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BRINES OF WADI AS SIRHAN

KINGDOM OF SAUDI ARABIA

by

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ABSTRACT

Evaporation of water in the playas of Wadi as Sirhan causes the precipitation of calcite, gypsum, and some halite. Salt is produced on a small scale from brine near the villages of Ithrah and Kaf, but no significant quantities of bedded salt were located in the study area. Some near-surface brines, including those at Hazawza and near Ithrah and Kaf, have relatively high potassium concentrations. Drilling at Hazawza, the largest playa in Wadi as Sirhan, indicates that the near-surface brine probably does not extend below 50 m and is underlain by relatively fresh artesian water. Salt and brine may exist below 319 m, the maximum depth of drilling at Hazawza, but the available data do not indicate that they do.

INTRODUCTION

The study area is within the Wadi as Sirhan depression in northernmost Saudi Arabia between lats 30°30' and 31°30'N. and longs 37°00' and 38°30'E. (fig. 1). Within Saudi Arabia, Wadi as Sirhan extends from the Jordan border southward to the An Nafud desert and contains several undrained depressions where playa sedimentary deposits and associated brines have formed.

Solar evaporation forms two types of deposits that have economic potential: bedded salt and brine. Both bedded salt and brine deposits are the product of the chemical evolution of dilute aqueous solutions. The chemistry of the solutions is

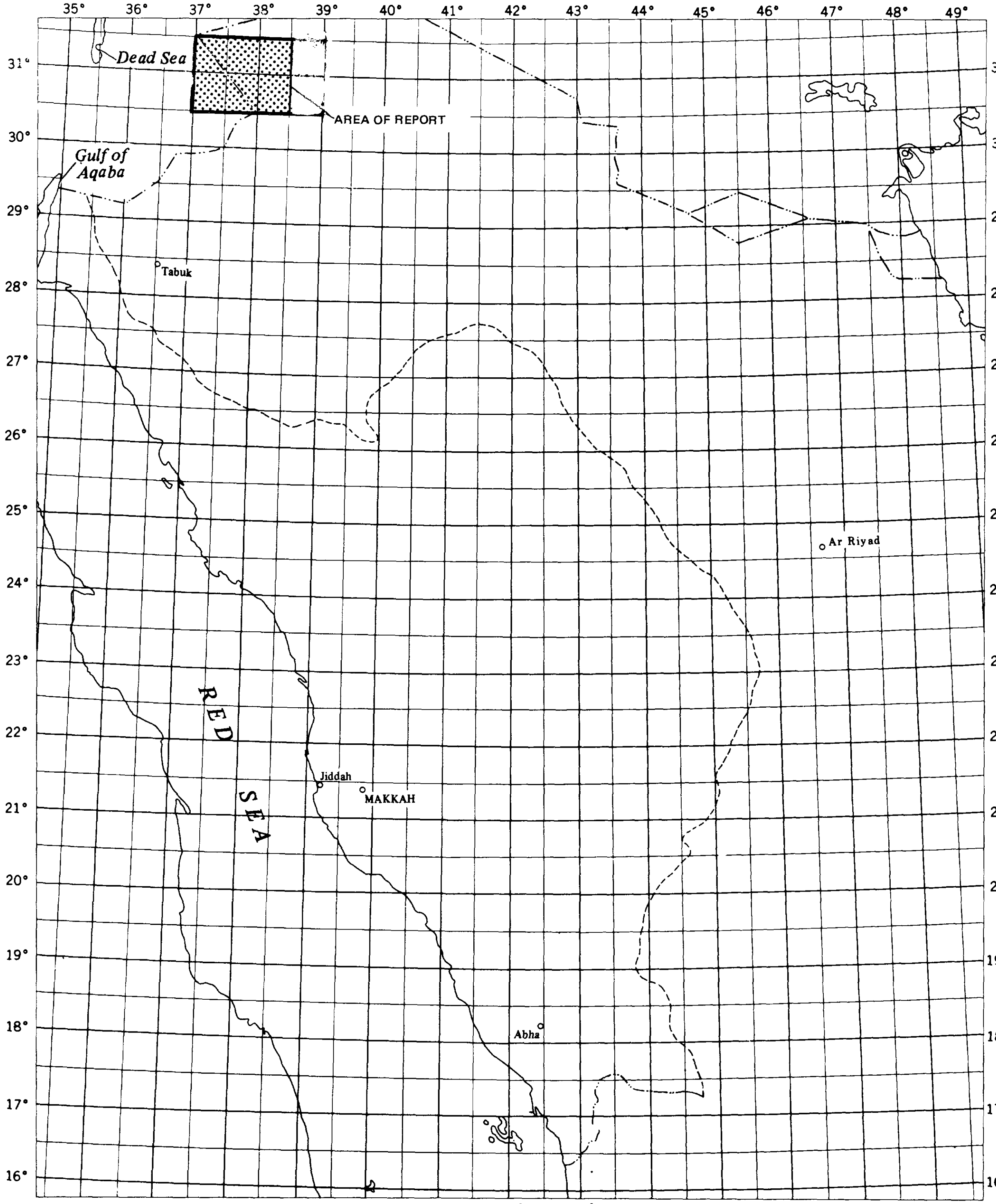

Figure 1. Index map of western Saudi Arabia showing area of report.

determined by the original composition of the rainwater and by the types of ions leached from the rocks with which the water was in contact. Brine and evaporite deposits can form in continental, marine, or coastal environments. Outside Saudi Arabia many materials used in the chemical and agricultural industries are being produced from both continental and marine evaporite deposits. Potassium, an element of particular importance in the production of fertilizer, has been produced since 1932 from brines of the Dead Sea, which is less than 200 km from the area of this report.

The author thanks M. E. Gettings and D. J. Faulkender for the timely completion of a gravity survey in the Hazawza area. This project could not have been completed without the chemical analyses of the waters by A. Barraja and the support of the field crews. The assistance of F.E. Elsass for mineral analyses is gratefully acknowledged.

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GENERAL GEOLOGY

The Sirhan-Turayf basin (Powers and others, 1966) in the northwest corner of Saudi Arabia developed either as a sag in a structurally flat area or as a result of the growth of the Hail arch to the east. The southwest flank of the Sirhan-Turayf basin may be a half graben controlling the present course of Wadi as Sirhan, a broad elongate trough. Faults whose strikes are northwest to west are common in the study area.

Rocks that crop out in the Wadi as Sirhan depression range in age from Eocene to Quaternary (Bramkamp and others, 1963). The Hibr Formation (Mytton, 1967; Meissner and Ankary, 1972), of Eocene age has been divided into three units and contains chert, marl, limestone, and marly gypsiferous limestone. Sandstone, marl, and limestone of Miocene and Pliocene age overlie the Hibr Formation and are interbedded with Tertiary basalt flows in some areas. Some of the Tertiary beds formed in an arid saline envirnoment and incorporate saline materials. Such an environment is indicated by secondary gypsum in some of the regolith covering Tertiary rocks and by the occurrence approximately 6 km south of Ayn al Bayda of an efflorescent crust, dominantly of halite, associated with an outcrop of Tertiary marl. Wadi as Sirhan is bounded on the northeast by Tertiary and Quaternary basalts, which are the southern end of an extensive basalt field in the Syrian desert. Small areas of windblown sand and extensive areas of desert pavement are common. An immature Quaternary calcrete (Goudie, 1973) has developed in much of the area. In many undrained depressions playa deposits of gypsum, calcareous clay, and silt have formed.

