RECONNAISSANCE INVESTIGATION OF BRINE IN THE EASTERN RUB AL KHALI, KINGDOM OF SAUDI ARABIA

by

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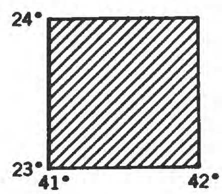

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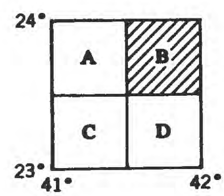
1-degree quadrangle



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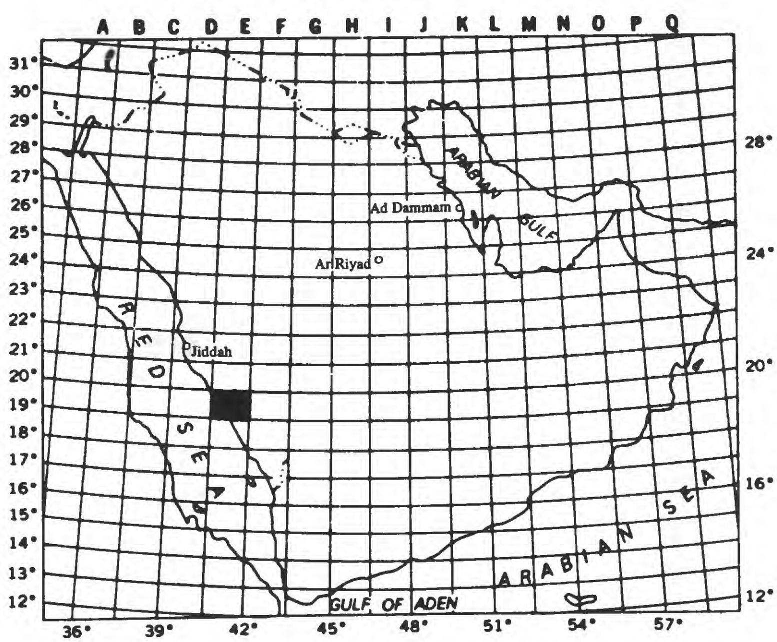

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RECONNAISSANCE INVESTIGATION OF BRINE IN THE EASTERN RUB AL KHALI, KINGDOM OF SAUDI ARABIA

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ABSTRACT

Al Uruq al Mu'taridah-Umm as Samim area is located in a large topographic depression in the eastern Rub al Khali desert where playas several thousand square kilometers in area are exposed. A crust of eolian sand cemented with gypsum and halite has formed on many playa surfaces. Anhydrite nodules are common in the sampled area, where the depth to ground water generally exceeds 172 cm. The chemistry of the three ground-water samples collected near the water well Ramallah-1 (lat 22°10'20" N., long 54°20'37" E.) is similar to that of sabkhah-related brines on the coast of the United Arab Emirates. Although there is no indication of economic quantities of evaporite minerals in the sampled area, the extent of the depression and its unique geologic environment recommend it for resource-evaluation studies.

INTRODUCTION

Salt flats of various types are widely distributed on the Arabian Peninsula. The greatest concentration of these features is east of long 51° E. and north of lat 19°30' N., in and near the eastern Rub al Khali desert (fig. 1). Many terms are currently used to describe salt flats (for example, Glennie, 1970), and there seems to be considerable overlap in their meaning. In this paper the term "sabkhah" (also spelled sabkha), made popular by Kinsman (1969), is used to describe salt flats on and near the coast of the United Arab Emirates (former Trucial States) and Qatar. However, following the suggestion of Illing and Taylor (1967), in this paper the use of the term "sabkhah" is restricted to coastal areas, and the older term "playa" is used to describe those salt flats that have formed in an interior topographic depression, irrespective of whether the hydrologic system associated with the salt flats is open or closed.

