TRONA OCCURRENCES WITHIN THE YUKON FLATS BASIN, ALASKA

By Karen H. Clautice
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DEPARTMENT OF THE INTERIOR
James G. Watt, Secretary
BUREAU OF MINES

ILLUSTRATIONS

TABLES

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ABSTRACT

Field work conducted by the U. S. Bureau of Mines as part of the mineral resource evaluation program of the Yukon-Tanana uplands and vicinity has delineated a northeasterly trend of evaporite deposits within the Yukon Flats basin. The deposits occur locally as efflorescent salt films less than one centimeter in depth about lake margins and dry lake beds within an area approximately 240 km. (150 mi.) by 48 km. (30 mi.) in size. The evaporites are precipitated from turbid lakes which are in contrast with clear lakes elsewhere in the Flats. The mineral trona has been identified by x-ray diffraction techniques in major amounts (greater than 25 weight percent) in the evaporites from numerous locations. Calcite and/or dolomite are ubiquitous associates. Trona has also been identified in minor amounts within some lake sediments to a maximum depth of 76 cm. (30 in.). X-ray emission spectrometric analysis has shown sodium to be the dominant element in all samples in the water soluble extract, with minor to trace amounts of magnesium, calcium, potassium, phosphorous, sulfur, chlorine and bromine present.

The source and significance of the deposits is not known. Factors that may affect the present trona deposition include climatic, hydrologic, geologic and biologic processes.

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INTRODUCTION

General

This investigation is a preliminary study undertaken during the 1980 field season to locate, sample and evaluate the surficial evaporitic material which occurs within the Yukon Flats. In particular, the presence or absence of the mineral trona [$Na_3H(CO_3)_2 \cdot 2H_2O$] was sought as this mineral was identified in a sample collected in the Yukon Flats region in 1978. Trona is processed to soda ash and used in the manufacture of glass, chemical compounds and paper and pulp products. The largest deposits being mined today are found in the Green River Basin of southwestern Wyoming.

Aerial, low level, false color infra-red U-2 photographs were used to delineate the deposits and 10 man-days were spent in the field during the summer of 1980, sampling the occurrences with float plane and helicopter support. All samples were subjected to x-ray diffraction analysis to determine the presence or absence of the mineral trona and other selected minerals and also were analyzed by x-ray emission (fluorescence) spectrometric techniques for sodium, magnesium, phosphorus, sulfur, chlorine, bromine, potassium and calcium. Other analytical methods included optical emission spectrometry, neutron activation, and specific ion electrode.

This study is part of the on-going mineral resource evaluation program of the Yukon-Tanana uplands and vicinity by the Bureau of Mines, Alaska Field Operation Center.

Acknowledgements

The original trona-bearing samples were collected and the project undertaken as a result of the interest of J. Barker, AFOC, Fairbanks. Namok Veach, chemist, State of Alaska, Division of Geological and Geo-

physical Surveys, performed x-ray diffraction determinations on samples collected by J. Barker in 1978 and 1979. The authors benefited considerably from technical discussions, insights and invaluable analytical support from J. Drake and W. Roberts, AFOC, Juneau. A. Schmidt, AFOC, Juneau, performed the bulk of the sample preparation and analytical work in a most competent and conscientious manner. Helpful discussions on evaporite genesis were contributed by D. Hawkins, Professor of Geology, University of Alaska. M. Albanese, and B. Porterfield, AFOC, Fairbanks, provided assistance in the field. This manuscript was reviewed by J. Barker and J. Foley, AFOC, Fairbanks.

General Geography

The evaporite deposits discussed in this report occur within the marshy, lake-dotted Yukon Flats basin in east-central Alaska (fig. 1). This region is drained by the Porcupine and Yukon Rivers and their tributaries. Elevations within the flats range from 120 m. (400 ft.) in the southwest to 180 m. (600 ft.) in the north and east. Surrounding uplands rise to over 610 m. (2000 ft.).

The continental climate of the Yukon Flats is characterized by extremes in temperature between summer and winter, and by low precipitation. Temperatures recorded at Fort Yukon range between a maximum of 37.8°C. (100°F.) to a minimum of -59.4°C. (-75°F.), with a yearly mean of -6.6°C. (20.1°F.). Average precipitation is 16.9 cm. (6.65 in.) and the average snowfall is 111 cm. (43.7 in.)(2). Permafrost is discontinuous, being absent beneath larger water bodies and well drained sites. It is recorded to a depth of 98 m. (320 ft.) at Fort Yukon, but may be much deeper (29).

