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Late Cenozoic Faulting in S.E. Iran

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Author: Manouchehr Ghorashi

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Presentation of The Problem and Methods of Investigation

Iran lies within the Alpine mountain system. It is commonly subdivided in to tree major geological zones: The Alborz range in the north; the Zagros-Makran range, which extends from the northwest to the southeast of the country; and, lying between them, the plateau and plains of central and eastern Iran (*Figure 1*).

The geological structure of Iran has been a matter of controversy for many years. One school, which includes Nowroozi (1972), McKenzie (1972), and Takin (1972), views it as the product of plate interaction. Bird, Toksoz and Sleep (1975), for example, have described Iran as a central plateau subject to oceanic subduction from the northeast and an Arabian continental subduction fron the southwest. In their model for the Zagros Mountains the transition from oceanic to continental subduction occurred over the last million years. More recently, on the basis of seismic evidence, McKenzie (1977) has revised his original sketch of the plate boundaries and motions of the Mediterranean area (*Figure 2*). The main difference between this and the earlier model (McKenzie,1972), is that in eastern Iran deformation is no longer seen to be continued eastward in to Afghanistan, being taken up by north-south structures which connect the Koppeh Dagh in the north to the Makran coast in the south (*Figure 3*).

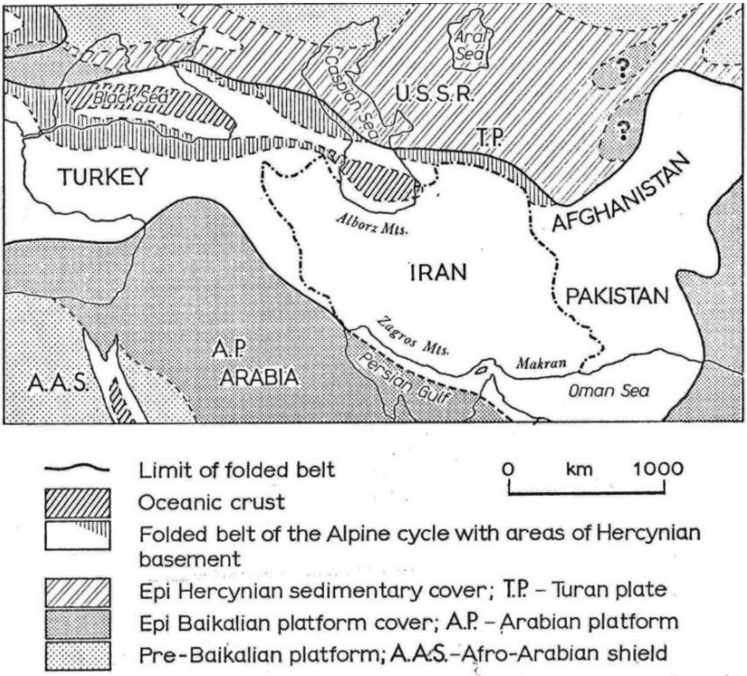

Figure 1: Iran as part of the "Mediterranean-Himalayan" Alpine folded belt (compiled from various sources).

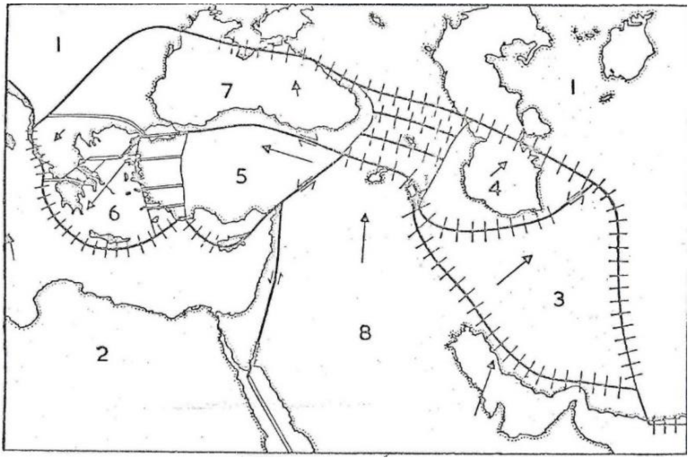

Figure 2: Sketch of plate boundary and motions in the Near East (after McKenzie,1977). The arrows show the directions of motion relative to Eurasia and their lengths are approximately proportional to the magnitude of the relative velocity. Except for the North Anatolian Fault in Northern Turkey, the plate boundaries are: 1 Eurasia, 2 Africa, 3 Iranian, 4 South Caspian, 5 Turkish, 6 Aegean, 7 Black Sea and 8 Arabian.

