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The Recent Sedimentary Facies of the Persian Gulf Region

G. Evans

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THE RECENT SEDIMENTARY FACIES OF THE PERSIAN GULF REGION

By G. Evans

Imperial College, London

The Persian Gulf, which is a shallow marginal sea of the Indian Ocean, is an excellent model for the study of some ancient troughs.

It is bordered on the west by the Arabian Precambrian shield and on the east by the Persian Tertiary fold mountains.

Persia is an area of extensive continental deposition. It is bordered by a narrow submarine shelf. The deeper trough of the Persian Gulf lying along the Persian Coast seaward of the shelf is floored by marly sediments. East of this, the Arabian shelf is covered with skeletal calcarenites and calcilutites. To the northwest is the Mesopotamian alluvial plain and deltaic lobe.

Arabia is bordered on the Persian Gulf littoral by a coastal complex of carbonate environments. Barrier islands, tidal deltas (the site of oolitic calcarenite formation) and reefs protect lagoons where calcilutites, pelletal-calcarenites and calcilutites and skeletal calcarenites and calcilutites are forming. There are Mangrove swamps, extensive algal flats and broad intertidal flats bordering the lagoons and landward sides of the islands. A wide coastal plain, the sabkha, borders the mainland. Here evaporation and reactions between the saline waters percolating from the lagoons, and calcium carbonate deposited during a seaward regression, leads to the production of evaporitic minerals including anhydrite, celestite, dolomite, gypsum and halite. Inland, wide dune sand areas pass into the outwash plains skirting the mountain rim of Arabia.

Since 1961 the Department of Geology and Geophysics of Imperial College has been engaged in the study of the Recent marine sedimentology of the Persian Gulf. This sea, until recently, has been almost completely neglected and only a few earlier geological studies have been made (Bramkamp & Powers 1955; Emery 1956; Houbolt 1957). Part of the study was carried out from H.M.S. *Dalrymple* during her survey work in the region and other studies have been made from a locally hired motor launch. More detailed work was done in the inshore waters using a small launch and on the coastal plain of the Sheikdom of Abu Dhabi, Trucial Coast.

The Persian Gulf is a shallow marginal sea of the Indian Ocean and is rarely deeper that 50 fm., although deeper water (exceeding 60 fm.) is found near the entrance. The deepest water is found close to the Persian shore. This deeper water area is separated into an eastern and western area, connected through a narrow depression, by a shoal area about 70 mi. inside the Straits of Hormuz. Whereas the deeper water is separated from the Persian Coast by a narrow shoal area, a broad area, less than 20 fm. in depth, occupies the southwestern side of the Gulf, being best developed in the south and narrowing towards the head of the Gulf.

Numerous islands and shoals are present, some representing crests of folds or salt plugs and others merely depositional features composed of unconsolidated and partially consolidated Quaternary deposits.

The Gulf has a small freshwater inflow, mainly from the Tigris, Euphrates and Karun rivers at its head, and also from intermittent streams on the Persian Coast. The water temperature is high, varying from 23 to 32 °C in the entrance of the Gulf and from 16 to

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32 °C in the extreme northwest with higher values in the shallow waters along the coasts. High salinities result from small freshwater inflow, and high temperatures and evaporation, in excess of the freshwater inflow. Salinities range from 37 to 38 ‰ in the Straits of Hormuz