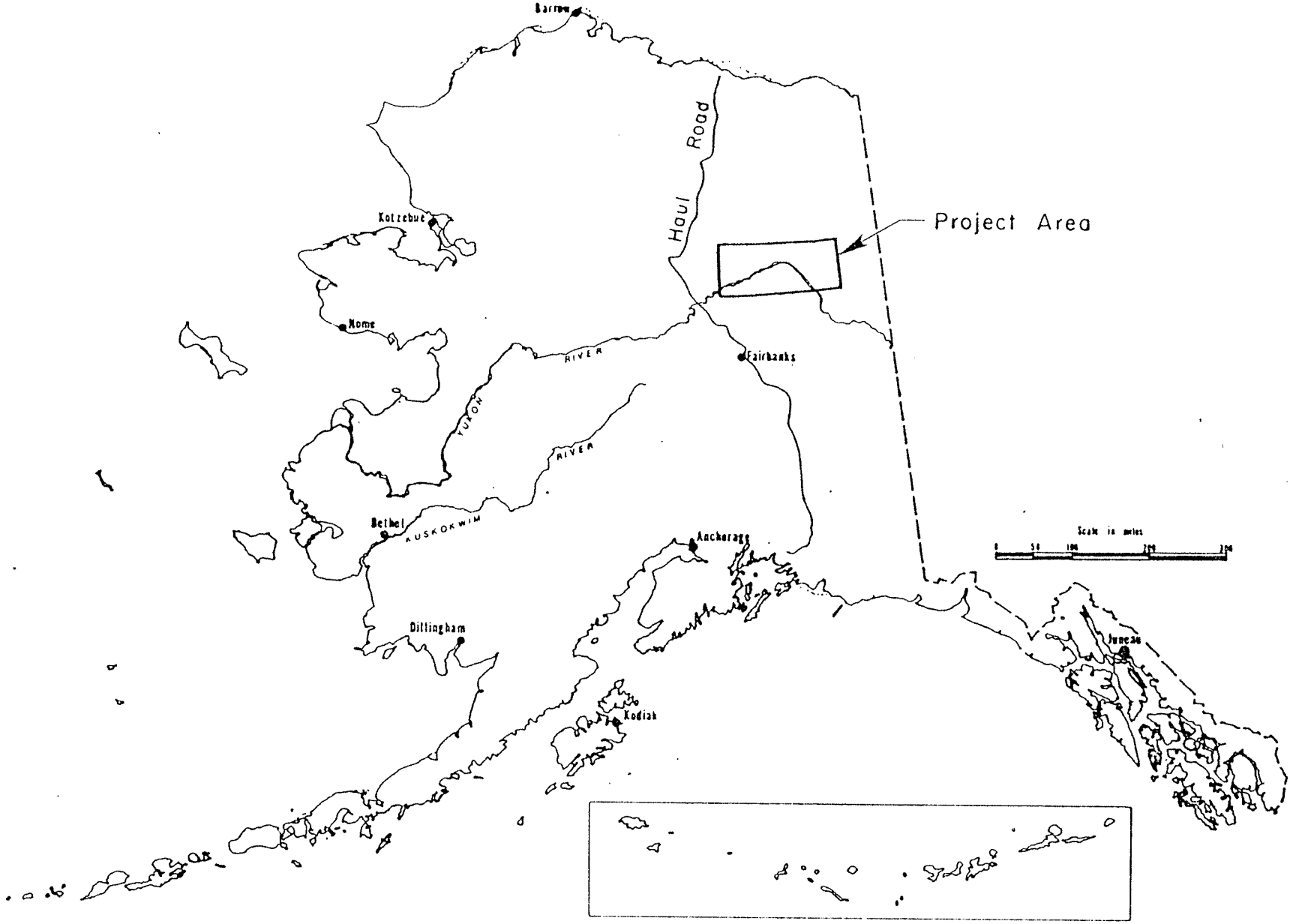

Figure 1.—Project location map

The population of the region is approximately 1060 and is centered at Fort Yukon (population 619)(1). Other settlements within the Yukon Flats include Beaver, Stevens Village, Venetie, Chalkyitsik, Birch Creek and Circle.

The district is accessible by air, by the Steese Highway from Fairbanks to Circle, from the Pipeline haul road which crosses the Yukon River at the western end of the basin, and by river boat and barge on the Yukon River between mid May and October.

Previous Investigations

White crusts about the margins of lakes and within dry lake beds have long been a recognized occurrence within the Yukon Flats basin. Smith in 1929 (25), reported the presence of potash salts in the waters of three lakes which did not freeze thoroughly in winter north of Fort Yukon. He concluded that while worthy of mention they were of no economic value. Local residents, particularly pilots, are aware of the deposits, which in places are so thick that large clouds resembling the smoke from forest fires will form on windy days above the deposits. A sample of white, evaporite material was collected in the Ohtig Lake area in the northeastern portion of the Flats and submitted to the Bureau in 1978 for analysis. X-ray diffraction patterns showed the sample to be composed of quartz, thermonatrite ($Na_2CO_3 \cdot H_2O$), feldspar and trona [$Na_3H(CO_3)_2 \cdot 2H_2O$] with minor kaolinite and mica (5). Several evaporite sites were visited and sampled by Bureau personnel one day during the 1979 field season. Thoughts on the origin of the deposits are reported by Barker (5) who suggests that the deposits appeared to be formed as a result of degassing of the substrata beneath ground water-fed lakes which intermittently dry up. He concludes that although the

source and significance of these minerals are uncertain, one interpretation could be the remobilization of evaporite deposits at depth likely to be originally derived from Tertiary felsic to intermediate volcanics north of the flats (5). Analyses of the 1979 samples are included in this report.

Published geologic data from the area is regional in nature. Numerous reconnaissance geologic studies were made within the Yukon River region at the turn of the century by early U. S. Geological Survey (USGS) geologists. A good summary of this early work is compiled in a geologic study of the Yukon Flats District by Williams (29-30). These reports also include the results of a 134 m. (440 ft.) test hole drilled at Fort Yukon, which is the only subsurface data available on the area. Regional geologic maps at 1:250,000 scale of areas bordering the Yukon Flats basin can be found in reports by Brosge and others (13), Brabb (7), Brabb and Churkin (8), Brosge and Reiser (12), and Chapman and others (15). Additional work on the age of the Rampart Group found in the western limits of the Yukon Flats has been done by Brosge and others (11). The age of the Christian Complex north of the flats has been reported by Reiser and others (24). Miller and others (21), have included a short discussion on the Yukon Flats in their study of possible petroleum provinces in Alaska.

An oil shale occurrence north of the Yukon basin has been investigated by numerous groups, both government and industry (3, 16, 17, 19, 20, 22, 26). Tertiary coal occurrences and anomalous uranium in the uplands marginal to the Yukon Flats have been reported in a recent study by Barker (5).

Available geophysical studies of the Yukon River basin are regional in nature and include a gravity survey of the Yukon Flats by Barnes (6), aeromagnetic studies of northeastern Alaska by Brosge and others (10) and Zietz and others (31), and an aerial gamma ray and magnetic survey by the U. S. Energy Research and Development Administration (27).

AREAL GEOLOGY

Quaternary flood plain, alluvial fan and related terrace deposits blanket the Yukon Flats basin. Loess deposits mantle the southern and eastern portions of the area. Glacial outwash is found in the alluvial fans of the Chandalar, Christian and Sheenjek Rivers in the northern portions of the region. The outwash represents several periods of Pleistocene glaciation (29). The composition of the bedrock underlying the flats is not known and can only be surmised from the geology of the highlands and marginal uplands surrounding the basin and from the published regional aeromagnetic and gravity data.

The Yukon Flats occupies a structural basin (23) representing the presumed intercept of the Kaltag-Porcupine lineament and the Tintina fault system. The Tintina fault system, along which there has been right lateral displacement, borders the southern margin of the basin and separates the Quaternary sediments of the Yukon basin from the Paleozoic and/or Precambrian metasedimentary and metaigneous rocks of the Yukon-Tanana uplands and a complicated package of allocthonous thrusted slices of lower Paleozoic and Mesozoic sedimentary rocks.

Occupying the eastern end of the basin are Paleozoic sedimentary rocks, consisting of limestone, dolomite, argillite, chert, graywacke, shale and siltstone which are overlain by extensive areas of Quaternary basalt flows. The north central portion of the basin is bounded by lower Paleozoic dolomite, argillite, chert and graywacke. It is within these rocks that the oil shale described earlier in this report is located.