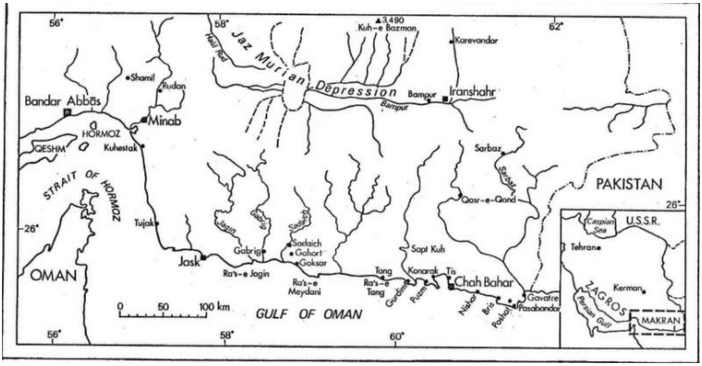

Figure 3: Iranian Makran: places mentioned in text.

Physiography

In terms of geological structure, physiography and climate, the area shows a certain individuality compared with its neighbors and more especially a marked deviation from the main Zagros system adjoining it to the west. The Makran and the Zagros Mountains differ profoundly in all aspects of their physical geography. There is no transition between the two regions, and the changes all take place abruptly across what is generally referred to as the "Oman line". The radical difference in the geology and geomorphology of southeastern Iran can be seen at a glance on satellite photographs. The great whale-back folds of the Zagros Mountains terminate suddenly and unnaturally against a roughly north-south line. This line was formerly called the Zandan Fault, but it has been renamed the Minab Fault by Berberian (1976) after the town of Minab in southeastern Iran (*Figure 4*).

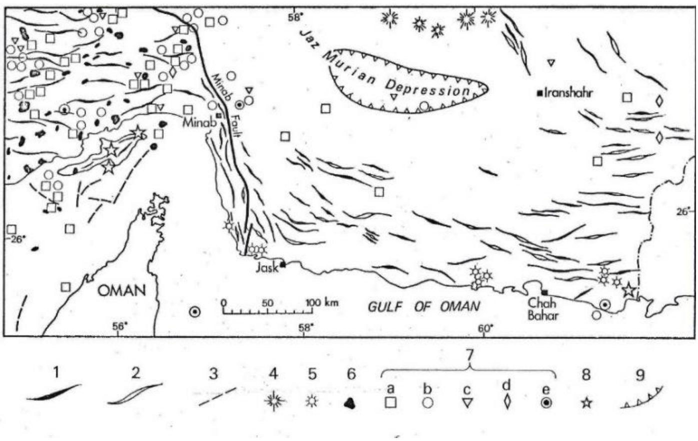

Figure 4: Schematic diagram of salt domes, anticlinal and synclinal axes, and earthquakes epicenters. 1 Anticlinal axes. 2 Synclinal axes. 3 Buried anticline inferred from geophysical

data. 4 Young volcanic cones. 5 Mud volcano. 6 Salt dome. 7 Earthquake epicenters, magnitude 5 or more and with focal depths of (a) less than 30 km, (b) between 30 and 59 km, (c) between 60 and 99 km, (d) more than 99 km, (e) no focal depth calculated. 8 Historical (pre-1900) destructive earthquakes. 9 Central part of major depression. Based on various sources.

The Zagros mountains form a fold belt of anticlines and synclines which is more than 1600 km in length. The long axes of the folds, which are arranged en echelon. Are generally oriented north-west to south-east. Some of the anticlinal ridges exceed 80 km in length and the highest reach about 3000 m above sea level. The rocks of the simply-folded zone of the Zagros consist of shallow water marine limestone with marls and evaporates or salt domes. Folding took place chiefly in Pliocene and Pleistocene times.

