1.9	.95	702	2.7	1.7	293	120	6.8	9	13
7	25	.90	20	.24	1,256	12.6	17	25	3.8	7.2	160	33	2.7	.89	480	2.5	2.2	546	375	4.4	12	16
7a	11	.83	13	.16	818	6.4	16	26	4.0	5.2	117	22	4.6	1.1	703	3.6	.54	172	65	5.6	10	10
8	9	.72	23	.25	1,356	13.4	17	31	3.7	11.3	178	31	4.4	.89	368	2.1	2.7	855	134	8.5	13	8.7
Mean		1.0	23	.26	1,234	8.7	17	26	3.8	7.9	185	30	3.5	.80	596	2.5	1.3	308	155	7.0	12	13
Std. dev.		.81	16	.16	667	6.6	5	12	.7	3.8	96	14	5.8	.33	448	.84	2.4	637	256	6.2	6	7
Average sandstone																						
Mean		.98	16	.07	1,500	35	30	90	2.5	40	170	20	0.5	.33	X0	1.1	3.9	X0	20	X	15	70
Claystones (n=53)																						
Mean		2.7	51	0.81	2,604	15.8	43	69	7.8	29	400	52	5	.69	612	3.3	1.4	374	336	15	25	26
Std. dev.		1.8	24	.38	1,068	9.6	17	28	1.9	13	231	27	5	.37	369	1.4	2.4	543	177	9.5	18	27
Average shale																						
Mean		4.7	95	1.5	4,600	90	9	60	8.0	26	700	130	4	.96	580	2.7	2.2	850	300	45	66	20

Church Rock deposits contain insignificant total amounts of organic carbon and sulfur, similar to ore samples in our cores (and other secondary deposits), but they contain less calcium and manganese and more strontium and barium.

All of the samples in the present study contain less iron, magnesium, and aluminum than other Grants deposits; however, this may be partly because we have defined samples containing more than 5.25 percent Al as claystones, whereas other studies classify all samples as sandstones. It is likely that the regional oxidation (alteration) front (Saucier, 1980) is responsible for mobilization of the uranium and vanadium originally in primary deposits and that the secondary deposits (Church Rock, Crown Point, Nose Rock) are a combination of remnants of primary and roll-type deposits.

No published geochemical data are available for the deposits adjacent to cores 3 and 4 (Crownpoint deposits of Conoco and Mobil) or cores 7 and 7a (Noserock deposit of Phillips), so we cannot compare or verify the geochemistry. It is quite likely, however, that the geochemistry of our ores and that of those deposits are similar.

CLUSTER ANALYSIS

Cluster analysis is a method of classification that places objects (chemical elements in this case) into more or less homogeneous groups; in other words, it is a form of numerical taxonomy. Dendrograms are formed from the individual correlation coefficients from a matrix with all the variables (Davis, 1973).

Figures 19–23 show results of R-mode cluster analysis of the samples. The vertical lines for each element are connected by horizontal lines to other elements that are related by multivariate correlation. The position of a horizontal line gives its correlation coefficient. Element lines that extend to the bottom of the chart have very low correlation with any other elements. A horizontal line shows the 98-percent confidence level (0.02 level) of significance, and all element horizontal lines above this are significant at a higher confidence level. This level is determined by the number of samples. Clustering is by the weighted pair-group method and arithmetic averaging (Davis, 1973).

Claystones

Element associations for the claystone (≥ 5.25 percent Al) non-ore samples (< 100 ppm U) provide a

baseline for the elements that occur in the clay fraction of the sandstone samples.

Samples from cores 4, 5, 6, 7, and 7a (fig. 19) show an association of the light rare-earth elements lanthanum and cerium and commonly yttrium, which behaves like a rare-earth element. These elements probably are in the clay itself, as indicated by their strong association with aluminum in cores 1, 4, 5, and 6. In core 3, aluminum and yttrium are closely related but only at the 0.05 (95 percent) confidence level.

Inspection of the data shows that the claystones all contain 2 ppm or more ppm of the heavy rare-earth element ytterbium, whereas the sandstones contain approximately 1 ppm; however, because of the many values of less than 1 ppm, these elements were not treated statistically. Calcium and manganese are related because manganese can substitute for calcium in the carbonate minerals as has been commented on earlier. In cores 4, 7, and 7a, sodium and barium are clustered, probably because of their occurrence together in feldspar and the lack of barite. Barium and strontium cluster in cores 5 and 6, perhaps as a result of strontium in barite and (or) feldspars.

Iron and titanium are clustered in core 1 (not shown) and are accompanied by aluminum in cores 7 and 7a, whereas titanium and aluminum are clustered alone in core 4. The iron-titanium grouping is expected from sedimentary weathering oxides, and the titanium-aluminum grouping may be due to high abundances in fine-grained sedimentary rocks.

Uranium and lead are closely related in cores 4, 7, and 7a. Presumably the lead is radiogenic lead from uranium; the fine-grained low porosity and permeability of the claystone probably has preserved the original endowment of uranium and its subsequently generated daughter lead.

The transition elements chromium and copper are closely related in cores 4, 5, 6, 7, and 7a, but the other transition elements are not. Lithium and zinc are clustered in cores 5, 6, 7, and 7a; however, there is no obvious geochemical explanation for this grouping.

Some associations that do not occur are interesting. The lack of calcium and magnesium clustering indicates a lack of dolomite. The fact that aluminum does not cluster with potassium, sodium, or calcium rules out the predominance of one clay type. Chlorite contains iron and magnesium, however; cores 7 and 7a may actually show this where iron and aluminum cluster and core 4 may show this where iron and magnesium cluster.

Uranium does not cluster with other elements in cores 1, 3, 5 and 6. Vanadium, which usually occurs with uranium in epigenetic processes, does not cluster with uranium in any of the claystone samples.

Sandstones

In our study of non-ore sandstones, recall first that sandstones are made up mostly of quartz and feldspar and lesser amounts of clays, and second that our goal is to determine the associations of minor and trace minor elements with these major phases.

Cores 1 and 4 (fig. 20) show a strong iron-magnesium cluster perhaps in chlorite. Cores 5, 6, and 8 (fig. 21) show an iron-zinc cluster (transition elements having similar chemistry); these two elements cluster to magnesium, again suggesting chlorite. Iron and lithium cluster to magnesium in cores 7 and 7a, perhaps in a clay. A cluster of magnesium with vanadium in cores 3 and 8 suggests an association of vanadium with chlorite. In all cores, the calcium-manganese association mentioned earlier is present.

Strong aluminum-potassium clustering occurs in cores 3, 4, 5, 6, 7a, 7, and 8; this cluster is joined by sodium in cores 4, 5, 6, 7, and 7a. This clustering is presumably due to potassium feldspar (K) and plagioclase (Na).

The rare-earth elements lanthanum and cerium are strongly clustered in cores 3, 4, 5, 6, 7, and 7a, presumably in the clay fraction, but are not clustered with yttrium or with aluminum (except in core 1). Strontium is clustered with barium in cores 3, 4, 5, and 6, due to residence in barite. In cores 7, 7a, and 8, strontium is clustered with calcium and manganese, due to incorporation or residence in anhydrite and calcite, respectively.

Titanium and vanadium are clustered in cores 3, 5, 6, 7, and 7a, perhaps as a discrete iron-free phase because iron is not clustered with titanium or possibly in a phase where these two adjacent transition elements show their similar chemistry.

Figure 22 shows a summary R-mode cluster for all non-ore sandstones.

Ore-bearing Sandstones

We next attempt to determine how the cluster arrangement of sandstone ores differs from that of nonmineralized sandstones.

Ore and non-ore sandstones both show iron-zinc (core 3) and (or) iron-magnesium (cores 4, 7, 7a) clustering (fig. 23), presumably from chlorite. All cores show calcium-manganese clustering. Ores from core 4 show lanthanum-cerium-yttrium clustering. Core 3 also shows this cluster, but it includes lead. All cores show a strong aluminum-potassium-sodium clustering accompanied by barium.

The unique clustering for the ores is, most prominently, the uranium-vanadium clustering in cores 3 and 7. In core 4, uranium is more related to calcite (Ca, Mn)

and chlorite (Fe, Mg) and vanadium to lithium and phosphorus and also to calcium and manganese. This relationship may be due to calcite, which acted as a pore-filling preservation agent and protected the ore from leaching at a later time (Fishman and Reynolds, 1982; Fishman and others, 1985; Hansley, 1986). It is important to recall, however, that vanadium is unusually low in these ores relative to most Grants ores, and thus the association of vanadium may represent both the ore formation process and partial mobilization.

COMPARISON OF PETROGRAPHIC, CHEMICAL, AND X-RAY DATA

A suite of samples having varying major chemical element compositions was selected for more detailed study. Most of the samples are sandstones, which, based on petrographic methods, are classified as arkose, subarkose, or lithic arkose by using the quartz-feldspar-lithic fragments total normalized to 100 percent (Steele, 1984). Matrix (such as clay) and cement (such as calcite) are not considered in the sandstone petrographic classification. For most samples, the matrix and cement make up less than 20 percent of the rock; however, they may be important in ore-forming or preservation processes. For samples in which matrix and cement make up less than 20 percent, the chemical, X-ray, and petrographic results are in reasonable agreement (see the first 13 samples, table 16).

The samples are listed in table 16 in order of decreasing SiO_2 content. The SiO_2 is contained in quartz and other silicates (mainly feldspars and clay). Based on petrographic examination (Steele, 1984), the quartz modal volume abundance is 45–63 percent. In terms of the rock itself, however, the percent quartz is actually higher because in most rocks 10–20 percent of the point counts are voids (porosity); thus, on a pore-free basis, the quartz content is 50–80 percent.

In general, chemical SiO_2 , X-ray quartz, and petrographic quartz values decrease from the top to bottom of table 16, and Al_2O_3 (chemical), plagioclase plus plagioclase/orthoclase (X-ray), and feldspar plus matrix (optical) values increase.

Several exceptions to this pattern exist. The sample at 2,641 ft in core 6 contains 16 percent silica cement, which is unusual because most samples contain less than 1 percent silica cement. If only optical quartz had been tabulated, the sum would be 48 percent, but, with the additional 16 percent, the quartz is compatible with the SiO_2 . The sample at 2,759 ft in core 6 contains 11.7 percent CaO, which is seen as a major calcite X-ray peak and as 29 percent carbonate (by volume) in petrographic examination. These two samples, by virtue of their silica and carbonate cements, have lower porosity (10 and

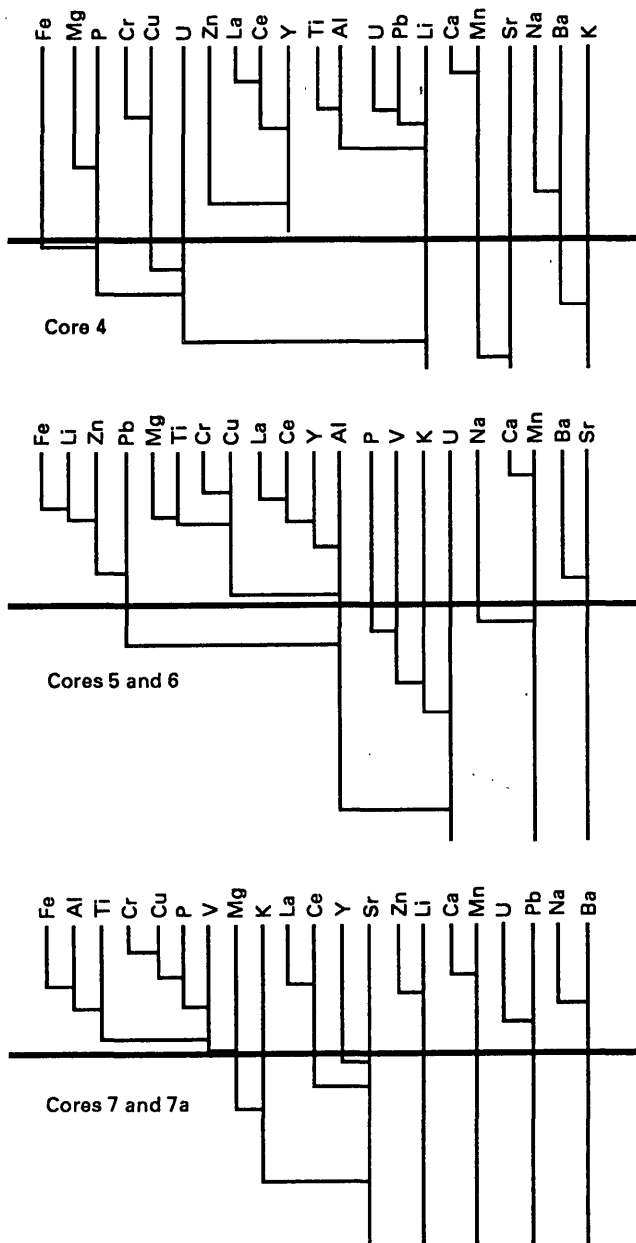


Figure 19. Dendrograms of R-mode cluster analysis for claystones from cores 4, 5 and 6 (combined), and 7 and 7a (combined). Heavy line indicates 98-percent confidence level.

1 percent, respectively) than most samples. The samples at 1,972 ft in core 4 and at 2,574 ft in core 6 contain large amounts of clay matrix (optical), as indicated by high Al_2O_3 and X-ray peaks near $13^\circ 2\theta$ for kaolinite and chlorite. These two samples have lower porosity (9 and 5 percent, respectively) than most sandstones because their primary porosity is partly filled with clay.

This comparison of three methods commonly used to characterize rocks demonstrates that the methods are complementary. Optical methods allow the tabulation of

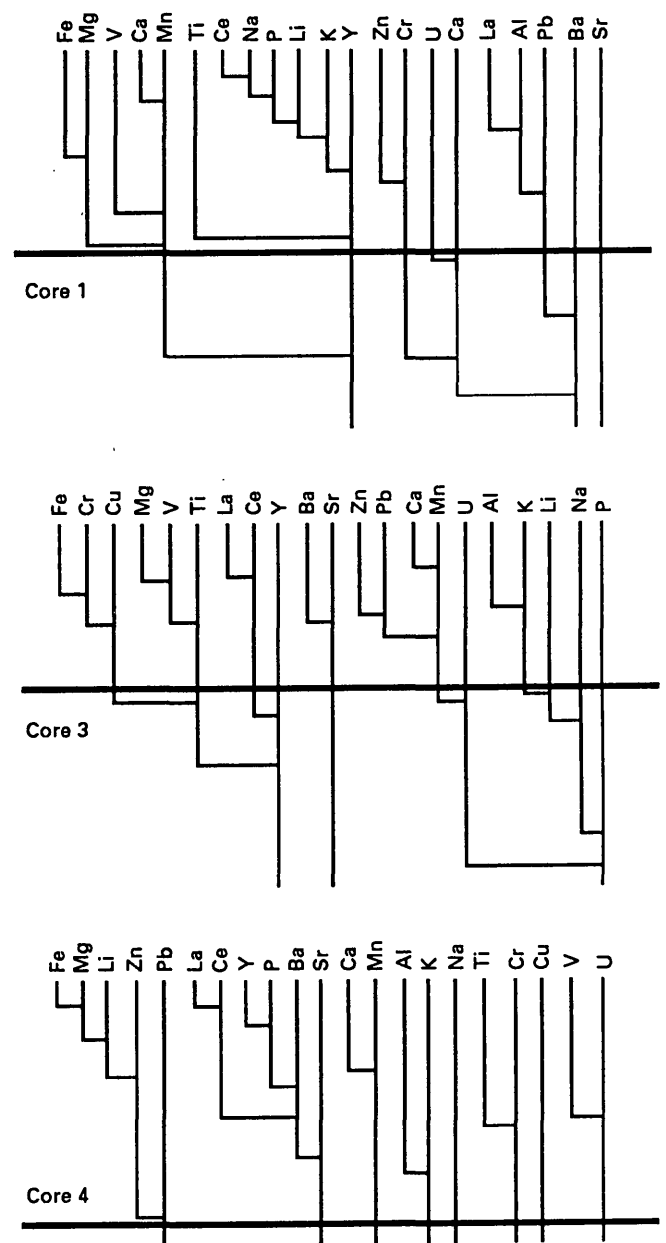


Figure 20. Dendrograms of R-mode cluster analysis for non-ore sandstones from cores 1, 3, and 4. Heavy line indicates 98-percent confidence level.

standard petrographic modal values; X-ray methods show mainly quartz and plagioclase/orthoclase and also indicate clays and carbonates. Chemical analysis, in addition to providing the major element content, indicates the presence of elements that do not form major phases or that can substitute in the major phases.