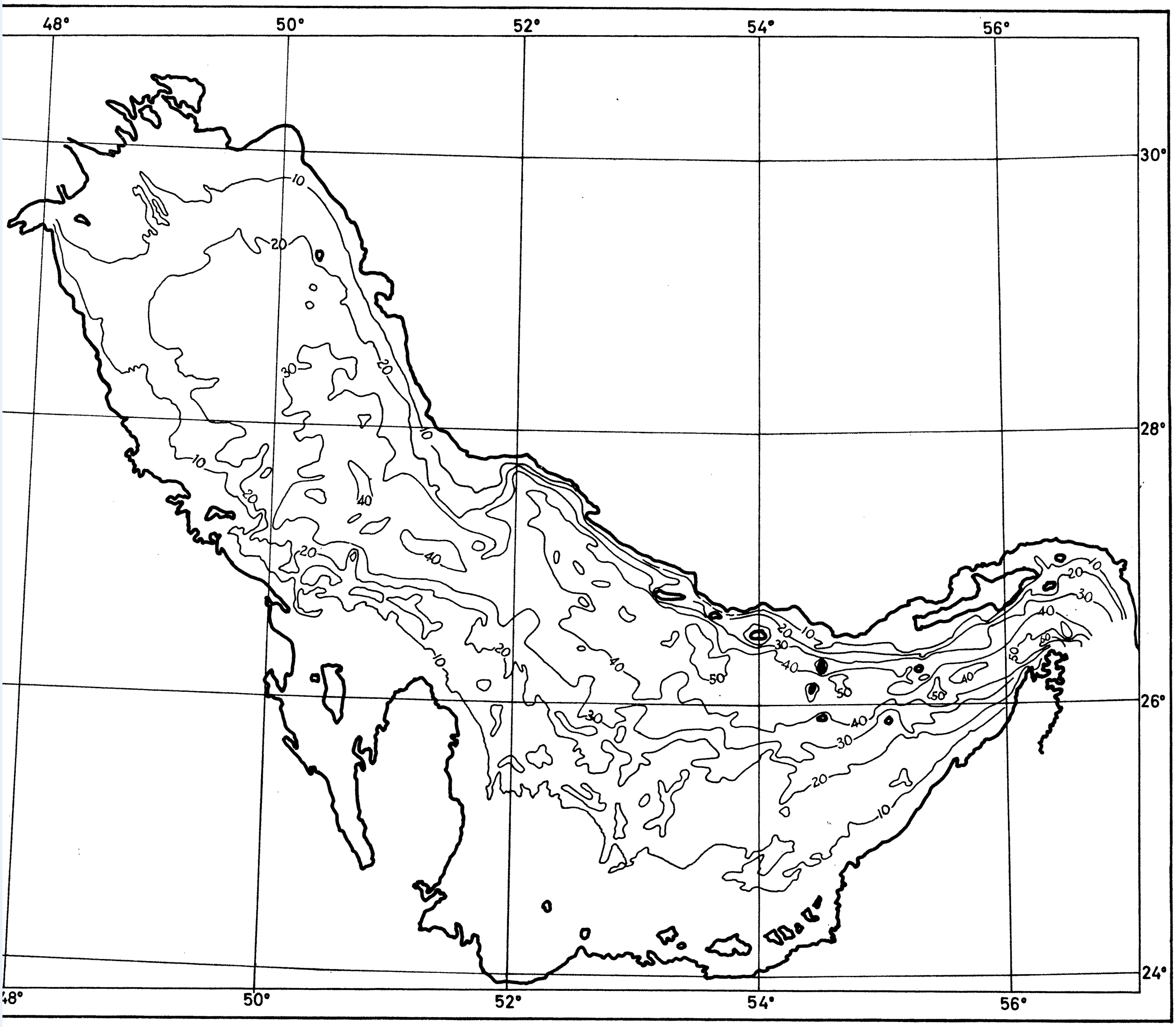

FIGURE 1. The bathymetry of the Persian Gulf. Taken from Geological map of Iran, compiled by the staff of Iran Oil Co. 1957. (Contours in fathoms.)

to 38 to 41 ‰ at the head of the Gulf depending upon river flow. Even greater salinities are recorded from the coastal areas along the southwestern shore (Emery 1956; Sugden 1963*b*; Kinsman 1964*c*).

The geological setting of the region is reasonably well known (Lees & Richardson 1940; Lees 1948). On the west is the Precambrian Arabian shield covered by gently north-easterly dipping thick Mesozoic and thinner Paleozoic and Cainozoic sediments, gently warped along north–south axes. The only strongly folded area on the Arabian peninsula are the rather anomalous Oman Mountains reaching the sea at the Straits of Hormuz. On the northeast are gently folded foothills passing into the high fold and thrust mountains of the Zagros ranges. Although movement started in Cretaceous times and even earlier in some places, the main structure of the mountain ranges and the broad physiography of the Persian Gulf and the adjoining areas is almost all due to Mio-Pliocene folding and subsequent warping. The area is still active (Lees & Falcon 1952; Falcon 1961).