Hazawza, the largest playa in the Wadi as Sirhan depression, has a surface area of about 40 km^2 and is bordered on the north and east by Tertiary and Quaternary basalt flows. The long axis of the playa surface is from northwest to southeast. A gravity low generally coincides with the playa surface but is offset to the northeast. The gravity low is interpreted as being due to an older trough or basin below the present surface of Hazawza (Gettings, 1979). Meissner and Ankary (1972) indicate the Wadi as Sirhan depression possibly connects with the Dead Sea rift belt of Jordan, where thick evaporite deposits are known to exist.

ANALYTICAL METHODS

Water samples were collected from pits, wells, springs, flowing surface water, and holes dug to groundwater. Sample localities are shown in figure 2. The samples were collected in 1 liter polyethylene bottles that had been cleaned with distilled water and dried. The bottles were rinsed with sample prior to filling and sealed after filling. The water samples were filtered in the field as soon as possible after collection through a 0.1 micrometer Nuclepore filter in a Millipore Hi-Flux cell using pressure filtration. After filtration the bottle was rinsed with a portion of the filtered sample, and the remaining filtered sample was placed in the original bottle. The pH was measured *in situ* and in the laboratory. Alkalinity, as defined by Stumm and Morgan (1970), was measured by titration with H_2SO_4 in the laboratory. Calcium, magnesium, sodium, and potassium concentrations were determined by atomic absorption techniques using a Perkin-Elmer model 460 atomic absorption spectrophotometer. Chloride and fluoride concentrations were measured with Orion electrodes. Concentrations of silica (molybdate blue method) and sulfate (turbidimetrically) (Tabatabai, 1974), were determined by means of a Model 54B Coleman spectrophotometer. Dilute conductivity was measured with a MCL Mark IV conductivity meter. The charge balance and agreement between measured and calculated specific conductance (Rossum, 1949) are within ±5 percent. The results of the analyses are presented in table 1.

PLAYAS

Several terms have been used to describe areas on the earth's surface where evaporites and brines form by solar evaporation. The term sabkhah is often used in Saudi Arabia to describe salt flats regardless of their location. Based on his field work on the Trucial Coast, Kinsman (1969) redefined the term sabkhah (sabkha) and defined coastal sabkhahs and continental sabkhahs. On the Trucial Coast, where Kinsman did much of his work on sabkhahs, he found the coastal sabkhahs often grade laterally into continental sabkhahs "without noticeable morphologic discontinuity" (p. 833). Those areas to which Kinsman refers as continental sabkhahs generally occur within a belt 100 km or less from the coast. Salt flats in the interior of Saudi Arabia that do not have associated marine sediments of Holocene age are

Table 1.--*Chemical analyses of water samples from Wadi as Sirhan*
[Results in milliequivalents per liter except for SiO_2, which is in milligrams per liter]

SAMPLE NUMBER	LATITUDE	LONGITUDE	Ca	Mg	Na	K	Cl	SO_4	HCO_3	SiO_2	SAMPLE DESCRIPTION
120020	30°54'47"	38°00'00"	19.01	40.31	1391.00	89.25	1537.00	54.13	1.31	18.10	Dug hole
120021	30°51'47"	38°00'00"	20.06	32.91	1000.00	51.15	1128.00	52.05	1.61	33.70	Dug hole
120022	30°51'57"	38°04'02"	37.92	90.49	2391.00	153.20	2680.00	84.95	1.47	47.10	Brine pool
120023	30°51'58"	38°04'02"	115.30	122.60	2696.00	189.00	3103.00	112.40	1.37	36.70	Brine pool
120024	30°51'59"	38°04'02"	120.80	95.43	2348.00	166.20	2821.00	118.70	2.31	21.40	Dug hole
120026	30°43'31"	38°12'32"	371.30	485.40	3304.00	268.50	4654.00	22.49	1.01	16.50	Dug hole
120027	30°47'07"	38°07'45"	124.30	231.20	2609.00	215.30	3385.00	16.03	1.68	24.20	Dug hole
120028	30°52'36"	38°09'35"	35.43	91.31	1130.00	65.73	1312.00	44.35	1.62	33.30	Dug hole
120029	31°18'28"	37°31'48"	30.94	69.92	695.70	44.50	874.40	94.94	5.62	18.70	Intermittent stream
120030	31°23'27"	37°29'12"	27.45	460.70	4044.00	260.90	5077.00	297.70	0.58	1.60	Dug hole
120031	31°23'27"	37°29'12"	94.81	279.70	3652.00	250.60	4513.00	185.30	0.66	3.70	Dug hole
120032	31°09'57"	37°39'52"	5.89	10.20	36.09	2.22	52.18	10.83	8.58	59.40	Spring
120034	31°23'19"	37°37'09"	89.32	773.30	1957.00	135.50	3103.00	197.80	7.54	7.00	Dug hole
120035	31°23'19"	37°37'09"	20.96	1316.00	3957.00	409.20	5867.00	418.50	6.16	10.60	Salt production pond
120036	31°23'19"	37°37'09"	18.46	2978.00	2609.00	588.20	6318.00	485.10	19.77	8.80	Salt production pond
120100	31°09'59"	37°40'01"	4.15	3.07	11.00	0.79	13.75	3.29	2.82	16.80	Spring
120101	31°23'28"	37°37'13"	86.00	167.20	1013.00	56.52	1275.00	117.10	1.50	35.40	Dug hole
120104	30°45'15"	38°19'28"	10.95	2.56	16.09	1.71	18.62	1.50	12.83	40.80	Spring
120221	31°23'27"	37°29'12"	57.00	450.80	3609.00	273.70	3833.00	225.00	1.08	1.90	Dug hole
120222	31°23'27"	37°29'12"	4.50	4.18	27.83	2.17	27.50	2.13	8.51	27.00	Spring
120223	31°23'27"	37°29'12"	54.00	75.41	339.10	18.16	400.00	56.46	9.36	33.20	Dug hole
120224	31°23'27"	37°29'12"	160.00	450.80	3870.00	161.30	4500.00	54.17	3.36	3.00	Dug hole
120225	31°21'57"	37°36'04"	4.50	2.70	18.70	1.56	19.18	1.38	9.26	24.40	Spring
120226	31°23'19"	37°37'09"	30.85	1287.00	5000.00	462.90	6000.00	256.30	9.96	45.60	Salt production pond
120227	31°23'27"	37"29'31"	187.50	803.10	1291.00	33.25	2167.00	100.00	3.32	8.00	Sump

best described by the well-established term *playa*. Playa is a Spanish term referring to "that shallow central basin of a desert plain, in which water gathers after a rain and is evaporated" (Fay, 1920). The salt flats of Wadi as Sirhan should probably be referred to as playas rather than as sabkhahs.

