

## MODERN EVAPORITE DEPOSITION AND GEOCHEMISTRY OF COEXISTING BRINES, THE SABKHA, TRUCIAL COAST, ARABIAN GULF<sup>1</sup>

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### ABSTRACT

Near Abu Dhabi, Trucial Coast, diagenetic evaporite minerals are developed within an accumulation of detrital Pleistocene sands and Recent carbonate sediments which form a supratidal flat (sabkha) 8 miles wide.

Field studies were carried out by the author and his co-workers of Imperial College in 1964. A further visit to the Trucial Coast was made by the author in 1967 under the auspices of the Dry Lands Research Institute, Riverside. A study of 260 interstitial brine samples showed that the distribution of the evaporite minerals, which include gypsum, anhydrite, dolomite, and halite, is largely controlled by the hydrology of the area. Interstitial brines within the sabkha sediments are replenished with sea water by abnormally high tides and storm surges. These surface waters, which soak down into the sediments, are concentrated both by solution of soluble salts and by evaporation. The subsequent equilibration between brines and host sediments leads to precipitation of aragonite, gypsum, and halite; alteration of gypsum to anhydrite, and dolomitization of carbonate sediment. A direct correlation exists between the frequency and extent of flooding, the mineral phases developed, and the chemical composition of interstitial brines.

Flooding of a 2- to 3-mile wide belt roughly concentric to lagoon margins, occurs at monthly or longer intervals. In this belt, a surface gypsum crystal mush up to 12 inches thick is present which, landwards, is overlain and progressively replaced by anhydrite. Dolomitization is extensive toward the landward margin of this zone. From the lagoon laterally across the 2- to 3-mile wide belt to its landward margin, chlorinity increases from 44‰ to 155‰; sulfate concentration rises from 6 to 17 gm/kg and then falls to less than 3 gm/kg; the  $Mg^{2+}/Ca^{2+}$  mole ratio increases from 5.3 to 35 and then decreases to about 4. Concentration of these components decreases with increasing depth below the sediment surface. Gypsum is the stable calcium sulfate mineral in contact with brines of chlorinities less than 145‰ and anhydrite at chlorinities greater than 145‰.

An additional 5-mile wide zone is flooded only at 4- to 5-year intervals. The original gypsum crystal mush in this zone is completely replaced by up to a 12-inch thick layer of chicken-wire mesh structure anhydrite, and the carbonates are highly dolomitized. Interstitial brines are saturated with NaCl at chlorinity 160‰ and specific gravity 1.20. These brines contain less than 1 gm/kg sulfate and have  $Mg^{2+}/Ca^{2+}$  mole ratios of about 4. In this zone, constant  $Mg^{2+}/Ca^{2+}$  values with increasing magnesium concentration suggest that there has been an approach to mutual equilibrium between brines and evaporite-carbonate minerals.

The remaining 1 to 2 miles at the landward margin of the sabkha are underlain by Pleistocene sands and are not flooded by marine waters. Ground waters in this zone are in part terrestrial in origin. Inland across this zone, chlorinity decreases from 160‰ to 107‰; the sulfate concentration is 2 gm/kg and the  $Mg^{2+}/Ca^{2+}$  mole ratio averages 3.5. Locally, anhydrite is hydrated to gypsum where brine chlorinity is less than 145‰.

Processes of gypsum precipitation and dolomitization are essentially restricted to the 2- to 3-mile wide belt close to the lagoon margin. In the mid-sabkha, equilibrium conditions probably prevail between brines, diagenetic minerals, and host sediments. Diagenesis at the landward margin of the sabkha is in part retrogressive. Both a progressive and a retrogressive diagenetic facies can be visualized as moving out with the progradation of the shore line.

The similarity between the stratigraphy and mineralogy of some Ordovician, Silurian, Pennsylvanian, and Jurassic evaporite sequences and the sabkha on the Trucial Coast suggest that evaporites of supratidal origin may be more common in older evaporite rocks than previously realized.

### INTRODUCTION

The environments in which modern evaporites form, the factors that control their composition and texture, and the significance of primary structures offer a key to interpreting ancient deposits. Perhaps the best developed evaporite environments occur on the sabkhas of the Arabian Gulf.

Field studies in the Trucial Coast were initiated at Imperial College, London, in 1962 by G. Evans, assisted by D. Kinsman. These work-

ers, who were later joined by D. Shearman, concentrated on the physiography of the Trucial Coast (Evans and others, 1963; Kinsman, 1963; and Evans and Shearman, 1964). Subsequently, Sir Patrick Skipwith (1966) and C. Kendall (1966) studied the lagoon and intertidal areas of the Khor al Bazam (Kendall and Skipwith, 1966) and J. Twyman (unpubl.), the oolite deltas near Abu Dhabi Island. In 1963, Kinsman carried out an extensive program of sediment and water sampling across the inshore areas southwest of Abu Dhabi, and made a reconnaissance study of the Abu Dhabi sabkha (Kins-

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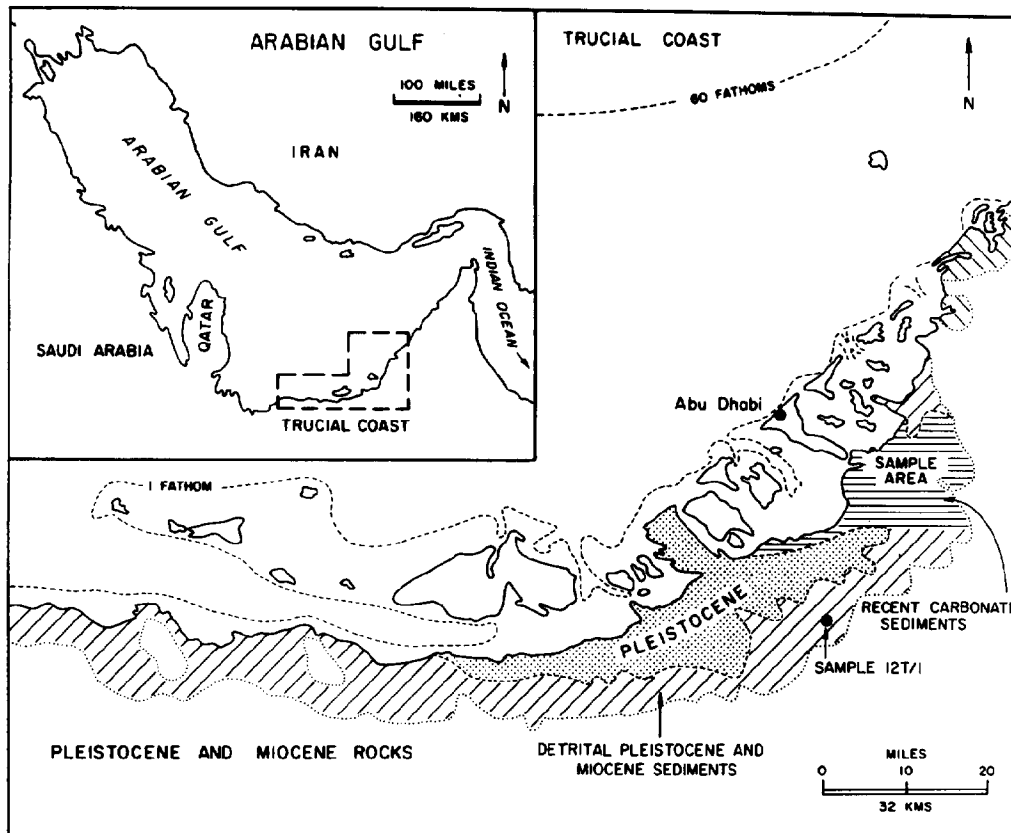


FIG. 1.—Location map of the Arabian Gulf and Trucial Coast. Area of sabkha approximately indicated by ornamentation.

man, 1963, 1964, 1966, and 1967). The author joined the project in 1963 with the purpose of continuing this initial study of the evaporite minerals and the chemistry of the associated brines in the sabkha. This paper essentially presents data collected by the author in 1964 (Butler, 1965). Additional data stem from a second visit to the Trucial Coast in 1967 with Frank Dickson under the auspices of the Dry Lands Research Institute of the University of California, at Riverside.

The sabkhas along the Trucial Coast, Southern Arabian Gulf, contain the classical sequence of evaporite minerals, dolomite, gypsum, anhydrite, and halite. The sabkha environment is considered to be analogous to that of many ancient evaporite forming environments, such as those described by West (1965), Gray (1967), Goldberg (1967), and Roehl (1967).

The purpose of this paper is to (1) describe the environment and stratigraphy of a sabkha on the Trucial Coast and (2) to show how the development of diagenetic evaporite minerals in

this sabkha is correlated with the hydrology and the chemistry of interstitial brines, based on a study of 120 cores and 260 samples of brine squeezed from sediments in the field.

#### PHYSICAL ENVIRONMENT

Sabkhas along the Trucial Coast (fig. 1) have formed by the infilling of lagoons by detrital Pleistocene quartzose sands and Recent carbonate sediments. The evaporite minerals are best developed in a relatively small sabkha on the mainland behind the island of Abu Dhabi. Their occurrence coincides with the largest accumulation of carbonate sediments (fig. 1).

The Abu Dhabi sabkha, the area studied, is about 8 miles wide. The seaward margin is delineated by algal mats, the landward edge feathers out against low hills underlain by sedimentary rocks of Pleistocene and Miocene age.

