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Sedimentology and Hydrocarbon Potentiality of Arid Sabkha, UAE

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Abstract: A multi-proxy study on the sediments of the sabkha area around Abu Dhabi indicated that these sediments are formed of a mixture of sand-sized carbonate and evaporite minerals. Algal mats are dominating the intertidal zone where they form an important sediment source after their disintegration adding micrite-size grains to the sediment budget. Dolomite also was reported from some of these sediments and believed to be resulted from mixing freshwater with seawater in the mixing zone. Whole rock pyrolysis of these algal materials yielded moderately high Hydrogen Indices (Hl) which are typical of marine Type II kerogen. This kerogen type is a common source of many of the major hydrocarbon accumulation in the region. The association of sabkhas with arid carbonate shorelines are still very intriguing subject and may shed light on the development of many textural features in both carbonates and evaporites. The development of the algal mats in the intertidal zone and their role in sediment formation is another worth-investigating subject. This may explain the inclination in this paper to use the term sabkha as an area rather than a depositional regime. This shift is also in alignment with the common understanding of the sabkha in the region.

Key words: Sabkha, Sedimentology, Hydrocarbon, Potentiality, UAE

INTRODUCTION

The sabkhas of Abu Dhabi had been the center of attraction for researchers for more than half a century. Their different components and processes were described by innumerable studies including Shearman[24] Bush[9], Hsu and Schneider[17] and McKenzie *et al.*[18]. For the purpose of this paper, the term sabkha would indicate the whole depositional setting in the supratidal (the *senso stricto* sabkha), the intertidal and the subtidal areas. The original sabkha concept as suggested by Shearman[24] provided a new vision on the formation of diagenetic evaporites and explained the association of carbonates-evaporites in what comes to be known as the sabkha sequence or cycle. The sabkha cycle typically stacks subtidal carbonates, intertidal algal mat and the supratidal nodular anhydrite in one depositional sequence. This sequence was applied to explain such associations in many carbonates-evaporites system around the world. The work of Sanford and Wood (2001), however, suggested that the sabkha is a hydrological regime resulted from the upward movement of groundwater and there are no indications of sea water evaporative pumping to the sabkha as were suggested earlier. This assumption, if proved true and there are a lot of evidence in its support, may reduce the sabkha into a continental depositional regime that is responsible only for a small amount of sediments.

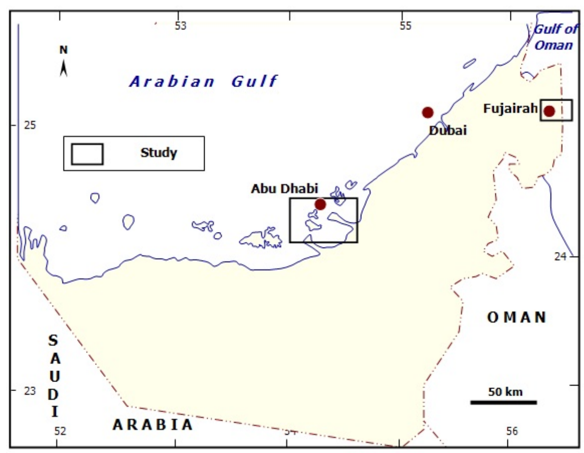

Fig. 1: Location map of the study areas.

This study will focus on the sabkha system west of Abu Dhabi (Fig. 1). Within the above defined scope, the whole sediment package in the sabkha area will be investigated. The area consists of a large supratidal flat which is dry in most of its parts due to the extensive urbanization in the region. Flanking these salt flats are remnants of the intertidal zone characterized by the presence of either algal mats or mangroves or both of them. To the east, oolites form on the inter island tidal deltas and coral reefs are restricted to small patches along channels and just seaward of the center of the

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islands. To the west, coral reefs grow along the northern edges of most of the offshore banks north of the Khor al Bazam. Eastward, in the protected lagoons, carbonate muds and pellets are accumulating, whereas to the west of Al Dhabaiya Island, carbonate muds only accumulate in a narrow belt south of the offshore bank. Grapestones and skeletal debris are the dominant components. The entire province is evolving. The offshore bank is accreting seaward through a combination of coral reef growth and tidal delta progradation. South of this bank, supratidal flats are encroaching on the lagoons through the development of beach ridges and cyanobacterial flats.