The salt flats of the Arabian Peninsula east of long 51° E. occupy an area of more than 40,000 km^2 and are found in four countries. Because of the indefinite boundaries between countries in this region of the Peninsula, it is not always possible to determine whether an individual salt flat belongs in the Kingdom of Saudi Arabia, Oman, the United Arab Emirates, or Qatar. The largest contiguous salt

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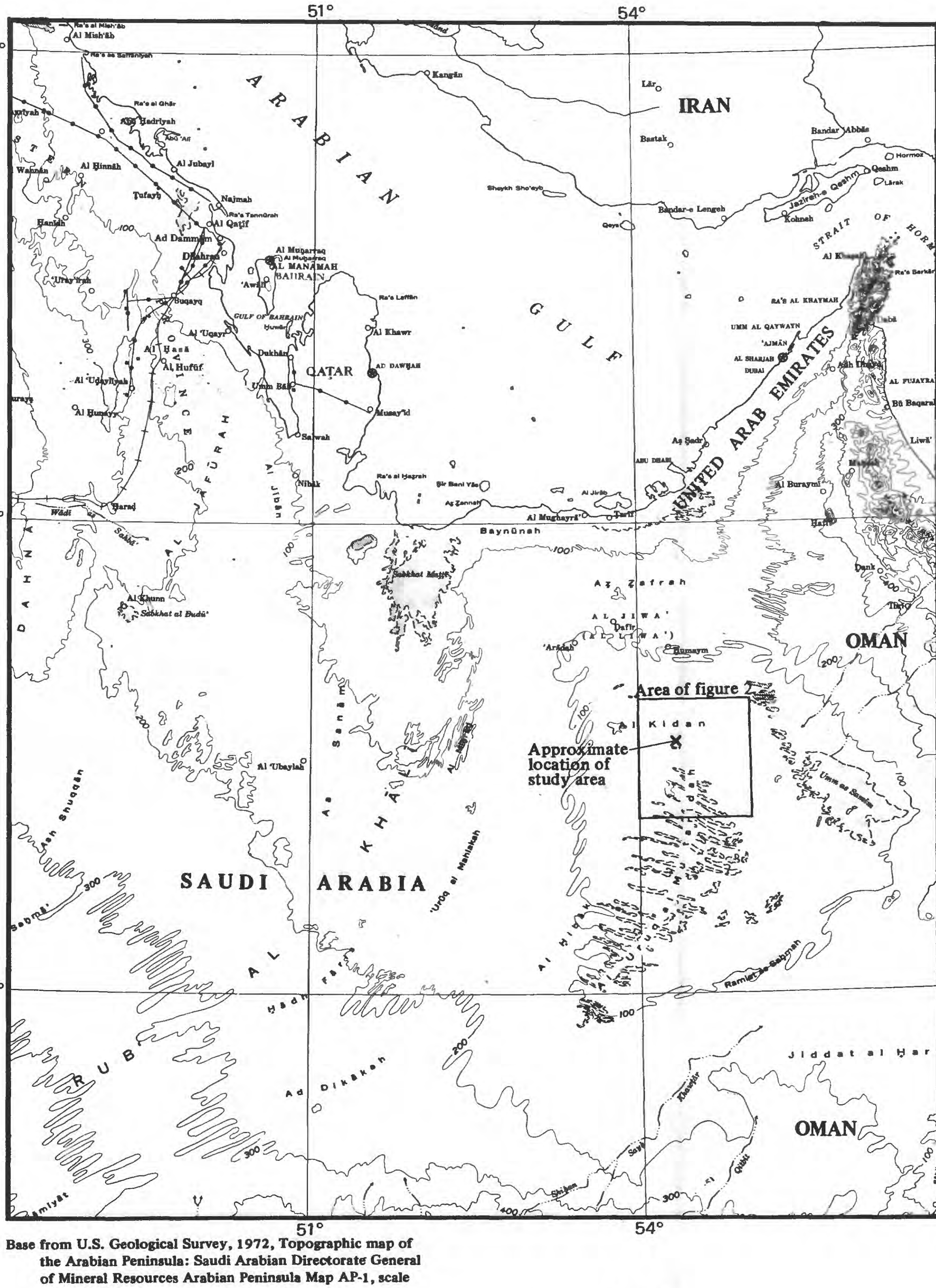
1/ U.S. Geological Survey, Denver, Colorado



Base from U.S. Geological Survey, 1972, Topographic map of the Arabian Peninsula: Saudi Arabian Directorate General of Mineral Resources Arabian Peninsula Map AP-1, scale 1:4,000,000.

