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Distribution of bromine in bedded halite in the Green River Formation, southwestern Wyoming

By

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TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

DISTRIBUTION OF BROMINE IN BEDDED HALITE IN THE GREEN RIVER FORMATION, SOUTHWESTERN WYOMING

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ABSTRACT

The Wilkins Peak Member of the Eocene Green River Formation of southwestern Wyoming contains a series of halite-trona beds deposited in ancestral Lake Gosiute. X-ray fluorescence analysis of 310 salt samples from 10 core holes revealed bromine contents ranging from 11 to 174 ppm. The average concentration, corrected to 100 percent sodium chloride, is approximately 80 ppm. The bromine content of most halite beds increases from the base upward. Variations or "spikes" in the bromine profile and reversals of the upward increase in bromine are evidenced within several salt beds. Bromine of bed 10 salt zones exhibits a high degree of correlation laterally. No increase in bromine concentration for correlated salt zones was noted from the basin margins to the depositional center in the northeastern part of the study area. A great disparity in salt thickness from the depositional center to the margins suggests stratified lake conditions in which denser, sodium-chloride-saturated bottom brines did not extend to the margins during part of the depositional history of bed 10.

Paleosalinity trends of Lake Gosiute determined from the bromine distribution include the following: (1) chemically stratified lake conditions with dense, highly saline bottom waters and a fresher water zone above during much of the depositional history of the halites, (2) gradual evaporation of lake waters in a closed basin with resultant upward increase in salinity for most intervals studied, and (3) absence of lateral lake-bottom salinity gradients or postdepositional salt alteration as determined by the lateral constancy of bromine concentrations for correlated bed 10 halite.

INTRODUCTION

This report investigates the paleosalinity history of selected halite intervals of the Wilkins Peak Member of the Eocene Green River Formation of southwestern Wyoming (fig. 1). Six halite beds from the Finley 2 core hole were sampled and analyzed for bromine by X-ray fluorescence (XRF). One of these beds, halite bed 10, was sampled in nine additional core holes. Bromine results from all 10 core holes were correlated to determine the horizontal and vertical variations in salinity for halite bed 10 across the basin.

Interpretation of the bromine distribution in salines is an important tool in geochemical studies of saline basins. The bromine concentration of chloride minerals is dependent upon the bromine content of the parent brine. During evaporation, the distribution is such that the amount of bromine substituting for chlorine in the sodium chloride lattice is less than the amount remaining in the parent solution (Valyashko, 1956, p. 570). This can be interpreted to mean that the bromine concentration of both precipitated chloride salts and parent brine in a closed basin would increase with time and evaporation; likewise, influxes of fresher water would dilute the bromine content of the solution, and precipitated chloride salts would contain lower amounts of bromine.

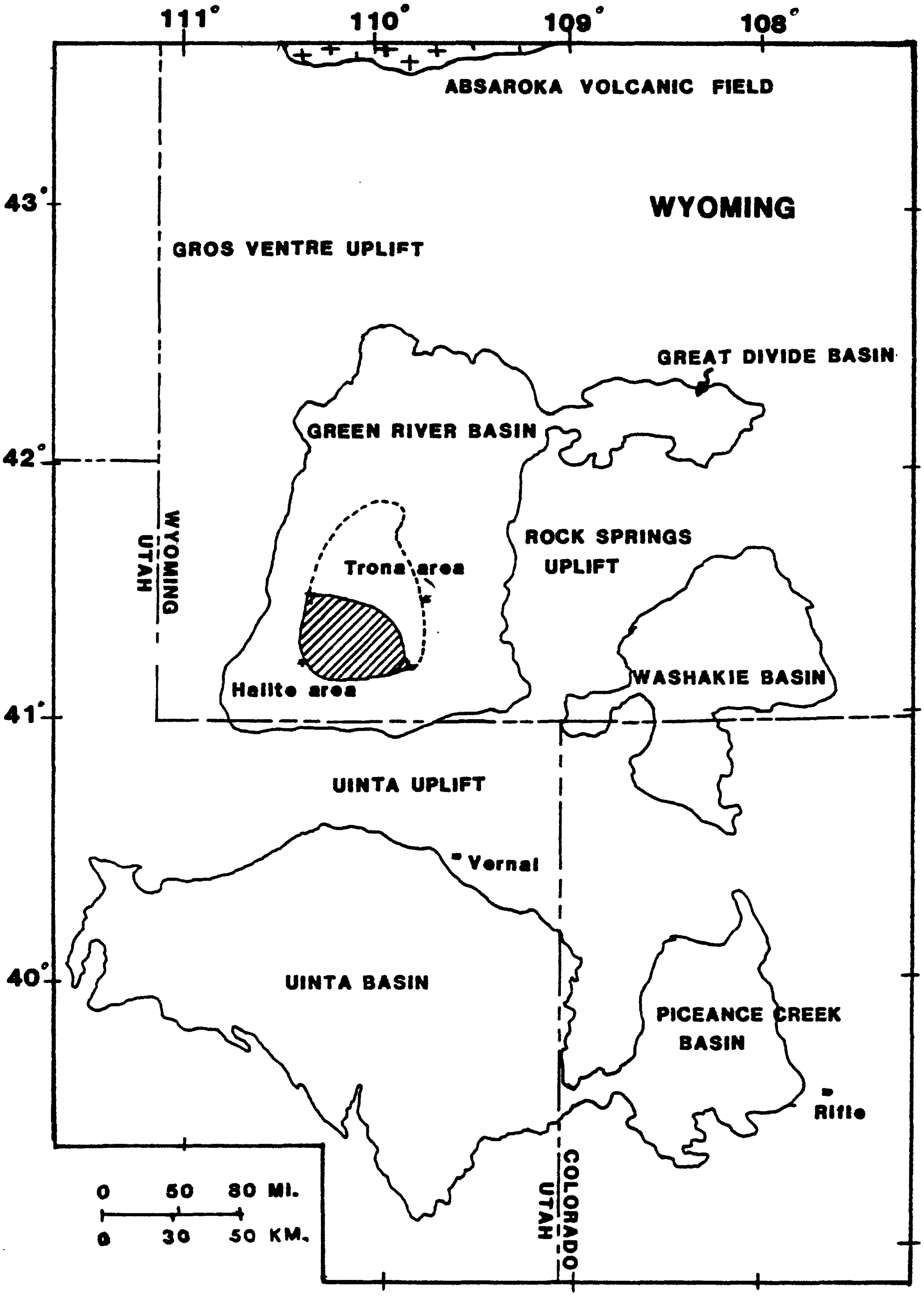

Figure 1. Index map of the Green River Basin of Wyoming.

GEOLOGIC SETTING

The Green River Basin is an asymmetrical structural and sedimentary basin. The Eocene age Green River Formation is composed of flat lying lacustrine sediments from ancestral Lake Gosiute. The saline facies of the Wilkins Peak Member is defined by Bradley and Eugster (1969, p. B-7) as the stratigraphically lowest and highest occurrences of saline minerals or their salt casts. The member is composed primarily of beds of lacustrine oil shale, marlstone, limestone, trona ($Na_2CO_3.NaHCO_3.2H_2O$), trona-halite, and halite interbedded with sandstone, siltstone, and mudstone (Culbertson and others, 1980, p. 7). The Wilkins Peak Member is as much as 400 m thick in the southeastern part of the basin and thins northward (Culbertson and others, 1980, p. 7). Halite at the basin depocenter grades laterally to the north into trona. Halite deposits of the Wilkins Peak Member cover an area of approximately 860 km^2 near the southern boundary of the basin. The areas of deposition are illustrated on figure 1.

The Wilkins Peak Member contains at least 42 beds of trona. The bed tops range from 120 to 1100 m below the surface. Individual trona beds vary in thickness from a film to as much as 11 m thick (Culbertson, 1971, p. 15). A composite columnar section (fig. 2) of the Wilkins Peak Member shows the 25 major trona beds 1 m or more thick, numbered from the base of the member upward (Culbertson, 1971, p. 15). Halite is present in major amounts in beds 6, 9, 10, 11, and 15; in moderate amounts in beds 5, 12, 14, and 16; in minor amounts in beds 2, 3, and 7; and is absent in beds 1, 4, 8, 13, and 19 to 25 (Burnside and Culbertson, 1979). Halite in beds 6, 9, 10, 11, 15, and 16 was sampled for bromine, chlorine, and potassium analysis.

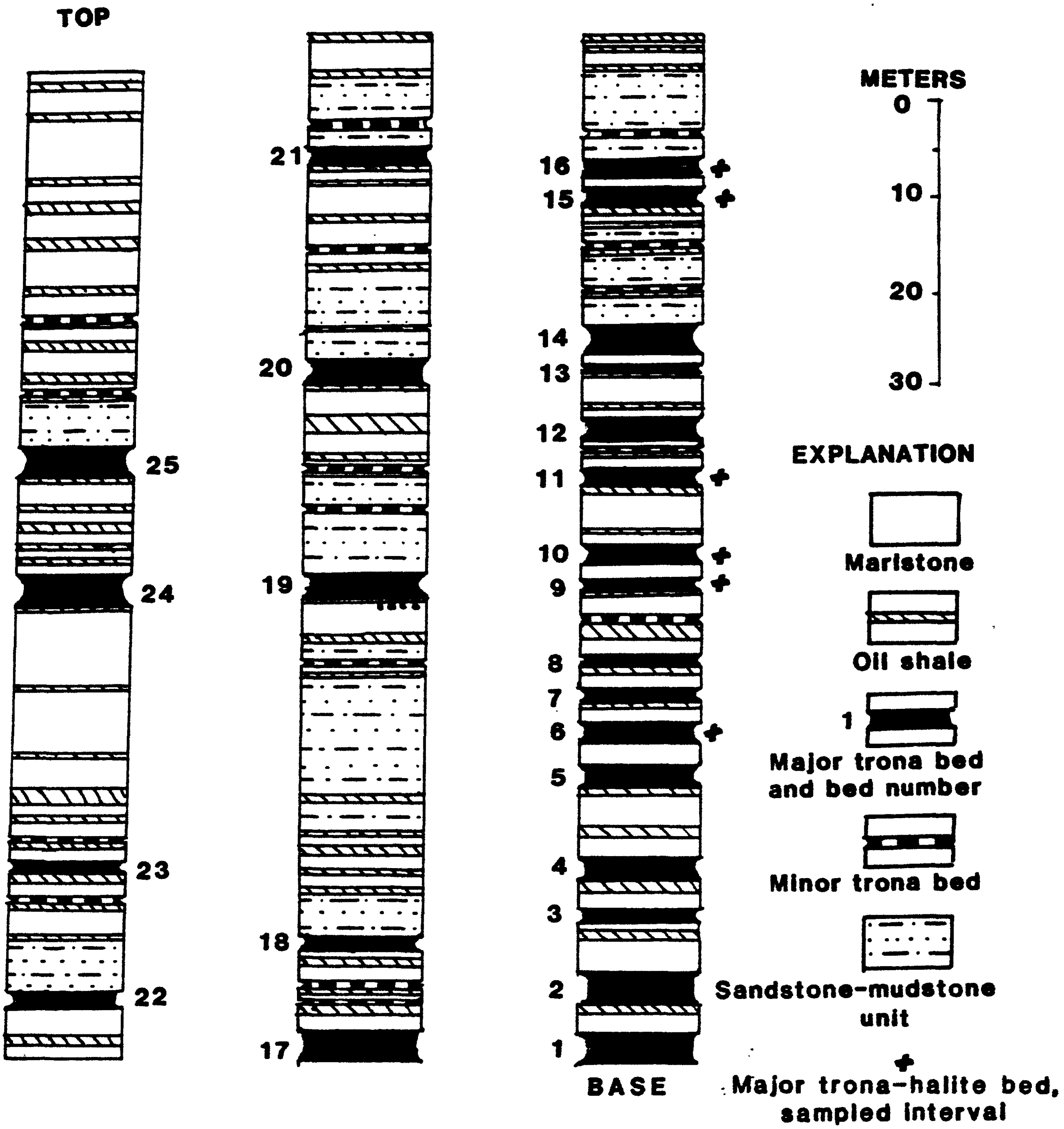

Figure 2. Composite columnar section of the Wilkins Peak Member in the trona area of Wyoming (Culbertson, 1971, p. 17).

SAMPLING METHODS

The locations of the 10 core holes which were sampled for bromine analysis are shown on figure 3 and listed in table 1. A total of 310 samples of halite and mixed halite-trona were collected from cores of the Wilkins Peak Member of southwestern Wyoming.