The width of the real sabkha paralleling the Khor al Bazam varies, reaching a width of as much as 32 km just south west of Abu Dhabi Island. It flanks intertidal flats and coastal terraces except where locally hills of Tertiary and Quaternary rocks jut out as peninsulas. In places the sabkha surface lies flush with eroded Quaternary rocks[4]. However, the geotechnical problems associated with the sabkha environment as indicated by Sabatan and Shehata[23], scares the planners from developing it without remedial measures. The sabkha problems may include strength reduction and soil subsidence during the dissolution of salts (Dames; Abu; Abu and Ali), corrosive action caused by the high salinity of the soil and groundwater (Fookes; Fookes; Fookes and Shehata), heave during salt recrystallization[2], flooding because of the low infiltration rate of sabkha soil and groundwater rise in already urbanized areas (Patterson; Fookes; James and Shehata). The magnitude of hazards in the sabkha is dependent upon its geologic and hydrogeologic settings. Therefore, the mineralogy, geology and hydrochemistry of any sabkha must be investigated before any development effort takes place. The description presented was conducted through field investigation to gain a better understanding the investigated coastal system.

MATERIALS AND METHODS

Sediment analyses: Forty nine surface sediment samples were collected. XRD techniques were used for mineralogical identifications of the samples. The x-ray profiles of the non-clay minerals in the silt and sand size fractions collected from Khor Bazem were identified by standard published methods (e.g.[8]). The evaporite samples were examined in the range of $2ø=2\text{-}60^{o}$ under the following conditions: Cu tube operated at Kv=40, Am=40, diffractometer operated at scanning rate of 1o/minute and the chart recorder is 1o/centimetre. The evaporite intervals were identified according to their basic reflections as given in the ASTM cards index. The X-ray analyses of the stoichiometric conditions of dolomite were inspected by the shift of the (112) diffraction peak as described by Supko *et al.*,[25]. The microcrystal variations and crystals morphology of the different mineral phases were studied using Scanning Electron Microscope housed at the central laboratory unit, UAE.

Geochemical analyses of algal mat: A sample (5 grams) of the algal mat materials was initially introduced to an inorganic carbon removal stage, where 10 % HCl acid was added to the sample. Total organic carbon analyzer instrument LECO CS 200 was used to oxidize and detect the organic carbon by combustion. Analysis was determined when carbon compounds are combusted in an oxygen-rich environment, resulting in the complete conversion of carbon to carbon dioxide. The carbon dioxide generated from the oxidation process is directly related to the TOC in the sample. This instrument is used to simultaneously determine carbon and sulfur employing Induction heating furnace and solid state Infra-Red detection system.

RESULTS AND DISCUSSION

Field Description of the studied Sabkhas: The present study is dealing mainly with the coastal sabkha in the vicinity of Khor Bazem which is located near Al-Dhabeah village. Khor Bazem located west of Abu Dhabi; it is 130 km long and 8 to 16 km wide. The eastern end is intertidal and terminates in a network of shoals and channels. The west end is relatively deep (25 m) and is connected to the Arabian Gulf. The bay offers a series of dynamic ecological habitats, including algal mats, coral reefs and black mangroves that are home to numerous species of fish and shrimp.

The investigated area includes both the upper intertidal and the supratidal flats. The intertidal flat is partly covered by algal mats. The burrows and pellets of crabs cover the surface of the sabkhas during low tide; during the next flood tide they will be partly destroyed. The pellets have a loose texture and are associated with a radial or irregular pattern of linear tracks around the burrows on the surface sediments and this makes the surface uneven. Some gastropod populations are dense in the intertidal flat zone of Khor Bazem sabkha, in which the surface of the carbonate sand is littered with live and dead shells. Mangroves occur sporadically at some places on the intertidal flat of the studied sabkhas.

Table 1: Summary of the X-ray diffraction results.