The stratigraphy of the sabkha sediments is shown in figure 2. Unlithified Recent carbonate sediments and Pleistocene eolian quartzose sands overlie Miocene sedimentary rocks. The

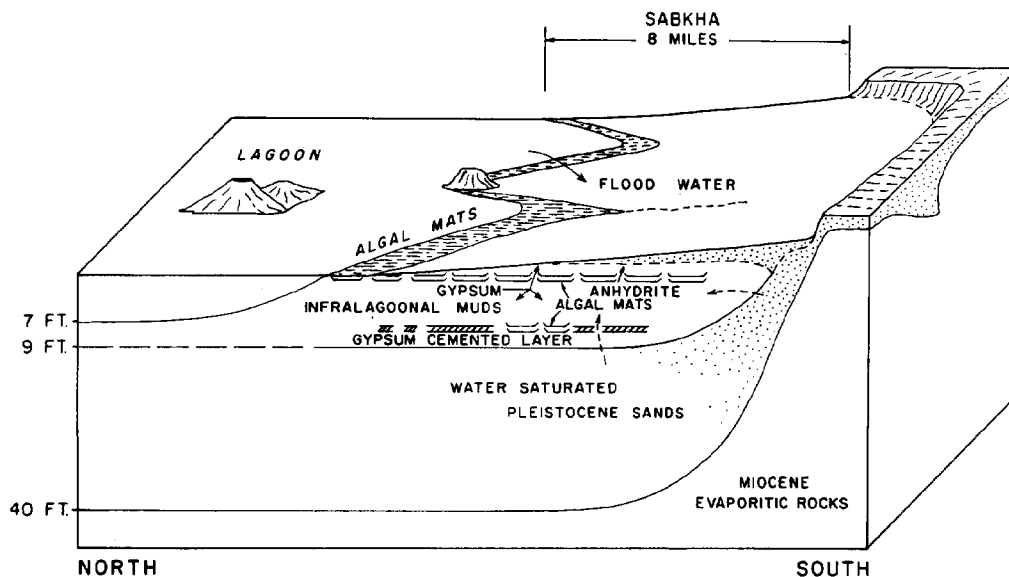


FIG. 2.—Stratigraphy of the Abu Dhabi sabkha. (Schematic cross section.)

quartzose sands form a unit up to 30 feet thick, which crops out at the landward margin of the sabkha to form a zone up to 2 miles wide. The carbonate sediments form a wedge shaped unit up to 6 miles wide and 7 feet thick. Towards the landward margin of the sabkha the unit grades into Pleistocene quartzose sands.

The upper intertidal zone is characterized by a living algal mat. An older algal mat can be traced inland for about 6 miles at the same horizon in the sabkha subsurface, signifying a long period of continued intertidal sedimentation and marine regression of the sea without change in sea level. The two layers of algal mat in the sabkha (fig. 2) show that two cycles of sedimentation have formed the carbonate unit. The second algal mat, which is only locally developed in the subsurface, is laterally continuous with a 3-inch thick gypsum cemented shell layer.

Inland from the intertidal zone, the present algal mat is buried beneath an increasing thickness of detrital quartzose sand. In the mid-sabkha region, these sands are up to 2.5 feet thick. Most of the gypsum and almost all the anhydrite of marine origin occur within these sediments overlying the older algal mat.

A most unusual feature of the Abu Dhabi sabkha is its almost planar surface, which rises inland from the lagoon with a slope of about 1:1000. The surface has formed primarily through reworking of the sediments by flood waters and by the accumulation of windblown

dust filling in small surface irregularities. Cavities in salt crusts and perched objects suggest that some local deflation of the surface is taking place. Deflation probably plays an important role locally in maintaining the surface at a fixed level relative to the water table (Evans and others, 1964). The surface is interrupted by elongate depressions, roughly normal to the shore line, which coincide with buried tidal channels in the former lagoon floor. These depressions act as conduits for flood and seepage waters into the sabkha interior.

The movement of water onto the sabkha surface plays a vital role in the development of the chemistry of the interstitial brines. A direct correlation exists between the frequency of flooding, the composition of the interstitial brines, and the nature of the diagenetic minerals developed.

The term *flood recharge* is suggested as being descriptive of the process which rejuvenates older interstitial brines by the delivery at the surface of sea water accompanied by downward soaking. The importance of flooding in supratidal areas has also been recognized by Masson (1955) and Holser (1966).

Flood recharge should not be confused with the reflux process described by Deffeyes and others, (1965) in the salina and supratidal flat of Bonaire, Netherlands Antilles.

The sabkha can be divided into five zones on the combined basis of tides and frequency of flooding, nature of diagenetic minerals devel-

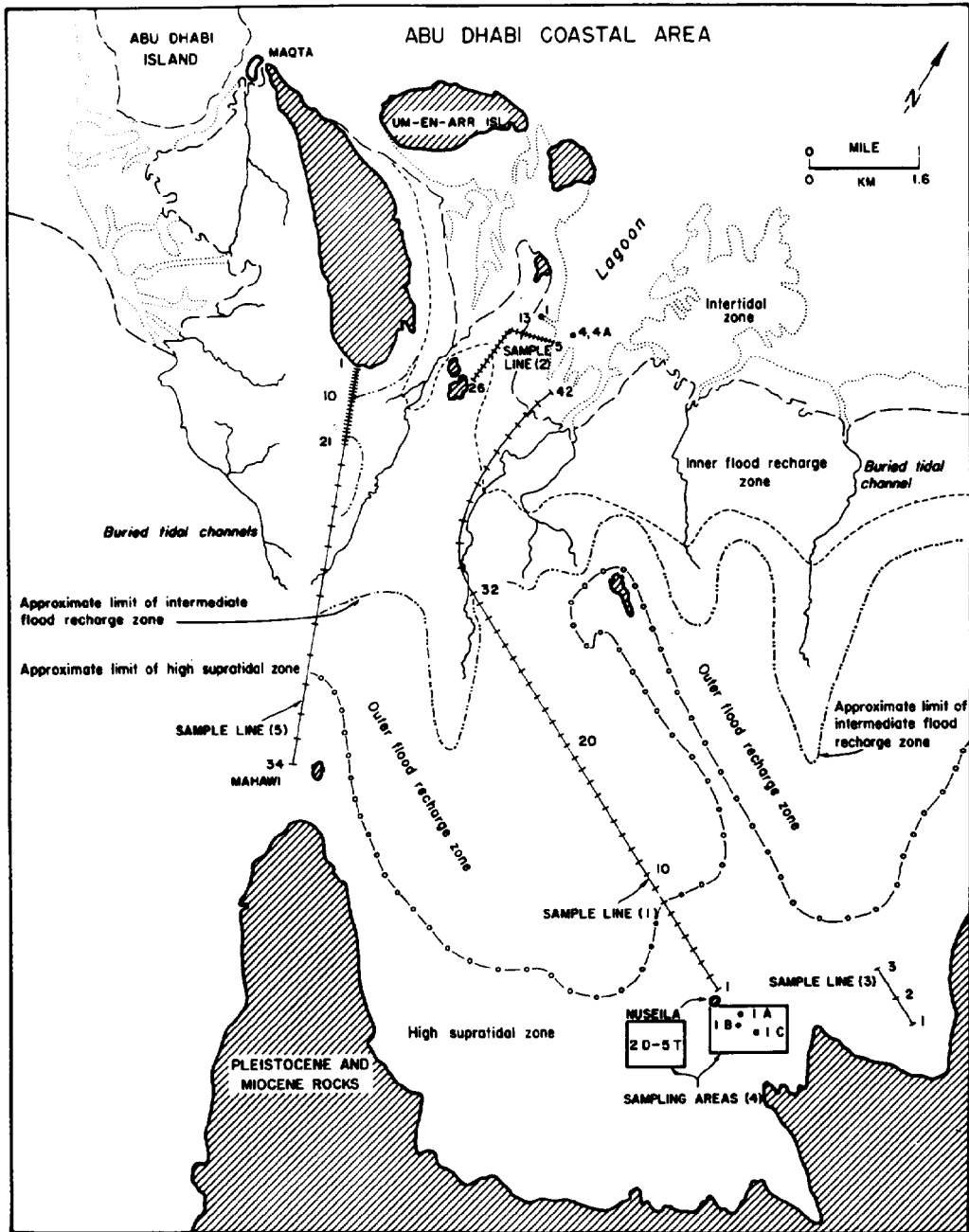


FIG. 3.—Sampling traverses and flood recharge zones across the sabkha.

oped, and nature of the host sediments (fig. 3). These zones are, in order of proximity to the lagoon:

(1) Intertidal zone, 0.25 to 0.5 mile wide, which is regularly flooded by tide waters. The

upper intertidal zone is covered by living mats of blue-green algae. The algal mats are inter-layered with lime muds and landwards contain pods of small euhedral gypsum crystals, which are less than 0.125 inch long. Below the algal

mats are lagoonal and intertidal carbonate muds.

(2) Inner flood recharge zone, 1 to 1.5 miles wide, which is subjected to monthly or more frequent flooding. The limits of this zone coincide approximately with a surface layer of randomly oriented gypsum crystals (gypsum mush), which is up to 12 inches thick. These gypsum crystals range in length from 0.015 to 0.75 inches with an average length of 0.25 inches. Most of the flood waters sink into the underlying sediments while the rest flows back into the lagoon along shallow surface channels. Underlying carbonate muds contain small amounts of dolomite and small aggregates of gypsum crystals.

(3) Intermediate flood recharge zone, 0.25 to 1 mile wide, flooded at intervals longer than one month. The gypsum mush is locally overlain by a skin of reworked detrital quartzose sand. The surface gypsum crystals are replaced by anhydrite nodules. The underlying carbonate muds contain much dispersed fine-grained dolomite and large lenticular gypsum crystals, ranging from 2 to 4 inches long. These crystals are similar to those from the Laguna Madre described by Masson (1955).