Also occurring along the north central margin of the basin is an extensive unit known as the Christian complex, which is of probable ophiolite affinity.

It is comprised predominantly of mafic volcanic rocks with subordinate, interbedded chert and shale. A Jurassic age has been assigned to the mafic igneous rocks based on two K-Ar determinations on hornblende (24), although more recent studies by Brosge, of the interbedded radiolarian cherts, have indicated a Carboniferous to Permian age (9). Similar-appearing rock units comprise the southwestern and northwestern end of the basin and are known as the Rampart volcanics. They are of probable Permian age, are interbedded with minor sandstone and limestone units and are intruded by sills and dikes of Triassic gabbro and greenstone (11). Regional aeromagnetics (10, 31) indicate that the Christian and Rampart volcanics may be related and may underlie the western portions of the basin as well as extend beneath the southern portions of the Yukon basin to the Circle area in the east, where limited exposures of the upper Paleozoic(?) Circle mafic volcanics occur (8).

The western Yukon Flats region is bordered to the west and north by the Hodzana Highlands (28), which are comprised of a series of northeast trending Cretaceous granitic plutons that have intruded lower Paleozoic schists and quartzite (13).

Continental sedimentary rocks occur in scattered Cenozoic basins and troughs in the highlands and marginal uplands bordering the Yukon Flats (4, 29, 30). These contain numerous occurrences of coal, which are interbedded in several areas with felsic to intermediate volcanic ash, most notably in the Coleen basin region at Fishhook Bend on the Porcupine River to the northeast of the Yukon basin and in the western uplands in the Coal Creek and Mudbank areas (4). A sample of tephra which appeared to overlie a coal section on Coal Creek has yielded a K-Ar date of 38.5 $\pm$ 1.6 m.y. on fresh glass shards and feldspar phenocrysts (4). Uranium enrichment to 20 to 50 ppm and phosphorous minerals have also been noted in tuffaceous sediments and mudstones in marginal uplands to the west (4).

Regional gravity studies suggest that small Cenozoic basins, which may or may not be connected or continuous, also underlie the alluvial and eolian deposits of the Yukon basin (6). Data from a test well drilled at Fort Yukon partly substantiates the gravity studies. Eighty-nine meters (292 ft.) of late Tertiary or Quaternary lacustrine(?) sediments are recorded in the well. The base of the sediments was not reached. Williams suggests that this thickness indicates that the probable lacustrine sediments are of widespread distribution beneath the Quaternary fill of the Yukon Flats (29).

DESCRIPTION OF OCCURRENCES

White efflorescent salt crusts occur locally along a northeast trend approximately 240 km. (150 mi.) long and 48 km. (30 mi.) wide within the Yukon Flats. They vary in size from small patches about lake margins to a maximum areal extent of approximately 2.6 sq. km. (1 sq. mi.) within a dry lake bed west of Ohtig Lake (T.20N., R.18E., Black River quadrangle). Their locations and extent are shown in figure 2. This map was compiled from a study of infra-red, low level U-2 photographs that were taken between 1977 and 1979. The occurrences were field checked from the air and selected occurrences were visited on the ground. Visited occurrences typically were salt crusts having a maximum thickness of one centimeter and occurring at the margins of turbid lakes and within dry lake beds (figs. 3 & 4). The turbid waters of these lakes are in sharp contrast to the clear lakes elsewhere in the flats (fig. 4). pH measurements of unfiltered lake waters from lakes which had surrounding salt crust were found to be alkaline, ranging from 8.0 to 9.8.

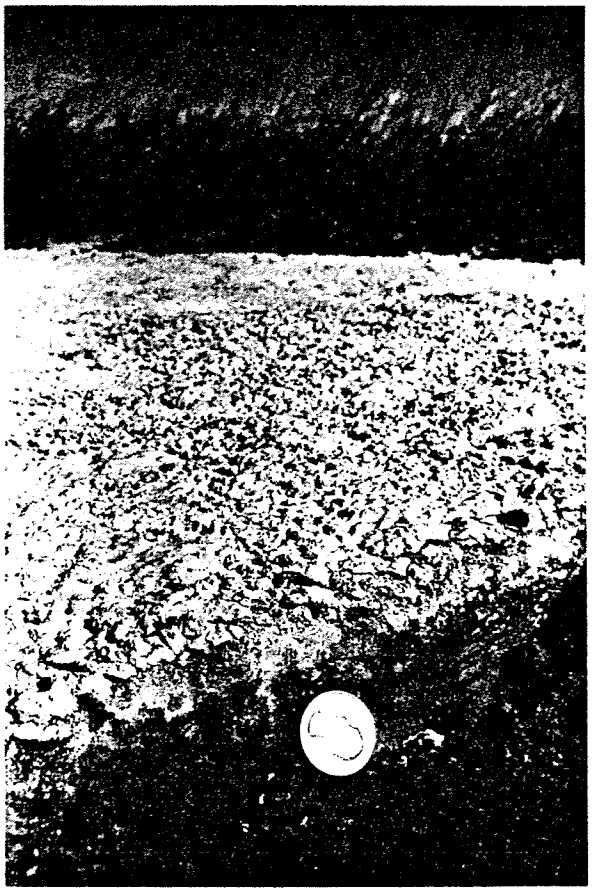

Figure 3. Efflorescent salt crust within a dry lake bed in the east central portion of T.18N., R.6E. in the Fort Yukon quadrangle.

Figure 4. Sampling efflorescent salt crust in the south central portion of T.23N., R.19E. in the Black River quadrangle.

Figure 5. Turbid lake waters with surrounding efflorescent salt crust that is typical of many lakes in the Yukon Flats. This photograph is from the south central portion of T.23N., R.19E. in the Black River quadrangle. Distant uplands shown in this photograph are mapped as Carboniferous to Permian shale (7).

It was observed that fluctuations in the water table, and in turn lake levels, had a direct affect on the areal distribution of the salts. The 1980 season was much wetter than the previous few years and fewer areas of precipitates were found than during the 1979 field season and in the 1977-1979 photographs. The yearly fluctuations in the water table could act as a concentrating mechanism for the salts. Eugster and Hardie (18) cite two processes available for producing the extreme concentration necessary for the formation of trona. Aside from straight-forward evaporative concentration, they state that the recycling of solutes through fractional dissolution of efflorescent crusts plays a very important role. The latter appears to be occurring in the flats.

A final observation that should be noted, as it may(?) play a part in the formation of the deposits, is the presence of numerous small vertical holes of 0.5-5 mm. in diameter occurring at a density of several to a square centimeter, immediately beneath the salt crust of one lake. It is not known whether these holes are due to physical and/or biogenic processes and if they occur in any other lakes.