Sample No.	Major Mineral (s)	Subordinate Mineral (s)	Minor Mineral (s)
1	Calcite, Quartz, Dolomite, Halite	Anhydrite	---------------
2	Halite	---------------	Dolomite, Quartz
3	Calcite, Halite, Quartz	Plagioclase, Anhydrite, Dolomite	---------------
4	Halite	---------------	Dolomite, Calcite, Quartz, Anhydrite
5	Halite, Aragonite, Quartz, Dolomite	Calcite, Plagioclase	Gypsum
6	Gypsum	Calcite	Aragonite, Halite
7	Gypsum, Calcite	Halite, Quartz	Anhydrite
8	Aragonite, Halite	Dolomite, Calcite, Quartz	Gypsum, Plagioclase
9	Aragonite	---------------	Calcite, Halite, Gypsum
10	Halite, Anhydrite	---------------	Calcite, Dolomite, Quartz
11	Dolomite, Halite	---------------	Calcite, Quartz
12	Calcite	---------------	Dolomite, Halite, Serpentine
13	Aragonite, Calcite, Halite	Quartz	---------------
14	Dolomite, Halite	---------------	Gypsum, Calcite, Quartz
15	Aragonite, Halite	Calcite, Dolomite, Plagioclase, Quartz	---------------
16	Calcite, Halite	Gypsum, Serpentine, Aragonite	Plagioclase
18	Halite	Dolomite, Calcite	Serpentine
20	Calcite, Halite	Aragonite, Quartz	---------------
23	Aragonite, Quartz, Calcite, Dolomite, Halite	---------------	---------------
RF1	Calcite	---------------	---------------
RF2	Serpentine (Antigorite)	---------------	---------------
RF3	Calcite	---------------	---------------
RF4	Gypsum	---------------	Anhydrite, Calcite
RF5	Gypsum	---------------	---------------

Extensive tidal flats are covered with dark to dark-brown laminated algal mat on the protected intertidal and supratidal flats that flank the Khor al Bazam and these are well displayed on a north south traverse at Qanatir. These cyanobacterial mat accumulations have an average width of approximately 2 km and can reach a thickness of at least 30 cm. At the east end of the lagoon, the largest flat is 42 km long, while to the west, another flat (at Khusaifa) is 9 km long[4]. In some areas the flats extend landward in the subsurface more than 2 km beneath a thin cover of evaporites and wind blown sediments.

Surface sediments: Surface sediments were collected from several sites within the study area to investigate the nature of these sediments, their diagenetic processes and their areal distribution. The collected samples were washed and examined under the binocular microscope. Some samples were selected to be examined under the Scanning Electron Microscope. This is the first time that these sediments were examined in such details. The sand size fraction is composed of calcite as major, while aragonite and dolomite are the minor carbonate minerals.

Microscopic investigation and XRD analyses (Table 1) have shown that these sediments are formed of both carbonate and evaporitic grains of the sand size. Some of them were formed of a mixture of

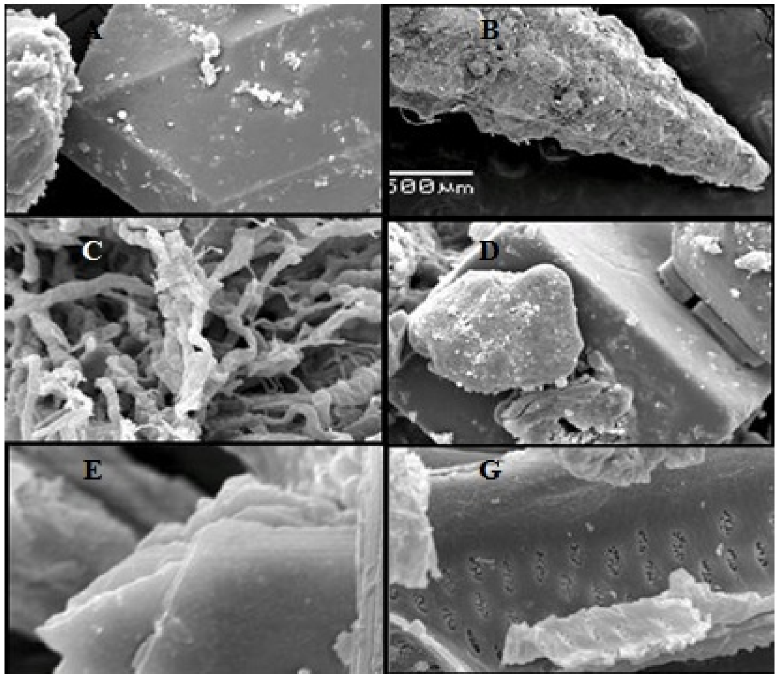

Fig. 2: Scanning electron micrographs for selected sediment samples collected from the area of interest.