Table 1.--Drill hole locations

Drill hole name	Location			
	1/4 section		Township N.	Range W.
(1) Finley 2 (F-2)		26	16	110
(2) SAP 1 (S-1)	NE 1/4	36	16	112
(2) SAP 2 (S-2)	C	36	17	110
(2) SAP 3 (S-3)	NW 1/4	36	14	111
(2) SAP 5 (S-5)	NW 1/4	36	16	110
(2) SAP 6 (S-6)	SW 1/4	16	16	110
(2) SAP 18 (S-18)	NE 1/4	16	15	109
(2) SAP T-3 (T-3)	SW 1/4	36	17	110
(2) SAP T-14 (T-14)	SE 1/4	36	17	110
(3) Yates (Y)		35	15	112

(1) Diamond Alkali Company, Finley 2 drill hole

(2) FMC Corporation, SAP drill holes

(3) Martin Yates III and Yates Drilling Company Fed A-1, Yates drill hole

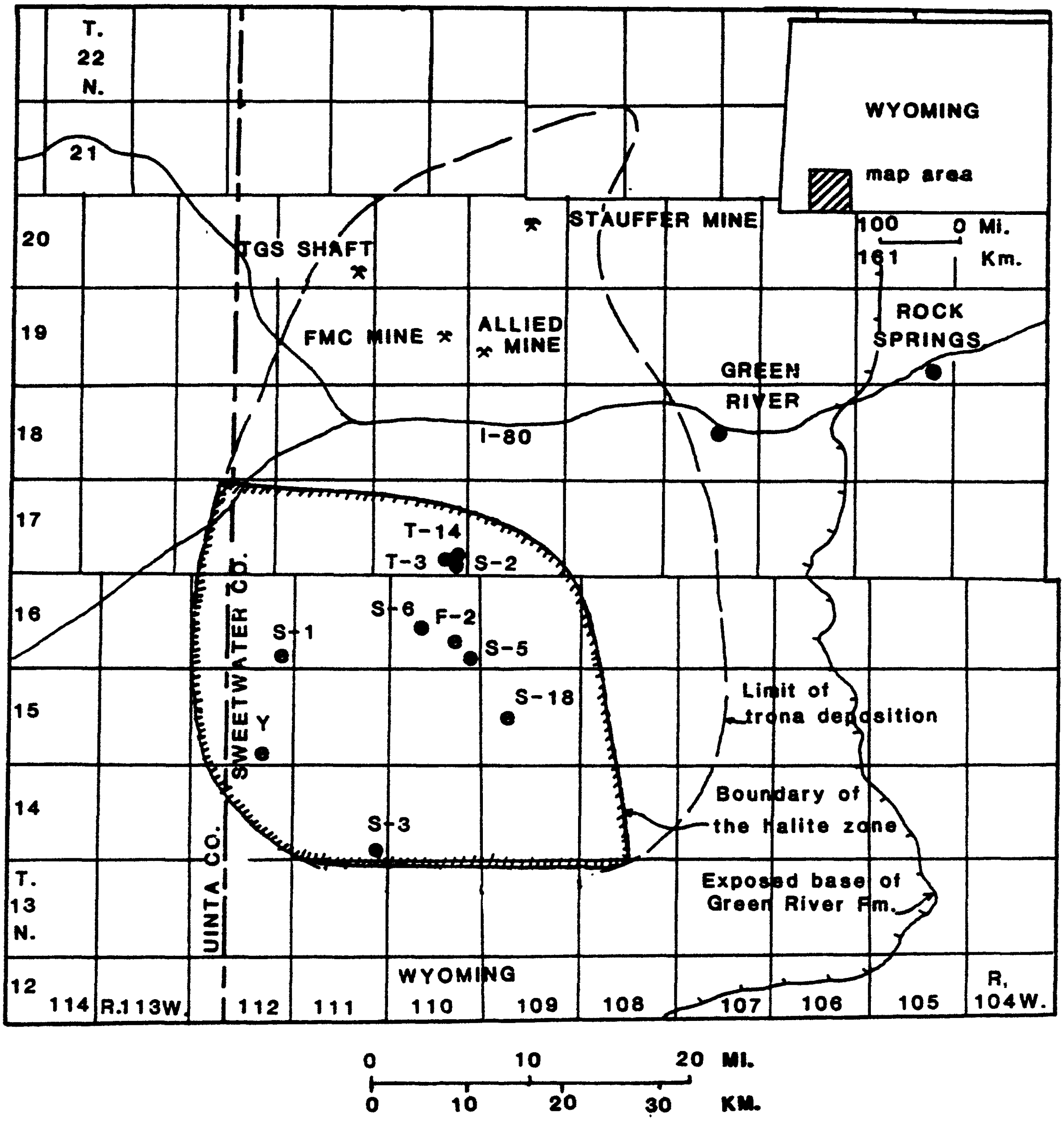

Figure 3. Map of the trona area in the Green River Basin showing sampled drill holes (numbered solid dots) (Deardorff and Mannion, 1971, p. 26).

The Finley 2 samples were taken from trona-halite beds 6, 9, 10, 11, 15, and 16. All major halite-containing intervals were sampled from the Finley 2 core hole. This was done to determine variations in the vertical bromine distributions over a relatively long period of time. The nine remaining drill holes were sampled from trona bed 10 only. Trona bed 10 was reserved for more detailed sampling due to several factors: (1) initial testing indicated a higher halite to trona ratio than appeared in other beds; (2) bed 10 has a wide distribution over the study area of the basin; (3) bed 10 had a greater core recovery than most of the other intervals; and (4) average bromine concentrations were higher than in other beds based on initial XRF tests.

The sample spacing ranged from 3 to 22 cm through each salt bed with an average spacing of approximately 9 cm. Several samples were taken for each lithologically similar core interval, as indicated by changes in halite color, crystal size and orientation; and shale and/or trona breaks.

Samples were collected by drilling into the side of the core, parallel to bedding, with a 13 mm diameter drill bit. Approximately 4 drill samples, spaced equidistant on the 9 cm (avg.) intervals, were recovered for each sample.

The drill bit was cleaned with distilled water between samples to minimize possible contamination. Approximately 7-20 g of recovered powder per sample were blended in a Spex mill. Five to six g of powder, approximately 15 percent of which was below -200 mesh, and 95 percent below -100 mesh, were compressed at 1.6 metric tons/cm^2 pressure into a metal cap. The resulting pellets were analyzed by XRF.

ANALYTICAL PROCEDURE

Total bromine and chlorine were determined for the salt samples by wavelength dispersive XRF. The intensities of the bromine and chlorine Kα peaks above background for the salt samples were compared to the peak above background intensities for a set of standards. The element concentration in the unknown was determined by the proportion (Birks, 1971, p. 102):

$$\frac{C_{i_u}}{C_{i_s}} = \frac{I_{i_u}}{I_{i_s}}$$

where I_{i_u}=X-ray intensity of the Kα peak for element i in the unknown

I_{i_s}=X-ray intensity of the Kα peak for element i in the standard

C_{i_u}=concentration of element i in the unknown

C_{i_s}=concentration of element i in the standard

when the concentration of the standard (C_{i_s}) is known and the X-ray intensity of the standard (I_{i_s}) equals the intensity of the unknown.

Least squares linear regression curves of the standards were constructed. X-ray intensities versus the element concentration in the standards were prepared for comparison to the X-ray intensities for that element in the samples.

Chlorine was determined by XRF for the purpose of correcting the bromine concentration to 100 percent sodium chloride. Initial XRF tests indicate either that trona does not contain bromine, or that bromine is present in amounts below the detection limit of the XRF method. To determine if K-salts were present, approximately 40 of the high bromine samples were analyzed by XRF for potassium.

Bromine, chlorine, and potassium were analyzed using a fixed-time counting rate. One reading of the element Kα peak intensity and two background intensities were recorded for each sample.

The minimum detection limit of an XRF method is defined by Birks in (Bertin, 1974, p. 529-530) as being the amount of analyte that gives a net-line intensity equal to 3x the square root of the background intensity (I) for a specified counting rate. The minimum detection for chlorine using this detection method is 2-9 percent. The detection limit for bromine is approximately 20 ppm for the machine parameters shown in table 2. Bromine Kα peaks of concentrations as low as 5 ppm may be visually detected on XRF chart readouts.

Eight bromine standards containing 15.99, 31.82, 66.23, 99.86, 184.6, 365.2, 824.6, and 1493 ppm bromine in a sodium chloride matrix were prepared. Sodium chloride used as the matrix was more than 99.8 percent pure and initially contained approximately 33 ppm bromine. Bromine-free sodium chloride was prepared from this salt by repeated evaporation of the sodium chloride in solution. Sodium bromide is much more soluble in water than is sodium chloride; therefore, the residual brine present prior to complete evaporation is enriched in sodium bromide. This residual brine was drawn off and discarded repeatedly until the bromine content of the halite was below the visual XRF detection limit of 5-10 ppm Br. Two additional brine separations were made to further reduce the bromine content.

Table 2.--XRF machine settings
(Picker X-ray Spectrodiffractometer)

Element	$K\alpha$ peak $^\circ 2\theta$	Bkgd readings $^\circ 2\theta$	Baseline, window volts	Counting time (sec)	Tube	Detector voltage	Detector type	Crystal
Br	29.95	29.00 30.95	8.58, 3.30	100	Mo	950	Scint.	LIF 200
Cl	65.55	63.00, 67.00	7.40, 3.08	100	Cr	1450	Flow proport.	PET
K	50.68	48.00, 52.00	9.06, 4.18	100	Cr	1450	Flow proport.	PET

Element	Generator voltage and current	Collimator (mm.)	Gas
Br	50 Kv.,30 MA.	0.20	Air
Cl	50 Kv.,35 MA.	0.20	He
K	50 Kv.,35 MA.	0.20	He

The bromine-free sodium chloride was mixed with measured amounts of more than 99.9 percent pure sodium bromide, blended, and ground to less than -200 mesh. The bromine standards were compressed into pellets and stored in a desiccator.

Standards used in the XRF analysis for chlorine were prepared of 99.8 percent pure reagent-grade sodium chloride with +99 percent pure trona from which soluble chlorides were removed by methanol extraction. Methanol extraction was used because sodium chloride and many other chlorides are much more soluble in methanol than is trona. Measured amounts of sodium chloride and trona were combined, crushed to less than -200 mesh, and blended, all at low temperatures to prevent the decomposition of trona. Five chlorine standards, containing 4.21, 9.25, 21.14, 48.20, and 60.55 percent chloride, were prepared and stored in a desiccator.

Bromine analysis by XRF compares favorably with other analytical methods. XRF analysis is faster (3-10 minutes) than oxidative methods (±30 minutes). Dunton (1968, p. 100), in her XRF analysis of bromine-containing brines, found an acceptable correlation between the two methods, despite a variation in sample density (table 3).

Table 3.--Comparison of X-ray and oxidation methods of bromine analysis of brines

(Dunton, 1968, p. 100)

Density (g/ml)	X-ray fluorescence	Oxidation method
1.268	800	789
1.211	100	97
1.300	400	410
1.261	360	350
1.219	380	388
1.122	440	437
.999	5	4.4
1.291	510	507
1.291	590	590
1.316	220	200
1.279	445	433
1.336	300	281
1.022	116	119

There are several potential sources of error in an XRF sample analysis. The possible sources of error and corrective measures which were taken follow:

(1) Machine-drift errors occur as the XRF unit warms up. To correct for this, all standards were run every 3 hours with intermediate runs of selected standards.

(2) Expansion of the LiF 200 and PET crystals was not found to be a problem; however, scans of the bromine and chlorine Kα peaks were made twice a day to determine if peak shift had taken place.

(3) Homogeneity effects were minimized by the use of a sample spinner, plus a fairly uniform sample particle size below -100 mesh.

(4) Matrix absorption-enhancement effects are important and will be dealt with in the next section.

(5) Sample integrity and changes in standard and sample composition through time as a result of radiation were not important effects as evidenced by the accuracy and precision test results. Upon exposure to X-rays, the sodium chloride standards and halite samples turn brown. No discoloraton or changes in sample texture or composition were apparent during the 8-month storage time.

Accuracy and precision tests were run on the six bromine standards over a period of 1 month. Using the same XRF instrument parameters listed in table 2, the standards were analyzed and a best-fit linear regression curve was applied to the results. The correlation coefficients for the resulting curves were in the range 0.9996 to 0.9999. The standards were again analyzed within 2 hours of the initial run, and the peak intensity was fitted to the curve. The resulting bromine concentration was then used to determine the relative error and standard deviation of the XRF method. In addition to analyzing the standards, two samples, numbers 46 and 49, were also analyzed. These samples were analyzed to check for any changes in sample integrity, as evidenced by a change in precision upon repeated exposure to X-rays over a prolonged period of time. The average relative error of the method at 100 ppm bromine is +0.98 percent with a standard deviation of ±2.21 ppm (table 4).

Accuracy and precision tests for the chlorine analyses, using the same method, were also conducted (table 5). In the range of composition of the samples, most of which are +80 percent sodium chloride, the average relative error is less than 1 percent.