MINERALOGIC AND CHEMICAL ANALYSIS RESULTS

A discussion of the analytical procedures used in the preparation of the following data is included as an appendix to this report.

Samples of efflorescent salt crusts and underlying sediments were collected in 1978-1979 and subjected to x-ray diffraction analyses to determine their mineralogy. Major constituents were found to be quartz and plagioclase, although one sample showed the presence of trona and thermonatrite (Table 1). Minerals present in minor amounts included K-feldspar, illite, amphibole, chlorite, dolomite, siderite-magnesite, calcite and kaolinite. Samples

TABLE 1. Mineralogy determined by x-ray diffraction of 1978-1979 samples*

Sample Number	Location		Mineralogy		Sample depth (cm)
	Twp.	Rge.	Major	Minor	
HZ-10351d	17N	8E	quartz plagioclase	K-feldspar illite amphibole chlorite dolomite siderite-magnesite calcite	1
HZ-10353d	18N	6E	quartz plagioclase	K-feldspar illite chlorite amphibole dolomite calcite	30
HZ-10350d	17N	8E	quartz plagioclase	K-feldspar amphibole illite chlorite dolomite siderite-magnesite	1
BM-1	20N	18E	quartz thermonatrite feldspar trona	kaolinite mica	1

* Sample locations shown on figure 2.

from this series were also subjected to multi-element analysis (Table 2). One sample of efflorescent crust contained 12.04 percent sodium and a general enrichment in chlorine.

X-ray diffraction was used to determine the presence of trona and selected other minerals in samples collected at varying depths within dry lakes and at lake margins during the 1980 field season (Table 3). Major quantities of trona were found only in the surficial films to a depth of 1 cm., although minor amounts of trona were identified in lake sediments to a depth of 76 cm. (30 in.). In addition, other minerals commonly present included quartz, feldspars, layer silicates ("illite"-micaceous materials, kaolinite group, chlorites, expandable materials) and occasional amphiboles. The minerals calcite and dolomite were present in detectable amounts in all samples, although only rarely in preponderant amounts. Gypsum was detected in only one sample (YT17776), although it may questionably be present in very minor amounts in three others. Halite was detected in two samples (YT17763, YT17877) and may questionably be present in very minor amounts in six others. Dawsonite was recognized in one sample (YT17877) and may questionably be present in one other (YT17763), together with the sole (and questionable) occurrence of aragonite. This sample also contained the sole occurrences of the minerals natron and polyhalite. X-ray emission spectrometric analyses showed sodium to be the dominant element in the water soluble extract from all samples, with at most, only minor amounts of magnesium, calcium, potassium, phosphorous, sulfur, chlorine and bromine present.

Analysis of the bulk samples for boron by Inductively Coupled Argon Plasma (ICAP) spectrograph, fluorine by specific ion electrode and sodium by atomic absorption did not indicate values for these elements in excess

TABLE 2. Multi-element analyses (ppm) of Yukon Flats sediments*

Sample No.	HZ10350d	HZ10351d	HZ10352d	HZ10353d
Location	T.17N., R.8E.	T.17N., R.8E.	T.18N., R.6E.	T.18N., R.6E.
Sample depth(cm)	30	1	1	30
Mg	18090	37100	-6164	25460
Mn	451	613	409	632
Na	52480	16050	120400	17140
Rb	-31	-23	-40	-31
Sb	-2	-2	-2	-2
Sc	9.1	9.9	7.2	10.9
Sm	5.0	3.6	2.9	4.3
Sr	-373	-201	-591	-280
Ta	-1	-1	-2	-1
Tb	-1		-1	-1
Th	6.5	6.4	4.1	5.9
Ti	4096	2892	3044	3030
V	76	86	74	86
Yb	2.7	-1.0	-1.6	3.3
Zn	67	44	-52	60
U/Th	0.520	0.267	0.727	0.351
Al	40660	44590	37800	47210
Au	-0.09	-0.06	-0.09	-0.08
Ba	693	916	827	1025
Ca	35470	60990	27320	46770
Ce	58	48	35	57
Cl	302	226	4833	416
Co	5.4	9.2	5.9	9.5
Cr	91	89	62	92
Cs	-1.7	2.3	-1.9	-1.7
Dy	4	3	-2	3
Eu	1.0	1.0	0.6	1.1
Fe	16070	22410	14690	24840
Hf	8.5	5.1	3.6	5.4
K	-4390	12050	-8328	12680
La	31	23	17	30
Lu	0.2	0.2	0.2	0.3
U	3.38	1.71	2.98	2.07
Ag	-5	-5	-5	-5
Bt	-5	-5	-5	10
Cd	-5	-5	-5	-5
Cu	-10	30	32	32
Nb	-20	-20	-20	-20
Ni	34	33	19	27
Pb	7	-5	13	5
Sn	-10	-10	-10	-10
W	-15	-15	-15	-15
As	8	18	38	12
Se	-5	-5	-5	-5
Zr	221	136	124	132
Be	1	-1	2	2
Li	42	76	49	88

* Sample locations shown in figure 2.

Analyses performed by: Los Alamos Scientific Laboratory
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Los Alamos, New Mexico 87545

TABLE 3. X-ray diffraction analysis for selected minerals*

Sample number	Location Twp.	Rge.	Sample depth (cm)	Trona	Calcite	Dolomite	Other minerals
YT 16619	23N	19E	91	ND	D	D	
16620	23N	19E	91	ND	ND	D	
16621	23N	19E	1	ND	ND	D	
16623	23N	18E	91	ND	D	D	
16625	23N	19E	91	ND	D	D	
16627	23N	19E	91	ND	Major	D	
16631	19N	2E	1	Major	D	D	
16632	19N	2E	45	ND	D	D	
16633	19N	2E	91	ND	D	D	
16634	19N	2E	15	ND	D	D	
17759	23N	13E	5	ND	D	D	
17760	23N	13E	30	ND	D	D	
17761	23N	13E	4	Minor	D	D	
17762	23N	13E	30	ND	D	D	
17763	23N	14E	5	Major	D	D	dawsonite(?), aragonite(?), halite, natron, polyhalite(?)
17764	23N	14E	30	ND	D	D	
17765	23N	14E	91	ND	D	D	
17767	23N	14E	1	Major	D	D	
17768	21N	15E	1	Major	D	D	
17769	21N	15E	91	ND	D	D	
17770	21N	15E	1	Minor	D	D	
17771	21N	15E	60	ND	D	D	
17772	21N	15E	1	Major	ND	----	
17773	21N	15E	15	ND	D	D	
17774	17N	8E	1	Minor	D	D	
17775	17N	8E	15	Minor	D	D	
17776	18N	7E	1	ND	D	D	
17781	18N	1E	1	Minor	D	D	
17782	18N	1E	9	ND	D	D	