algal mats and sediments. The algal materials were deformed and added to the sediment budget (Fig. 2). Authigenic growth of clay minerals was also noticed in such sediments. Secondary growth of probably calcite cement was found within the vents of the algal structure (Fig. 2E). The algal structure was found to be responsible for the development of either aragonitic or clay minerals in the form of thin needles of authigenic crystals that are growing on the algal structure itself (Fig 2 D and G). In other parts of the area, sediments are formed of sand sized calcite grains with some benthic foraminifera such as *Peneroplis* (Fig. 2C). Other biological components include possible spines of unidentified organisms or some benthic foraminifera.

The carbonate grains (calcite and aragonite) are derived either from the disintegration of the skeletal grains including the algal mats or from direct precipitation from seawater in the shallow tidal flats. Dolomite is found in only few samples and in small quantities. Some of the samples contain plagioclase and serpentine, which are probably eolian input from the desert clastic materials that are windborne from the Arabian Shield to the west. This may be true for the quartz content of some of the samples. Evaporite minerals are mainly halite and gypsum with rare occurrence of anhydrite.

Judging from the nature of the collected sediments, it seems that the sabkha area sediments consists mainly of carbonate grains (either aragonite or calcite) that are formed in shallow marine water as reflected in the type of marine organisms found with these sediments such as foraminifera tests and spines. The algal mats are decaying and degrading into microscopic grains that are added to the sediment budget. These algal structures are the sites of local cement growth in their vents and openings. Parts of these sediments derived from the disintegration of the algal mats in the intertidal zone may be transported to the subtidal zone and mixed with the carbonate mud there.

Diagenetic processes also have been studied to delineate their effects on the sabkha sediments. Two main processes were recorded, namely dolomitization and the growth of secondary evaporites. Dolomite has been reported from the sabkha sediments by the early workers (e.g.). This is, however, the first time to examine it under the SEM in order to see its petrographic features. Dolomite is found as idiotopic rhombs within the fossiliferous carbonate sediments. Secondary growth of clay minerals was found on these rhombs. Some of these clays were filling cavities within the dolomite (Fig. 2D). The large size of these dolomite rhombs, their presence in a normal, shallow marine carbonates and the absence of evaporites may indicate that they were formed by the process of sea

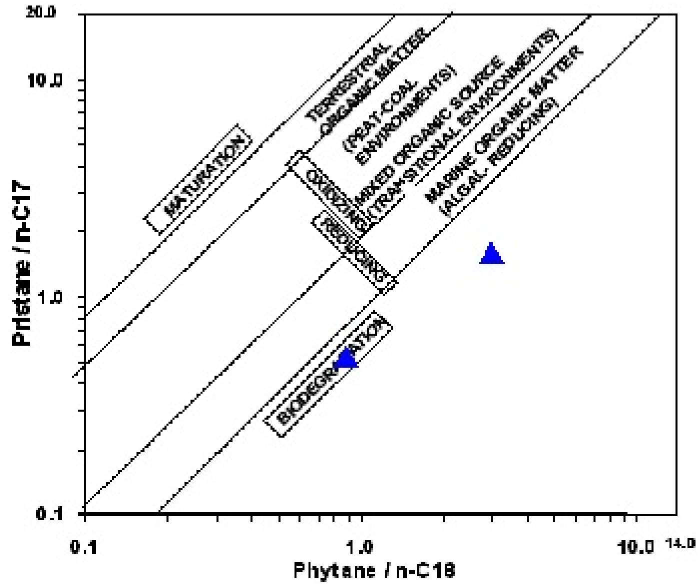

Fig. 3: Standard plot between Pr/C17 and Ph/C18 (after Shanmugam, 1985).

water- fresh water mixing. Such dolomite was reported from many other sabkha regions and normally indicates the mixing zone between the marine conditions and the continental fresh water zone.

Thick gypsum plates (Fig. 2A) were reported from some of the studied sediments. They are well-developed with well-defined boundaries although encrusted with secondary mineral growth. These sediments are probably the result of local growth due to strong evaporation under arid conditions.

