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Geochemical Study of Evaporite and Clay Mineral-Oxyhydroxide Samples from the Waste Isolation Pilot Plant Site*

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Abstract

Samples of clay minerals, insoluble oxyhydroxides, and their host evaporites from the WIPP site have been studied for their major and minor elements abundances, x-ray diffraction characteristics, K-Ar ages, and Rb-Sr ages. This study was undertaken to determine their overall geochemical characteristics and to investigate possible interactions between evaporites and insoluble constituents.

The evaporite host material is water-soluble, having Cl/Br ratios typical of marine evaporites, although the Br content is low. Insoluble material (usually a mixture of clay minerals and oxyhydroxide phases) yields very high Cl/Br ratios, possibly because of Cl from admixed halide minerals. This same material yields K/Rb and Th/U ratios in the normal range for shales; suggesting little, if any, effect of evaporite-induced remobilization of U, K, or Rb in the insoluble material. The rare-earth element (REE) data also show normal REE/chondrite (REE/CHON) distribution patterns, supporting the K/Rb and Th/U data.

Clay minerals yield K-Ar dates in the range 365 to 390 Ma and a Rb-Sr isochron age of 428 ± 7 Ma. These ages are well in excess of the 220- to 230-Ma formational age of the evaporites, and confirm the detrital origin of the clays. The ages also show that any evaporite or clay mineral reactions that might have occurred at or near the time of sedimentation and diagenesis were not sufficient to reset the K-Ar and Rb-Sr systematics of the clay minerals. Further, x-ray data indicate a normal evaporitic assemblage of clay minerals and Fe-rich oxyhydroxide phases.

The clay minerals and other insoluble material appear to be resistant to the destructive effects of their entrapment in the evaporites, which suggests that these insoluble materials would be good getters for any radionuclides (hypothetically) released from the storage of radioactive wastes in the area.

*The work presented in this report was done by the late Dr. Brookins for Sandia National Laboratories under Contract No. 52-9984

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Foreword

This report is part of a series of contractor reports produced by the late Dr. Douglas Brookins and his associates (graduate students, research fellows, and colleagues), to provide detailed documentation of fundamental geochemical data collected to characterize the geological environment of the Waste Isolation Pilot Plant (WIPP). Previous works in this series have dealt with *individual* topics such as major and minor minerals (Register, 1981; Brookins and Lambert, 1987a; Brookins et al., 1990), potassium-argon and rubidium-strontium isochron dating (Brookins et al., 1980; Brookins, 1981; Brookins and Lambert, 1987b), strontium-isotope distributions determined by mass spectrometry (Brookins and Lambert, 1988), and rare-earth element distributions determined by neutron-activation analysis (Register and Brookins, 1980). Many of these studies have been pivotal in illuminating the nature, degree, and timing of the interactions between evaporite rocks and groundwaters in the Ochoan (Permian) evaporite section of the northern Delaware Basin, southeastern New Mexico.

Not only have most of these previous works been written on individual topics, but they have dealt with core recovered from exploratory boreholes as part of WIPP site characterization, which (except for limited investigations in nearby potash mines) was conducted entirely from the surface. Also, previous work has examined a variety of stratigraphic horizons, including those that bear witness to water/rock interactions in veining, paragenesis, and secondary mineralization. While consistent with the previous work, this mineralogical, elemental, and isotopic study represents a significant departure from that work. First, this work sampled only the horizon in the lower part of the Salado Formation (about 660 meters depth, just above marker bed 139) in the drifts excavated for WIPP. Second, this work uses many of the geochemical tools of the previous works, integrating the results into an internally consistent interpretation. Finally, this work illustrates that many of the previous results showed large variations because of regional heterogeneities that are less apparent on the scale of the WIPP facility itself. Nevertheless, the regional studies have proven justified to provide a more complete geologic history of the WIPP host-environment than can be obtained from only local sampling and investigation restricted to the WIPP itself.

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Acknowledgments

Editorial handling of early forms of this document was facilitated by E. Roberta Voelker. The manuscript was critically reviewed by Karen Robinson and Craig Novak. Final editing and production was done by Daniel P. Garber.

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Geochemical Study of Evaporite and Clay Mineral-Oxyhydroxide Samples from the Waste Isolation Pilot Plant (WIPP) Site

Introduction

The purpose of this investigation is to obtain chemical, mineralogical, and geochronological data to assess the nature and history of the clay and other accessory minerals from the Waste Isolation Pilot Plant (WIPP) site area in southeastern New Mexico. For this purpose, samples of evaporites, most with clay minerals and other secondary or non-evaporitic minerals, were obtained from the underground WIPP-facilities.

Sample Treatment

The samples are briefly described in Table 1. The series of samples designated "FH" were originally collected by IT Corporation during the WIPP Site and Preliminary Design Validation program, as the WIPP drifts were first excavated in the Salado Formation. The samples designated "WP" were collected on-site by the author with the assistance of S. J. Lambert.

Table 1. Sample Descriptions.

Sample	Location*	Brief Description
<i>Samples collected from underground workings at the WIPP on September 23, 1983.</i>		
WP-1	N440-0E, Marker Unit 4, east rib	Very argillaceous halite
WP-2	20 ft south of WP-1, at break between Marker Units 4 and 5	Gray clay seam
WP-3	N780, 40E, Marker Unit 4	Massive brown argillaceous halite
WP-4	N1100, 0E, southeast corner, Marker Unit 4 at contact with Marker Unit 5	Dark-gray clay seam
WP-5	Room 1, 1250N, basal part of Marker Unit 3	Polyhalite-bearing halite
WP-6	Room 2, 1200N, on east wall	Polyhalite-bearing halite
WP-7	S3650, E140, between Marker Units 4 and 5	Dark-gray clay seam with minor halite
WP-8	S2800, E140 same seam as WP-7	Brown-to-black clay seam
WP-9	S2550, 140E	Polyhalite in break between brown and black clay seams
WP-10	S400, 140E	Reddish-brown clay seam
WP-11	From cage area	Polyhalite in halite

(continued)

Table 1. (continued)

Sample	Location*	Brief Description
<i>Samples from WIPP underground facilities collected during excavation</i>		
FH4	0E drift, N53 ft, 4 ft west of east rib	Massive halite, some polyhalite and clay
FH6A	S90 drift, 145 ft east, floor	Polyhalite from Unit 3
FH6B	S90 drift, 145 ft east, floor	Argillaceous halite from Units 0 and 1
FH10	0E drift, S436 ft, east rib	Clear halite, some polyhalite; from Sandia corehole H1SE, 0-9 and 13-23 inches depth
FH26	E140 drift, S733 ft, back, 8 ft east of west rib	Clear, coarsely crystalline halite, trace clay, from Unit 5
FH27	E140 drift, S1193 ft, 11 ft from west rib	Halite with some polyhalite, from Unit 3(4?)
FH32	E140 drift, S1777 ft, 10 ft from east rib), 4 ft below back	Argillaceous, coarsely crystalline halite with irregular masses of gray clay, Unit 4
FH40	Intersection of 0E and S90 drifts, SE corner	Argillaceous halite, medium to coarsely crystalline, reddish-brown with colorless halite, reddish-brown clay
FH42	Unknown	Clear, coarsely crystalline halite; minor reddish-brown clay
FH45	E140 drift, S3080 ft, floor, 3 ft west of east rib	Argillaceous halite; from vertical downward corehole DH-224, 0.45 ft to 1.0 ft, Unit 0

*relative to mine coordinates and informal marker units exposed in drift walls, as established during the WIPP Site and Preliminary Design Validation.

The samples were split into two aliquots, whenever possible. The first aliquot was dissolved in water; the insoluble residue and the re-precipitated water-soluble fraction were analyzed separately. In some samples the clay minerals and other minerals (e.g., polyhalite) could be hand-separated from the evaporite minerals. The second aliquot, if available, was analyzed directly as a whole rock. Separate subaliquots of the above materials were selected for x-ray study and for K-Ar and Rb-Sr age-determination studies.

X-Ray Studies

Samples from both the FH and WP series were analyzed by x-ray diffraction to determine the mineralogy, with emphasis on the insoluble residues (I) and/or clay-mineral-rich separates (C) from the whole rocks. The data are presented in Table 2. The FH series samples, which were analyzed first, were not as well documented as the WP series. Hence, in Table 2A no attempt is made to estimate the

Table 2. Mineralogy, from X-Ray Diffraction Data.

A. FH Series								
Sample	HA	PH	GY	AN	SM	IL	CH	Q
<i>Insoluble residues and clays</i>								
FH4-I	—	—	X	X	—	—	—	X
FH6A-I	—	X	X	X	—	—	—	—
FH6B-C	—	—	—	—	X	X	X	—
FH27-I	—	—	X	X	—	—	—	—
FH27-C	—	—	—	—	—	X	X	—
FH32-C	—	—	—	—	—	X	X	X
FH40-I	X	—	X	X	—	—	—	—
FH42-I	X	—	X	X	—	—	—	—
FH42-C	—	—	—	—	X	X	X	X
FH45-C	—	—	—	—	X	X	X	X

X — present in readily identifiable amounts

HA — halite

PH — polyhalite

GY — gypsum

AN — anhydrite

SM — smectite

IL — illite

CH — chlorite

Q — quartz

B. WP Series										
Sam- ple	HA	PH	GY	AN	SM*	IL	CH	MG	Q	KA
<i>Clay separates and insoluble residues</i>										
WP-1C	—	—	—	—	M	X	t	t	M	—
WP-2C	—	—	—	—	M	X	—	X	M	—
WP-3C	—	—	—	—	M	M	—	t	X	—
WP-4C	—	—	—	—	M	X	t	t	M	—
WP-7C	—	—	—	—	M	X	t	t	M	—
WP-8C	—	—	—	—	M	M	—	t	X	—
WP-9C	—	—	—	—	M	X	t	t	M	—
WP-10I	—	—	—	—	M	X	—	t	M	—

(continued)

Table 2 (continued).