Table 4.--Precision and accuracy results of the XRF method of analysis for bromine

[Leaders (---) not analyzed]

Standards	Date of analyses and results (ppm), 1982							Average	Std. dev.	Average relative error
(ppm Br)	11/28	11/28	12/1	12/8	12/10	12/14	12/14	(ppm)	(±ppm)	(pct)
16	16.5	16.9	17.1	18.9	15.7	15.1	15.6	16.5	1.27	+3.21
32	32.8	31.2	32.6	34.9	32.9	30.3	31.4	32.3	1.49	+1.38
66	67.3	66.7	67.9	65.8	69.5	61.8	66.7	66.5	2.39	+0.801
100	100.3	101.5	105.1	99.6	---	98.8	100.6	100.9	2.21	+0.983
185	184.7	187.1	183.7	185.3	184.0	181.4	181.4	183.9	2.06	-0.407
365	375.6	---	377.6	374.4	---	365.3	371.5	372.9	4.78	+2.17

Unknowns	Date of analyses and results (ppm), 1982									Average	Std.dev.
sample no.	11/15	11/17	11/19	11/24	11/26	11/29	12/1	12/6	12/8	(ppm)	(±ppm)
46	114	113	113	114	116	114	113	112	110	113	2(1.64)
49	47	49	50	50	49	51	49.8	53	43	49	3(2.79)

Table 5.--Precision and accuracy results of the XRF method of analysis for chlorine

Standards	Date of analyses and results (pct Cl), 1982, 1983							Average	Std. Dev.	Average relative
(pct Cl)	12/23	12/23	12/23	12/23	12/30	1/5	1/5	(pct Cl)	(± pct)	error (pct)
9.25	9.39	10.17	10.11	10.24	10.09	9.58	9.66	9.89	0.37	+6.96
22.14	20.84	20.06	19.71	19.89	22.03	21.28	21.46	20.75	0.89	-5.62
48.20	48.45	47.99	48.15	48.26	50.41	49.08	48.61	48.71	0.83	+1.05
60.55	60.33	60.92	60.95	60.74	63.06	60.63	60.87	60.07	0.90	+0.86

Sample no.	Date of analyses and results (pct Cl), 1982, 1983				Average (pct Cl)	Std. Dev.
	12/28	12/30	1/3	1/5		(± pct)
194	54.81	54.15	55.61	54.05	54.66	0.72

MATRIX ABSORPTION CORRECTIONS

One problem with XRF analyses is that each element absorbs X-rays in different amounts. The bromine standards are composed of sodium bromide and sodium chloride. The core samples consist predominantly of trona ($NaHCO_3 \cdot Na_2CO_3 \cdot 2H_2O$) and halite. Bromine Kα peak intensities may be affected by X-ray absorption of matrix elements not found in the standards and by element weight-ratio differences between the samples and standards.

To determine the effect of trona on the bromine peak intensity, an additional set of 100 percent trona matrix plus sodium bromide standards was prepared. The five 100 percent trona standards contain 0, 32, 89, 145, and 291 ppm bromine respectively. Four standards of intermediate composition were also prepared. They are the following: (1) 69.5 percent trona, 30.5 percent bromine-free halite and 146 ppm bromine; (2) 74.1 percent trona, 25.9 percent halite, and 174 ppm bromine; (3) 87.0 percent trona, 13.0 percent halite, and 183 ppm bromine; and (4) 89.5 percent trona, 10.5 percent halite, and 174 ppm bromine. To maximize the effect of absorption, these intermediate composition standards contain significantly more trona than the majority of the samples. The nine standards were analyzed by XRF and the bromine peak above background intensities were compared to halite based standard runs. The results are shown on figure 4.

The mathematical calculation for absorption effects is a first approximation to the correction. The equation is derived from Bertin (1974) and has been adapted by Slaughter (1982) for this purpose.

$$\frac{I_i}{I_{100i}} = e^{-\mu\rho\omega_i\chi} \cdot$$

where $-\mu\rho\omega_i = \Sigma\alpha_i\omega_i\rho_i + \alpha_j\omega_j\rho_j + \ldots.\alpha_n\omega_n\rho_n$

i = element i
j = element j
n = the nth element
I_{100i} = The X-ray intensity at 100 percent element i.
I_i = The X-ray intensity at some other weight fraction of i.
μ = The mass absorption coefficient
ρ = The density of the element in the crystal lattice.
ω_i = The weight fraction of element i.
χ = A variable derived from the ratio of the slopes of the 100 percent trona and 100 percent sodium chloride matrix curves and equal to -0.0436 cm.
$\alpha_{i,j}$ = The absorption coefficients for elements i, j.
α_n = The mass absorption of each element n at the Br Kα wavelength of 1.04 Å and 1.19 Kev (table 6) (Bertin, 1974).

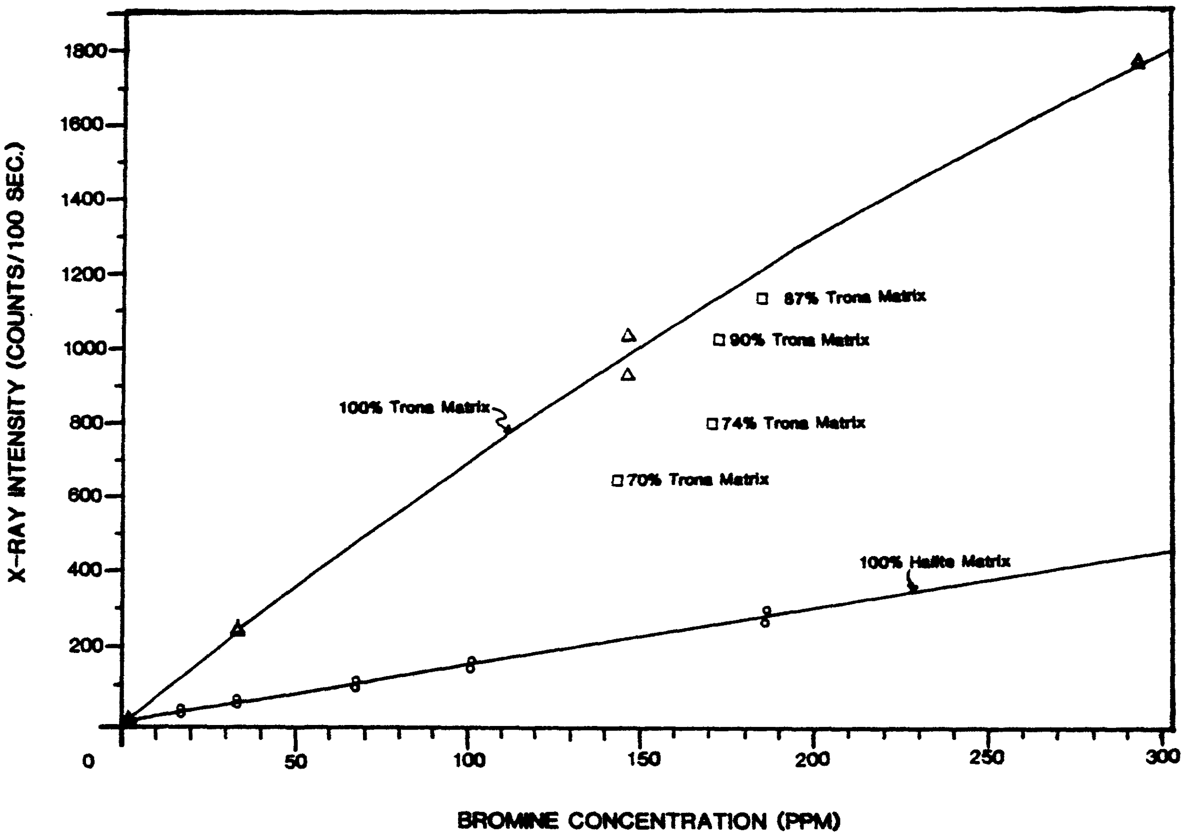

Figure 4. Curves of X-ray intensity versus bromine concentration for a series of halite, trona, and mixed trona-halite standards.

Table 6.--Absorption data for trona and halite

[Halite density 2.16 g/cm^3; trona density 2.13 g/cm^3]
[Leaders (---) not applicable]

Element	Absorption (cm^2/g) coefficent	Wt. fraction 100% halite	Wt. fraction 100% trona	ρ (g/cm^3) 100% halite	ρ (g/cm^3) 100% trona
C	1.44	---	0.1068	---	0.2274
Cl	34.92	0.6065	---	1.3100	---
H	0.4532	---	0.0179	---	0.0382
Na	8.99	0.3935	0.3065	0.8539	0.6529
O	3.58	---	0.5688	---	1.2116

A sample with a matrix containing 90 percent halite and 10 percent trona would have the following correction applied:

$$\frac{I_{90\ \mathrm{NaCl}}}{I_{100\ \mathrm{NaCl}}} = e^{\begin{gathered}(\overset{(\chi)}{-.04362}\ \mathrm{cm}) \times [(0.900 \times \overset{\overset{(\mathrm{Cl})}{(\omega)}}{0.60649} \times \overset{(\alpha)}{34.92}\ \mathrm{cm}^2/\mathrm{g} \times \overset{(\rho)}{1.3100}) + \\ (0.900 \times \overset{(\omega)}{0.3935} \times \overset{(\alpha)}{8.99}\ \overset{(\mathrm{Na})}{\mathrm{cm}^2}/\mathrm{g} \times \overset{(\rho)}{0.8539}\ \mathrm{g/cm}^3) + \\ (0.100 \times \overset{[\omega)}{0.3065} \times \overset{(\alpha)}{8.99}\ \overset{(\mathrm{Na})}{\mathrm{cm}^2}/\mathrm{g} \times \overset{(\rho)}{0.6529}\ \mathrm{g/cm}^3) + \\ (0.100 \times \overset{(\omega)}{0.10675} \times 1.44\ \overset{\overset{(\mathrm{C})}{(\alpha)}}{\mathrm{cm}^2}/\mathrm{g} \times \overset{(\rho)}{0.2279}\ \mathrm{g/cm}^3) + \\ (0.100 \times \overset{(\omega)}{0.5688} + 3.58\ \overset{\overset{(\mathrm{O})}{(\alpha)}}{\mathrm{cm}^2}/\mathrm{g} + \overset{(\rho)}{1.212}\ \mathrm{g/cm}^3) \\ (0.1 \times \overset{(\omega)}{.0179} \times \overset{\overset{(\mathrm{H})}{(\alpha)}}{0.4532}\ \mathrm{cm}^2/\mathrm{g} \times \overset{(\rho)}{0.0382}\ \mathrm{g/cm}^3)]\end{gathered}}$$

$= e^{1.2265} = 3.4094$--The ratio of slopes of the 100% NaCl and the 90% NaCl standards.

The slope ratio of 100 percent trona to 100 percent NaCl is 3.8261. The ratio of 3.4094 to 3.8261 is 0.8911. The bromine Kα peak intensity for a sample containing 90 percent NaCl is multiplied by 0.891 to correct to a 100 percent NaCl matrix.

The absorption effect for a series of sample matrix compositions is illustrated in figure 5. It is clear that for samples composed of 60 or more percent NaCl, the absorption factor is primarily a dilution effect by trona. At 47 percent NaCl, the intensity multiplication factor is 0.5425, at 26 percent it is 0.4257, and at 10 percent it is 0.3539. As more than 90 percent of the samples contain more than 60 percent NaCl, absorption effects do not result in significant changes in bromine concentration.

The accuracy of this method is indicated by comparison to the four intermediate composition standards prepared. The 69 percent trona (146 ppm Br) standard, taken from experimental data, has an intensity multiplication factor of 0.4313. Using the absorption correction equations, the multiplication factor is 0.4486. There is a difference of 3.854 percent between the two factors. The 74 percent trona (174 ppm Br) test has factors of 0.4158 for the experimental and 0.4257 for calculated absorption. This is a variation of 2.102 percent. Standards containing a higher percentage of trona exhibit somewhat greater error. The 87 percent trona (183 ppm Br) standard shows an 8.418 percent difference between the experimental value of 0.3084 and the calculated absorption correction of 0.3663. At 89 percent trona (174 ppm Br), the 0.3253 experimental value and the 0.3559 calculated factor have a 8.616 percent variation. The absorption calculations exhibit significantly greater rates of error in the very high trona standards. Within the primary range of sample matrix composition, however, the error associated with this "first approximation" method is acceptable.

Two major sources of error in the correction are:

(1) errors asssociated with XRF detection of bromine and chlorine concentrations, and

(2) interference by other minerals and elements in the samples.

Wet chemical analyses of the core by FMC Corporation indicate insolubles in the range of 1-4 percent for high halite intervals, to 10-25 percent for low halite, high trona sections. X-ray diffraction analyses of the insoluble material from several samples indicate a high percentage of K-feldspars, clays, and quartz, and some pyrite. Results of semiquantitative analyses of six samples are given in Appendix B. These samples were selected primarily from high trona and shale zones.

The presence of water-insoluble material was ignored in the absorption correction calculations. Their concentrations are too low to have appreciable absorption effects.