Figure 1.–Map of eastern Saudi Arabia showing location of study area.

flats are Sabkhah Matti, a coastal sabkhah in the northern part of the area, and Umm as Samim, a playa in the eastern Rub al Khali (fig. 1). A playa area larger than either Umm as Samim or Sabkhah Matti is partly covered by eolian sand in the region of Al Uruq al Mu'taridah.

The coast of the United Arab Emirates has become a classic area for the study of sabkhahs (Kinsman, 1965, 1969, Butler, 1969, 1973, Patterson, 1972). These investigations demonstrate that many of the sedimentary features and evaporite minerals found in ancient evaporite deposits are also present in modern sabkhahs on and near the coast of the United Arab Emirates. A wide variety of evaporite minerals are forming in these sabkhahs, and studies of currently active geochemical processes involved in formation of these minerals hāve provided new information concerning geochemical problems such as deposition of dolomite and transition of gypsum to anhydrite under near-surface conditions. Major revisions in theories of evaporite formation, which had been based on studies of ancient evaporite deposits, were possible following identification of the evaporite mineral suite and the sedimentary structures in these sabkhahs. These investigations of recent deposits have prompted reexamination of many ancient evaporite deposits for evidence of formation in a sabkhah environment.

The hydrologic system underlying the coastal sabkhahs of the United Arab Emirates contains both continental-derived and marine-derived water (Patterson and Kinsman, 1977). Surfaces of sabkhahs in the United Arab Emirates tend toward a state of deflational equilibrium (Patterson, 1972). Kinsman (1969) first suggested that continental sabkhahs are equilibrium deflation-sedimentation surfaces and that some level above the capillary fringe marks the base level of wind deflation. Below the top of the capillary fringe of the water table, the sediment is too damp to be moved by wind (Patterson, 1972). Therefore, a raising or lowering of the water table is accompanied either by accretion or deflation. Because of capillarity and deflation, the depth to the water table is never greater than 1.5 m (Patterson, 1972).

Although much has been published about the sediment composition and brine chemistry of the sabkhahs of the United Arab Emirates, there is no published information concerning the sediment composition and brine chemistry of the much more extensive salt flats in Al Uruq al Mu'taridah area of the eastern Rub al Khali. A reconnaissance investigation was conducted in Al Uruq al Mu'taridah (fig. 1) from February 2 to February 4, 1981 by the U.S. Geological Survey. Samples of brine were collected, and observations concerning sediment composition of near-surface playa sediments were recorded within a 10-km radius of the water well Ramallah-1 (lat 22°10'20" N., long 54°20'37" E., fig. 2). Geological