Immediately east of Bandar Abbas, the trend of the Zagros ridges changes abruptly. For a distance of about 250 km between Bandar Abbas and Jask the direction of folding is north-south; then, eastwards of Jask, there is a second change to west-north-west / east-south-east trends.

A narrow coastal plain bordering the Gulf of Oman and the Indian Ocean is succeeded inland by a zone of plateau country with an average elevation of 700 m to some 1000 m, and this plateau is crossed in places by lines of hills which occasionally reach to about 1800 to 2100 m above sea level. Northwards beyond the

Makran Mountains lies the Jazmurian basin, a depression with its lowest point about 300 m above sea level. This basin is partly filled by a thick layer of silt and windblown material. There is no drainage from the basin, and the center is occupied by a salt lake fed by two streams, the Halil Rud and the Rud-e Bampur. The JazMurian depression is defined on the north by a single narrow line of high-lands which act as a divide between the JazMurian depression and the interior plateau of Central Iran. The average height of the ridges is about 120 m, but a single peak of 3490 m occurs at Bazman.

The Zagros is a region of frequent and severe earthquakes (*Figure 4*). By contrast, the Makran is seismically relatively quiet, although it has a significant record of minor tremors. Earthquakes are generally shallow and are scattered over a broad belt that stretches several hundred kilometers to the north of the Gulf and the study area. The earthquake of magnitude 8.3 (Richter) which occurred in 1945 off the Makran coast of Pakistan at 25°N, 64°E was an exception to this pattern (Pendse,1946).

The drainage pattern through the Makran Ranges is also different from that of the Zagros. In the Makran the rivers have not carved deep gorges directly across the strike of the mountains (Oberlander,1965). Instead, they tend to insinuate themselves between and around ranges in fairly wide valleys, with the result that almost all provide gradual gradients inland from the coast.

According to Snead (1970) the Makran coastal zone can be divided in to three broad physiographic regions: (1) the coastal terraces, developed along the coast and mainly in the eastern part of the area; (2) low-lying alluvial plains which lie behind the terraces but extend to the coast as large tidal flats west of Ra's-e Tang; and (3) the hills and mountains of the Makran coast ranges. Marine terraces are well exposed along the Makran coast both in Iran and in Pakistan.

The rocks of the Makran coast consist of Clays and Soft, poorly consolidated silts and sandstones of Late Tertiary age which are undergoing rapid erosion by rare but frequently torrential rainfalls of the region. The coast between Gohort and Gwader is characterized by a series of low plateau, of which Ra's-e Meydani, Kuh-e Puzm, Kuh-e Bris, and Kuh-e Gavatre are typical (for location see *Figure 3*). These plateau are capped by raised beach deposits.

Terrace gravels are an important feature of the landscape of southern Iran, and indeed of the country as a whole (Blanford,1876). In coastal Makran, terraces, some consisting of rock-cut beaches overlain by gravels, occur along the rivers. Nine mud volcanoes have been reported along the coast (Geological Map of Iran,1959) (*Figure 4*). According to Ahmed (1969) the mud volcanoes on land are aligned with major fault zones or zones of weakness.

The Makran coast ranges form the rugged southern escarpment of the great interior plateau and basins. They form a significant barrier to the coastal plains of southern Iran. Physiographically, these ranges fill the gap between Zagros on the northwest and the extra-peninsular Himalayan ranges on the east, which lie on the west side of the Indus River and form the mountains pf the northwest frontier of Pakistan. The structure of the Makran ranges in Iran is identical with that of the Makran ranges of Pakistan (Snead,1970).

Marine Beaches

In coastal areas around the world there is ample evidence of changes in sea level relative to the land. It is necessary to use the term relative in this context, as there is no certainty that the effects are caused solely by a rise or fall in sea level rather than by a rise or fall of the land. Indeed, both may be involved to produce the net result. The first kind of change is necessarily world-wide and is term "eustatic".