In the Wadi as Sirhan area basalt flows interrupted the drainage system and formed playas. X-ray analysis indicates the playa sediments are dominantly composed of gypsum, quartz, and calcite (table 2). An efflorescent crust, with halite as its major constituent, covers much of the surface of some playas. The clay minerals are kaolinite, illite, smectite, chlorite, and a mixed-layer clay of randomly stacked chlorite and smectite sheets (table 2). Attapulgite may also be present in some samples. Anhydrite ($CaSO_4$) was found in playa sediments near the groundwater table near Ithera in the summer of 1977 but was not found in the same area that winter. As temperature and evaporation rates decreased the anhydrite probably converted back to gypsum ($CaSO_4$-$2H_2O$). The conditions necessary for this conversion are discussed by Butler (1969).

Currently the only economic production of salt from the Wadi as Sirhan area is in the playas near Kaf and Ithrah. Salt is produced on a small scale by digging shallow pits in the playa surface and periodically flooding them with brine from deeper holes in which groundwater collects. Although halite has precipitated in small natural brine pools on the surface of Hazawza, no salt is currently being harvested.

Table 2.--*Relative abundance of minerals in playa sediments, Wadi as Sirhan, as determined by X-ray diffraction*

Relative abundance of the clay minerals
was determined after they were separated from the playa sediments
(X) rare   XX abundant
X present   XXX very abundant
- not detected

SAMPLE NUMBER	LATITUDE	LONGITUDE	DEPTH (CM)	GYPSUM	HALITE	QUARTZ	CALCITE	CLAY	CLAY MINERALS					
									KAOLINITE	ILLITE	CHLORITE	SMECTITE	CHLORITE-SMECTITE	ATTAPULGITE(?)
120032	31°23'27"	37°29'12"	1	X	XXX	X	X	X	X	X	-	-	X	X
120034	"	"	5	X	XX	XX	X	X	X	XX	-	-	X	X
120031	"	"	30	XX	X	X	X	(X)	X	X	-	-	X	(X)
120228	"	"	100	-	X	(X)	XXX	X	X	X	X	X	-	-
120213	31°23' 19"	37°37'09"	30	XX	-	X	(X)	(X)	X	X	-	X	-	-
120212	"	"	50	XXX	-	(X)	-	(X)	X	XX	-	XXX	-	-
120211	"	"	70	XXX	(X)	(X)	(X)	(X)	X	XX	-	XXX	-	-
120229	30°47'07"	38°07'45"	20	XX	-	X	X	X	X	X	X	X	-	-
120230	31°23'36"	37°37'03"	90	XX	X	XX	(X)	(X)	X	X	-	-	-	(X)

WATER CHEMISTRY

The chemical composition of groundwater indicates the types of minerals from which it has derived its solute load. Two common ways for the solute load of water to be increased are solar evaporation and dissolution of solid phases. The solid phases can be primary minerals that formed at high temperatures, such as many of the silicates, or they can be secondary minerals, such as halite, calcite, or gypsum, which may form in the soil at ambient surface temperatures. Minerals weather at different rates in a sequence mainly determined by their solubility. In many instances, the greatest effect on groundwater chemical composition is produced by dissolution of the more soluble minerals. Therefore the chemical composition of groundwater may indicate when rainwater has been in contact with soluble minerals such as gypsum or halite.

In marine water, the logarithm (base 10) of the ratio of sodium ion concentration to chloride ion concentration on a molar basis is about -.07. When interstitial marine water is evaporated the primary chloride formed is halite, which releases sodium and chloride in equal molar amounts when it is redissolved. In most of the Wadi as Sirhan waters the logarithm of the sodium to chloride ratio is between 0 and -.1 (fig. 3) and indicates sodium and chloride might be derived from marine chlorides. Because chloride is one of the most soluble major elements in water, its concentration is used as the x-axis in several of the figures to indicate the range in the solute load of the water samples.