The geological framework has emerged by the folding of a thick series of deposits which have accumulated in a northwest southeast alined trough lying northeast of the Arabian Shield (Lees & Richardson 1940). In this trough a series of dominantly calcareous sediments accumulated with occasional phases of clastic sedimentation. These calcareous sediments consist of marly sediments deposited in deeper water passing into shoal water deposits including oolitic, reefal and dolomitic limestones, the shoal water deposits being noticeably well developed on the southwest flank of the trough. In places, on several occasions, evaporite sediments accumulated, particularly near the Arabian shoreline, and were sometimes very widespread.

The Persian Gulf and adjoining regions show a striking modern sediment pattern. On the northeast, Persia is a region of extensive continental sedimentation. Large interior basins, such as Dasht-i-Khavir, Dasht-i-Lut and Gavkhuni, consisting of extensive outwash fans, dune sand areas and saline flats and swamps, are the repositories of much of the products of erosion. Some sediment, however, escapes to the coast to build up a complex coastal plain consisting of alluvial, estuarine, deltaic, intertidal mud flat and beach ridge environments. There is a narrow coastal shelf. No modern work has been done on this Persian coastal plain and shelf facies.

Seaward of this zone the deeper parts of the Persian Gulf are floored by silty clays and clayey silts with a high content of carbonate (20% CO_2). They contain 0·83 to 1·51% organic carbon and 0·14 to 0·23% organic nitrogen with carbon nitrogen ratios varying from 6·9 to 9·2, usually being less than ten. The carbonate fraction consists of low magnesium calcite and dolomite with some aragonite (cf. Houbolt 1957; Pilkey 1964). The coarse fraction of these sediments contains whole and fragments of small molluscan shells, lamellibranchs, gastropods, scaphopods and some pteropods; echinoid spines and plates; foraminifera, with planktonic forms abundant near the entrance to the Gulf; ostracods, polyzoa, serpulid worms and crab fragments; pellets, composite grains, quartz and other insolubles. Pyrite is found infilling some of the foraminifera and molluscan shells. These marls are thought to be thin, as in some places sediments containing oolites and having other shoal water characteristics are sometimes found exposed with only a small admixture of marl. It is inferred that these formed at periods of lower sea levels. Farther to the north, frosted quartz grains are prominent. These are unlikely to reach their position under present conditions and are probably drowned and reworked coastal deposits (cf. Emery 1956; Houbolt 1957). Prominent subbottom reflections are found in the deeper trough from depths up to 8 fm. beneath the sediment surface. These die out as areas of coarser sediments are approached. These marly sediments are thought to have been produced by local production and breakdown of shell material, locally reworked material, wind blown material mixed with mud from the Persian Coast and delta and fine

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grained carbonate derived from the shelf to the southwest. These sediments pass through a series of deposits of intermediate character into the sediments of the Arabian Shelf (cf. Houbolt 1957).