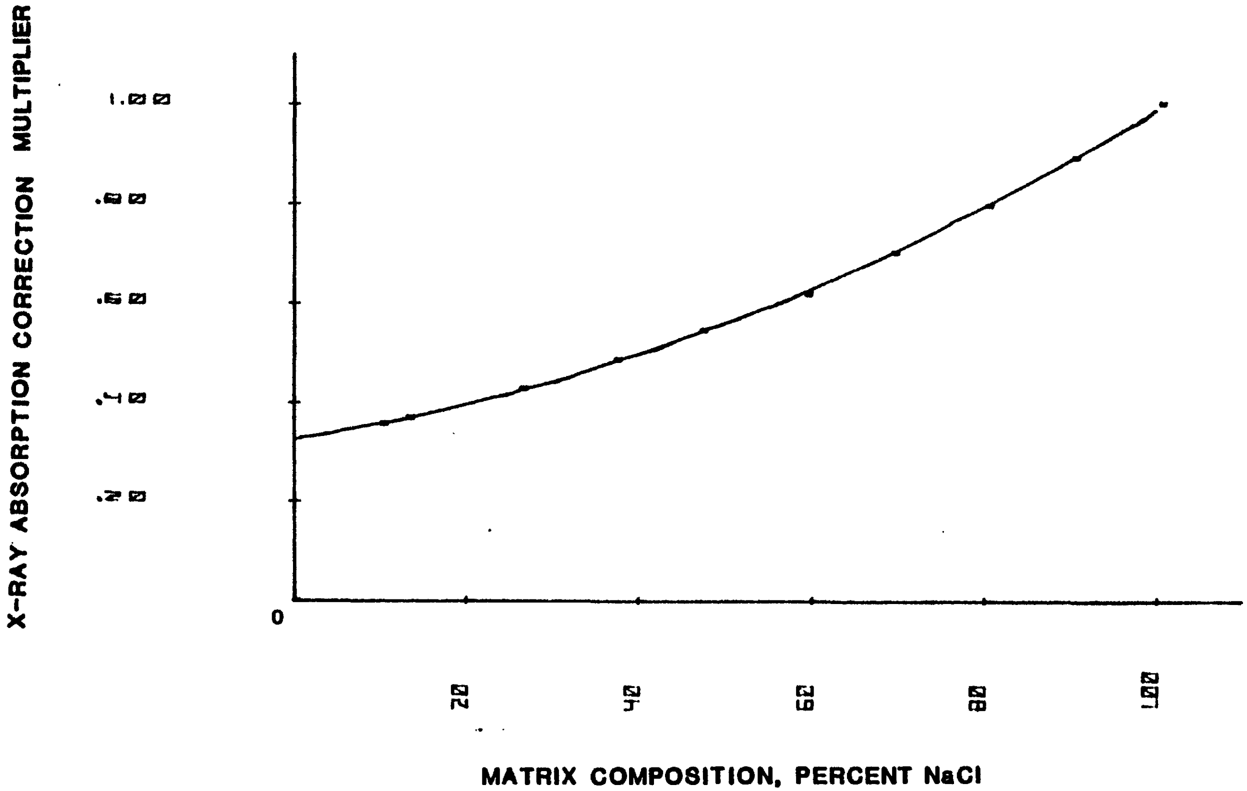

Figure 5. X-ray absorption correction curve of sample sodium chloride content versus the correction multipliers for 0 to 100 percent sodium chloride.

RESULTS OF ANALYSES

Bromine sample concentrations range from a low of 11 ppm bromine to a high of 423 found in samples 61 and 48, respectively, of the Finley 2 core hole. The next highest reading, of 174 ppm bromine, is for sample 165 of the SAP 6 drill hole. The average bromine concentration of bed 10 is approximately 80 ppm. The results of the bromine and chlorine analyses are listed on a drill-hole by drill-hole basis in Appendix A.

Finley 2 Drill Hole

The major saline minerals present in bedded evaporites of the Wilkins Peak Member are trona and halite. XRF tests run on several samples of trona and on trona-halite in which halite was removed by methanol extraction did not detect measurable amounts of bromine. Other chloride salts, such as northupite, also may contain bromine, but X-ray diffraction analyses of selected samples did not reveal northupite to be common. Some bromine may be adsorbed on clays and organic material. Dyni (1970, p. 174-176) found no clear correlation between total chlorine, bromine, and organic matter in his Piceance Creek Basin, Colorado study. Zak (1974, p. 356), in a study of evaporites of the Dead Sea Basin, determined that no important diagenetic or exchange reaction involving bromine and chlorine took place in laminated carbonate and marly sediments. The bromine content of halite is largely independent of both crystal size (Holser, 1968, p. 7 and 8), and the presence of brine inclusions, which generally make up less than 1 percent of the rock (Kuhn, 1968, p. 446). Therefore, it can be assumed that most of the bromine in the samples is within the crystal lattice of halite.

The Finley 2 core hole (Plate 1) exhibits some interesting variations in the bromine profile in halite beds 6, 9, 10, 11, 15, and 16. The sample depth intervals and percent sodium chloride are listed in Appendix A. Average bromine concentrations for sampled halite intervals are shown on table 7. Two major stages of lake evaporation and concentration, separated by a return to fresher water conditions, are indicated by the bromine profiles. These halite beds were divided into zones A, B, and C which represent major stages of evaporation and salt deposition. Average bromine concentrations of both sampled halite and the parent brine are listed according to salt zones. An asterisk indicates averages for repeated, more detailed sampling.

The average bromine concentrations listed in tables 7 and 8 are in the range from 55 to 133 ppm. A partition coefficient of 0.14 was used to indicate the bromine concentration of the parent brines.

Table 7.--Bromine concentration in Finley 2 halite samples by zones A, B, and C

Bed	Halite zone	No. of analyses	Halite interval (m)	Average sample thickness (cm)	Average halite conc (ppm Br)			Bromine Std. Dev. ± ppm	Average brine conc (ppm Br)		
					A halite	B	C zones		A halite	B	C zones
16	A	3	583.192-583.738	18.19	55			18	390		
15	A	1	586.886-587.024	13.72	69				490		
11	A	16	617.284-618.631	7.95	88			31	630		
	B	9	618.738-619.335	7.62		133		22		950	
10	A	2	625.306-625.449	7.77	235			267	1680		
	A*	6	625.306-625.449	2.05	68			27	490		
	B	11	625.459-627.141	9.97		90		41		640	
	C	13	627.202-628.537	9.19			63	19			450
9	A	13	630.430-631.521	8.71	74			20	530		
6	A	12	644.841-646.136	8.99	97			30	690		
	B	9	646.386-647.172	9.65	59			8		420	

*Re-sampled interval

Table 8--Average Bromine concentration in bed 10 by zones A, B, and C.

Drill Hole	Halite zone	No. of analyses	Halite interval (m)	Avg. sample thickness (cm)	Average halite concentration (ppm Br) A	B	C	Std. dev. ± ppm	Average brine conc. (ppm Br) (b = 0.14) A	B	C
SAP 1	B	9	781.721-782.687	9.85		84		25	600		
	C	6	782.787-783.309	8.69			72	13			510
SAP 2	A	2	596.268-596.478	10.52	94			6	670		
	B	16	596.606-598.143	9.60		102		32		728	
	C	9	598.267-599.222	10.59			65	13			460
SAP 3	B	12	922.428-923.703	8.71		72		16		510	
	C	5	923.703-924.288	9.14			80	13			570
SAP 5	B	15	617.647-619.043	9.18		99		26		710	
	C	17	619.076-620.819	8.62			67	22			480
SAP 6	B	19	660.319-662.007	8.73		103		31		736	
	C	9	662.178-663.007	10.33			64	22			460
SAP 18	B	15	652.463-654.052	10.04		86		25		610	
	C	17	654.052-655.569	7.96			79	8			560
SAP T-3	B	16	601.370-602.894	9.52		99		37		710	
	C	11	602.986-604.074	9.83			53	27			380
SAP T-14	A	2	601.809-601.962	7.78	143			13	1020		
	B	12	601.962-603.132	9.73		101		20		721	
	C	8	603.138-603.964	8.36			71	11			510
YATES	B	11	910.499-911.224	6.53		76		19		540	
	C	4	911.224-911.788	6.63			71	6			510
FINLEY 2	A	2	625.306-625.449	7.77	235			267	1680		
	A*	6	625.306-625.449	2.05	68			27	490		
	B	11	625.459-627.141	9.97		90		41		640	
	C	13	627.202-628.537	9.19			63	19			450

* Asterisk indicates repeated sampling.

Dyni and others (1970) used XRF to analyze approximately 170 samples of halite from the Parachute Creek Member of the Green River Formation in the Savage core hole 24-1 for bromine. Like the Green River Basin halite, the Piceance Creek Basin halite has unusually high bromine concentrations for continental halite deposits. They are in the range of 15-182 ppm bromine. Several trends are evident from the profile shown in figure 6: (1) a marked upward increase in bromine content for individual halite beds, indicating gradual evaporation and salinity increase through time, and (2) "spikes" of anomalously high or low bromine concentration representing perhaps extreme brine evaporation and influxes of fresher water with resulting lower lake salinity or halite recrystallization, respectively. There appears to be an over-all increase in bromine concentration from the base of the lowest to the highest halite bed. This may be the result of brine carry-over from one bed to higher ones. The similarities in bromine behavior for the two regions suggest similar climatic, geochemical, and source-rock conditions for these at-times interconnected basins.

For halite of the Green River Basin no clear trend emerges of increasing average bromine concentrations upward from bed 6 through bed 16. This indicates that little or no brine carry over occurred from one halite interval to later ones. The high initial bromine concentration at the base of bed 11 could be the result of brine carry over from the highly saline brine responsible for deposition of trona bed 10. Were this to have occurred, it would indicate that Lake Gosiute did not dry up in the latter stages of deposition of halite bed 10. Flushing of the lake with loss of bromine and salts also would be unlikely between the time halite beds 10 and 11 were deposited. The apparent lack of brine carry over for the other halite zones could be the result of extreme desiccation consistent with a playa-lake model. Evidence against total evaporation of the lake includes the following: (1) the total absence of salts such as sylvite (KCl) which are indicative of late stages of evaporation; (2) a return to fresher water conditions is indicated at the tops of halite beds 6, 9, 11, 15, and 16 by an increase in trona content prior to shale deposition; (3) bromine could have been lost between halite beds by flushing of waters through a lake outlet; (4) some bromine could have been removed from lake waters by adsorption by clays, feldspars, or organic matter in thick interbedded shales which were not analyzed for bromine. The trend towards lower average bromine concentrations in the lower half of each halite bed is apparent in Finley 2 results, as well as in findings from the other nine drill holes (table 8). Trona bed 11 is the only interval that departs from this trend. High bromine contents indicate a greater brine concentration during the time of deposition of the lower half of bed 11. This was possibly followed by an influx of fresher water during deposition of the upper half resulting in lower average bromine contents due to decreased lake salinity.

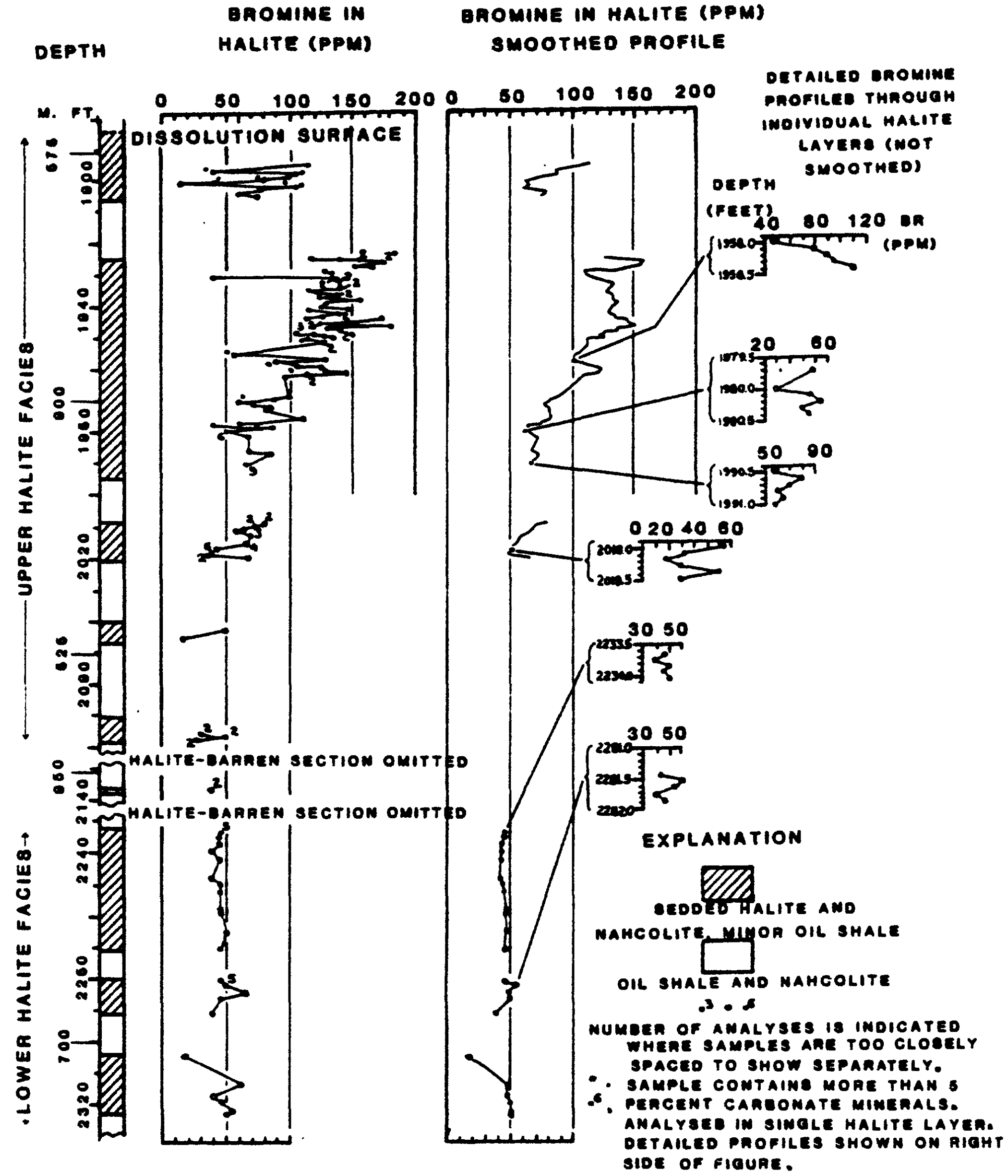

Figure 6. Generalized lithologic section and bromine profiles of halite deposits in the Savage core hole 24-1 (from Dyni and others, 1970, p. 173).