Sam- ple	B. WP Series									
	HA	PH	GY	AN	SM*	IL	CH	MG	Q	KA
Salts										
WP-5S	X	M	t	—	?	—	—	—	—	—
WP-6S	X	M	M	X	—	—	—	—	—	—
WP-11S	M	M	M	M	—	—	—	—	—	?
M — major					GY — gypsum					
X — easily identifiable					AN — anhydrite					
t — trace					IL — illite					
? — uncertain					CH — chlorite					
SM* — smectite, with possibly some corrensite					Q — quartz					
HA — halite					KA — kainite					
PH — polyhalite					— — not detected					

relative proportions of minerals identified, whereas for the WP series such an attempt is made.

Smectites, including some possible corrensite and mixed-layer smectite-illite and smectite-chlorite, are the dominant clay minerals identified. Illite and chlorite are subordinate to the smectites. Magnesite is common in the WP series and probably also present in the FH series. In general, the observed clay minerals appear to be a suite typical of marine evaporites. Quartz, anhydrite, gypsum, $\pm$ halite, $\pm$ polyhalite were also observed in small amounts.

Elemental Geochemical Analysis

Table 3 contains data for all the trace and major elements determined by the instrumental neutron activation analysis (INAA). The samples were irradiated at the Los Alamos National Laboratory (LANL) Omega West Reactor by S. Garcia, analyst, using standard

procedures (Minor et al., 1981). Where possible, samples of untreated whole rock (WR), clay mineral (C) or polyhalite (P), insoluble residue (I), and soluble fraction (S) were analyzed. Not enough material was available for analyses of all four principal fractions (WR, I, C, and S). In some samples (e.g., especially the S fractions), many trace elements were present in amounts that were below detection limits, indicated by the "<" values.

The present study emphasizes the Cl/Br ratios of soluble versus insoluble samples, the K/Rb and Th/U ratios of insoluble residue and clay mineral-oxyhydroxide separates, and the rare-earth element (REE) distribution patterns in the insoluble residues and clay mineral-oxyhydroxide separates. The other trace-element data are very erratic. In some samples small amounts of Sb, Zn, Au, and Mo are observed, but there is very little consistency in their distribution (i.e., Sb/Au ratios vary considerably, as do ratios for Zn/Sb, Sc/W, etc.). These other elemental data, while of interest as routine abundance information, are not discussed further in this report.

Table 3. Chemical Data.*

A. Sample FH4			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
Na-24	262400±7600	953±41	323100±9000
Mg-27	< 32000	34900±1700	< 31000
Al-28	< 17000	7950±520	< 16000
Cl-38	375000±21000	960±63	467000±26000
K-42	< 47000	6400±720	< 45000
Ca-49	< 17000	177400±8000	< 18000
Ti-51	< 6400	616±97	< 6300
V-52	< 110	18.5±1.9	< 100
Mn-56	< 16	52.2±2.0	< 15
Cu-66	< 4100	< 110	< 3900
Sr-87	< 3000	9840±740	< 3000
In-116	< 2.2	< 0.075	< 2.2
I-128	< 190	< 8.3	< 190
Ba-139	< 1500	126±23	< 1400
Dy-165	< 14.0	1.07±0.14	< 10.1
U-235	< 0.016	0.483±0.014	< 0.0030
Ga-72	< 130	< 3.2	< 119
As-76	< 10.4	0.620±0.082	< 9.2
Br-82	54.4±5.6	0.66±0.11	45.4±5.2
Mo-99	< 82	< 2.0	< 58
La-140	< 4.7	19.45±0.70	< 4.2
Sm-153	< 0.39	3.44±0.16	< 0.25
Yb-175	< 5.5	0.478±0.046	< 4.8
W-187	< 16.7	< 0.43	< 14.1
Au-198	< 0.12	0.0200±0.0017	< 0.10
Sc-46	< 0.0123	1.758±0.069	0.0441±0.0035
Cr-51	< 6.1	12.46±0.95	< 0.71
Fe-59	< 240	15070±570	297±35
Co-60	< 0.0035	1.145±0.085	< 0.0027
Zn-65	< 0.12	11.3±3.4	< 0.080

*Data were taken by neutron activation analysis at Los Alamos National Laboratory's Omega West Reactor Site by S. Garcia, analyst. Data are reported in parts per million (ppm) unless noted otherwise. The isotopes listed on the page are those used for counting after the irradiations. Standards were independently run at LANL. The errors ("±") given are for one standard deviation, based on counting statistics. Where possible, three samples of each unknown were analyzed: (1) an aliquot of the whole rock (WR), (2) the soluble fraction (S) of a separate aliquot of sample (i.e., taken to dryness after dissolution and reprecipitated by evaporation), and (3) the insoluble (I) or clay mineral-rich (C) or polyhalitic (P) separate of the sample aliquot from which the dissolution experiment was carried out.

(continued)

Table 3 (continued).

A. Sample FH4			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
Se-75	< 1.05	< 0.98	< 0.54
Rb-86	< 66	< 8.0	< 3.2
Zr-95	< 88	< 93	< 31
Ag-110	< 0.49	< 1.02	< 0.35
Sb-124	< 0.37	< 0.29	< 0.131
Cs-134	< 0.121	0.77±0.11	< 0.098
Ce-141	< 3.2	41.2±1.6	< 0.48
Nd-147	< 830	29.4±5.1	< 5.7
Eu-152	< 0.033	0.484±0.044	< 0.027
Tb-160	< 0.0037	0.225±0.062	< 0.055
Lu-177	< 98	0.052±0.011	< 0.025
Hf-181	< 0.35	0.694±0.053	< 0.075
Ta-182	< 0.28	< 0.28	< 0.190
Hg-203	< 0.73	< 0.42	< 0.19
Th-233	< 0.95	1.341±0.074	< 0.105

B. Sample FH6A	
Isotope	Soluble (S)
Na-24	328400±9200
Mg-27	< 32000
Al-28	< 17000
Cl-38	477000±26000
K-42	< 46000
Ca-49	< 17000
Ti-51	< 6100
V-52	< 100
Mn-56	< 15
Cu-66	< 4000
Sr-87	< 2800
In-116	< 2.2
I-128	< 180
Ba-139	< 1300
Dy-165	< 9.6
U-235	0.2070±0.0058
Ga-72	< 160
As-76	< 12
Br-82	27.3±4.0
Mo-99	< 94
La-140	< 5.4

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(continued from previous column)

B. Sample FH6A	
Isotope	Soluble (S)
Sm-153	< 0.45
Yb-175	< 6.3
W-187	< 20
Au-198	< 0.14
Sc-46	< 0.0058
Cr-51	< 0.76
Fe-59	< 64
Co-60	0.160±0.045
Zn-65	< 3.6
Se-75	< 0.56
Rb-86	< 3.3
Zr-95	< 34
Ag-110	< 0.35
Sb-124	< 0.140
Cs-134	< 0.104
Ce-141	< 0.49
Nd-147	< 5.7
Eu-152	< 0.027
Tb-160	< 0.057
Lu-177	< 0.028

(continued)

Table 3 (continued).

B. Sample FH6A	
Isotope	Soluble (S)
Hf-181	< 0.085
Ta-182	< 0.166

(continued from previous column)

B. Sample FH6A	
Isotope	Soluble (S)
Hg-203	< 0.21
Th-233	< 0.116

(continued next column)

C. Sample FH6B			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
Na-24	324400±9100	1017±42	298100±8600
Mg-27	< 35000	164900±6900	< 36000
Al-28	< 19000	37600±1400	< 20000
Cl-38	474000±26000	604±43	440000±24000
K-42	< 52000	6500±1200	< 54000
Ca-49	< 20000	4550±740	< 20000
Ti-51	< 6700	2670±170	< 7300
V-52	< 120	53.0±3.3	< 120
Mn-56	< 16	239.2±8.4	< 18
Cu-66	< 4400	< 120	< 4600
Sr-87	< 3100	< 200	< 3400
In-116	< 2.4	< 0.082	< 2.5
I-128	< 200	< 13	< 220
Ba-139	< 1400	215±31	< 1700
Dy-165	< 10.2	4.00±0.34	< 16
U-235	0.1100±0.0031	1.993±0.056	0.0620±0.0017
Ga-72	< 140	7.5±1.0	< 120
As-76	< 11.0	2.19±0.19	< 9.0
Br-82	117.3±10.0	2.35±0.21	61.1±6.4
Mo-99	< 84	1.36±0.17	< 56
La-140	< 4.9	21.04±0.74	< 4.0
Sm-153	< 0.40	3.83±0.20	< 0.24
Yb-175	< 5.6	2.295±0.096	< 4.6
W-187	< 16.9	0.86±0.16	< 13.2
Au-198	< 0.12	< 0.0034	< 0.099
Sc-46	< 0.00023	7.30±0.28	0.187±0.011
Cr-51	< 1.0	50.8±2.5	< 3.7
Fe-59	< 87	25090±930	613±78
Co-60	< 0.0047	4.98±0.23	0.239±0.036
Zn-65	< 4.4	< 5.4	24.1±4.1
Se-75	< 0.79	< 2.7	< 0.55
Rb-86	< 4.5	42.3±4.7	< 42

(continued)

Table 3 (continued).