Statistical comparison of chemical, optical, and X-ray results was made by using linear least-squares regression to determine the correlation coefficient (r) and the slope and intercept of the line (table 17). Comparison of the Al_2O_3 content and the sum of feldspar (table 16) plus matrix shows a value for r of

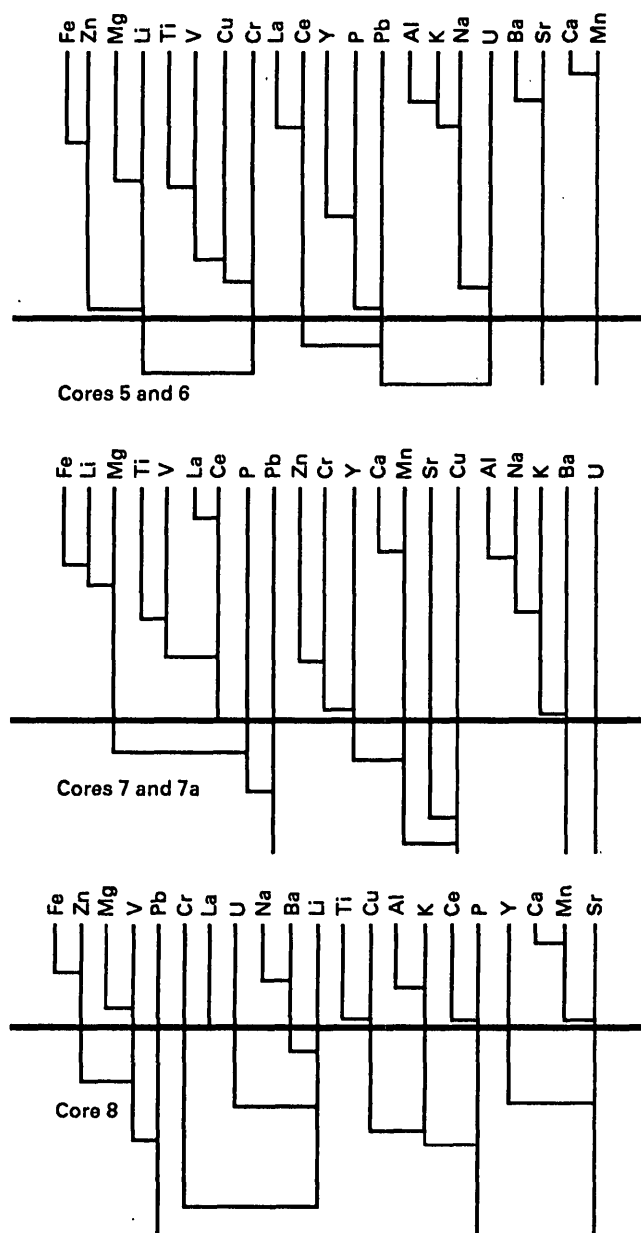


Figure 21. Dendrograms of R-mode cluster analysis for non-ore sandstones from cores 5 and 6 (combined), 7 and 7a (combined), and 8. Heavy line indicates 98-percent confidence level.

0.80 (for 14 samples, 0.64 is significant at the 99-percent level). This result confirms that clays and feldspars are the main minerals that contain Al_2O_3 (see table 16).

Comparison of optical quartz and calculated quartz contents (table 16) also shows good correlation, the r value being 0.69. The calculated quartz was obtained by subtracting the sum of percent voids and percent Al_2O_3 times 2.4 (representing the SiO_2 in clay and feldspar) from the chemical percent SiO_2 (see table 16).

Comparison of the X-ray quartz and optical quartz contents (table 16) gives an r value of 0.59, which is



Figure 22. Dendrograms of R-mode cluster analysis for all non-ore sandstones in study. Heavy line indicates 98-percent confidence level.

significant at the 98-percent confidence level. These data sets and the statistical parameters are shown in table 17. The table also gives results for $n=13$; that is, excluding the sample farthest from the linear least-squares fit. The excluded sample is from core 1 at 782 ft for the first two comparisons and from core 6 at 2,574 ft for the third comparison. Note that for the optical quartz comparison, optical porosity is subtracted from calculated quartz, whereas for the X-ray quartz, comparison is with the calculated quartz because the X-ray method does not detect porosity.

CONCLUSIONS

Geochemical results of the USGS-BIA Mariano Lake-Lake Valley drilling project of the Upper Jurassic Morrison Formation in McKinley County, N. Mex., are reported for about 280 samples from four uranium-mineralized cores, four unmineralized cores, and one stratigraphically equivalent set of outcrop samples. The outcrop samples show the effects of weathering and oxidation in that they contain more silica than the cores or than average sandstones. Samples from unmineralized core 1 show the effects of oxidation, mainly in physical appearance (oxidized iron), but their geochemistry is not greatly different from that of the unoxidized core samples or outcrop samples.

Statistically significant (greater than the 94-percent level) differences in chemical element mean contents exist between the Westwater Canyon and Recapture Members of the Morrison Formation for sodium (enriched in Westwater Canyon in cores 1, 6, and 7), potassium (enriched in Westwater Canyon in cores 1, 6,

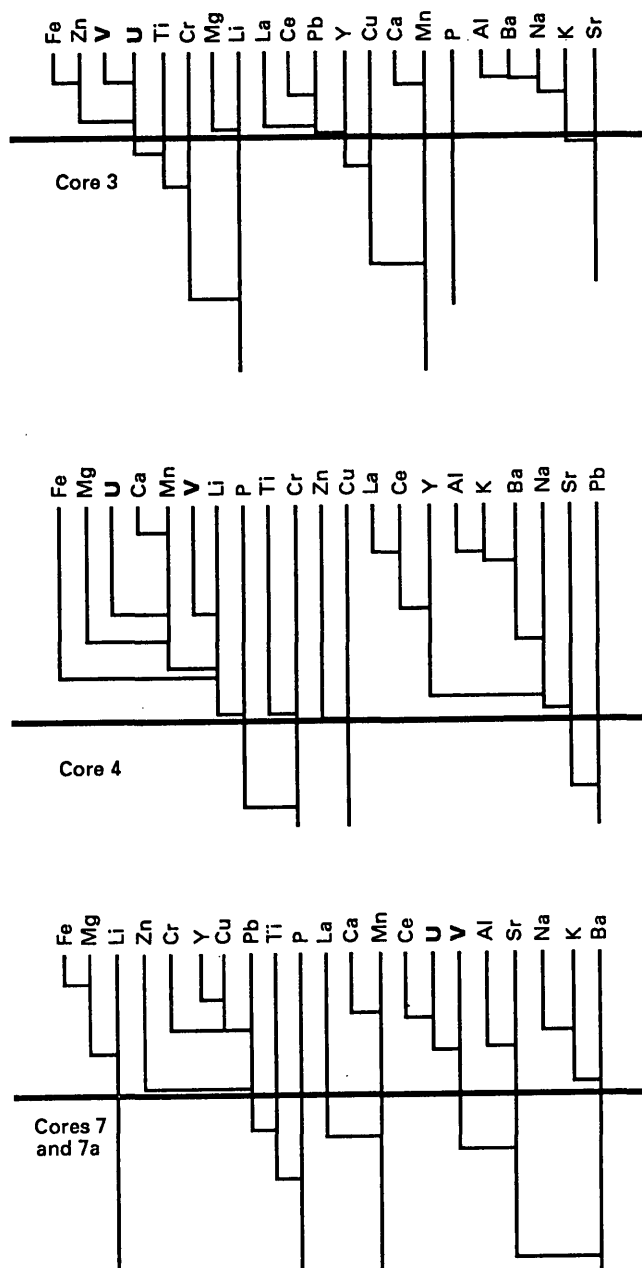


Figure 23. Dendrograms of R-mode cluster analysis for ore-bearing sandstones from cores 3, 4, and 7 and 7a (combined). Heavy line indicates 98-percent confidence level.

and 7), and aluminum (enriched in Westwater Canyon in cores 1, 6, 7). These samples contain more feldspar. Iron is enriched in the Westwater Canyon in cores 1 and 5 relative to cores 3 and 6.

Ore-bearing samples (>100 ppm U) are enriched in U and V and perhaps Y, Pb, and Zn relative to non-ore sandstones and depleted in Ca, Mn, Sr, and P and perhaps Cr and Ti. The small amounts of organic carbon (<0.03 percent) in all ore samples indicate that the ore is secondary or redistributed. Although the ores are

enriched in vanadium relative to non-ores, they contain much less vanadium than most Grants uranium region deposits. This low vanadium content is similar to that of the Church Rock deposit and may be due to the impingement of a regional oxidation front on these deposits (Saucier, 1980).

Downhole plots for each core show geochemical relationships that are related to ores, non-ores, and clays and also to mineral phases such as calcite. R-mode cluster analysis of non-ore sandstones shows a coherence between iron, magnesium, and zinc, which may be a result of iron- and magnesium-bearing clays. The cluster of calcium and manganese is related to carbonate minerals. In most cores, an aluminum-potassium cluster also includes sodium; this cluster presumably represents potassium and sodium feldspars. The rare-earth elements lanthanum and cerium are clustered because of their similar chemical behavior. In several cores, titanium and vanadium are clustered and may occur in a discrete phase or in magnesium-containing clay because they are not associated strongly with iron.

The ore samples show some of the same R-mode clusters as non-ore sandstones: Fe, Zn, and Mg; Ca and Mn; La and Ce; and Al, K, and Na. Uranium and vanadium are clustered alone in two cores, however, and in another core uranium is related to calcium and manganese and to iron and magnesium. The former may represent calcite cement preserving the uranium, whereas the latter may represent adsorption on illite surfaces or on iron oxide minerals.

Special studies show that closely spaced samples (2-cm intervals) contain similar, but not identical, amounts of uranium over a 0.5-m interval in unmineralized cores. Th/U ratios and uranium contents of the unmineralized samples show that small amounts of uranium have been added. Closely spaced samples in ore zones show that uranium, vanadium, and selenium contents vary greatly over centimeter and 10–20 cm distances. Samples near ore zones or in non-ore cores commonly contain as much sulfide (0.1 percent) as samples in ore zones, and thus the presence of sulfide alone is not sufficient to account for ore.

Four samples were size fractionated by sieving to determine the chemical differences between the quartz and feldspar grains and the clay matrix. The fine-grained fraction for two of these samples shows the major element chemistry of a clay; however, the fine-grained fraction for the other two is merely a fine-grained sandstone.

Comparison of results from geochemistry, optical petrography, and X-ray diffraction studies on a set of samples shows acceptable agreement between these methods for determination of SiO₂ (chemical), quartz

Table 16. Comparison of chemical, X-ray and optical data for samples from Mariano Lake-Lake Valley drilling project

[Depth in feet. X-ray fluorescence analysis by J.W. Baker; X-ray diffraction analysis by G. Whitney and B. Brown; optical data from Steele (1984). Leaders (--) indicate not measured]

Core	Depth	X-ray fluorescence (wt. percent)		X-ray diffraction (peak height)			Optical (volume percent)				Calculated (percent)			
		SiO ₂	Al ₂ O ₃	Quartz 26.6 ^a	Plag+orth 28.1 ^a	Plagioclase 27.8 ^a	Quartz	Feldspar	Matrix	Porosity	Opt feld+ matrix	Clay ^b + feldspar	Quartz ^c	Quartz- porosity
6	2,641	91.3	4.8	224	22	27	64 ^d	17	1	10	18	12	80.0	70
1	820	88.9	5.8	240	18	22	--	--	--	19	--	14	75.0	56
6	2,751	87.6	4.4	222	13	35	63	9	3	13	12	11	77.0	64
1	782	86.7	6.9	240	26	34	54	7	0	33	7	17	70.0	37
1	881	84.9	7.4	217	38	31	52	10	9	21	19	18	67.0	46
3	1,957	85.6	6.7	183	46	47	55	7	1	18	8	16	69.5	50
6	2,575	84.2	7.4	156	25	43	46	23	1	16	24	18	66.0	50
3	1,833	83.0	7.6	138	56	53 ^e	43	16	0	17	16	18	75.0	48
1	747	81.8	9.5	158	33	53	--	--	--	--	--	23	59.0	--
6	2,518	83.1	9.0	122	50	48	38	28	1	15	29	22	61.5	46
6	2,532	81.6	8.8	170	44	57	45	22	1	14	23	21	60.5	46
6	2,549	81.0	8.8	183	49	76 ^e	34	28	1	21	29	21	60.0	39
3	1,868	81.1	7.7	198	30	49	42	15	1	17	16	19	62.5	46
4	2,105	79.2	10.0	130	42	110 ^e	--	--	--	--	--	24	55.5	--
4	2,105 ^f	78.7	10.0	140	54	99 ^e	--	--	--	--	--	24	54.5	--
4	1,972	75.2	9.8	165	63	87 ^g	37	18	25	9	43	24	51.5	43
6	2,574	76.5	10.9	116	38	42 ^g	48	18	20	5	38	26	50.5	45
6	2,657.5	72.7	13.2	111	37	29 ^h	--	--	--	--	--	31	41.0	--
6	2,759 ⁱ	68.7	5.6	178	35	64 ⁱ	54	12	0	1	12	13	55.5	54
3	1,796	63.9	16.8	86	8	9 ^e	--	--	--	--	--	40	23.5	--

^aPeak used, in degrees 2θ

^bAl₂O₃×2.4

^cSiO₂-(Al₂O₃×2.4)

^dIncludes 16 percent silica cement.

^eSmall calcite peak at 29.4°2θ 10-20 units.

^fSplits of same sample.

^gPeak at 13°2θ indicating kaolinite/chlorite.

^hBroad peaks at 8°2θ indicating clay.

ⁱCalcite X-ray peak at 29.4 2θ=100, optical carbonate 29 percent, 11.7 percent CaO by XRF.

Table 17. Statistical data comparison for optical, chemical, and X-ray data for samples from Mariano Lake-Lake Valley drilling project

X	Y	n	r	Slope	Intercept
Optical feldspar	$\text{Al}_2\text{O}_3 \times 2.4$	14	0.80	0.33	12
		13	.83	.36	10
Optical quartz	Calculated quartz ^a -porosity	14	.69	.65	18
		13	.84	.77	15
X-ray quartz	Optical quartz	14	.59	.14	23
		13	.67	.18	14
X-ray quartz	Calculated quartz ^a	20	.76	.23	23
		19 ^b	.71	.17	33
		19 ^c	.85	.24	18

^aCalculated quartz = $\text{SiO}_2 - (\text{Al}_2\text{O}_3 \times 2.4)$.

^bExcluding sample 1,796 ft from core 3.

^cExcluding sample 1,833 ft from core 3.

(petrography and X-ray), Al_2O_3 (chemical), plagioclase and feldspar (X-ray and petrography), and silica and carbonate cements (chemical, X-ray, and petrography).

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APPENDIX

Chemical Analyses and Precision

By J.S. Leventhal, C.A. Gent, and
F.E. Lichte

INTRODUCTION

Geochemistry is based on the analytical chemistry of rock samples, which in turn is based on quantitative elemental analysis. In order to make geochemical comparisons, inferences, and correlations, the analytical data must be precise and without interference or bias.

In the present study we are concerned with common rock types ranging from sandstone to shale; some samples have higher than normal uranium and vanadium contents. This appendix gives the data that were used to evaluate the precision of one technique for many elements and several techniques for the same element. The results are representative of the routine analytical work performed during 1980–1981 at facilities of the U.S. Geological Survey in Denver, Colo., using mostly inductively coupled plasma (ICP) and X-ray fluorescence (XRF) techniques.

Comparison of splits and replicates included in the analysis of 256 samples of sandstone and sandstone-related uranium ore from eight drill holes and one outcrop section in McKinley County, N. Mex., shows that inductively coupled plasma (ICP) and X-ray fluorescence (XRF) spectroscopy are compatible for major elements. The ICP data are precise to ± 3 percent or better for Al, Fe, K, P, Ce, La, Sr, V, Y, and Zn; to ± 5 percent or better for Mg, Ca, Na, Ti, and Mn; and to 10 percent or better for Cr, Li, and Mo. The data are less precise for Cu (± 15 percent), Ni (± 12 percent), Pb (± 20 percent), and much less precise for Co and Yb (± 50 percent) because of the occurrence of these elements at concentrations near the detection limit of the analytical method.

The XRF data are precise to ± 3 percent or better for SiO_2 , Al_2O_3 , Fe_2O_3 , MgO , Na_2O , and K_2O . The XRF data are less precise for CaO (± 4 percent) and TiO_2 (± 10 percent).

Comparisons of rare-earth element analysis by ICP, INAA, and radiochemical neutron activation are given. Precision is also given for LOI (loss on ignition), U, Th, Se, As, C, and S.

ANALYTICAL METHODS AND SAMPLING PROCEDURES

Samples were analyzed using ICP (Crock and others, 1983) for seven major (excluding Si), three minor (Ti, Mn, P), and sixteen trace elements (Ba, Ce, Co, Cr,

Cu, La, Li, Nd, Ni, Pb, Sr, V, Y, Yb, Zn, and U > 100 ppm). The elements Mo (4 or 2), Nb (5), Ag (20), Au (20), Be (1), Bi (20), Cd (1), Sc (2), Sn (10), Ga (10), Ge (10), Pr (10), Sm (10), Eu (5), Gd (20), Tb (20), Ho (5), Dy (10), Er (5), and Tm (10) were not detected in most samples at the value shown in parentheses (in parts per million). Molybdenum results for 27 samples are given, however, because of its importance in the genesis of uranium deposits.

About one-third of the samples were analyzed by XRF for major element oxides and TiO_2 , P_2O_5 , and MnO ; LOI at 900 °C was also determined (Taggart and others, 1981).

Most samples were analyzed by delayed neutron (DN) analysis for U and Th (when $\text{Th/U} > 1$) by Dave McKown (Millard, 1976; McKown and Millard, 1987).

One set of samples was analyzed by selective volatilization emission spectroscopy for the chalcophile elements, including As and Se, by Jim Seeley.

Selected samples were analyzed by hydride atomic absorption or XRF for As (Crock and Lichte, 1982a).

Samples were analyzed by radiochemical neutron activation analysis using the method of Wandless (1987) and by instrumental neutron activation analysis (INAA) using the method of Baedeker and McKown (1987).

Selected samples were analyzed by Mark Stanton in laboratories of the USGS for organic carbon, carbonate carbon, and S (Stanton and others, 1983).

Selected samples were re-analyzed for V, Pb, and Ag and for Zr by emission spectroscopy. A suite of non-ore samples was analyzed by INAA, and some of the ores were analyzed by radiochemical neutron activation and column separation-ICP for the rare-earth elements (Crock and Lichte, 1982b).