Fairbridge (1961) has placed the sources of sea-level changes into four main categories: (1) tectono-eustasy; (2) sediment-eustasy; (3) glacio-eustasy; and (4) other eustatic processes, such as changes in the total volume of the oceans with expansion or contraction of their mass due to changes in solar radiation, the addition of juvenile water from volcanoes, etc.

Objections against the classic glacio-eustatic theory are numerous (Guilcher,1969). The investigation at see-floor spreading and magnetic data supporting the concept of continental displacements raise the question whether any coast is in fact stable.

Late- Quaternary changes in sea level

However, the search for a generalized, global eustatic curve continues, and during recent years numerous carbon dating have yielded curves of Holocene sea level. No brief survey could pretend to cover the scattered literature on geologic evidence of changes in sea levels, but it is possible to identify three main schools of thought in this subject: (1) that sea level rose to its current level 3,000 – 5,000 years ago and has since fluctuate above and below it; (2) that sea level has remained relatively stable since that time; and (3) that the rise has been continuous. Bloom (1971) has suggested that most of the published submergence curves, show that sea level lay between 8 and 12 m below present sea level about 7,000 years ago. However, the divergence remains striking even within restricted areas.

Recently Clark (1977), using a computer model, studied global sea level changes since the last glacial maximum. He divided the earth in to zones of relative uplift and subsidence, and traced Holocene Sea level in different parts of the world. The curve that is applicable to the Makran is illustrated below (*Figure 5*).

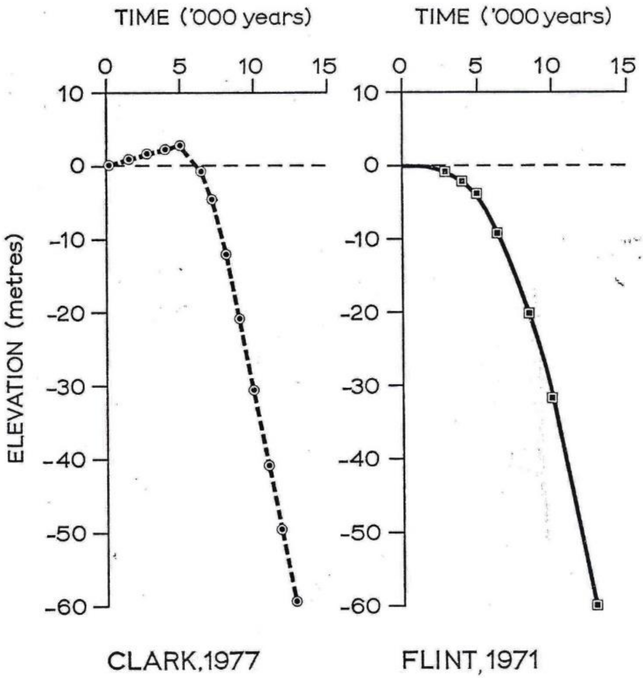

Figure 5: left, sea-level curve for parts of zone III of Clark (1977) that were distance from Pleistocene ice margin; right, global sea-level curve after Flint (1971).

Earth movements

Changes in sea level are more complex in those areas that have been subjected to both eustatic and isostatic changes resulting from deglaciation. A large ice sheet probably constitutes a load greater than the material strength of the upper mantle beneath the crust.

Walcott (1975) observed that oscillations in sea level of a few meters have been identified in many areas, but questioned the widespread belief that these were eustatic changes related to variable ice volumes. He suggested that the error in determining eustatic sea deformable. Where the earth is subjected to differential surface loading, as at a coastline during a eustatic change, there will the movements of local datums which can be correlated with the movements of water. Thus the earth must be stressed to support surface loads, and because it has a finite rigidity these stresses lead to body strains and surface displacements.

Although the theory that the creation of basins causes flow in the mantle cannot easily be questioned, the disposition of the displaced material during the glacial maximum is a matter of debate (Flint, 1971). It had been suggested that such material would elevated the crust in an area peripheral to the ice sheet. But the evidence is wholly negative, even where shore features and stream terraces should reflect much movement and afford a basis for measuring it. In addition, extensive areas along the margins of former ice sheets are now submerged, making their reconstruction difficult.