Thermal maturation of the organic contents: TOC of the studied samples ranges from 0.95 to 12.07 wt%. Total organic carbon (TOC) of the sediment in the study area shows a wide range of organic enrichment (0.95 TO 12.070% TOC) indicating excellent quantity of organic matter productivity. Also, sulfur content of these samples varies from 0.09 to 4.39 which reflect more marine input to these organic matters. Another data obtained from literature[4] indicates that whole rock pyrolysis yielded moderately high Hydrogen Indices (Hl) of 389 597, which are typical of marine Type II kerogen. These values vary slightly from the values (0.5 2.7% TOC and Hl 510 to 675). Elemental composition (C, H, N, 0, S) of isolated solid organic material (kerogen precursors) showed atomic hydrogen to carbon (H/C) ratios (1.20 1.54) that fall directly on the Type II evolutionary pathway as shown in a modified van Krevelen diagram Stable carbon isotope ratios ranged from 8.41 to 10.78 %.

Table 2: Selected results from the geochemical analyses of the analyzed algal mat

Sample no.	TOC%	Sulfur%	Pr/C17	Ph/C18	CPI
S1 - 1	3.516	4.395			2.227352
S1 -2	1.64	0.1791	3.195846	1.461626	0.680369
S1 -3	0.9528	0.0152			2.864495
S1 -4	3.155	1.885			2.373858
S2	7.559	0.08515			1.557551
S3	10.37	0.0907	0.925663	0.298709	0.938989
S4	10.6	0.1144			2.765551
S5	12.07	0.1699			2.066802

The samples analyzed in this study were extracted through Soxhlet Apparatus by using chloroform as organic solvent. The extracts were analyzed using GC/FID (Varian CP-3800 GC) to extensively analyze the n-alkanes and the isoprenoids within the studied samples. The followings could be concluded: 1) The Carbon Preference Index of the studied samples is more than one which indicate immature recent materials. 2) The studied samples have no pristine and phytane except two samples, 3) The standard plot between Pr/C17 and Ph/C18 (Fig. 3) shows that the studied samples (only two) were originated from marine algal organic matter under reducing conditions which reflect good hydrocarbon source potential for these mats and 4) The n-alkane distribution is characterized by the predominance of the heavy fraction (except for sample S1-3) which also confirms the immaturity of these mats. These analyses are for mats were compared by the work of Kendall, Alsharhan, & Cohen, 2002 and Alsharhan and Kendall, 2003. It supports the notion that algal mats may be a possible source for oil generation given enough burial depth and time.