During the course of the work, 11 pairs of samples were analyzed as blind splits to check on precision of ICP and XRF. In addition, the analysts often ran replicates and, of course, standards (both synthetic and reference standards).

The analytical methods used in this study are also described in an updated summary by Baedeker (1987).

COMPARISON OF METHODS AND PRECISION

Comparison of analytical splits can give important information on the other results. The precision is listed in tables 1 and 2: the element or constituent is in the first column. The mode percent deviation—the percent deviation of the two splits from the mean for the 6th sample (if 11 splits are compared)—is given in the second column. Choosing the mode value tends to minimize the

Table A1. Precision of ICP results based on replicates

Element	Mode percent deviation of the pairs	Numerical deviation from mean (percent or ppm)	Number of pairs
Al	1	0.05 percent	11
Fe	2	.03	11
Mg	5	.01	11
Ca	5	.02	11
Na	5	.05	11
K	2	.05	11
Ti	4	.01	11
P	0	.005	11
Ba	1	10 ppm	11
Ce	3	1	10
Co	50	1	5*
Cr	8	0.5	8*
Cu	15	1	11
Ga	20	2	4*
La	3	1	11
Li	8	.5	11
Mn	5	1.5	11
Mo	10	.5	2*
Ni	12	.5	7*
Pb	20	3	10
Sr	3	3	10
V	2	1	11
Y	3	.5	11
Yb	50	1	5*
Zn	3	1	10

*Remaining pairs below detection limit.

effects of one bad analysis or split. The numerical deviation from the mean (percent or parts per million) is given for that mode analysis in the third column. The poorest replicate analyses were for Yb, Co, Ga, and Pb by ICP. The first three of these elements are near their detection limits, as seen by the fact that less than half the pairs could be compared. To be cautious, we decided that although having both splits below detection (less than 5 ppm, for example) could be considered good agreement, we would not use this type of comparison in these tabulations. Copper and nickel by ICP also have precision of less than 10 percent. The other elements by ICP and those by XRF and other techniques have precision of 10 percent or better.

If elements were analyzed by more than one technique, the results were compared. Figure 1 shows results for Al (ICP) and Al_2O_3 (XRF), figure 2 results for Ca and CaO, figure 3 results for Fe and Fe_2O_3 , and figure 4 results for Ti and TiO_2 . These results all show excellent agreement.

Somewhat less satisfactory agreement is shown by results for K and K_2O (fig. 5); we believe that the K_2O results by XRF are more accurate because of poor sensitivity by the ICP technique for this element. Results for Na and Na_2O (fig. 7) show somewhat more scatter, but we are not certain if one data set is better. Results for

Table A2. Comparison of precision of other analytical results (other methods)

	Mode percent deviation	Numerical deviation from mean ¹	Number of pairs	Method
SiO_2	0.4	0.3	8	X-ray fluorescence
Al_2O_3	1	.1	8	X-ray fluorescence
Fe_2O_3	3	.2	8	X-ray fluorescence
MgO	1	.01	8	X-ray fluorescence
CaO	4	.05	8	X-ray fluorescence
Na_2O	3	.03	8	X-ray fluorescence
K_2O	1	.02	8	X-ray fluorescence
TiO_2	10	.02	8	X-ray fluorescence
LOI	5	.5	8	X-ray fluorescence
U	4	.08	8	Delayed neutron analysis
Th	7	.5	5	Delayed neutron analysis (3 pairs below detection)
Se	5	.05	1	Spectrometry
As	10	.2	1	Spectrometry
Total C	3	.02	11	Combustion
Org C	5	.03	2	Combustion
$\text{CO}_3\text{-C}$	5	.03	2	Combustion
Total S	8	.02	25	Combustion

¹In percent or parts per million; all constituents in percent except U, Th, Se, and As in parts per million.

Mg and MgO (fig. 6) show a secondary trend for several sample sets; we assume that the MgO (XRF) results are better.

The ICP data for U were reported above 50 or 100 ppm and are compared with results obtained using DN analysis (fig. 8). It can be seen that the correspondence is quite good.

Results of comparison between ICP and INAA for Fe, K, Na, Ba, Co, Cr, and Mn are given in table 3. The mode deviation from the mean of 10 percent or less for these comparisons is quite satisfactory for our purpose because many of the samples differ by much more than 10 percent.

Results of comparison between chemical-ion exchange separation ICP analysis (Crock and Lichte, 1982b) and INAA and radiochemical neutron activation analysis for the rare-earth elements are given in table 4. The radiochemical comparison is for ore samples, and the poorer precision indicates some problem in one of the techniques; however, for our purposes this error is not significant.

Table 5 shows analytical results for a sandstone sample that was heavily contaminated with drilling mud. These results do not indicate any major or trace elements that obviously need to be corrected for in less contaminated samples.

Tables A6–A13 show analytical results for all the samples. Analytical splits are shown by an asterisk (*).

Table A3. Comparison of analytical results for ICP analysis and INAA

	Mode percent deviation	Numerical deviation from mean	Number of pairs
Fe	4	0.04 percent	21
K	5	.15	15
Na	4	.04	21
Ba	2	10 ppm	20
Co	10	1	5
Cr	10	1	11
Mn	4	8	16

Table A5. Analysis of drilling mud

[Mixed with about 50 percent sandstone. Major element oxides and LOI (900 °C) in percent; all other results in parts per million]

SiO ₂	79.5	Mn	254
Al ₂ O ₃	6.84	Ba	609
Fe ₂ O ₃	.76	La	14
MgO	.2	Mo	<2
CaO	1.32	Ni	4
Na ₂ O	1.6	Sr	118
K ₂ O	3.05	V	7
TiO ₂	.05	Zn	13
P ₂ O ₅	<.1	Yb	<1
MnO	<.02		
LOI	2.13		
SO ₃	.20		

Table A4. Results of ICP-column rare earth element analysis as compared to INAA and radiochemical activation analysis

Element	Mode percent deviation	Number of pairs
INAA QZ52 (non-ore sandstones)		
La	7	7
Ce	10	7
Nd	7	7
Sm	10	7
Eu	8	7
Gd	10	7
Dy	9	7
Yb	5	6
Lu	10	7
Radiochemical(sandstone ores)		
La	10	2
Ce	10	2
Nd	15	2
Sm	15	2
Eu	25	2
Gd	20	2
Dy	15	2
Tm	15	2
Yb	15	2
Lu	15	2

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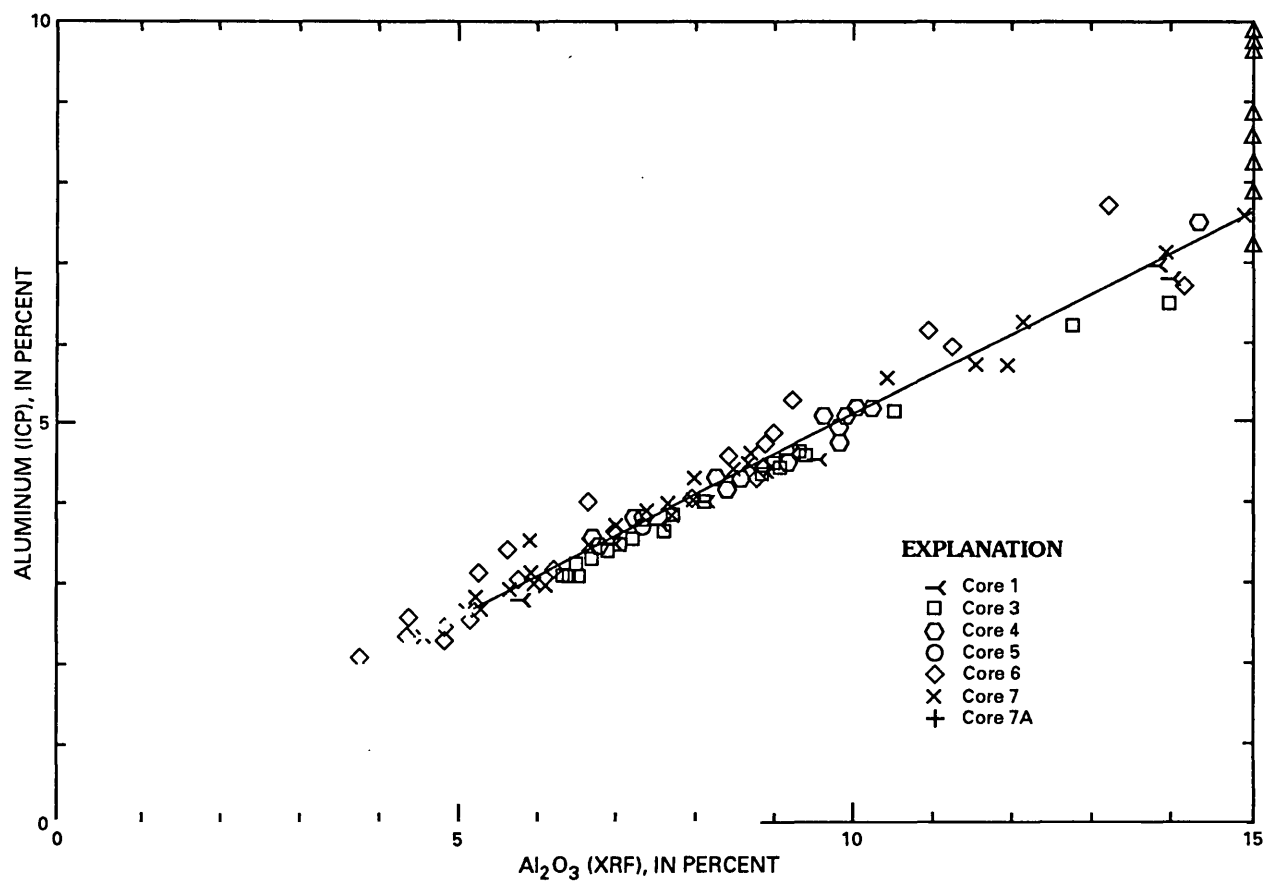


Figure A1. Comparison of analytical results by ICP and XRF for aluminum. Line denotes one-to-one relationship; triangle indicates data point is off scale of plot.

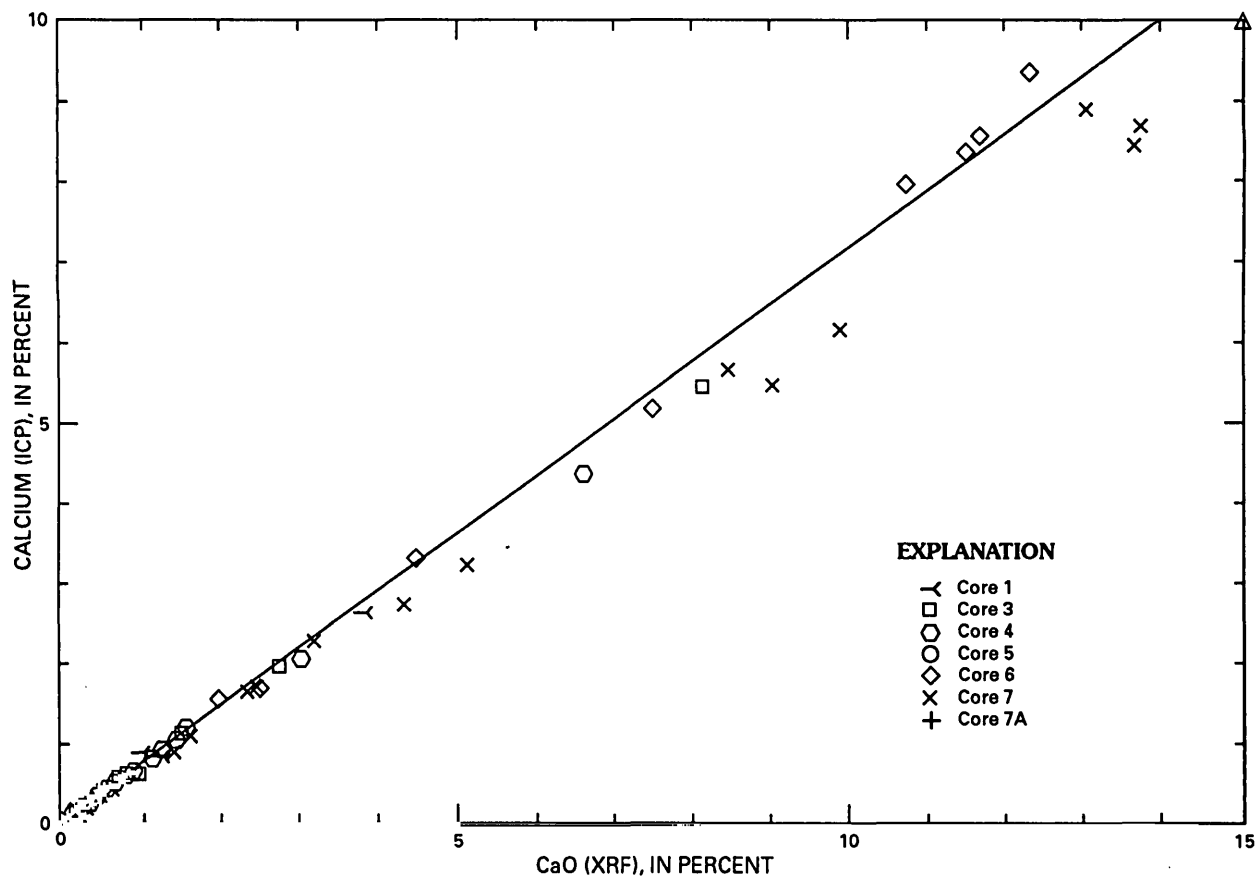


Figure A2. Comparison of analytical results by ICP and XRF for calcium. Line denotes one-to-one relationship; triangle denotes data point is off scale of plot.

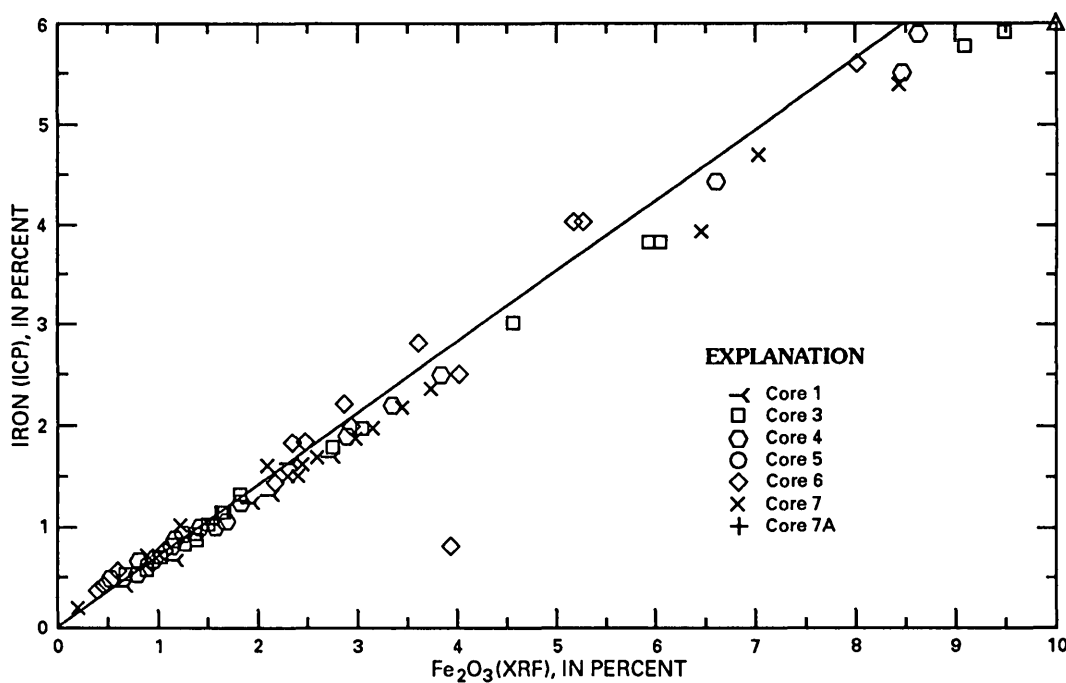


Figure A3. Comparison of analytical results by ICP and XRF for iron. Line denotes one-to-one relationship; triangle indicates data point is off scale of plot.

