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Geochemical characteristics of the Church Rock 1 and 1 East uranium deposits, Grants uranium region, New Mexico

By

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ABSTRACT

In the Church Rock 1 and 1 East mines, Grants uranium region (GUR), New Mexico, uranium orebodies occur within three sandstone units in the upper part of the Westwater Canyon Member of the late Jurassic Morrison Formation. Geochemical analyses reveal that organic carbon contents in ore samples from all three sand units are uniformly low (most are less than 0.01 percent). Vanadium (ranging from 0.0002 to 0.19 percent) and sulfur (ranging from <0.01 to 0.74 percent) typically show positive correlations with uranium; however, vanadium contents rarely exceed those of uranium in ore samples. Although no systematic relationship of either selenium or molybdenum to uranium is evident, some ore samples contain anomalously high concentrations of either of these elements.

Geochemically, the ore deposits of the Church Rock area contrast greatly with primary (tabular) uranium orebodies in the GUR which contain abundant organic carbon and greater amounts of vanadium and sulfur.

These differences and radiometric age determinations strongly suggest that the Church Rock ores formed as a result of the redistribution of uranium from preexisting uranium deposits within the last 1 m.y. However, the Church Rock deposits differ geochemically from redistributed orebodies in the Westwater Canyon Member elsewhere in the GUR. Specifically, redistributed orebodies in the Ambrosia Lake district, which are comparable in contents of uranium and organic carbon with the Church Rock deposits, are characterized by vanadium contents typically higher than those of uranium. Similarly, sulfur contents in the redistributed deposits of the Ambrosia Lake district are greater than those found in the Church Rock ores. In addition, anomalously high concentrations of molybdenum have rarely been found in other redistributed orebodies of the GUR.

INTRODUCTION

Two types of uranium orebodies, which display markedly different geochemical signatures, occur within the sandstone units of the Jurassic Morrison Formation in the Grants uranium region (GUR) of New Mexico. The two types of orebodies, referred to as (1) primary (or tabular) and (2) redistributed (secondary) orebodies were originally described by Granger and others (1961) for the deposits in the Ambrosia Lake area of the GUR (fig. 1). Such terminology has since been widely used in describing deposits elsewhere in the GUR. In this paper we address the question of whether the deposits exposed in the Church Rock 1 and adjacent 1 East uranium mines, both

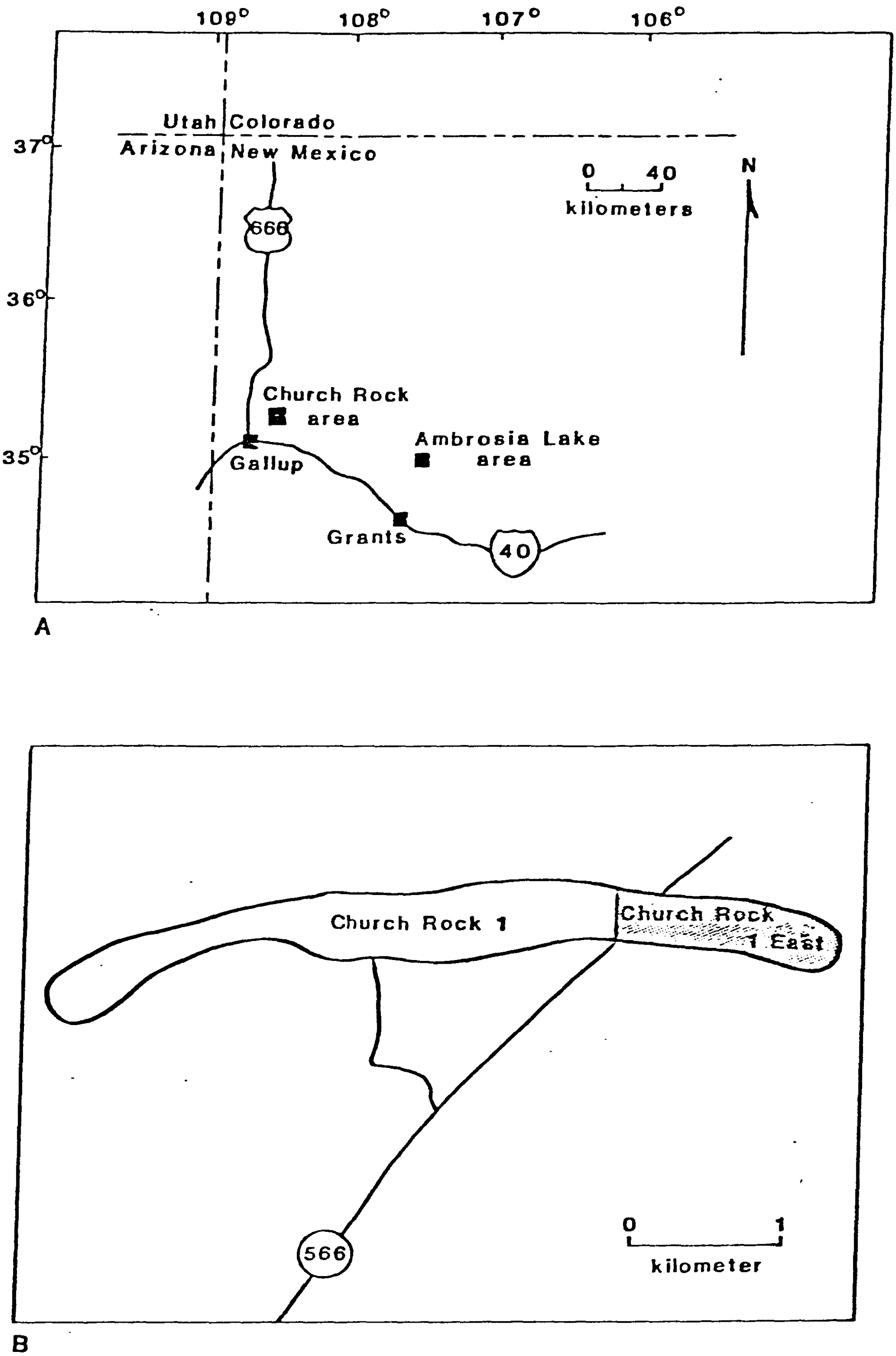

Figure 1.--Maps showing, A, the locations of the Church Rock and Ambrosia Lake areas, and B, the approximate limits of uranium mineralization at the Church Rock 1 and 1 East mines which together comprise mineralization in the Church Rock area.

of which occur in the westernmost part of the GUR (fig. 1), represent primary or redistributed ores. Such determinations are important in understanding the mechanisms of epigenetic uranium mineralization throughout the GUR and particularly in the vicinity of the Church Rock deposits.

Primary deposits, which formed at least 100 m.y. ago (Lee and Brookins, 1978; Ludwig and others, 1982; Ludwig and Webster, 1983) are peneconcordant tabular layers of mineralized rock suspended within the host sandstone and characterized by an enrichment of organic carbon in ore zones. The abundance of organic carbon in these primary deposits results from the partial impregnation of the host sandstone with a post-depositionally introduced amorphous organic material; the organic material is of paramount importance in that it served to localize and concentrate uranium to form the primary orebodies (Granger and others, 1961; Adams and others, 1978; Leventhal, 1980). As a result, a positive (nearly 1:1) correlation exists between whole rock abundances of uranium and organic carbon in ore zones (Granger and others, 1961; Leventhal, 1980; Fishman and Reynolds, 1982). In addition, ore zones commonly contain anomalous amounts of vanadium, but vanadium abundances are far less than those of uranium. Selenium and molybdenum may be enriched in ore zones but more typically occur in anomalous concentrations along the margins of the orebodies (Granger and others, 1961; Squyres, 1970).

In contrast, the redistributed orebodies in the Ambrosia Lake area, which formed about 8-10 m.y. ago (Ludwig and Webster, 1983), display more irregularities in orebody shape than do primary deposits. Redistributed orebodies represent accumulations of uranium recycled from preexisting primary deposits (Granger and others, 1961; Squyres, 1970). Such recycling resulted from the partial destruction of primary deposits by oxygenated groundwaters which began infiltrating Morrison strata in late Tertiary time (Saucier, 1980). Redistributed deposits characteristically contain only very minor amounts of organic carbon (Granger and others, 1961). Moreover, vanadium contents in redistributed ores commonly exceed those of uranium (Granger and others, 1961; Squyres, 1970; Spirakis and others, 1981). Although selenium enrichments may occur throughout ore zones, anomalously high selenium concentrations often occur along boundaries between mineralized and unmineralized rock. Detectable amounts of molybdenum have rarely been observed in ore zones or unmineralized rock adjacent to those redistributed orebodies studied thus far (Granger and others, 1961; Squyres, 1970).

The enrichment of sulfur and iron may occur in ore zones of both primary and redistributed deposits (Granger and others, 1961; Spirakis and others, 1981; Fishman and Reynolds, 1982; M. B. Goldhaber, oral commun., 1982). As such, neither element provides adequate diagnostic information useful in distinguishing primary from redistributed deposits.