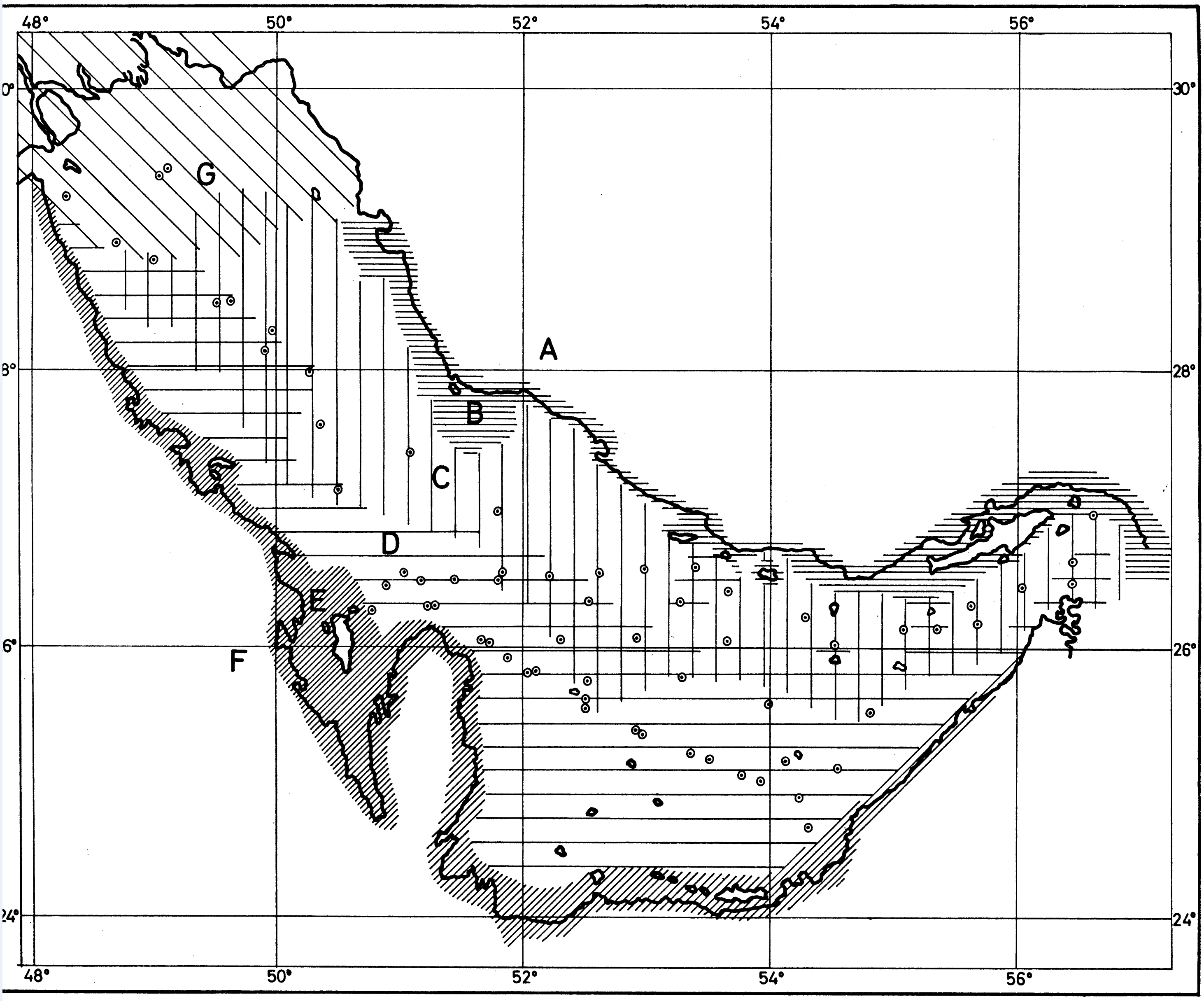

FIGURE 2. A provisional sediment facies map of the Persian Gulf. A, Persian continental facies; B, Persian coastal and shelf facies; C, Persian Gulf trough facies; D, Arabian shelf facies; E, Arabian coastal complex facies; F, Arabian continental facies; G, Mesopotamian deltaic complex facies. ⊙, Indicates stations occupied by H.M.S. *Dalrymple* during 1961–62 and 1962–63 survey seasons.

The broad shallow shelf, generally less than 20 fm. in depth, has a complex topography with numerous banks and shoals. There are some small islands, which are salt plugs, surrounded by reefs and rims of sediment extending southeast away from the dominant northwest wind and wave attack. Some of the shoals are capped with coral reefs and small sand cays. The sediments consist dominantly of skeletal sands with variable

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amounts of coarser shell debris, calcilutite and some insolubles. There is a good macrofauna of molluscs and echinoids with subsidiary corals and crabs.

The carbonate fraction consists mainly of aragonite mixed with varying amounts of low and high magnesium calcite. These sediments usually contain less than 0·5 % organic carbon and less than 0·05 % organic nitrogen. The carbon nitrogen ratio varies from 5·0 to 14·2 and is usually greater than 10. The sediment consists of molluscan debris, lamellibranchs, gastropods and some scaphopods; echinoid plates and spines; foraminifera, ostracods, crab fragments, polyzoa and serpulid worm tubes often coating shells; and rarer sponge spicules. Coral and algal fragments, the latter sometimes forming concretionary growths, are found in some shoal areas. Composite grains including derived rock fragments and faecal pellets are also found, with varying amounts of quartz and other non-calcareous material. Many of the grains, particularly some species of foraminifera, have a shiny black coating (Houbolt 1957).