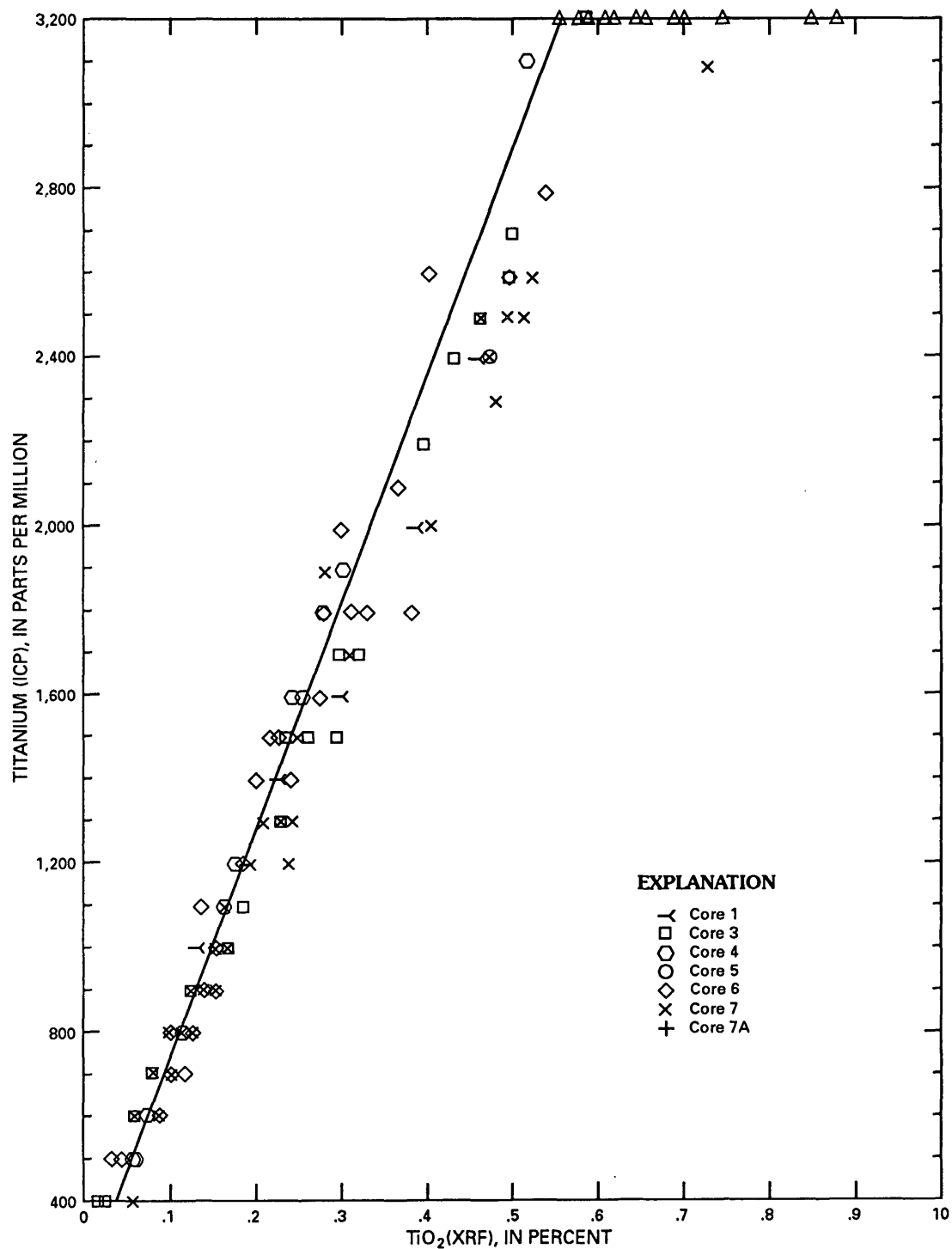


Figure A4. Comparison of analytical results by ICP and XRF for titanium. Line denotes one-to-one relationship; triangle indicates data point is off scale of plot.

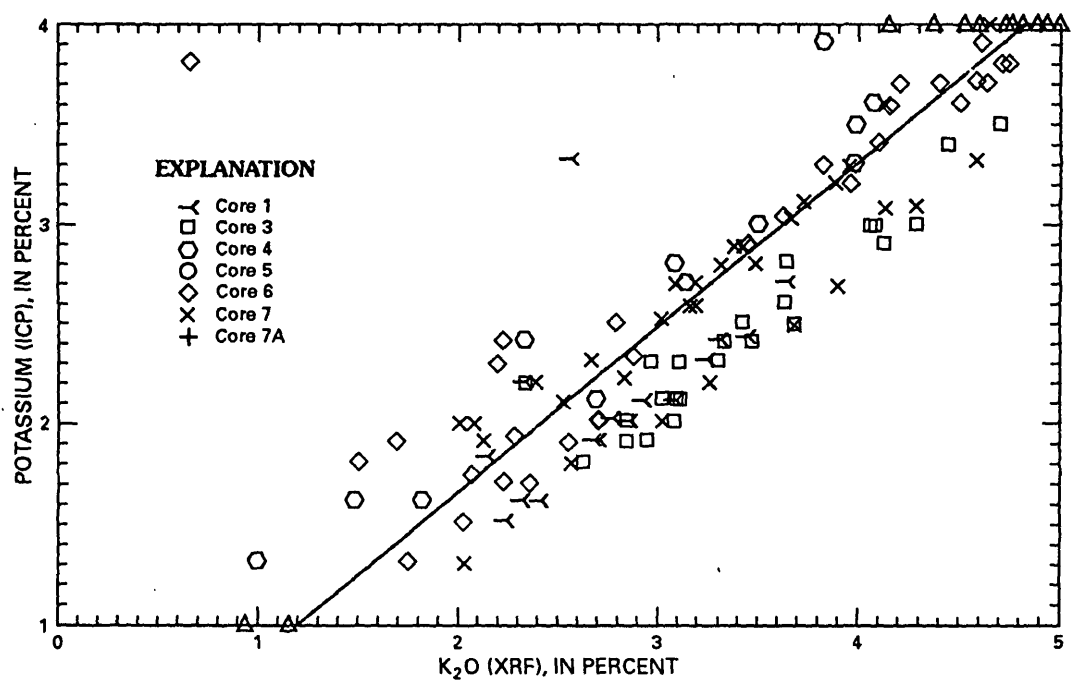


Figure A5. Comparison of analytical results by ICP and XRF for potassium. Line denotes one-to-one relationship; triangle indicates data point is off scale of plot.

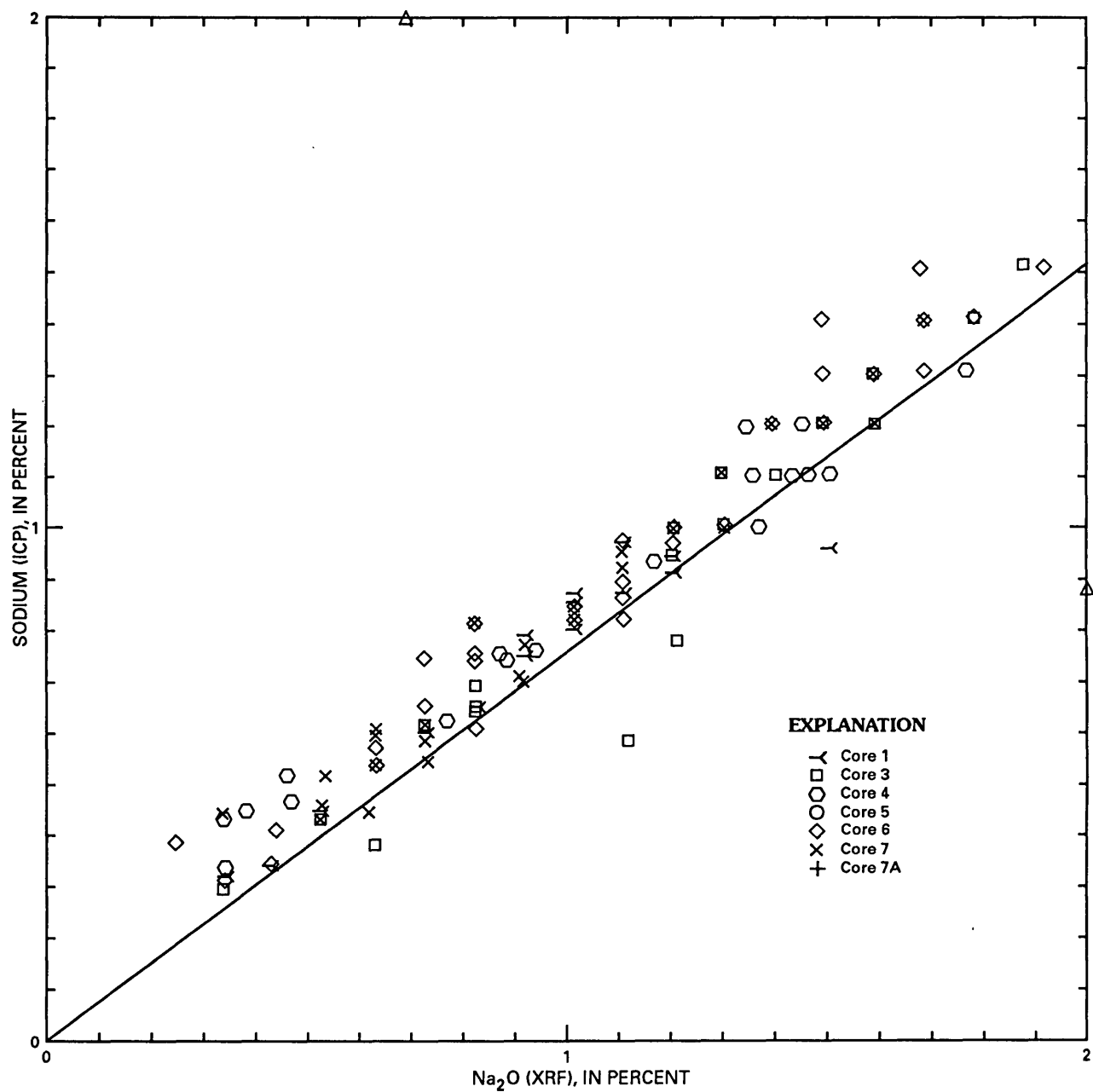


Figure A6. Comparison of analytical results by ICP and XRF for sodium. Line denotes one-to-one relationship; triangle denotes data point is off scale of plot.

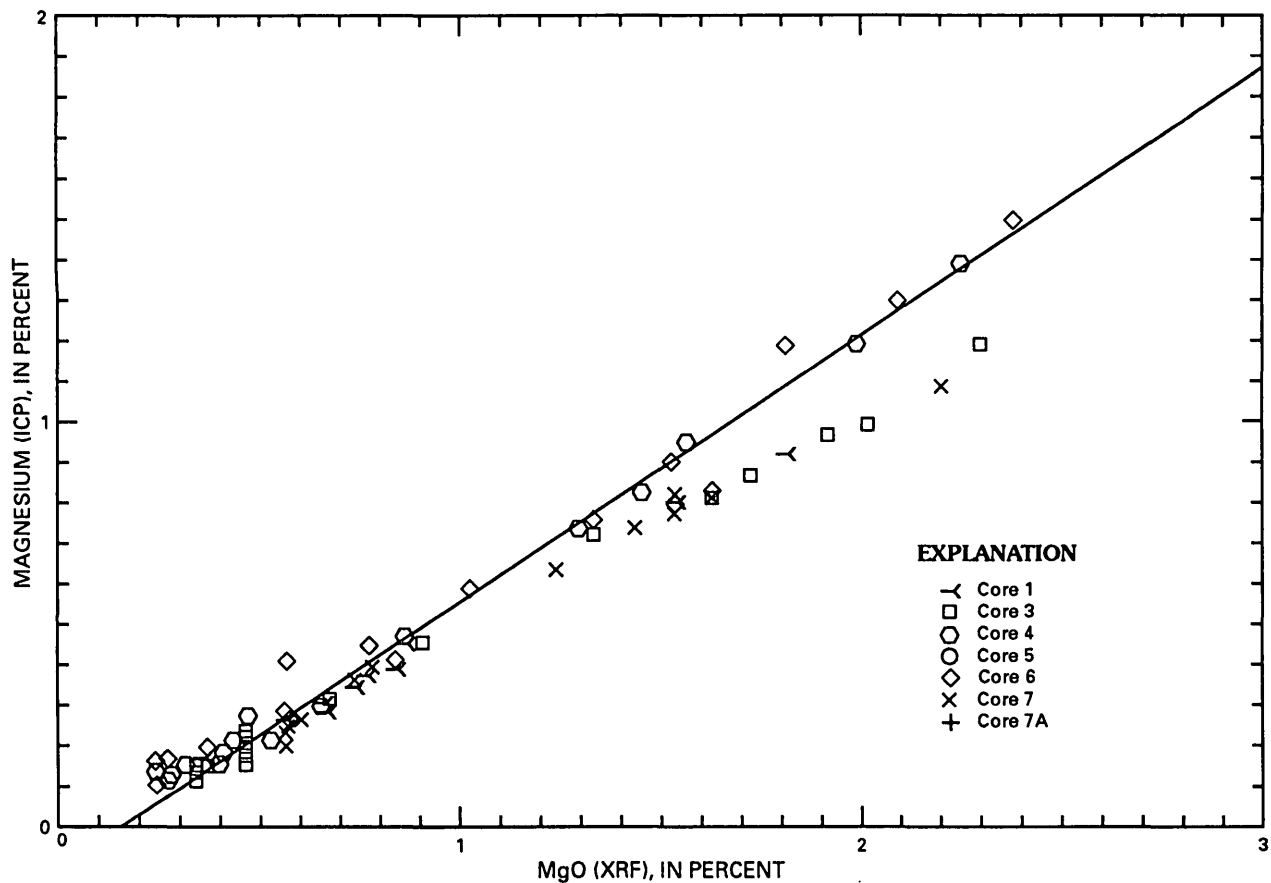


Figure A7. Comparison of analytical results by ICP and XRF for magnesium. Line denotes one-to-one relationship.

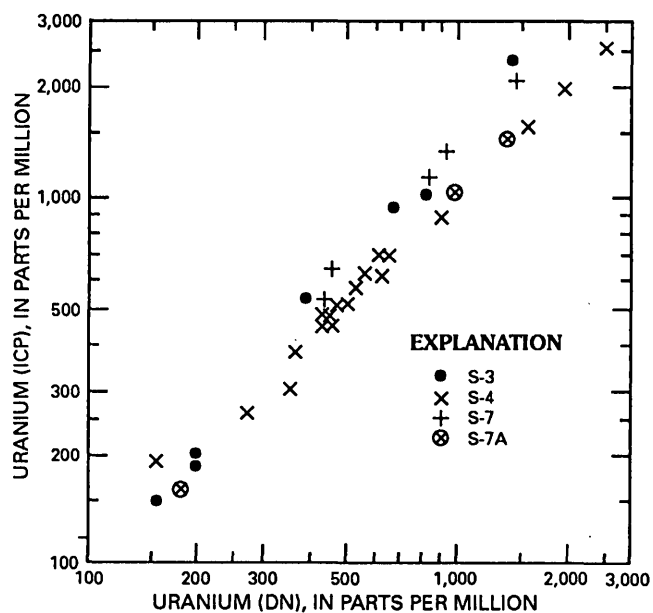


Figure A8. Comparison of analytical results by DN and XRF for uranium (logarithmic scale). Comparison only includes samples containing more than 130 ppm U.

Table A6. Analytical results for samples from Mariano Lake-Lake Valley drilling project core 1

[Asterisk (*) indicates replicate of previous sample; blank in data column indicates sample not run for that element. Core hole locality shown in text figure 1. Elements Dy (10), Gd (20), Mo (4), Cd (2), Co (5), Yb (2), Sc (15), Sm (12), and Ga (20) are not listed because they are at or below limit of detection (given in parentheses)]

Sample depth (feet)	Fe (pct)	Zn (ppm)	Mg (pct)	Ti (ppm)	Cr (ppm)	Nb (ppm)	La (ppm)	Ce (ppm)	Al (pct)	Y (ppm)	P (ppm)	V (ppm)	U - DNA (ppm)	SiO ₂ (pct)	Na (pct)	Ba (ppm)	K (pct)
561	1.70	32	0.33	800	5	6	23	30	4.5	8	200	38	1.4	81.5	0.98	570	2.0
579	0.75	17	0.22	1400	9	7	24	36	4.4	8	200	32	2.0	82.9	0.95	651	2.1
588	1.80	55	0.94	2400	19	14	48	63	7.0	30	300	41	5.8	85.1	0.32	315	1.9
594	1.60	34	0.39	1000	6	6	18	25	4.4	9	200	20	2.4	81.1	0.86	2330	2.1
615	0.95	21	0.36	1000	8	6	15	26	4.7	10	300	22	2.8	82.5	0.93	598	2.3
636	1.20	30	0.34	1200	16	7	21	28	4.5	10	200	50	3.1	81.8	0.90	630	2.1
667	0.82	19	0.25	1300	8	7	26	37	4.1	10	200	25	4.2	82.8	0.90	635	2.0
677	0.88	19	0.21	800	6	5	12	12	3.2	7	200	17	2.4	86.8	0.63	535	1.5
726	1.20	36	0.29	900	9	6	23	34	4.1	8	200	32	3.9	82.3	0.80	787	2.4
740	2.00	49	0.81	2400	15	18	48	68	7.1	36	300	36	2.4	70.3	0.32	446	2.7
747	0.86	35	0.28	700	13	7	22	34	4.7	8	200	28	4.0	81.8	0.86	715	2.4
782	0.81	53	0.21	600	23	5	15	21	3.5	6	200	18	3.0	86.7	0.75	561	1.6
810	1.30	27	0.46	1600	9	7	20	29	4.1	12	200	30	2.0	82.5	0.42	418	1.9
820	0.87	17	0.23	900	5	6	8	35	2.9	5	300	18	2.5	88.9	0.57	428	1.8
851	0.73	<20	0.17	800	8	<4	10	13	2.6	5	100	19	2.6		0.52	310	1.3
861	0.40	14	0.19	800	4	<5	13	21	3.4	6	200	24	1.1	85.2	0.78	484	1.6
881	0.99	26	0.42	2000	11	6	23	130	3.7	13	600	37	2.0	84.9	0.57	638	1.9
900	0.79	<20	0.28	1600	6	<4	20	33	3.5	6	100	39	3.9		0.75	480	0.94
928	2.20	40	0.66	1300	7	<4	15	25	3.3	10	100	65	1.1		0.32	320	1.4
948	0.24	<20	0.26	300	2	<4	12	15	2.9	4	70	42	0.5		0.28	330	0.65
972	0.32	<20	0.25	900	4	<4	8	15	2.6	3	90	29	0.5		0.32	1400	1.3
995	0.59	<20	0.30	1200	5	<4	10	15	2.6	4	100	27	0.6		0.36	400	0.93
1000	3.60	50	1.20	3100	28	10	30	53	6.8	18	500	45	2.4		0.52	310	2.6
1049	0.58	<20	0.37	1100	6	<4	15	19	3.3	7	200	22	0.7		0.46	430	1.5