C. Sample FH6B			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
Zr-95	< 44	214±43	< 62
Ag-110	< 0.44	< 1.6	< 0.34
Sb-124	< 0.19	< 0.40	< 0.25
Cs-134	< 0.136	2.78±0.21	< 0.084
Ce-141	< 0.71	45.5±1.8	< 1.5
Nd-147	< 8.1	< 9.6	< 490
Eu-152	< 0.039	0.660±0.051	< 0.0167
Tb-160	< 0.011	0.529±0.087	< 0.088
Lu-177	< 0.036	0.323±0.022	< 56
Hf-181	< 0.111	5.24±0.19	< 0.20
Ta-182	< 0.213	0.768±0.096	< 0.219
Hg-203	< 0.27	< 0.61	< 0.45
Th-233	< 0.150	6.87±0.23	< 0.59

D. Sample FH26		
Isotope	Soluble (S)	Whole Rock (WR)
Na-24	369000±10000	335500±9400
Mg-27	< 35000	< 31000
Al-28	< 19000	< 17000
Cl-38	527000±29000	488000±27000
K-42	< 51000	< 45000
Ca-49	< 21000	< 18000
Ti-51	< 7100	< 6000
V-52	< 120	< 100
Mn-56	< 17	< 14
Cu-66	< 4400	< 3900
Sr-87	< 3300	< 2800
In-116	< 2.5	< 2.1
I-128	< 210	< 180
Ba-139	< 1500	< 1200
Dy-165	< 11.4	< 9.3
U-235	0.0700±0.0020	0.1040±0.0029
Ga-72	< 190	< 121
As-76	< 14	< 8.8
Br-82	74.2±8.0	43.4±4.6
Mo-99	< 106	< 54
La-140	< 6.0	< 3.9
Sm-153	< 0.51	< 0.24
Yb-175	< 6.9	< 4.4

(continued)

Table 3 (continued).

D. Sample FH26			
Isotope	Soluble (S)	Whole Rock (WR)	
W-187	< 23	< 13.7	
Au-198	< 0.15	< 0.096	
Sc-46	< 0.0017	< 0.0039	
Cr-51	2.99±0.33	< 0.55	
Fe-59	< 55	< 42	
Co-60	0.092±0.031	< 0.022	
Zn-65	< 0.088	< 0.069	
Se-75	< 0.46	< 0.39	
Rb-86	< 2.6	< 2.2	
Zr-95	< 28	< 23	
Ag-110	< 0.29	< 0.23	
Sb-124	< 0.117	< 0.095	
Cs-134	< 0.087	< 0.071	
Ce-141	< 0.39	< 0.34	
Nd-147	< 4.5	< 4.0	
Eu-152	< 0.0218	< 0.0188	
Tb-160	< 0.048	< 0.040	
Lu-177	< 0.023	< 0.020	
Hf-181	< 0.069	< 0.058	
Ta-182	< 0.042	< 0.110	
Hg-203	< 0.17	< 0.15	
Th-233	< 0.091	< 0.083	

E. Sample FH27			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
Na-24	269200±7500	125100±3600	306400±8900
Mg-27	< 31000	< 14000	< 37000
Al-28	< 17000	< 8300	< 20000
Cl-38	390000±21000	185000±10000	445000 < 24000
K-42	< 46000	< 23000	< 55000
Ca-49	16000±4900	< 18000	< 20000
Ti-51	< 5900	< 2500	< 7200
V-52	< 100	< 50	< 120
Mn-56	< 15	< 6.4	< 18
Cu-66	< 3900	< 1800	< 4700
Sr-87	< 2700	< 1200	< 3400
In-116	< 2.1	< 0.93	< 2.6
I-128	< 170	< 75	< 220
Ba-139	< 1200	< 500	< 1700

(continued)

Table 3 (continued).

E. Sample FH27			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
Dy-165	< 9.0	< 3.6	< 16
U-235	0.03500±0.00098	3.409±0.095	0.0370±0.0010
Ga-72	< 150	7.6±1.5	< 10.7
As-76	< 11.2	5.25±0.44	< 0.79
Br-82	36.4±5.5	3.31±0.33	3.45±0.37
Mo-99	< 85	< 4.1	< 4.8
La-140	< 4.9	17.32±0.62	< 0.34
Sm-153	< 0.41	3.38±0.16	< 0.021
Yb-175	< 5.6	1.90±0.10	< 0.38
W-187	< 18.5	< 0.98	< 1.16
Au-198	< 0.12	0.0078±0.0019	< 0.0085
Sc-46	< 0.00043	9.29±0.35	0.0058±0.0018
Cr-51	< 7.6	55.4±2.7	< 0.54
Fe-59	< 310	23170±860	< 45
Co-60	< 0.064	9.38±0.40	< 0.016
Zn-65	< 0.15	< 5.5	< 0.070
Se-75	< 1.31	< 2.4	< 0.38
Rb-86	< 85	39.9±4.5	< 2.3
Zr-95	< 105	112±26	< 24
Ag-110	< 0.58	< 1.8	< 0.24
Sb-124	< 0.46	< 0.51	< 0.099
Cs-134	< 0.144	2.79±0.21	< 0.072
Ce-141	< 4.0	32.1±1.3	< 0.32
Nd-147	< 1030	< 9.3	< 3.1
Eu-152	< 0.041	0.514±0.047	< 0.0177
Tb-160	< 0.170	0.48±0.12	< 0.040
Lu-177	< 129	0.310±0.024	< 0.020
Hf-181	< 0.42	3.50±0.15	< 0.058
Ta-182	< 0.224	0.70±0.11	< 0.109
Hg-203	< 0.94	< 0.65	< 0.15
Th-233	< 1.17	7.48±0.25	< 0.085

F. Sample FH32			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
Na-24	362000±10000	4240±140	316100±8900
Mg-27	< 35000	164500±7100	< 29000
Al-28	< 19000	43900±1600	< 16000
Cl-38	519000±29000	3580±210	463000±25000

(continued)

Table 3 (continued).

F. Sample FH32			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
K-42	< 51000	8100±1100	< 43000
Ca-49	< 19000	< 440	< 17000
Ti-51	< 7100	2180±190	< 5700
V-52	< 120	55.7±3.7	< 98
Mn-56	< 17	341±12	< 14
Cu-66	< 4400	< 180	< 3700
Sr-87	< 3300	< 250	< 2600
In-116	< 2.4	< 0.119	< 2.0
I-128	< 210	< 16	< 170
Ba-139	< 1500	157±33	< 1200
Dy-165	< 11.4	2.92±0.27	< 8.9
U-235	0.0680±0.0019	3.337±0.093	0.0550±0.0015
Ga-72	< 140	9.7±1.5	< 160
As-76	< 10.2	5.59±0.44	< 11.1
Br-82	73.4±6.5	2.64±0.27	44.9±4.8
Mo-99	< 63	2.73±0.29	< 82
La-140	< 4.3	18.12±0.65	< 4.8
Sm-153	< 0.27	2.78±0.13	< 0.40
Yb-175	< 5.1	1.565±0.078	< 5.3
W-187	< 15.1	1.70±0.31	< 18.3
Au-198	< 0.11	0.0068±0.0020	< 0.12
Sc-46	< 0.0047	8.32±0.32	0.0379±0.0034
Cr-51	< 0.67	51.0±2.5	< 0.76
Fe-59	< 56	21490±800	138±33
Co-60	< 0.053	10.02±0.42	< 0.00033
Zn-65	< 2.8	36.5±5.9	< 0.089
Se-75	< 0.47	< 1.3	< 0.57
Rb-86	< 2.8	40.7±4.2	< 3.4
Zr-95	< 28	< 150	< 35
Ag-110	< 0.29	< 1.7	< 0.35
Sb-124	< 0.114	0.53±0.15	< 0.138
Cs-134	0.053±0.026	2.96±0.22	< 0.102
Ce-141	< 0.40	39.7±1.5	< 0.52
Nd-147	< 5.0	< 8.8	< 6.1
Eu-152	< 0.0228	0.510±0.045	< 0.028
Tb-160	< 0.048	0.457±0.098	< 0.055
Lu-177	< 0.024	0.243±0.020	< 0.027

(continued)

Table 3 (continued).

F. Sample FH32			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
Hf-181	<0.071	2.54±0.12	<0.084
Ta-182	<0.137	0.607±0.088	<0.212
Hg-203	<0.18	<0.60	<0.20
Th-233	<0.102	6.35±0.22	<0.112

G. Sample FH40		
Isotope	Soluble (S)	Whole Rock (WR)
Na-24	325300±9100	295700±8600
Mg-27	<35000	<36000
Al-28	<19000	<19000
Cl-38	472000±26000	433000±24000
K-42	<52000	<53000
Ca-49	<19000	<20000
Ti-51	<6600	<7100
V-52	<120	<120
Mn-56	<16	<17
Cu-66	<4300	<4600
Sr-87	<3100	<3300
In-116	<2.3	<2.5
I-128	<200	<210
Ba-139	<1400	<1600
Dy-165	<10.1	<15.3
U-235	0.03000±0.00084	0.0790±0.0022
Ga-72	<140	<170
As-76	<10.1	<12
Br-82	22.7±3.0	50.7±5.5
Mo-99	<63	<87
La-140	<4.2	<5.1
Sm-153	<0.27	<0.42
Yb-175	<4.9	<5.6
W-187	<15.9	<20
Au-198	<0.11	<0.13
Sc-46	<0.0034	0.0226±0.0023
Cr-51	<0.58	<0.51
Fe-59	<45	72±14
Co-60	<0.059	0.054±0.022
Zn-65	<0.073	<0.067
Se-75	<0.42	<0.36

(continued)

Table 3 (continued).