In contrast with thinking earlier this century, the current view is that tectonic movements can occur on all coasts, though by widely differing amounts. According to Wellman (1972) all sudden movements are directly associated with earthquakes, whereas gradual movement may be isostatic or may precede or follow earthquakes.

Three cases must be considered for both gradual and sudden movements, namely faulting, uplift, and tilting.

The faulting of fossil beaches and marine terraces is a well-known phenomenon and has been reported by many workers (for example, Schrouder and Kelletat, 1976; Orme, 1972). The measurement of uplift and tilting after sudden movement depends on the pre-existence of some reference, either cultural or natural. For coast lines a few simple observations the degree of accuracy to which earthquake uplift is determined. Plafker (1965) determined vertical tectonic movements in coastal Alaska principally by making more than 800 measurements of the displacement of intertidal sessile marine organism along the intricately embayed coast affected by the 1964 earthquake. He found that this deformation included two major northeast-trending zones of uplift and subsidence from 700 to 800 km long and from 150 to 250 km wide. The seaward zone was one in which uplift of as much as 10 m on land and 15 m on the sea floor occurred as a result of both crustal warping and local faulting. This suggests that great earthquakes may be accompanied by regional deformation on a larger scale than previously thought.

In order to determine the average rate of uplift since the formation of a specific shoreline feature it is necessary to know the age of the feature, the height above mean see level at which it formed, its present height above mean see level, and the height of mean see level relative to that of the present day at the time when the feature firmed. Eustatic changes are of concern to us solely when absolute vertical displacements have to be computed, as see-level changes have to be allowed for. Where relative displacement is at issue, however, such changes can often be disregarded. Needless to say the though still surprisingly common.

Morphology of marine terraces

Marine terraces as defined here are uplifted shore platforms. The morphological features which are used in their identification (*Figure 6*) also make it possible to evaluate the amount of vertical displacement and deformation they have undergone.

The most important feature of the shore platform is the nip, which is an unequivocal indicator of sea level as it was during the cutting of the platform. The nip is formed close to the mean high water mark, and serves as the cutting edge for widening the shore platform. When measuring the height of a fossil marine terrace it is therefore most important to measure its elevation in the vicinity of the nip at the back edge of the terrace. Where wave activity is most intense, the nip is more developed although not as deep on the leeward portions of coastal headlands consisting of calcareous rocks, where chemical and biochemical solution processes are probably the most important erosional agents. Where nips do not occur, lines of holes produced by rock-boring organisms may give an approximate indication of the high water mark.

Another area where solution is dominant over abrasional wave action is below the outer edge of the platform, corresponding to the low water mark. The notch is influenced by smaller waves and is less abrasional material is present there. It develops at a much slower rate than the nip.

Solution pits may be found at the top of coastal cliffs in the zone which is drenched by the spray of high tide waves. Chemical and biochemical reactions are the most important agents causing these features. A complex process of physical and chemical solution, termed "water-layer weathering" (Hills, 1949), has also been postulated. At all events, the resulting features can merely be said to have lain somewhere above High Water.

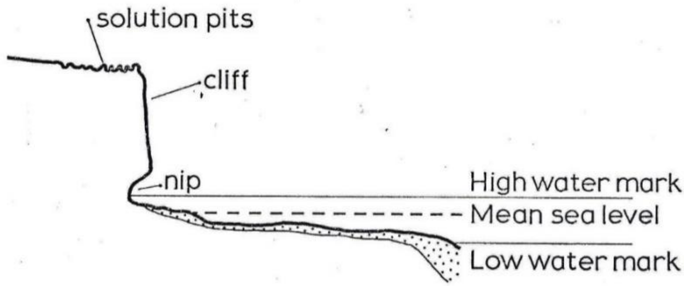

Figure 6: Coastal morphology: terms used in text.

Faults in Fossil Beaches

<u>Gavatre Terrace</u>

This terrace is located approximately 5 km west of the Iran / Pakistan border and lies 29 m above sea level. The total thickness of beach deposits in this area is 5.70 m. In the basal part, this unit consists of a shelly horizon about 50 cm thick resting on greenish grey Neogene marls and is overlain by a cross-bedded sandstone. Generally, the lower part of the Gavatre beach deposits consist of clay material whereas the sands increase in proportion upwards and tend to dominate the upper two-thirds of the formation.

