Qatar Univ. Sci. J. (2003), 23: 41-58

Geologic Evolution of the Dukhan salt flats in Western Qatar Peninsula, Arabian Gulf

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التطور الجيولوجي لمسطحات دخان الملحية في الجزء الغربي من شبه جزيرة قطر، الخليج العربي

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يظهر تحليل الصور الفضائية (الملتقطة من قبل الماسح النوعي لاندسات) لمسطحات دخان الملحية الواقعة على الساحل الغربي من دولة قطر الى وجود العديد من أنطقة الترسبات ضمن هذه المسطحات. وتشغل أنطقة الترسبات حوضا شبه تبخري ومحدد حركة المياه في الجزء الأسفل من القسم الشمالي الشرقي من منطقة السباخ الداخلية الكبيرة. تملأ هذه السباخ منخفضا مقعرا محددا بطية محدبة واسعة وقليلة الميل مشكلة قوس قطر الى الشرق وطية حقل دخان الحادة الواضحة الى الغرب. وتتشكل الترسبات التي تملأ المنخفض من ترسبات الغرين الكلسي والطين والرمل التي تكون مشبعة جدا بالملح البلوري كما تحتوي على طبقات من الطحالب. تتميز مسطحات دخان الملحية بملوحة مرتفعة جدا نتيجة للظروف المناخية الجافة السائدة واقتحام المياه البحرية والتدفق المالح من الجريان السطحي. وتتكون الترسبات الحالية بشكل رئيسي من الجبس وطبقة علوية من الملح محاطة بمقدار ثانوي من الكلسايت. وبسبب محتواها الملحي العالي، فأن هذه الترسبات الرطبة يمكن أن تمتص الرطوبة أثناء ليالي الصيف عندما تتجاوز الرطوبة النسبية ٩٠%. وفي المقطع العلوي جدا من قطاع المسطح، قد يفقد الجبس ماءه متحولا الى أنهايدرايت. وتبعا لذلك، يمكن أن تكون مسطحات دخان الملحية قد تعرضت الى دورة تبخرية في أحواض ملحية موسمية. ويقدر أن سباخ دخان قد نشأت خلال الخمسة آلاف سنة الأخيرة.

Key Words: *Dukhan, Qatar, Sabkha, Evaporite, Geology. Landsat*

ABSTRACT

Photo-interpretation of landsat Thematic Mapper images of the Dukhan salt flats, on the west coast of Qatar, reveals several deposit zonations within the salt flats. The deposit zonations occupy a restricted sub-evaporite basin in the lowest northeastern part of a large inland sabkha area. This sabkha occurrence is of limnic type, filling a recent synclinal depression bounded by a broad and gentle anticline forming the Qatar Arch to the east, and a conspicuous sharp anticline of the Dukhan anticline to the west. The sediments filling the depression are mainly calcareous silts, mud and sand, which are highly impregnated with crystalline salts and contain layers of algae. The Dukhan salt flats are characterized by a markedly high salinity (hypersaline), as a result of the prevailing dry climatic conditions, seawater intrusion, and saline influx from surface runoff. The present deposits consist primarily of gypsum and an uppermost dazzling white crust of halite, surrounded by minor amounts of calcite. With their high salt content, the hygroscopic sediments can absorb moisture during summer nights, when relative humidity may exceed 90 %. In the uppermost section of the flat profile, gypsum may lose its water and is transformed into anhydrite. Accordingly, Dukhan salt flats are considered to have undergone an evaporitic cycle of ephemeral saline basins. The Dukhan sabkha was developed within the last 5,000 year.

Introduction

The Arabian Gulf is an area of major recent carbonate sedimentation with contemporaneous deposition of sulphates (gypsum and anhydrite), carbonate and halite in the coastal lagoons, lakes and tidal zones. The study of these features provides a better understanding of the geological processes that formed the oil – bearing carbonate reservoirs and seals at the Arabian Gulf region through different geologic ages. Several researchers have studied these aspects of the Arabian Gulf and similar arid regions[1-15].

The coastal area of Qatar form is about 700 km². Sabkha deposits, of saline flats or plays with fine silts and calcareous sands, are widespread along the coastal margins of Qatar peninsula, especially along the eastern coast from south of umm Said to Khor El-Udied. Extensive inland sabkhas are found east of the Dukhan ridge (Dukhan sabkha) and along the southern frontiers with Saudi Arabia (Sauda Nathil sabkha). Dukhan sabkha of western Qatar is the largest and is of particular hydrological importance to Qatar.

Dukhan sabkha have been mentioned in a general way in most of the geological works on the Dukhan area or the whole Peninsula of Qatar [16-24].

However, Salt flats of the Dukhan sabkha have not yet been studied in detail. The present work is concerned mainly with studying the various geological and environmental conditions that influence the formation of salt flats in the Dukhan sabkha.

Geological Setting

Qatar forms an exposed part of the Arabian Shelf between the Arabian Shield and the mobile belt of Iran. It is located between 25° N and 51° E. Topographically, Qatar has a low relief landscape with a maximum elevation of about 103 meters above sea level. The major part of the peninsula has an average elevation of less than 40 m above sea level. Structurally, Qatar appears as an elliptical anticlinal arch with a North-South main axis (Fig. 1). The exposed geological succession is made up of Tertiary limestones and dolomites with interbedded clays, shale, gypsum and marls, covered in places by a series of Quaternary and recent deposits [17]. The Tertiary sedimentation started in Qatar with a marine transgression in the Paleocene. Shallow marine to sabkha conditions prevailed until the end of the Eocene. A carbonate-evaporite sequence (Rus and Dammam Formation) was deposited during this period. The sea regressed at the end of Eocene, and a widespread unconformity, causing the absence of Oligocene deposits over most of the area, marked the event.