G. Sample FH40		
Isotope	Soluble (S)	Whole Rock (WR)
Rb-86	< 2.4	< 2.2
Zr-95	< 24	< 23
Ag-110	< 0.26	< 0.23
Sb-124	< 0.103	< 0.093
Cs-134	< 0.075	< 0.069
Ce-141	< 0.36	< 0.30
Nd-147	< 4.5	< 4.0
Eu-152	< 0.0202	< 0.0177
Tb-160	< 0.038	< 0.035
Lu-177	< 0.021	< 0.018
Hf-181	< 0.060	< 0.054
Ta-182	< 0.089	< 0.133
Hg-203	< 0.16	< 0.13
Th-233	< 0.087	< 0.079

H. Sample FH42			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
Na-24	341700±9600	8500±260	323200±9000
Mg-27	< 33000	168100±7200	< 30000
Al-28	< 18000	40100±1600	< 16000
Cl-38	496000±27000	7470±420	468000±26000
K-42	< 49000	4600±1100	< 44000
Ca-49	< 19000	< 720	< 18000
Ti-51	< 6800	2980±210	< 5900
V-52	< 110	50.8±3.5	< 100
Mn-56	< 16	258.6±9.1	< 14
Cu-66	< 4200	< 250	< 3800
Sr-87	< 3100	< 270	< 2700
In-116	< 2.3	< 0.155	< 2.1
I-128	< 200	< 18	< 170
Ba-139	< 1500	205±41	< 1200
Dy-165	< 10.8	3.84 ±0.33	< 9.2
U-235	0.0690±0.0019	3.82±0.11	0.0870±0.0024
Ga-72	< 160	< 7.3	< 140
As-76	< 12	5.43±0.45	< 10.1
Br-82	138±11	2.87±0.27	54.3±5.2
Mo-99	< 72	< 3.7	< 61
La-140	< 4.8	21.30±0.77	< 4.1
Sm-153	< 0.31	3.51±0.19	< 0.27

(continued)

Table 3 (continued).

H. Sample FH42			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
Yb-175	< 5.7	2.113±0.099	< 4.8
W-187	< 17.6	1.38±0.33	< 15.2
Au-198	< 0.13	< 0.0061	< 0.11
Sc-46	< 0.0072	7.70±0.29	0.1509±0.0074
Cr-51	< 0.99	49.9±2.5	1.55±0.26
Fe-59	< 85	14280±540	299±25
Co-60	< 0.026	8.76±0.39	0.315±0.037
Zn-65	< 0.12	< 5.7	< 0.065
Se-75	< 0.78	< 3.1	< 0.38
Rb-86	< 4.3	38.6±4.6	< 2.5
Zr-95	< 44	198±42	< 29
Ag-110	< 0.41	< 1.7	< 0.30
Sb-124	< 0.18	0.84±0.25	< 0.110
Cs-134	< 0.133	2.30±0.19	0.097±0.028
Ce-141	< 0.71	40.0±1.9	1.08±0.12
Nd-147	< 7.9	22.9±	< 3.9
Eu-152	< 0.039	0.742±0.058	< 0.0183
Tb-160	< 0.075	0.613±0.089	< 0.046
Lu-177	< 0.037	0.380±0.025	< 0.020
Hf-181	< 0.113	6.09±0.22	0.144±0.023
Ta-182	< 0.201	0.631±0.088	< 0.146
Hg-203	< 0.28	< 0.64	< 0.15
Th-233		7.38±0.25	0.152±0.020

I. Sample FH45			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
Na-24	348700±9800	10020±300	326800±9500
Mg-27	< 38000	155900±6700	< 39000
Al-28	< 21000	40100±1600	< 21000
Cl-38	511000±28000	9830±550	475000±26000
K-42	< 57000	7900±1300	< 57000
Ca-49	< 22000	< 770	< 22000
Ti-51	< 7300	2760±210	< 7500
V-52	< 130	48.7±3.7	< 130
Mn-56	< 18	263.6±9.2	< 19
Cu-66	< 4900	< 270	< 4900
Sr-87	< 3400	< 270	< 3600
In-116	< 2.6	< 0.164	< 2.7

(continued)

Table 3 (continued).

I. Sample FH45			
Isotope	Soluble (S)	Insoluble (I)	Whole Rock (WR)
I-128	< 220	< 18	< 230
Ba-139	< 1500	219±40	< 1800
Dy-165	< 11.2	3.88±0.34	< 17
U-235	0.0800±0.0022	1.799±0.050	0.0960±0.0027
Ga-72	< 170	< 8.2	< 116
As-76	< 11.5	2.31±0.25	< 8.1
Br-82	118 ±10	4.65±0.41	46.0±4.3
Mo-99	< 66	< 4.7	< 47
La-140	< 4.8	19.77±0.71	< 3.3
Sm-153	< 0.29	3.20±0.17	< 0.21
Yb-175	< 5.3	2.21±0.11	< 3.7
W-187	< 17.0	< 1.13	< 12.6
Au-198	< 0.12	0.0163±0.0020	< 0.083
Sc-46	0.0166±0.0030	7.63±0.29	0.0897±0.0065
Cr-51	< 1.00	48.8±2.4	< 4.0
Fe-59	< 86	27200±1000	940±150
Co-60	< 0.0046	6.20±0.28	0.240±0.045
Zn-65	< 0.12	< 5.3	< 0.085
Se-75	< 0.77	< 2.7	< 0.65
Rb-86	< 4.5	43.2±4.8	< 46
Zr-95	< 43	< 150	< 61
Ag-110	< 0.48	< 1.7	< 0.34
Sb-124	< 0.18	0.97±0.25	< 0.25
Cs-134	< 0.131	3.03±0.22	< 0.081
Ce-141	< 0.70	37.3±1.5	< 1.9
Nd-147	< 7.9	< 9.8	< 580
Eu-152	< 0.039	0.636±0.052	< 0.0195
Tb-160	< 0.074	0.71±0.12	< 0.092
Lu-177	< 0.037	0.349±0.025	< 71
Hf-181	< 0.108	4.34±0.16	< 0.23
Ta-182	< 0.220	0.68±0.10	< 0.222
Hg-203	< 0.27	< 0.63	< 0.51
Th-233	< 0.148	6.51±0.23	< 0.63

(continued)

Table 3 (continued).

Isotope	J. Sample WP-1	
	Soluble (S)	Clay Mineral (C)
Na-24	342400±9600	18540±540
Mg-27	< 36000	126800±5600
Al-28	< 20000	49100±1900
Cl-38	507000±28000	20200±1100
K-42	< 55000	7300±1400
Ca-49	< 24000	< 1200
Ti-51	< 7200	2870±260
V-52	< 120	56.0±4.6
Mn-56	< 17	184.1±6.6
Cu-66	< 4700	< 350
Sr-87	< 3400	< 310
In-116	< 2.5	< 0.21
I-128	< 220	< 20
Ba-139	< 1700	< 150
Dy-165	< 16	2.86±0.39
U-235	< 0.039	3.015±0.084
Ga-72	< 106	< 81
As-76	< 9.0	< 2.5
Br-82	173±14	10.2±1.0
Mo-99	< 72	< 10.6
La-140	< 4.5	25.3±1.1
Sm-153	< 0.34	3.66±0.18
Yb-175	< 5.0	2.45±0.19
W-187	< 13.5	< 5.3
Au-198	< 0.11	< 0.014
Sc-46	< 0.00019	9.09±0.35
Cr-51	< 0.84	53.2±2.8
Fe-59	< 73	26300±1000
Co-60	0.102±0.044	8.88±0.39
Zn-65	< 0.11	< 12
Se-75	< 0.68	< 2.7
Rb-86	< 3.4	45.4±5.7
Zr-95	< 39	220±49
Ag-110	< 0.41	< 2.1
Sb-124	< 0.16	< 0.52
Cs-134	< 0.116	3.63±0.27
Ce-141	< 0.59	57.0±2.6

(continued)

Table 3 (continued).

J. Sample WP-1		
Isotope	Soluble (S)	Clay Mineral (C)
Nd-147	<5.9	< 15
Eu-152	0.152 ± 0.033	0.879 ± 0.069
Tb-160	<0.066	0.71 ± 0.11
Lu-177	<0.023	0.375 ± 0.028
Hf-181	<0.095	5.38 ± 0.22
Ta-182	<0.108	0.81 ± 0.11
Hg-203	<0.23	<0.79
Th-233	<0.124	8.16 ± 0.29

K. Sample WP-2		
Isotope	Soluble (S)	Clay Mineral (C)
Na-24	351900 ± 9900	7400 ± 220
Mg-27	< 34000	180900 ± 7600
Al-28	< 19000	37400 ± 1500
Cl-38	514000 ± 28000	5900 ± 340
K-42	< 51000	5100 ± 1200
Ca-49	< 24000	< 710
Ti-51	< 6300	2360 ± 200
V-52	< 110	46.8 ± 3.4
Mn-56	< 16	331 ± 12
Cu-66	< 4200	< 230
Sr-87	< 2900	< 260
In-116	< 2.3	< 0.141
I-128	< 190	< 17
Ba-139	< 1300	174 ± 42
Dy-165	< 9.5	3.44 ± 0.31
U-235	0.02700 ± 0.00076	2.383 ± 0.067
Ga-72	< 240	< 64
As-76	< 6.9	< 2.0
Br-82	34.5 ± 3.2	3.63 ± 0.59
Mo-99	< 22	< 8.3
La-140	< 2.1	16.71 ± 0.77
Sm-153	< 0.12	2.77 ± 0.14
Yb-175	< 1.6	2.16 ± 0.16
W-187	< 12.2	< 3.8
Au-198	< 0.040	< 0.011
Sc-46	< 0.000014	7.91 ± 0.30
Cr-51	< 0.55	45.7 ± 2.4

(continued)

Table 3 (continued).