Each bed records an upward increase in bromine concentration which indicates an increase in lake salinity through time. This increase in bromine content is also present in halite of the Piceance Creek Basin (Dyni, 1970), and in Holser's analyses of Great Basin salts (1970). Searles Lake salts (fig. 7) contain several high bromine intervals, although the average bromine contents are lower than salts of the Piceance Creek or Green River Basins. The bromine high at 170 m on figure 7 is the result of extreme desiccation. Intercalated clastics and the return to low bromine contents represent new inflows of fresh water (Holser, 1970).

Bed 6 is typified by relatively high halite concentrations of approximately 70 percent in the lowermost part of the section and 80-90 percent near the top. Decreases in the bromine content, which occur at 646.1 and 646.7 m, are associated with shale breaks. The high trona content suggests this halite was deposited after an influx of fresher water. Abrupt changes in bromine concentration, such as is present at 645.7 m, could indicate either recrystallization, variation due to the sampling method, or changes in lake salinity due to rapid evaporation or influx. The low amount of bromine (35 ppm) for this "spike" is probably the result of an influx of fresher water. Evidence against recrystallization is that they generally exhibit high halite concentrations, whereas the amount of halite in this sample is 30 percent. The general increase in bromine stratigraphically higher in the section is the result of progressive evaporation and concentration of the lake brines.

Bed 9 exhibits a similar but less pronounced upward increase in bromine content. The low of 24 ppm bromine for sample 78 at 630.75 m is primarily the result of initial salt precipitation following a freshening sequence, as indicated by the shale break. The low average bromine concentrations and high trona content for most samples indicate that the lake did not totally evaporate during deposition of this thin halite bed. Some brine carry over could have taken place from bed 9 to bed 10 as the last-precipitated salt from bed 9 is approximately equal in bromine concentration to the first deposited salts of halite bed 10.

The vertical distribution of bromine in bed 10 is similar to that of beds 6 and 9, suggesting intervals of brine concentration followed by a return to fresher water conditions as evidenced by shale breaks and lower bromine contents. Halite from bed 10 exhibits a gradual upward increase in bromine content that is apparent from 627.3 m and above. Numerous shale breaks and lower bromine concentrations with no net increase in bromine upward in the bottom half of the section indicate fresher water conditions than in the top half. During deposition of the lower half of the bed, the rate of influx of fresher water was approximately equal to lake evaporation. Sample 48, located at a depth of 625.3 m, contains an anomalously high bromine concentration (423 ppm) followed by sample 49 with a low bromine content (46 ppm). Repeated sampling of the sample 48 interval failed to verify the 423 ppm reading. Subsequent XRF analysis of the resampled interval showed an average of 74 ppm Br with a high of 113 ppm Br. Several explanations for the anomalously high reading are possible. Although sample contamination is possible, it is not likely due to the painstaking care taken to avoid it. Another possibility is that bromine was concentrated in inclusions in the salt. Sample 48 was

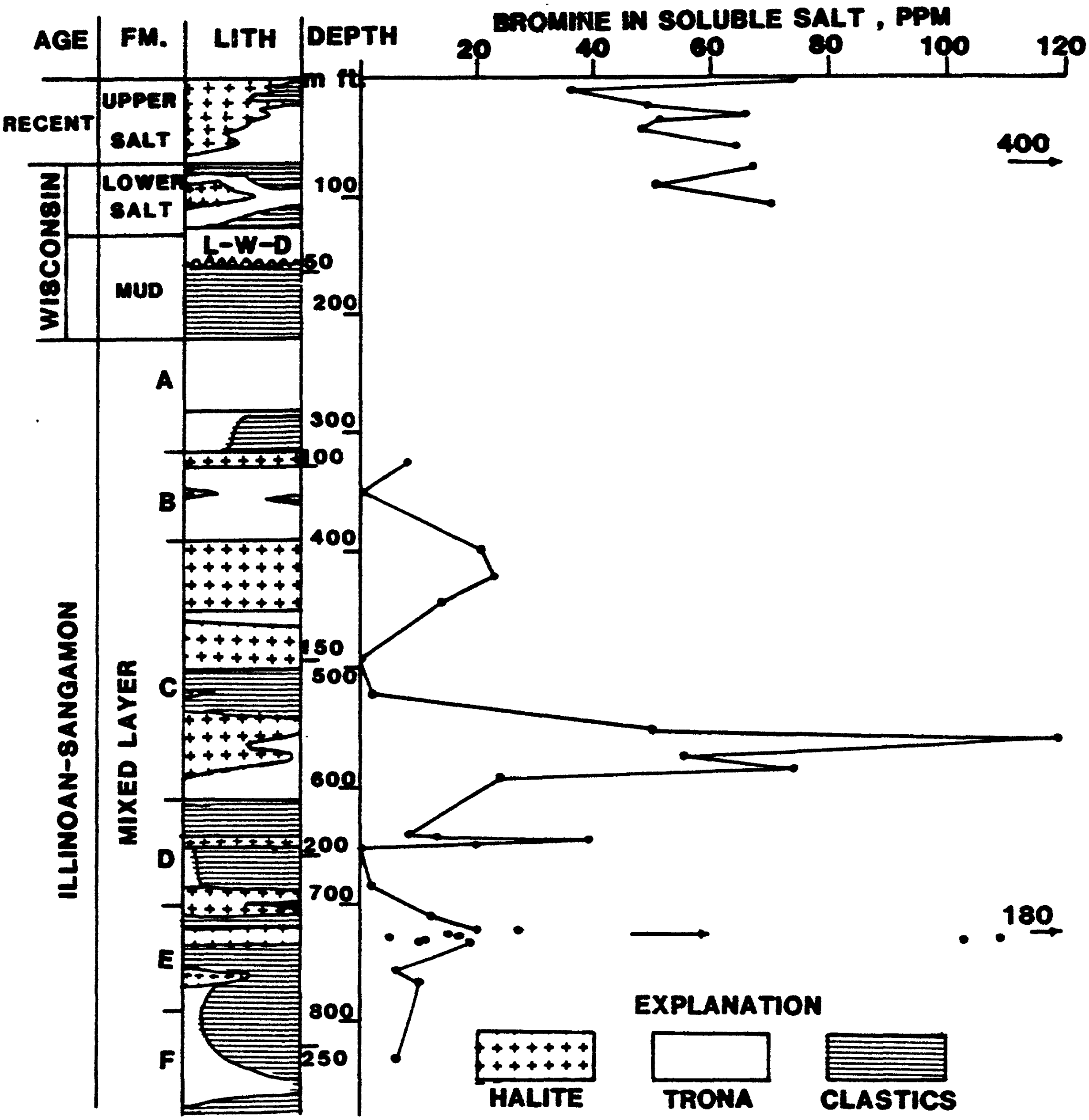

Figure 7. Bromine profile of Searles Lake salts (Holser, 1970, p. 311).

anomalous in that the upper 2 cm of the sample consisted of clear, almost 100 percent halite with crystals up to 0.5 cm in diameter and orientated perpendicular to bedding. This possibly recrystallized salt contained from 5 to 10 percent large fluid inclusions, 5 to 10 times the usual amount. To determine if other salts with a higher partition coefficient were present, samples 48 and 326-331 were analyzed for potassium by XRF, also X-ray diffraction patterns were studied (fig. 8). Definite sylvite diffraction peaks were present for samples 48 and 326 to 329 and possibly for sample 330. XRF analysis of these samples revealed potassium in the range of 0.01 and less to as high as 0.02 percent. These are amounts easily attributed to clay content. Because sylvite has a much higher bromine partition coefficient than halite, a very small amount of KCl in inclusions or as crystals could account for the 423 ppm Br reading.

Recrystallized salt containing 11 ppm Br is located between two shale partings at 626.7 m (sample 57). This sample contains more than 95 percent NaCl. Other low bromine concentrations appear to be the result of a decrease in lake salinity as indicated by larger amounts of trona and the presence of shale breaks.

Much more drastic variations in lake salinity are indicated in bed 11 because of the wide fluctuations in bromine content. Generally high amounts of bromine and halite in the lower half of the section are evidence of a high degree of lake brine concentration. With an average bromine content of 88 ppm in halite of the upper half of bed 11, the lake was fairly saline. This may represent a higher lake stage than the lower half which contains 133 ppm Br average.

Salt beds 15 and 16 contain an average of 69 and 59 ppm bromine, respectively. This is considerably less than the average bromine content of other salt beds tested in the 10 drill holes. Samples from beds 15 and 16 have large amounts of trona, which is the major mineral present. Halite occupies a thin bed in each core, bounded by trona (see Appendix A). Low bromine and high trona contents indicate a return to much fresher water conditions in which lake waters were saturated in sodium chloride for only a brief period. Recrystallized zones were not apparent in these samples.

To summarize, each halite bed records a history of gradual evaporation with a general upward increase in lake salinity. Within each halite interval, periods of evaporation and influx of fresher or more saline waters are indicated by changes in lithology and bromine content.

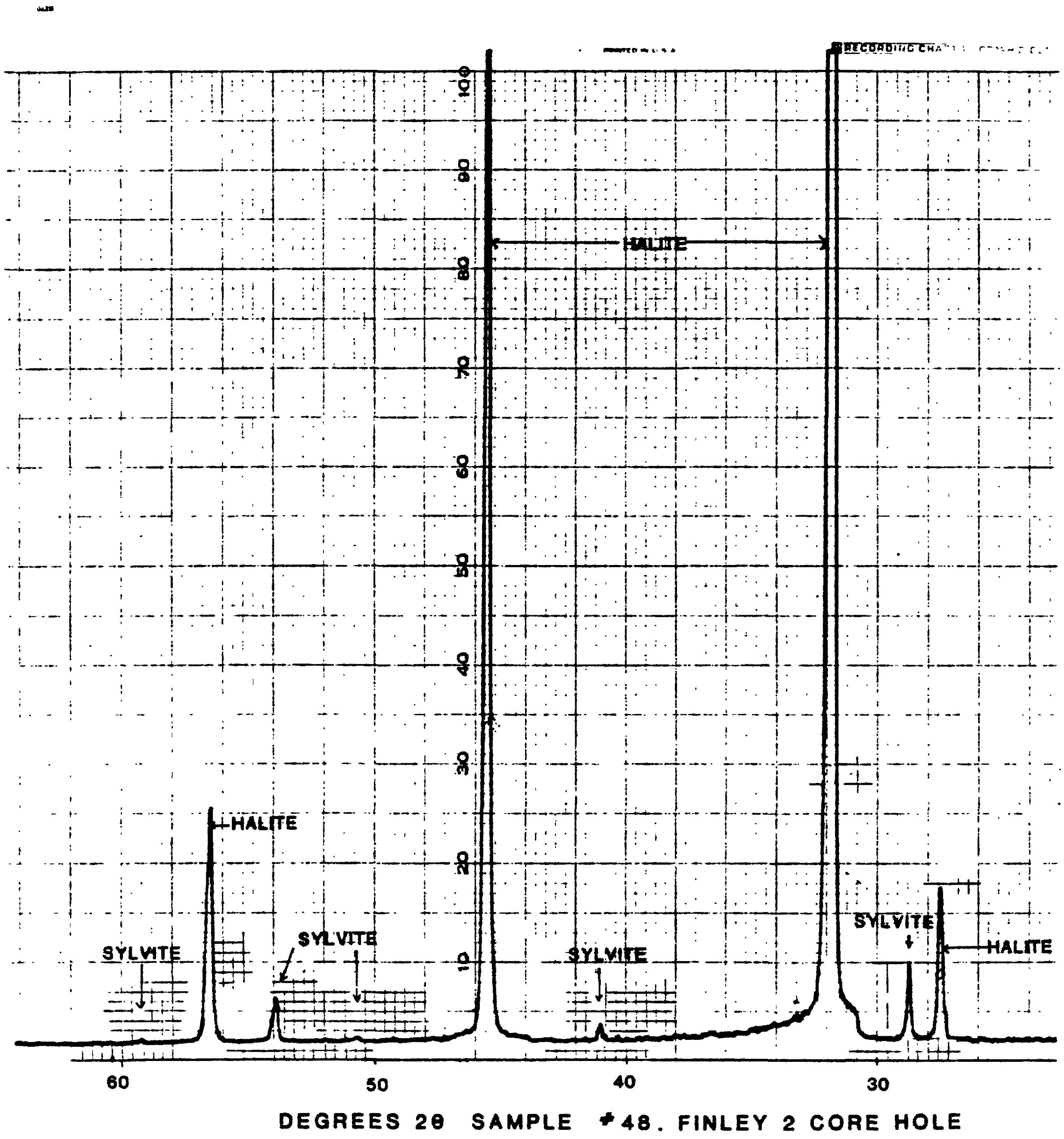

Figure 8. X-ray diffraction chart for sample no. 48 from bed 10 in the Finley 2 core hole.