Qatar lies within a torrid sub-region of the northern desert belt extending from North Africa to Central Asia. It is classified as being among the world's most arid desert regions. The study area is generally characterized by scanty, irregular and variable rainfall. The annual average ranges between 50 and 80 mm. The mean annual temperature is 25-26°C, with a mean minimum of 21°C and a mean maximum of 31°C, occasionally reaching 45-50°C in summer. Relative humidity ranges from 45% to more than 95% with a mean of 70%. Open water evaporation ranges from a minimum of 2 mm/day in December to 10 mm/day in June. The prevailing wind is from the NNW to NW direction.

The Dukhan salt flats area is located approximately 10 km east of Dukhan city, near the western coast of Qatar Peninsula, and at about 2 km south of the main Dukhan – Doha road (Fig 1). It occurs at the northern part of a wide and elongated depression, which is mostly occupied by sabkha deposits locally called Dukhan sabkha. These salt flats also contain the lowest point in Qatar Peninsula, which is six meters below the mean sea level.

Method of study

Sequential satellite images and aerial photographs of the study area have been used to detect changes on a regional scale. Various types of remotely – sensed data, covering the study area at different dates, have been thoroughly investigated to study the spatial distribution of the salt flats and to detect any temporal changes within the last 30 years. Normal black and white aerial photographs are available at scale 1:16,000, 1:38,000 and 1: 50,000 from different coverage studies of 1971, 1976, 1988 and 1998 respectively. Landsat digital data acquired from Multispectral Scanner System (MSS) in 1972 and from Thematic Mapper (TM) in 1985 and 2000 have been processed to produce thematic maps emphasizing the area of Dukhan sabkha and the encountered salts(Fig 2). Several field transects have been done across these salt flats at different seasons during the period between 1988 and 1996 and 2001.

Results

1. Remotely – Sensed Data Interpretation

The landsat images have been mainly used to delineate the configuration of the salt flats, which are characterized by bright white crust and very smooth texture. This high reflectance is found to represent the dry crystalline halite crust, which forms the nucleus of the salt flat surrounded by greyish zones of mixed halite – gypsum and gypsiferous soil, but without sharp boundaries (Fig. 3). The photographs can help only in delineating the shape of the salt crust and in detecting any changes in their areal extension. In addition, Landsat – TM images with their high spectral capability have been used to investigate any possible zonation of the evaporite minerals and their relative concentration within the salt flats. Various image-processing techniques have been applied to maximize spectral discrimination of the salt flats from the surrounding sabkha material. Enhanced false – color composite (FCC) images from Landsat – TM bands 7, 4 and 2 combined in red, green and blue (RGB) colors respectively, are found to produce a remarkable discrimination and zoning within the salt flats. Comparing the results obtained from the interpretation of sequential satellite data show a significant sharp variation and good zonation of the area covered by the salt flat (Fig. 3). Figure ٤ shows a detailed zonation of the salt crust drawn from the landsat images. Gypsum is commonly present as an accumulation in the subsoil above the bedrock or close to the soil surface as a crystallized layer of some 5 to 10 cm thickness. Halite covers the surface of

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the sabkha deposits, particularly in the northeastern part, where it forms a characteristic white, hard and uneven crust. The central part of the salt flat which appears in dark blue to purple, corresponds to halite and is surrounded by an irregular rim of greenish color, formed of mixed halite and gypsum (Fig. 3). A light blue zone, formed mostly of gypsum, follows this zone. Brines and saline water pools appear generally very dark or black (Fig. 3). The development of the salt crust in a period of three decade 1972 to 2000 is presented in Figure 4.

2. Geology of the Sabkha

The Dukhan anticline is bordered by the Dukhan syncline of a general NNW-SSE trend. The Dukhan sabkha depression represents a NNW-SSE synclinal structure bounded from the east by a broad anticline forming the Qatar Arch, and from the west by sharp conspicuous, oil– producing anticline forming the Dukhan hills (Fig. 1). Physiographically, the sabkha is characterized by its billarrd table flatness. In the northeastern part of Dukhan Sabkha, an extensive salt flat is well developed with thick layers of crystalline gypsum, a thin halite crust, and scattered small pools filled with brine encrusted with thick layers of well-formed gypsum crystals and halite cubes. The area forms a natural drainage basin for the surface runoff of rainwater, which becomes saline due to dissolution of halite and gypsum from the salt flat surface and from the dispersed evaporites in the surrounding catchment area. In the winter season, particularly during the rainy period of January to February, a water sheet accumulates in the area to form pools over the salt flat. By the end of summer, the intensive evaporation leads to spectacular shrinking of the salt crust leaving several hypersaline pools. In these pools and the surrounding area, evaporite minerals, mainly gypsum, anhydrite, and halite, and some dolomite, are formed. During the evaporation process, salt precipitates only after most of the gypsum has been formed. Upon burial, both temperature and pressure increase, and gypsum commonly loses its water and is transformed into anhydrite. Thus, surface gypsum can be regarded as a predecessor of subsurface anhydrite, which represents a good seal rock. However, anhydrite may also form on the surface when the calcium sulphate is exposed to high temperatures and / or higher salinities. The sabkha sediments consists mostly of brown, laminated, fine quartz and carbonate sand of both windblown and flood origin, with various quantities of gypsum.