(4) Outer flood recharge zone, 0.5 to 5 miles wide, flooded at four- to five-year intervals, with a sequence of sediment types similar to zone 3. The anhydrite progressively replaces the gypsum mush until, at the landward margin of the zone, the anhydrite forms a layer up to 12 inches thick, composed of small (< 0.5 inch diameter) nodules of anhydrite separated by thin films of dolomitic carbonate sediment and quartzose sand (Butler, 1965). The anhydrite displays a rough chickenwire mesh structure of the type commonly observed in ancient anhydrite. Much thin-bedded anhydrite is also present in highly contorted layers within 18 inches of the surface. Underlying carbonate sediments contain fine-grained dolomite and abundant large lenticular gypsum crystals up to 10 inches long.

(5) High supratidal zone, 1 to 2 miles wide, bordered by Pleistocene and Miocene sedimentary rocks. This area is not flooded by sea water and the groundwaters are in part terrestrial (Butler and others, 1965). The underlying sediments are eolian Pleistocene sands, largely uncemented, which contain both gypsum and anhydrite, halite, and some polyhalite and sylvite. The components of these minerals have been supplied in some localities by terrestrial groundwaters. The gypsum occurs largely as an interstitial cement and the anhydrite as nodules concentrated in layers of variable thickness. At

a location outside the area considered in this paper (fig. 1, 12T/1) the anhydrite forms a layer 8 feet thick with nodules ranging from less than 1 inch to 6 inches in diameter, separated by films of detrital clays (see analysis of associated brine, sample 12T/1, appendix).

The high supratidal zone is characterized by the local alteration of pre-existing anhydrite to gypsum, as a result of the dilution of interstitial brines with less saline terrestrial groundwaters. The secondary gypsum crystals are zoned with corroded anhydrite laths, and are up to 4 inches long. They are flattened in the a-c plane and differ from those formed in the intertidal and flood recharge zones, which are flattened approximately normal to the c-crystal axis. Illing and others (1965) described similar gypsum crystals, flattened in the a-c plane, from a sabkha on Qatar (fig. 1).

The Lower Purbeckian evaporite beds of Southern England (West, 1965) exhibit almost identical anhydrite textures and structures as those in the Trucial Coast sabkha. West considers that the anhydrite in the Purbeckian also originated from a gypsum precursor. The origin of anhydrite in the sabkha, its texture, and the primary structures developed have already been noted (Butler, 1967) and will be discussed in detail elsewhere (Butler, 1968).

#### CHEMICAL ENVIRONMENT

##### *Climate and Temperature*

The climate of the Trucial Coast is hot and arid. Air temperatures range annually from 16°C to 44°C, and the average rainfall is less than 1.5 inches. Relative humidity varies from an average maximum of 90 percent during the night to an average minimum of 30 percent during the day. The net rate of evaporation is consequently high. Evaporation rates for the Arabian Gulf are estimated by Privitt (1959) to be as much as 50.4 inches per year, compared with a value of 39.6 inches for a similar evaporite-forming environment on Bonaire (Defeyes and others, 1963).

Temperatures within 0.5 inches of the sabkha surface show a daily range of from 18°C to 53°C (February to April 1964). In general, the highest surface temperatures were recorded in the inner flood recharge zone, where they were about 8°C higher than elsewhere. Diurnal temperature fluctuations were not detected below a depth of 12 inches. Below 12 inches, temperatures remained constant to a depth of about 25 inches and then increased almost linearly with depth to the Pleistocene sands in which temperatures were constant near 31°C. At a depth of 20 inches the average monthly temperature

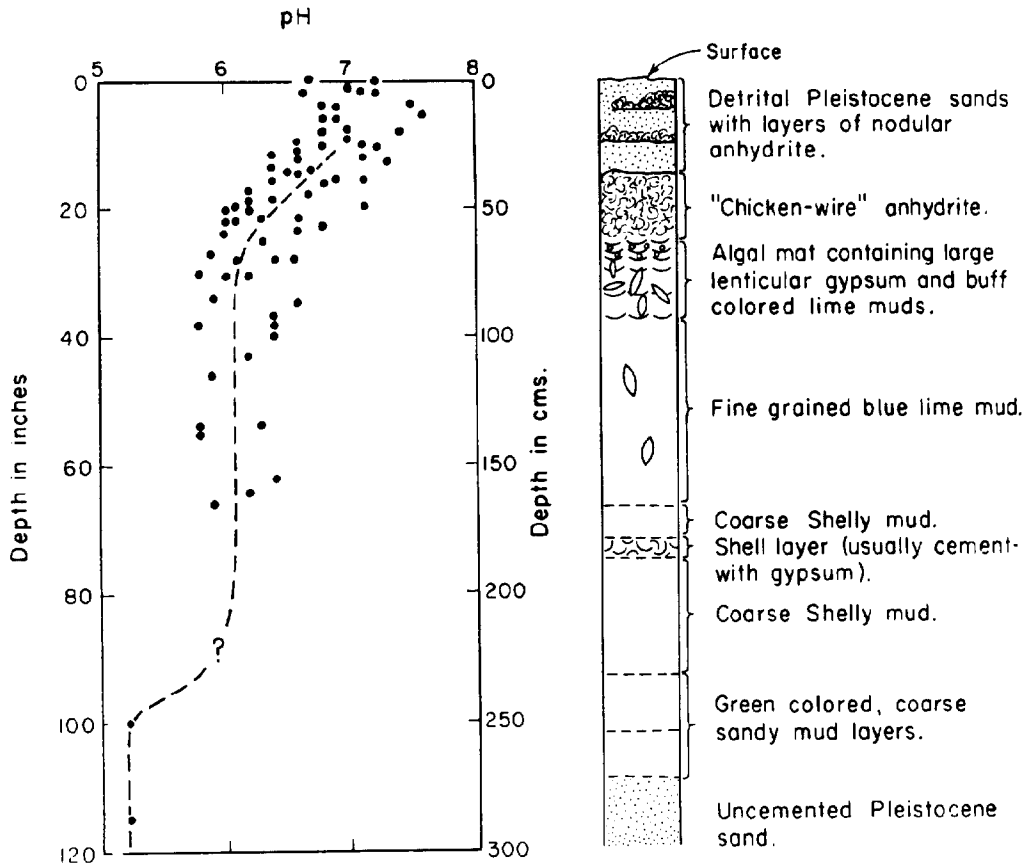


FIG. 4.—Vertical profile of sediment pH and generalized vertical sediment section in the outer flood recharge zone.

variation is calculated to be  $\pm 3^{\circ}\text{C}$ . A probable annual temperature range at 20 inches depth is  $23^{\circ}\text{C}$  to  $41^{\circ}\text{C}$  with an average temperature of  $32^{\circ}\text{C}$ .

*pH Measurements*

Lagoon waters are recorded as having pH values of about 8.3, interstitial algal flat waters 7.5, which in the mid and inner sabkha fall to 6.0 to 6.4 (Kinsman, 1966). Data on pH collected by the author were not extensive. In general, pH decreased inland from the lagoon and then rose again towards the inland margin of the sabkha. Marginal lagoon waters averaged pH 7.8, which decreased to 6.8 across the inner flood recharge zone, and reached a minimum of 6.0 in the outer flood recharge zone. The pH then rose to about 7.2 across the high supratidal zone. In the outer flood recharge zone, pH decreased from about pH 7 at the surface to a

limiting value of between 5.8 and 6.4 at depths of 30 to 40 inches (fig. 4). Values of pH 5.2 were, however, recorded in the Pleistocene sands and immediately overlying sediment. The overall acidity of the brines in the sediments has probably been caused by decomposition of organic matter releasing carbon dioxide and hydrogen sulphide, as indicated by the following analysis of a sample of the usually abundant gas in these sediments. The composition of air is shown for comparison.

	Sabkha gas (mol %)	Normal air (mol %)
N <sub>2</sub>	94.99	79.9
O <sub>2</sub>	4.76	20
CO <sub>2</sub>	0.19	0.03
CH <sub>4</sub>	0.06	—
H <sub>2</sub> S	>0.01	—

### Brine Chemistry

Two hundred and sixty interstitial fluids squeezed from the sediments constituted the bulk of the samples used for analysis. Techniques of sampling and chemical analysis of the fluids are given in the appendix, together with the detailed analytical results, field temperatures, and host sediment type.

The brines in the evaporitic-carbonate sediments, as observed in samples taken along traverses landward from the lagoon margins (fig. 3), are of increasing ionic strengths. They range from lagoon water concentrations to saturation with sodium chloride. The minerals enclosing the brines are dominantly aragonite, calcite, gypsum, anhydrite, dolomite, and halite. Other minerals of minor occurrence are celestite (Evans, and Shearman, 1964) and huntite (Kinsman, 1967). Except for anhydrite and dolomite, the mineral association resembles that group of solid phases which initially separate from sea water subjected to progressive evaporation (Usiglio, *in* Stewart, 1963). The presence of anhydrite and dolomite reflects the combined processes of evaporation and reaction of brines with pre-existing gypsum and calcium carbonate.

*Chlorinity.*—From the lagoon across the sabkha, brine chlorinity rises to a maximum and decreases again towards the inland margin (fig. 5). The greatest change takes place across the intertidal zone where a three-fold increase in chlorinity was observed. From the intertidal zone inland over the rest of the sabkha, chlorinity rises more slowly to a maximum of 170‰ and then falls to 107‰ or less close to the landward margin of the high supratidal zone. The maximum recorded chlorinity of 170‰ is unusual. The average maximum chlorinity is 160‰ with a corresponding brine specific gravity of 1.20. A brine specific gravity of 1.20 agrees approximately with the data of Usiglio (1963) and Miller (1961) for initial precipitation of sodium chloride from evaporated sea water (fig. 6).

The brines across a smaller sabkha in Qatar (Illing and others, 1965) show similar changes in chlorinity from the lagoon landward, but a maximum of about 125‰ (150 gm/liter) was reported and no decrease in chlorinity towards the inland margin was observed.