The complete set of geochemical data from samples collected in the Church Rock mines is presented in this report, particular attention is paid to contents of uranium, organic carbon, vanadium, selenium, and molybdenum in sandstone units. A positive correlation between whole rock abundances of organic carbon and uranium would suggest primary-type uranium mineralization for the Church Rock deposits. If such were the case, one could also expect to find vanadium and selenium enrichment in ore zones and molybdenum in rock adjacent to ores. Conversely, low contents of organic carbon, and vanadium concentrations in excess of those of uranium would imply a redistributed-type origin for the Church Rock deposits. If so, one would anticipate finding selenium enrichment at the margins of mineralized rock and little or no molybdenum.

SAMPLING AND ANALYTICAL METHODS

Fluvial sandstones of the Westwater Canyon Member of the Morrison Formation host a majority of the uranium deposits, both primary and redistributed, throughout the GUR. Detailed stratigraphic and sedimentologic studies of the Morrison Formation, including the Westwater Canyon interval, can be found in Craig and others (1955), Turner-Peterson and others (1980), and Kirk and others (1982).

The orebodies discussed in this paper comprise a significant portion of uranium mineralization in the Church Rock area. Studies of uranium deposits in other parts of the Church Rock area can be found in Ludwig and others (1982) and Peterson (1980). Uranium mineralization (mineralization defined as rock containing greater than 0.01 percent uranium) in the Church Rock 1 and 1 East deposits occurs within three sandstone units in the upper half of the Westwater Canyon Member. These three units, all of which occur below the pre-mining groundwater table, are informally designated the C, D, and E sand units (fig. 2) and separated from each other by mudstone units of variable thicknesses. Although each of the three units was sampled, 66 of the 89 sandstone samples collected for our studies were from the lowermost (E) sand exposed in the Church Rock 1 mine. Eight sandstone samples from various localities in the D sand and seven from the C sand were also collected from the Church Rock 1 mine. Eight sandstone samples from the C sand were collected in the Church Rock 1 East mine. Two samples of mudstone galls incorporated as detrital rip-up clasts in the sandstone were also collected (CR-3-2 and CR-4-1) from the E sand. Although the analytical results for these galls are presented in this paper, our discussion of the geochemical characteristics of the Church Rock ores is limited to the sandstone samples.

A portion of each sample was submitted to the laboratories of the U.S. Geological Survey in Denver for chemical analyses. Uranium contents were determined by delayed neutron techniques (Millard, 1976), organic carbon and sulfur by induction furnace techniques (Stanton and others, 1983), and selenium by X-ray fluorescence. Contents of the remaining elements listed in this paper were determined by inductively coupled plasma (ICP) techniques (Taggart and others, 1981).

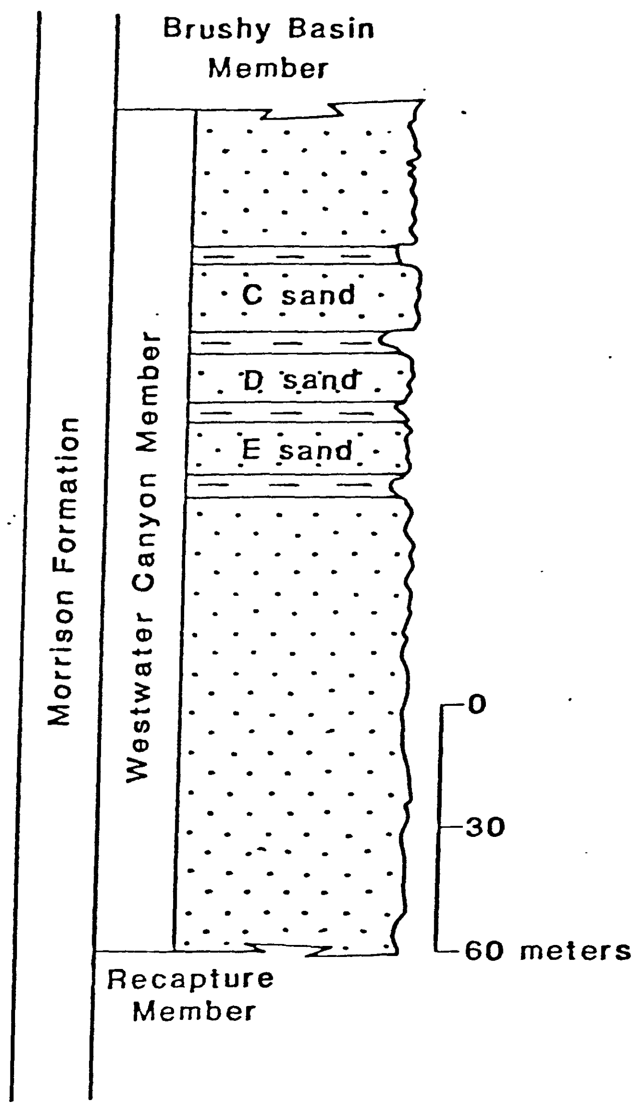

Figure 2.--Stratigraphic column showing the positions of C, D, and E sand units within the Westwater Canyon Member of the Morrison Formation.

DATA PRESENTATION

The locations of samples[1/] collected from the E sand are shown in figure 3. Analytical data from the E sand samples are listed in appendix 1, and the abundance and distribution of selected elements in sampling suites CR-1, CR-2, CR-6, CR-31, and CR-35 are shown in figures 4, 5, 6, 7, and 8 respectively. Locations of D sand samples are shown in figure 9, and the analytical data for these samples are listed in appendix 2. Sampling locations of the C sand samples are shown in figure 10 with respective analytical data listed in appendix 3 and elemental abundances and distribution in figure 11. The location of samples collected from the Church Rock 1 East mine are shown in figure 12 and the corresponding analytical data are listed in appendix 4. Rock colors shown in the above figures were made by direct comparison of the samples with the Rock-color Chart (Goddard and others, 1948).

Numerous elements were not detected in any of the samples by the ICP techniques and are listed, along with detection limits for those elements, in appendix 5. Additionally, some elements were detected in only a few samples; these samples and their respective analytical data are also listed in appendix 5.

DISCUSSION AND CONCLUSIONS

Whole rock abundances of organic carbon are commonly less than 0.01 percent (see app. 1-4) in 55 of the samples from the Church Rock deposits. The remaining 32 samples contain organic carbon contents ranging from 0.02 to 0.84 percent with uranium contents for the same samples ranging from 0.001 to 3.68 percent. No positive correlation exists between whole rock abundances of uranium and organic carbon for samples from any single sand unit (fig. 13).

Vanadium contents of samples from the E sand correlate positively with those of uranium (figs. 4,5,6,7, and 8); however, vanadium contents (ranging from 0.0025 to 0.035 percent) are typically less than those of uranium in ore samples (ranging from 0.01 to 0.418 percent). Vanadium contents of samples from the D sand range from 0.0062 to 0.41 percent with uranium values of these samples ranging from 0.071 to 1.090 percent. Vanadium concentrations in C sand (ranging from 0.010 to 0.10 percent) samples also correlate somewhat with concentrations of uranium (ranging between 0.021 to 3.86 percent).

Molybdenum contents are ubiquitously low (less than 0.005 percent) in all samples from the E sand, whereas, molybdenum contents as high as 0.085 percent were detected in samples from the C sand (appendix 3) and as high as 0.036 percent from the D sand (appendix 2). Inasmuch as our sample control from the C and D sands is very limited, it is unclear whether differing molybdenum

[1/] Our sample numbering is explained by the following: sample CR-1-2 was collected from the Church Rock deposit (CR-1-2), at sampling location 1 (CR-1-2), and is the second sample in a suite collected from that location (CR-1-2).