The Zekreet ridge was formerly beach and dune ridge of carbonate sand. It is developed as the coast progressed southwards during the Pleistocene (Fig. 6). Inspire of Quaternary regression, the ridge is retreating gulf ward. The sabkha is characterized by numerous nebkhas, small mounds or dunes, about 1 to 2 m in diameter, of blown silt, developed around the small halophytic shrubs. The flat surface between the mounds has a thin, firm crust surrounded by halite and gypsum. Depth of groundwater ranges between a few centimeters to 120 cm. The groundwater beneath the water table is hypersaline (Table 1). The sabkha slopes gently northward toward the Zekreet ridge, adjacent to which the water table is closest to the surface. The brine probably receives seawater mainly by seepage through the Zekreet ridge.

3. Chemistry of brine water

Water samples from the main pool of the Dukhan salt flats were collected and analyzed in July of the years 1990, 1996 and 2001 and compared to analyses from [17]. The results of these analyses (Table 1) show a great variation in the chemical characteristics of these samples. The composition of the groundwater brine indicates derivation mainly from the Gulf through the Zekreet ridge. Na, K, Cl and SO_4 contents, electric conductivity and the total dissolved solids increased from the year 1970 through 2001, whereas Ca, Mg, HCO_3 and pH decreased. This is in accord with the field investigations and aerial photo interpretations which show that the deposition of halite and gypsum increased with time in the brine relative to dolomite and calcite. Total dissolved solids increased from 306 g/l in the year 1970 to 374 g/l in the year 2001 (Table 1). The water is saturated with halite and gypsum.

Discussion

Image processing of Landsat-TM bands 2, 4, and 7 combined in blue, green and red respectively, is found to produce an informative color composite image showing the horizontal concentric zoning within the Dukhan salt flats (Fig. 7). Being formed in a depression with an internal drainage, and the prevailing arid climate support considering the Dukhan salt flats as "ephemeral saline basins[25]. Zonation of evaporite minerals is due to evaporative concentration of saline water or brines precipitating evaporites of increasing solubility progressively away from the brines source. This results in a concentric zonation with the most soluble salts at the center and the least soluble ones towards the edge of the salt flat. On the other hand, evaporites, which precipitate from rising groundwater, have a vertical zoning, with the precipitation of the most soluble minerals at the upper layers.

The Holocene sequence of sediments beneath the sabkha is similar in most places. It can be divided into a series of zones based on mineralogical characteristics (Fig. 8). Carbonate sediments underlie the sabkha. The lowest sediments consist of sand, silt and shelly limestone. These sediments probably represent lagoonal sediments. The second zone consists of laminated calcareous silty sandstone which contains gypsum crystals. This zone lies beneath the water table in contact with hypersaline groundwater. Zone 3 consists of medium to coarse-grained sand and contains coarse lenticular to tabular gypsum crystals. Zone 4 consists of light gray silt and fine-grained gypsum crystals. The uppermost zone consists of laminated fine-grained sand with plant roots and dispersed halite and gypsum. Laminar algal mats are found only in the northern part of the sabkha.

The present sabkha surface reflects the last 5000 years of depositional [26, 27]. Depostion began when a rapid transgression infilled synclines and depressions with marine-reworked sediments around 3000 year PB (Fig. 8). About 4000 years ago the Arabian Gulf shoreline reached its maximum Holocene strandline. This was followed by progradation of the sabkha sequence to its present configaration. Wind deflation and local groundwater levels account for the flatness of the sabkha and have played an important role in creating the now well-known sabkha depositonal signature. Groundwater brines are largely derived from seepage of seawater through the very permeable sediments under the Zakrite ridge. The sediment sequences of the Dukhan sabkha are strikingly similar to those of the Supratidal sediment facies of Abu Dhabi and Kuwait of the Arabian [28,29] and the Mediterranean coast of Egypt [30].

The general history of the Dukhan sabkha during the Pleistocene has been one of regression and progradation of carbonate sediments. The Holocene has been characterized by a slow transgression [27]. A shallow sea presumably flooded the Sabkha depression (Fig. 6). Lagoon environment was created by the growth of Zekreet ridge, which was a low, narrow and incomplete barrier. With greater restriction and regression of sea, there was precipitation of gypsum in the lagoon. Blown sand and silts filled most of the lagoon; and sabkha was developed.

Under the prevailing arid climatic conditions, the land surrounding Dukhan sabkha only occasionally has surface runoff from storms, which may wash in dissolved and detrital material. Such water drains into this depression, dissolving salts on the way, and supplies different ions for evaporate minerals. Excessive evaporation leads to the lowering of the water level and eventually induces subsurface inflow of seawater through the surrounding carbonate formation. When the evaporation rate exceeds the inflow rate, the water completely evaporates, leaving a relatively thin layer of evaporate minerals. Towards the end of the dry season in successive years, extensive evaporate precipitation takes place inside the pools and within the surrounding sabkha deposits. Algal and/or halo-bacterial blooms, which are related to specific salinity levels, give the pools and their margins a reddish-brown, pink, or greenish appearance. Finally, layers of halite may precipitate over the gypsum, forming a hard surface crust that reduces surface erosion of sabkha deposits by wind action.

Table (1) Chemical Analysis of Brine Samples Collected at different periods From the main surface pool of the Dukhan Sabkha.

