J. Univ. Kuwait (Sci.) **11**, 1984

Sedimentological interpretation of a sedimentary sequence in Kuwait, Arabian Gulf

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ABSTRACT

During foundation drillings in Suleibikhat, NW of Kuwait City, an interbedded sedimentary clastic sequence with different grades of lithification was encountered to a depth of 30 m below natural ground surface. A fluviatile and/or aeolian kind of deposition during a regressive period of the Pleistocene is postulated. Strongly lithified, silty, calcareous sands are interpreted as surface sediments (surface crusts), which have undergone cementation during sea level rise. Besides calcareous cement, quartz cement is present. This paper should be considered as a preliminary contribution to the sedimentary geology of Kuwait and should be followed by more detailed investigations.

INTRODUCTION

A sedimentary sequence with different grades of lithification was encountered up to 30 m below ground surface during foundation exploration drillings for the National Housing Authority of Kuwait in early 1980.

The area investigated is situated at the southern rim of Kuwait Bay, approximately 500 m from the shoreline (Fig. 1).

Medium dense to dense unconsolidated sediments are interrupted by strongly lithified and cemented sand layers. These layers show a thickness in the range of 0·1 to 1·0 m, but most of them are 0·2 to 0·3 m thick. They could be correlated with each other throughout the boreholes (Fig. 2).

TECTONICS AND EUSTATIC SEA LEVEL CHANGE

The Arabian Gulf is a tectonic basin of late Pliocene to Pleistocene age (Kassler 1973). The latest tectonic movements took place during the Zagros orogeny in Pleistocene, but the area has been locally rejuvenated by Holocene tectonic adjustments.

During the Pleistocene the sea level was approximately 120 m below the recent sea level—the sediments of the Arabian Gulf have been exposed nearly to the Strait of Hormuz. According to Fairbridge (1961) the recent unconsolidated sediments are products of the post-glacial Flandrian Transgression, beginning 18,000 years B.P. and reaching its present level about 5000 years B.P. (Fig. 3). The sediments encountered