Chlorinities across the sabkha, excluding the high supratidal zone, are consistent with the process of flood recharge (fig. 7). During and

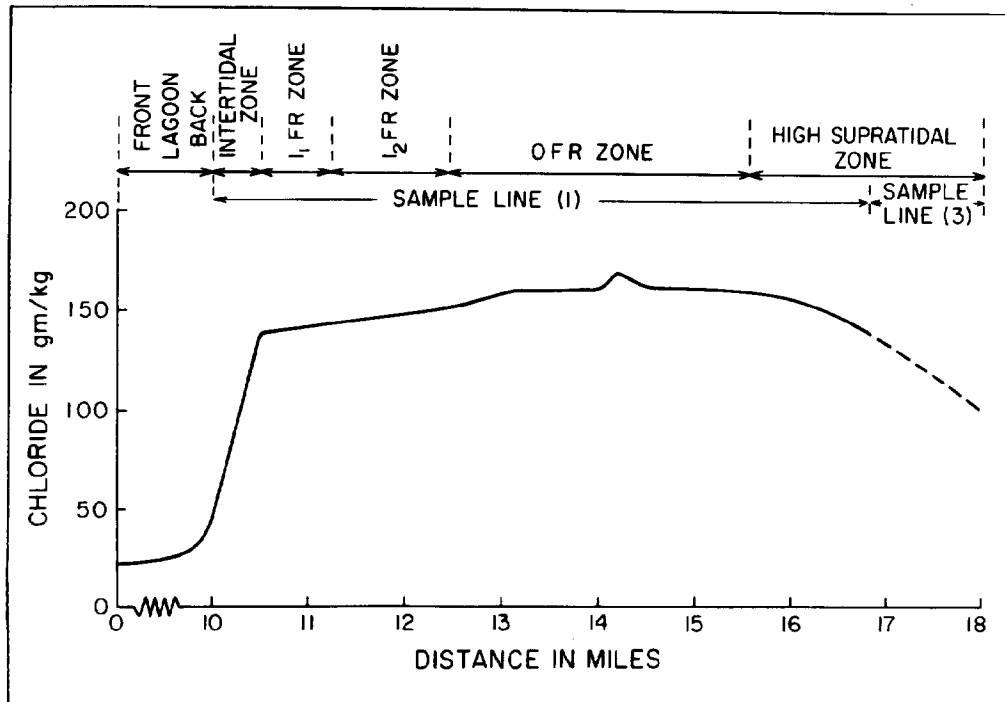


FIG. 5.—Generalized chlorinity gradient across the sabkha. I<sub>1</sub>FR = inner flood recharge zone; I<sub>2</sub>FR = intermediate flood recharge zone; OFR = outer flood recharge zone.

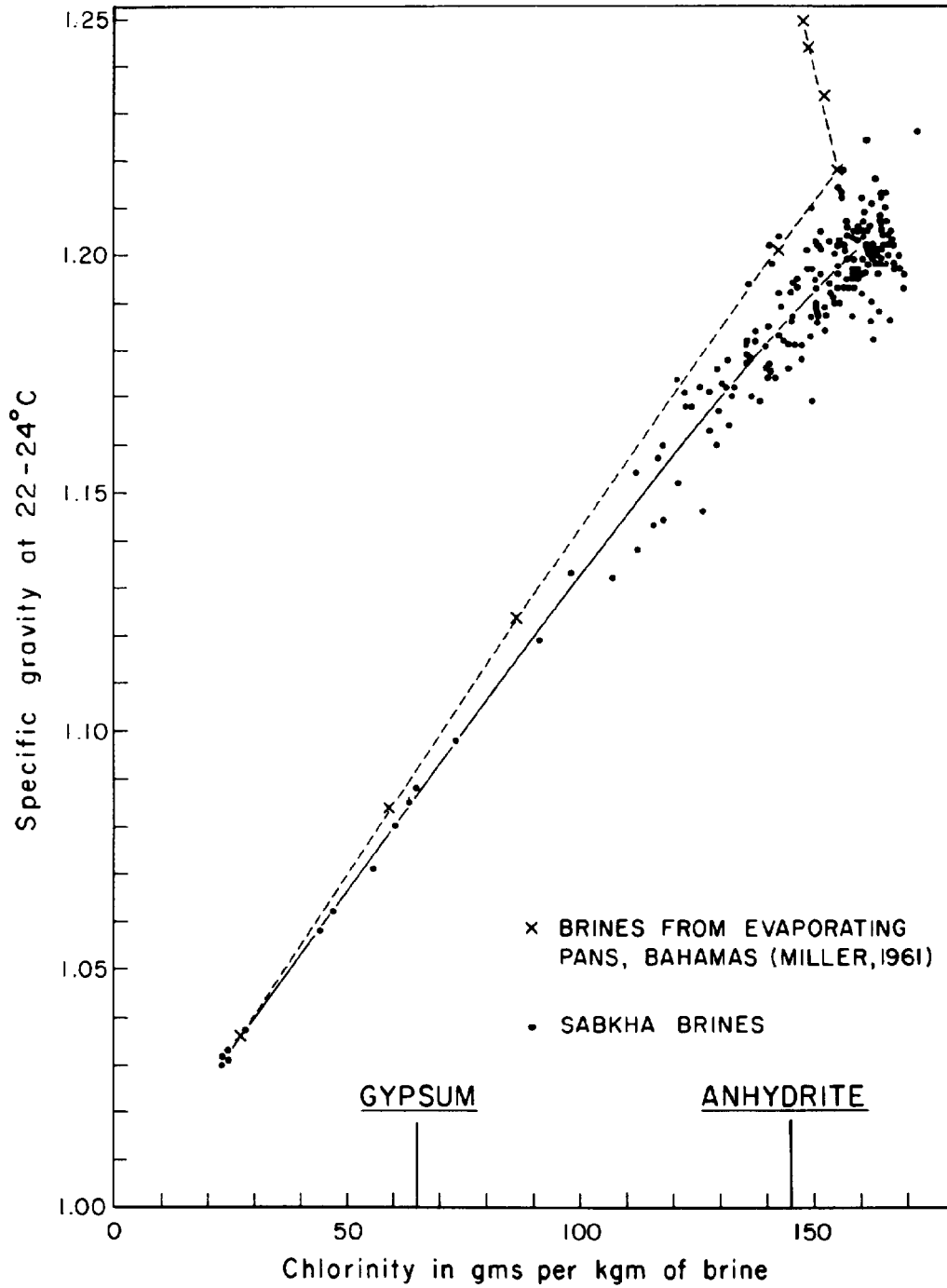


FIG. 6.—Change in brine specific gravity with increasing brine concentration. Gypsum precipitates at chlorinity 65‰, specific gravity 1.085. Gypsum-anhydrite equilibrium at chlorinity 145‰, specific gravity 1.186.



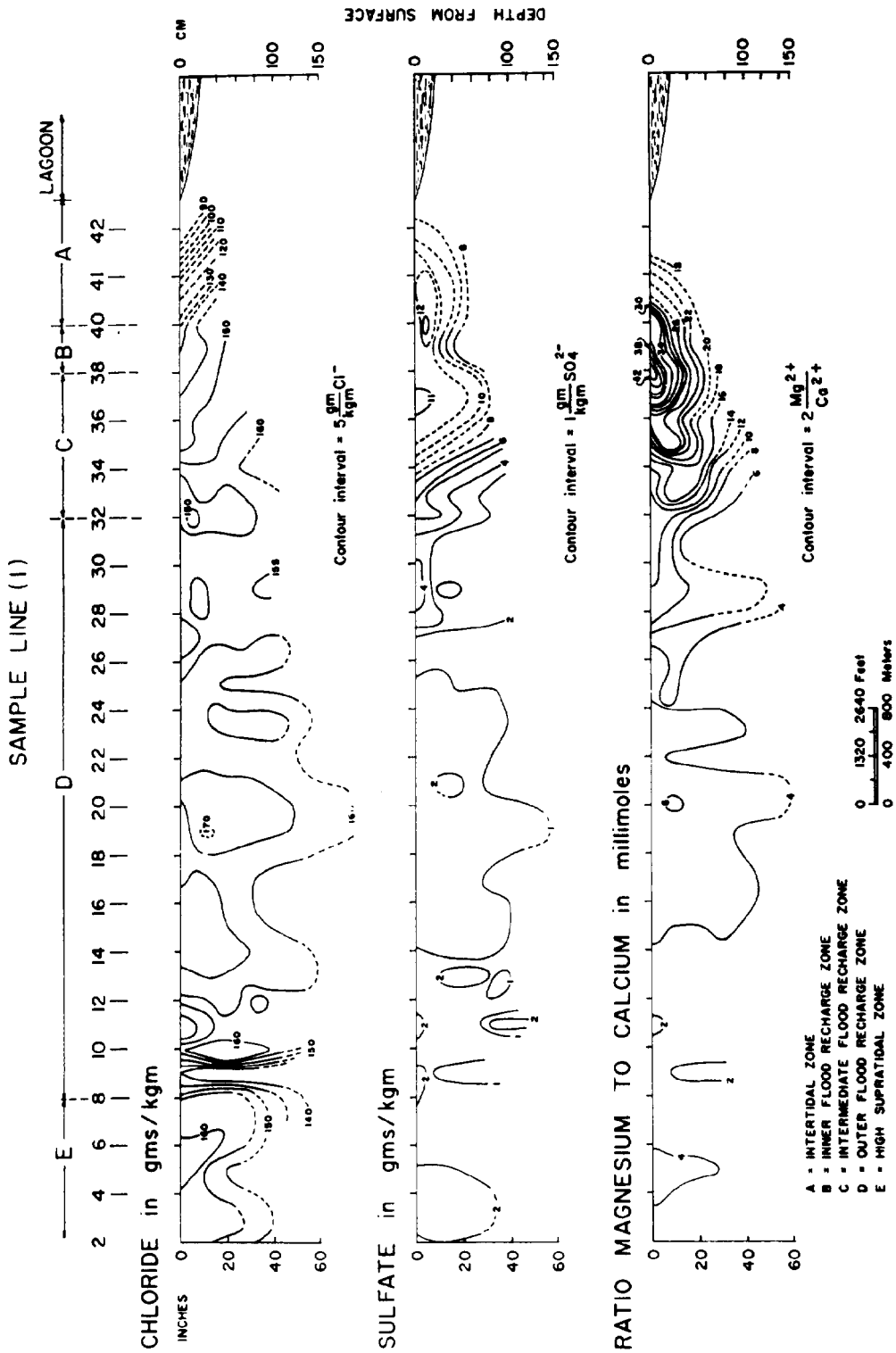


FIG. 7.—Distribution of chloride and sulphate concentration and magnesium-to-calcium ratio laterally across and vertically within the sediments of the sabkha.

immediately following flooding, the sea water concentrates by solution of soluble salts from the surface and within the sediments. Between flooding the brines further concentrate by evaporation.