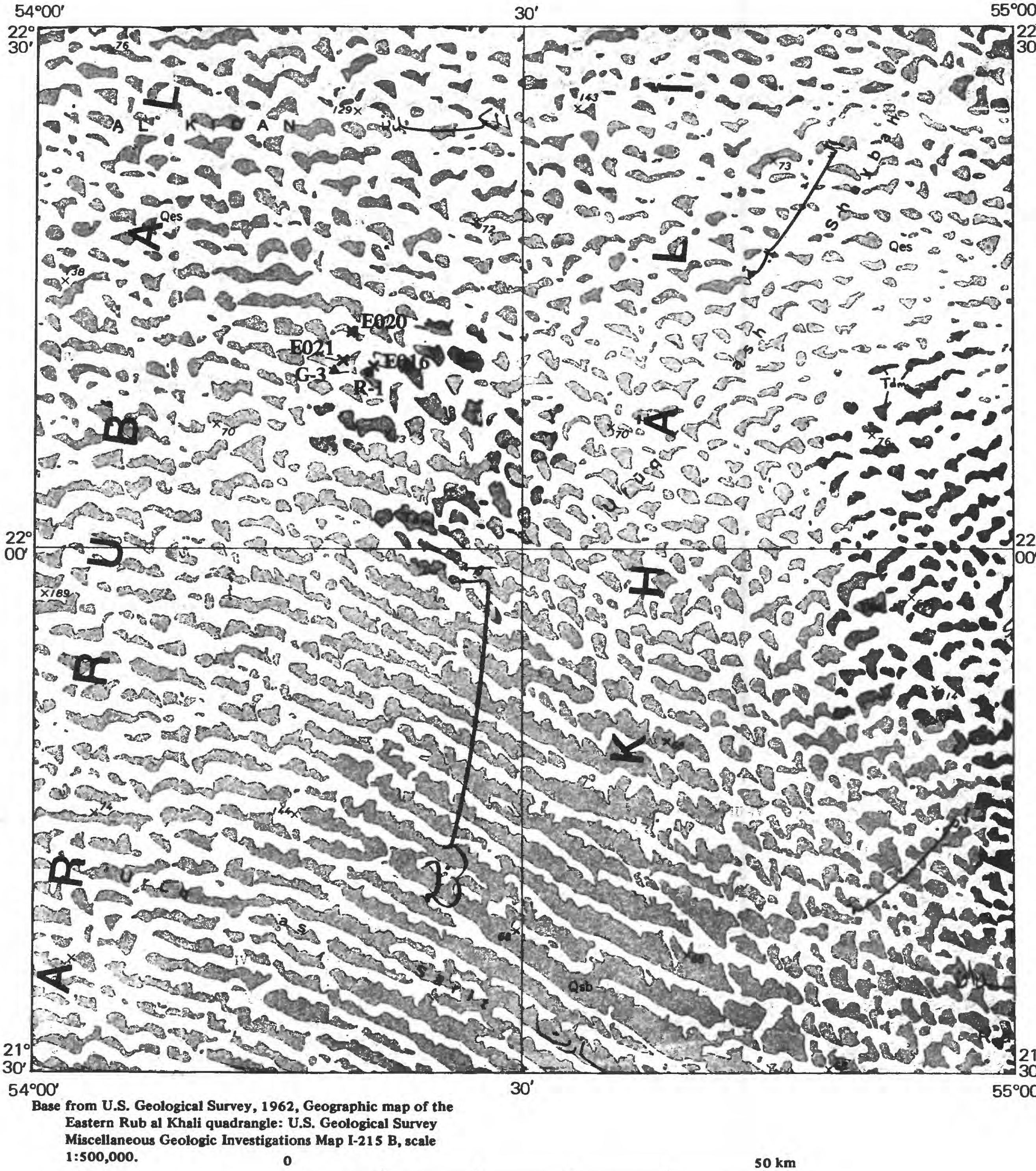


Figure 2.–Map of study area showing approximate location of samples (E016, E020, E021), camp G-3, and water well Ramallah-1 (R-1). Dark areas (some labelled Qsb and Tdm) are playa deposits, and light areas (some labelled Qes) are eolian sand.

and geochemical information provided by this reconnaissance survey allows a preliminary evaluation of the potential of the area for the discovery of evaporite deposits. It also allows a preliminary comparison of this area with salt flats on the coast of the Arabian Peninsula.

Access by ground transportation to the area where samples were collected is difficult. Most of the roads that do exist in the eastern Rub al Khali were established either by or for the Arabian American Oil Company. Vehicular traffic to and from Ramallah-1 is infrequent, and many of the supplies brought in for geophysical crews currently working in the area are transported by aircraft.

The author thanks D. J. Faulkender (U.S. Geological Survey) for supplying the latitude and longitude of Ramallah-1 and for his help with sampling, and also thanks A. Baraja (Saudi Arabian Directorate General of Mineral Resources) for chemical analyses of the brines. The author gratefully acknowledges the Arabian American Oil Company (ARAMCO) and the Geophysical Services Company for their cooperation and logistic support. Special thanks are due H. A. McClure (ARAMCO) for his help in making field arrangements and for many interesting discussions on the geology of the Rub al Khali desert.