Lateral trends--Halite bed 10

Halite bed 10 was sampled in ten drill holes (table 1, fig. 9). This detailed sampling across the halite depositional area of the basin was conducted to determine horizontal variations in the bromine concentration of halite, with changes in salt thickness and distribution.

Stratigraphic cross sections A-A' through E-E' (plates 2-6), bromine profiles for bed 10 in each core hole (plate 7), and a table of average bromine concentrations for zones within bed 10 (table 8) were prepared.

The isopach map (fig. 9) indicates a gradual thickening of bed 10 to the northeast with a depositional center near the southwest corner of T. 16 N., R. 109 W. Three salt zones, A (upper), B (middle), and C (lower) were derived by dividing the salt at stratigraphically correlated lower and upper shale breaks (fig. 10, plates 2-4). The division is based on similarities in the bromine profiles of the 10 core holes and also lithologic similarities, as indicated by fig. 10. The purpose of this subdivision is to compare the average bromine contents of these correlated halites (table 8). The average bromine content listed in table 8 appears to increase towards the basin depositional center. This disparity is the result of differences in salt thickness between the southwestern and northeastern parts of the study area, and does not represent an increase in bromine concentration to the northeast. Core holes in the southwestern part of the study area do not contain the lower half of the C and upper half of the B high-bromine zones. Drill holes were correlated by overlaying bromine profiles and comparing the concentrations on a sample-by-sample and zone-by-zone basis. Interval A is an upper halite zone that is present only in drill holes Finley 2, SAP 2, and SAP T-14 (plate 7). The high degree of correlation between average bromine concentrations for the the lower two zones, sections B and C, indicates that minor gradients may have been present in the lake, but on the whole horizontal salinity gradients were not important. If salinity gradients were present, higher bromine contents would be expected basinward due to a higher degree of salinity in that direction.

Bromine profiles shown on plate 7 indicate that extremely similar and correlatable salinity conditions were present in bed 10 across the halite zone of the Green River Basin.

All 10 core holes exhibit the same salinity behavior explained earlier for the Finley 2, bed 10 interval. The lower half of the salt bed (C zone) exhibits no overall increase in bromine content upward and even appears to decrease slightly in the SAP 2 and SAP 5 drill holes. This behavior indicates that lake salinity remained essentially constant during deposition of this interval. The shale break located between zones B and C appears to be fairly continuous across the basin and is the stratigraphic datum for the cross sections (plates 2-6). A return to more saline conditions with renewed halite precipitation followed deposition of the shale (zone B). The upper half of B is not present in the SAP 1, 3, and Yates drill holes. Where present, an increase in bromine up the section is noticeable and is most dramatic in the upper half of the B zone. A closed basin with a greater rate of evaporation and brine concentration than fresher water influx may explain this profile.

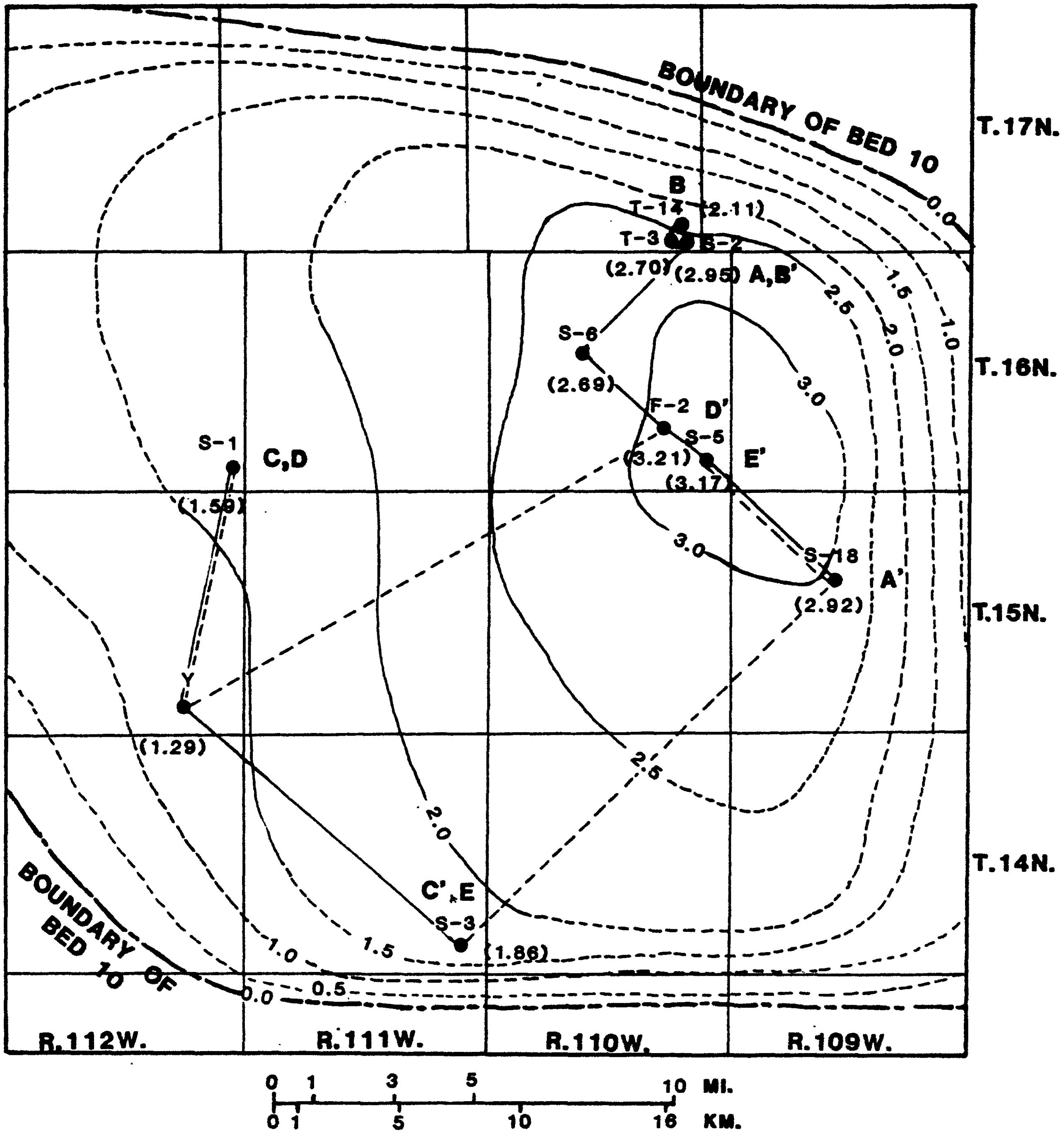

Figure 9. Isopach map (in meters) of bed 10 showing lines of cross-sections A-A' through E-E' (plates 2-6). Isopach lines are dashed where inferred.

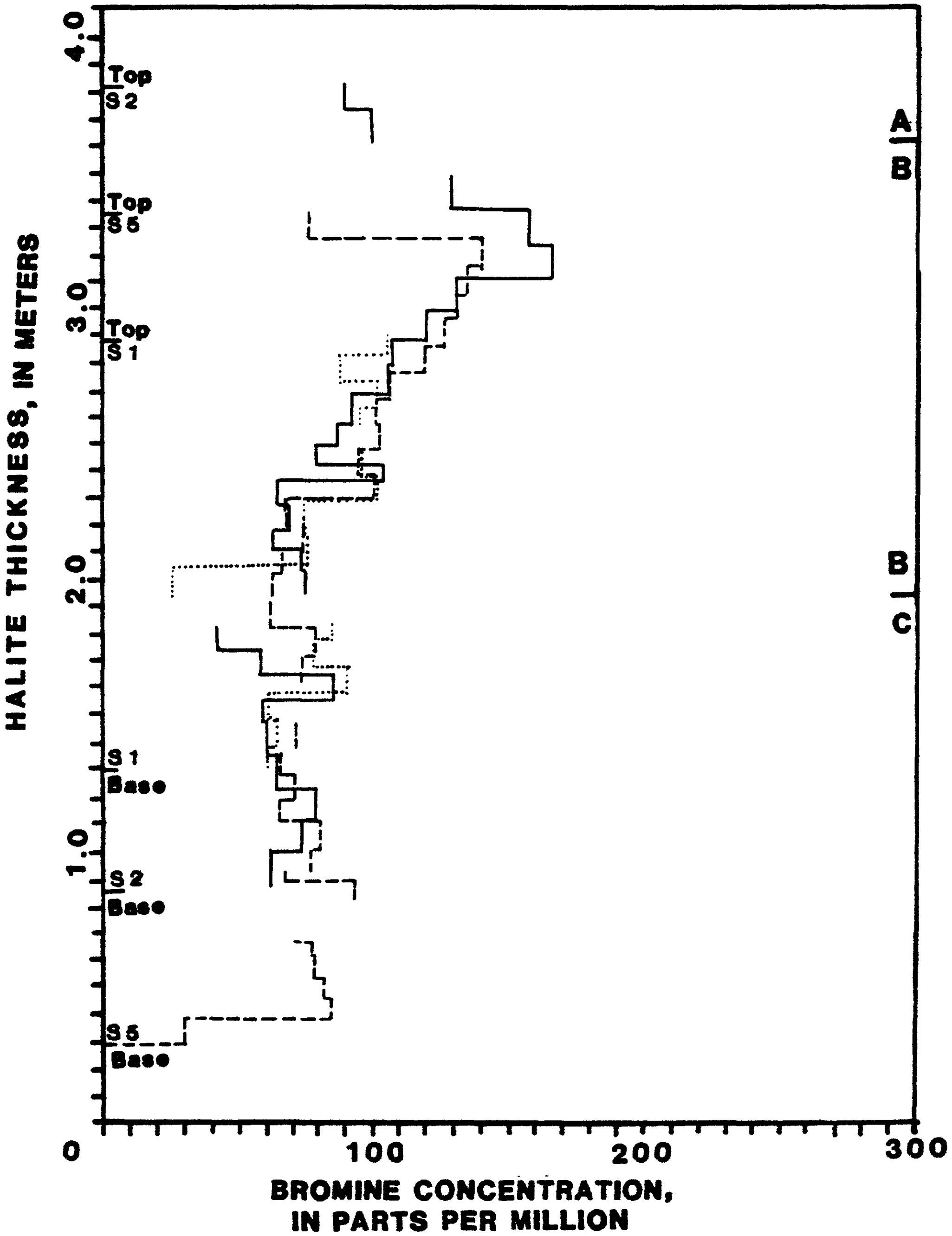

Figure 10. Overlay of bromine profiles for SAP 1 (dotted line), SAP 2 (line), and SAP 5 (dashed line) drill holes.

Zone A, at the top of bed 10 in figure 10, is present only in drill holes Finley 2, SAP 2, and SAP T-14. The presence of recrystallized salt at the top of A (marked by asterisks) indicates that fresher water influx may have dissolved and re-precipitated some of the original halite. This salt, however, contains more bromine than would have been expected from a recrystallized halite. The absence of this and other intervals in other drill holes may be explained by several possibilities: (1) deposition of zone A halites in other drill holes was followed by dissolution of the beds following fresher water influx and accompanying decrease in salinity, or (2) the halite interval was not deposited in the other drill holes. No dissolution surfaces, which would indicate erosion, were present at the boundaries of the halite.