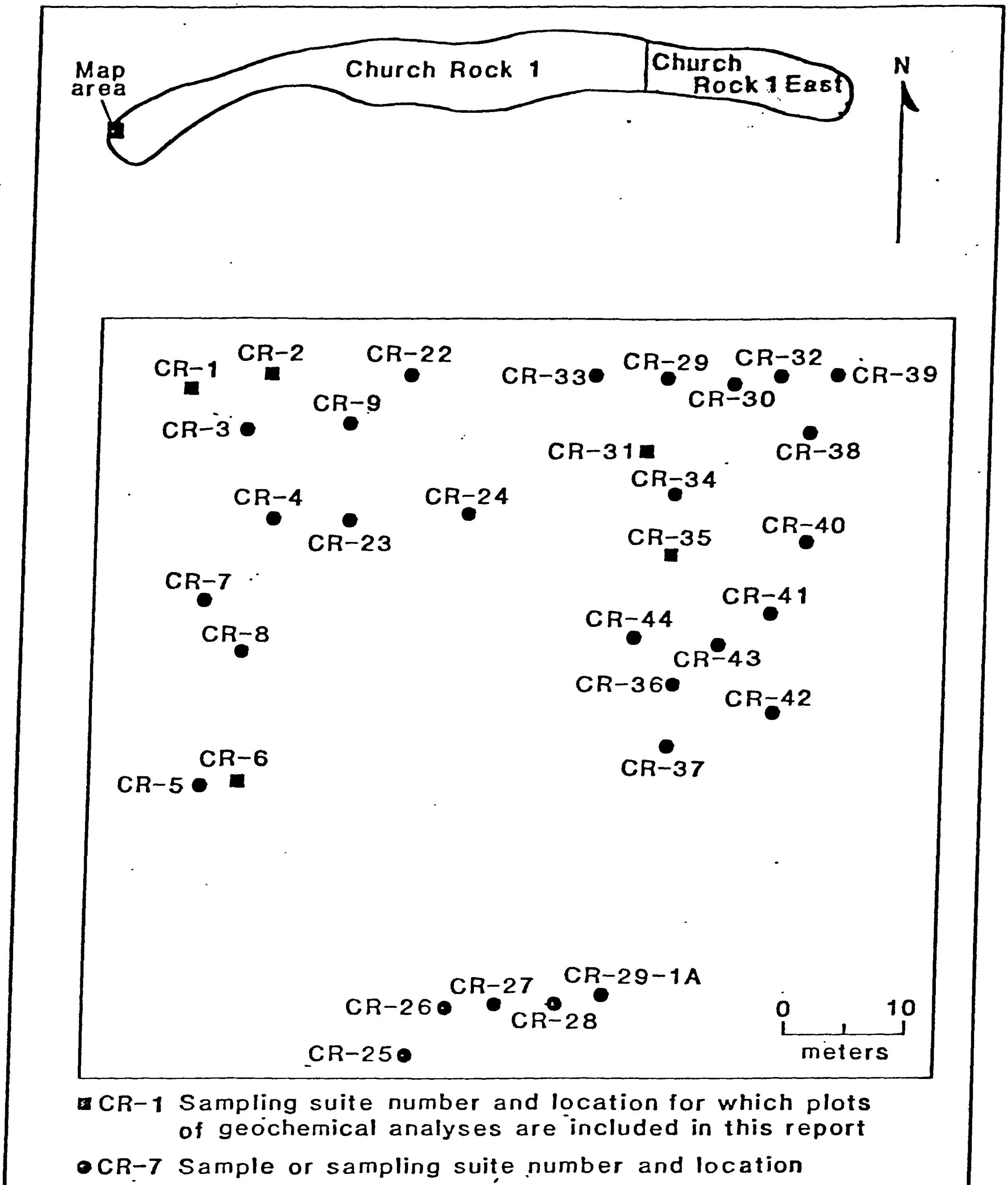

Figure 3.--Plan map of the Church Rock deposits showing the location of samples and sampling suites collected from the E sand unit, Church Rock 1 mine.

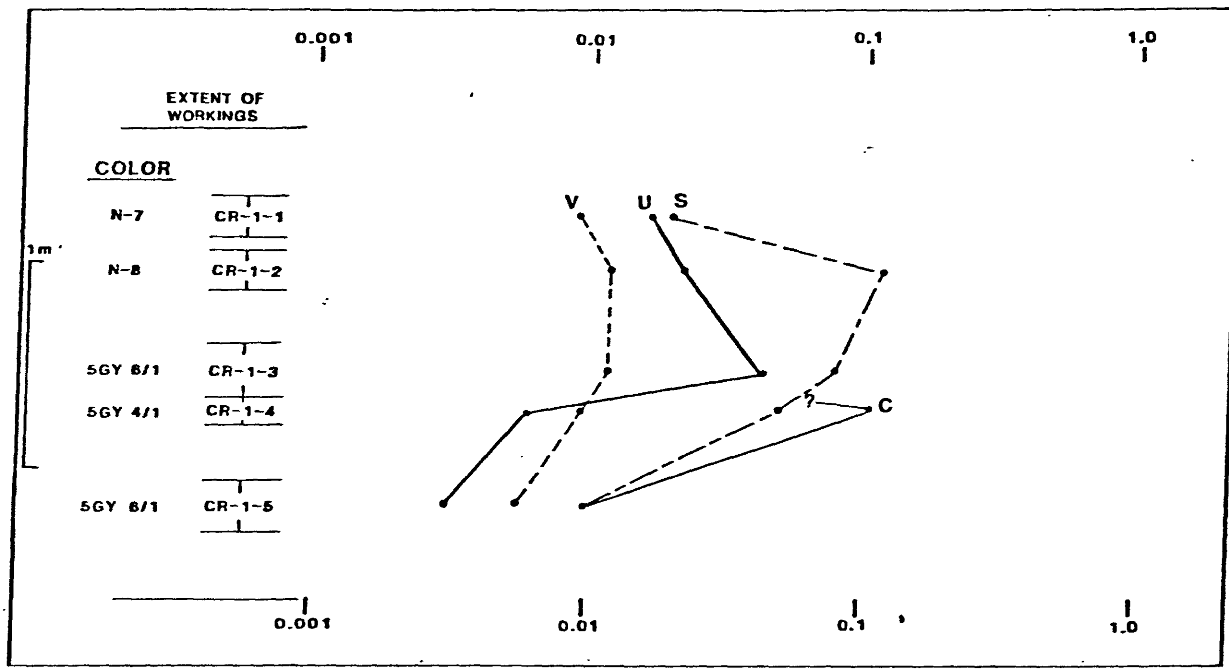

Figure 4.--Distribution of uranium (U), organic carbon (C), vanadium (V), and sulfur (S) in vertical sampling suite CR-1. Analyses reveal indeterminate amounts less than 0.01 percent for organic carbon contents in CR-1-1, CR-1-2, and CR-1-3.

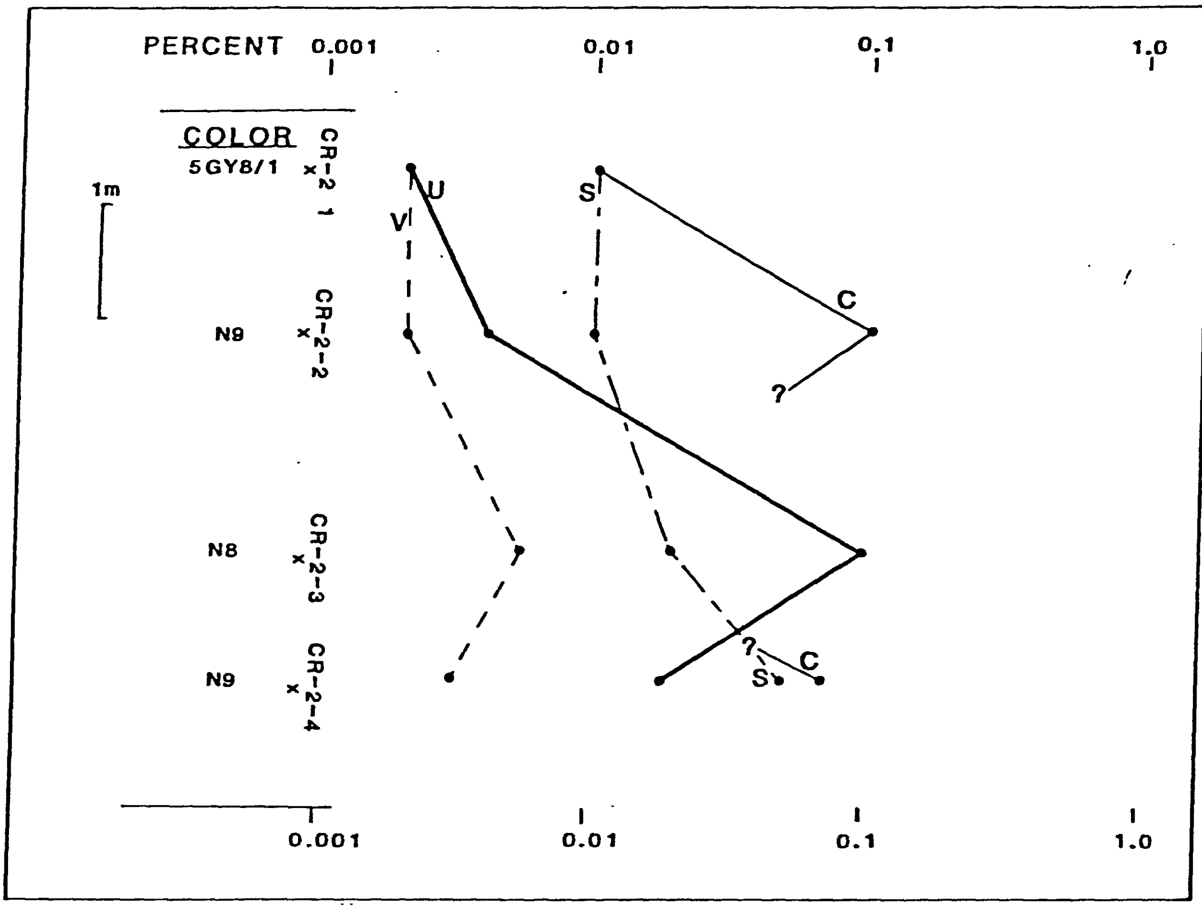

Figure 5.--Distribution of uranium (U), organic carbon (C), vanadium (V), and sulfur (S) in horizontal sampling suite CR-2. Analyses reveal indeterminate amounts less than 0.01 percent for organic carbon contents in CR-2-3.