The work on which this report is based was performed in accordance with a work agreement between the U.S. Geological Survey (USGS) and the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia.

GENERAL GEOLOGY

All playas in the eastern Rub al Khali desert are associated with the Rub al Khali structural basin, which formed during Tertiary time (Powers and others, 1966). By the beginning of the Quaternary, this basin was essentially filled with sediments brought in by the Wadi ad Dawasir and Wadi as Sah'ba drainage systems in western Saudi Arabia and with sediments derived from the Hadhramaut and Oman mountains of South Yemen and Oman (McClure, 1978). McClure indicated that inflow of sediments to the basin terminated with the onset of Pleistocene aridity and that eolian reworking of deposited sediments has created the eolian geomorphic features found in the Rub al Khali desert.

Two of the most obvious geomorphic features in Al Uruq al Mu'taridah area are sand dunes and playas. Many sand-dune chains are continuous for more than 100 km and are wholly or partly separated by interdunal playa surfaces. Individual peaks within some sand-dune chains rise more than 100 m above adjacent playa floors (Elberg and others, 1963). Dune chains and playas in Al Uruq al Mu'taridah area trend west-northwest.

Eolian sand is the most common sediment in Al Uruq al Mu'taridah area, but the Dammam Formation of Eocene age crops out in some interdune areas (Elberg and others, 1963).

Both Al Uruq al Mu'taridah and Umm as Samim areas occupy the same topographic depression in the eastern Rub al Khali desert and are probably underlain by the same hydrologic system (fig. 1). Proximity of the Oman mountains to the depression suggests that they are the likely source of water in the present hydrologic system; however, some portion of the water might be contributed from the southwestern third of the Arabian Peninsula. It is also possible that some portion of this ground water is fossil water dating back to a moister climate during Holocene and Pleistocene time.

SAMPLING AND ANALYTICAL METHODS

Brine samples were collected from holes that were mostly about 40 to 50 cm in diameter at the playa surface and about 30 cm in diameter at the hole bottom. A hole of this configuration can usually be dug with a shovel in sandy playas to depths of as much as 150 cm in approximately 30 minutes. Depending on the depth to the water table, larger pits can take 2 hours or more to excavate by hand.

Three brine samples were collected from pits and holes dug to ground water. The approximate positions of the sample localities are indicated on figure 2. Samples were collected in 500-ml polyethylene bottles that had been cleaned with distilled water and dried. The bottles were rinsed with sample prior to filling and sealed after filling. Brine samples were filtered in the laboratory to remove suspended sediment. The pH and other chemical properties of the brine samples were measured in the laboratory. Alkalinity (as defined by Stumm and Morgan, 1970) was measured by titration with H_2SO_4. 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 using Orion electrodes. Concentrations of silica (molybdate blue method) and sulfate (turbidimetric method) (Tabatabai, 1974) were determined using a Model 54B Coleman spectrophotometer. Water density was measured using a Troemner chain gravitometer. Charge balance is within $\pm$ 5 percent. Results of these analyses are presented in table 1.

Table 1--*Chemical analyses of brine samples from the eastern Rub al Khali, Kingdom of Saudi Arabia*
[Results in meq/l, except for SiO_2, fluorine, and lithium, which are in mg/l, and density, which is in g/cm^3. Analyses by A. Baraja, DGMR/USGS geochemical laboratory, Jiddah]

Site	E016	E020	E021
Sample number	144065	144067	144068
Calcium (Ca)	125	185	140
Magnesium (Mg)	82	147	66
Sodium (Na)	1990	4480	1570
Potassium (K)	45	102	33
Chloride (Cl)	2140	5010	1720
Sulfate (SO_4)	63	35	83
Bicarbonate (HCO_3)	0.5	0.26	0.59
Silica (SiO_2)	6.9	5.1	9.2
Lithium (Li)	.31	.24	.21
Fluoride (F)	1.41	.55	1.17
Density	1.088	1.192	1.075