Sample depth (feet)	Ca (pct)	Mn (ppm)	Sr (ppm)	Fe ₂ O ₃ (pct)	TiO ₂ (pct)	LOI (pct)	Al ₂ O ₃ (pct)	MgO (pct)	K ₂ O (pct)	CaO (pct)	Cu (ppm)	Li (ppm)	Nd (ppm)	Ni (ppm)	Na ₂ O (pct)	Pb (ppm)	Th - DNA (ppm)	Co (ppm)
561	0.23	213	115	2.72	0.12	2.15	8.97	0.59	2.77	0.32	12	18		<2	1.2	20	4	2
579	0.39	165	130	1.12	0.24	2.05	8.90	0.40	2.98	0.57	10	13		4	1.5	19	4	<2
588	2.6	787	294	2.78	0.45	9.58	14.0	1.80	2.62	3.87	20	14		11	0.3	26	13	6
594	0.28	161	149	2.31	0.15	2.32	8.73	0.71	2.86	0.38	9	17		9	1.0	22	7	4
615	0.27	153	114	1.43	0.17	2.35	9.27	0.68	3.18	0.39	6	13	12	4	1.1	18	4	3
636	0.30	177	109	1.90	0.20	2.29	8.90	0.62	3.00	0.43	35	15	12	4	1.2	16	5	2
667	0.48	135	115	1.31	0.22	2.38	8.13	0.40	2.69	0.70	34	12	17	4	1.1	12	5	2
677	0.21	76	94	1.12	0.12	1.84	6.24	0.40	2.17	0.29	32	9	10	4	0.8	14	<3	<2
726	0.47	151	127	1.80	0.14	2.08	8.18	0.53	3.26	0.64	56	15		<2	1.0	17	<3	2
740	0.61	114	175	3.12	0.45	6.18	13.8	1.50	3.61	0.88	22	14	33	7	0.4	20	14	5
747	0.23	98	114	1.26	0.11	2.21	9.53	0.50	3.39	0.32	19	13		3	1.1	18	6	3
782	0.19	91	94	1.19	0.08	1.70	6.86	0.40	2.34	0.25	6	13		4	0.9	14	<3	2
810	0.30	130	122	2.10	0.30	2.81	8.00	0.81	2.64	0.43	8	14	13	4	0.5	12	6	3
820	0.20	96	91	1.39	0.15	1.58	5.82	0.40	2.07	0.29	6	12	<10	3	0.7	14	3	2
851	0.22	77	88								4	11	14	3		9		1
861	1.00	206	169	0.64	0.13	2.44	6.71	0.40	2.25	1.52	5	9		2	0.9	14	3	<2
881	0.26	105	170	1.61	0.38	2.41	7.36	0.78	2.52	0.36	12	33	19	2	0.7	13	7	3
900	0.29	65	180								7	9	10	3		12	<3	1
928	5.5	500	190								10	17	14	6		8	4	5
948	3.2	210	270								6	8	7	4		7	3	<1
972	0.56	82	240								6	6	<4	<2		11	3	1
995	0.33	87	170								7	9	6	4		9	3	2
1000	1.2	270	450								25	24	21	15		24	9	8
1049	3.3	290	290								6	7	13	4		13	5	2

Table A7. Analytical results for samples from Mariano Lake-Lake Valley drilling project core 3

[Asterisk (*) indicates replicate of previous sample; blank in data column indicates sample not run for that element. Core hole locality shown in text figure 1. Elements Dy (10), Gd (20), Sm (12), Mo (4), Cd (2), Sc (15), Ga (20) are not listed because they are at or below limit of detection (given in parentheses)]

Sample depth (feet)	Fe (pct)	Zn (ppm)	Mg (pct)	Ti (ppm)	Cr (ppm)	Nb (ppm)	La (ppm)	Ce (ppm)	Al (pct)	Y (ppm)	P (ppm)	V (ppm)	U - DNA (ppm)	SiO ₂ (pct)	Na (pct)	Ba (ppm)	K (pct)	Ca (pct)	Mn (ppm)
1648	2.0	60	0.82	2700	17	16	44	67	7.5	46	1000	42	3	67.8	0.65	556	2.5	0.75	151
1713	3.8	58	0.87	2500	18	17	33	52	6.7	29	500	48	4	67.0	0.60	197	3.0	0.50	200
1783	0.86	48	0.18	1100	6	6	16	23	3.8	10	300	14	52	70.9	1.1	637	2.3	5.4	1690
1784	5.8	93	1.0	2200	12	12	27	36	6.4	21	700	40	8	67.5	0.69	385	2.0	0.45	371
1796	3.0	48	0.97	3300	17	23	68	94	8.5	51	500	72	5	63.9	0.37	410	3.5	0.66	238
1798	0.82	21	0.16	900	4	8	11	17	3.7	7	100	14	8	66.1	1.1	580	2.0	0.16	71
1808	0.67	15	0.16	700	8	5	20	30	4.7	7	100	31	199	81.2	1.5	807	3.0	0.14	58
1833	0.55	14	0.13	400	3	6	13	19	3.7	7	200	14	4	83.0	1.1	637	2.3	1.1	290
1855	0.54	14	0.13	400	3	5	11	15	3.2	5	100	15	3	86.5	1.0	513	1.9	0.45	129
1863	0.65	14	0.14	600	7	5	18	25	4.8	8	200	66	390	82.5	1.4	771	3.0	0.45	130
1864	1.1	26	0.22	900	8	6	12	20	3.6	6	200	100	670	83.7	1.1	564	2.3	0.14	90
1866	1.3	27	0.18	2400	11	18	26	44	3.8	10	200	170	1410	82.3	1.1	630	2.1	0.83	274
1868	0.98	22	0.18	1300	7	7	20	28	3.9	7	200	102	830	81.1	1.2	646	2.4	0.18	94
1874	0.87	19	0.20	700	4	7	13	20	4.1	8	300	31	44	84.1	1.2	594	2.5	0.13	62
1882	0.88	18	0.17	1500	6	8	16	28	3.5	7	200	51	201	85.8	1.0	552	2.1	0.22	105
1892	0.55	13	0.12	800	6	4	18	25	3.7	8	200	31	156	79.9	1.1	590	2.4	1.9	404
1905	0.63	12	0.13	800	4	5	21	27	4.5	8	200	16	3	80.8	1.3	679	2.9	0.92	196
1916	0.85	21	0.18	1500	7	6	17	23	3.2	6	200	25	6	86.8	1.0	440	1.9	0.22	100
1939	3.8	51	0.73	2600	13	11	45	64	5.3	20	400	56	2	72.1	0.3	452	2.8	1.0	391
1943	1.8	31	0.47	1700	13	7	20	28	4.7	10	<100	36	2	80.1	0.63	471	2.6	0.18	118
1957	0.85	16	0.17	1000	4	5	17	20	3.4	6	200	25	2	85.6	0.94	431	2.1	0.28	110
2005	0.84	18	0.21	1500	10	7	14	21	3.2	7	200	25	2	86.1	0.78	414	2.1	0.20	104
2016	1.0	22	0.33	1700	9	6	18	28	3.6	8	200	24	1	81.9	0.59	504	1.8	0.38	132
2072	0.88	20	0.29	1800	6	<4	18	31	4.1	7	200	36	1	1.0	720	1.8	0.60	130	
2076	5.9	98	1.2	3200	18	17	66	91	8.1	29	700	68	3	58.0	0.41	265	3.4	0.96	282
2123	0.95	30	0.49	1900	9	5	20	26	3.6	9	200	52	4	0.48	1700	1.7	4.6	680	
2167	0.76	<20	0.24	1500	6	<4	13	16	2.4	6	100	30	1	0.45	1300	1.3	2.8	250	

Sample depth (feet)	Sr (ppm)	Fe ₂ O ₃ (pct)	TiO ₂ (pct)	LOI (pct)	Al ₂ O ₃ (pct)	MgO (pct)	K ₂ O (pct)	CaO (pct)	Cu (ppm)	Li (ppm)	Nd (ppm)	Yb (ppm)	Ni (ppm)	Na ₂ O (pct)	U - ICP (ppm)	Pb (ppm)	Th - DNA (ppm)	Co (ppm)
1643	531	3.02	0.49	6.59	15.3	1.6	3.37	1.11	21	20	39	4	5	0.8		23	16	3
1713	379	6.10	0.45	6.31	13.9	1.7	4.25	0.74	21	17	28	3	12	0.7		27	13	7
1783	132	1.29	0.20	6.95	7.5	0.40	2.91	8.22	9	15	<10	1	<2	1.3		62		3
1784	184	9.17	0.39	4.23	12.7	2.0	2.78	0.64	11	52	25	3	9	0.8		34	8	8
1796	308	4.58	0.60	6.19	16.8	1.9	4.68	0.96	16	18	49	5	8	0.6		187	15	7
1798	92	0.90	0.14	0.98	7.30	0.30	3.02	0.14	8	15	<10	<1	3	1.3		21	<4	<2
1808	123	0.96	0.10	1.26	9.29	0.30	4.02	0.17	9	15	12	<1	13	1.9	200	22		2
1833	108	0.81	0.04	1.88	7.57	0.20	3.25	1.62	5	13	<10	<1	4	1.4		15	<3	<2
1855	78	0.73	0.05	1.11	6.40	0.20	2.89	0.65	7	11	<10	<1	<2	1.2		16	3	<2
1863	117	0.93	0.08	1.47	9.11	0.30	4.05	0.63	9	14	16	<1	4	1.8	530	16		2
1864	86	1.59	0.14	1.21	7.09	0.40	3.05	0.19	6	18	<10	<1	7	1.3	910	13		2
1866	110	1.80	0.42	1.86	7.26	0.30	3.07	1.22	13	14	14	2	4	1.4	2300	35		10
1868	105	1.48	0.24	1.85	7.74	0.30	3.41	0.26	4	15	10	<1	4	1.6	1000	13		<2
1874	88	1.23	0.10	1.53	8.12	0.40	3.63	0.16	5	14	10	1	2	1.5		16	<9	2
1882	82	1.29	0.27	1.40	6.91	0.30	3.05	0.31	5	13	13	<1	<2	1.3	190	18		2
1892	97	0.77	0.09	2.99	7.06	0.30	3.28	2.84	10	10	15	<1	2	1.3	150	16		<2
1905	94	0.92	0.13	1.45	9.02	0.30	4.08	1.38	4	13	11	<1	5	1.6		15	5	2
1916	62	1.27	0.30	1.05	6.35	0.30	2.79	0.30	9	14	12	<1	3	1.2		21	6	2
1939	161	5.96	0.48	4.18	10.5	1.3	3.60	1.52	14	19	40	2	7	0.3		20	11	4
1943	116	2.75	0.32	2.24	9.35	0.86	3.58	0.23	16	14	16	1	4	0.8		20	8	3
1957	56	1.33	0.18	1.21	6.75	0.30	2.99	0.39	8	13	14	<1	2	1.2		13	4	<2
2005	77	1.23	0.25	1.03	6.48	0.40	2.98	0.28	13	10	13	1	6	1.2		16	4	3
2016	150	1.55	0.30	2.09	7.12	0.61	2.56	0.53	6	10	12	<1	5	1.1		14	6	<2
2072	190								9	9	18	<1	<2		<100	11	3	2
2076	350	9.56	0.57	7.19	16.3	2.3	4.42	1.41	52	24	50	3	11	0.5		42	16	8
2123	240								10	12	19	1	4		<100	10	7	3
2167	470								5	6	7	<1	2		<100	9	4	2

Table A8. Analytical results for samples from Mariano Lake-Lake Valley drilling project core 4

[Asterisk (*) indicates replicate of previous sample; blank in data column indicates sample not run for that element. Core hole locality shown in text figure 1. Elements Dy (10), Gd (20), Sm (12), Mo (4), Cd (2), Sc (15), and Ga (20) are not listed because they are at or below limit of detection (given in parentheses)]

Sample depth (feet)	Fe (pct)	Zn (ppm)	Mg (pct)	Ti (ppm)	Cr (ppm)	Nb (ppm)	La (ppm)	Ce (ppm)	Al (pct)	Y (ppm)	P (ppm)	V (ppm)	U - DNA (ppm)	SiO ₂ (pct)	Na (pct)	Ba (ppm)	K (pct)	Ca (pct)	Mn (ppm)	Sr (ppm)
1739.1	1.9	53	0.48	5400	4	14	77	130	15.0	39	200	42	26	42.4	0.43	250	1.6	2.0	490	510
1739.2	1.2	40	0.33	3100	<2	<5	43	72	11.0	24	90	23	14	29.2	0.35	150	1.3	13.0	3100	500
1739.3	1.0	58	0.14	2400	8	15	100	160	8.1	43	200	31	12	24.4	0.21	83	0.04	0.15	70	130
1759.0	2.5	83	0.75	5100	54	8	54	91	12.0	40	400	89	8	53.3	0.42	340	2.4	0.32	170	310
1779.0	2.9	40	0.58	2800	16	10	42	71	7.4	21	100	25	2		1.1	1100	2.7	1.0	360	520
1782.0	1.8	60	0.70	2400	8	74	62	110	8.5	49	100	27	5		0.80	1200	1.5	0.66	140	670
1810.0	2.0	40	0.78	2500	10	21	43	77	8.5	29	300	24	2		0.78	1100	2.2	0.71	210	540
1823.0	1.2	30	0.72	2000	7	12	21	42	7.5	22	300	25	3		1.0	1100	1.5	0.86	130	610
1843.0	1.7	50	1.00	2000	8	19	39	79	7.3	30	500	19	3		0.85	1100	1.1	1.30	290	690
1867.0	5.9	110	1.40	1800	11	<5	34	62	5.2	37	1000	29	1	70.5	0.33	3600	1.6	0.40	560	270
1875.0	1.8	40	1.10	2600	10	18	50	92	8.9	41	500	67	2		0.89	1400	2.3	0.81	230	720
1876.5	1.5	70	0.77	2600	14	15	40	78	7.8	37	500	160	4		0.71	1100	3.3	0.49	160	410
1878.0	2.7	72	0.35	800	8	<5	12	24	3.4	9	200	43	9		0.48	450	2.8	0.11	130	78
1878.3	2.8	60	0.51	1100	8	6	14	27	4.0	12	300	64	5		0.60	180	2.2	0.13	150	90
1899.5	0.29	40	0.12	600	11	<4	16	25	3.1	8	200	67	12		0.88	490	2.1	0.13	44	71
1900.0	0.46	11	0.11	1100	4	<5	16	28	2.7	6	200	63	11		0.68	390	2.3	0.09	73	59
1909.0	0.69	10	0.12	500	2	<5	18	33	4.0	7	200	92	277		0.96	680	3.3	0.10	100	87
1911.5	0.73	8	0.11	500	3	<4	24	50	4.5	9	60	68	153		1.2	870	3.2	0.10	69	110
1913.5	0.54	9	0.14	500	3	<4	22	45	3.5	9	80	67	428		1.2	780	2.7	0.09	110	100
1914.5	0.70	11	0.17	600	5	<4	33	66	4.6	12	70	87	566		1.3	940	3.4	0.09	120	110
1915.5	0.50	8	0.12	1000	4	<4	17	38	2.8	8	50	66	650		0.88	550	2.1	0.06	110	70
1916.5	0.69	19	0.15	900	4	<4	20	40	3.6	10	60	60	534		1.1	790	2.6	0.07	140	80
1917.0	0.81	14	0.16	800	6	<5	22	38	4.2	9	200	76	462		1.0	790	3.0	0.10	160	83
1917.5	0.59	20	0.13	400	3	<4	17	35	3.4	9	50	49	474		1.1	640	2.4	0.08	110	81
1919.8	0.45	12	0.11	400	1	<4	16	35	3.3	9	60	49	367		1.0	630	2.4	0.05	97	78
1921.0	0.66	15	0.18	1500	5	8	15	32	2.3	8	50	69	632		0.73	410	1.6	0.04	160	58
1923.0	0.64	10	0.16	1100	4	<4	24	52	3.4	10	50	60	455		1.1	650	2.3	0.06	120	83
1925.0	0.45	7	0.13	1100	4	7	24	48	3.3	11	60	60	431		1.1	610	2.4	0.08	110	83
1928.0	0.49	8	0.12	800	3	<5	14	24	2.8	6	100	64	352		0.71	470	1.9	0.07	100	60
1930.0	0.65	<20	0.18	1000	8	6	16	26	3.5	8	100	89	626		1.1	590	2.2	0.10	130	80
1931.0	0.53	11	0.15	700	4	<4	13	28	3.2	7	50	74	509		1.1	550	2.2	0.07	95	77
1933.0	0.93	16	0.23	1600	5	<5	19	32	3.3	10	200	110	1560		0.78	540	2.2	3.3	1100	110
1933.5	0.74	15	0.19	1100	5	<5	19	30	3.6	9	100	100	1990		0.88	650	2.5	1.9	700	99
1934.0	0.76	16	0.19	1100	7	<5	18	28	3.6	7	100	120	2430		0.88	650	2.2	1.3	600	93
1935.0	1.5	35	0.57	2300	15	<5	43	74	7.1	29	300	430	911		0.87	850	3.7	0.62	430	140
1936.0	1.7	31	0.38	1300	4	<5	14	25	4.1	5	100	45	10		0.99	580	2.4	0.17	270	78
1960.0	0.89	18	0.23	1900	5	<5	14	26	4.4	8	200	33	3		1.0	600	3.2	0.11	120	93
1972.0	4.4	93	0.84	600	3	<5	8	15	5.1	5	100	35	1	75.2	1.1	520	2.1	0.08	420	63
1981.0	0.72	13	0.15	700	4	<5	25	40	5.3	7	200	38	2	79.6	1.3	1200	4.0	0.13	73	120
1998.0	0.85	18	0.23	1100	5	<5	21	33	5.2	8	100	56	2	79.9	1.1	690	4.0	0.22	82	100
2006.0	0.46	8	0.10	700	3	<5	9	16	2.7	4	100	17	6		0.64	420	2.0	0.06	42	57
2010.0	0.82	13	0.17	1400	7	<5	14	26	3.2	6	200	51	17		0.78	440	2.1	0.08	75	60
2010.0*	0.99	<20	0.23	1200	8	5	14	28	3.6	6	200	62	12		1.1	490	2.3	0.10	81	71
2027.0	0.51	7	0.09	700	3	<5	17	29	4.3	5	200	16	2		1.0	700	2.8	0.16	55	90
2030.0	1.2	14	0.15	3200	10	<5	14	25	2.8	6	100	28	4		0.69	400	1.8	0.10	130	63
2030.0*	1.6	<20	0.20	4800	17	14	13	27	3.0	10	200	38	4		0.80	380	1.9	0.10	170	69
2041.0	1.1	17	0.29	900	3	<5	11	18	4.4	5	90	28	2	82.3	1.2	900	3.3	0.15	76	77
2055.5	0.62	<20	0.13	900	7	4	13	25	2.8	5	100	19	3		0.79	420	1.8	0.14	52	60
2076.0	2.2	40	0.96	3300	18	8	67	110	7.7	40	600	51	4	67.4	0.46	680	4.4	0.44	200	190
2087.0	2.1	43	0.28	600	13	<5	18	27	6.5	7	300	18	1		1.6	930	5.6	0.31	95	130
2097.0	0.80	14	0.18	1600	6	<5	14	27	3.5	6	200	24	1	85.6	0.88	430	2.7	0.09	61	83
2097.0*	0.88	16	0.20	1900	7	<5	16	28	3.6	7	200	27	2	86.2	0.93	440	2.8	0.11	71	68
2099.0	0.87	<20	0.21	1100	8	4	13	20	3.8	7	300	26	2		0.92	480	2.5	0.12	56	73
2105.0	0.47	9	0.12	500	<2	<5	17	28	4.9	6	200	13	1	79.2	1.1	720	4.1	0.76	120	89
2105.0*	0.51	10	0.13	600	3	<5	18	32	5.3	7	200	13	1	78.7	1.2	780	4.5	0.78	120	95
2123.0	1.2	11	0.19	700	11	<5	12	22	4.2	6	200	19	1		1.0	520	3.8	0.12	52	73
2128.0	1.5	<20	0.37	900	7	<4	9	20	3.9	5	200	25	3		0.97	440	2.4	0.11	72	68
2137.0	0.86	13	0.23	1200	5	<5	13	22	3.9	7	200	24	1	84.3	0.72	430	3.0	0.13	58	76
2148.0	0.99	<20	0.22	700	6	<4	22	45	4.3	6	200	25	1		1.1	580	2.8	0.33	83	89
2156.0	0.84	13	0.20	900	4	<5	16	28	4.4	7	200	18	1	81.8	1.1	570	3.6	0.31	86	76
2159.0	0.66	10	0.18	600	<2	<5	15	26	4.3	6	200	14	1	81.4	1.0	560	3.5	0.78	160	75
2177.0	0.66	<20	0.16	800	6	4	12	21	3.4	6	200	16	1		0.74	350	2.4	0.10	60	75
2188.0	0.56	81	0.23	1100	6	<5	26	47	3.9	14	300	38	2	72.4	0.61	330	3.9	4.3	980	110
2195.0	5.5	57	1.20	3900	24	<5	44	79	8.5	21	600	73	3	57.2	0.51	230	4.8	1.1	300	410
2204.0	0.62	13	0.23	900	7	<5	12	17	3.9	5	100	19	1	85.4	0.76	1600	2.7	0.37	110	170
2215.0	0.52	<20	0.21	1000	6	62	12	27	3.3	6	200	23	1		0.79	370	1.8	0.21	54	150
2232.0	0.80	15	0.25	1600	6	<5	14	24	3.6	5	200	26	1	85.2	0.73	630	2.2	0.32	110	180
2265.0	1.7	21	0.41	1300	13	<5	16	24	5.4	7	200	35	1		1.1	510	3.5	0.30	87	270
2293.0	1.8	23	0.55	2200	18	<5	16	24	4.6	17	200	58	2		0.71	340	3.0	1.6	210	240