The beach deposits are mainly composed of shelly limestone (lumachelle), sandstone and conglomerates. The lumachelle beds are 10 – 20 cm thick and consist of shell fragments in a sandy or pebbly, hard, calcareous matrix. Microscopically the rock is vesicular, well-sorted, well-rounded, poorly packed, moderately indurated, and sub mature. It is mainly composed of plagioclase, quartz, and epidotite minerals and its texture is detritic-granular. The deposites weather to greyish brown or dark grey, but on fresh surfaces they are light brown. They are generally horizontal but the upper part dips gently seawards, that is towards the south, at about 7°. The underlying Tertiary rocks display slight or negligible dips. Various species of fossil shells such as gastropods and bivalves are well preserved in the deposit.

Two prominent north – south lineaments pass through the beach deposits of the Gavatre terrace. The larger one can be traced on aerial photographs for about 3.5 km and in some localities, it has apparently displaced some of the stream courses. The other is about 2 km long and convex towards the east (*Figure 7*).

An attempt to trace these lineaments in the field failed. Since the slopes are covered with huge rocky debris from the capping surface it is impossible to study them in vertical section. The features are believed to be faults because they are extremely straight and continuous. To judge from the displaced stream courses and the protrusion of the eastern part of terrace beyond the western side, the first lineament represents strike slip left-lateral movement. The second lineament displays no diagnostic feature but it too appears to be a strike-slip fault. Both features apparently postdate a fossil beach.

Little (1970) had reported a ^{14}C date of 5780 ± 115 years BP (I-4064) for shells from his Gavatre terrace at an elevation of 24 m. This date appeared unacceptably young but two feature dates of 4477 ± 50 and 5810 ± 100 years BP have recently been obtained for this surface (Vita-Finzi, perss. Comm.). If these should prove valid, the faulting episode will be seen to be not only very localized but also extremely recent.

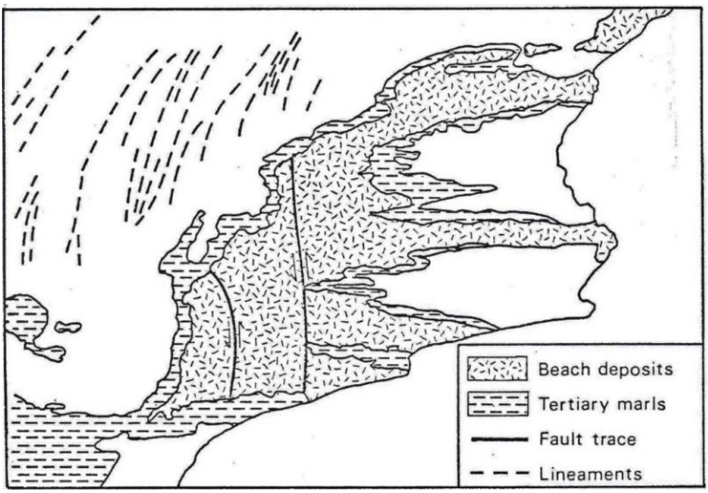

Figure 7: Fault traces southwest of Gavatre.

Poshat Terrace

The poshat terrace is located southeast of the small village of poshat. It is about 2 km loge and 200 to 700 m wide, and has an elevation of 65 m. The thickness of the beach deposits in this area is about 4 m and consists mainly of light brown to dark grey, rounded, medium grained, cross-bedded cemented sands which form a hard protective capping over the underlying soft Tertiary deposits. The structure of the Poshat marine deposits is similar to the Gavatre terrace. The poorly indurated Neogen marls and claystone are unconformably overlain by the marine deposits of the Poshat terrace. The Neogene rocks consist of greenish grey marls, light grey siltstone and mudstone dipping toward the south-southeast. Marine shells of different species are observed in the Poshat beach deposits.

One of the remarkable features of the Poshat terrace is that it is stepped. These features are clearly recognizable on vertical aerial photographs and can also be traced on the ground; they are defined by three main faults.