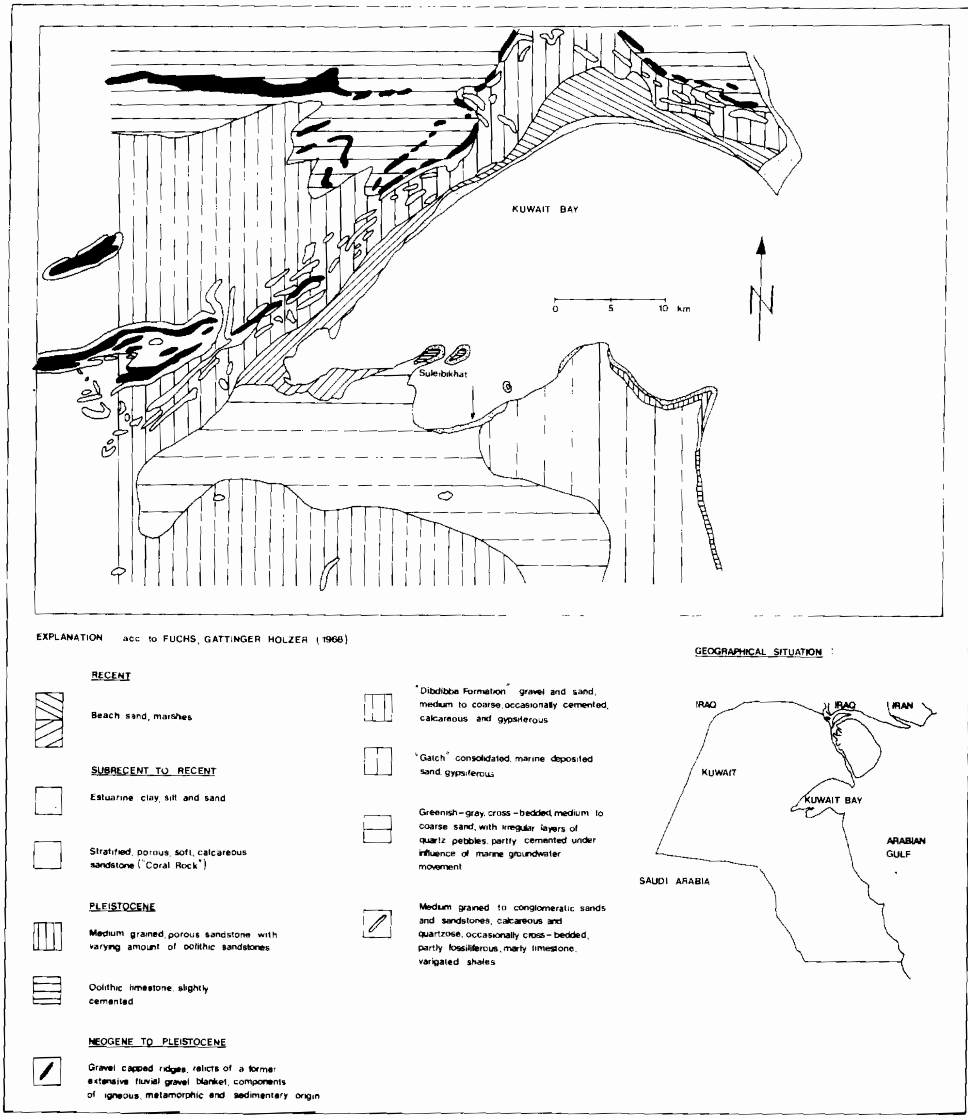

Fig. 1. Geological map of Kuwait, showing the surroundings of Kuwait Bay.

during the foundation drilling, therefore, should have been deposited during a regressive period before the Flandrian Transgression in Pleistocene.

SEDIMENT PETROGRAPHICAL INVESTIGATION

The sedimentary sequence was investigated to a depth of 30 m below ground surface. The groundwater level ranged from approximately 1·0 m to about 5·0 m below the surface. The unconsolidated quartz sand is interrupted by 12 to 13 cemented quartz sand layers (Fig. 2). Twenty-three boreholes were drilled over the area. Samples from

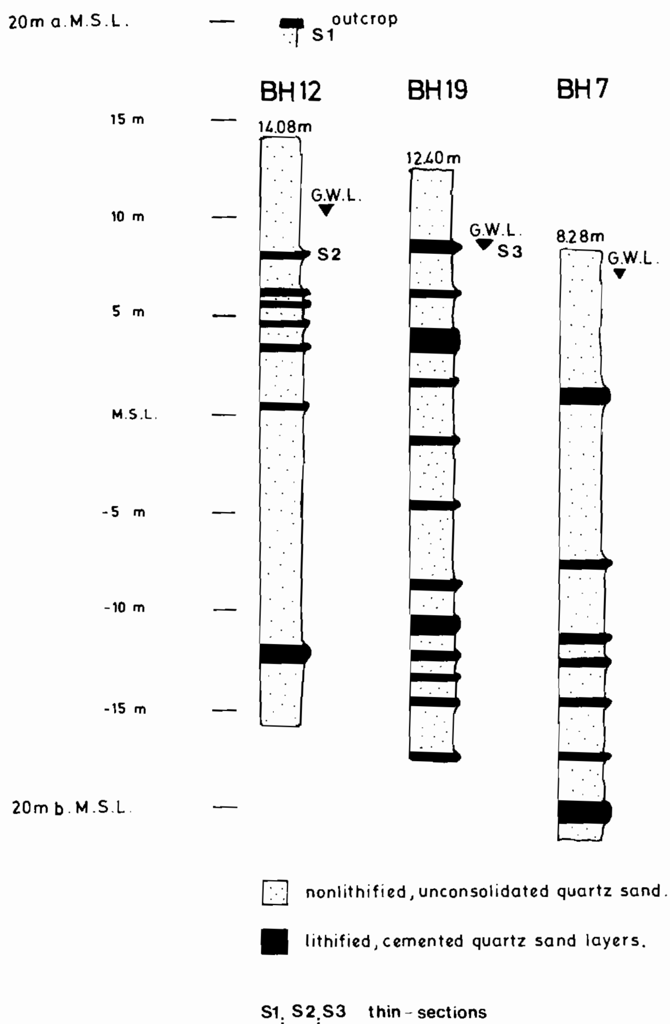

Fig. 2. Subsurface profiles showing the interbedding between non-lithified and lithified, cemented layers.

the cemented sand layers have been investigated from an outcrop near borehole No. 12, borehole No. 12 itself, and borehole No. 19 (Fig. 2). Ten open pits, next to the boreholes, were dug down to the water level. The cemented sand layers from deeper parts of the boreholes have been identified by drill cuttings and drilling penetration rates. Forty-two grain size analyses from the unconsolidated sand layers have been performed. The samples were taken by a split spoon sampler.