*note: Sample locations shown in figure 2.
D = detected
ND = not detected
---- = sample not analyzed
Major = 25 per cent trona by weight
Minor = 25 per cent trona by weight

X-ray diffraction analyses for selected minerals - continued

Sample number	Location Twp.	Rge.	Sample depth (cm)	Trona	Calcite	Dolomite	Other minerals
YT 17783	18N	1W	1	Major	D	D	
17784	18N	1W	45	ND	D	D	
17785	17N	3W	1	Minor	D	D	
17786	17N	3W	1-5	ND	D	D	
17787	17N	3W	45-76	ND	D	D	
17789	17N	3W	1	ND	D	D	
17810	20N	18E	1	Major	D	D	
17811	20N	18E	45	ND	D	D	
17812	20N	18E	1	ND	D	D	
17814	20N	18E	5	ND	ND	D	
17815	20N	18E	60	ND	D	D	
17816	20N	18E	7	ND	ND	D	
17817	20N	18E	91	ND	D	D	
17818	20N	18E	5	ND	ND	D	
17819	20N	18E	91	ND	D	D	
17820	20N	18E	1	Minor	ND	D	
17821	20N	18E	91	ND	D	D	
17822	20N	18E	10	ND	D	D	
17823	20N	18E	91	ND	ND	D	
17824	20N	18E	91	ND	D	D	
17825	20N	18E	5	ND	ND	D	
17826	20N	18E	76-91	ND	D	D	gypsum(?)
17827	20N	18E	5	ND	ND	Major	
17828	20N	18E	76-91	ND	D	D	
17829	20N	18E	1	Major	ND	D	
17830	20N	18E	30	Minor	ND	D	gypsum(?)
17831	20N	18E	76-91	ND	D	D	
17833	22N	13E	8	ND	D	D	
17834	22N	13E	30-60	ND	D	D	
17835	22N	13E	60	ND	D	D	
17836	22N	13E	1	ND	D	D	
17837	22N	13E	60	ND	D	Major	
17838	24N	11E	1	ND	D	D	
17839	24N	11E	91	ND	D	D	
17841	24N	11E	1	ND	D	Major	

X-ray diffraction analysis for selected minerals - continued

Sample number	Location Twp.	Rge.	Sample depth (cm)	Trona	Calcite	Dolomite	Other minerals
YT 17842	24N	11E	91	ND	----	----	
17843	23N	11E	5	ND	Major	D	
17846	23N	11E	1	ND	D	D	
17847	23N	11E	91	ND	D	D	
17848	23N	11E	1	Minor	D	D	halite(?)
17849	23N	11E	60	ND	D	D	
17851	23N	11E	1	Major	----	----	
17852	23N	11E	60	ND	D	D	halite(?)
17854	23N	12E	1	Major	ND	D	halite(?)
17855	18N	7E	45-76	ND	Major	D	gypsum(?)
17856	18N	7E	1	ND	D	D	
17857	18N	7E	45-76	Minor	D	D	
17858	18N	7E	1	ND	D	D	
17859	18N	7E	30	Minor	D	D	
17860	18N	6E	1	Major	D	D	
17861	18N	6E	5	ND	D	D	
17862	18N	6E	76-91	ND	ND	D	
17864	19N	6E	4	ND	D	D	
17865	19N	6E	60	ND	D	D	
17866	19N	6E	3	Minor	D	D	halite(?)
17867	19N	6E	30	ND	D	D	
17868	19N	5E	1	Major	D	D	halite(?)
17869	19N	5E	30	ND	D	D	
17870	19N	5E	1	Major	D	D	halite(?)
17872	19N	5E	1	Major	D	D	
17873	19N	5E	30	ND	D	D	
17874	19N	5E	76	ND	D	D	
17875	19N	5E	30	ND	D	D	
17877	19N	5E	5	Minor	D	D	dawsonite, halite
17878	19N	5E	30	ND	D	D	
17879	18N	4E	1	Minor	D	D	
17881	18N	4E	10-40	ND	D	D	
17882	18N	2E	1	Major	D	D	
17883	19N	2E	45	ND	Major	D	

of the normal geochemical values characteristic of sediments of this nature (Table 4). Similarly, semi-quantitative optical emission spectrometric analysis of bulk samples for eleven selected elements (Table 5) did not indicate concentration levels for any of these elements sufficiently high to suggest potential economic significance.

CONCLUSIONS AND RECOMMENDATIONS

A northeasterly trend of evaporite deposits occurring locally within an area approximately 240 km. (150 mi.) by 48 km. (30 mi.) has been delineated in the Yukon Flats basin. Trona, a mineral processed into soda ash that is used by the glass and chemical industries, has been identified in many of the evaporite locations. In most cases trona occurs within evaporitic films less than 1 cm. in depth that form about lake margins and within dry lake beds. It has also been identified in minor amounts, in the subsurface of some lake sediments to a maximum depth of 76 cm. (30 in.).

It is likely that trona is forming today as a result of a combination of natural processes both surficial and fault controlled, unique to the geologic environment of the Yukon Flats, rather than being remobilized from a larger trona source at depth. Factors that may affect the present trona deposition are climatic, hydrologic, geologic and vegetative processes. These factors include temperature and precipitation conditions, groundwater movement within the active layer above permafrost, groundwater movement along the many splays of the Kaltag-Porcupine and Tintina fault systems, type of vegetation and rate of organic decay (which regulates the chemical composition of the groundwater), and composition of bedrock and sediments through which groundwaters travel. Further field work should be done before