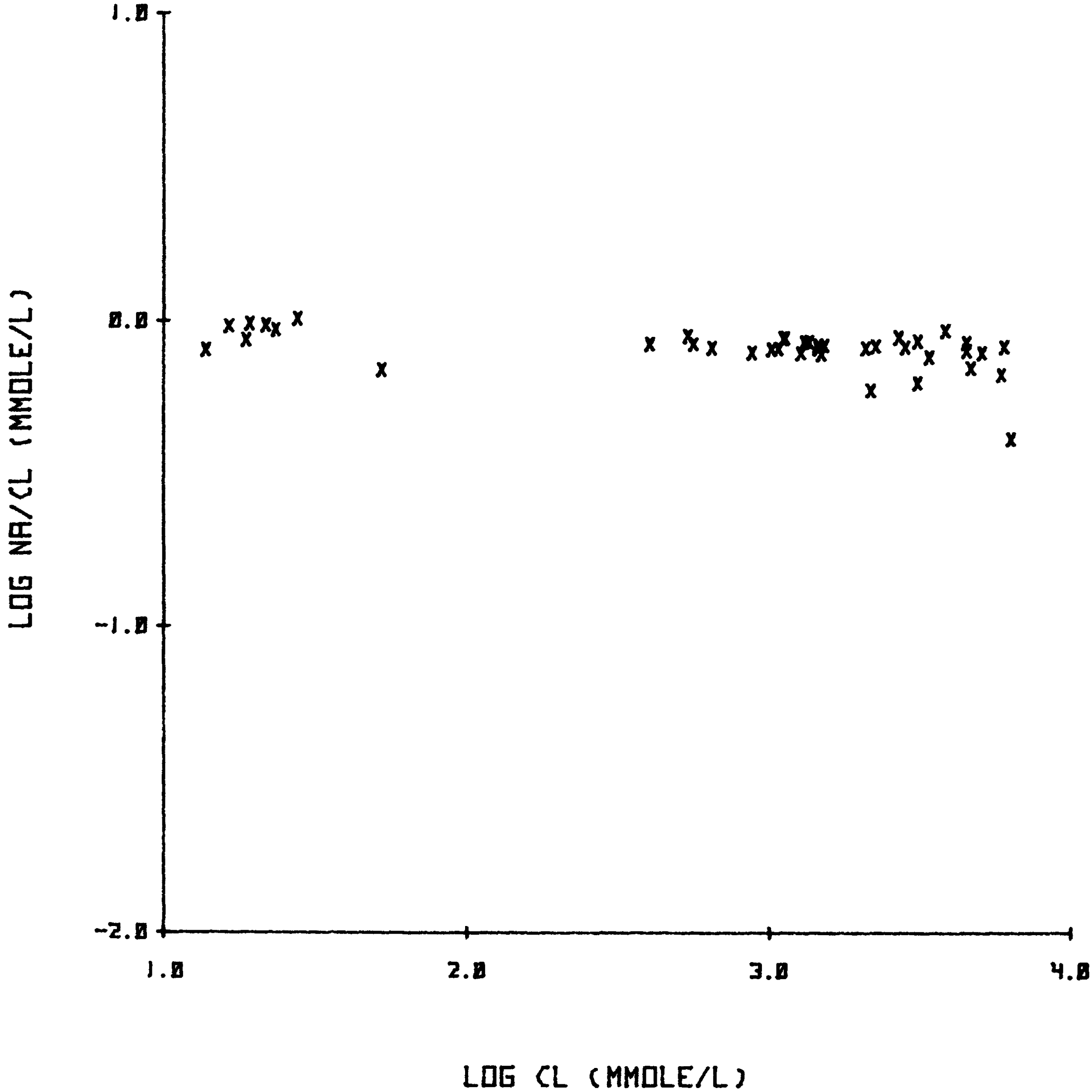

Figure 3. Sodium-chloride ratio and chloride content of water samples from Wadi as Sirhan.

The activities of the ions and the degree to which the sample was saturated with respect to certain solid phases were calculated by use of the computer program WATEQF (Plummer and others, 1976). Calculations indicated that most of the samples were saturated or supersaturated with calcite and only a few of the more concentrated samples were undersaturated with calcite (fig. 4). In highly saline brines the liquid junction potential probably differs significantly from that associated with the dilute pH standards used to calibrate the pH meter. This difference probably affected the measurement of sample pH in the highly saline samples and subsequently affected the calculation of calcite saturation. Only the playa waters containing considerable dissolved salts were saturated or supersaturated with gypsum (fig. 5). Although gypsum is common in the regolith covering the sedimentary rocks of the area, the spring waters are undersaturated with gypsum.

The chemical characteristics of water determine the type of salt deposit that will probably form if the water is sufficiently evaporated (Hardy and Eugster, 1970). In Wadi as Sirhan, trona and other highly soluble salts containing carbonate are not likely to form because most of the carbonate ions are progressively precipitated as calcite or possibly protodolomite. Because the calcium ion concentration, on a molar basis, nearly balances the sum of the bicarbonate-plus-sulfate ions, large quantities of sulfate-rich salts other than gypsum are unlikely to form. Halite is one of the few highly soluble salts that might precipitate in sufficient quantity to form beds. The formation of the potassium-containing salts carnallite and sylvite is also a possibility.

In some locations, such as Searles Lake, California, Clayton Valley, Nevada, and the Dead Sea, brines are directly exploited for elements such as potassium and lithium. The amount of a potentially economic element in a brine partly determines if the brine can be exploited. Several of the water samples from freshly dug holes in the playas have potassium concentrations as high as those in the Dead Sea (fig. 6) where potassium has been commercially produced since 1932. The high potassium concentration in the Dead Sea probably results from the evaporation of inflowing waters to the extent that halite is precipitated (Bentor, 1961). In Wadi as Sirhan, a small amount of potassium is removed from solution (fig. 7), possibly by sorption on clay minerals, as the waters become more saline by evaporation and/or by dissolution of previously precipitated salts. The potassium-to-sodium ratio increases as the waters are further evaporated and sodium is removed from solution by precipitation of halite (fig. 7). Except for two or three samples from the brine pits at Ithrah, where halite is being produced, the water samples from Wadi as Sirhan have not been enriched in potassium relative to sodium to the same degree as the brines of the Dead Sea. The lower sodium-to-potassium ratio indicates that halite is unlikely to exist near the surface in any of the areas sampled in Wadi as Sirhan.

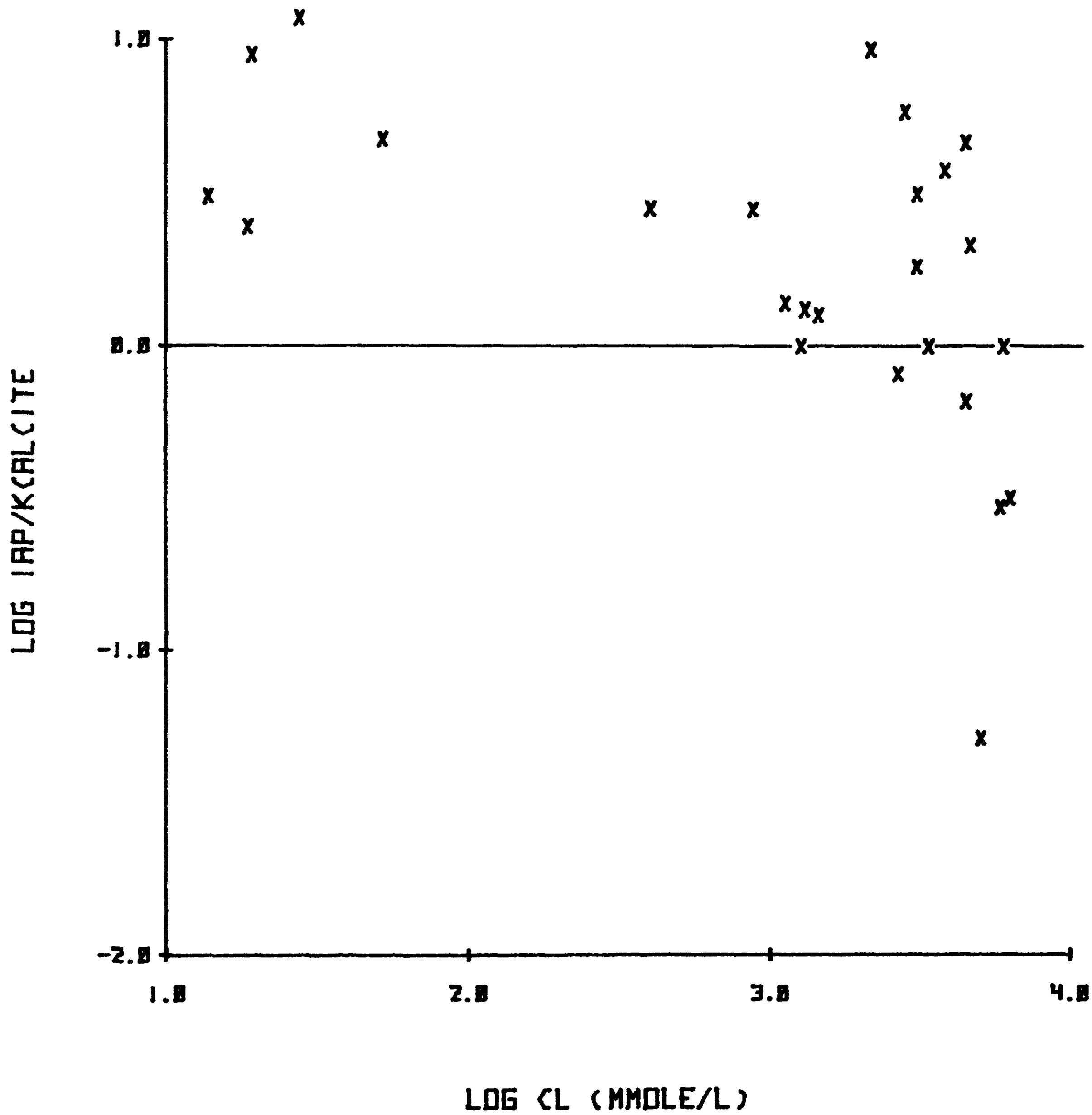

Figure 4. State of saturation of calcite in water samples from Wadi as Sirhan. Samples with a log IAP/Kcalcite equal to or greater than zero are saturated or supersaturated with calcite; IAP is the ion activity product and Kcalcite is the equilibrium constant of the reaction: $Ca^{++} + HCO_3^- = CaCO_3 + H^+$.