Sample Year	DK-C 1970(C)	DK-2 1990	DK-3 1996	DK-4 2001	Ground water	Gulf water
ppm						
Na	115.38	44.5	45.0	45.0	9.95	20.0
K	0.4	0.80	1.45	1.5	-	0.76
Ca	1.52	1.1	0.63	0.51	0.8	0.85
Mg	2.22	11.22	9.8	5.21	1.46	1.8
HCO_3	46	38	31	22	15	-
Cl	182.5	146.86	150.0	150.67	15.0	35.0
SO_4	50	47.54	68.53	69.8	8.0	4.62
E.C*	-	51.5	55.5	56.0	-	-
TDS	306.7	316.6	367.1	373.9	35.35	63.12
pH		8.0	7.8	7.7		8.1

* Electroconductivity in µmho/cm

(C) Reference [17]

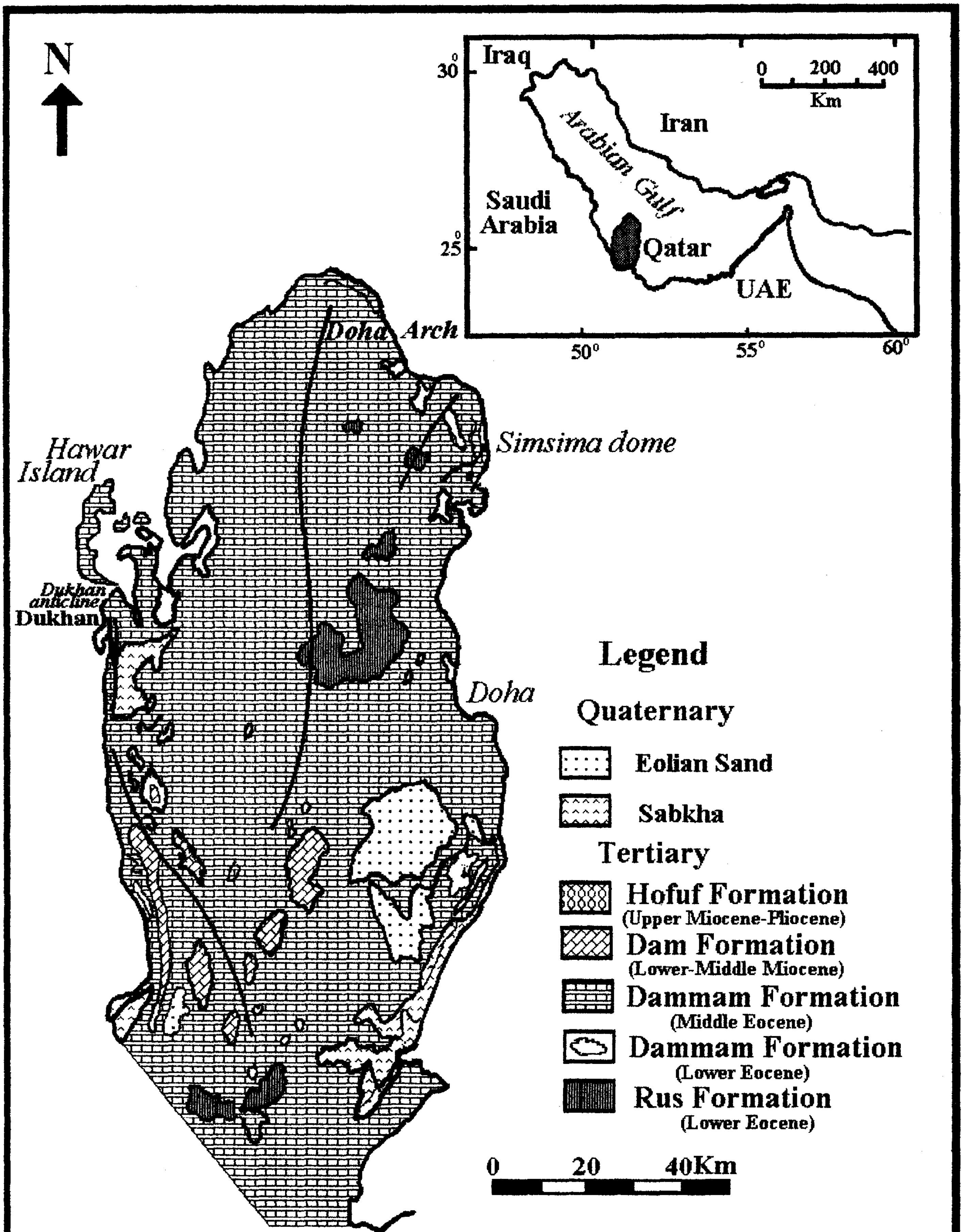
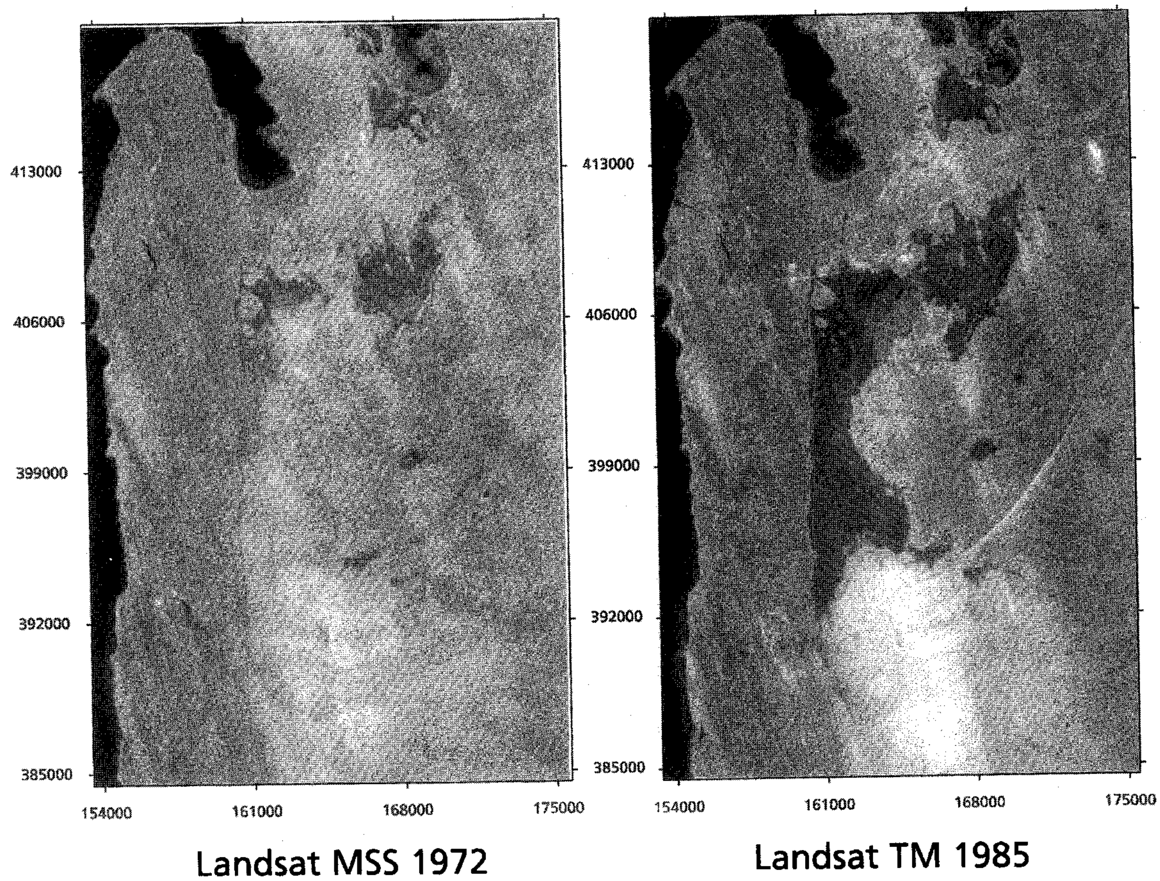