TABLE 4. Boron, fluorine and sodium analyses (ppm)*

Sample No.	B	F	Na
YT 17761	50	290	32500
17762	71	460	17000
17763B	33	130	130000
17764A	52	320	24000
17764B	65	480	21500
17765	84	360	14000
17767	41	180	105000
17768	65	380	47000
17769	65	340	16000
17770	67	400	43000
17771	84	320	16000
17772	54	230	110000
17773	82	450	22000
17774	45	320	6400
17775	44	480	39500
17781	44	230	10000
17782	44	400	4500
17783	46	180	90000
17784	46	380	15000
17785	38	220	10500
17786	50	450	20000
17787	62	450	21000
17789	59	340	45000
17810	32	450	23000
17811	68	520	18000
17812	86	550	15500
17814	58	520	17000
17815	77	520	16000
17816	66	430	20000
17817	71	500	18000
17818	33	500	17000
17819	61	470	15000
17821	70	450	17000
17823	45	390	110000
17824	71	470	22000
17825	45	520	18000
17826	90	550	17500
17827	60	590	17000
17828	42	470	17000
17829	110	320	13000
17830	80	470	25000
17831	101	390	16000
YT 17833A	101	450	17000
17833B	54	530	13500
17834	110	470	9000
17835	72	550	13000
17836	89	470	6000
17837	68	340	38000
17838	72	380	8000
17839	75	330	6000
17843	42	300	2700
17846	120	480	45000
17847	160	590	10000
17848	67	290	50000
17849	92	360	12000
17851	37	230	85000
17852	41	320	12000
17853	56	470	17500
17854	44	220	85000
17855	92	420	13000
17856	61	420	17000
17857	52	360	50000
17858	53	500	64000
17859A	58	420	18000
17859B	47	210	7000
17860A	65	570	15000
17860B	41	220	96000
17861A	79	550	20000
17861B	50	400	22000
17862	56	480	16300
17865	74	550	17500
17866	59	440	48500
17867	59	520	16000
17868	68	460	110000
17869	81	620	18500
17870	54	380	40000
17872	63	480	75000
17874	72	420	18500
17875	54	450	17000
17877	35	470	48500
17878	52	500	22000
17879	37	380	70000
17881	61	530	20500
17882	43	300	55000

* note: sample locations and depths listed in table 3
sample locations shown in figure 2

Analyses performed by: TSL Laboratories Ltd.
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Opportunity, Wa. 99214

TABLE 5. Emission spectrometric analyses (%)*

Sample No.	Al_2O_3	Ba	B	Cr	Fe	Mn	MgO	SiO_2	Na_2O	Ti	Zr
YT 17761	6	ND	0.002	0.002	1.5	0.02	2	+20	3	0.2	0.01
17762	8	0.1	0.005	0.002	4	0.02	4	+20	2	0.2	0.01
17763	3	ND	0.002	ND	0.5	0.01	0.6	+20	+4	0.02	0.005
17764A	6	0.07	0.002	0.002	1.5	0.01	4	+20	1.5	0.1	ND
17764B	6	ND	0.002	0.002	1	0.02	2	+20	2	0.2	0.005
17765	8	0.1	0.005	0.006	2	0.02	3	+20	1.5	0.2	0.005
17767	4	ND	0.002	ND	1	0.01	0.6	+20	+4	0.08	0.01
17768	6	0.1	0.005	0.004	1.5	0.02	2	+20	+4	0.2	0.005
17769	6	0.07	0.005	0.004	1.5	0.03	3	+20	1.5	0.2	ND
17770	6	0.07	0.005	0.008	1.5	0.03	3	+20	+4	0.4	0.08
17771	8	0.07	0.005	0.008	2	0.02	2	+20	1	0.4	0.03
17772	4	0.07	0.002	0.004	1	0.03	1	+20	+4	0.1	0.005
17773	8	0.07	0.005	0.006	1.5	0.03	2	+20	2	0.2	ND
17774	6	0.1	0.002	0.004	1	0.02	4	+20	+4	0.2	0.01
17775	4	0.1	ND	0.002	1	0.02	+4	+20	4	0.1	ND
17781	3	ND	ND	0.002	0.6	0.01	0.6	+20	+4	0.1	ND
17782	10	0.1	0.002	0.008	2	0.03	3	+20	3	0.2	0.005
17783	3	ND	ND	ND	1	0.01	0.6	+20	+4	0.1	ND
17789	6	0.2	0.002	0.002	1.5	0.05	3	+20	+4	0.1	0.01
17810	6	0.07	0.002	0.005	1	0.02	2	+20	+4	0.2	0.01
17811	8	0.07	0.003	0.002	2	0.03	3	+20	1	0.3	0.005
17812	10	ND	0.003	0.002	2	0.03	2	+20	1	0.2	ND
17814	8	ND	0.003	0.005	1	0.02	3	+20	1	0.3	0.005
17815	8	0.07	0.002	0.005	2	0.02	3	+20	1	0.3	ND
17816	8	ND	0.003	0.002	1	0.02	3	+20	2	0.3	0.005
17817	10	0.1	0.003	0.005	2	0.03	3	+20	3	0.3	0.01
17818	8	0.07	0.003	0.005	1	0.02	4	+20	3	0.3	0.01
17819	10	0.07	0.003	0.01	2	0.03	3	+20	2	0.4	0.01
17821	9	0.1	0.005	0.01	2	0.06	3	+20	3	0.3	0.005
17823	4	ND	0.002	0.002	0.5	0.02	3	+20	+4	0.2	ND
17824	8	ND	0.003	0.005	1	0.05	3	+20	2	0.3	0.005
17825	8	0.07	0.003	0.005	1	0.02	4	+20	3	0.2	ND
17826	6	0.07	0.003	0.005	1	0.02	4	+20	3	0.3	ND
17828	8	0.07	0.003	0.01	1	0.03	2	+20	2	0.3	0.005
17829	5	0.07	0.002	0.005	1	0.02	2	+20	+4	0.2	0.005
17830	8	0.07	0.005	0.005	1.5	0.03	5	+20	4	0.3	0.01
17831	8	0.07	0.003	0.005	2	0.03	2	+20	2	0.3	0.01
17833	8	0.07	0.003	0.005	2	0.03	3	+20	3	0.3	0.005
17834	8	0.07	0.005	0.007	2	0.03	3	+20	1	0.3	0.005
17835	6	0.01	0.005	0.005	2	0.03	3	+20	2	0.2	0.005
17836	6	0.07	0.007	0.005	2	0.03	3	+20	3	0.2	0.005

* Sample locations shown in figure 2.
ND = not detected
Analyses performed by TSL Laboratories, Ltd.
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Emission spectrometric analyses (%) - continued