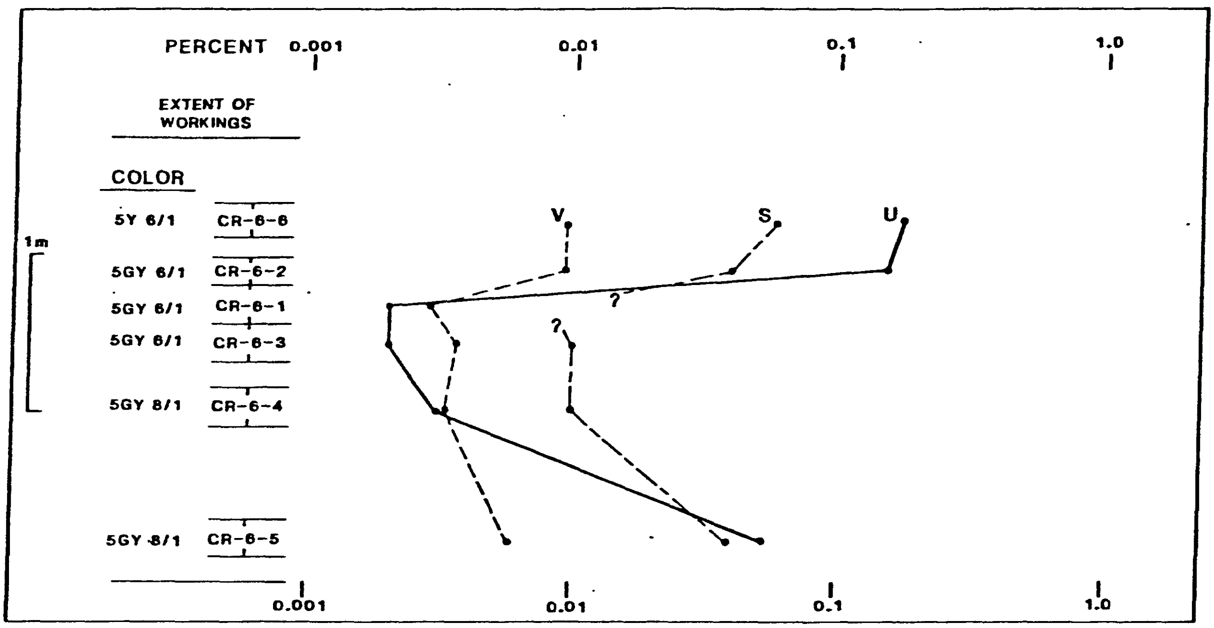

Figure 6.--Distribution of uranium (U), vanadium (V), and sulfur (S) in vertical sampling suite CR-6. Analyses reveal indeterminate amounts less than 0.01 percent for organic carbon in all samples and less than 0.01 percent for sulfur contents in CR-6-1.

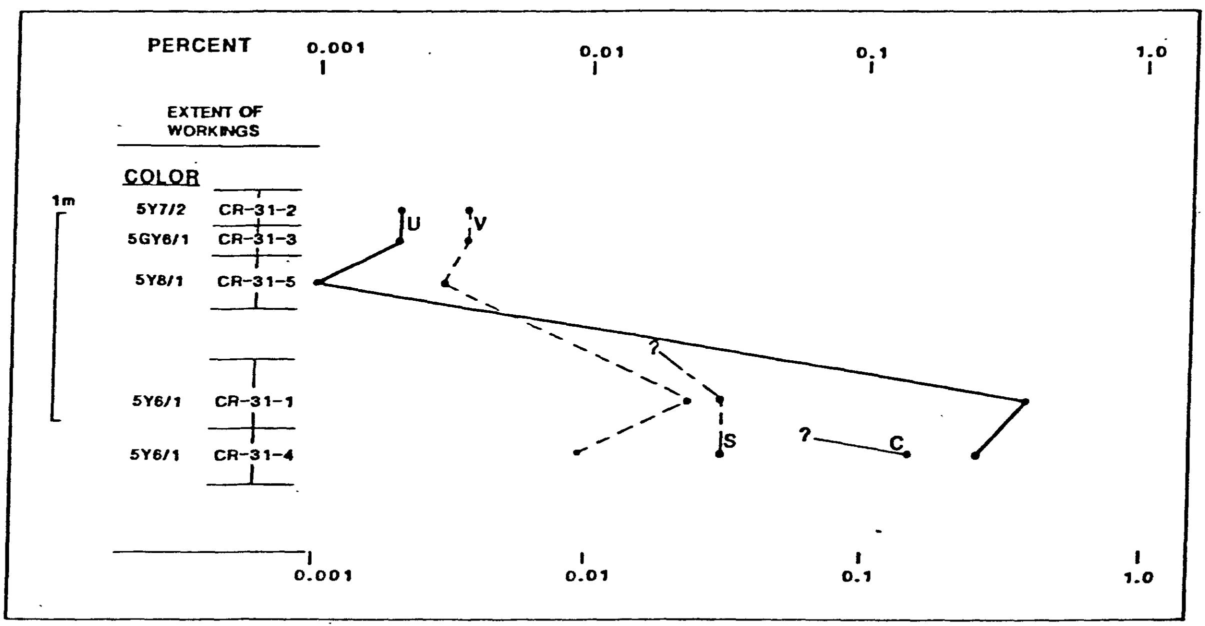

Figure 7.--Distribution of uranium (U), vanadium (V), and sulfur (S) in vertical sampling suite CR-31. Analyses reveal indeterminate amounts less than 0.01 percent for organic carbon contents in all samples except CR-31-4 and less than 0.01 percent for sulfur contents in CR-31-2, CR-31-3, and CR-31-5.

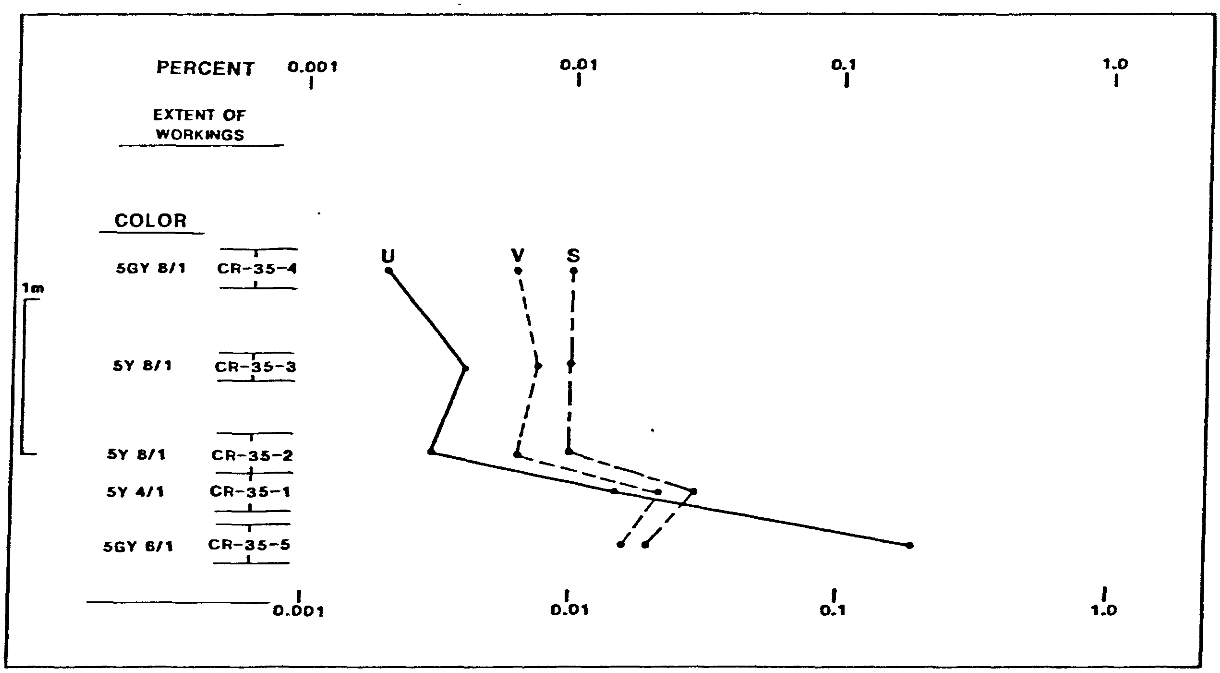

Figure 8.--Distribution of uranium (U), vanadium (V), and sulfur (S) in vertical sampling suite CR-35. Analyses reveal indeterminate amounts less than 0.01 percent for organic carbon in all samples.