Sample depth (feet)	Fe ₂ O ₃ (pct)	TiO ₂ (pct)	LOI (pct)	Al ₂ O ₃ (pct)	MgO (pct)	K ₂ O (pct)	CaO (pct)	Cu (ppm)	Li (ppm)	Nd (ppm)	Yb (ppm)	Se (ppm)	Ni (ppm)	Na ₂ O (pct)	U - ICP (ppm)	Pb (ppm)	Th - ICP (ppm)	Th - DNA (ppm)	Co (ppm)
1739.1	2.85	0.82	19.6	28.7	0.81	1.42	3.10	12	93	57	4		<4	0.34	<40	77	51	61	<2
1739.2	1.78	0.51	24.6	20.7	0.59	0.92	20.70	6	60	28	2		<4	<0.15	<40	52	38	48	<2
1739.3	1.64	0.46	54.3	17.8	0.28	0.23	0.27	10	62	69	5		5	<0.15	<40	51	40	58	<2
1759.0	3.83	0.85	13.7	23.1	1.26	2.27	0.45	24	99	43	4		23	0.30	<40	52	23	27	9
1779.0								12	20	42	<2		12		<20	9	12		<2
1782.0								8	20	39	5		6		<100	27	5	17	5
1810.0								11	23	31	3		4		<100	15	8	12	5
1823.0								6	14	26	2		2		<100	12	10	14	4
1843.0								7	20	31	3		4		<100	20	12	14	6
1867.0	8.73	0.28	4.47	9.6	2.26	1.76	0.57	<2	42	28	5		7	0.30	<40	25	7	12	6
1875.0								8	17	39	5		3		<100	12	18	16	5
1876.5								11	14	42	4		3		<100	17	11	14	6
1878.0								4	15	9	<1	<1	4		20	9	4		3
1878.3								4	20	8	1		5		<100	10	<4	<3	6
1899.5								5	10	7	<1		<2		<100	<4	5	<5	1
1900.0								5	10	15	<1	1	<3		20	6	4		<1
1909.0								10	9	14	<1	1	<3		260	6	4		1
1911.5								4	6	23	<1		2		190	8	8		3
1913.5								3	5	18	<1		<2		450	32	9		2
1914.5								5	3	29	1		2		610	15	13		2
1915.5								2	6	19	<1		<2		680	8	15		2
1916.5								15	3	25	1		<2		560	10	17		4
1917.0								9	11	17	<1	90	4		450	11	<3		3
1917.5								17	2	17	<1		<2		500	9	12		2
1919.8								16	4	16	<1		<2		370	11	7		2
1921.0								5	3	14	1		3		690	9	14		2
1923.0								2	3	24	<1		<2		470	6	10		2
1925.0								3	<2	25	1		<2		460	10	12		2
1928.0								8	10	14	<1	1	<3		300	<5	<3		<1
1930.0								4	12	19	<1		<2		600	11	6		2
1931.0								2	5	6	<1		<2		510	<4	6		<1
1933.0								7	16	14	1	1	<3		1500	10	4		<1
1933.5								9	13	19	1	4	<3		1900	11	<3		2
1934.0								10	13	11	<1	3	<3		2400	11	<3		1
1935.0								24	20	32	3	12	7		860	37	9		6
1936.0								8	27	10	<1	3	<3		30	5	<3		2
1960.0								6	14	13	<1	<1	<3		20	<5	<3	3	1
1972.0	6.65	0.09	1.93	9.80	1.42	2.64	0.10	<2	53	5	<2		5	1.44	<40	26	<4	4	7
1981.0	1.04	0.10	0.95	10.2	0.28	4.63	0.18	6	12	17	<2		<4	1.78	<40	21	<4	6	<2
1998.0	1.26	0.18	1.74	9.91	0.46	4.63	0.30	2	12	15	<2		<4	1.51	<40	18	<4	4	<2
2006.0								4	8	8	<1	1	<3		30	<5	<3		1
2010.0								6	12	8	<1	1	5		50	5	<3		1
2010.0*								3	14	14	<1		2		<100	9	6	<5	2
2027.0								5	8	11	<1	<1	<3		30	<5	<3		2
2030.0								9	10	17	<1	<1	<3		40	8	4	5	1
2030.0*								8	13	11	1		3		<100	15	12	9	5
2041.0	1.63	0.14	1.32	8.29	0.41	3.94	0.08	3	15	<5	<2		<4	1.35	<40	19	<4	3	<2
2055.5								6	9	18	<1		<2		<100	6	9	4	2
2076.0	3.34	0.57	6.19	14.3	1.54	4.59	0.62	15	19	51	4		11	0.43	<40	36	13	12	5
2087.0								8	20	8	<2		10		<20	10	5		<2
2097.0	1.21	0.26	1.20	6.70	0.33	3.07	0.12	3	13	7	<2		<4	1.10	<40	16	<4	5	<2
2097.0*	1.25	0.30	1.35	6.72	0.34	3.04	0.13	5	14	17	<2		<4	1.16	<40	21	7	6	<2
2099.0								4	13	22	1		3		<100	8	<4	3	3
2105.0	0.72	0.08	1.52	9.81	0.22	4.74	1.14	5	11	11	<2		<4	1.47	<40	20	5	4	<2
2105.0*	0.74	0.08	1.91	10.0	0.23	4.84	1.14	8	11	12	<2		<4	1.46	<40	24	4	5	<2
2123.0								10	12	15	<2		9		<20	7	4		<2
2128.0								3	16	10	<1		3		<100	<4	<4	5	3
2137.0	1.27	0.19	1.17	7.36	0.39	3.46	0.18	4	9	12	<2		<4	0.88	<40	14	4	6	<2
2148.0								2	15	17	<1		<2		<100	8	8	4	3
2156.0	1.26	0.14	1.08	8.61	0.35	4.05	0.42	4	11	10	<2		<4	1.38	<40	19	4	5	<2
2159.0	1.00	0.09	1.74	8.40	0.30	3.96	1.17	7	10	6	<2		<4	1.37	<40	15	<4	5	<2
2177.0								3	8	4	<1		<2		<100	10	<4	3	2
2186.0	0.83	0.18	6.45	7.60	0.40	3.80	6.70	6	9	22	<2		<4	0.74	<40	18	6	5	<2
2195.0	8.54	0.67	7.87	16.2	1.97	4.89	1.59	15	24	29	3		13	0.42	<40	29	11	15	4
2204.0	0.85	0.15	1.64	7.23	0.37	3.08	0.54	5	8	9	<2		<4	0.92	<40	14	<4	5	2
2215.0								4	8	15	<1		<2		<100	5	<4	<3	2
2232.0	1.13	0.25	2.04	6.58	0.40	2.27	0.44	6	9	6	<2		<4	0.86	<40	19	<4	5	<2
2265.0								8	13	11	<2		8		<20	6	5		<2
2293.0								4	15	8	3		12		<20	<5	5		<2

Table A9. Analytical results for samples from Mariano Lake-Lake Valley drilling project core 5

[Asterisk (*) indicates replicate of previous sample; blank in data column indicates sample not run for that element. Core hole locality shown in text figure 1. Elements Dy (10), Gd (20), Sm (12), Mo (4), and Cd (2) are not listed because they are at or below limit of detection (given in parentheses)]

Sample depth (feet)	Fe (pct)	Zn (ppm)	Mg (pct)	Ti (ppm)	Cr (ppm)	Nb (ppm)	La (ppm)	Ce (ppm)	Al (pct)	Y (ppm)	P (ppm)	V (ppm)	U - DNA (ppm)	Na (pct)	Ba (ppm)
2319	2.00	60	0.83	3100	12	21	47	90	9.8	43	100	43	5	0.87	740
2359	1.30	23	0.24	1500	12	<5	15	21	4.0	8	80	15	1	0.81	330
2380	1.30	30	0.85	2500	7	18	38	72	8.8	33	200	22	2	0.88	1200
3403	1.80	40	0.98	2400	10	14	31	52	7.9	28	200	99	5	0.83	1100
2421	1.70	26	0.48	2600	11	6	19	35	6.1	18	300	49	7	0.78	830
2425	0.81	13	0.17	1700	6	<5	16	29	4.2	6	200	28	2	0.81	480
2439	0.56	6	0.08	100	12	<5	18	25	4.2	6	100	12	3	1.3	670
2510	2.00	14	0.42	1200	13	<5	15	24	3.7	10	200	25	3	0.94	440
2517	3.30	60	0.95	1900	13	10	22	42	5.2	17	300	32	2	0.89	440
2555	1.30	20	0.27	1400	10	<4	14	21	3.8	5	100	25	2	0.99	420
2561	0.55	14	0.10	900	13	<5	16	24	4.4	6	200	29	1	1.0	570
2622	2.20	16	0.34	1100	14	<5	17	26	4.7	8	200	19	2	1.2	450
2649	1.20	<20	0.23	1400	10	5	14	22	3.6	7	200	45	2	0.88	380
2698	1.60	16	0.23	1200	3	<5	18	31	3.8	5	100	30	2	0.82	430
2714	1.90	30	0.24	2900	9	8	22	41	2.6	7	200	51	2	0.81	290
2723	1.20	<20	0.19	1300	6	<4	19	27	3.3	5	100	34	1	0.85	940
2759	2.50	24	0.32	2300	18	<5	13	23	4.6	8	300	35	2	0.90	460
2788	0.65	<20	0.38	1300	6	<4	17	22	4.5	12	300	22	1	0.97	400
2812	0.50	<20	0.33	900	4	<4	15	22	2.9	12	100	18	1	0.32	250
2845	0.36	<20	0.27	800	4	<4	18	14	2.4	6	100	17	1	0.38	310

Sample depth (feet)	K (pct)	Ca (pct)	Mn (ppm)	Sr (ppm)	Cu (ppm)	Li (ppm)	Nd (ppm)	Yb (ppm)	Ni (ppm)	Pb (ppm)	Th - ICP (ppm)	Th - DNA (ppm)	Co (ppm)	Sc (ppm)	Ga (ppm)
2319	2.8	0.72	150	590	11	13	47	4	3	16	18	19	6	12	23
2359	1.7	0.11	86	74	5	19	13	<2	9	11	4	3	<2	<4	<10
2380	2.3	0.72	130	550	5	13	33	4	<2	20	13	13	4	10	21
2403	2.3	0.71	160	540	10	17	25	2	<2	16	13	14	5	9	11
2421	5.1	0.19	100	140	7	13	19	<2	6	26	8	13	3	7	<10
2425	3.9	0.10	56	74	3	8	14	<2	<4	17	4	7	<2	<4	<10
2439	4.1	0.10	49	71	5	11	17	<2	9	7	8	5	<2	<4	<10
2510	3.2	4.9	1600	96	4	20	14	<2	9	<5	<4	4	<2	<4	<10
2517	2.2	0.77	370	180	7	25	19	2	6	14	6	8	8	6	13
2555	2.6	0.17	68	60	4	11	15	<1	<2	<4	17	6	3	<2	<4
2561	4.4	0.57	90	76	5	9	15	<2	12	6	4	4	<2	<4	<10
2622	4.2	0.16	86	55	10	17	16	<2	8	9	6	4	<2	<4	<10
2649	2.5	0.69	150	58	6	12	21	<1	8	8	<4	3	3	3	10
2698	3.2	0.54	130	50	<2	12	14	<2	<4	14	5	4	<2	<4	<10
2714	1.1	0.59	280	36	9	11	22	<1	3	10	7	7	4	<2	5
2723	1.7	0.14	76	57	7	8	16	<1	<2	19	<4	4	2	<2	6
2759	4.1	0.18	120	78	7	12	10	<2	11	6	6	4	<2	<4	<10
2788	2.2	4.2	520	150	10	8	16	1	2	15	<4	5	2	4	8
2812	1.2	5.8	650	100	7	7	13	1	3	8	<4	4	1	<2	5
2845	1.2	7.8	400	81	5	8	11	<1	3	9	<4	3	1	<2	<4

Table A10. Analytical results for samples from Mariano Lake-Lake Valley drilling project core 6

[Asterisk (*) indicates replicate of previous sample; blank in data column indicates sample not run for that element. Core hole locality shown in text figure 1. Elements Dy (10), Gd (20), Sm (12), Mo (4), Cd (2), Sc (15), and Ga (20) are not listed because they are at or below limit of detection (given in parentheses)]