Fig.1. Geological Map of Qatar showing the study area.



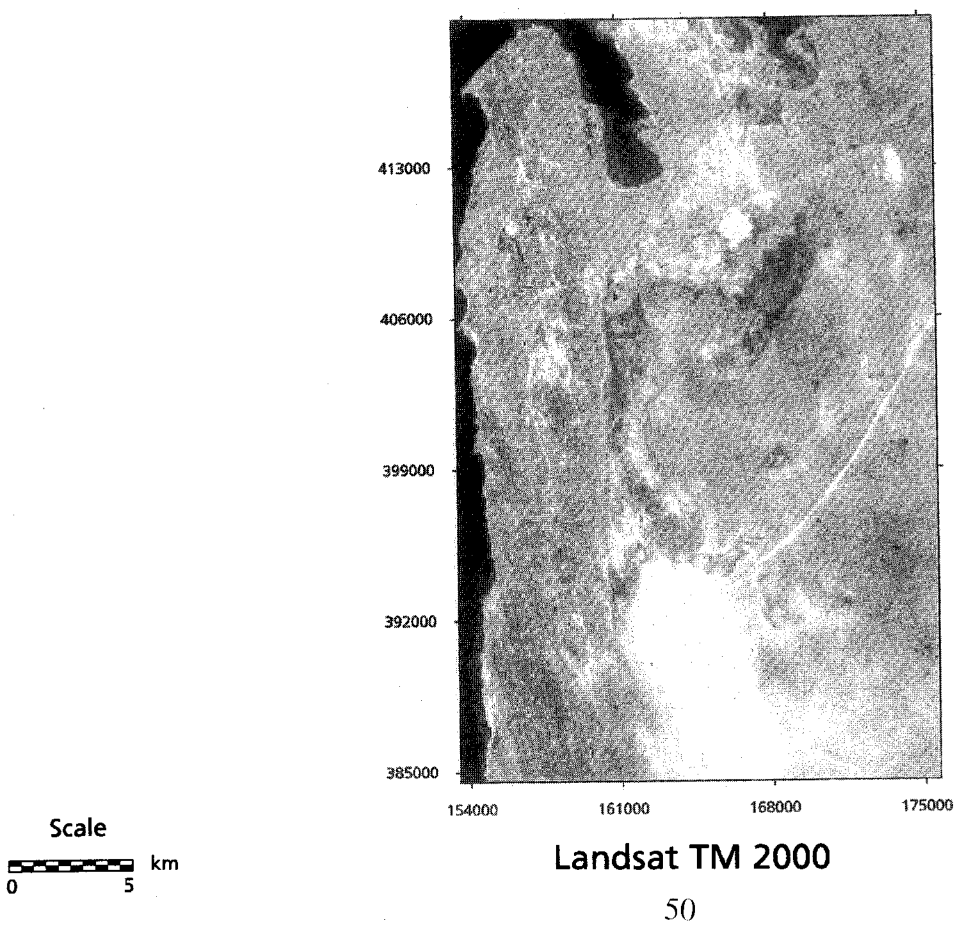


Fig.2. Dukhan Inland Sabkha , 1972 - 2000

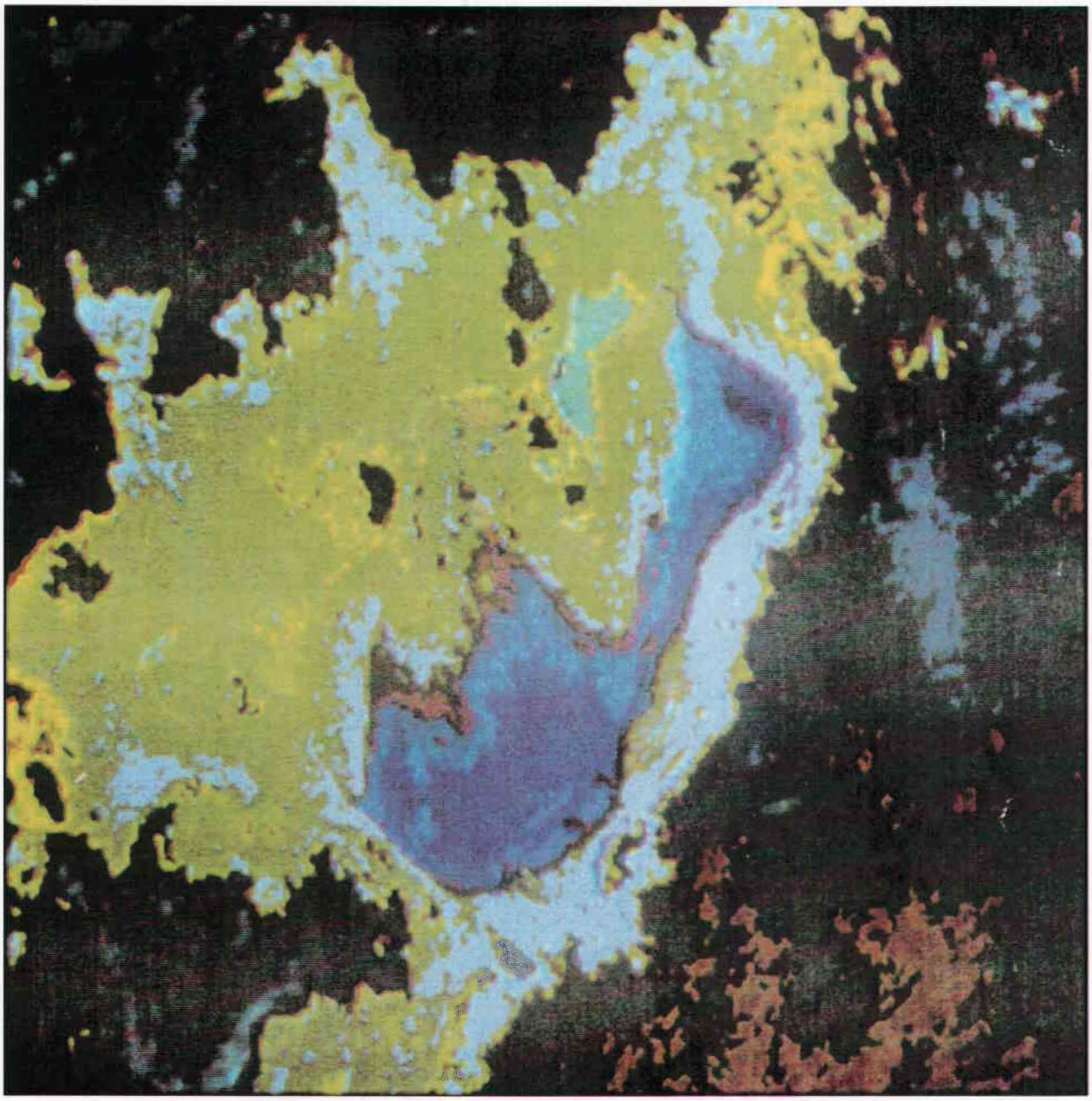