Chlorinity increases with depth across the 2- to 3-mile wide belt of sabkha just inland from the lagoon margin, which has a high average frequency of flooding. Chlorinity, on the other hand, decreases with depth across the outer flood recharge zone, where flooding is relatively infrequent. Chlorinities in this zone suggest a chemically mature environment which has not been seriously perturbed by the influx of brines at the surface or from depth and where ionic diffusion possibly plays a role of smoothing out the concentration gradient. The brines in the outer flood recharge zone are saturated with respect to sodium chloride. Halite occurs as thin (< 0.5 inch) ephemeral crusts at the surface, as hopper crystals in sediments, and veneers around sand grains within the upper 2 to 4 feet of sediment.

The composition of brines from the high supratidal zone (fig. 7) differs significantly from that of brines to the seaward of the zone. Chlorinity, the  $Mg^{2+}/Ca^{2+}$  ratio, and potassium are all relatively low, and sulfate and pH are both relatively high in comparison with brines to seaward. These high supratidal brines are considered initially to have been sea water which has been chemically modified by simple evaporation, and to a greater degree, by influx of terrestrial groundwaters.

Note the distribution of isochlors about station 9 (fig. 7), suggesting the influx from depth of terrestrial brines with chlorinities lower than those of the surroundings. Influx of terrestrial brines may also have occurred in the past at station 19 (fig. 7) where the previously mentioned subsurface shell layer is locally un cemented. This would account for the abnormally high chlorinity of 170‰. Brines derived from concentrated terrestrial waters attain sodium chloride saturation at a chlorinity of about 170‰ and specific gravity between 1.21 and 1.23.

Comparison between the first field occurrence of gypsum in the intertidal zone and anhydrite in the inner flood recharge zone, and the chlorinities of co-existing brines, shows that gypsum and anhydrite first occur in contact with brines of average chlorinity 65‰ and 145‰ respectively (sample line 2, appendix). The chlorinity for gypsum precipitation agrees with that found experimentally by Posnjak (1940). In the high supratidal zone where hydration of anhydrite to gypsum takes place, gypsum occurs in contact with brines with average chlorinity

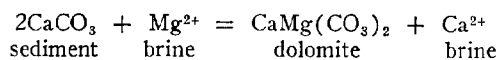
less than 145‰ and anhydrite with average chlorinity greater than 145‰ (sample area 4, appendix). Thus anhydrite is the stable calcium sulphate mineral in the sabkha brines where chlorinity exceeds 145‰.

*Sulfate.*—Figure 7 shows the adjustment of sulfate concentration to a progressive increase in brine ionic strength. Adjustment occurs by the precipitation of gypsum. The lateral and vertical distribution of sulfate in the brines across the sabkha is similar to the distribution of chlorinity. Sulfate increases from 3.2 to 3.9 gm/kg in the lagoon to a maximum of about 16 gm/kg at the landward margin of the inner flood recharge zone, and then decreases rapidly to less than 1 gm/kg in the outer flood recharge zone. Across a large portion of this zone, sulfate remains fairly constant with values slightly greater than 0.5 gm/kg. Sulfate concentration increases to more than 2 gm/kg across the high supratidal zone and probably reaches values in excess of 4.4 gm/kg (sample line 3, appendix).

The vertical variation of sulfate within the sabkha reflects the vertical variation in ionic strength of the brines (fig. 7).

*Magnesium-to-calcium ratio.*—The distribution of the  $Mg^{2+}/Ca^{2+}$  ratios both laterally across and vertically within the sabkha parallels that of the chlorinity and sulfate (fig. 7). The ratio increases from about 5.3 in the lagoon to a maximum of approximately 35 at the landward margin of the inner flood recharge zone and decreases rapidly to about 10 across the intermediate flood recharge zone. Across the outer flood recharge zone the  $Mg^{2+}/Ca^{2+}$  ratio remains nearly constant between 3 and 4. The brines from the high supratidal zone have  $Mg^{2+}/Ca^{2+}$  ratios which vary between 1.5 and 4, but average 3.5 (fig. 8). Vertically within the sediments, seaward of the high supratidal zone, the ratio decreases in value downward from the surface (fig. 7).

High  $Mg^{2+}/Ca^{2+}$  ratios are attained by the precipitation of calcium ions as carbonate and sulfate minerals. The subsequent decrease in the ratio across the sabkha is attributed to dolomitization of pre-existing aragonite and calcite (Curtis and others, 1963; Illing and others, 1965; Kinsman, 1966) by the reaction:



In addition, a study of three sabkha cores suggests a quantitative relationship between dolomitization and gypsum formation (table 1, data in appendix). All samples contained dolomitized carbonate mud. Sample A at station 32 con-

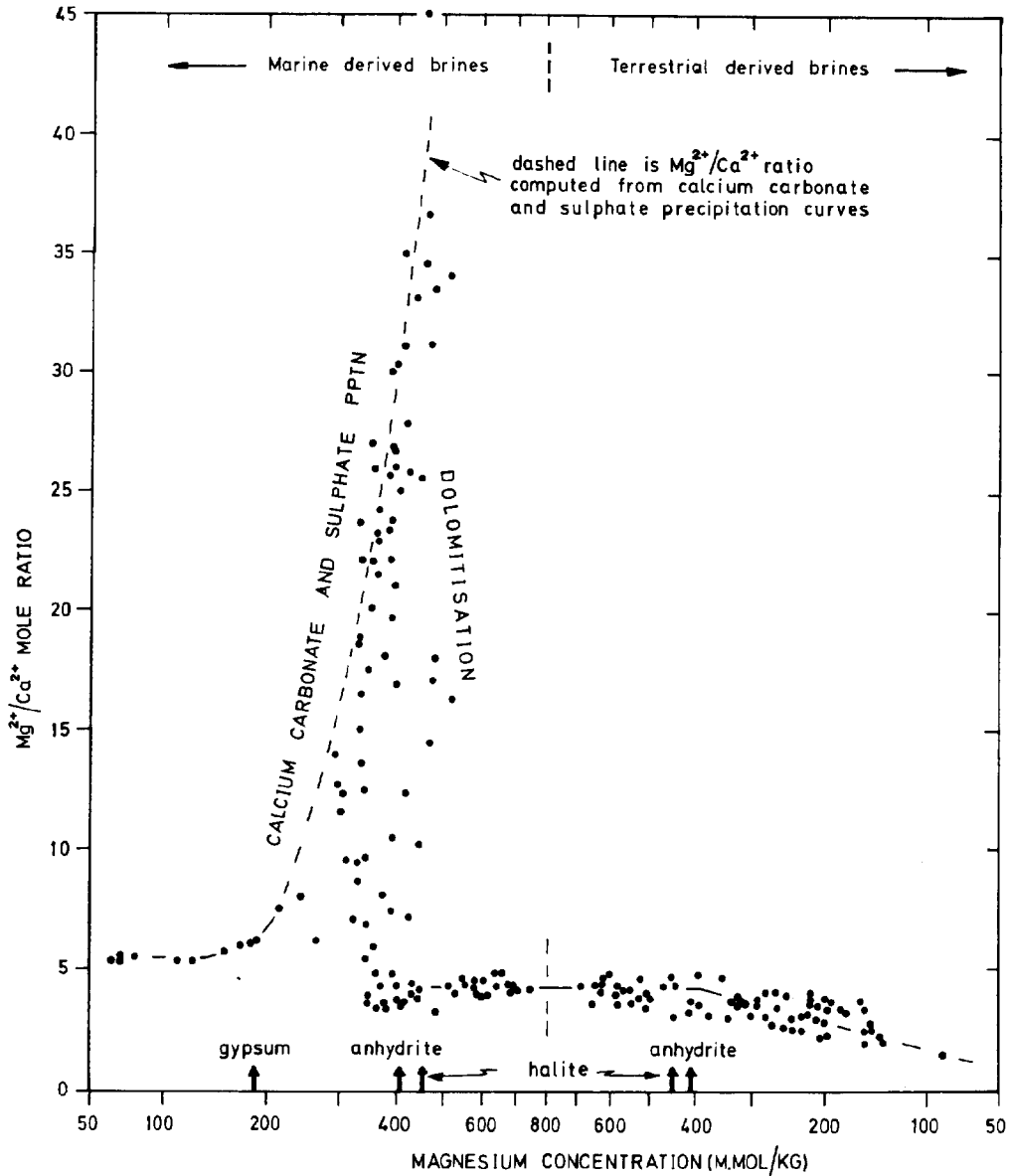


FIG. 8.—Variation in magnesium-to-calcium ratio with magnesium concentration across the sabkha. Brines from outer flood recharge zone have magnesium-to-calcium mole ratios of approximately 4 and magnesium concentration greater than 450 m.mol/kg. See data points near base of figure.

tained anhydrite; the remaining samples, gypsum crystals.