Sample depth (feet)	Fe (pct)	Zn (ppm)	Mg (pct)	Ti (ppm)	Cr (ppm)	Nb (ppm)	La (ppm)	Ce (ppm)	Al (pct)	Y (ppm)	P (ppm)	V (ppm)	U - DNA (ppm)	SiO ₂ (pct)	Na (pct)	Ba (ppm)	K (pct)	Ca (pct)	Mn (ppm)
2476.0	1.8	85	0.77	1800	12	20	39	52	6.1	24	300	20	2	76.2	0.85	818	2.5	0.54	197
2508.0	5.6	76	0.43	1800	18	6	5	<10	4.6	15	200	30	3	65.7	0.81	1270	3.8	0.13	93
2518.0	0.43	38	0.19	2600	10	7	26	38	4.6	10	200	41	3	83.1	1.5	918	3.8	0.12	54
2532.0	0.95	25	0.20	900	4	<5	24	31	4.5	8	200	20	2	81.6	1.3	621	3.6	0.19	79
2540.0	0.64	28	0.18	900	3	<5	23	33	4.6	9	200	23	3	81.2	1.4	879	3.7	0.50	192
2549.0	0.55	17	0.16	700	3	<5	24	18	4.4	9	200	13	3	81.0	1.3	706	3.7	0.88	300
2565.0	2.5	<20	0.84	2800	18	13	22	29	6.9	<2	400	47	5	71.5	0.64	639	3.8	0.34	161
2566.5	4.0	73	1.20	3700	25	20	60	90	9.1	47	500	94	3	65.9	0.55	1170	5.0	0.46	263
2567.5	2.5	40	0.92	3100	21	15	49	90	8.0	39	600	61	5	66.6	0.66	940	3.7	0.38	150
2574.0	2.8	45	0.62	1400	10	8	35	46	6.3	32	1100	78	11	76.5	1.2	682	4.2	0.32	176
2575.0	0.35	22	0.10	800	10	6	14	15	3.9	7	200	35	2	84.2	1.3	506	3.3	0.08	35
2584.0	0.90	45	0.14	1600	5	10	22	23	4.6	10	300	38	3	81.8	1.4	1150	3.7	0.17	100
2604.0	0.65	15	0.14	1200	7	<5	17	25	4.1	9	300	23	2	84.4	1.2	559	3.2	0.13	68
2604.0*	0.79	17	0.17	1100	8	<5	19	26	4.7	10	300	25	2	83.7	1.4	632	3.7	0.15	70
2616.0	1.0	35	0.24	500	4	<5	31	37	5.4	11	200	36	2	74.9	1.5	764	4.3	3.3	819
2641.0	0.44	10	0.13	600	4	<5	11	14	2.4	4	100	18	3	91.3	0.74	314	1.7	0.17	54
2651.5	0.42	12	0.12	700	3	<5	21	25	4.0	7	200	19	1	83.0	1.00	494	3.4	0.34	86
2653.0	1.0	22	0.24	700	6	<5	11	14	2.5	4	100	22	1	87.8	0.82	287	1.7	0.05	51
2657.5	2.2	48	0.92	3400	22	8	32	41	7.9	26	500	49	6	72.7	0.74	532	4.2	0.36	158
2686.0	0.96	20	0.21	800	5	<5	15	21	3.7	7	200	17	1	84.1	0.97	1180	2.9	0.24	85
2702.0	0.54	20	0.15	500	6	<5	22	28	5.0	7	200	18	1	82.9	1.3	634	3.9	0.45	97
2714.0	4.0	80	1.30	4000	27	18	75	114	9.9	44	800	68	3	63.9	0.31	261	4.9	0.54	206
2729.0	1.8	32	0.30	1500	9	<5	27	37	4.9	10	300	41	2	80.0	1.2	610	3.6	0.34	135
2743.0	0.77	20	0.22	500	5	<5	15	21	4.0	5	200	18	1	84.0	1.0	496	3.3	0.16	48
2743.9	0.61	16	0.14	1400	12	<5	17	11	3.6	6	200	22	2	85.1	0.93	484	3.0	0.42	107
2744.1	1.4	25	0.28	800	3	<5	15	18	3.3	5	100	24	1	86.4	0.87	453	2.3	0.16	74
2751.0	2.0	30	0.22	3800	14	14	27	42	2.4	10	200	56	3	87.6	0.65	455	1.5	0.08	140
2759.0	0.66	20	0.23	1800	8	<5	17	22	3.5	15	300	25	1	68.7	0.73	434	2.3	8.4	1630
2783.0	0.79	18	0.28	1500	9	<5	12	<10	3.2	8	200	25	1	86.4	0.59	3310	1.9	0.21	89
2808.0	1.3	25	0.20	2100	12	6	22	27	3.1	7	200	38	1	86.0	0.80	539	1.7	0.64	191
2826.0	0.68	20	0.23	600	3	6	13	15	3.8	6	200	18	2	84.8	0.99	550	2.0	0.31	70
2867.0	0.99	21	0.23	1000	11	<5	14	23	3.4	6	200	20	2	80.9	0.82	403	1.9	1.6	286
2892.0	8.6	119	1.50	4000	25	16	58	78	9.8	38	200	102	4	53.8	0.40	207	4.2	1.5	384
2907.0	0.54	18	0.25	2600	14	5	22	23	3.2	13	200	33	2	70.6	0.43	287	1.9	8.0	1000
2907.0*	0.41	19	0.19	2000	11	<5	20	28	2.6	13	200	23	1	70.5	0.38	269	1.8	9.3	1190
2950.0	0.69	16	0.34	1800	6	<5	11	18	2.1	7	100	28	1	78.5	0.32	211	0.93	5.1	643
2993.0	0.46	13	0.44	700	4	<5	0	<10	2.7	4	100	15	1	87.2	0.52	884	1.3	0.98	119
3063.0	0.47	20	0.47	1500	10	<5	21	32	4.1	13	300	73	5	67.0	0.96	379	2.4	8.6	974

Sample depth (feet)	Sr (ppm)	Fe ₂ O ₃ (pct)	TiO ₂ (pct)	LOI (pct)	Al ₂ O ₃ (pct)	MgO (pct)	K ₂ O (pct)	CaO (pct)	Cu (ppm)	Li (ppm)	Nd (ppm)	Yb (ppm)	Ni (ppm)	Na ₂ O (pct)	Pb (ppm)	Th - ICP (ppm)	Th - DNA (ppm)	Co (ppm)
2476.0	496	2.44	0.31	4.09	11.20	1.30	2.74	0.78	9	27	28	3	4	1.1	25	17	13	4
2508.0	208	8.09	0.33	5.09	9.13	0.51	4.70	0.18	12	8	<10	1	8	1.1	11	<5	11	10
2518.0	102	0.40	0.48	0.80	9.01	0.20	4.64	0.15	8	5	13	1	3	1.9	17	<5	8	2
2532.0	94	1.37	0.16	0.99	8.84	0.30	4.49	0.27	6	8	<10	1	<2	1.7	13	<5	4	2
2540.0	103	0.87	0.16	1.00	9.09	0.30	4.62	0.77	6	8	<10	1	6	1.8	13	<5	<3	2
2549.0	94	0.73	0.12	1.30	8.76	0.20	4.38	1.34	3	11	<10	<1	2	1.6	14	<5	3	<2
2565.0	331	4.01	0.53	3.93	14.10	1.60	4.74	0.48	19	16	<10	2	9	0.8	16	10	15	7
2566.5	429	5.18	0.56	4.51	15.30	1.80	5.26	0.49	26	27	50	5	11	0.6	20	18	15	12
2567.5	370								19	15	40	4	8		4	17		9
2574.0	141	3.61	0.21	1.73	10.90	0.97	4.52	0.42	8	28	35	2	<2	1.4	12	6	<4	4
2575.0	70	0.37	0.12	0.96	7.39	0.20	3.96	0.10	7	8	15	<1	2	1.6	13	8	3	<2
2584.0	81	1.24	0.28	1.04	8.78	0.30	4.56	0.24	7	10	18	<1	<2	1.7	22	11	8	3
2604.0	66	0.83	0.20	0.98	7.90	0.30	3.93	0.15	7	9	18	1	2	1.5	11	<5	5	<2
2604.0*	74	0.89	0.15	0.93	8.40	0.30	4.18	0.12	6	10	15	1	5	1.5	22	<5	5	2
2616.0	117	1.26	0.07	1.25	9.20	0.40	4.36	4.56	4	13	34	2	<2	1.7	16	<5	4	<2
2641.0	35	0.54	0.08	0.68	4.80	0.30	2.29	0.10	17	12	10	<1	<2	0.8	<5	<3	<2	
2651.5	65	0.51	0.12	1.29	7.58	0.20	4.07	0.44	5	8	17	1	<2	1.3	14	<5	4	<2
2653.0	36	1.46	0.13	0.95	4.80	0.40	2.16	0.05	7	11	12	<1	4	1.0	7	<5	3	<2
2657.5	203	2.85	0.54	3.60	13.20	1.50	4.51	0.45	22	23	32	3	5	0.7	21	13	13	5
2686.0	62	1.30	0.14	1.19	6.95	0.40	3.41	0.34	4	11	15	<1	<2	1.2	13	6	4	<2
2702.0	86	0.62	0.06	1.16	8.98	0.30	4.60	0.61	21	9	21	<1	3	1.5	<5	3	1	
2714.0	204	5.27	0.62	5.50	17.10	2.10	5.23	0.69	29	28	61	4	9	0.3	34	15	17	4
2729.0	69	2.35	0.24	1.49	8.90	0.50	4.12	0.46	8	15	23	1	6	1.5	21	8	5	4
2743.0	62	1.05	0.08	1.08	7.68	0.30	3.79	0.19	4	7	<10	<1	3	1.2	6	<5	2	2
2743.9	62	0.81	0.25	1.23	7.07	0.20	3.59	0.63	6	<2	<10	<1	<2	1.2	16	<5	5	2
2744.1	48	2.13	0.14	0.98	6.53	0.51	2.83	0.23	3	9	<10	<1	6	1.1	<10	<5	4	3
2751.0	39	2.89	0.72	0.95	4.40	0.40	1.96	0.09	8	12	23	1	2	0.7	7	9	10	3
2759.0	192	0.75	0.28	9.86	5.61	0.40	2.15	11.70	7	8	13	2	2	0.8	18	10	5	<2
2783.0	839	1.10	0.26	1.29	6.20	0.50	2.49	0.18	10	9	12	1	4	0.8	14	<5	5	<2
2808.0	129	1.80	0.36	1.51	5.76	0.40	2.02	0.92	10	9	21	1	<2	0.8	13	8	6	2
2826.0	108	0.95	0.10	1.46	7.58	0.40	2.65	0.46	4	11	14	<1	4	1.3	11	<5	4	<2
2867.0	103	1.41	0.17	2.44	6.51	0.40	2.23	2.54	5	5	<10	<1	3	1.0	8	<5	3	4
2892.0	150	11.20	0.59	7.06	16.30	2.40	4.14	2.02	39	46	58	4	4	0.4	46	25	22	12
2907.0	144	0.55	0.39	9.50	5.23	0.40	1.63	10.90	9	10	14	1	<2	0.3	15	10	6	<2
2907.0*	189	0.39	0.30	10.50	4.40	0.30	1.45	12.50	7	8	22	2	<2	0.2	15	5	4	<2
2950.0	106	0.89	0.38	7.09	3.80	0.59	0.94	7.58	7	10	<10	1	3					

Table A11. Analytical results for samples from Mariano Lake-Lake Valley drilling project core 7

[Asterisk (*) indicates replicate of previous sample; blank in data column indicates sample not run for that element. Core hole locality shown in text figure 1. Elements Dy (10), Gd (20), Sm (12), Mo (4), Cd (2), Sc (15), and Ga (20) are not listed because they are at or below limit of detection (given in parentheses)]

Sample depth (feet)	Fe (pct)	Zn (ppm)	Mg (pct)	Ti (ppm)	Cr (ppm)	Nb (ppm)	La (ppm)	Ce (ppm)	Al (pct)	Y (ppm)	P (ppm)	V (ppm)	U - DNA (ppm)	SiO ₂ (pct)	Na (pct)	Ba (ppm)	K (pct)	Ca (pct)	Mn (ppm)	Sr (ppm)
2855	1.60	128	0.28	1500	<10	31	41	51	6.4	32	<100	15	3	74.4	0.16	419	0.91	1.6	1310	208
2898	1.50	28	0.42	1600	<10	12	14	<10	4.6	9	200	19	4	81.3	0.70	439	2.0	0.53	288	230
2911	0.54	11	0.11	400	<10	<10	17	19	3.8	8	<100	4	1	62.1	1.2	578	2.2	8.4	4600	294
2924	2.20	47	0.75	3600	<10	41	50	72	8.8	46	300	52	2	65.3	0.84	454	4.1	0.45	188	389
2978	0.64	18	0.24	1000	<10	12	24	34	4.7	10	100	51	2	83.2	0.84	578	2.6	0.25	123	192
3013	2.00	47	0.82	2000	<10	27	49	66	7.3	26	200	34	7	69.4	0.69	782	2.9	0.57	213	566
3038	0.78	18	0.26	900	<10	18	30	49	5.7	10	200	38	3	79.4	1.4	697	4.0	0.14	59	143
3045	3.90	41	0.78	2300	<10	25	50	75	7.8	34	200	34	6	65.5	0.43	612	4.1	0.32	124	341
3051	0.83	17	0.26	1300	<10	14	22	28	4.6	7	200	44	4	82.5	1.2	509	3.2	0.10	58	94
3088	0.70	13	0.20	1200	<10	15	18	25	4.4	6	100	29	3	83.8	1.2	489	3.3	0.07	40	75
3108	0.99	20	0.31	1000	12	5	24	39	4.8	10	200	54	3		0.88	450	3.5	0.14	45	100
3133	0.50	8	0.16	600	<10	<10	14	17	4.0	6	200	37	2	84.9	1.2	402	3.1	0.14	41	49
3133*	0.50	8	0.16	600	<10	<10	13	16	3.9	6	200	37	2	84.2	1.2	382	3.0	0.18	40	
3178	1.30	37	0.65	2500	20	17	36	67	5.9	16	400	43	18	76.8	0.52	380	3.1	0.32	90	190
3179	1.50	369	0.43	1800	11	12	19	44	4.4	146	200	110	1450	78.7	0.56	600	2.5	0.20	110	120
3190	0.62	8	0.18	400	<10	<10	17	22	4.6	6	200	17	1	82.1	1.3	1050	3.6	0.51	143	91
3213	0.55	6	0.18	600	<10	<10	13	20	3.2	6	100	21	1	80.4	0.85	445	2.7	2.70	639	57
3223	1.90	72	0.81	500	<10	<10	14	17	2.9	7	100	45	1	60.5	0.57	310	2.0	8.6	2940	110
3227	4.70	83	0.83	1300	6	5	12	28	3.9	51	100	93	830	79.0	0.43	340	1.3	0.15	230	61
3229	1.70	22	0.37	3100	<10	24	24	38	3.6	4	200	82	4	82.9	0.94	876	2.1	0.45	235	77
3247	1.50	17	0.32	2600	<10	23	25	38	4.1	6	200	47	3	82.8	1.0	730	2.7	0.20	111	65
3258	0.76	43	0.21	700	4	9	20	44	4.4	7	100	137	940	79.2	1.1	550	3.1	1.6	520	84
3259	0.78	20	0.22	900	7	11	11	20	3.1	7	100	55	460	85.9	0.80	370	2.0	0.34	130	58
3263	1.10	30	0.28	900	4	6	14	23	4.1	6	200	54	390	82.8	0.83	420	2.7	0.41	110	81
3267	0.66	13	0.16	900	<10	<10	11	17	3.1	3	100	17	10	83.8	0.65	208	2.5	1.0	61	259
3272	0.45	10	0.11	700	<10	<10	11	15	2.8	3	100	15	5	67.0	0.57	59	2.2	5.4	39	1730
3272*	0.46	13	0.12	700	<10	<10	12	<10	2.7	3	100	15	5	68.5	0.52	54	2.3	5.6	36	1690
3282	0.20	9	0.14	1100	<10	13	15	27	2.4	14	200	14	3	66.1	0.50	458	2.2	8.8	2100	1410
3298	1.50	22	0.22	2500	<10	16	17	22	3.7	6	200	50	2	81.3	0.77	379	2.6	0.98	310	143
3300	1.20	24	0.21	2400	10	14	23	45	3.7	8	200	49	2	83.7	0.84	400	2.2	0.48	120	150
3302	1.60	23	0.22	1300	7	11	25	45	4.1	8	200	36	3	81.8	0.94	440	2.8	0.60	93	140
3302*	0.83	16	0.19	1700	<10	16	16	14	3.9	6	200	34	2	83.3	0.85	346	2.8	0.45	81	127
3313	5.40	76	1.10	3700	23	31	54	76	9.1	27	600	77	2	58.2	0.41	245	4.2	0.88	273	139
3320	1.00	24	0.29	1900	33	13	12	20	3.6	7	200	26	1	85.2	0.80	1360	2.0	0.87	192	250
3336	0.64	16	0.24	800	5	9	21	32	4.1	12	100	51	2	79.7	0.90	400	1.8	2.2	230	100
3358	0.78	77	0.19	1200	47	<10	19	25	3.6	14	200	21	1	69.2	0.82	389	1.9	6.1	953	130
3388	0.81	17	0.23	1300	21	<10	15	20	3.9	6	<100	25	1	85.3	1.0	380	2.2	0.63	132	106
3396	2.40	47	0.83	2500	18	12	26	29	5.9	14	300	77	3	64.8	0.58	205	2.9	3.2	280	139