Unconsolidated sands

The non-lithified sediments are partly whitish, but mostly brown, grey to greenish, silty sands. The maximum grain size can locally range up to fine or medium sized gravel.

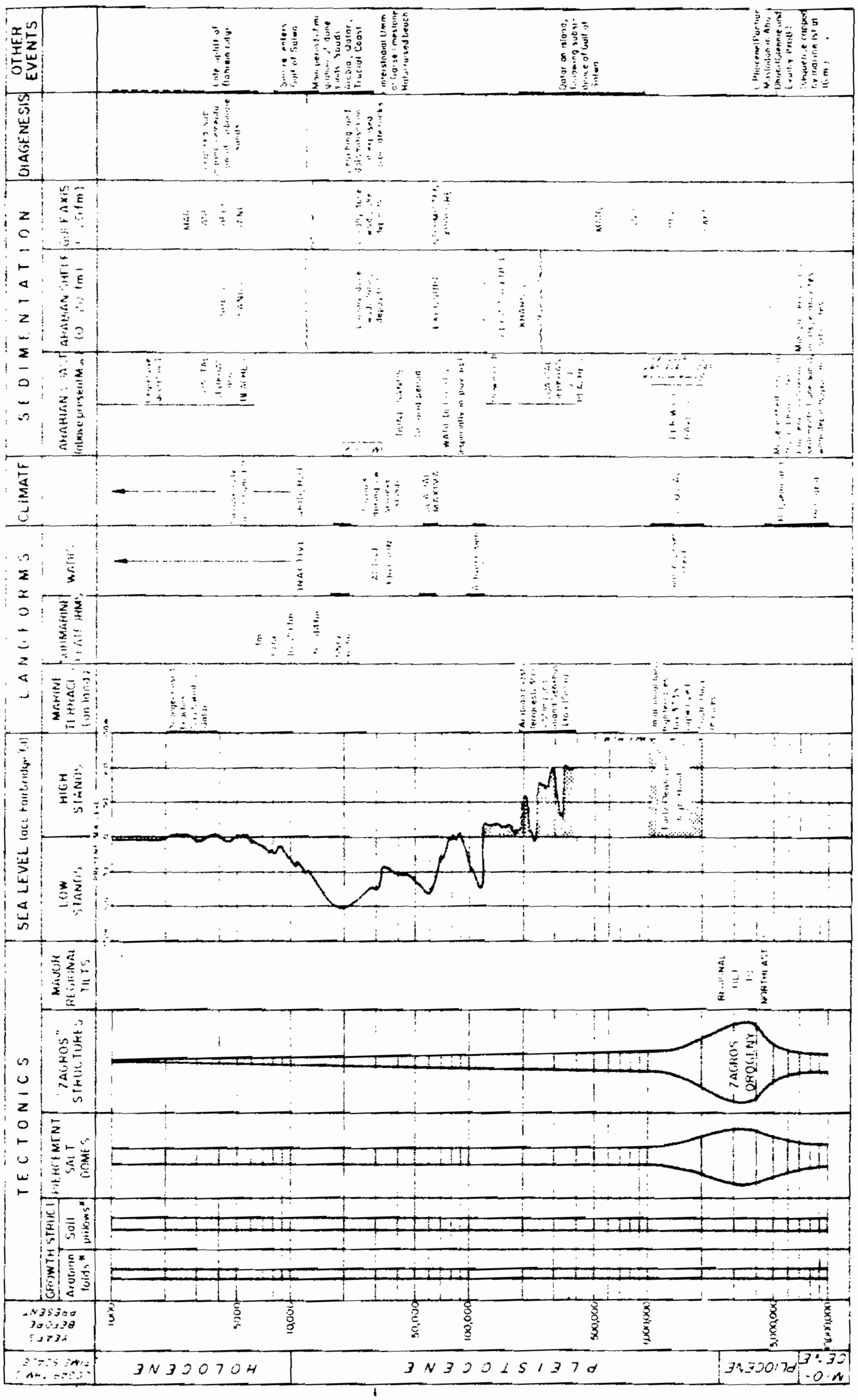

Fig. 3. Generalised late Tertiary and Quaternary history of the Arabian Gulf (from Kassler 1973).