Lack of deposition may be the result of stratified lake conditions. Under this model one or more NaCl-rich brine pools were present around the Finley 2, SAP 2, and SAP T-14 drill holes. Stratigraphically equivalent shortite-rich laminated shale was deposited in the surrounding area, and indicates fresher water conditions. Assuming a stratified lake model, shale deposition would continue until the lake was sufficiently saline for trona and then halite deposition to occur. The halite-rich bottom layer is saturated with respect to sodium chloride, resulting in its precipitation, whereas less dense upper waters are undersaturated in sodium chloride. This process explains the presence of essentially monomineralic trona beds north of the study area where lake waters remained under-saturated for sodium chloride.

Plates 2-4 show the horizontal change in bromine profiles and salt thickness for zones A, B, and C in three northwest-to-southeast-trending stratigraphic sections across the basin. Core holes plotted on each of these three cross sections show a high degree of lateral correlation of bromine content. This correlation is illustrated in an overlay of three widely separated drill holes (fig. 10). Two noticeable differences in salt thickness occur. Bed 10 is much thinner on the southwestern part of the basin (plate 4) than in the northeastern part (plates 2 and 3). Stratified lake conditions such as are illustrated in the two NE-SW cross sections across the halite zones of the basin (plates 5 and 6) could explain the absence of halite in zone A, the upper 1/4 to 1/2 of B, and the lower part of C in drill holes SAP 1, SAP 3, and Yates. Plates 5 and 6 show hypothetical halite zone lake stages for a stratified lake model. Salt beds shown on the cross sections are lens shaped with the thickest salt zones located near the basin depocenter, thinning slightly toward the basin margins. Under this stratified model, the sodium-chloride-rich bottom layer extends to the SAP 1, SAP 3, and Yates drill holes only during deposition of the lower half of zone B and the upper half of zone C. During the rest of the history of trona bed 10, the bottom brines were confined to the northeastern part of the study area, the area of thickest salt deposition (fig. 9). The absence of halite from some intervals may also be the result of dissolution of previously deposited halite by an influx of fresher water.

Horizontal salinity gradients were not present as noted by the similarity of bromine concentrations across the basin for most intervals (fig. 10). The close similarity of bromine profiles over hundreds of square miles also indicates that postdepositional changes involving remobilization of bromine from precipitated halites or bromine addition by later processes is unlikely. Smaller scale differences between the drill holes shown on figure 10 are evident. Shale breaks, particularly thinner ones, may not extend across the basin. Some halite samples contain widely different amounts of bromine for the same interval. Sampling technique may account for some of the divergent values. The bromine low of 25 ppm Br for the SAP 1 core hole above the C zone (fig. 10) contains 56 percent trona. This sample, much lower in bromine and higher in trona than surrounding core holes, may indicate local conditions of lower salinity or a proportionally greater sampling of bromine-deficient trona and halite located at the shale break.

SUMMARY AND CONCLUSIONS

Interpretation of the bromine profiles reveals several notable trends. They are the following:

(1) Most beds record a history of gradual evaporation of lake waters in a closed basin as evidenced by upward increase in bromine content, and therefore, salinity.

(2) The bromine profiles of all of the thicker salt beds indicate two or more stages of lake evaporation and salinity increase, separated by a return to fresher water conditions.

(3) Horizontal salinity gradients appear to have been very minor or absent as no trend of increasing bromine content towards the basin depositional center was detected in correlated bed 10 zones.

(4) Evidence presented in this report supports the idea that Lake Gosiute was a chemically stratified (Na^+-HCO_3^--$CO_3^{=}$-Cl^-) lake with a lower, denser brine enriched in sodium chloride. This stratified model was present during deposition of trona bed 10, and based on previous mineralogical and on bromine data, probably existed during deposition of beds 6, 9, 11, 15, and 16.

(5) The extreme constancy of the bromine profiles for bed 10 over long distances indicates that postdepositional alteration of salt beds involving remobilization and removal or addition of bromine did not occur.

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APPENDIX A

Bromine and Chlorine (NaCl) XRF Results

Finley 2 Drill Hole, Beds 16, 15, 11, 10, 9, and 6

Sample No.	Drill Hole Sample	Sample Interval (m)	Sample Thickness (cm)	Br (ppm)	NaCl (%)
1-16	Not analyzed				
	Bed 16				
17	F_2-16-4	583.192-583.308	11.6	72	51.18
18	F_2-16-5	-583.527	21.9	56	54.76
19	F_2-16-6	-583.738	21.0	37	17.33
	Bed 15				
20	F_2-15-2	586.89-587.02	13.7	69	58.55
21, 22	No NaCl				
	Bed 11				
23	F_2-11-3	617.284-617.339	6.4	72	92.02
24	-4	-617.409	7.0	73	76.18
25	-5	-617.464	5.5	74	81.59
26	-6	-617.525	6.1	88	76.48
27	-7	-617.589	6.4	62	67.23
28	-8	617.691-617.781	8.5	91	89.09
29	-9	-617.888	10.7	77	88.80
30	-10	-617.954	8.8	140	88.65
31	-11	-618.043	9.8	80	96.79
32	-12	-618.144	9.8	76	82.89
33	-13	-618.241	9.8	155	97.40
34	-14	-618.336	9.5	128	98.86
35	-15	-618.427	9.1	111	96.69
36	-16	-618.509	8.2	54	79.08
37	-17	-618.592	8.2	83	91.68
38	-18	-618.631	3.9	34	47.83
39	-19	-618.738	10.7	153	86.53
40	-20	-618.802	6.4	148	99.00
41	-21	618.814-618.872	5.8	133	97.98

APPENDIX A

Finley 2 Drill Hole, Beds 16, 15, 11, 10, 9, and 6--Cont.

Sample No.	Drill Hole Sample	Sample		Br (ppm)	NaCl (%)
		Interval (m)	Thickness (cm)		
42	-22	618.875- 618.951	7.6	124	99.35
43	-23	-619.028	7.6	95	100.35
44	-24	-619.104	7.6	166	95.42
45	-25	-619.210	10.7	118	99.16
46	-26	619.213- 619.274	6.1	113	99.86
47	-27	-619.335	6.1	144	98.11
	Bed 10				
48	F_2-10-3	625.306- 625.370	7.6	423	99.41
49	-4	-625.449	7.9	46	96.18
50	-5	625.459- 625.564	10.7	128	101.44
51	-6	-625.648	8.2	151	99.29
52	-7	626.242- 626.349	9.1	119	100.41
53	-8	-626.440	9.1	133	99.97
54	-9	-626.526	8.5	89	98.32
55	-1	-626.632	10.7	75	98.69
56	-11	-626.693	6.1	65	97.08
57	-12	-626.809	11.6	68	96.39
58	-13	-626.876	10.7	108	88.43
59	-14	-627.041	16.5	31	96.99
60	-15	-627.141	8.5	27	80.97
61	-16	627.202- 627.248	4.6	11	95.28
62	-17	627.251- 627.339	8.8	67	69.69
63	-18	-627.437	9.8	73	70.43
64	-19	-627.528	9.1	85	84.76
65	-20	-627.632	10.4	50	80.59

APPENDIX A

Finley 2 Drill Hole, Beds 16, 15, 11, 10, 9, and 6--Cont.

Sample	Drill Hole	Sample		Br	NaCl
No.	Sample	Interval (m)	Thickness (cm)	(ppm)	(%)
66	-21	627.675-627.745	7.0	66	86.16
67	-22	-627.867	12.2	67	95.31
68	-23	627.869-627.967	9.8	67	95.84
69	-24	-628.065	9.8	63	94.52
70	-25	-628.168	10.4	79	97.36
71	-26	628.178-628.281	10.4	61	86.25
72	-27	-628.385	10.4	48	92.82
73	-28	628.467-628.537	7.0	79	96.23
	Bed 9				
74	F_2-9-2	630.430-630.467	3.7	55	81.88
75	-3	630.482-630.573	9.1	94	99.09
76	-4	-630.665	9.1	86	99.01
77	-5	-630.753	8.8	83	99.96
78	-6	-630.784	3.1	25	61.01
79	-7	630.811-630.887	7.6	95	80.54
80	-8	-631.009	12.2	84	82.30
81	-9	-631.098	8.8	82	100.00
82	-10	-631.186	8.8	84	100.60
83	-11	631.189-631.296	10.7	64	99.57
84	-12	-631.396	10.1	77	85.90
85	-13	-631.521	12.5	64	76.32
86	-14	631.542-631.604	6.2	0	5
	Bed 6				
87	F_2-6-3	644.841-644.969	12.8	108	78.92
88	-4	-645.195	9.8	114	80.94
89	-5	645.198-645.228	3.0	124	88.80

APPENDIX A

Finley 2 Drill Hole, Beds 16, 15, 11, 10, 9, and 6--Cont.

Sample No.	Drill Hole Sample	Sample		Br (ppm)	NaCl (%)
		Interval (m)	Thickness (cm)		
90	-6	645.234-645.253	1.8	156	91.01
91	-7	645.301-645.414	11.3	108	85.36
92	-8	-645.475	6.1	65	31.06
93	-9	-645.612	13.7	86	72.02
94	-10	-645.709	9.8	93	80.33
95	-11	-645.792	8.2	35	29.82
96	-12	-645.902	7.9	103	95.19
97	-13	-646.002	10.1	90	93.18
98	-14	-646.136	13.4	87	94.86
99	-15	646.219-646.341	12.2	56	71.56
100	-16	646.386-646.478	9.1	64	73.96
101	-17	-646.575	9.8	58	75.06
102	-18	-646.652	7.6	68	68.70
103	-19	646.685-646.779	9.5	41	54.30
104	-20	-646.889	10.9	64	75.11
105	-21	-646.981	9.1	67	73.48
106	-22	-647.059	7.9	57	63.22
107	-23	647.066-647.173	10.7	58	66.88
108	No NaCl				0

APPENDIX A

SAP T-14 Drill Hole Bed 10

Sample	Drill Hole	Sample		Br	NaCl
No.	Sample	Interval (m)	Thickness (cm)	(ppm)	(%)
109	SAP T-14-1	601.809- 601.870	6.1	34	102.75
110	-2	-601.962	9.5	153	88.86
111	-3	-602.059	9.5	104	57.93
112	-4	-602.151	9.1	140	70.64
113	-5	-602.242	9.1	137	59.70
114	-6	-602.334	9.1	112	69.64
115	-7	-602.422	8.8	96	62.57
116	-8	-602.523	10.1	86	78.12
117	-9	-602.617	9.4	104	77.02
118	-10	-602.712	9.4	106	79.41
119	-11	-602.818	10.7	81	78.22
120	-12	-602.925	10.7	89	82.43
121	-13	-603.032	10.7	85	74.44
122	-14	-603.132	10.1	77	103.46
123	-15	603.138- 603.205	6.7	78	103.89
124	-16	-603.260	5.5	68	103.64
125	-17	-603.318	5.8	83	55.49
126	-18	603.321- 603.397	7.6	70	95.99
127	-19	603.549- 603.650	10.1	71	69.84
128	-20	-603.751	10.1	77	79.86
129	-21	-603.858	10.7	73	75.32
130	-22	-603.964	10.7	47	49.31

APPENDIX A

SAP 18 Drill Hole, Bed 10

Sample No.	Drill Hole Sample	Sample		Br (ppm)	NaCl (%)
		Interval (m)	Thickness (cm)		
131	SAP 18-1	652.403-652.473	7.0	77	101.34
132	-2	652.516-652.613	9.8	123	74.04
133	-3	-652.711	9.8	103	67.29
134	-4	-652.851	14.0	98	73.86
135	-5	-652.958	10.7	102	87.73
136	-6	-653.061	10.4	93	86.62
137	-7	-653.165	10.4	98	81.93
138	-8	-653.259	9.4	98	86.68
139	-9	-653.354	9.4	77	76.33
140	-10	-653.461	10.7	76	77.26
141	-11	-653.567	10.7	78	90.13
142	-12	-653.674	10.7	72	84.15
143	-13	653.775-653.839	6.4	117	71.81
144	-14	-653.945	10.7	34	44.57
145	-15	-654.052	10.7	38	31.81
146	-16	-654.162	10.9	98	76.30
147	-17	-654.272	10.9	80	62.83
148	-18	-654.381	10.9	78	68.57
149	-19	-654.479	9.8	61	65.51
150	-20	-654.579	10.1	79	71.64
151	-21	-654.659	7.9	78	92.16
152	-22	-654.738	7.9	89	88.25
153	-23	654.747-654.906	15.8	77	96.65
154	-24	654.908-654.957	4.9	80	99.18
155	-25	654.960-654.994	3.4	81	96.01
156	-26	654.997-655.073	7.6	70	82.52
157	-27	-655.149	7.6	85	91.80
158	-28	655.152-655.195	4.6	74	90.78
159	-29	655.198-655.244	4.6	70	92.56
160	-30	655.381-655.427	4.6	91	78.82
161	-31	655.433-655.499	6.7	82	81.07
162	-32	-655.569	7.0	80	59.43