K. Sample WP-2		
Isotope	Soluble (S)	Clay Mineral (C)
Fe-59	< 52	23820±910
Co-60	0.106±0.030	7.77±0.35
Zn-65	16.9±2.9	30.0±6.5
Se-75	< 0.41	< 2.8
Rb-86	< 2.5	46.6±5.4
Zr-95	< 26	< 180
Ag-110	< 0.26	< 2.0
Sb-124	< 0.104	< 0.58
Cs-134	< 0.080	2.42±0.22
Ce-141	< 0.33	39.2±1.6
Nd-147	< 3.9	< 14
Eu-152	< 0.0200	0.661±0.060
Tb-160	< 0.043	0.528±0.087
Lu-177	< 0.017	0.349±0.028
Hf-181	< 0.063	3.56±0.16
Ta-182	< 0.065	0.64±0.12
Hg-203	< 0.15	< 0.72
Th-233		6.56±0.24

L. Sample WP-3		
Isotope	Soluble	Clay Mineral
Na-24	285100±8000	15040±440
Mg-27	< 31000	137000±5900
Al-28	< 17000	52600±1900
Cl-38	444000±24000	14390±810
K-42	< 47000	9700±2000
Ca-49	< 23000	< 820
Ti-51	< 6000	3110±230
V-52	< 110	64.3±4.6
Mn-56	< 14	189.7±6.8
Cu-66	< 3900	< 260
Sr-87	< 2800	< 240
In-116	< 2.1	< 0.151
I-128	< 180	< 15
Ba-139	< 1400	294±48
Dy-165	< 12.8	4.00±0.35
U-235	0.01000±0.00028	2.688±0.075
Ga-72	< 230	< 78

(continued)

Table 3 (continued).

L. Sample WP-3		
Isotope	Soluble	Clay Mineral
As-76	< 7.2	< 2.4
Br-82	591±44	2.87±0.56
Mo-99	< 22	< 10.1
La-140	< 1.97	25.4±1.1
Sm-153	< 0.11	3.81±0.19
Yb-175	< 1.6	2.33±0.17
W-187	< 11.5	< 5.3
Au-198	< 0.041	< 0.013
Sc-46	< 0.0014	8.88±0.34
Cr-51	< 0.54	55.2±2.8
Fe-59	< 45	33900±1300
Co-60	0.123±0.031	7.13±0.33
Zn-65	14.7±2.7	< 12
Se-75	< 0.40	< 3.1
Rb-86	6.4±1.3	39.7±5.1
Zr-95	< 25	< 190
Ag-110	< 0.26	< 2.1
Sb-124	< 0.099	< 0.50
Cs-134	0.227±0.038	3.30±0.28
Ce-141	< 0.32	56.8±2.2
Nd-147	< 3.9	26.0±6.8
Eu-152	0.152±0.022	0.952±0.072
Tb-160	< 0.041	0.54±0.14
Lu-177	< 0.017	0.402±0.031
Hf-181	< 0.060	5.11±0.20
Ta-182	< 0.0334	0.70±0.10
Hg-203	< 0.15	< 0.78
Th-233	< 0.081	7.82±0.27

M. Sample WP-4		
Isotope	Soluble (S)	Clay Mineral (C)
Na-24	321700±9000	18310±530
Mg-27	< 31000	138900±6100
Al-28	< 17000	57600±2100
Cl-38	471000±26000	18700±1000
K-42	< 47000	9100±1500
Ca-49	< 23000	< 1200
Ti-51	< 5800	3260±310

(continued)

Table 3 (continued).

M. Sample V.P-4		
Isotope	Soluble (S)	Clay Mineral (C)
V-52	< 100	66.3±4.6
Mn-56	< 14	237.7±8.3
Cu-66	< 3900	< 360
Sr-87	< 2700	< 320
In-116	< 2.1	< 0.21
I-128	< 170	< 21
Ba-139	< 1200	< 150
Dy-165	< 8.7	3.33±0.47
U-235	< 0.024	3.97±0.11
Ga-72	< 260	< 85
As-76	< 7.4	5.80±0.84
Br-82	253±19	2.88±0.66
Mo-99	< 23	< 10.5
La-140	< 2.1	23.1±1.0
Sm-153	< 0.12	3.51±0.17
Yb-175	< 1.6	2.06±0.16
W-187	< 12.3	< 5.0
Au-198	< 0.042	< 0.014
Sc-46	< 0.0013	10.10±0.38
Cr-51	< 0.62	61.8±3.2
Fe-59	< 56	25120±950
Co-60	0.184±0.045	10.15±0.45
Zn-65	16.8±3.2	< 13
Se-75	< 0.47	< 2.2
Rb-86	< 2.6	57.0±5.8
Zr-95	< 31	< 200
Ag-110	< 0.30	< 2.2
Sb-124	< 0.122	< 0.57
Cs-134	< 0.092	3.75±0.28
Ce-141	< 0.38	53.5±2.1
Nd-147	< 4.4	28.7±8.0
Eu-152	< 0.0226	0.852±0.072
Tb-160	< 0.049	0.56±0.10
Lu-177	< 0.019	0.330±0.028
Hf-181	< 0.071	4.36±0.19
Ta-182	< 0.0384	0.79±0.12
Hg-203	< 0.18	< 0.82

(continued)

Table 3 (continued).

M. Sample WP-4		
Isotope	Soluble (S)	Clay Mineral (C)
Th-233	<0.094	8.82±0.31

N. Sample WP-5		
Isotope	Soluble (S)	Polyhalite (P)
Na-24	2881000±8100	332±18
Mg-27	<29000	38300±1800
Al-28	<17000	<270
Cl-38	422000±23000	70±10
K-42	<46000	120200±5900
Ca-49	<26000	128600±5500
Ti-51	<5600	<210
V-52	<100	<1.7
Mn-56	<14	16.73±0.77
Cu-66	<3700	<78
Sr-87	<2600	6770±510
In-116	<2.0	<0.056
I-128	<170	<5.7
Ba-139	<1300	<51
Dy-165	<11.9	<0.037
U-235	<0.022	0.02100±0.00059
Ga-72	<230	<20
As-76	<6.4	<0.64
Br-82	68.0±5.4	<0.62
Mo-99	<20	<3.9
La-140	<1.87	5.26±0.31
Sm-153	<0.11	0.501±0.028
Yb-175	<1.39	<0.14
W-187	<11.2	<1.26
Au-198	<0.036	<0.0038
Sc-46	<0.00013	0.0501±0.0035
Cr-51	<0.52	<0.86
Fe-59	<47	385±33
Co-60	0.132±0.036	0.095±0.032
Zn-65	14.1±2.7	<0.039
Se-75	<0.38	<0.62
Rb-86	<2.3	<2.7
Zr-95	<24	<30

(continued)

Table 3 (continued).

N. Sample WP-5		
Isotope	Soluble (S)	Polyhalite (P)
Ag-110	<0.25	<0.31
Sb-124	<0.037	<0.117
Cs-134	<0.074	<0.091
Ce-141	<0.31	10.08±0.50
Nd-147	<3.7	<4.6
Eu-152	<0.0187	0.115±0.022
Tb-160	<0.041	<0.010
Lu-177	<0.016	<0.023
Hf-181	<0.054	<0.079
Ta-182	<0.053	<0.170
Hg-203	<0.14	<0.22
Th-233	<0.081	<0.129

O. Sample WP-6	
Isotope	Soluble (S)
Na-24	ND (not determined)
Mg-27	ND
Al-28	ND
Cl-38	ND
K-42	ND
Ca-49	ND
Ti-51	ND
V-52	ND
Mn-56	ND
Cu-66	ND
Sr-87	ND
In-116	ND
I-128	ND
Ba-139	ND
Dy-165	ND
U-235	0.001000±0.000028
Ga-72	<250
As-76	<6.9
Br-82	69.8±5.6
Mo-99	<21
La-140	<1.99
Sm-153	<0.11
Yb-175	<1.5

(continued next column)

(continued from previous column)

O. Sample WP-6	
Isotope	Soluble (S)
W-187	<11.5
Au-198	<0.038
Sc-46	<0.0047
Cr-51	<0.57
Fe-59	<51
Co-60	0.111±0.037
Zn-65	13.7±2.7
Se-75	<0.42
Rb-86	<2.5
Zr-95	<27
Ag-110	<0.26
Sb-124	<0.105
Cs-134	<0.079
Ce-141	<0.34
Nd-147	<4.1
Eu-152	<0.0204
Tb-160	<0.044
Lu-177	<0.017
Hf-181	<0.063
Ta-182	<0.123
Hg-203	<0.16
Th-233	<0.085

(continued)

Table 3 (continued).