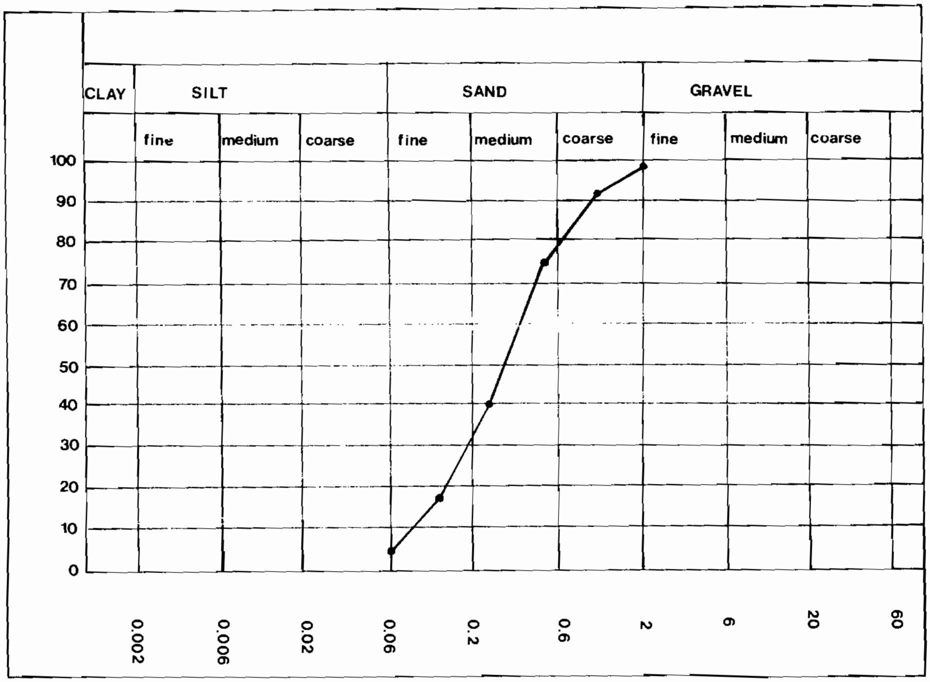

Fig. 4. Grain size distribution of the unconsolidated sands. Number of grain size analyses: 42.

Trask's parameters:

Median M_d (average) Q_2	0·37
Gradation S_0 (average) $\sqrt{Q_3/Q_1}$	1·78
Skewness S_k (average) Q_1Q_3/Q_2	0·97
Uniformity coefficient $U=3{\cdot}1$	$C=100$

The permeability coefficient k can be calculated, using the formula of Beyer (1964)

$$k=c\times(d_{10})^2 \text{ (cm/sec)}$$

where k = coefficient of permeability (in this case $k=0{\cdot}81\times10^{-6}$ m/sec),
c = factor (according to Beyer 1964) based on the uniformity factor U.

$$U=\frac{d_{60}\%}{d_{10}\%}$$

d_{10} = apparent grain size diameter (according to Hazen 1893).

These values indicate a deposition of these sediments by fluviatile mechanisms (Füchtbauer & Müller 1970). The components of the sand are quartz and felspar whereas the silt is partly calcareous. The grains are well rounded. In two of 23 borings, a thin horizon of red-coloured sediments could be observed.

Lithified and cemented quartz sand layers

The cemented layers show a grain size distribution of silty, fine to medium sized sand.

Thin-section investigation showed about 60% quartz, 30 to 35% felspar, and a small amount of other minerals, cemented partly by carbonate and partly by quartz. X-ray diffraction shows perthite (Ca–Na felspars), and in the heavy fraction zircon and apatite (?) could be identified. The calcareous cement is partly replaced by siliceous cement. There are no indications of marine depositional factors in the encountered sequence. One outcrop up to 20 m above M.S.L. can be found near borehole 12, but according to Fairbridge (1961), no sea level high of more than 20 m above recent sea level had been reported after the Flandrian Transgression.

Shinn (1973) describes a cemented quartz sand layer from NE Qatar, and postulates marine cementation, based on fast deposition of the sediments.

The author suggests a delta-and-wadi depositional environment for the encountered sedimentary sequence. North of Suleibikhat, at the N and NW rim of Kuwait Bay, a range of hills, some 150 m above M.S.L., is exposed, striking NE. These ridges are relicts of a former extensive fluvial gravel blanket (see Fuchs *et al.* 1968). On the basis of this morphological evidence it appears likely that the sediments were deposited by rivers that flowed from a westerly direction (Wadi Al Batin in Saudi Arabia).