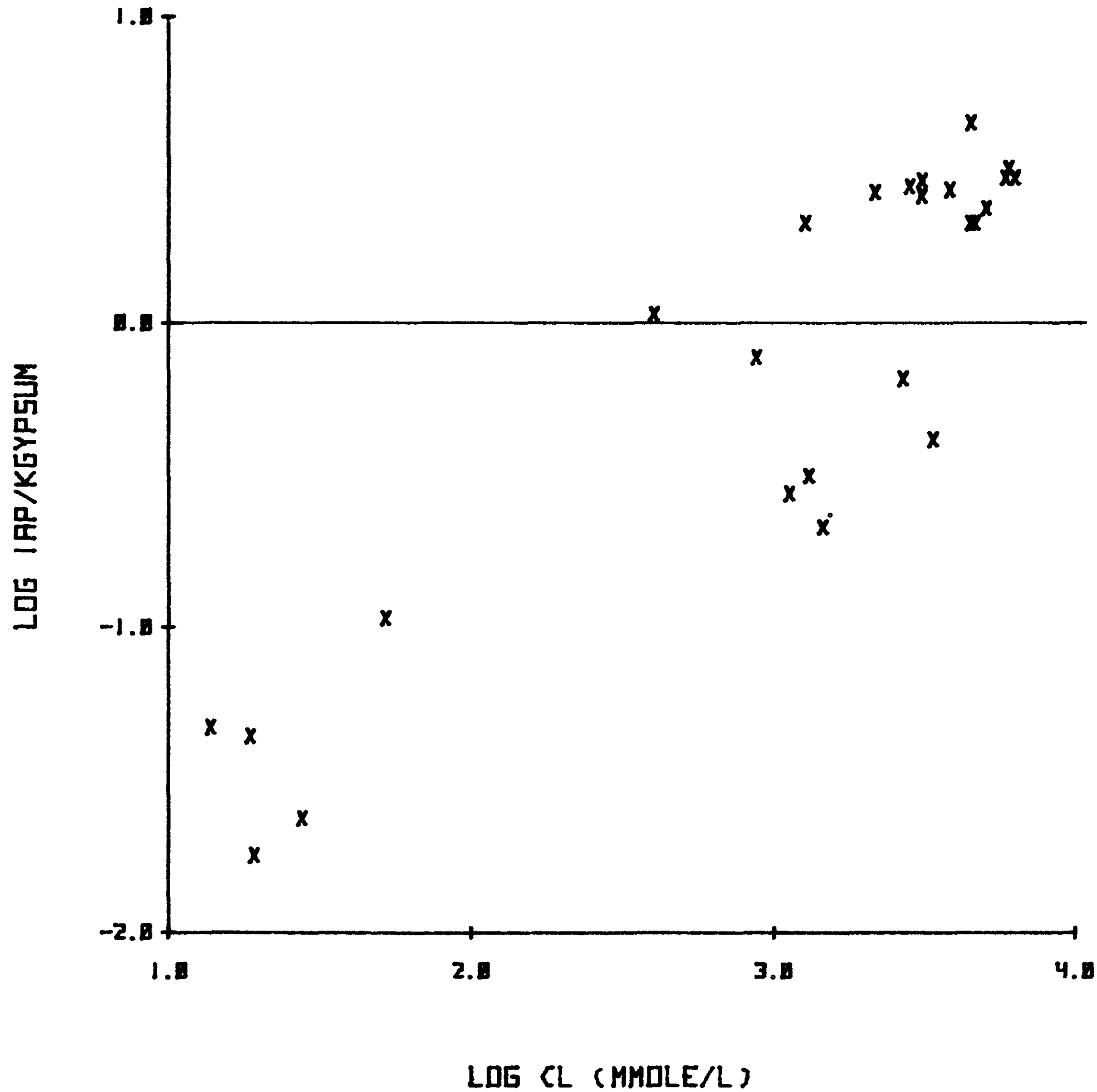

Figure 5. State of saturation of gypsum in water samples from Wadi as Sirhan. Samples with a log IAP/KGypsum equal to or greater than zero are saturated or supersaturated with gypsum; IAP is the ion activity product and KGypsum is the equilibrium constant of the reaction: $Ca^{++} + SO_4^{=} + 2H_2O = CaSO_4 \cdot 2H_2O$.