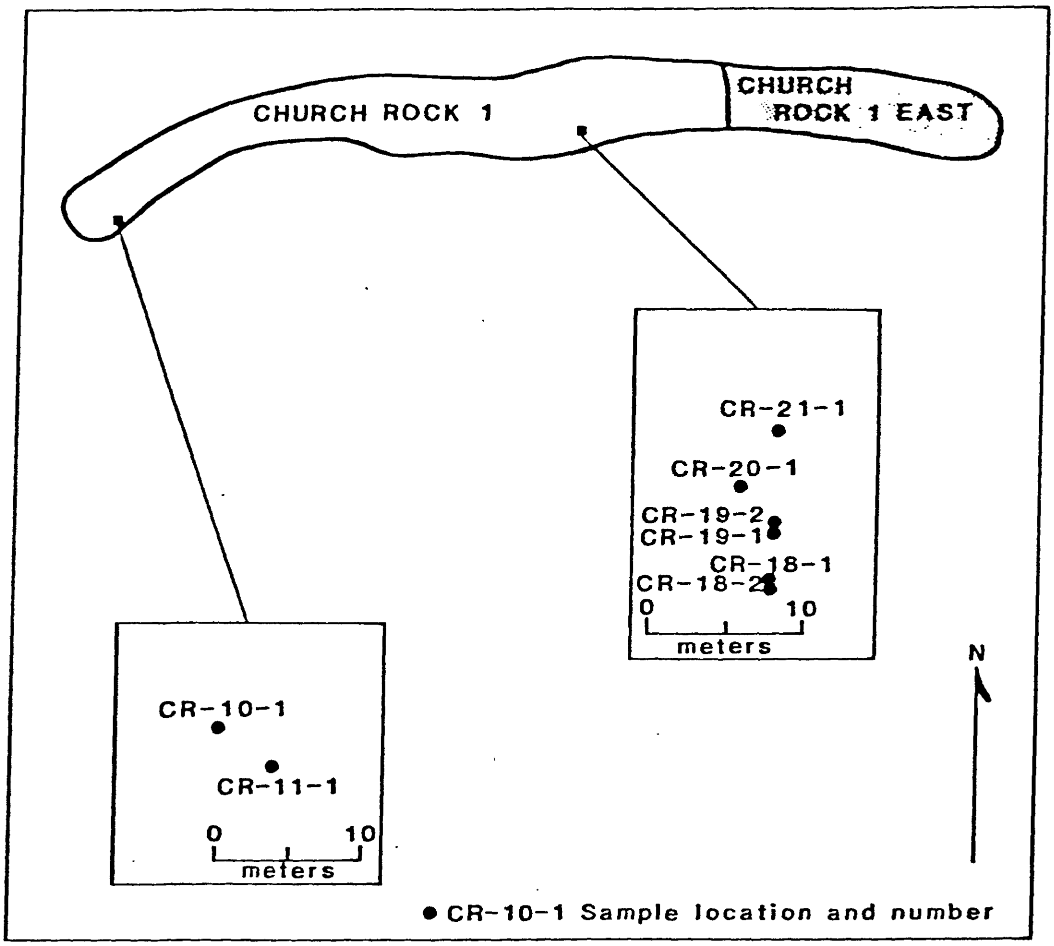

Figure 9.--Plan map of the Church Rock deposits showing the locations of samples collected from the D sand unit, Church Rock 1 mine.

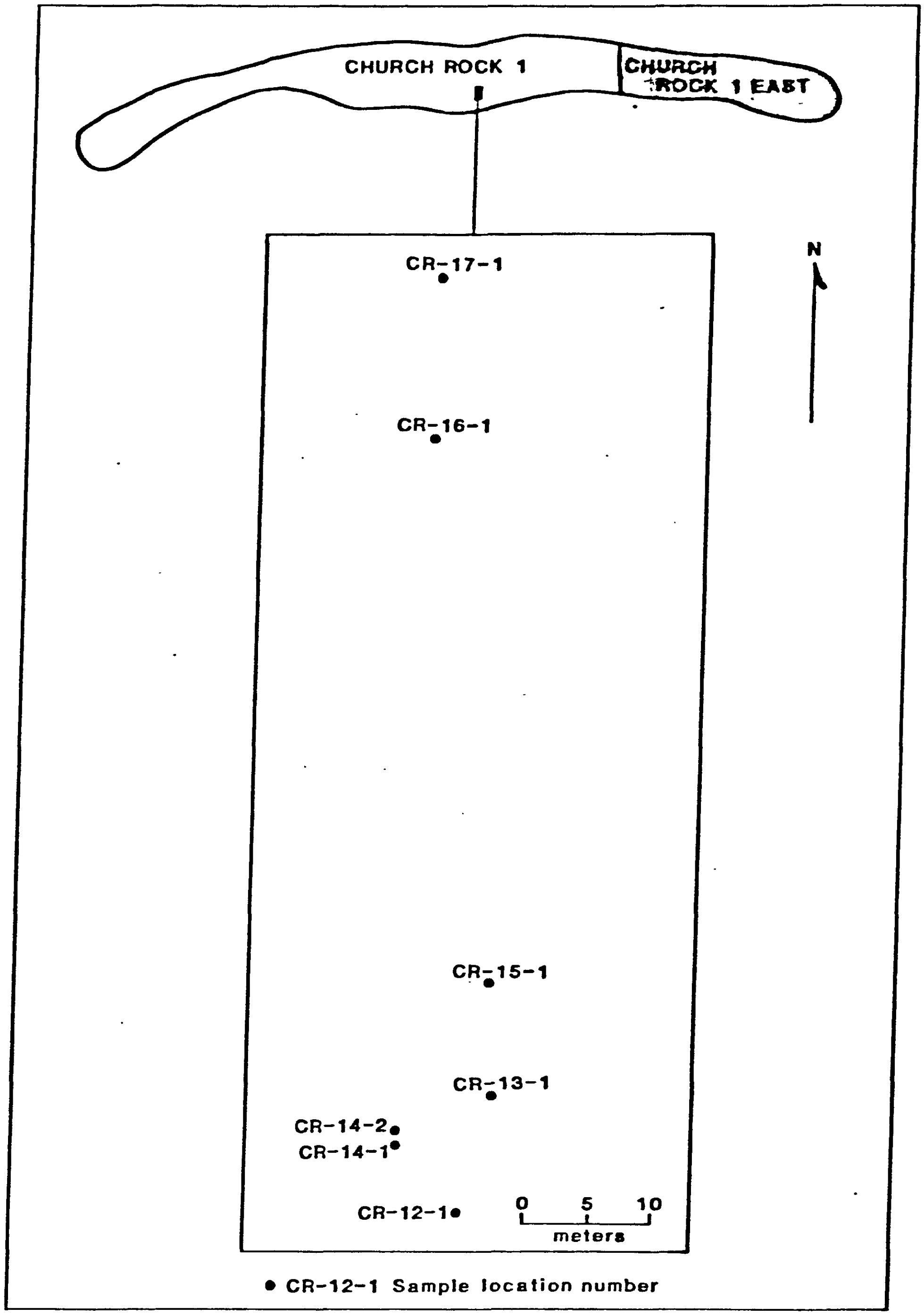

Figure 10.--Plan map of the Church Rock deposits showing the locations of samples collected from the C sand unit in the Church Rock 1 mine.