Sample No.	Al_2O_3	Ba	B	Cr	Fe	Mn	MgO	SiO_2	Na_2O	Ti	Zr
YT 17837	4	ND	0.002	ND	1.5	0.02	2	+20	3	0.1	ND
17839	4	ND	0.005	0.002	1	0.02	1	+20	ND	0.1	ND
17843	1	ND	0.002	ND	0.5	0.01	0.6	15	ND	ND	ND
17846	6	ND	0.002	0.004	2	0.03	2	+20	+4	0.2	ND
17847	8	0.07	0.005	0.01	2	0.03	2	+20	2	0.4	ND
17848	4	ND	0.002	0.002	1	0.03	2	+20	+4	0.2	ND
17849	6	0.07	0.002	0.004	1.5	0.02	1	+20	1	0.2	0.005
17851	3	ND	0.002	ND	1	0.02	1	+20	+4	0.1	ND
17852	4	ND	0.004	0.002	1.5	0.02	3	+20	2	0.1	ND
17853	8	0.07	0.002	0.002	1	0.03	3	+20	3	0.2	0.005
17854	4	0.07	0.002	0.004	1	0.02	0.6	+20	+4	0.1	0.01
17855	6	0.1	0.002	0.004	1.5	0.03	2	+20	1	0.1	ND
17856	6	0.1	0.002	0.004	1.5	0.04	3	+20	2	0.1	ND
17857	6	0.07	0.002	0.008	1	0.03	3	+20	4	0.2	0.01
17858	6	ND	0.002	0.004	1	0.03	2	+20	+4	0.1	0.005
17859A	4	ND	0.002	0.002	1.5	0.02	1	+20	+4	0.2	0.03
17859B	8	0.1	0.002	0.004	1.5	0.03	3	+20	2	0.2	0.005
17860	6	ND	0.005	0.002	1.5	0.03	3	+20	1.5	0.1	0.005
17861	3	ND	0.004	0.002	1.5	0.01	4	+20	3	0.1	ND
17862	3	ND	0.004	0.002	1.5	0.01	4	+20	1.5	0.1	ND
17866	6	ND	0.002	0.004	1.5	0.01	3	+20	+4	0.2	0.005
17867	4	ND	ND	0.004	1.5	0.01	4	+20	1	0.1	ND
17868	4	ND	ND	0.004	1	0.01	0.6	+20	+4	0.2	0.02
17869	8	0.1	0.002	0.008	2	0.02	0.8	+20	2	0.2	0.01
17870	3	ND	ND	0.002	1	0.01	0.6	+20	+4	0.1	0.01
17872	4	ND	0.002	0.002	1	0.02	1	+20	+4	0.1	ND
17874	6	0.07	0.002	0.002	2	0.02	3	+20	1.5	0.2	0.01
17875	8	0.1	0.005	0.005	2	0.04	3	+20	3	0.2	0.005
17877	6	0.07	0.002	0.005	1	0.04	2	+20	4	0.2	0.01
17878	8	0.07	0.002	0.005	2	0.05	2	+20	2	0.2	0.005
17879	4	0.07	ND	0.002	0.5	0.02	2	+20	+4	0.1	ND
17881	4	0.1	0.002	0.003	1	0.02	3	+20	1	0.1	ND
17882	4	ND	0.002	0.002	0.5	0.02	1	+20	+4	0.1	ND

a statement as to any potential economic significance of the Yukon Flats occurrences can be made.

A study of lake water composition, both from lakes containing the trona precipitate and those not containing it, may indicate whether the natural surficial conditions within the flats could develop the brines from which the trona is precipitated. It could also suggest the bedrock source of the deposits. More complete, and quantitative, characterization of the mineralogic compositions of the evaporitic materials is essential to further understanding of these occurrences.

The Yukon Flats trona occurrences are not by themselves presently of economic significance. It is estimated that the large trona reserves of Wyoming are sufficient to supply the U. S. with over 3,800 years supply of soda ash at the 1974 demand level. The Wyoming deposits are comprised of at least 11 beds which exceed 1.8 m. (6 ft.) in thickness and cover an area of about 3,100 sq. km. (1,200 sq. mi.)(14).

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APPENDIX

ANALYTICAL PROCEDURES

ANALYTICAL PROCEDURES

The unambiguous identification of the crystalline constituents of the complex assemblages of mineral phases encountered in the present study, frequently involving various hydration states within otherwise chemically similar materials, compounded by very fine grain sizes, is quite an involved task, fraught with uncertainties and complications. In order to facilitate analyses useful within the present context, budgetary limitations, and time constraints, the following scheme was devised and adopted. It should be appreciated that the results obtained represent, essentially, a status report regarding the nature of the materials examined, presented in a somewhat simplified format. Considerably more work would be involved in delving more deeply into these assemblages, endeavoring to characterize the mineralogy more completely. Such further work is quite feasible (although fairly involved), and could be done in part from the data which has now been acquired, but the foregoing considerations precluded this for the purpose of the present report.

Unless otherwise noted, the analytical work was performed at the AFOC Facility in Juneau, Alaska. The approach adopted is as follows:

I. Sample preparation

Samples as received were air-dried, and reduced to less than 100 mesh pulps by grinding in ceramic mills. Thus, there is some potential problem introduced here by heating of the samples during grinding, with attendant recrystallization/dehydration of various phases. It was felt that this was a necessary compromise, in terms of the number of samples to be analyzed, the time and budget constraints, and the fact that the study was focused principally on recognizing the presence of trona, which mineral seemed not to be recognizably affected by these grinding procedures, based on results of control analyses of known trona-bearing material.

II. X-ray diffraction mineralogic analysis -

Portions of each sample pulp were ground further by hand in a ceramic mortar and pestle, loaded into standard deep-well sample holders, as random powder amounts, and subjected to x-ray diffraction analysis. The x-ray instrumentation used is a Philips XRG 3100 diffractometer, with crystal-monochromator, nickel-filtered copper K-alpha radiation, continuously-scanned by wide-range goniometer over the relevant two-theta region. The resultant x-ray diffraction traces were examined manually, by one investigator, who made all determinations regarding mineralogy.