Isotope	P. Sample WP-7	
	Soluble (S)	Clay Mineral (C)
Na-24	327400±9200	14160±410
Mg-27	< 30000	146100±6300
Al-28	< 17000	50800±1900
Cl-38	476000±26000	12830±720
K-42	< 46000	8000±1400
Ca-49	< 25000	< 940
Ti-51	< 5600	3010±220
V-52	< 100	63.7±4.2
Mn-56	< 14	229.7±8.0
Cu-66	< 3800	< 300
Sr-87	< 2600	< 280
In-116	< 2.0	< 0.179
I-128	< 170	< 18
Ba-139	< 1100	< 120
Dy-165	< 8.3	4.18±0.37
U-235	< 0.015	3.390±0.095
Ga-72	< 300	< 72
As-76	< 8.2	11.2±1.1
Br-82	33.2±3.3	3.32±0.52
Mo-99	< 32	< 6.9
La-140	< 2.4	23.06±0.97
Sm-153	< 0.18	3.60±0.18
Yb-175	< 1.8	2.22±0.14
W-187	< 15.3	< 4.0
Au-198	< 0.046	0.0243±0.0050
Sc-46	< 0.0013	9.27±0.35
Cr-51	< 0.89	57.1±2.7
Fe-59	< 77	25280±940
Co-60	< 0.037	9.56±0.40
Zn-65	< 0.11	5.2±1.3
Se-75	< 0.69	< 2.7
Rb-86	< 3.7	37.4±4.0
Zr-95	< 40	< 120
Ag-110	< 0.40	< 1.7
Sb-124	< 0.16	< 0.47
Cs-134	< 0.122	3.06±0.23
Ce-141	< 0.61	51.1±1.9

(continued)

Table 3 (continued).

P. Sample WP-7		
Isotope	Soluble (S)	Clay Mineral (C)
Nd-147	< 6.4	< 8.2
Eu-152	< 0.035	0.808±0.057
Tb-160	< 0.067	0.748±0.099
Lu-177	< 0.027	0.345±0.022
Hf-181	< 0.098	4.41±0.17
Ta-182	< 0.082	0.691±0.095
Hg-203	< 0.24	< 0.61
Th-233	< 0.131	7.96±0.26

Q. Sample WP-8		
Isotope	Soluble (S)	Clay Mineral (C)
Na-24	239900±6700	18750±540
Mg-27	< 26000	146800±6500
Al-28	< 15000	50300±2000
Cl-38	334000±18000	19700±1100
K-42	< 40000	< 3700
Ca-49	< 25000	< 1000
Ti-51	< 4800	2900±240
V-52	< 90	63.5±5.0
Mn-56	< 11.9	210.8±7.6
Cu-66	< 3200	< 300
Sr-87	< 2300	< 270
In-116	< 1.75	< 0.179
I-128	< 150	< 18
Ba-139	< 1100	< 120
Dy-165	< 10.2	3.28±0.33
U-235	< 0.0060	3.438±0.096
Ga-72	< 280	< 81
As-76	< 7.8	< 2.2
Br-82	196±15	4.14±0.58
Mo-99	< 29	< 7.0
La-140	< 2.2	19.59±0.86
Sm-153	< 0.17	3.33±0.16
Yb-175	< 1.6	1.76±0.12
W-187	< 13.5	< 4.6
Au-198	< 0.043	< 0.012
Sc-46	< 0.0059	8.94±0.34
Cr-51	< 0.79	53.7±2.6

(continued)

Table 3 (continued).

Q. Sample WP-8		
Isotope	Soluble (S)	Clay Mineral (C)
Fe-59	< 68	60300±2200
Co-60	0.106±0.052	5.62±0.26
Zn-65	< 0.098	5.75±0.52
Se-75	< 0.63	< 2.7
Rb-86	< 3.4	37.5±4.8
Zr-95	< 35	116±36
Ag-110	< 0.36	< 1.9
Sb-124	< 0.15	0.68±0.17
Cs-134	< 0.110	2.86±0.23
Ce-141	< 0.55	45.2±1.7
Nd-147	< 5.7	< 8.7
Eu-152	< 0.031	0.711±0.056
Tb-160	< 0.060	0.448±0.098
Lu-177	< 0.025	0.321±0.023
Hf-181	< 0.089	3.65±0.15
Ta-182	< 0.169	0.76±0.11
Hg-203	< 0.22	< 0.66
Th-233	< 0.120	7.79±0.26

R. Sample WP-9		
Isotope	Soluble (S)	Clay Mineral (C)
Na-24	296000±8300	35220±990
Mg-27	< 28000	136800±6200
Al-28	< 16000	47900±2100
Cl-38	462000±25000	43300±2400
K-42	< 43000	< 6500
Ca-49	< 22000	< 2200
Ti-51	< 5300	1880±380
V-52	< 97	48.9±6.4
Mn-56	< 13	186.3±6.7
Cu-66	< 3600	< 550
Sr-87	< 2500	< 440
In-116	< 1.9	< 0.31
I-128	< 160	< 28
Ba-139	< 1100	< 210
Dy-165	< 7.9	2.09±0.50
U-235	0.00400±0.00011	2.153±0.060
Ga-72	< 310	< 97

(continued)

Table 3 (continued).

R. Sample WP-9		
Isotope	Soluble (S)	Clay Mineral (C)
As-76	< 8.8	< 2.6
Br-82	507±39	10.2±1.1
Mo-99	< 32	< 8.2
La-140	< 2.3	18.85±0.85
Sm-153	< 0.19	3.13±0.16
Yb-175	< 1.8	2.07±0.17
W-187	< 15.1	6.1±1.9
Au-198	< 0.048	< 0.014
Sc-46	< 0.00020	8.67±0.33
Cr-51	< 0.88	53.5±2.6
Fe-59	< 77	14380±550
Co-60	< 0.0038	9.19±0.39
Zn-65	< 0.11	< 0.62
Se-75	< 0.70	< 1.4
Rb-86	< 3.7	37.8±4.2
Zr-95	< 41	< 150
Ag-110	< 0.39	< 1.7
Sb-124	< 0.24	< 0.44
Cs-134	0.246±0.050	2.77±0.20
Ce-141	< 0.62	41.5±1.8
Nd-147	< 6.5	< 8.2
Eu-152	< 0.035	0.715±0.056
Tb-160	< 0.067	0.352±0.062
Lu-177	< 0.028	0.280±0.020
Hf-181	< 0.100	3.05±0.13
Ta-182	< 0.179	0.749±0.091
Hg-203	< 0.25	< 0.58
Th-233	< 0.128	7.23±0.24

S. Sample WP-10	
Isotope	Soluble (S)
Na-24	293900±8200
Mg-27	< 31000
Al-28	< 17000
Cl-38	448000±25000
K-42	< 47000
Ca-49	< 26000
Ti-51	< 5900

(continued next column)

(continued from previous column)

S. Sample WP-10	
Isotope	Soluble (S)
V-52	< 110
Mn-56	< 14
Cu-66	< 3900
Sr-87	< 2800
In-116	< 2.1

(continued)

Table 3 (continued).

S. Sample WP-10	
Isotope	Soluble (S)
I-128	< 180
Ba-139	< 1300
Dy-165	< 12.6
U-235	< 0.024
Ga-72	< 310
As-76	< 8.0
Br-82	28.5±2.8
Mo-99	< 30
La-140	< 2.2
Sm-153	< 0.17
Yb-175	< 1.7
W-187	< 14.8
Au-198	< 0.043
Sc-46	< 0.00019
Cr-51	< 0.82
Fe-59	< 71
Co-60	0.104±0.050

(continued next column)

T. Sample WP-11	
Isotope	Soluble (S)
Na-24	332700±9300
Mg-27	< 31000
Al-28	< 17000
Cl-38	485000±27000
K-42	< 47000
Ca-49	< 27000
Ti-51	< 5900
V-52	< 110
Mn-56	< 14
Cu-66	< 4000
Sr-87	< 2700
In-116	< 2.1
I-128	< 170
Ba-139	< 1200
Dy-165	< 8.8
U-235	< 0.0020

(continued next column)

(continued from previous column)

S. Sample WP-10	
Isotope	Soluble (S)
Zn-65	< 0.10
Se-75	< 0.66
Rb-86	< 3.5
Zr-95	< 37
Ag-110	< 0.38
Sb-124	< 0.15
Cs-134	< 0.114
Ce-141	< 0.58
Nd-147	< 6.3
Eu-152	< 0.032
Tb-160	< 0.062
Lu-177	< 0.026
Hf-181	< 0.089
Ta-182	< 0.116
Hg-203	< 0.23
Th-233	< 0.124

T. Sample WP-11	
Isotope	Soluble (S)
Ga-72	< 270
As-76	< 6.9
Br-82	52.7±4.4
Mo-99	< 20
La-140	< 1.97
Sm-153	< 0.11
Yb-175	< 1.42
W-187	< 11.8
Au-198	< 0.037
Sc-46	< 0.0045
Cr-51	0.69±0.18
Fe-59	< 51
Co-60	0.136±0.039
Zn-65	14.2±2.7
Se-75	< 0.43
Rb-86	< 2.5

(continued)

Table 3 (concluded).