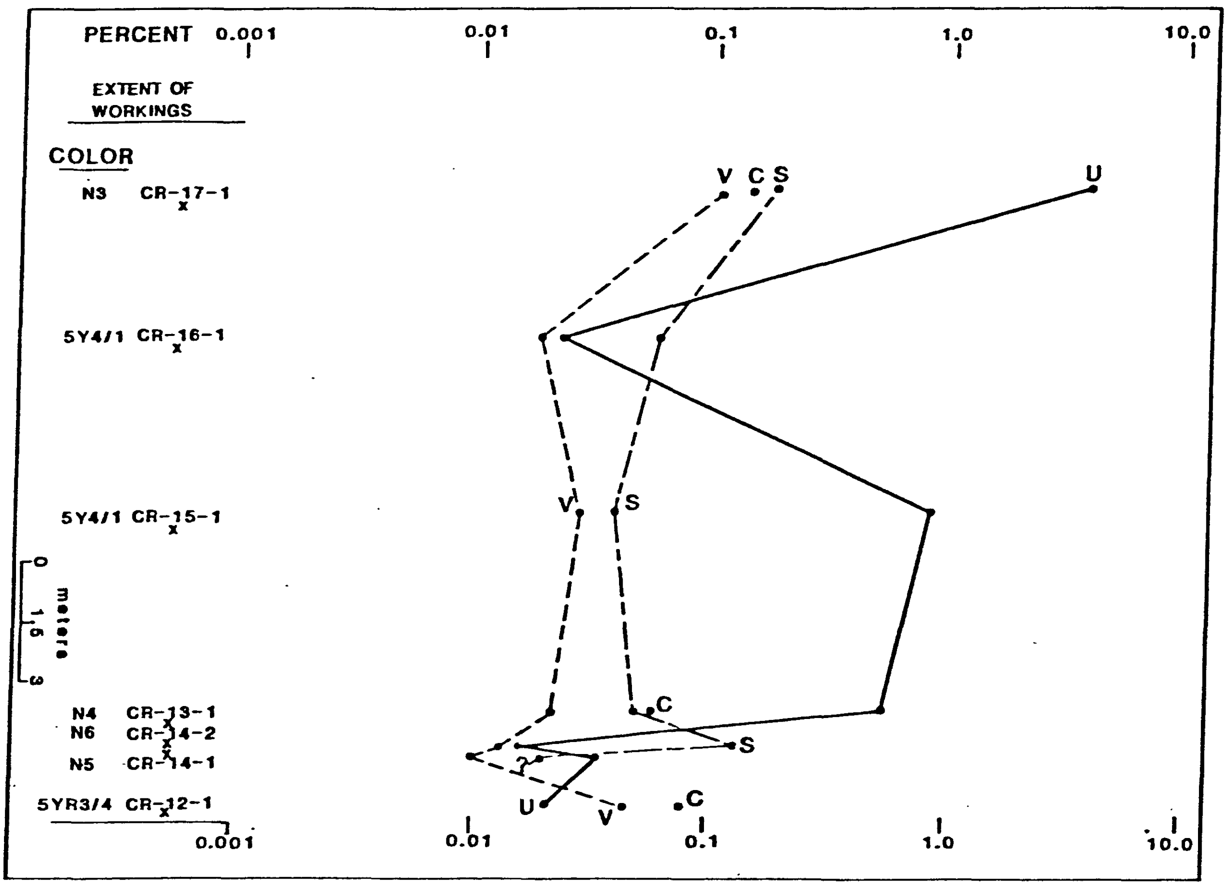

Figure 11.--Distribution of uranium (U), organic carbon (C), vanadium (V), and sulfur (S) in a horizontal sampling suite collected from the C sand unit, Church Rock 1 mine. Analyses reveal indeterminate amounts less than 0.01 percent for organic carbon contents in CR-14-1, CR-14-2, CR-15-1 and CR-16-1 and less than 0.01 percent for sulfur contents in CR-12-1.

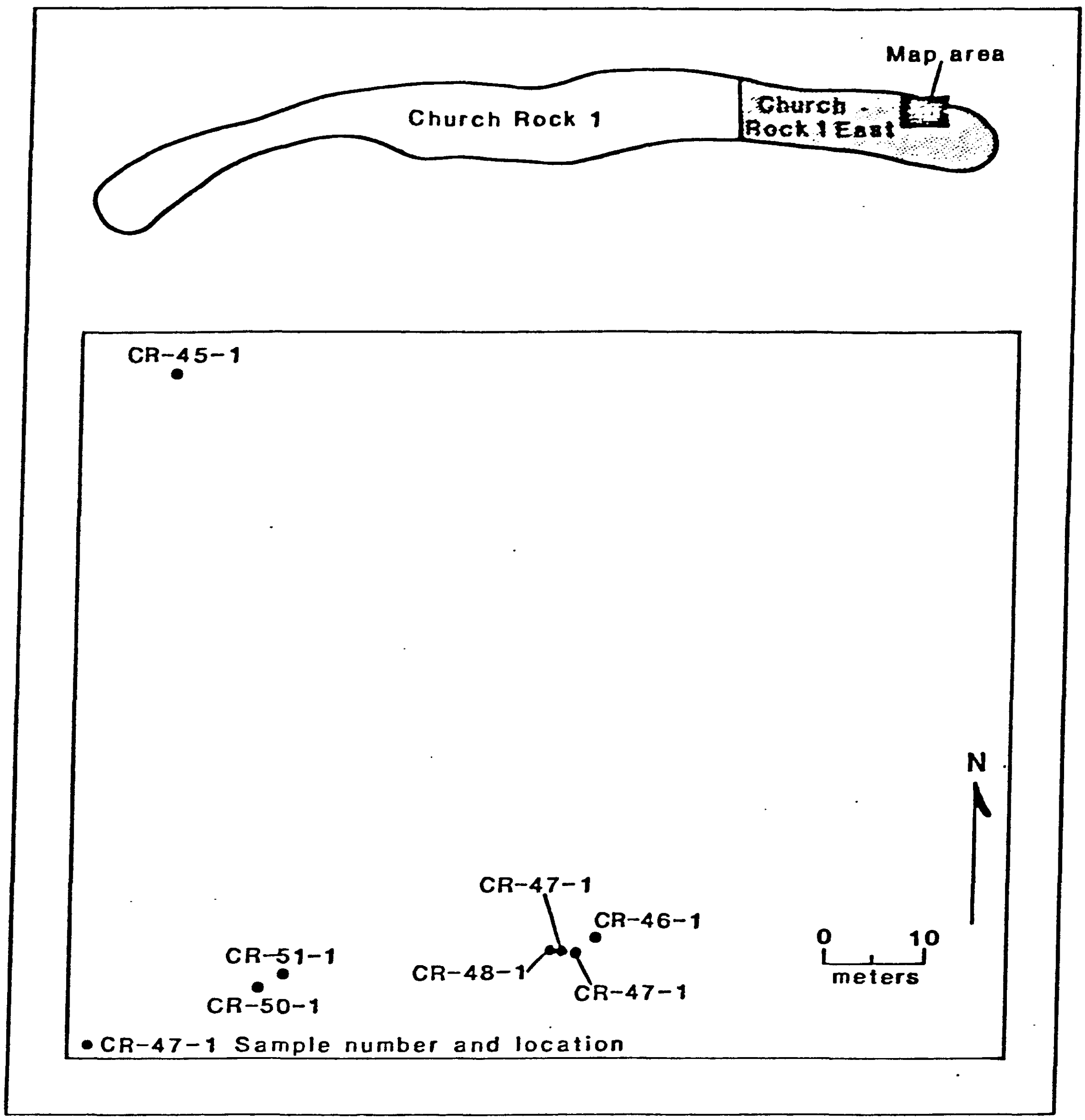

Figure 12.--Plan map of the Church Rock deposits showing the locations of samples collected from the C sand unit in the Church Rock 1 East mine.

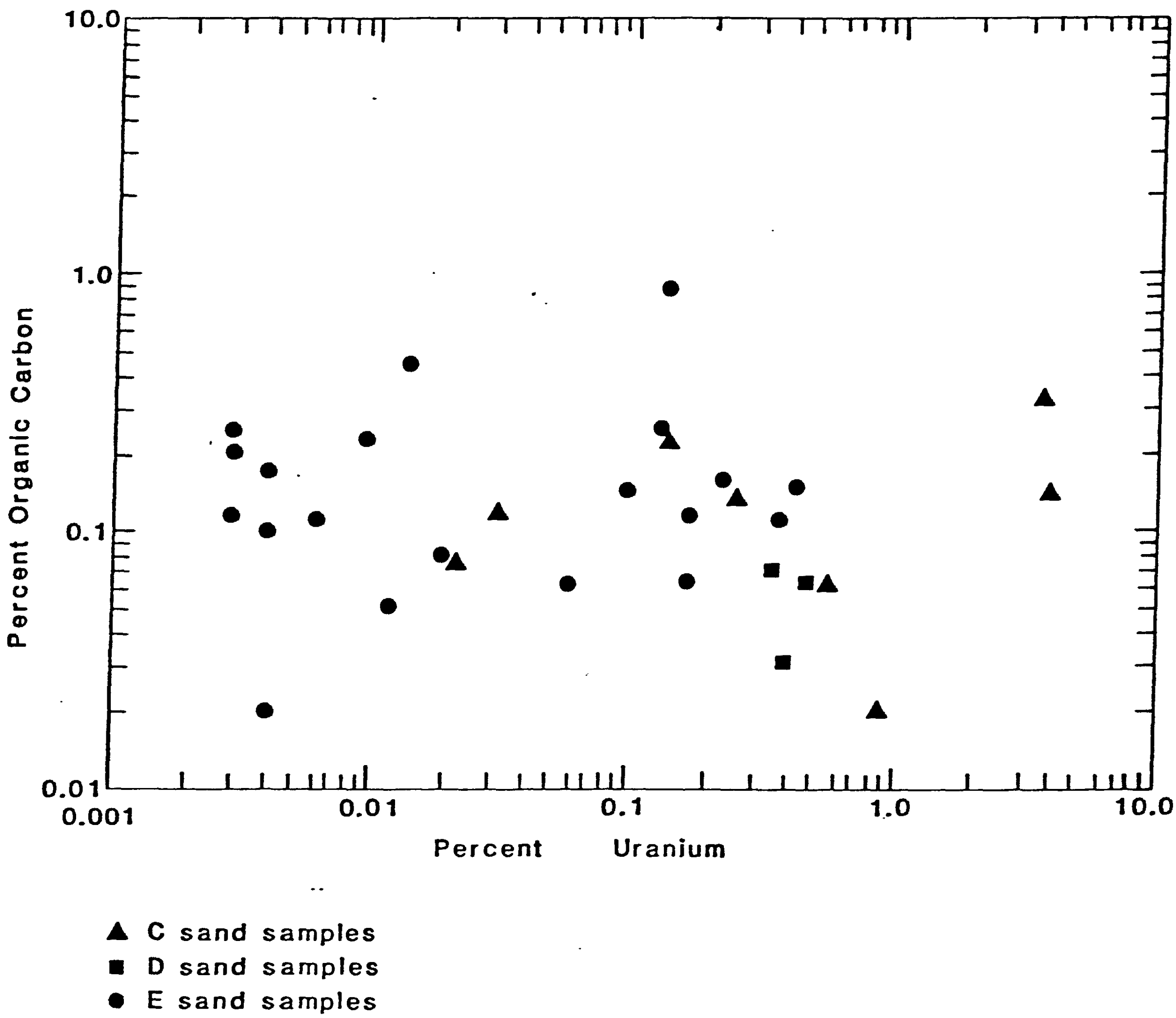

Figure 13.--Plot of organic carbon versus uranium in samples containing organic carbon in excess of 0.01 percent.

contents in the three sands units is significant. Selenium contents in C and D sand samples (appendices 3 and 2 respectively) generally appear to be higher than in E sand samples (appendix 1); however, we feel that because of the limited sampling control in the C and D sands and because selenium contents were determined on only a few E sand samples, the data are inconclusive.