This model bears no relation to the recent Tigris–Euphrates delta. Various authors have reported that these rivers lose their sand and gravel fraction in the Mesopotamian plains, and only the clay- and silt-fraction reaches the Arabian Gulf. The northern rim of Kuwait Bay and the island of Bubiyan consist of Shatt-El-Arab sediments such as estuarine clay, silts, and sands.

INTERPRETATION OF THE DEPOSITIONAL ENVIRONMENT

An interpretation of the depositional environment of the sediments will now be made. Since there is no indication of a marine deposition, a fluviatile and/or aeolian

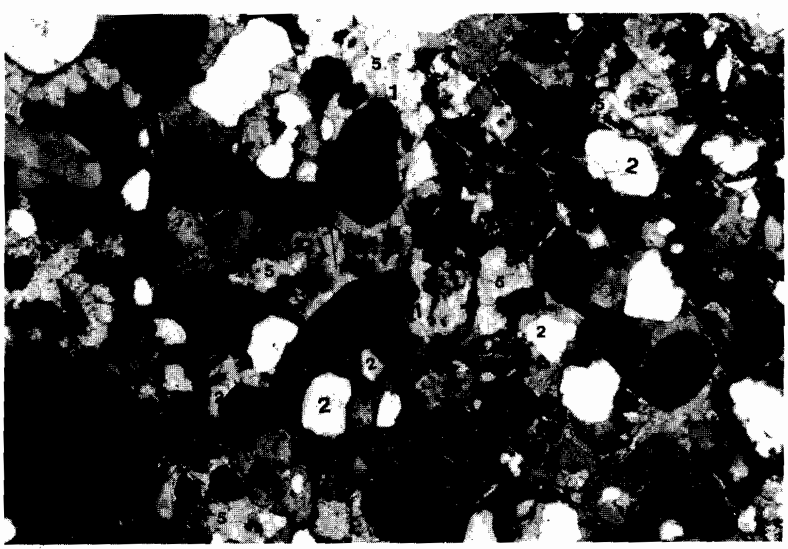

Fig. 5. Thin-section photograph, crossed nicols, horizontal scale 4 mm. Cemented quartz sand layer, sample S1. The black components are felspar grains, partly in light coloured $CaCO_3$ cement. (1) $CaCO_3$ cement (2) quartz components; the arrow on the quartz grain in the centre of the photo indicates replacement by $CaCO_3$ (3) $CaCO_3$ cement and SiO_2 cement (5) pure $CaCO_3$ cement.

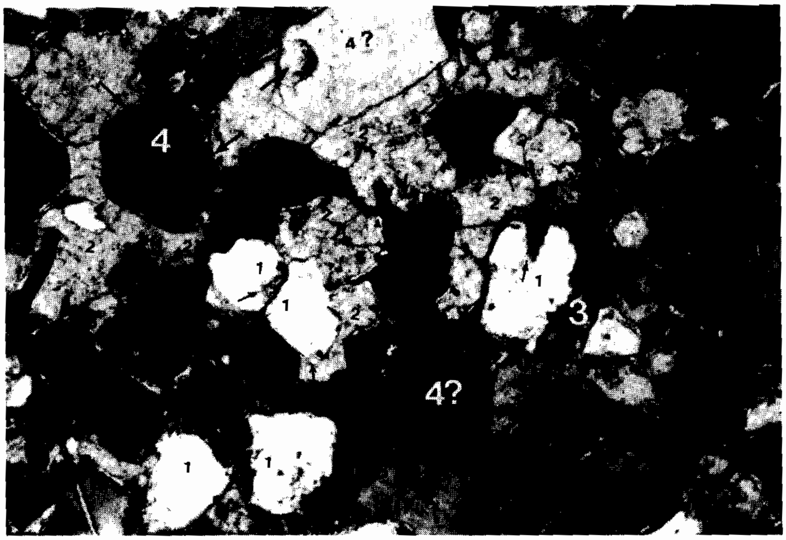

Fig. 6. Thin-section photograph, crossed nicols, horizontal scale 2 mm. Cemented quartz sand layer, sample S1. (1) quartz components solved by $CaCO_3$ (arrows) (2) $CaCO_3$ cement (3) new crystallised SiO_2 (dark) (4) felspar grains, locally replaced by $CaCO_3$.