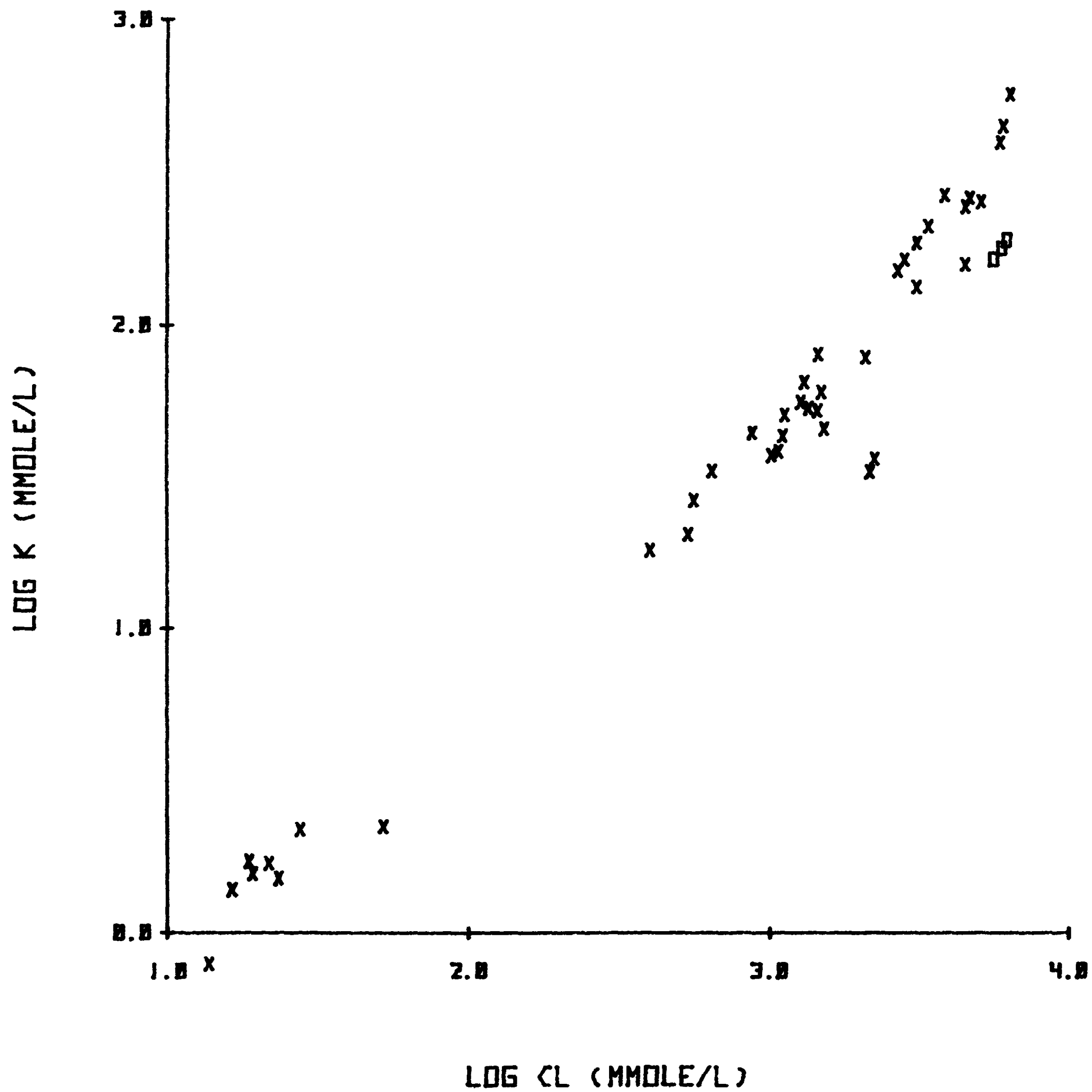

Figure 6. Potassium and chloride content of water samples from Wadi as Sirhan and the Dead Sea. The symbol x is used to represent water samples from Wadi as Sirhan. The symbol o is used to represent water samples from the Dead Sea (Bentor, 1961).

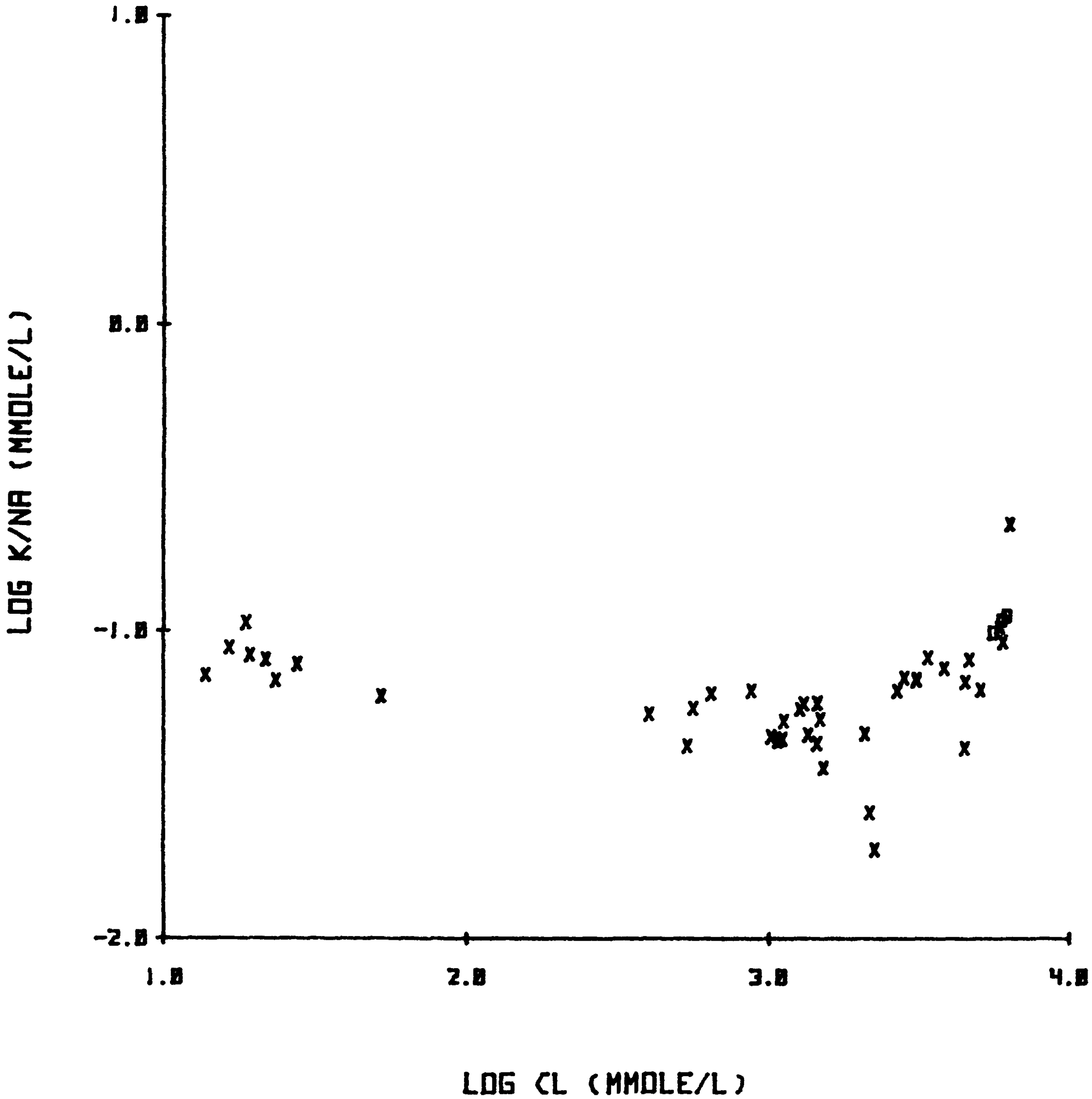

Figure 7. Potassium–sodium ratio and chloride content of water samples from Wadi as Sirhan and the Dead Sea. The symbol x is used to represent water samples from Wadi as Sirhan. The symbol o is used to represent water samples from the Dead Sea (Bentor, 1961).

DRILLING

Preliminary investigations showed that the Hazawza playa was an attractive target for further exploration. Hazawza has more than twice the surface area of the next largest playa in Wadi as Sirhan and in some of the near-surface brine samples the potassium concentration is higher than that found in the brine of the Dead Sea. The gravity data (Gettings, 1979) suggest a pre-existing trough or basin below the present surface of Hazawza, which might contain dense brine.