The low concentrations of organic carbon in the many of the uranium mineralized samples from the Church Rock orebodies and the general lack of a correlation between organic carbon and uranium contents in remaining ore samples indicates the deposits are not primary orebodies. That the geochemical data suggest the Church Rock ores do not represent primary uranium mineralization is consistent with U-Pb apparent ages of less than 1 m.y. for the Church Rock ores[2/] (Ludwig and others, 1982).

The relatively low concentrations of vanadium and sulfur in the Church Rock ores and the presence of molybdenum in some mineralized samples indicates the Church Rock ores display different geochemical characteristics from redistributed deposits that have been described from the Ambrosia Lake area in the GUR. In addition, the Pleistocene ages determined for the Church Rock ores (with the exception of CR-17-1) are somewhat younger than the Pliocene ages determined for redistributed deposits in the Ambrosia Lake area (Ludwig and Webster, 1983). As such, the geochemical characteristics and ages of the Church Rock ores are previously undocumented for uranium deposits in the GUR.

The differences in geochemical characteristics and ages between the Church Rock ores and the redistributed ores in the Ambrosia Lake area raise several fundamental questions. Do the geochemical differences between the Church Rock and Ambrosia Lake ores reflect different geochemical signatures of the parent primary orebodies from which they were derived? Alternatively, could the geochemical dissimilarities between the Church Rock and Ambrosia Lake redistributed ores have resulted from differing pore water conditions (pH, Eh, etc.) in the two areas during mineralization? On the other hand, could the geochemical characteristics and young ages of the Church Rock ores reflect multiple recycling of metals (especially U, V, Mo, and Se) through several, perhaps temporally discrete events? If so, could such multiple recycling have resulted in the depletion of vanadium and possible enrichment of molybdenum, and selenium in the geochemical system from which the Church Rock orebodies also formed? Finally, in that chemical reductants (organic carbon, sulfur, vanadium) typically responsible for epigenetic uranium mineralization are only present in minor amounts in the Church Rock deposits,

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[2/] U-Pb apparent age of $\leq$ 1 m.y. was determined for 4 of 5 Church Rock ore samples; one exception, CR-17-1, gave a U-Pb apparent age of about 10 m.y. (Ludwig and others, 1982). We suggest the anomalously old age of CR-17-1 reflects the presence of minor amounts of old uranium ore with abundant younger ore. This suggestion is based on petrographic and autoradiographic observations of CR-17-1 which reveal the presence of minor amounts of uraniferous amorphous organic material and uranium minerals not associated with the organic material.

could other processes (e.g. adsorption of uranium by authigenic clay minerals) have led to Church Rock uranium mineralization? Addressing these questions will not only contribute to understanding the geochemical and age differences between the Church Rock and Ambrosia Lake ores, but also help to identify those factors responsible for Church Rock uranium mineralization.

ACKNOWLEDGEMENTS

We wish to thank the Kerr-McGee Corporation for allowing access and sampling privileges to the Church Rock mines. We are also grateful to mine geologist Russ Branyan for many helpful discussions and for supplying us with additional information concerning the geology of the Church Rock area. Analytical work performed by P. Briggs, M. Coughlin, S. Danahey, Y. d'Agelis, G. Mason, V. Shaw, J. Storey, and B. Vaughn is greatly appreciated.

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Appendix 1.--Analyses of samples from the E sand unit in the Church Rock 1 mine, McKinley County, New Mexico [--, not determined; Ss, sandstone; M, mudstone gall; a, organic carbon contents; b, total sulfur contents; c, total iron contents]

Sample number	CR-1-1	1-2	1-3	1-4	1-5	2-1	2-2	2-3	2-4	3-1
Lithology	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss
%										
U	0.017	0.023	0.045	0.006	0.003	0.002	0.004	0.099	0.019	0.276
C[a]	<0.01	<0.01	<0.01	0.11	0.01	0.01	0.10	<0.01	0.08	<0.01
S[b]	0.02	0.12	0.08	0.05	0.01	0.01	0.01	0.02	0.05	0.05
Al	5.0	4.8	5.1	8.3	5.5	3.5	3.6	4.3	5.0	5.0
Fe[c]	0.39	0.64	0.60	2.7	4.3	0.47	0.35	0.44	0.39	0.41
Mg	0.09	0.12	0.13	1.0	0.81	0.11	0.11	0.11	0.10	0.13
Ca	0.11	0.11	0.11	0.42	0.20	0.08	8.9	0.13	0.12	0.17
Na	1.1	1.1	1.1	0.35	0.42	0.78	0.80	0.93	1.1	1.3
K	2.7	2.5	2.3	3.3	1.9	1.4	1.8	1.8	2.4	2.6
Ti	0.07	0.11	0.07	0.33	0.19	0.11	0.08	0.09	0.06	0.06
ppm										
Ba	800	830	1000	1100	710	530	590	670	780	1300
Be	<1	<1	<1	4	2	<1	<1	<1	<1	<1
Ce	33	32	31	22	51	16	23	30	28	28
Co	<2	<2	<2	8	4	<2	<2	<2	<2	<2
Cr	<5	<5	<5	20	8	<5	<5	<5	<5	<5
Cu	<2	6	5	18	12	<2	2	3	3	3
Ga	10	10	10	30	20	<10	<10	<10	10	<10
La	16	16	15	14	26	10	12	16	18	16
Li	10	10	11	25	26	9	8	8	11	9
Mn	5	15	15	180	310	11	3200	18	<5	25
Mo	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ni	<5	<5	<5	9	<5	<5	<5	<5	<5	<5
Pb	20	<20	<20	20	<20	40	<20	<20	<20	<20
Sc	<5	<5	<5	15	<5	<5	<5	<5	<5	<5
Se	--	11	--	--	--	--	--	<0.1	--	44
Sr	110	110	120	230	130	75	200	88	100	120
Th	<5	<5	<5	9	<5	<5	<5	<5	<5	<5
V	90	120	120	98	56	20	20	56	31	200
Y	5	<5	5	26	17	<5	12	5	6	<5
Zn	9	12	18	70	71	8	13	9	9	19
Nd	5	7	18	12	17	<4	4	13	11	11
Gd	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Yb	<2	<2	<2	3	<2	<2	<2	<2	<2	<2

Appendix 1.--Analyses of samples from the E sand unit in the Church Rock 1 mine, McKinley County, New Mexico--continued

Sample number	CR-3-2	3-3	4-1	4-2	4-3	5-1	5-2	5-3	6-1	6-2
Lithology	M	Ss	M	Ss	Ss	Ss	Ss	Ss	Ss	Ss
%										
U	4.180	0.257	2.320	0.089	0.287	0.015	0.005	0.002	0.002	0.151
C[a]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
S[b]	0.14	0.05	0.16	0.08	0.04	0.41	0.03	0.03	<0.01	0.04
Al	5.0	4.3	4.1	5.7	3.5	5.2	4.3	4.8	4.6	5.3
Fe[c]	1.0	0.45	2.3	2.8	1.8	0.70	0.60	0.54	2.2	1.2
Mg	0.30	0.10	0.45	0.69	0.28	0.15	0.29	0.12	0.49	0.25
Ca	0.30	0.10	0.18	0.24	0.09	0.12	0.23	0.11	0.16	0.14
Na	0.91	0.96	0.64	0.52	0.70	1.1	0.91	1.0	0.64	1.0
K	3.1	1.9	1.6	2.3	1.4	3.1	2.1	2.4	2.0	2.7
Ti	0.15	0.07	0.16	0.21	0.23	0.07	0.12	0.08	0.13	0.07
ppm										
Ba	3600	970	500	680	1300	900	880	720	590	830
Be	3	<1	2	3	<1	<1	<1	<1	2	1
Ce	82	20	52	38	41	47	29	36	52	78
Co	7	<2	6	4	3	2	<2	<2	3	3
Cr	13	<5	9	9	6	<5	6	<5	<5	<5
Cu	46	3	14	9	5	5	6	2	6	7
Ga	60	<10	40	20	10	<10	10	<10	<10	20
La	63	14	32	23	23	25	14	20	24	48
Li	12	9	19	18	17	12	9	11	15	16
Mn	150	15	170	190	110	26	29	13	140	63
Mo	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ni	11	<5	8	7	7	5	<5	5	8	7
Pb	170	<20	50	<20	20	20	<20	<20	<20	<20
Sc	5	<5	<5	8	<5	<5	<5	<5	<5	<5
Se	--	--	--	--	110	0.4	0.2	<0.1	0.1	0.2
Sr	280	110	150	140	83	120	120	95	120	130
Th	20	<5	5	<5	<5	<5	<5	<5	<5	<5
V	1300	190	1900	85	370	66	32	28	28	92
Y	30	<5	20	23	7	6	7	6	10	10
Zn	23	17	64	45	56	19	13	11	36	21
Nd	12	12	18	15	19	20	5	16	12	39
Gd	90	<20	80	<20	<20	<20	<20	<20	<20	<20
Yb	9	<2	5	3	<2	<2	<2	<2	<2	<2