T. Sample WP-11	
Isotope	Soluble (S)
Zr-95	< 26
Ag-110	< 0.28
Sb-124	< 0.109
Cs-134	< 0.082
Ce-141	< 0.35
Nd-147	< 25.3

(continued next column)

(continued from previous column)

T. Sample WP-11	
Isotope	Soluble (S)
Eu-152	< 0.0214
Tb-160	< 0.044
Lu-177	< 0.019
Hf-181	< 0.064
Ta-182	< 0.124
Hg-203	< 0.16
Th-233	< 0.088

Cl/Br, K/Rb, Th/U Ratios

The Cl/Br ratios for soluble material are shown in Table 4. Values range from 750 to 21,000. The content of Br varies from 22.7 ppm (Sample FH40-S) to 591 ppm (WP-3-S). The seawater Cl/Br ratio is only 280, but in halites this ratio varies considerably. Dean (1978) has presented data indicating a range in Br contents of halites from ~20 to 400 ppm and, for a theoretical Na percentage of 38, the range in halite Cl/Br is from 950 to 19,000. Br tends to concentrate in the evaporite brines well above its seawater concentration of 67 ppm under certain conditions, and minerals

Table 4. Cl/Br Ratios

<u>Sample</u>	<u>Cl/Br</u>	<u>Sample</u>	<u>Cl/Br</u>
Soluble Fractions*			
WP-1-S	2900	WP-11-S	9200
WP-2-S	15000	FH-4-S	6900
WP-3-S	750	FH6A-S	17000
WP-4-S	1900	FH6B-S	4000
WP-5-S	6200	FH26-S	7100
WP-6-S	—	FH27-S	1100
WP-7-S	14000	FH32-S	7100
WP-8-S	1700	FH40-S	21000
WP-9-S	910	FH42-S	3600
WP-10-S	16000	FH45-S	4300
		Avg. sea-water	280
Whole Rocks, FH Series			
FH4-WR	10000	FH32-WR	10000
FH6B-WR	7200	FH40-WR	8500
FH26-WR	11000	FH42-WR	8600
FH27-WR	13000	FH45-WR	10000

* from the solid left after filtering and evaporation.

such as sylvite and carnallite incorporate high amounts of Br into their structures, leaving the halite somewhat depleted in Br. The range in Cl/Br ratio for the soluble material (Table 3) is not considered anomalous in terms of Cl/Br, but some samples (WP-10-S, FH6A-S, FH40-S) do contain very low Br contents.

The Cl/Br ratios of whole-rock samples range from 7200 to 13,000, well within the range of normal halites (Dean, 1978). This is not surprising, because in most samples the amount of nonhalide material is small.

The Cl/Br, K/Rb, and Th/U ratios for clay minerals and insoluble clay-oxyhydroxide mixtures are shown in Table 5. The range in Cl/Br ratios is from 260 to 6500. The Cl/Br ratio for average shale (representing "typical" marine clay minerals) is only 34; hence the data in Table 5 show either excess Cl or somewhat depleted Br contents with respect to the

Table 5. Cl/Br, K/Rb, and Th/U Ratios for Insoluble Residues and Clay Separates

<u>Sample*</u>	<u>Cl/Br</u>	<u>K/Rb</u>	<u>Th/U</u>
WP-1-C	2000	160	2.7
WP-2-C	1600	110	2.8
WP-3-C	5000	240	2.9
WP-4-C	6500	160	2.2
WP-7-C	3900	210	2.4
WP-8-C	4800	—	2.3
WP-9-C	4200	—	3.4
FH4-I	1500	—	2.8
FH6B-I	260	150	3.4
FH27-I	56000	—	2.2
FH32-I	1400	200	1.9
FH42-I	2600	120	1.9
FH45-I	2100	180	3.6
Avg. shale	34	180	3.4

*I=Insoluble Residue; C=Clay Separate

averages for shale. We attribute the high Cl/Br ratios of the samples to (1) small amounts of halide minerals present in the hand-picked clay mineral-oxyhydroxide mixtures, and (2) incomplete removal of soluble salts in the insoluble fractions.

The K/Rb ratios, however, are less sensitive to such contamination. The ratios vary from 110 to 240, with a mean of 170. This value is very close to that of average shale of 178 (Table 5). The relevance of this is discussed below.

Th/U ratios for the same samples range from 1.9 to 3.6 (Table 5) with a mean of 2.7, which is comparable to the average Th/U ratio for shale of 3.43. Both the Th and U contents of these samples (Table 3) are lower than for average shale (i.e., 12 ppm Th, 3.5 ppm U). This is probably due to simple dilution of the Th- and U-bearing phases with Th- and U-poor material. These data indicate that uranium has apparently not been leached from these samples, as discussed below.

Studies of Rare-Earth Elements

Rare-earth element (REE) studies are of relevant to determining the integrity of minerals such as clays in an evaporitic environment, because the REE can be mobilized in Cl-SO₄-CO₃ environments (Brookins, 1983), and depletions of total REE will result. Also, more subtle effects of the differences in light REE (LREE) versus heavy REE (HREE) can be correlated with the amount of interaction of the clay minerals with the brine. Furthermore, the REE studies represent an independent check on the K-Ar geochronology and other tests for the stability of clay minerals.

Following the convention of Haskin and Schmitt (1967), the REE data of Table 3 have been normalized to the analogous REE data for chondrite meteorites (CHON) using the new values recommended by Anders and Ebihara (1982). Also following the convention, the ratios of lanthanide concentrations in samples to those in chondrite meteorites

Figure 1. REE/CHON Normalized Distribution, Sample WP-1-C

Figure 2. REE/CHON Normalized Distribution, Sample WP-2-C

Figure 3. REE/CHON Normalized Distribution, Sample WP-3-C

Figure 5. REE/CHON Normalized Distribution, Sample WP-5-P

Figure 4. REE/CHON Normalized Distribution, Sample WP-4-C

Figure 6. REE/CHON Normalized Distributions, Sample WP-7-C

(REE/CHON) were plotted versus relative position of the REE from La through Lu in order of increasing atomic number. The individual plots are shown in Figures 1 through 8 for the WP samples and in Figures 9 through 14 for the FH samples. The samples represent either clay mineral-oxyhydroxide separates (C) or insoluble residues (I) except for WP-5-

P, which is a hand-picked polyhalite sample (Figure 5).

Most samples show moderate enrichment in the LREE, as is consistent with studies of clay minerals from many locations (see Brookins, 1979, for discussion). In the absence of Gd analyses, the line connecting the Sm and Tb points is projected as a dashed line from the

Figure 7. REE/CHON Normalized Distribution, Sample WP-8-C

Figure 9. REE/CHON Normalized Distribution, Sample FH-4-I

Figure 8. REE/CHON Normalized Distribution, Sample WP-9-C

Figure 10. REE/CHON Normalized Distribution, Sample FH-6B-I

Tb point to the position corresponding to Gd (midway between Eu and Tb on the horizontal coordinate); the dashed line connecting the Eu and projected Gd points approximately defines the HREE end of the Eu anomaly (i.e., selective exclusion of Eu from minerals other than feldspar, where it concentrates as the divalent, rather than trivalent cation). The Eu anomaly is consistent with a normal-type

LREE distribution for clays and for shales. At the HREE end of the curves, however, there is a pronounced tendency for the curves to flatten out, as is commonly noted in many clays. Any hypothetical scenario of REE exchange with an evaporitic brine should take into account the very small REE content of seawater, and thus of brines formed by evaporation (Elderfield and Greaves, 1982). Sev-

Figure 11. REE/CHON Normalized Distribution, Sample FH-27-I

Figure 13. REE/CHON Normalized Distribution, Sample FH-42-C

Figure 12. REE/CHON Normalized Distribution, Sample FH-32-I

Figure 14. REE/CHON Normalized Distribution, Sample FH-45-I

eral types of effects of interactions between REE and evaporite-brine are possible. Such interactions include an overall depletion of the REE because of removal into the brines, and preferential loss of HREE as a result of the effects of Mg-exchange between brine and clay mineral. Only sample FH-4-I (Figure 9) shows a pronounced HREE downward trend, and none of the other clay-mineral-rich sam-

ples (C, I) reflect HREE loss. In fact, the flattening of the curves could suggest HREE addition except that there is no source for such addition. In the case of the polyhalite, WP-5-P (Figure 5), the curve reflects the preferential enrichment of the LREE (i.e., in the Ca sites) versus HREE.

The REE data for the clay minerals strongly suggest that residence in the evaporitic brines was not sufficient to affect the REE abundance distribution in the clay minerals. This is important because it demonstrates the ability of such clay- oxyhydroxide materials to serve as getters for the lanthanide REE, which may act as analogues for actinides.

Table 6. K-Ar Age Determinations

K-Ar Dates

K-Ar dates were obtained by Geochron Laboratories of Cambridge, Massachusetts. Table 6 contains the data for radiogenic argon (^{40}Ar), in ppm, total K, in %, ratio of radiogenic Ar to total Ar ($^{40}\text{Ar}/\epsilon^{40}\text{Ar}$, to indicate

Sample	$^{40}\text{Ar}(\text{ppm})$	K(%)	$^{40}\text{Ar}/\epsilon^{40}\text{Ar}$	t (Ma)
FH-4-I	0.005578	0.634	0.243	114±5
	0.004565	0.684	0.173	
	0.006156	—	0.195	
FH-6A-I	0.09240	6.687	0.894	187±7
	0.1056	7.245	0.795	
	0.08967	6.987	0.790	
FH-6B-C	0.02195	0.0694	0.387	378±15
	0.02007	0.741	0.526	
FH-26-C	0.02783	0.931	0.548	382±15
	0.02516	0.860	0.492	
FH-27-C	0.02315	0.821	0.659	365±14
	0.02259	0.806	0.546	
FH-27-I(P)	0.001913	0.491	0.125	55.5±3
	0.001873	0.475	0.138	
FH-27-WR	0.000898	0.045	0.164	324±20
	0.000555	0.050	0.193	
	0.002236	0.057	0.415	
	0.001311	—	0.334	
FH-32-C	0.02272	0.769	0.714	387±15
	0.02305	0.757	0.555	
FH-42-I	0.005177	0.147	0.053	88.7±5.3
	0.001335	0.197	0.087	
FH-45-C	0.02755	0.904	0.753	390±15
	0.02583	0.860	0.657	
	—	0.273		

Ma — millions of years before the present, based on the mean of all replicates

C — clay mineral separate

I — insoluble residue

O — oxyhydroxide minerals

P — polyhalite

magnitude of air correction), and K/Ar age in millions of years before the present (Ma). The ages as reported by Geochron have been corrected to the most recently available decay constants for ^{40}K . Background information on the K-Ar dating of the WIPP and related evaporites and associated materials may be found in Brookins et al (1980), Register and Brookins (1980), and Brookins (1981; 1982).