The sediments seem to have formed mainly of locally produced skeletal material being broken down by bottom scavengers, boring algae, wave and current action. They appear to show evidence of reworking and mixing of sediment of various ages. Mixed with this material is some wind blown material from the bordering land masses. The calcilutite is produced by breakdown of skeletal material and precipitation of aragonite by local spontaneous plankton blooms (Wells & Illing 1964). The local differences in topography control sediment characteristics producing a distribution of calcarenite with small patches of calcilutite in the depressions and sheltered locations on the shelf. The latter areas may be more common off the Saudi Arabian coast where the topography appears to be more broken and complicated. Echogram and stratigraphic profiler traces show that the sediments are thin and in places barely cover the underlying rock. Sedimentation is obviously slow and has hardly started to bury the inherited topography.

The southwest shore of the Gulf is the site of intensive rapid deposition of carbonate sediments in a complex of shoal water environments (Evans, Kinsman & Shearman 1964; Kinsman 1964*a*). On the Trucial Coast, near Abu Dhabi, a series of islands composed mainly of Recent unconsolidated sediments with cores of Quaternary limestone of aeolian and shallow water origin enclose a series of tidal embayments and lagoons. Waters attain high temperatures and salinities in these lagoons (Kinsman 1964*c*). Strong tidal currents draining the embayments produce large tidal deltas where the waters debouch into the southern Gulf from between the islands. These deltas are the site of extensive oolite formation. Fringing and barrier reefs are sometimes found between the tidal deltas fronting the islands and also some coral reefs are found in the outer parts of the lagoons (Kinsman 1964*b*). The islands have sandy frontal beaches and dunes composed mainly of oolitic and skeletal sands. The sediments of the frontal barrier are composed mainly of aragonite with low percentages of low and high magnesium calcite with higher percentages of high magnesium calcite in the reefal sediments. The importance of offshore supply and onshore sand transport by the waves and subsequent building into dunes by the wind, both of which are dominantly onshore here, is well illustrated on this coast. Where the deltas, where sand production is rapid, front the coast, dunes are high; in the intervening areas where there is only a slow production of skeletal sand, on the shelf to seaward, and where the nearshore profile is steep, they are low.

Inside the lagoons and embayments the islands are fringed by narrow beaches and dunes; broad intertidal flats inhabited by crabs and gastropods; algal flats and mangrove swamps where calcilutite heavily burrowed by crabs accumulates. The tidal channels die out inland. They are floored by pelletal and skeletal calcarenites and calcirudites with oolites near the deltas. The shoal areas in the outer lagoon are floored by pelletal and skeletal calcarenites. Local beach ridges enclosing the intertidal flats and swamps are almost pure pelletal and skeletal sands. The inner part of the lagoons are much muddier and pelletal and skeletal calcilutites predominate. The sediments of the lagoons are dominantly aragonitic with low percentages of low and high magnesium calcite.

Broad intertidal flats fringe the inner shoreline and here pelletal and skeletal calcilutites and calcarenites are common. Extensive algal flats develop which are often more than a mile wide. The waters enclosed under the algal mats are highly saline and mushes of gypsum crystals occur particularly in the higher parts of the flats.

The algal flats and intertidal flats pass landwards either directly or across low beach ridges, composed almost entirely of gastropod shells, into a low coastal plain. This salt encrusted plain, the so-called sabkha, shows many old strand line features such as old beach ridges and infilled tidal creeks. It has originated by the progradation of the inner coastline by extensive intertidal flat deposition over a distance of approximately 15 mi. (Evans, Kendall & Skipwith 1964). The sabkha is sandy with many beach ridges where the coast is more exposed, and muddier with channels and few ridges where it is better protected.