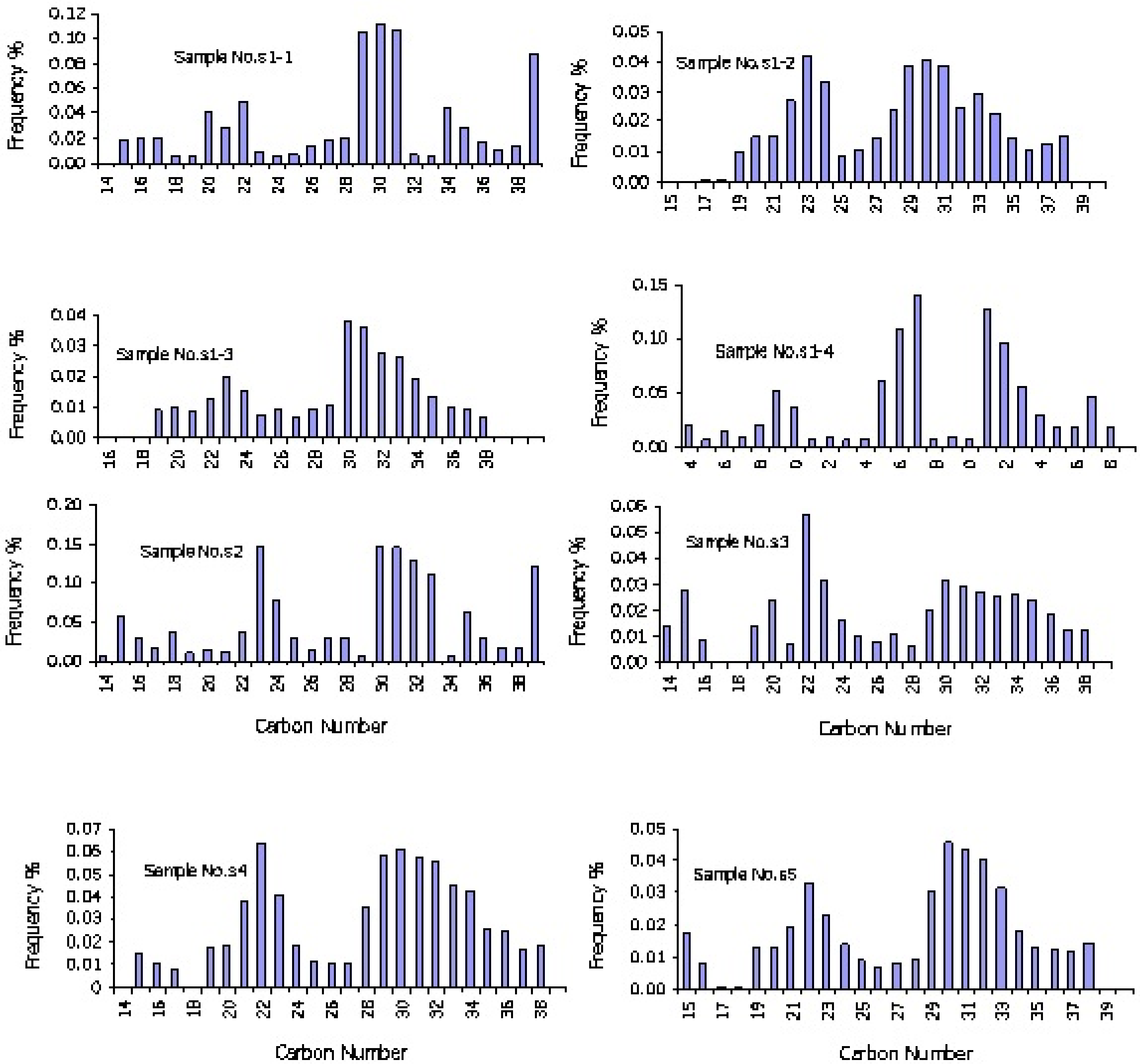

Fig. 4: The relation between carbon number and the frequency % of the analyzed samples.

The obtained results are summarized in Table 2 and Figure 4. However, the picture needed to be more clarified through carrying out the hydrous pyrolysis experiments (artificial maturation experiments) in order to predict the actual hydrocarbon potentiality of these algal mats and their hydrocarbon products if they are subjected to sufficient temperatures.

Total organic carbon (TOC) of the sediment in the study area shows a wide range of organic enrichment (0.95 TO 12.070% TOC). Whole rock pyrolysis yielded moderately high Hydrogen Indices (Hl) of 389 597, which are typical of marine Type II kerogen. These values vary slightly from the values (0.5 2.7% TOC and Hl 510 to 675). Elemental composition (C, H, N, 0, S) of isolated solid organic material (kerogen precursors) showed atomic hydrogen to carbon (H/C) ratios (1.20 1.54) that fall directly on the Type 11 evolutionary pathway as shown in a modified van Krevelen diagram Stable carbon isotope ratios ranged from 8.41 to 10.78 %[4].

Conclusions: The sediments of the sabkha area around Abu Dhabi are formed of a mixture of sand-sized carbonate-evaporite minerals. Algal mats and mangrove dominate the intertidal zone in some parts of the studied areas. Examination of the algal mats under the SEM indicated that these materials are disintegrating adding micrite-size grains to the sediment budgets. Dolomite also was reported from some of these sediments and believed to be resulted from mixing freshwater with seawater in the mixing zone. Geochemical analysis of the algal materials has shown a wide range of organic enrichment (0.95 TO 12.070% TOC). Whole rock pyrolysis yielded moderately high Hydrogen Indices (Hl) of 389 597, which are typical of marine Type II kerogen. This kerogen type is a common source rock type in the Arabian Basin during the Mesozoic and these results may support that some these hydrocarbons were generated from algal mats. Further hydrous pyrolysis (artificial maturation experiments) is needed to predict the actual hydrocarbon potentiality of these algal mats and their hydrocarbon products if they are subjected to sufficient temperatures.

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