Sample depth (feet)	Fe ₂ O ₃ (pct)	TiO ₂ (pct)	LOI (pct)	Al ₂ O ₃ (pct)	MgO (pct)	K ₂ O (pct)	CaO (pct)	Cu (ppm)	Li (ppm)	Nd (ppm)	Yb (ppm)	Se (ppm)	Ni (ppm)	Na ₂ O (pct)	U - ICP (ppm)	Pb (ppm)	Th - ICP (ppm)	Th - DNA (ppm)	Co (ppm)
2855	2.42	0.26	6.39	12.10	0.54	1.15	2.53	6	32		2		5	<0.2	<50	22	6	9	<2
2896	2.15	0.27	3.12	8.67	0.72	1.95	0.77	<2	23		2		4	0.9	<50	43	<5	6	<2
2911	0.73	0.05	11.20	6.99	0.30	2.28	13.80	3	12		<1		<2	1.4	87	20	<5	2	<2
2924	3.41	0.83	5.66	16.50	1.40	4.76	0.72	10	20	33	6		7	1.0	<50	17	14	15	4
2978	0.91	0.18	1.88	8.69	0.50	3.13	0.25	5	12		1		<2	1.0	<50	15	<5	5	<2
3013	3.14	0.40	5.75	13.90	1.60	3.35	0.94	13	20	30	3		6	0.9	<50	23	10	15	4
3038	1.11	0.16	1.41	10.40	0.50	4.64	0.20	6	14		1		2	1.7	<50	16	<5	5	<2
3045	8.49	0.47	4.85	14.90	1.50	4.93	0.53	5	16	39	4		6	0.6	<50	21	15	13	4
3051	1.16	0.25	1.38	8.38	0.50	3.85	0.15	5	15		1		2	1.5	<50	18	5	7	<2
3068	1.09	0.25	0.99	7.98	0.40	3.92	0.10	4	12		<1		<2	1.4	<50	12	<5	5	<2
3108								4	12	23	1		3		<100	12	7		4
3133	0.67	0.10	1.09	7.38	0.30	3.67	0.22	3	9		<1		3	1.4	<50	11	<5	5	<2
3133*	0.65	0.10	1.14	7.50	0.30	3.63	0.21	3	8	<10	<1		2	1.6	<50	11	<5	3	<2
3178	1.84	0.45	3.41	11.50	1.20	4.26	0.45	18	14		2		6	0.6	230	50	8		4
3179	2.21	0.32	3.49	8.74	0.78	3.64	0.26	13	16		8	70	8	0.7	2000	87	41		10
3190	0.87	0.08	1.59	8.46	0.30	4.11	0.83	<2	13		<1		<2	1.6	<50	15	<5	<2	<2
3213	0.73	0.09	4.05	5.92	0.40	3.04	4.39	<2	8		<1		<2	1.0	<50	<10	<5	2	<2
3223	2.96	0.08	12.70	5.21	1.50	2.02	13.90	7	19		<1		4	0.6	99	13	<5	<2	<2
3227	7.06	0.24	2.34	7.74	1.50	1.97	0.19	7	30		3	<5	<2	0.5	1100	21	19		4
3229	2.58	0.70	1.74	6.56	0.68	2.47	0.54	4	23		<1		3	1.1	<50	21	7	8	3
3247	2.28	0.51	1.28	7.63	0.61	3.15	0.28	5	21		<1		3	1.2	<50	17	7	7	<2
3258	1.00	0.10	2.82	8.37	0.40	4.10	2.41	4	11		1	<5	2	1.3	1300	37	24		2
3259	1.01	0.14	1.38	6.09	0.40	2.94	0.48	4	8		1	<5	<2	0.7	630	30	11		2
3263	1.59	0.15	1.09	7.97	0.51	3.85	0.60	5	14		1	<5	3	1.0	510	16	8		4
3267	1.00	0.14	1.10	5.94	0.30	2.98	1.69	2	9		<1		2	0.8	<50	12	<5	<4	<2
3272	0.58	0.12	0.96	5.28	0.30	2.78	9.13	5	9		<1		3	0.7	80	12	<5	<3	<2
3272*	0.60	0.10	1.20	5.10	0.30	2.61	8.57	11	6	<10	<1		6	0.7	66	12	<5		<2
3282	0.18	0.18	9.48	4.60	0.30	2.34	13.20	5	8		1		6	0.5	140	10	10	3	<2
3296	2.38	0.48	1.62	7.25	0.50	3.16	1.43	5	10	16	<1		<2	0.9	<50	14	6	6	2
3300	1.74	0.46	1.02	7.25	0.40	3.20	0.68	6	10		1	<5	2	1.0	130	19	9	6	3
3302	2.08	0.22	1.69	7.72	0.40	3.44	0.81	8	10		1	<5	3	1.1	130	28	<5	3	4
3302*	1.20	0.31	1.51	7.76	0.40	3.27	0.72	3	8	<10	<1		<2	1.0	<50	11	<5	5	3
3313	8.52	0.66	7.00	16.80	2.20	4.77	1.44	24	32	36	4		12	0.5	<50	32	11	16	9
3320	1.16	0.28	2.09	5.90	0.50	2.04	1.04	5	12	<10	1		6	0.8	<50	20	<5	4	<2
3336	0.85	0.14	3.74	7.93	0.40	2.51	3.23	3	11		1	<5	<2	1.1	120	17	9	4	3
3358	1.10	0.20	9.02	6.52	0.40	2.07	10.00	5	9	16	1		2	1.0	73	15	<5	4	<2
3368	1.14	0.24	2.00	7.30	0.40	2.26	0.89	<2	12	<10	<1		4	1.2	<50	15	<5	5	<2
3396	3.72	0.50	8.19	11.90	1.50	3.40	5.19	14	22	19	2		14	0.6	<50	19	<5	12	5

Table A12. Analytical results for samples from Mariano Lake-Lake Valley drilling project cores 7a and 8

[Asterisk (*) indicates replicate of previous sample; blank in data column indicates sample not run for that element. Core hole locality shown in text figure 1. Samples 3030–3206 from core 7a, 3360–3508 from core 8. Elements Dy (10), Gd (20), Sm (12), Yb (2), Mo (4), Cd (2), Co (5), Sc (15), and Ga (20) are not listed because they are at or below limit of detection (given in parentheses)]

Sample depth (feet)	Fe (pct)	Zn (ppm)	Mg (pct)	Ti (ppm)	Cr (ppm)	Nb (ppm)	La (ppm)	Ce (ppm)	Al (pct)	Y (ppm)	P (ppm)	V (ppm)	U - DNA (ppm)
3030.0	1.50	15	0.22	1700	14	<5	27	44	5.1	8	200	36	3
3042.0	1.10	12	0.18	700	13	<5	30	45	6.6	10	200	51	3
3062.0	1.30	13	0.26	1100	14	<5	15	24	4.6	6	200	26	3
3072.0	1.10	12	0.15	700	13	<5	21	32	4.4	6	100	30	3
3108.0	0.67	9	0.18	700	3	<5	16	24	4.2	5	100	19	2
3108.0*	0.69	9	0.18	700	3	<5	15	25	4.0	5	100	19	2
3110.0	0.19	50	0.07	600	3	<5	18	32	3.9	5	100	24	2
3119.0	2.90	50	1.30	2600	22	11	27	44	7.1	31	400	56	5
3122.0	8.30	63	1.60	4600	38	12	50	96	11.0	36	600	89	3
3124.0	5.60	43	2.00	2600	27	6	41	67	7.8	41	400	56	1
3136.0	0.53	5	0.12	700	<2	<5	14	23	3.8	<4	100	13	6
3137.0	1.70	19	0.42	600	4	5	10	39	5.2	20	60	130	982
3138.0	0.33	5	0.08	400	<2	<5	11	16	3.4	<4	90	16	9
3156.0	0.46	5	0.12	500	2	<5	9	16	3.0	<4	100	11	2
3162.7	1.60	290	0.35	800	4	<4	10	41	3.5	39	90	160	1380
3164.0	1.40	16	0.36	600	2	<5	9	14	3.8	7	100	90	181
3168.0	0.72	10	0.18	1100	4	<5	15	23	3.2	6	100	38	112
3180.0	0.50	5	0.12	700	3	<5	10	18	2.7	<4	100	13	14
3199.0	0.74	10	0.18	1200	4	<5	15	24	3.3	6	100	39	122
3206.0	1.90	13	0.27	1200	12	<5	22	33	5.1	6	100	30	5
3360.0	0.57	<20	0.18	2200	8	10	22	41	5.1	9	200	28	6
3372.0	0.34	<20	0.11	900	4	4	15	23	3.2	17	100	13	5
3373.0	1.80	80	0.81	2700	11	26	60	110	9.6	32	400	58	21
3374.0	1.10	30	0.36	1300	7	6	16	25	4.2	11	200	38	4
3377.0	0.59	<20	0.21	1600	7	6	12	27	2.9	14	200	27	3
3439.0	0.85	<20	0.20	900	6	<4	15	16	3.3	5	100	20	3
3441.0	1.00	30	0.32	1100	56	5	21	34	3.9	13	200	41	8
3443.0	1.00	30	0.32	1300	11	5	19	40	3.4	15	200	32	7
3507.0	4.10	40	0.94	2800	36	13	42	83	7.4	41	600	82	7
3508.0	0.60	<20	0.28	1500	11	5	16	38	3.8	9	200	42	2
3508.0*	0.59	<20	0.28	1400	11	6	15	30	3.7	9	200	42	2

Sample depth (feet)	Na (pct)	Ba (ppm)	K (pct)	Ca (pct)	Mn (ppm)	Sr (ppm)	Cu (ppm)	Li (ppm)	Nd (ppm)	Ni (ppm)	Pb (ppm)	Th - ICP (ppm)	Th - DNA (ppm)
3030.0	1.6	820	4.2	0.13	76	86	9	18	18	8	6	4	4
3042.0	1.8	1200	5.8	0.47	130	110	8	16	20	10	<5	7	5
3062.0	1.5	1500	4.3	0.22	73	75	6	13	12	9	<5	5	
3072.0	1.2	580	3.7	2.80	670	85	12	13	15	8	8	<4	
3108.0	0.98	450	3.9	0.10	56	50	5	9	15	<4	15	<4	4
3108.0*	0.94	430	3.5	0.09	51	48	2	9	14	<4	16	<4	4
3110.0	1.1	780	3.6	0.78	250	67	7	6	16	<4	13	<4	4
3119.0	0.18	160	3.6	4.60	860	310	20	21	33	11	6	15	
3122.0	0.57	280	7.0	1.20	270	380	34	29	42	25	<5	19	17
3124.0	0.41	150	5.3	11.0	2200	350	24	24	34	18	<5	11	12
3136.0	0.90	1200	3.5	1.20	460	94	5	7	10	<4	6	<4	
3137.0	1.4	960	3.5	0.23	190	96	3	8	26	2	31	21	
3138.0	0.83	630	3.2	0.23	83	60	4	6	8	<4	14	5	
3156.0	0.89	450	2.6	0.07	27	42	<2	7	9	<4	13	4	4
3162.7	0.74	390	2.2	0.16	90	65	4	4	22	4	22	21	
3164.0	0.66	800	2.8	0.16	81	60	<2	15	8	<4	18	<4	
3168.0	0.71	510	2.7	0.36	150	48	2	9	10	<4	14	4	
3180.0	0.62	350	2.7	0.10	47	37	<2	6	12	<4	12	<4	
3199.0	0.72	490	2.9	0.37	150	48	<2	9	14	<4	17	5	
3206.0	1.3	540	4.4	0.19	95	71	8	17	17	9	<5	6	
3360.0	1.6	530	2.7	0.18	67	140	15	17	23	3	9	5	
3372.0	0.97	410	1.7	12.0	4400	230	8	9	8	<2	<4	<4	
3373.0	0.75	390	3.8	1.10	230	420	10	23	53	7	24	29	
3374.0	0.96	470	2.2	2.40	650	180	6	17	27	4	31	5	
3377.0	0.71	320	1.8	8.40	2100	300	14	12	14	2	7	5	
3439.0	0.92	330	2.0	0.34	120	65	5	12	16	3	<4	4	
3441.0	1.0	370	2.1	0.56	180	79	5	15	23	5	7	6	
3443.0	0.85	320	1.8	0.19	88	58	4	14	15	3	8	5	
3507.0	0.30	170	3.6	5.30	1500	180	14	13	39	9	12	11	
3508.0	0.52	280	2.4	0.22	46	76	10	8	16	3	<4	4	
3508.0*	0.51	280	2.3	0.21	46	74	10	10	19	4	<4	4	

Table A13. Analytical results for samples from Mariano Lake-Lake Valley drilling project Pinedale West measured section [Minus (–) indicates less than; asterisk (*) indicates replicate of previous sample; blank in data column indicates sample not run for that element. Measured section locality shown in text figure 1. Sample feet is distance above Recapture Member-Westwater Canyon Member contact. Total thickness of Westwater Canyon is 246 ft. Elements Dy (10), Gd (20), Mo (4), and Cd (2) are not listed because they are at or below limit of detection (given in parentheses)]

Sample feet	Zn (ppm)	Cr (ppm)	La (ppm)	Ce (ppm)	Y (ppm)	V (ppm)	U - DNA (ppm)	SiO ₂ (pct)	Ba (ppm)	Mn (ppm)	Sr (ppm)	Fe ₂ O ₃ (pct)	TiO ₂ (pct)
190	16	<2	26	44	15	32	6	82.7	630	60	120	1.05	0.19
182	9	5	16	30	5	54	5	86.9	520	191	69	2.03	0.18
154	10	5	10	19	7	19	1	85.3	500	180	70	1.65	0.20
150	<2	3	14	21	5	61	7	82.8	780	130	110	0.44	0.16
142	<2	5	25	34	7	60	7	80.7	1000	94	120	0.48	0.10
139	3	4	23	26	12	33	8	71.7	820	150	170	0.70	0.12
131	3	6	12	24	4	4	3	86.0	560	70	74	0.78	0.09
118	4	5	26	29	12	23	3	62.0	940	1400	148	0.62	0.06
102	11	6	16	25	6	29	4	84.7	740	85	100	1.00	0.18
85	10	3	14	19	8	24	4	86.6	590	85	82	1.20	0.16
74	30	5	22	33	10	49	4	83.4	460	180	76	2.22	0.30
67	17	4	20	38	10	34	2	83.4	660	80	87	1.58	0.30
66	3	4	19	20	18	30	1	66.0	380	2500	260	0.93	0.19
57	13	9	16	29	9	45	2	84.9	510	140	75	1.65	0.47
55	42	4	14	15	6	22	1	86.5	530	60	73	1.06	0.10
53	4	4	10	15	6	22	1	87.5	490	61	67	0.96	0.15
51	12	<2	11	23	8	29	1	80.4	650	67	90	1.82	0.09
49	15	7	22	39	11	43	2	84.0	520	110	77	1.85	0.36
47	6	4	15	26	8	25	1	86.2	500	52	73	0.90	0.18
45	9	8	21	39	12	40	2	84.1	500	91	76	1.06	0.40
44	6	5	14	25	6	19	1	85.4	560	46	77	1.00	0.12
39	7	5	13	12	7	26	1	86.6	500	60	80	1.12	0.12
15	3	3	15	23	12	24	9	86.7	420	120	76	1.10	0.23
0	9	5	22	21	10	22	3	62.5	630	1300	210	0.63	0.08
<19	<2	3	13	18	8	23	1	68.8	250	1100	230	0.28	0.12

Sample feet	LOI (pct)	Al ₂ O ₃ (pct)	MgO (pct)	K ₂ O (pct)	CaO (pct)	Cu (ppm)	Li (ppm)	Sm (ppm)	Nd (ppm)	Ni (ppm)	Na ₂ O (pct)	Co (ppm)	Ga (ppm)
190	3.09	7.76	0.57	2.83	0.74	4	9	5	12	<2	0.6	<2	7
182	1.75	4.90	0.50	1.76	0.22	<2	12	7	7	9	0.5	<2	7
154	1.90	5.61	0.52	2.17	0.14	<2	13	5	<5	<2	0.7	<2	<5
150	1.92	8.56	0.20	3.24	0.27	<2	10	10	<5	3	1.0	2	11
142	1.71	10.30	0.20	4.03	0.27	<2	11	<5	10	<2	1.3	4	13
139	6.52	9.09	0.30	3.35	6.42	<2	11	<5	8	<2	1.2	<2	<5
131	1.80	7.00	0.30	2.32	0.22	<2	10	<5	<5	22	0.9	2	5
118	11.20	7.87	0.20	3.02	13.40	<2	10	9	5	<2	1.0	<2	8
102	1.74	7.53	0.30	2.77	0.27	2	12	10	<5	3	0.9	6	<5
85	1.84	6.42	0.40	2.39	0.32	4	11	<5	<5	10	0.8	<2	6
74	2.90	6.40	0.68	2.26	0.37	4	15	6	14	3	0.6	4	5
67	3.22	7.16	0.71	2.60	0.43	2	10	10	4	3	0.6	4	<5
66	11.70	4.10	0.30	1.45	13.80	<2	9	7	<5	6	0.5	<2	<5
57	2.30	5.82	0.40	2.05	0.35	<2	14	7	<5	<2	0.6	3	<5
55	1.94	6.15	0.30	2.19	0.39	2	12	<5	<5	68	0.7	6	6
53	1.82	5.50	0.30	1.90	0.45	3	10	7	11	<2	0.6	2	9
51	2.96	9.09	0.50	3.00	0.67	<2	15	6	<5	<2	1.2	2	<5
49	2.54	6.39	0.50	2.27	0.44	4	14	9	6	<2	0.7	<2	<5
47	2.08	6.34	0.30	2.32	0.25	<2	11	<5	5	<2	0.7	<2	<5
45	2.38	6.44	0.40	2.34	0.33	<2	12	11	14	<2	0.7	<2	9
44	1.78	6.53	0.30	2.44	0.26	<2	10	9	<5	4	0.8	<2	8
39	1.79	6.64	0.30	2.39	0.27	<2	12	8	9	<2	0.8	<2	<5
15	1.65	5.44	0.30	1.87	1.37	<2	11	<5	6	<2	0.7	<2	7
0	11.80	6.26	0.30	2.26	14.20	<2	11	11	<5	<2	0.8	<2	7
<19	11.70	3.40	0.30	0.98	13.80	<2	7	<5	10	34	<0.2	<2	<5