Fig. 3. Landsat Digital Data showing the zonation in salt crust within Dukhan Sabkha

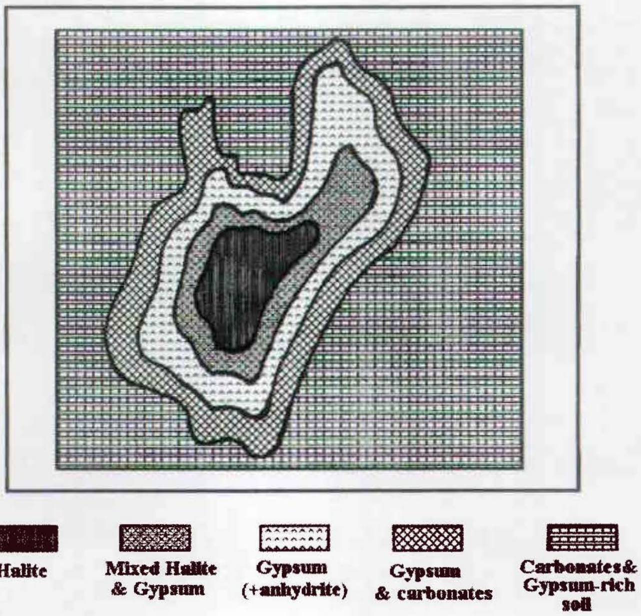


Fig.4. Development of the salt crust in the period 1972 - 2000.