DISCUSSION

From February 1 to February 5, 1981, a Geophysical Services Company field camp named G-3 (fig. 2) was visited, and three brine samples were collected. The camp was located on a playa surface about 4 km west of the artesian water well Ramallah-1 (R-1, fig. 2). The playa is covered by eolian sand that has a 2-cm-thick crust composed of sand cemented with halite and gypsum. This type of crust is common on all playas within a 10-km radius of camp G-3. Although no consolidated sediments were found in the playa on which the camp was located, limestone is exposed on other playas within a 10-km radius of camp. According to the geologic map by Elberg and others (1963), the limestone is probably part of the Dammam Formation. On some playas the Dammam Formation is partly covered by eolian sand only a few centimeters deep, whereas on others the Dammam Formation was not found at depths of almost 2 m.

The playas are bordered on their north and south sides by west-trending chains of sand dunes. These dune chains are connected by smaller and lower dunes whose direction of movement is or was approximately parallel with the long axes of the dune chains and playas. Smaller and lower dunes separate playas that have formed between adjacent dune chains. At least some smaller sand dunes are mobile. At two localities, either on or near a playa surface, the former position of a sand dune is indicated by the preservation, by cementation, of the lower edge of the windward slope of the dune. X-ray analysis indicates that the cementing material is predominately halite, with subordinate amounts of gypsum, calcite, and possibly sylvite. No indications that the positions of the major dune chains had shifted were observed.

In addition to the three holes that reached the water table, several other holes were dug in playas in attempts to collect samples of ground water. Some holes, which did not reach ground water, were dug to depths ranging from 120 to almost 200 cm. Sediments removed from the bottom of these holes appeared only slightly moist, and, rather than excavate a larger pit to an unknown depth, digging was terminated at those localities. On some playas the digging of holes was terminated because a hard, dense limestone layer, the Dammam Formation, was encountered below the surface layer of eolian sand and could not be penetrated.

The chemistry of two brine samples (144065 and 144067) collected within a 10-km radius of camp G-3 may have been strongly affected by man's activities in the area (fig. 2, table 1). Sample site E016 is on a playa less than 30 m in diameter and less than 200 m from Ramallah-1. At E016, gypsum layers 2 to 3 mm thick were found at different depths below the playa surface. The ground-water surface at this sample locality is at a depth of 104 cm. Because Ramallah-1 is within 200 m of E016, it is possible that water flowing from Ramallah-1 has raised the water table at the sample site and affected the chemistry of the water sample by contaminating the near-surface ground water.

Sample site E020 (fig. 2, table 1) is more than 8 km northwest of Ramallah-1. At this sample site, a bulldozer had excavated a pit about 90 cm deep to provide sand to make a drilling platform for well Ramallah-7. The sand at the bottom of the pit is well cemented with gypsum. When a hole was dug below a depth of 90 cm, ground water began to seep in. After approximately 40 minutes, the water in the hole had risen to a level 82 cm below the bottom of the bulldozer excavation and about 172 cm below the playa surface. By decreasing the distance between the ground-water surface and the sediment-air interface, the bulldozer excavation may have caused an increase in the rate of evaporation of ground water below the excavation. An increased evaporation rate would explain the relatively large amounts of interstitial gypsum at this site and the higher solute concentrations of sample 144067 (table 1).

Sample site E021 is about 2 km northeast of camp G-3 on the same playa, more than 2 km west of water well Ramallah-1 (fig. 2) and about 15 m from the edge of a sand-dune chain that forms the playa's northern border. Of the three sites sampled, this one probably has been least affected by man's activities, and water sample 144068 is probably fairly representative of the ground-water chemistry at the water table (table 1). After the pit at this sample locality had been excavated to a depth of 195 cm, ground water was observed to seep into the bottom of the pit. Approximately 50 minutes after excavation had ceased, the water level in the pit had risen to 186 cm below playa surface. Although there were scattered authigenic gypsum fragments in sand below the playa surface, the sand was not cemented to the same degree as that found in the hole dug at sample site E020.