Fig. 7. Thin-section photograph, crossed nicols, horizontal scale 2 mm. Cemented quartz sand layer, sample S2. (3) $CaCO_3$ cement (4) quartz grains (5) new SiO_2 crystallisation.

deposition is suggested, approximately in the middle Pleistocene, during a regressive period when the sea level was some 10 m below the recent level. Cross-bedding at the outcrop near borehole 12, as well as the occurrence of well-rounded quartz grains in the unconsolidated sediments, indicate a long transport process in a fluviatile environment.

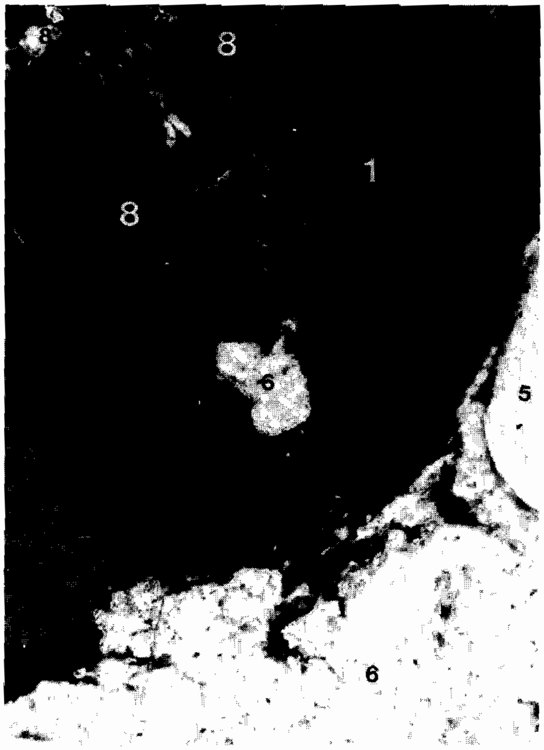

Fig. 8. Thin-section photograph, crossed nicols, horizontal scale 2 mm. Cemented quartz sand layer, sample S2. (1) pore space (5) quartz grain, (6) $CaCO_3$ cement, (8) SiO_2 cement.

On the basis of the available evidence it appears that the cemented layers represent previous land surfaces. After each period of aeolian or fluviatile deposition, the upper surface became preconsolidated by both subaerial processes and perhaps the precipitation of salts associated with capillary rise from the shallow water table. After a surface crust had developed there was then a period of further rapid sand deposition. The surface of these later sediments in turn became preconsolidated. Implicit within this depositional model is a corresponding rise in the sea level. It appears that the buried preconsolidated land surfaces provided favourable conditions for the precipitation of a calcium carbonate cement derived from intruding sea water. The present conditions are different because fresh groundwater is percolating through the sands and the buried calcium carbonate cemented land surfaces. It appears that the groundwater may cause a progressive replacement of the calcium carbonate cement by a silica cement. A possible process is that the calcium carbonate is dissolved by a low pH groundwater. As the carbonate is dissolved the pH is increased and this in turn brings about the precipitation of silica. (The solubility of silica is, in part, dependent upon pH.)

A second hypothesis to explain the formation of the cemented layers is that, as in the first model, the layers represent old surfaces that have been exposed to arid phase subaerial processes. During exposure it is possible that the underlying water table was close to the surface. The water table may have been fed by upwelling groundwater from a deeper aquifer such as the Dammam formation. (The Dammam formation contains