Because much of the playa surface would not support drilling equipment, three holes were drilled within the northeastern edge of the basalt field. Although the holes were within the gravity low, they were offset to the northeast from the absolute gravity minimum. The drilling of the hole HZ23 was terminated because the target depth of 200 m was exceeded. Holes HZ22 and HZ25 did not reach their target depth because it was not possible to complete the holes through a layer of unconsolidated sand and associated artesian flow.

The results of the drilling show that playa sediments are interbedded with basalt flows to depths as great as 30 m. Below this depth a series of basalt flows can be distinguished by changes in the vesicularity of the basalt and, locally, by thin carbonate beds or soil zones. The basalt flows continue to a depth of about 100 m in holes HZ22 and HZ25 and to a depth of 150 m in hole HZ23. In the transition zone between the basalt flows and the underlying sedimentary sequence, the basalts are more weathered and are interbedded with carbonate. Below the interbedded basalt and carbonate is a sedimentary sequence that is dominantly calcareous sandstone and unconsolidated sand but that also contains limestone, dolomite, and some silty clay. The lithologies penetrated by the holes are given in more detail in the appendix. J. E. Elliott submitted a sample of limestone from hole HZ22 to the United States Geological Survey in Denver, Colorado. The sample was barren of pollen, spores, dinoflagellates, foraminifers, coccoliths, diatoms, ostracods, and charophytes so that no age or environmental interpretation could be made on the basis of fossils. The similarity of lithology to that mapped by Bramkamp and others (1963), however, indicates a late Tertiary age.

The procedure for collecting water samples from the drill holes was to drill the hole to the desired depth, drive casing to just above the bottom of the hole, and then clean the hole of contaminating water by bailing, air lift, or natural artesian flow. Groundwater within 50 m of the surface had higher concentrations of some ions (table 3) than did water below 50 m. In two of the drill holes, HZ22 and HZ25, an artesian flow, as much as 12000 liters per hour, occurred in or near the base of the interbedded basalt and carbonate sequence (114 to 136 m). The deeper artesian water is much less saline than the near-surface groundwater of the playa. The existence of relatively fresh water below 150 m indicates that brines formed near playa surface are unlikely

Table 3.--*Chemical analyses of water samples from holes drilled in Hazawza playa, Wadi as Sirhan*
[Results in milliequivalents per liter except for SiO_2, which is in milligrams per liter]

SAMPLE NUMBER	HOLE NUMBER	DEPTH (METERS)	Ca	Mg	Na	K	Cl	SO_4	HCO_3	SiO_2
120800	HZ23	9	79.50	150.00	1174.00	60.87	1489.00	40.42	2.08	26.40
120801	HZ23	47	42.00	79.51	1170.00	53.96	1354.00	23.52	3.22	26.00
120802	HZ23	130	30.50	57.39	982.61	43.73	1110.00	21.46	2.82	8.80
120803	HZ23	163	44.00	76.23	1226.00	52.94	1450.00	23.75	3.15	6.80
120804	HZ22	32	89.00	121.30	1883.00	36.70	2251.00	24.79	0.30	34.80
120805	HZ22	67	59.00	109.00	1722.00	80.05	2088.00	29.17	2.52	32.80
120806	HZ22	85	37.00	53.28	878.30	38.62	1072.00	14.79	3.02	24.60
120807	HZ22	134	25.00	28.69	482.60	20.46	536.00	8.15	9.56	21.60
120808	HZ22	144	38.00	49.18	830.40	37.60	1016.00	13.54	7.95	35.20
120809	HZ22	150	5.90	2.07	15.65	1.38	16.40	1.73	8.96	30.60
120810	HZ25	61	34.00	61.48	473.90	26.60	558.50	9.38	3.84	31.20
120811	HZ23	200	49.50	83.61	1283.00	46.04	1523.00	24.17	2.62	5.80
120812	HZ25	75	47.00	82.79	530.40	33.25	643.20	9.38	3.22	11.00
120813	HZ25	114	7.95	4.18	20.87	1.69	21.66	1.56	11.88	52.20
120814	HZ25	124	8.55	2.62	21.74	1.50	23.33	1.53	11.47	48.00

to be trapped at greater depths. Salt deposits could exist in the center of the gravity low below the depth of drilling, but their presence was not indicated by the overlying sediment or water chemistry.

At Hazawza high concentrations of potassium are restricted to the near-surface brine and none of the water recovered from the holes had potassium concentrations as high as those in the brines exploited in the Dead Sea. The relatively low potassium concentrations in the subsurface water coupled with the expense of drilling for recoverable brines makes it unlikely that the Hazawza brine can be economically produced.

CONCLUSIONS

The playa brine samples did not evolve through precipitation of large amounts of halite, and thick halite beds are unlikely to occur near the surface in the sampled areas. The potassium concentration in the subsurface water at Hazawza is much lower than the potassium concentrations in either the Dead Sea or in many of the near-surface brines of Wadi as Sirhan. It is possible that evaporites or brines exist in the center of the gravity minimum at depths greater than the drill penetrated in those holes drilled on the northeast side of the playa. However, high volume flows of relatively fresh artesian water associated with the basalt suggest that large evaporite or brine deposits are unlikely at Hazawza.

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APPENDIX

Appendix 1-*Lithologic logs of holes HZ22, HZ23, and HZ25 drilled in the Hazawza playa, Wadi as Sirhan area, Kingdom of Saudi Arabia.*

HZ22

Depth (Meters)	Lithology
0.00 - 1.00	Silt
1.00 - 2.45	Basalt
2.45 - 5.85	Silt
5.85 - 6.00	Basalt, weathered
6.00 - 8.00	Silt
8.00 - 8.35	Basalt, weathered
8.35 - 11.00	Silt with basalt fragments
11.00 - 27.90	Basalt
27.90 - 28.00	Silt
28.00 - 96.00	Basalt with some weathered zones
96.00 - 98.00	Limestone with fragments of basalt
98.00 - 100.15	Limestone, sandy
100.15 - 108.80	Basalt
108.80 - 114.00	Limestone
114.00 - 115.00	Limestone with basalt fragments
115.00 - 132.00	Basalt with weathered zones
132.00 - 134.00	Limestone, hematite stained
134.00 - 137.00	Limestone
137.00 - 139.00	Limestone, sandy
139.00 - 142.80	Limestone
142.80 - 146.00	Limestone, sandy
146.00 - 151.60	Sand, unconsolidated

HZ23

0.00 - 0.25	Silt
0.25 - 2.30	Basalt
2.30 - 3.20	Sandstone, quartz
3.20 - 3.85	Silt with basalt fragments
3.85 - 21.55	Silt
21.55 - 23.15	Silt with basalt fragments
23.15 - 33.85	Basalt
33.85 - 34.85	Silt
34.85 - 39.90	Basalt with some weathered zones; vesicules chert filled
39.90 - 40.00	Silt