The sabkha plain is of exceptional interest. The highly saline waters of the lagoons percolate into the subsurface of this coastal plain and are drawn up to the surface by capillary action (Shearman 1963). As they move inland they become more concentrated and differentiated and a complex reaction occurs between them and the earlier deposited intertidal and coastal plain carbonate sediments. The result is that an interesting suite of evaporite minerals is found forming in the sabkha and the upper parts of the intertidal flats. Gypsum occurs at various levels and appears to be of several generations and origins. Anhydrite is found developing above the ground water table at slightly higher levels (Curtis, Evans, Kinsman & Shearman 1963). It occurs as courses of nodules and beds up to 2 ft. thick with remarkable contortions and sedimentary structures seen so often in the ancient evaporites (Butler, Kendall, Kinsman, Shearman & Skipwith 1964). Dolomite is found and it appears that penecontemporaneous dolomitization of earlier calcareous sediments is taking place (Wells 1962; Curtis *et al.* 1963). Other rarer evaporitic minerals are also present. Celestite is found particularly under the older algal mats in the sabkha and is probably formed as a by-product of dolomitization (Evans & Shearman 1964). Halite is also common in the sediments. The sabkha 'evaporite' plain is bordered by the low bluffs of Tertiary rocks, which pass under the dunes of the desert inland.

The Arabian peninsula is fringed by a highland rim. Large outwash plains slope down from this rim to the interior lowlands. Much of Arabia is covered by large deserts, inside the outwash plains, such as the Great Nafud, Dahna and the Rub al Khali (Holm 1960). The sands are mainly composed of quartz, but are being diluted near the coast by the inland migrating carbonate sands of the Trucial Coast. As the present cycle progresses, there is the possibility of a large sheet of carbonate sand transgressing inland over the continental quartz sand, this, taking place, purely by aeolian action and not by a marine transgression. This situation would pose a problem for the stratigrapher, when encountered in fossil sequences. Occasionally because of the different relation between wind and coastal trend some of the quartz sands reach the coast to become entrained in the sediments of the Arabian coastal complex facies (Emery 1956; Sugden 1963*a*). Arabia appears to be a large sediment trap losing some and gaining small amounts of sediment along its shores.

Finally in the northwest end of the Persian Gulf are the vast alluvial plains and swamps of the Mesopotamian plains, produced by the Tigris–Euphrates and Karun rivers. The history of the deltaic complex is complicated by Recent tectonic movements. It appears that subsidence is taking place and accommodating the incoming river borne sediment. The delta does not appear to be extending appreciably seaward at present (Lees & Falcon 1952). However, Recent marine deposits overlain by alluvium have been described from boreholes far inland from the present coast (Hudson, Eames & Wilkins 1957). The sediments in the vicinity of the delta contain considerable non-calcareous material but still have fairly high carbonate contents (15 to 20% CO_2). They seem generally to have lower carbonate, organic carbon and organic nitrogen values than sediments of equivalent grade elsewhere in the Gulf. They contain molluscan shell debris with some corals, foraminifera, echinoid fragments and spines, ostracods serpulid worm tubes and crab fragments. Exactly how much sediment escapes seawards to the Persian Gulf and how far the delta's influence extends is not known. However, the presence of some apparently relict sediments near the delta suggest the rate of seaward escape of sediment is not great, unless these would have been covered.

The modern facies pattern is in many ways similar to that of the past, the modern trough deposits being equivalent to the marls of the earlier troughs. The shelf and coastal complex having many analogous situations in the Mesozoic when lagoonal, reefal and evaporitic sediments were common on the southwest of the trough (Lees 1948; Dunnington 1959; Steineke, Bramkamp & Sanders 1959). Because of the narrow shoal area, approximately 70 mi. inside the Gulf, a drop in sea level could convert a large part of the Persian Gulf into a shallow area separated from the open sea by a very narrow inlet. Such a situation could be an ideal one for the development of extensive evaporites. Perhaps similar barriers might have been responsible for the development of the extensive Mesozoic and Tertiary evaporitic sediments (Lees & Richardson 1940; Sugden 1963*b*).

In conclusion, it appears that the modern Persian Gulf with its striking facies pattern is an excellent model for the interpretation and understanding of the older deposits of the Middle East and elsewhere on the Earth's surface.

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