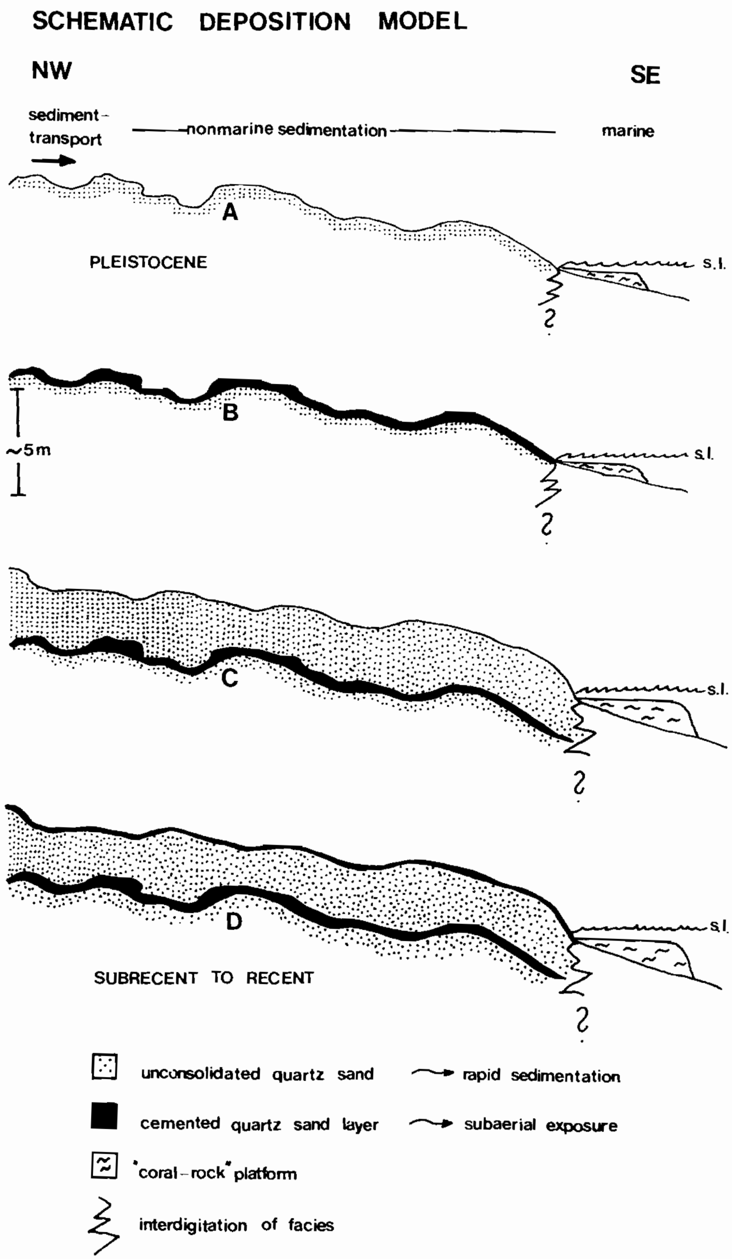

Fig. 9. Schematic deposition model.

limestones that have undergone Karst solution processes, therefore the groundwater could be rich in calcium carbonate.) A sequence of daily and seasonal fluctuations in both the groundwater level and the extent of the zone of capillary rise may have brought about precipitation of a calcium carbonate cement. Subsequent burial and exposure to low pH groundwater may have brought about the replacement of the calcium carbonate cement, as described in the first model.

In conclusion it is evident that there are several cemented horizons within the Pleistocene to Recent sediments at the southern rim of Kuwait Bay. The horizons are interpreted as representing old land surfaces that have presented favourable conditions for the precipitation of both calcareous and siliceous cements. The hydrochemical conditions under which these cements were preferentially precipitated are not clear. Several models (including the two described above) could be invoked to explain the cementation process. Further work on the carbon and oxygen isotopes and the ionic chemistry of the present shallow groundwater, deeper groundwaters, calcium carbonate cement and intrusive sea water may not only shed light on the cementation process, but may also provide relative ages for the succession of land surfaces. These ages could be very useful in charting the rise of post glacial sea levels in the Gulf region.

ACKNOWLEDGEMENTS

The author thanks Mr H. W. Holzapfel and Mr M. Dworatzek of the University of Marburg, West Germany for critical assistance and fruitful discussions.

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(Received 13 October 1981, revised 28 April 1983)

دراسة تتابع رسوبي في الكويت

هانز جيورج بوفه
٨ شارع فاون ، ليمبورج ، ألمانيا الغربية

خلاصة

خلال الحفريات للأساسات في الصليبخات شمال غربي مدينة الكويت ، وجد تكوين من المتطابقات الحبيبية المتلاحمة الرسوبية بدرجات متفاوتة التصخر على عمق ٣٠ مترا تحت سطح الأرض . وقد افترض بأنها عبارة عن رواسب مائية أو هوائية ترسبت خلال تراجع البحر في عصر البلايستوسين .

ويفسر التصخر الشديد للرمال الكلسية ذات الحبيبات الدقيقة على انها رواسب سطحية ساعد في التحامها ارتفاع سطح البحر . وبجانب المواد اللاحمة الكلسية هناك مادة الكوارتز .

ويعتبر هذا البحث مجرد مساهمة أولية في دراسات الجيولوجيا الرسوبية في الكويت .