Some earlier work indicated that primary evaporite minerals such as sylvite and polyhalite retained radiogenic ^{40}Ar well enough to give reliable dates, many of which clustered in the age range 180 to 220 Ma. Brookins et al. (1980) showed that an empirical correction factor could be applied to polyhalites for admixed halide minerals (i.e., halide minerals lose ^{40}Ar easily) with resultant corrected ages > 200 Ma. Register (1981; see also Register and Brookins, 1980) examined the Rb-Sr Systematics of clay minerals from the WIPP area evaporites, with a resultant isochron date of 390 ± 77 Ma. Brookins et al. (1980) and Brookins (1981) interpreted this result as evidence that the internal Rb-Sr systematics of clay minerals, presumably of aeolian origin, had not been altered to reflect the age of evaporites (e.g., 220 to 230 Ma) during entrapment in the evaporite mother-liquor.

The present study emphasizes clay minerals from the WIPP underground workings. Two types of samples were used for study; those from which enough clay and oxyhydroxide minerals could be mechanically separated, and those in which an attempt was made to separate these minerals by dissolution of halite. One sample (WP-5) also contained enough polyhalite for hand separation.

The attempt at concentrating sufficient uncontaminated insoluble material by dissolution was not successful. The x-ray diffraction data (Table 2) show that the samples so

treated contain moderate amounts of gypsum, halite, and anhydrite; their chemistry (Table 3) reflects the presence of significant amounts of K, presumably derived from the evaporitic salts. This excess K is thought to be the prime reason for the wide range (55 to 114 Ma) in the K-Ar dates for the insoluble residues (Table 6). No geological significance can be attributed to these dates.

However, the clay minerals (with or without oxyhydroxide minerals) separated by hand yield dates from 365 to 390 Ma, in agreement with the Rb-Sr work of Register and Brookins (1980). These dates are offered as evidence that the K-Ar systematics of these clay minerals were not reset to the age of evaporitic mineral formation when these minerals were entrapped in the evaporitic brine environment. The significance of this conclusion is discussed below.

One hand-picked polyhalite sample (FH6A) yields a date of 187 ± 7 Ma. Data are not available for the Na content of the sample; hence, a correction (e.g., Brookins et al., 1980) cannot be applied; hence, it is not known if this polyhalite would yield a corrected date of 210 to 230 Ma like the other samples from the area.

K-Ar dating was attempted on one sample of clay-bearing halite (FH27). Surprisingly, it yielded an apparent K-Ar date of 324 ± 20 Ma. This age may reflect the presence of the 365 Ma clay in the sample (FH27-C), diluted with polyhalite and halite.

Rb-Sr Dates

Rb-Sr dates were determined in the University of New Mexico Geology Department Geochronology Laboratory. Samples were

Table 7. Rb/Sr Geochronologic Data

Sample ¹	Rb (ppm)	Sr (ppm) ²	⁸⁷ Sr/ ⁸⁶ Sr ²	⁸⁷ Rb/ ⁸⁶ Sr
FH4-I	10.96	9041.0(1)	0.7072(8)	0.00351
FH6A-I	0.54	3481.7(1)	0.7076(3)	0.00045
FH6B-I	42.18	58.3(6)	0.7199(9)	2.0937
FH26-WR	0.15	1.2(2)	0.7083(0)	0.3557E
FH27-I	2.55	7449.1(4)	0.7080(5)	0.00099
FH32-WR	0.45	1.7(6)	0.7130(0)	0.74016
FH10-I	11.41	4179.5(3)	0.7073(5)	0.00799
FH42-I	40.57	83.7(3)	0.7159(9)	1.40306
FH45-I	48.17	42.0(2)	0.7271(0)	3.32312
WP-1-I	46.31	25.1(4)	0.7405(7)	5.34694
WP-2-I	36.77	33.0(0)	0.7759(2)	3.22964

1. I – insoluble; WR – whole rock

2. least significant digit is parenthesized

prepared using standard dissolution methods for silicate-oxide assemblages, involving dissolution in HF/deionized water, cooling, filtering, and separation of Rb and Sr by ion exchange chromatography with 2.2 N HCl as the eluant. Samples were spiked with ⁸⁴Sr and ⁸⁷Rb spikes before dissolution. After the ion exchange procedure, samples were fused in quartz beakers, cooled, and stored. Samples were then loaded onto rhenium filaments, and isotopic data were obtained using a Nier-design thermal ionization mass spectrometer. The data are presented in Table 7 and plotted in Figure 15.

Table 7 shows total Rb and Sr in ppm and the ⁸⁷Sr/⁸⁶Sr isotopic ratio. The total Rb and Sr data are precise to $\pm 0.25\%$ (1σ) of the reported value, and the reported ⁸⁷Sr/⁸⁶Sr ratios are precise to ± 0.00002 (2σ). The isochron in Figure 15 was calculated using five iterations of the least-squares method of York (1969). The regression of the data in Figure 15 yields a Rb-Sr isochron date of 428 ± 7 Ma with initial ⁸⁷Sr/⁸⁶Sr = 0.70707 ± 0.00013 .

K-Ar dates for clay minerals (discussed above) are tightly clustered between ~ 360 and 390 Ma. The insoluble residues from the samples of this study define a fairly good isochron with a date of 428 Ma. This date is within reasonable agreement with previously reported K-Ar and Rb-Sr dates (see above).

Figure 15. Rb-Sr Isochron for Clay Minerals and Oxyhydroxide Minerals

The original interpretation of these pre-Permian dates, by Brookins et al (1980) and Brookins (1981) was that the clay minerals were of aeolian origin, and that their K-Ar and Rb-Sr isotopic systematics had not been reset upon incorporation into and reaction with the evaporitic brines. The data defining the 390 ± 77 Ma Rb-Sr isochron date for clay minerals from several locations (Register, 1981) were more scattered than those in the present study, and no quantitative comments could be made concerning provenance and thus extent of diagenetic reaction. The linear isochron of Figure 15, however, is a much better fit (i.e., the error on the age is only 7 Ma, and the error on the initial intercept only ± 0.00013). Because the samples used for this study are all from the WIPP site, problems such as mixed provenance may have been avoided. For example, if samples with different prehistories, including different initial ratios, are homogenized at some time, then several parallel isochrons all of the same age may result (Brookins, 1985). This possibility cannot be dismissed for the samples reported by Register (1981). The data of this study also suggest, but do not unequivocally prove, that there may have been a 400- to 450-Ma source area for the clay minerals that dominated the aeolian input. This is surprising, because source areas theoretically could have included everything from older Permian to Precambrian rocks.

The 428-Ma isochron of Figure 15 suggests, as do the REE distributions, that the samples were largely unaffected by their diagenetic residence time in the evaporitic brines. This is important because it indicates that these clay mineral- oxyhydroxide assemblages may serve as getters for radioisotopes hypothetically released from breached containers of radioactive waste.

Conclusions: Implications of the Geochemistry of the Clay Minerals and Insoluble Residues of WIPP Samples

This report has emphasized primarily the importance of Cl/Br, K/Rb, Th/U ratios, REE patterns, K-Ar ages, and Rb-Sr ages in assessing water/rock interactions in the horizons of the Salado Formation where the WIPP facility has been excavated. Although admittedly limited, the study allows the following observations to be made:

- The x-ray data indicate the presence of clay minerals and other insoluble phases normally expected in evaporites.
- Cl/Br ratios for soluble material fall in the normal range for marine evaporites, although some samples are very low in total Br.
- Cl/Br ratios in insoluble material are very high, partly because of excess Cl from included halide minerals, and partly because of Br deficiency.
- The K/Rb and Th/U ratios for the insoluble material fall in the normal range for shales, suggesting that their internal alkali element content has been largely undisturbed by residence in the evaporites. Furthermore, there is no evidence to suggest that uranium has migrated from the samples, because the Th/U ratios are fairly uniform and close to the values for shale. The overall Th and U concentrations are somewhat lower than in shales.

- The REE data for the insoluble material strongly suggest that the residence of these insoluble materials in the evaporite environment has not affected their internal REE systematics. No evidence is noted for loss or gain of the REE in these insoluble materials.
- K-Ar dates for clay minerals range from 365 Ma to 390 Ma, corresponding to the range for clay minerals from nearby sites (Brookins, 1981). These dates, well in excess of the evaporitic formational age of 220 to 230 Ma, suggest that residence in the evaporites has not significantly perturbed the K-Ar systematics.
- WIPP-site clay minerals yield a Rb-Sr isochron age of 428 ± 7 Ma. This indicates little if any perturbation of Rb-Sr systematics as a result of evaporite brine-clay mineral reaction.
- The clay minerals and other insoluble materials appear resistant to destructive effects of their entrapment in the evaporites, suggesting that these insoluble materials would be good getters for radionuclides hypothetically released from radioactive wastes into the Salado Formation.

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