The calculated addition of calcium to the deeper brine samples as a consequence of the carbonate/brine reaction, and the subsequent adjustment of equilibrium with sulfate ions, compared remarkably well with the observed increase of calcium in the deeper brines. Wells

(1962) similarly concluded that dolomitization and gypsum precipitation were concurrent processes.

An almost constant  $Mg^{2+}/Ca^{2+}$  ratio with increasing ionic strength and magnesium concentration would suggest that near equilibrium conditions existed between brines and associated dolomite, gypsum and (or) anhydrite, and

halite. Such a constant ratio was observed in the brines from the outer flood recharge zone (fig. 8).

CONCLUSIONS

(1) The brines and diagenetic evaporite minerals developed in the Abu Dhabi sabkha show zonation based on the frequency of periodic flooding by sea waters and its subsequent soaking down into the sediments (flood recharge).

(2) The present elevation of evaporite development in the sabkha is determined by the level of flood water above the level of high tide. Subsequent development of evaporites above this elevation in the same area would only come about by down warping of the sabkha and (or) rise in sea level. Continued prograding of the shore line would yield a widespread deposit of evaporites of uniform thickness without change in sea level or down warping.

(3) Most of the anhydrite in the sabkha is of secondary origin; the component ions being derived from gypsum. There is no conclusive evidence to suggest that any anhydrite has formed by direct precipitation from concentrated sea water.

(4) The  $Mg^{2+}/Ca^{2+}$  balance of evaporite brines is controlled in part by evaporation leading to precipitation of calcium carbonate and gypsum, and in part by concomitant dolomitization causing gypsum precipitation.

(5) Three major diagenetic facies occur in the sabkha. Gypsum precipitation and dolomitization are essentially limited to a 2- to 3-mile wide belt adjacent to the lagoon margin. This belt is characterized by a high average frequency of flooding. In the mid-sabkha, brine compositions are consistent with an approach to mutual equilibration of brines and evaporitic-carbonate minerals. The landward margin of the sabkha is characterized by retrogressive diagenesis. The location of the progressive and the retrogressive diagenetic facies has moved seaward with the progradation of the shore line.

(6) The similarity between the stratigraphy and mineralogy of some Ordovician, Silurian, Pennsylvanian, and Jurassic evaporite sequences and the sabkha on the Trucial Coast, suggest that evaporites of supratidal origin may be more common in older evaporite rocks than previously realized.

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APPENDIX

Sample and Analytical Procedures and Data

The major portion of the field work was carried out by sampling in regularly spaced pits, dug along lines oriented to cross the various sabkha zones. Most sampling was done along one sampling line (sampling line 1, figure 3) at a spacing of about 660 feet. Other shorter sampling lines were established to obtain information on areal variations and in places of special-

TABLE 1.—Quantitative relationship between dolomitization and calcium sulphate formation\*

Station	Sample line (1)			
	Sample A depth 6 in.	Sample B depth 26.5 in.	Difference B-A	
	Cl <sup>-</sup>	146.3	151.2	+4.9
	Mg <sup>2+</sup>	302	265	-37
	SO <sub>4</sub> <sup>2-</sup>	60	35	-25
	Ca <sup>2+</sup>	26	43	+17
	or	74 CaCO <sub>3</sub> + 37 Mg <sup>2+</sup> = 37 CaMg(CO <sub>3</sub> ) <sub>2</sub> + 37 Ca <sup>2+</sup>		
	sediment	brine	dolomite	brine
	and	37 Ca <sup>2+</sup> + 25 SO <sub>4</sub> <sup>2-</sup> = 25 CaSO <sub>4</sub> + 12 Ca <sup>2+</sup>		
	brine	brine	gypsum	brine
Station 34	Sample B depth 19 in.	Sample C depth 28 in.	Difference C-B	
	Cl <sup>-</sup>	157.0	160.9	+3.9
	Mg <sup>2+</sup>	481	445	-36
	SO <sub>4</sub> <sup>2-</sup>	60	43	-17
	Ca <sup>2+</sup>	27	44	+17
	72 CaCO <sub>3</sub> + 36Mg <sup>2+</sup> + 17SO <sub>4</sub> <sup>2-</sup>			
		= 36CaMg(CO <sub>3</sub> ) <sub>2</sub> + 17CaSO <sub>4</sub> + 19Ca <sup>2+</sup>		
Station 39	Sample B depth 10 in.	Sample C depth 16 in.	Difference B-A	
	Cl <sup>-</sup>	140.8	149.5	+8.7
	Mg <sup>2+</sup>	436	392	-44
	SO <sub>4</sub> <sup>2-</sup>	125	82	-38
	Ca <sup>2+</sup>	13	19	+6
	88CaCO <sub>3</sub> + 44Mg <sup>2+</sup> + 38SO <sub>4</sub> <sup>2-</sup>			
		= 44CaMg(CO <sub>3</sub> ) <sub>2</sub> + 38CaSO <sub>4</sub> + 6Ca <sup>2+</sup>		

\* Cl<sup>-</sup> in gm/kg; Mg<sup>2+</sup>, SO<sub>4</sub><sup>2-</sup>, Ca<sup>2+</sup> in m. mol/kg

ized interest (sampling lines 2, 3, and 4, figure 3). Multiple samples were taken in a small area in the extreme southeastern part of the area (sampling area 4, samples 1A through 1T, figure 3). In all, 260 samples of interstitial brines and surface samples of lagoon water were taken for analysis. The brines were analyzed for specific gravity, chloride (total

halides), calcium, magnesium (plus strontium), sulfate, and in part for potassium. The data are summarized in table 2; temperature (February to April 1964) and sediment type are also indicated.

Interstitial fluids squeezed from the sabkha sediments constituted the bulk of the samples used for analysis. Other samples were of brines

TABLE 2.—Analytical data

<u>Key</u>	
(W)	= Groundwater sample. All other samples are interstitial waters
C	= Lime mud (aragonite, high and low magnesian calcite)
H	= Algal mat + interlayered lime mud
M	= Algal mat + interlayered lime mud + gypsum crystals
S	= Lime mud + shells (ceritherids) + selenite gypsum crystals
B	= Detrital Pleistocene quartzose sand
G	= Gypsum crystal mush
(G)	= Corroded gypsum crystals
[G]	= Gypsum crystals after anhydrite
A	= Anhydrite
(G)/A	= Coexisting gypsum and anhydrite, where gypsum is dehydrating to anhydrite
Intertidal zone	: Sample line 1: samples 42 to 41 Sample line 2: samples 1 to 13
Inner flood recharge zone	: Sample line 1: samples 40 to 38 Sample line 2: samples 14 to 22
Intermediate flood recharge zone:	Sample line 1: samples 37 to 32 Sample line 5: samples 10 to 18; 25 to 27
Outer flood recharge zone	: Sample line 1: samples 31 to 9 Sample line 5: samples 1 to 9; 19 to 24; 28 to 30
High supratidal zone	: Sample line 1: samples 8 to 1 Sample line 3: samples 3 to 1 Sample area 4: samples 1A to 5T Sample line 5: samples 31 to 34 Sample 12T/1

TABLE 2.—(continued)

Sample Loc.	Depth (ins.)	Sediment/ Brine Type	T°C	Specific Gravity	grams per kilogram solution, of			
					Cl <sup>-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	SO <sub>4</sub> <sup>2-</sup>
NORMAL SEA WATER (Salinity 35 <sup>0</sup> /oo)			22-24	1.024	19.35	0.41	1.29	2.71
LAGOON SAMPLES								
L1	surface	(W)	25.6	1.030	23.14	0.49	1.57	3.25
L2	"	(W)	24.4	1.031	24.52	0.52	1.68	3.35
L3	"	(W)	26.0	1.032	23.30	0.48	1.60	3.24
L4	"	(W)	25.4	1.033	24.40	0.49	1.66	3.39
L5	"	(W)	26.0	1.037	28.12	0.56	1.91	3.94
SABKHA SAMPLES								
<u>Sample line 1</u>								
42	-	(W)	24.7	1.119	91.47	1.22	5.86	9.30
41	-	(W)	26.5	1.171	122.9	0.68	8.87	14.14
40A	2	G	-	1.194	136.6	0.48	10.07	11.73
B	4	S	-	1.204	142.8	0.53	11.17	15.33
39A	5	G	32.5	1.202	140.8	0.53	10.61	11.99
B	19	S	-	1.197	149.5	0.75	9.54	7.84
38A	2	G + C	38.4	1.198	141.5	0.40	11.08	16.81
B	13	C	29.0	1.201	149.2	0.60	11.39	-
37A	2	(G)/A	36.0	1.192	145.6	0.51	11.27	10.68
B	10	S	28.0	1.210	150.4	0.57	11.60	-
C	16	S	29.0	1.202	151.5	0.70	10.92	11.50
36A	2	A	-	1.193	146.8	0.61	10.23	11.17
B	8	G	-	1.196	152.0	0.66	10.36	11.65
35A	6	G	26.0	1.197	149.5	0.61	12.59	10.59
B	24	S	29.5	1.212	156.5	1.13	11.58	-
34A	2	A	38.0	1.213	156.4	1.13	11.21	8.32
B	19	S	29.5	1.218	157.0	1.07	11.69	5.77
C	28	S	30.0	1.196	160.9	1.75	10.82	4.11
33A	7.5	G + C	26.5	1.199	159.1	1.28	12.62	4.19
B	34	S	30.0	1.206	158.0	2.11	9.48	2.23
32A	6	C + A	26.0	1.194	146.3	1.05	7.36	5.78
B	26.5	S	30.0	1.189	151.2	1.70	6.45	3.37
31A	2	B + A	28.0	1.204	158.4	1.44	9.60	3.59
B	9	C	30.5	1.201	157.6	1.84	9.03	-
C	12.5	M	28.8	1.207	157.7	2.27	8.62	2.65
D	26.5	S	29.0	1.214	156.2	2.50	8.18	-
30A	2	A	28.7	1.202	156.4	1.36	10.17	4.23
B	5	M	30.1	1.198	156.3	1.85	10.23	3.07
29A	3	B + A	28.5	1.196	156.3	1.29	7.55	4.42
B	8.5	G	30.8	1.195	151.2	1.52	8.07	2.98
C	13	M	31.1	1.203	155.7	1.40	8.09	3.11
D	31	S	29.5	1.200	155.1	2.29	-	2.47
28A	2	B + A	-	1.193	155.8	1.40	8.24	3.95
B	10	(G)/A	30.1	1.203	154.3	1.81	7.80	3.01
C	20	M	30.0	1.199	158.0	2.00	8.35	2.81
D	32	S	30.5	1.202	157.2	-	-	2.42
27A	3	A	29.0	1.193	151.1	2.97	8.74	1.95
B	13.5	(G)/A	30.6	1.197	159.4	3.30	9.60	1.59