Appendix.--*Lithologic logs of holes HZ22, HZ23, and HZ25 drilled in the Hazawza playa, Wadi as Sirhan area, Kingdom of Saudi Arabia (continued)*

HZ23 (Continued)

Depth (Meters)	Lithology
40.00 - 66.30	Basalt, weathered zones
66.30 - 67.20	Silt
67.20 - 92.65	Basalt
92.65 - 92.95	Silt
92.95 - 126.70	Basal
126.70 - 127.00	Sand with hematite staining
127.00 - 148.60	Basalt with some highly leached zones
148.60 - 149.70	Limestone
149.70 - 151.45	Limestone with basalt fragments
151.45 - 185.60	Basalt
185.60 - 188.50	Shale, calcareous
188.50 - 191.25	Limestone, argillaceous
191.25 - 200.40	Limestone
200.40 - 202.35	Limestone, hematite stined with basalt fragments
202.35 - 208.40	Limestone
208.40 - 211.05	Limestone, argillaceous
211.05 - 218.30	Shale, calcareous
218.30 - 228.20	Sandstone, calcareous
228.20 - 230.00	Limestone, sandy
230.00 - 231.90	Sandstone, argillaceous, slightly calcareous
231.90 - 234.15	Sand, unconsolidated

HZ25

0.00 - 1.20	Silt
1.20 - 2.05	Basalt
2.05 - 11.00	Silt
11.00 - 23.30	Basalt
23.30 - 28.00	Sand, unconsolidated and quartz
28.00 - 40.00	Basalt
40.00 - 40.20	Sand, unconsolidated and quartz
40.20 - 107.35	Basalt with highly leached zones
107.35 - 112.50	Limestone
112.50 - 113.00	Limestone with basalt fragments

Appendix.--*Lithologic logs of holes HZ22, HZ23, and HZ25 drilled in the Hazawza playa, Wadi as Sirhan area, Kingdom of Saudi Arabia (continued)*

HZ25 (Continued)

Depth (Meters)	Lithology
113.00 - 117.00	Limestone
117.00 - 121.20	Basalt with limestone seams
121.20 - 122.20	Limestone with layers of oxidized material
122.20 - 127.00	Basalt
127.00 - 140.30	Limestone
140.30 - 141.00	Sandy limestone
141.00 - 151.80	Sandstone, calcareous
151.80 - 154.00	Sand, unconsolidated, calcareous
154.00 - 155.00	Sandstone, calcareous
155.00 - 157.65	Sand, unconsolidated
157.65 - 157.80	Limestone, sandy
157.80 - 163.80	Sand, unconsolidated
163.80 - 165.55	Sandstone, calcareous
165.55 - 167.15	Sand, unconsolidated
167.15 - 173.50	Sandstone, calcareous
173.50 - 176.10	Limestone, sandy
176.10 - 177.55	Sand, unconsolidated
177.55 - 178.55	Sandstone, calcareous
178.55 - 181.60	Sand, unconsolidated
181.60 - 182.10	Limestone, sandy
182.10 - 183.15	Silt
183.15 - 319.00	Sand, unconsolidated

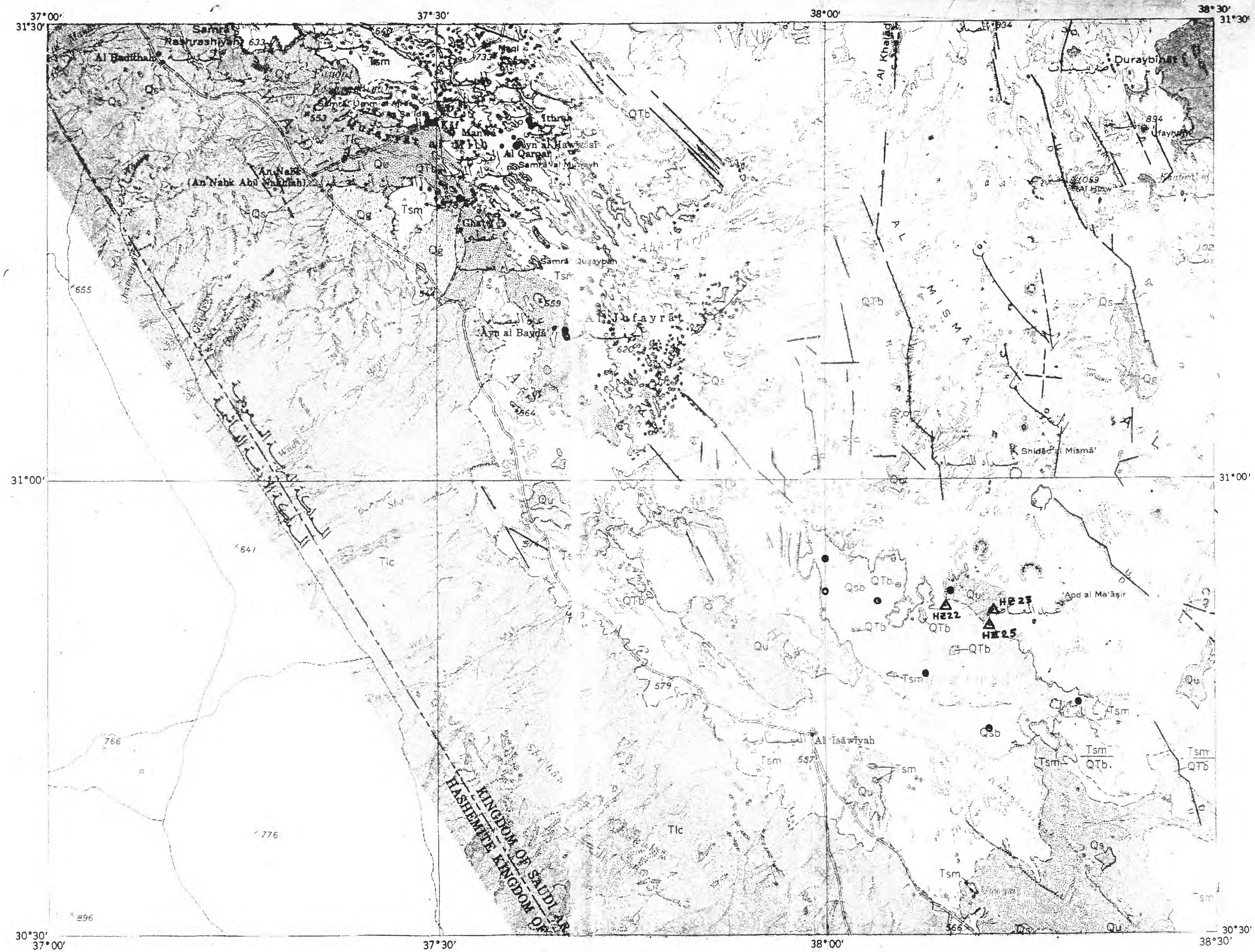

Figure 2. Location of samples (circles) and drill holes (triangles) in Wadi as Sirhan area, Kingdom of Saudi Arabia.