APPENDIX A

SAP 6 Drill Hole, Bed 10

Sample No.	Drill Hole Sample	Sample		Br (ppm)	NaCl (%)
		Interval (m)	Thickness (cm)		
163	SAP 6-1	660.319-660.410	9.1	129	90.65
164	-2	-660.496	8.5	160	87.12
165	-3	-660.581	8.5	174	81.25
166	-4	-660.651	3.9	141	70.74
167	-5	-660.742	9.1	130	71.16
168	-6	-660.834	9.1	120	70.81
169	-7	-660.922	8.8	100	74.45
170	-8	-661.044	9.1	107	62.81
171	-9	-661.114	10.1	93	78.48
172	-10	-661.218	10.4	99	70.13
173	-11	-661.312	9.4	92	80.89
174	-12	-661.407	8.8	98	76.12
175	-13	-661.492	9.1	72	95.21
176	-14	-661.587	9.4	77	64.94
177	-15	-661.681	9.4	85	76.90
178	-16	-661.769	8.8	86	67.24
179	-17	-661.837	6.7	72	77.94
180	-18	-661.907	7.0	65	63.24
181	-19	-662.007	10.1	66	77.26
182	-20	662.178-662.303	12.5	30	23.94
183	-21	-662.413	10.9	49	48.90
184	-22	-662.510	9.8	65	73.00
185	-23	-662.608	9.8	32	56.60
186	-24	-662.672	6.4	88	90.70
187	-25	-662.782	10.9	74	83.70
188	-26	-662.871	10.9	84	89.10
189	-27	-662.995	10.4	76	95.30
190	-28	-663.077	11.3	77	90.30

APPENDIX A

SAP 1 Drill Hole, Bed 10

Sample	Drill Hole	Sample		Br	NaCl
No.	Sample	Interval (m)	Thickness (cm)	(ppm)	(%)
191	SAP 1-1	781.721-781.812	9.1	106	89.07
192	-2	-781.906	9.4	88	81.48
193	-3	-782.001	9.4	102	87.06
194	-4	-782.074	7.6	96	90.34
195	-5	782.156-782.248	9.1	94	80.39
196	-6	-782.339	9.1	100	89.40
197	-7	-782.458	11.9	74	87.34
198	-8	-782.592	13.4	75	88.50
199	-9	-782.687	9.4	25	43.89
200	-10	782.787-782.864	7.6	84	39.38
201	-11	-782.955	9.1	77	93.00
202	-12	-783.046	9.1	89	100.10
203	-13	-783.147	10.1	60	65.62
204	-14	-783.245	9.8	63	77.03
205	-15	-783.309	6.4	60	97.81
206	SAP T-3-1	601.370-601.401	3.0	157	100.03
207	-2	-601.495	9.4	146	70.40
208	-3	-601.589	9.4	152	76.52
209	-4	-601.681	9.1	142	78.65
210	-5	-601.779	9.8	123	72.28
211	-6	-601.879	10.1	104	71.12
212	-7	-601.989	10.9	63	76.78
213	-8	-602.081	9.1	115	77.38
214	-9	-602.187	10.7	49	64.41
215	-10	-602.294	10.7	104	82.52
216	-11	-602.404	10.9	93	75.18
217	-12	-602.507	10.4	86	74.12
218	-13	-602.614	10.7	66	67.42
219	-14	-602.721	10.7	76	68.18
220	-15	-602.803	8.2	53	53.93
221	-16	-602.894	9.1	58	62.63

APPENDIX A

SAP T-3 Drill Hole, Bed 10--Cont.

Sample No.	Drill Hole Sample	Sample Interval (m)	Sample Thickness (cm)	Br (ppm)	NaCl (%)
222	-17	Not analyzed	9.1	--	0
223	-18	602.986- 603.080	9.4	41	36.89
224	-19	-603.193	11.3	86	75.81
225	-20	-603.339	11.6	79	73.73
226	-21	-603.434	12.5	58	66.31
227	-22	-603.528	9.4	61	65.81
228	-23	-603.619	9.1	86	81.10
229	-24	-603.699	7.9	26	18.20
230	-25	-603.803	10.4	27	40.45
231	-26	-603.906	10.4	57	60.62
232	-27	-604.004	9.8	62	80.15
233	-28	604.010- 604.074	6.4	0	14.50

APPENDIX A

SAP 2 Drill Hole, Bed 10

Sample No.	Drill Hole Sample	Sample		Br (ppm)	NaCl (%)
		Interval (m)	Thickness (cm)		
234	SAP 2-1	596.268- 596.366	9.8	90	96.56
235	-2	-596.478	11.3	99	88.93
236	-3	596.606- 596.737	13.1	129	79.0
237	-4	-596.868	13.1	158	73.24
238	-5	-596.987	11.9	167	76.84
239	-6	-597.106	11.9	131	77.85
240	-7	-597.209	10.4	120	70.85
241	-8	-597.314	10.4	107	57.04
242	-9	-597.417	10.4	106	75.78
243	-10	-597.524	10.7	92	83.59
244	-11	-597.603	7.9	87	75.06
245	-12	-597.679	7.6	79	75.69
246	-13	-597.734	7.5	104	83.74
247	-14	-597.826	9.1	65	79.92
248	-15	-597.917	9.1	69	65.46
249	-16	-597.987	7.0	64	74.56
250	-17	-598.063	7.6	74	70.59
251	-18	-598.143	7.9	75	59.23
252	-19	598.268- 598.359	9.1	42	35.94
253	-20	-598.450	9.1	58	58.68
254	-21	-598.539	8.8	86	76.91
255	-22	-598.627	8.8	59	65.34
256	-23	-598.752	12.5	60	77.48
257	-24	-598.874	12.2	64	68.06
258	-25	-598.984	10.9	79	85.41
259	-26	-599.094	10.9	73	85.04
260	-27	-599.222	12.8	62	72.36

APPENDIX A

SAP 3 Drill Hole, Bed 10

Sample No.	Drill Hole Sample	Sample		Br (ppm)	NaCl (%)
		Interval (m)	Thickness (cm)		
261	SAP 3-1	922.429- 922.474	4.6	85	97.38
262	-2	-922.569	9.4	77	91.98
263	-3	-922.663	9.4	71	71.53
264	-4	-922.758	9.4	63	18.14
265	-5	922.986- 923.084	9.8	28	36.78
266	-6	-923.190	10.7	84	98.55
267	-7	-923.270	7.9	77	79.11
268	-8	-923.346	7.6	83	68.78
269	-9	-923.422	7.6	81	82.80
270	-10	-923.489	6.7	78	98.42
271	-11	-923.571	8.2	62	85.45
272	-12	-923.703	13.1	82	85.41
273	-13	-923.767	6.4	58	63.82
274	-14	923.895- 924.010	11.6	87	37.94
275	-15	-924.105	9.4	93	90.06
276	-16	-924.196	9.1	82	75.19
277	-17	-924.288	9.1	82	89.74
278	SAP 5-1	617.647- 617.738	8.2	75	79.01
279	-2	617.747- 617.833	9.4	139	62.78
280	-3	-617.939	10.7	134	57.81
281	-4	-618.031	9.1	130	62.75
282	-5	618.131	10.1	125	69.03
283	-6	-618.232	10.1	118	63.29
284	-7	-618.333	10.1	104	61.09
285	-8	-618.424	9.1	100	72.38
286	-9	-618.515	9.1	101	77.68
287	-10	-618.607	9.1	93	70.41
288	-11	-618.698	9.1	99	79.54
289	-12	-618.793	9.4	67	57.38
290	-13	618.799- 618.899	10.1	73	81.23
291	-14	618.902- 618.973	7.0	65	75.08

APPENDIX A

SAP 5 Drill Hole, Bed 10--Cont.

Sample	Drill Hole	Sample		Br	NaCl
No.	Sample	Interval (m)	Thickness (cm)	(ppm)	(%)
292	-15	-619.043	7.0	62	83.14
293	-16	619.076-619.174	9.8	61	62.87
294	-17	-619.277	10.4	78	75.96
295	-18	-619.375	9.8	73	67.44
296	-19	619.524-619.625	10.1	70	98.60
297	-20	619.631-619.713	7.6	65	62.83
298	-21	-619.808	9.4	70	73.97
299	-22	-619.884	7.6	64	65.56
300	-23	-619.991	10.7	80	80.52
301	-24	-620.058	6.7	76	93.76
302	-25	620.061-620.097	3.7	68	71.86
303	-26	-620.167	7.0	92	83.87
304	-27	Missing			
305	-28	620.280-620.372	9.1	70	83.94
306	-29	-620.463	9.1	78	84.19
307	-30	-620.536	7.3	82	78.21
308	-31	-620.609	7.3	84	75.13
309	-32	-620.704	9.4	30	30.78
310	-33	-620.819	11.6	0	8.45

APPENDIX A

Yates Drill Hole, Bed 10

Sample No.	Drill Hole Sample	Sample		Br (ppm)	NaCl (%)
		Interval (m)	Thickness (cm)		
311	Y-1	910.499- 910.559	6.1	26	25.19
312	-2	-910.587	2.7	69	81.12
313	-3	910.593- 910.633	3.9	77	82.61
314	-4	-910.672	3.9	78	66.92
315	-5	910.675- 910.752	7.9	95	86.77
316	-6	-910.828	7.6	100	90.59
317	-7	910.904	7.6	87	69.79
318	-8	-910.980	7.6	87	63.64
319	-9	-911.053	7.3	79	63.53
320	-10	-911.139	8.5	67	66.72
321	-11	-911.224	8.5	75	77.57
322	-12	-911.306	8.2	73	72.97
323	-13	-911.383	7.6	67	94.79
324	-14	-911.682- 911.733	5.2	79	79.28
325	-15	-911.788	5.5	65	76.87

APPENDIX A

Finley 2 Drill Hole, detailed sampling of sample number 48, bed 10

Sample No.	Drill Hole Sample	Sample Interval (m)	Sample Thickness (cm)	Br (ppm)	NaCl (%)
326	F_2-10-29	625.306- 625.316	1.0	77	99.25
327	-30	-625.325	1.0	64	97.65
328	-31	-625.334	1.0	88	101.02
329	-32	-625.343	1.0	112	100.67
330	-33	-625.352	1.0	52	101.22
331	-34	-625.370	1.4	35	93.87

APPENDIX B

Semiquantitative analyses by U. S. Geological Survey
(Analyst: N. Conklin)

Element	Sample No. (311) Y-10-1	Sample No. (222) T-3-17	Sample No. (86) F-2-9-14	Sample No. (61) F-2-10-10	Sample No. (309) S-5-32	Sample No. (108) F-2-6-24
Fe %	0.015	1.5	0.15	0.07	0.05	0.1
Mg %	0.07	1.5	0.3	0.07	0.05	0.3
Ca %	0.15	2.	1.	0.15	0.03	0.2
Ti %	0.03	0.15	0.015	0.007	0.003	0.007
Mn ppm	7.	150.	30.	7.	5.	15.
B ppm	70.	100.	20.	<20.	<20.	<20.
Ba ppm	200.	300.	70.	15.	20.	30.
Co ppm	<5.	7.	<5.	<5.	<5.	<5.
Cr ppm	<1.	50.	7.	7.	<1.	2.
Cu ppm	<1.	30.	1.5	3.	<1.	1.5
Mo ppm	<3.	15.	<3.	<3.	<3.	<3.
Ni ppm	7.	70.	30.	7.	<5.	3.
Pb ppm	<10.	10.	<10.	<10.	<10.	<10.
Sc ppm	<5.	7.	<5.	<5.	<5.	<5.
Sr ppm	50.	700.	100.	70.	15.	20.
V ppm	<7.	70.	15.	15.	<7.	15.
Zr ppm	<10.	30.	<10.	<10.	<10.	<10.
Si %	0.15	5.	0.3	0.2	0.1	0.15
Al %	0.05	5.	0.3	0.3	0.1	0.2
Na %	>10.	>10.	>10.	>10.	>10.	>10.
K %	<0.7	7.	0.7	0.7	<0.7	<0.7
Ga ppm	<5.	15.	<5.	<5.	<5.	<5.

The abundances of the following elements are below their listed detection limits.

Ag (0.5 ppm)	As (1000 ppm)	Au (20 ppm)	Re (1 ppm)
Bi (10 ppm)	Cd (50 ppm)	Ce (200 ppm)	Dy (50 ppm)
Er (50 ppm)	Eu (50 ppm)	Gd (50 ppm)	Ge (10 ppm)
Hf (100 ppm)	Ho (20 ppm)	In (10 ppm)	Ir (50 ppm)
La (30 ppm)	Li (100 ppm)	Lu (30 ppm)	Nb (10 ppm)
Nd (70 ppm)	Os (50 ppm)	P (0.2%)	Pd (2 ppm)
Pr (100 ppm)	Pt (50 ppm)	Re (50 ppm)	Rb (2 ppm)
Ru (10 ppm)	Ta (500 ppm)	Tb (300 ppm)	Te (2000 ppm)
Th (200 ppm)	Tl (50 ppm)	Tm (20 ppm)	U (500 ppm)
W (100 ppm)	Y (10 ppm)	Yb (1 ppm)	Zn (300 ppm)