Appendix 1.--Analyses of samples from the E sand unit in the Church Rock 1 mine, McKinley County, New Mexico--continued

Sample number	CR-6-3	6-4	6-5	6-6	7-1	8-1	8-2	9-1	22-1	22-2
Lithology	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss
%										
U	0.002	0.003	0.054	0.175	0.004	0.006	0.233	0.009	0.064	0.078
C[a]	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	0.24	<0.01	<0.01
S[b]	0.01	0.01	0.04	0.06	0.01	0.03	0.05	0.02	0.04	0.03
Al	4.4	4.2	4.5	5.4	5.6	4.8	4.6	3.5	3.6	4.9
Fe[c]	1.5	0.61	0.81	0.53	2.2	1.7	1.4	0.54	0.95	0.48
Mg	0.41	0.22	0.18	0.13	0.53	0.48	0.28	0.14	0.24	0.12
Ca	0.16	0.15	0.11	0.14	0.23	0.18	0.15	9.5	0.11	0.11
Na	0.67	0.78	0.95	1.2	0.57	0.63	0.79	0.78	0.65	1.1
K	2.2	1.8	1.9	2.8	1.9	2.1	1.5	2.0	2.1	2.8
Ti	0.14	0.11	0.11	0.06	0.18	0.16	0.12	0.12	0.18	0.1
ppm										
Ba	580	630	660	950	690	600	670	600	590	820
Be	2	<1	<1	<1	2	2	1	<1	<1	<1
Ce	31	28	31	39	52	36	39	28	31	32
Co	2	<2	3	2	3	<2	3	<2	<2	<2
Cr	<5	<5	<5	<5	<5	6	<5	<5	9	6
Cu	5	3	3	2	7	6	5	<4	6	3
Ga	10	10	<10	10	10	20	20	<10	<10	10
La	17	14	17	21	33	19	21	13	17	20
Li	14	9	11	12	17	14	17	9	11	11
Mn	88	19	35	10	150	100	87	3600	90	52
Mo	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ni	<5	<5	<5	<5	7	<5	<5	6	<5	<5
Pb	<20	<20	<20	<20	<20	<20	<20	<20	20	20
Sc	<5	<5	<5	<5	6	<5	<5	<5	<5	<5
Se	0.1	<0.1	<0.1	<0.1	<0.1	--	0.2	--	--	--
Sr	110	110	94	130	150	120	110	210	83	98
Th	<5	<5	<5	8	<5	6	7	120	7	<5
V	36	32	57	93	40	53	71	26	62	54
Y	9	6	6	6	20	11	11	15	6	6
Zn	26	16	15	14	45	36	22	12	17	14
Nd	5	<4	5	18	21	24	18	15	12	26
Gd	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Yb	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2

Appendix 1.--Analyses of samples from the E sand unit in the Church Rock 1 mine, McKinley County, New Mexico--continued

Sample number	CR- 23-1	24-1	25-1	26-1	27-1	27-2	28-1	29-1	29-1A	30-1
Lithology	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss
%										
U	0.237	0.316	0.234	0.273	0.418	0.234	0.176	0.387	0.092	0.001
C[a]	0.17	<0.01	<0.01	<0.01	0.16	<0.01	<0.01	<0.01	0.15	0.06
S[b]	0.02	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.01	0.01
Al	4.8	3.6	4.9	5.2	3.2	5.1	3.5	4.2	3.4	2.7
Fe[c]	1.0	0.72	0.44	0.52	0.43	0.71	0.54	0.48	0.40	0.41
Mg	0.25	0.17	0.10	0.12	0.13	0.17	0.13	0.11	0.10	0.10
Ca	0.18	0.10	0.11	0.12	0.10	0.17	0.09	0.10	8.7	10.0
Na	1.1	0.76	1.10	1.2	0.73	1.3	0.84	0.96	0.78	0.61
K	2.9	2.1	2.8	3.0	1.8	2.9	1.7	2.1	2.1	1.6
Ti	0.06	0.10	0.05	0.06	0.10	0.07	0.08	0.06	0.06	0.06
ppm										
Ba	1000	1200	810	840	540	1000	550	650	560	470
Be	<1	<1	<1	1	<1	<1	<1	<1	<1	<1
Ce	38	24	31	33	25	31	15	20	21	15
Co	2	<2	<2	<2	<2	3	<2	<2	<2	<2
Cr	5	<5	<5	5	5	6	<5	<5	<5	<5
Cu	2	2	2	5	2	3	3	2	<2	<2
Ga	10	10	10	10	<10	<10	<10	<10	<10	<10
La	19	12	17	18	14	19	9	13	13	7
Li	15	10	11	11	10	12	10	10	7	8
Mn	92	64	45	47	45	68	45	50	2800	4500
Mo	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ni	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Pb	20	20	20	20	<20	30	<20	<20	20	<20
Sc	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Se	--	--	--	--	--	--	--	--	--	--
Sr	110	80	110	110	83	110	83	91	210	330
Th	<5	<5	6	<5	<5	<5	<5	<5	<5	<5
V	75	290	64	85	120	66	47	53	29	12
Y	6	6	5	6	6	6	<5	<5	13	10
Zn	18	14	9	11	19	13	65	170	8	7
Nd	14	12	17	15	16	19	5	6	12	13
Gd	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Yb	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2

Appendix 1.--Analyses of samples from the E sand unit in the Church Rock 1 mine, McKinley County, New Mexico--continued

Sample number	CR-30-2	30-3	30-4	30-5	31-1	31-2	31-3	31-4	31-5	32-1
Lithology	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss	Ss
%										
U	0.013	0.003	0.003	0.002	0.396	0.002	0.002	0.262	0.001	0.172
C[a]	0.05	<0.01	0.12	<0.01	<0.01	<0.01	<0.01	0.14	<0.01	0.11
S[b]	0.02	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.03	<0.01	0.02
Al	5.2	5.0	2.7	4.1	4.4	4.0	3.1	4.5	4.4	4.6
Fe[c]	0.44	0.33	0.74	0.49	0.67	0.43	1.1	0.52	0.40	0.55
Mg	0.12	0.10	0.15	0.11	0.14	0.14	0.21	0.20	0.10	0.19
Ca	0.19	0.16	9.6	0.13	0.11	0.12	0.09	0.22	0.09	0.18
Na	1.1	1.1	0.56	0.94	1.1	0.98	0.71	1.3	1.1	1.3
K	3.2	3.0	1.7	2.2	2.0	1.8	1.3	2.1	1.9	2.0
Ti	0.07	0.06	0.15	0.06	0.12	0.09	0.19	0.12	0.05	0.05
ppm										
Ba	820	760	430	640	1300	650	520	1300	690	1200
Be	<1	<1	<1	<1	2	<1	<1	<1	<1	<1
Ce	35	32	17	24	40	29	30	34	24	23
Co	<2	<2	<2	<2	6	3	5	4	3	3
Cr	<5	<5	<5	<5	7	5	6	6	2	5
Cu	4	2	3	<2	4	2	5	3	<1	<1
Ga	10	<10	<10	<10	<4	8	8	<4	8	<4
La	20	17	8	12	16	18	16	17	12	14
Li	11	10	10	10	9	9	12	10	9	9
Mn	65	56	4400	70	69	49	110	69	47	66
Mo	<5	<5	<5	<5	<2	<2	<2	<2	<2	<2
Ni	<5	<5	<5	<5	<2	9	<2	<2	<2	<2
Pb	30	<20	20	20	21	14	20	31	13	11
Sc	<5	<5	<5	<5	<2	4	3	2	<2	<2
Se	--	--	--	--	--	--	--	--	--	--
Sr	100	100	240	88	100	96	70	110	94	100
Th	6	<5	<5	<5	6	<4	6	6	<4	<4
V	40	24	19	20	240	36	37	91	30	81
Y	7	6	11	5	7	7	6	7	5	4
Zn	7	7	11	11	7	5	14	5	14	9
Nd	14	11	12	11	10	11	10	10	9	6
Gd	<20	<20	<20	<20	<10	<10	<10	<10	<10	<10
Yb	<2	<2	<2	<2	2	2	1	1	1	1