TABLE 2.—(continued)

Sample Loc.	Depth (ins.)	Sediment/ Brine Type	T°C	Specific Gravity	grams per kilogram solution, of			
					Cl <sup>-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	SO <sub>4</sub> <sup>2-</sup>
27C	22	M	29.6	1.204	159.3	3.50	9.06	1.47
D	34	S	29.6	1.197	159.6	3.90	8.45	1.60
26A	2	B + A	28.6	1.202	155.8	3.59	8.51	1.58
B	10	(G)/A	30.5	1.202	161.7	4.37	10.89	1.06
C	12.5	G	30.8	1.190	163.0	4.45	11.03	1.19
D	20.5	M	29.5	1.186	162.9	4.54	10.61	1.44
E	32.5	S	29.0	1.192	161.2	4.62	9.94	1.26
25A	2	B	24.5	1.182	163.3	3.95	8.53	-
B	10	A	29.0	1.206	160.5	3.74	9.68	0.81
C	13.5	(G)/A	29.0	1.204	161.2	4.66	9.39	-
D	17	M	29.5	1.205	159.5	4.60	9.33	1.04
E	24	H	29.0	1.203	159.7	4.59	9.28	-
F	40	S	28.5	1.193	158.7	4.46	8.86	1.21
24A	2	B	40.7	1.209	161.5	5.55	14.44	-
B	15.5	A	30.5	1.200	166.4	5.97	14.21	0.88
C	20.5	(G)	30.0	1.210	165.3	6.10	14.54	0.44
D	34	S	29.5	1.198	165.0	5.21	12.96	0.88
23A	13	A	29.5	1.211	162.8	6.24	16.57	-
B	20	(G)	30.0	1.207	165.4	6.15	15.95	0.73
C	41	S	29.0	1.198	166.3	5.81	14.22	1.03
22A	12	A	29.0	1.205	162.5	4.70	10.85	-
B	17	A	30.0	1.212	161.1	4.48	10.08	1.15
C	22	M	30.0	1.212	161.5	4.39	9.83	1.13
D	36	S	29.3	1.205	161.2	4.23	9.29	-
21A	2	B	26.3	1.202	165.6	3.96	10.57	-
B	14.5	A	29.5	1.202	167.5	5.23	14.68	3.23
C	22	A	29.7	1.204	166.1	5.06	14.10	0.90
D	34.5	M	29.5	1.198	165.4	5.02	13.44	1.13
E	45	S	29.0	1.201	163.4	4.79	12.50	-
20A	2	B + A	28.4	1.208	164.9	4.84	13.41	-
B	9.5	A	29.0	1.213	166.3	4.47	18.21	0.80
C	16.5	A	29.5	1.207	166.2	5.56	16.07	0.82
D	31	M	29.0	1.210	166.2	5.35	15.50	-
E	48	S	28.5	1.213	164.7	5.14	13.65	1.00
19A	3.5	B	26.0	1.188	164.4	5.49	14.09	-
B	8.5	A	28.0	1.196	169.6	7.15	18.28	0.56
C	14	A	29.5	1.193	169.8	6.77	17.32	0.65
D	26.5	M	29.5	1.200	167.8	6.65	16.68	0.77
E	46	S	28.0	1.212	165.3	6.39	15.04	0.81
18A	2	B	25.5	1.224	162.1	3.76	10.80	-
B	8	A	25.7	1.216	163.7	6.43	16.67	0.68
C	14	A	28.3	1.205	164.7	5.96	15.20	0.70
D	23.5	M	29.0	1.206	162.6	5.78	14.24	0.93
E	42	S	28.0	1.207	161.2	5.21	12.06	1.01
17A	2.5	B	25.0	-	-	-	-	-
B	12.5	A	29.5	1.199	164.8	5.27	14.93	0.89
C	21	A	29.0	1.202	163.5	4.91	14.67	0.86
D	29.5	M	28.0	1.205	160.0	4.55	12.67	1.12
16A	2	B	24.0	1.203	167.6	5.86	15.13	0.59
B	14.5	A	29.2	1.202	166.2	5.91	15.50	0.80
C	20.5	A	29.0	1.198	164.2	5.39	14.19	0.29

TABLE 2.—(continued)

Sample Loc.	Depth (ins.)	Sediment/ Brine Type	T°C	Specific Gravity	grams per kilogram solution, of			
					Cl <sup>-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	SO <sub>4</sub> <sup>2-</sup>
16D	26.5	(G)/A	28.5	1.199	163.0	5.24	13.50	0.99
E	30	M	28.0	1.198	162.2	5.15	13.36	0.90
15A	2	B	32.0	1.200	162.6	4.04	10.74	0.98
B	8	B + A	28.0	1.204	165.7	5.91	14.18	0.85
C	20	A	30.0	1.196	164.5	5.06	12.21	0.41
D	30	M	29.0	1.200	162.5	4.32	11.32	0.78
E	42	S	28.0	1.195	159.0	4.42	10.00	1.22
14A	3	B	27.0	1.204	165.6	5.75	13.00	1.00
B	14	B + A	29.0	1.205	166.8	6.95	15.80	0.73
C	20	A	29.6	-	-	-	-	0.60
D	38	M	28.8	1.201	164.2	5.33	11.74	1.06
E	50	S	28.3	1.201	162.2	4.84	-	1.12
13A	2	B	25.0	1.200	164.0	4.96	9.44	1.28
B	24	A	28.6	1.200	163.7	6.05	12.43	2.66
C	36	H	28.3	1.200	163.8	5.86	13.09	0.98
D	48	S	28.0	1.199	162.4	4.63	9.09	1.66
12A	2	B + A	21.5	-	-	-	-	-
B	16	A	29.0	1.201	162.3	5.19	10.07	0.93
C	33	M	28.0	1.184	152.7	4.38	8.41	1.05
D	45	S	28.0	1.193	158.3	4.41	9.56	1.21
11A	2	B + A	-	1.181	148.2	3.05	3.75	2.09
B	20	G	30.0	1.195	157.8	3.66	5.48	1.41
C	33	C	28.5	1.193	157.1	3.58	5.57	2.48
10A	2	B + A	26.0	1.196	159.8	3.39	4.80	1.56
B	17	A	30.0	1.199	162.9	3.90	6.08	1.21
C	26	M	29.0	1.196	161.0	3.67	5.78	1.32
D	38	H	28.0	1.195	159.8	3.09	5.80	1.35
9A	2	B	32.0	1.169	139.0	2.74	3.45	2.56
B	7	G	31.5	1.165	135.4	2.71	3.36	1.01
9		(W)	30.5	1.177	141.4	2.64	3.70	6.96
8A	2	B + A	32.0	1.191	154.5	3.60	6.67	-
B	13	A	30.0	1.193	156.1	3.91	6.42	1.28
8		(W)	29.0	1.194	154.7	3.75	7.34	3.55
7A	2	B + A	26.5	1.190	156.0	3.47	6.83	1.57
B	18	B + A	28.0	1.195	158.9	3.51	7.73	1.43
C	24	A	29.0	1.189	153.3	3.37	7.48	1.53
7		(W)	29.0	1.190	151.3	3.24	7.74	4.77
6A	2	B	29.0	1.201	161.9	3.15	5.77	1.60
B	12	B + A	30.5	1.196	161.6	3.29	7.06	1.49
C	24	A	29.5	1.190	156.0	3.14	6.99	1.49
5A	2	B	27.5	1.199	161.2	2.58	11.50	2.07
B	16	B + A	28.0	1.186	151.4	2.65	6.68	1.96
C	22	A	28.0	1.183	148.7	2.55	6.35	2.21
5		(W)	28.5	1.182	144.3	2.47	6.17	3.04
4A	2	B	26.0	1.196	159.0	2.62	9.52	2.03
B	18	B + A	30.0	1.189	153.1	2.90	6.26	1.74
3A	2	B	24.0	1.197	159.1	2.93	5.59	1.72
B	12	B + A	28.5	1.197	158.9	3.56	8.07	1.91
C	22	C + A	28.0	1.197	158.4	3.39	7.64	1.46
3	-	(W)	27.5	1.198	158.3	3.35	7.79	0.99



TABLE 2.--(continued)