The most common authigenic evaporite minerals found on or below playa surfaces are gypsum, anhydrite, and halite. Gypsum crystal fragments approximately 1 to 2 cm long were found below playa surfaces at several sample sites. Nodular anhydrite is also believed to be widely distributed below playa surfaces because dried nodules of anhydrite were found in several areas where bulldozers had piled sediments excavated from playas. Nodular anhydrite was also found in situ in moist sand in holes that terminated above the phreatic zone. Gypsum and anhydrite in playas in the sampled area are either disseminated or as stringers in eolian sand; however, they do not form layers such as those described in sabkhahs on the United Arab Emirates coast (Butler, 1969).

Based on his studies of almost 600 pits dug in coastal sabkhahs of the United Arab Emirates, Patterson (1972) suggested that the maximum depth to the ground-water surface from sabkhah surfaces in the area is 150 cm. At most places within a 10-km radius of camp G-3, the depth to the ground-water surface from the playa surface appears to be more than 150 cm. Other than at sample site E016, where the ground-water surface has possibly been raised because of proximity to the outflow from well Ramallah-1, holes that were dug to the water table indicate the surface of the phreatic zone is at least 172 cm below the playa surface. One hole, which was dug in the bottom of a bulldozer-excavated pit, did not reach ground water at a depth of almost 200 cm below the playa surface. Maximum depth to the ground-water surface from a playa or sabkhah surface in deflational equilibrium should depend on the height that the capillary fringe extends above the phreatic zone. This dependence is a function of several known factors. Composition of fluid and sediment, as well as sediment size (capillary radius) and permeability, helps determine how far a capillary fringe extends above the phreatic zone. From Patterson's (1972) description of sediment and brine compositions in the United Arab Emirates, it is probable that the limited range of sediment and brine compositions found in the sampled area around camp G-3 is within the range of sediment and brine compositions described by Patterson. As the 150-cm limit described by Patterson is an observational rather than theoretical limit, it may not apply to areas other than the United Arab Emirates coast. An alternate explanation for the water table in the camp G-3 area being more than 150 cm deep is that playa surfaces in this area may no longer be in deflational equilibrium. Current playa surfaces may be preserved from an earlier and possibly more humid time when the water table was higher.

The small area sampled and the limited number of samples collected prevent any definite conclusion concerning the significance and causes of the greater depth to the ground-water surface observed near camp G-3 compared with depth to the ground-water surface on the United Arab Emirates coast.

CONCLUSIONS

Within a 100-km^2 area, which contains water well Ramallah-1, only three brine samples were collected and about 15 holes were dug. Extrapolation from interpretations and observations made in this area to Al Uruq al Mu'taridah-Umm as Samim area, which is more than 60,000 km^2 in extent, should be made with great caution. Before any definite conclusions concerning this area can be reached, many more samples need to be collected and a much larger area investigated.

Although several interesting questions concerning basic geology could be answered in this area, none of them is of immediate economic interest. Reconnaissance investigations near camp G-3 suggest that the chemistry of ground water is fairly typical of an area containing gypsum. Even if a potential economic element such as potassium was present in unusually high concentrations in the ground water, remoteness of the area and difficulties in transportation would result in high production costs. These conditions probably make recovery of evaporite raw materials uneconomic because such materials usually must be produced in large volumes and at low cost. Conditions that presently make economic recovery of evaporites unlikely, however, can change in the future, and any significant quantities of evaporites and brines in Al Uruq al Mu'taridah-Umm as Samim area should be located, evaluated, and reported. It should be emphasized that only a small fraction of the total area containing playas is described in this report, and this extremely large evaporative environment is virtually unexplored for evaporite minerals and brines. Other evaporative environments, which have been previously described in the literature, may not be reliable guides to the types of authigenic minerals and the chemistry of the brines in this area, and further studies of this unique geologic environment are warranted.

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