Due to the complexity of these diffraction patterns, representing mineral assemblages consisting of numerous phases within each sample, with attendant uncertainties with regard to resolving overlapping/convoluted diffraction maxima, unambiguous characterization of discrete minerals was often not possible directly. In order to improve matters, attempts were made to effect separations of various sub-portions of selected samples, by magnetic separation, as well as by leaching in boiling distilled water. In some instances these efforts were indeed helpful, particularly the aqueous extraction technique, but the time and effort involved, both in performing the extractions, and in the additional repetitive steps required to dry the insoluble residue, prepare new random powder x-ray diffraction mounts, perform the x-ray diffraction analyses, and interpret the resultant additional diffraction data made this approach impracticable, in the context of the present study. Hence, the quantitative x-ray diffraction mineralogic work, ultimately, was restricted to determining the detectable presence

or absence of trona in each untreated sample. Quantitative mixtures of pure trona and alpha quartz were prepared, in various proportions, and used to ascertain a working curve of trona concentration as a function of intensities of selected diffraction maxima characteristic of trona, as well as to establish the lower limit of detectability of the mineral trona, by the x-ray diffraction methods employed. Admittedly this represents a "best case" situation, with standard mixes of only two phases, quartz and trona, as opposed to additional complicating matrix effects and convolution problems which exist in the more complex analysis sample assemblages. However, this technique should at least afford a means to approximately define the present usage of the term "detectable" trona, in the analysis samples. On the basis of our experimental work, as little as 6.4 percent trona, by weight, physically mixed with alpha quartz, was readily detectable at an acceptable level ($\pm$ 10 percent) of reproducibility. In terms of the analysis samples, the complexities mentioned above probably can be interpreted conservatively to indicate that a minimum of perhaps twice this limit, ie. at least 12.8 percent trona, by weight, should be readily detectable in these more complex assemblages. Thus, those samples in which trona has been recognized in the present study contain, as a minimum at least 12.8 percent (more likely as little as 6.4 percent) trona by weight. Semi-quantitative estimates were made of samples which contained detectable trona, and are given in Table 3 as "major (+25 %), minor, ND(-12.8 to 6.4%)", as evaluated by the relative sizes of selected diffraction maxima characteristic of trona, assisted by comparison with maxima for other crystalline phases (quartz,

feldspar, etc.) present in predominant amounts, in each sample. More rigorous quantification is possible, but was not done, due to the limitations of the study. Additionally, the x-ray diffraction data were examined, quantitatively, in order to determine the presence or absence of certain other minerals. These were selected primarily on the basis of their anticipated relevance to furthering the understanding of these occurrences, as well as on the basis of analytical feasibility in terms of time and budget constraints. These minerals were gypsum, dawsonite, aragonite, calcite, dolomite, searlesite, and halite. No attempt was made at quantification of the amounts of these minerals, for present purposes. The detection of any of these, thus, merely indicates its presence in excess of perhaps five to ten percent, by weight, of the original bulk sample. In the few cases where one of these minerals was obviously a dominant constituent in a given sample, it was reported as being present in "major" amounts. In cases where detection was indicated but not definitive, a questionable presence ("?") was assigned. These data are presented in Table 3.

III. X-ray emission (fluorescence) spectrometric analysis -

In order to attempt to obtain additional information regarding the nature of the saline evaporite-type minerals present in the analysis samples, a portion of each sample was subjected to a boiling distilled water extraction procedure. Many if not most of the minerals of potential interest are soluble to degrees sufficient to thus betray their presence. A portion of each sample pulp material was treated with boiling distilled water, the resultant aqueous phase was put through filter paper, evaporated to dryness,

and analyzed for selected chemical elements by a Kevex 0700 x-ray spectrometer system. Elements analyzed for were selected as representative of and typically associated with saline/evaporite geologic environments, subject to the further restrictions imposed by the capabilities of the spectrometer system. Elements of atomic weight less than sodium are not determinable by this system. Sodium, magnesium, phosphorus, sulfur, chlorine, bromine, potassium, and calcium where chosen as being both feasible analytically, as well as potentially informative for the purposes of this study. The presence, and the proportions of these elements in the boiling water extractable portion of an original analysis sample is potentially useful information. Combined with x-ray diffraction mineralogic study of the analysis samples before and after such leaching, in some cases this chemical information permitted more definitive characterization of water-extractable phases originally present in the geologic sample. However, due to time and budget constraints, only a few selected samples were analyzed with this degree of thoroughness. The insoluble material residual from all of these extractions has been preserved, and could be analyzed further, should this be desired, at some later date. The chemical analyses are, at best, semi-quantitative, but certainly are definitive of the presence or absence of the elements sought, as well as providing an estimate of their proportions, relative to one another, in the soluble extracts. No attempts were made to evaluate rigorously the overall analytical precision, accuracy, or detection limits, for the limited purposes of the present work. The precision inherent to the x-ray analytical system is at least $\pm$ 10 percent of the amount present for a given

element. Accuracies are not likely to depart by more than ± 25 percent from the "true" value, and inherent detection limits for the elements analyzed range from approximately 2-5 percent for sodium (worst case) to below 1 percent for potassium and calcium.

In every sample thus treated, sodium was the dominant element detected in the water-soluble extract, with, at most, minor, to trace amounts of magnesium, calcium, potassium, phosphorous, sulfur, chlorine, bromine. Hence, apparently there were no original samples examined which contained more than minor to trace amounts of these latter elements in phases readily soluble in boiling distilled water. The sodium may be available for such extraction in various phases in the original sample, including carbon, boron, nitrogen, fluorine, etc. - bearing compounds, but major proportions of sulfur, phosphorus, chlorine or bromine - rich phases are not present. Extractable sodium might also be derived from other phases, including occurrences as absorbed and/or interlayer ions associated with clay minerals, as well as from other sources, such as zeolites, feldspars, and amorphous material.

IV. Other analyses -

A. The elemental analyses presented in Table 2 were performed by the Los Alamos Scientific Laboratory, Los Alamos, New Mexico, under a joint U. S. Bureau of Mines/Dept. of Energy arrangement. The Los Alamos Scientific Laboratory analyzed for beryllium and lithium by emission spectrography, and for silver, bismuth, cadmium, copper, niobium, nickel, lead, tin, tungsten, arsenic, selenium and zirconium by x-ray fluorescence. The elements aluminum, barium,

calcium, chlorine, dysprosium, potassium, magnesium, manganese, sodium, strontium, titanium, and vanadium were analyzed using neutron activation with a short time delay before analysis; and for gold, cerium, cobalt, chromium, cesium, europium, iron, hafnium, lanthanum, lutetium, rubidium, antimony, scandium, samarium, tantalum, terbium, thorium, ytterbium, and zinc by using neutron activation with a long time delay before analysis.

B. Boron, fluorine and sodium analyses were performed by TSL Laboratories, Ltd., Opportunity, Washington. The results are presented in Table 4. Boron was determined by a technique utilizing acid extraction followed by Inductively Coupled Argon Plasma (ICAP) spectrograph analysis. Fluorine analyses were done via a KOH fusion procedure, followed by specific ion electrode analysis and sodium values were determined with standard atomic absorption techniques.

C. Semi-quantitative optical emission spectrometric analysis for eleven selected elements was carried out by TSL Laboratories, Ltd. Results are tabulated in Table 5.