Sample Loc.	Depth (ins.)	Sediment/ Brine Type	T°C	Specific Gravity	grams per kilogram solution, of			
					Cl <sup>-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	SO <sub>4</sub> <sup>2-</sup>
2A	2	B + A	23.5	1.197	160.2	2.34	4.99	2.08
B	13	B + A	29.5	1.190	155.0	2.58	6.26	1.96
C	32	B + A	29.2	1.197	149.9	2.38	5.20	2.33
2	-	(W)	27.5	1.181	144.8	2.36	4.89	2.27
1	-	(W)	27.5	1.176	140.6	2.07	4.68	3.00
<u>Sample line 2</u>								
1	-	(W)	30.5	1.160	118.3	0.61	8.16	14.13
3	-	(W)	28.7	1.058	44.23	0.96	3.06	6.22
4A	6	C	23.5	1.062	47.21	1.03	3.47	6.61
5A	2	H	24.5	1.071	55.73	1.07	3.74	7.44
B	13	C	24.0	1.085	63.60	1.21	4.44	9.00
6A	2	H	26.0	1.080	60.35	1.14	4.17	8.30
7A	2	M	-	1.088	65.13	1.22	4.54	9.06
8A	2	M	-	1.098	73.47	1.14	5.25	10.12
9A	2	M	-	1.133	97.93	0.84	7.12	9.51
10A	2	G	29.0	1.154	112.4	0.71	8.01	13.27
B	12	C	24.3	1.174	121.2	0.70	8.56	13.42
11A	2	G	30.5	1.157	116.8	0.71	8.01	13.12
B	16	C	24.5	1.168	123.0	0.65	8.67	14.32
12A	2	G	31.0	1.172	126.5	0.60	8.07	13.49
B	8	C	25.0	1.178	132.3	0.58	8.67	13.21
13A	2	G	-	1.172	133.6	0.58	8.58	14.24
14A	2	G	36.0	1.144	117.9	0.83	9.11	10.12
B	7.5	M	28.8	1.152	121.5	0.70	9.49	12.78
C	20	C	28.0	1.168	124.3	0.79	8.30	12.17
15A	2	G	37.5	1.171	128.4	0.63	8.87	12.75
B	7.5	M	28.5	1.176	129.4	0.61	8.91	13.03
C	19.5	C	28.0	1.173	130.6	0.64	8.88	12.96
16A	3	G	36.8	1.177	136.0	0.66	9.48	13.23
B	21	S	28.0	1.184	138.2	0.65	9.82	12.71
C	33	S	28.5	1.179	135.7	0.60	9.37	12.56
17A	2	G	36.0	1.182	138.4	0.66	9.38	12.31
B	6	S	30.8	1.181	135.7	0.71	9.53	15.61
C	21	S	28.5	1.178	137.3	0.89	8.13	7.61
18A	2	G	36.0	1.182	136.4	0.52	9.45	13.47
B	6.5	S	30.0	1.181	139.7	0.53	9.71	13.11
C	22	S	29.0	1.187	146.1	0.54		12.93
19A	2	G	39.6	1.185	140.5	0.59	9.63	12.20
B	14	S	29.5	1.189	143.5	0.61	9.63	10.73
20A	2	(G)/A	43.4	1.183	143.1	0.81	9.67	11.71
21A	2	(G)	42.8	1.170	133.1	0.96	8.28	9.83
22A	2	(G)	46.5	1.172	131.6	0.98	7.24	9.64
23A	2	(G)	46.1	1.167	129.6	0.99	7.41	10.05
24A	2	(G)/A	47.1	1.205	152.4	0.60	8.70	10.91
25A	2	(G)/A	42.4	1.192	143.1	0.83	8.17	8.99
26A	2	(G)/A	41.9	1.195	147.6	0.98	8.09	5.83

TABLE 2.—(continued)

Sample Loc.	Depth (ins.)	Sediment/ Brine Type	T°C	Specific Gravity	grams per kilogram solution, of			
					Cl <sup>-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	SO <sub>4</sub> <sup>2-</sup>
<u>Sample line 3</u>								
3	-	(W) G	27.5	1.143	115.9	1.72	3.91	4.14
2	-	(W) G	27.0	1.138	112.5	1.75	3.92	4.11
1	-	(W) G	25.0	1.132	106.9	1.74	3.75	4.42
<u>Sample area 4</u>								
1A	-	(W) [G]	27.7	1.163	128.1	2.14	5.40	3.62
1B	4	A	-	1.187	153.0	2.38	2.12	3.36
1C	30	[G]	-	1.176	145.4	1.32	4.46	3.29
2D	12	[G]	26.0	1.146	126.5	2.51	3.36	3.58
2E	12	[G]	27.4	1.164	132.5	2.46	3.78	2.71
2F	12	A	27.0	1.192	153.9	2.97	8.54	1.77
3G	-	(W) [G]	29.4	1.186	146.1	2.38	5.08	2.69
3H	-	(W) A	29.4	1.169	150.3	2.42	5.28	1.13
3I	2	[G]	34.0	1.160	129.6	2.11	5.25	3.39
3J	7	A	27.5	1.178	148.4	2.18	3.69	2.62
3K	2	A	36.5	1.187	151.6	2.36	3.59	3.12
3L	14	A	29.5	1.188	151.0	2.14	4.68	2.49
4M	-	(W) [G]	-	1.181	146.3	2.33	5.25	2.67
4N	-	(W) A	-	1.186	167.5	2.50	5.35	0.31
5O	-	A	-	1.164	132.2	2.09	4.23	3.41
5P	-	[G]	-	1.174	141.8	2.10	4.31	2.98
5Q	-	[G]	-	1.174	141.0	2.31	5.33	2.75
5R	-	A	-	1.187	150.0	2.25	4.77	2.39
5S	-	(W) [G]	28.5	1.170	137.2	2.13	4.87	3.50
5T	-	[G]	-	1.175	141.0	2.13	4.86	3.51
<u>Sample 12T/1</u>								
12T/1	-	(W) A	22.0	1.226	172.9	34.2	23.8	0.11

(Table 2 continued on following page)

TABLE 2.—(continued)

Sample Loc.	T <sup>o</sup> C	Specific Gravity	grams per kilogram solution, of				
			Cl <sup>o</sup> / <sub>100</sub>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	SO <sub>4</sub> <sup>2-</sup>	K <sup>+</sup>
<u>Sample line 5</u>							
1	24.0	1.177	143.3	2.96	5.53	2.12	2.91
2	24.5	1.182	145.3	2.82	5.81	1.73	-
3	24.0	1.184	146.2	2.96	5.99	1.27	2.95
4	25.0	1.181	145.3	3.14	5.52	1.86	-
5	25.0	1.185	148.5	3.38	5.74	1.49	2.92
6	25.0	1.181	145.2	3.20	6.28	2.12	-
7	25.0	1.180	142.6	2.98	5.83	2.21	2.92
8	25.0	1.174	151.1	3.14	5.44	2.36	-
9	25.5	1.184	148.1	3.19	5.83	2.15	2.93
10	26.0	1.196	156.6	2.58	6.86	2.27	-
11	25.0	1.197	156.8	3.34	8.25	1.74	2.92
12	27.0	1.197	159.7	3.15	7.48	1.84	-
13	25.2	1.194	155.1	2.93	7.51	2.07	3.15
14	26.7	1.190	152.4	2.77	6.42	2.51	-
15	28.5	1.196	155.4	2.92	7.91	1.93	3.65
16	26.2	1.195	155.7	3.29	8.41	1.73	-
17	25.3	1.198	152.2	3.33	8.24	1.70	3.63
18	25.5	1.193	148.3	3.10	8.67	2.09	-
19	22.8	1.192	152.6	2.85	6.67	2.13	3.05
20	27.5	1.192	147.4	2.38	6.27	2.45	-
21	28.0	1.193	148.6	2.09	6.13	1.83	2.86
22	30.5	1.193	149.1	2.63	7.55	1.90	-
23	-	1.194	150.0	2.45	8.12	1.71	3.22
24	27.5	1.191	148.1	2.60	7.10	1.87	-
25	28.0	-	-	-	-	-	-
26	28.0	1.189	145.7	1.69	8.30	1.94	-
27	25.8	1.201	153.9	1.44	11.64	2.54	3.52
28	26.5	1.198	154.5	2.56	9.09	1.83	-
29	26.3	1.183	146.0	2.49	5.02	1.73	2.03
30	27.0	1.189	147.1	2.68	5.49	1.60	-
31	27.0	1.175	136.6	2.77	4.88	1.97	1.80
32	26.4	1.179	138.9	2.82	5.13	1.11	-
33	25.5	-	-	-	-	-	-
34	25.7	1.183	141.9	2.75	5.35	1.02	1.93

that accumulated at the bottom of pits (3-4 feet deep) within the sediments. The interstitial sediment fluids were extracted in the field using a "squeezer" (Siever, 1962). A few drops of chloroform were added to the samples to nullify the possible action of suspended organic matter. Sediment samples for processing were taken at vertical intervals from within the sediments at the various sampling stations.

The techniques used for analysis of the brines were: (1.) chloride—titration, using sil-

ver nitrate with potassium chromate as indicator in neutral solution; (2) sulfate—gravimetric determination as barium sulfate (Bather and Riley, 1954); (3) magnesium plus calcium—titration using E.D.T.A. and Erichrome Black T as indicator; (4) calcium—selective titration in the presence of magnesium with E.G.T.A. using an indirect indicator of Zincon and Zinc—E.G.T.A. (Culkin, 1965); and (5) magnesium—determination by difference. The values are reproducible within the following limits as percent

of value reported: Chloride  $\pm 0.1\%$ ; Sulfate  $\pm 0.2\%$ ; Calcium  $\pm 0.3\%$ ; Magnesium  $\pm 0.4\%$ ; and Potassium  $\pm 2\%$ . Specific gravity was measured in the laboratory by weighing and is reproducible to within  $\pm 0.0005$  ( $22-24^{\circ}\text{C}$ ).

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