Fig. 5. Detailed Geological zonation of Salt Crust

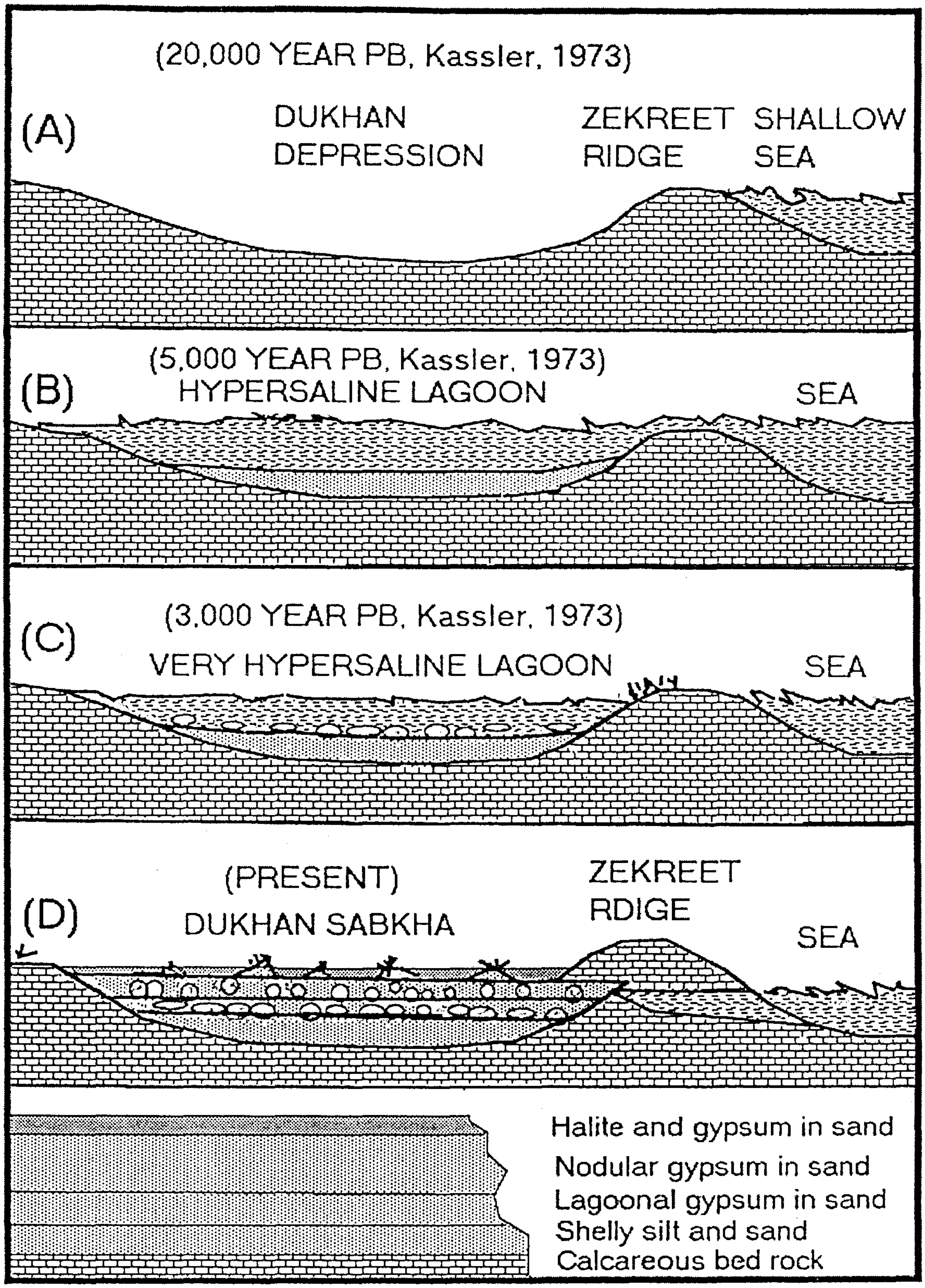


Fig.6. A typical profile through the Dukhan Sabkha.

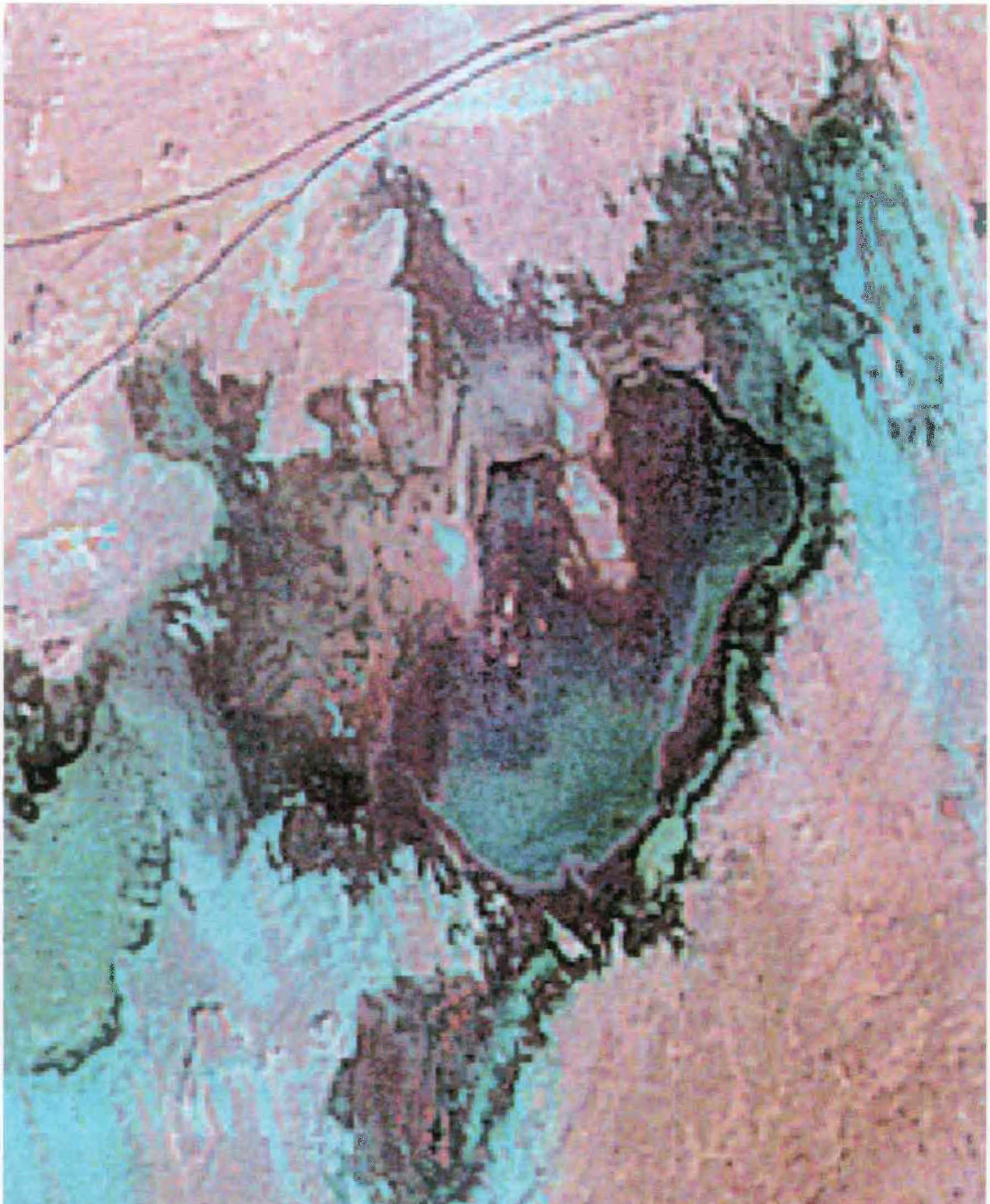


Fig. 7. Edge Enhancement of color composit 742 regarding subset of the salt flat in the northeast area of dukhan Sabkha

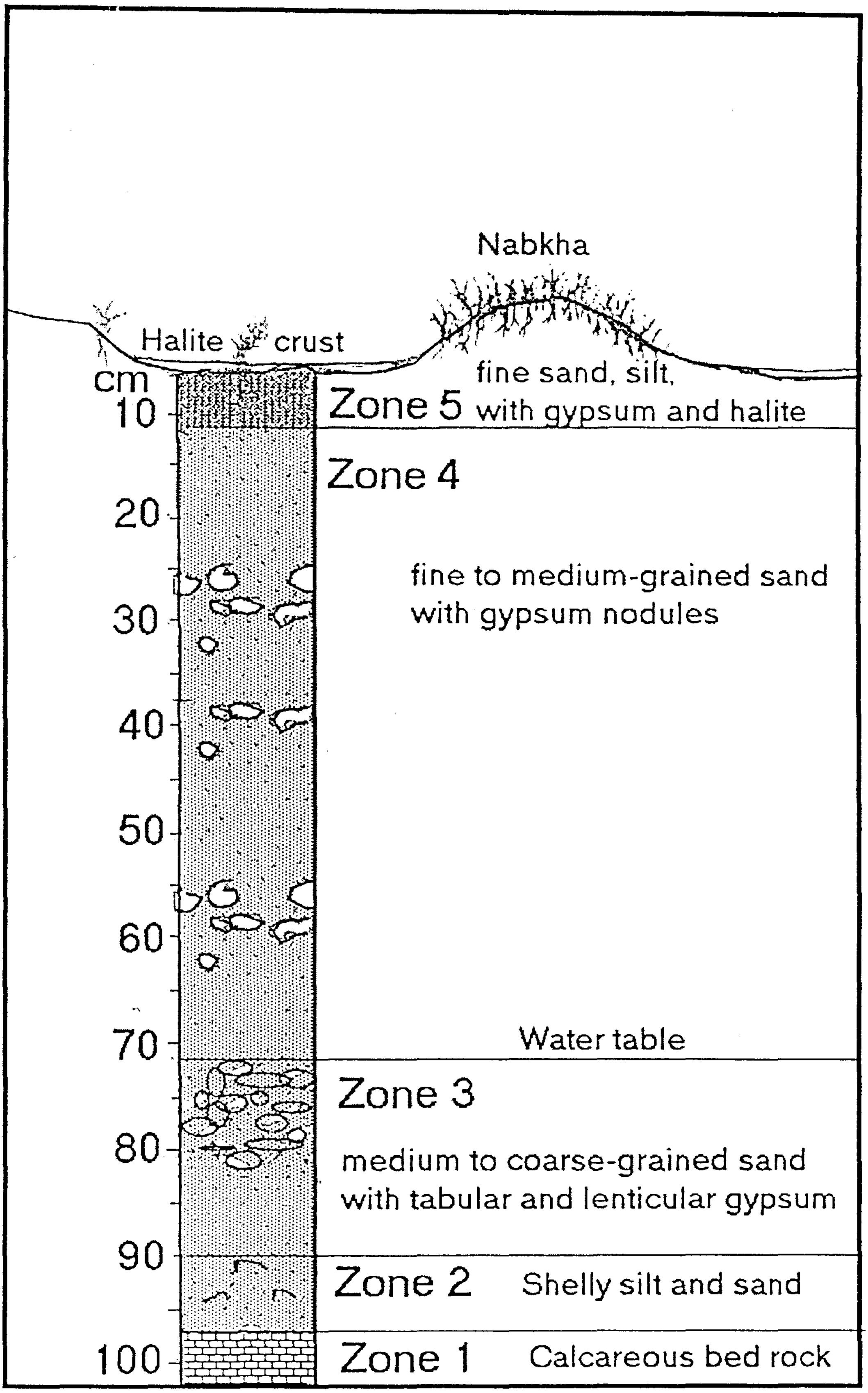


Fig.8. Hypothetical development of the Dukhan Sabkha.

Acknowledgements

Thanks always go to God, first and last, for providing me with the health and opportunity to accomplish this work. Thanks to everyone who has helped me and given me advice and guidance to complete this study. Also, thanks to all staff at geology department and SARC.

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