The western fault is approximately 600 m in length. The vertical displacement of the fault varies along its strike, with a maximum displacement of 3.30 m in the north. On its southern and the fault is much reduced in its vertical separation and gradually dies out (*Figure 8*). The fault has a strike of N 170° E and dips

80° towards the west. The fault plane has exposed cross-bedded, fossiliferous beach deposit.

A minor fracture runs parallel to the first main faults. This fault has a strike of N 170° E and dips 68° towards the east. The maximum vertical displacement of this fault is about 50 – 7- cm. the fault zone comprises a graben about 200 cm wide. Some enechelon sub-fractures can be seen along the fault zone (*Figure 9*).

The second main vertical displacement is located approximately 600 m east of the first main fracture zone. This is a fault which is 500 m along with a maximum vertical displacement of 4 m in its northern part (*Figure 10*). Again, the fault is much reduced in vertical separation at its southern end. The fault trace is approximately N 165° E and its dip is 85° towards the west. Along the edge of this fault some gravitational sub-fractures can be observed.

The third main fault, which has a maximum vertical displacement of 3 m, is found approximately 400 m east of the second fracture zone. The fault has a strike of N 170° E and dips 82° towards the west (*Figure 11*). It is about 450 m long. A minor fracture can be seen running parallel to it. Its maximum displacement is 50 cm and it dips 80° towards the east. The fault zone comprises a graben about 100 m wide.

Figure 8: Westernmost normal fault at Poshat. View from northwest.

Figure 9: Minor fractures along fault shown in Fig 6.5. View from south.

Figure 10: Central normal fault at Poshat. View from north.

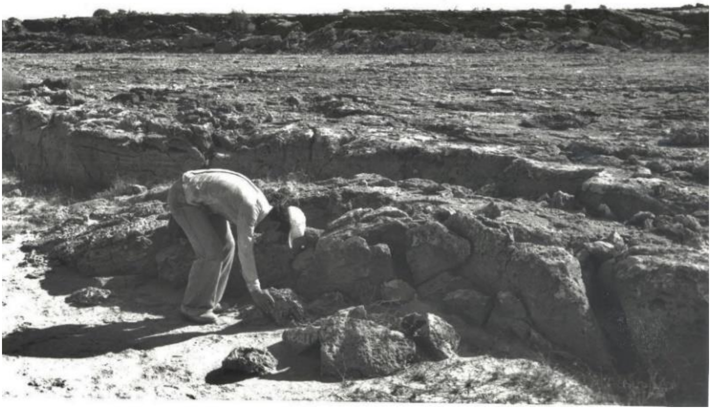

Figure 11: Easternmost normal fault at Poshat. View from west.

The measurements obtained by field investigation were plotted on the wulf Stereonet and maximum concentration were selected from the stereonet (*Figure 12*). The average strike of the Poshat terrace was found to be N 175° E and the average dip about 86° SW.

A sample of Anadara uropigmelana (Bory St. Vincent) from the eastern part of this beach was selected for ^{14}C dating. It gave an age of 20,555 ± 245 years BP (UM-1265). The $\delta^{13}C$ value of + 0.83 corroborates the evidence for no recrystallization obtained by X-ray diffraction and thin-section analysis. This result must be considered provisional until further samples are dated. If correct, it suggests that the faulting episode is apparently younger than 20,000 years.

Konarak peninsula

Of the localities in the Iranian Makran which display spectacular fossil beach sequences, Konarak is perhaps the best known. The konarak terraces are located south of the fishing village of Konarak approximately 130 km west of the Iran-Pakistan border. They form an elongated block, extending up to 4 km inland and 18 km parallel to the coast.

The Konarak terraces generally be divided into three major levels. The lowest level (A) is located in the southeastern part of the peninsula, the main terrace lavel (B) covers most central portion of the Konarak terraces, and the highest level (C), which is located in northwestern part of the peninsula and is highly eroded, is topographically controlled by the underlying structure (*Figure 13*). The highest area of the peninsula reaches a maximum elevation of about 100 m in the northwest corner.

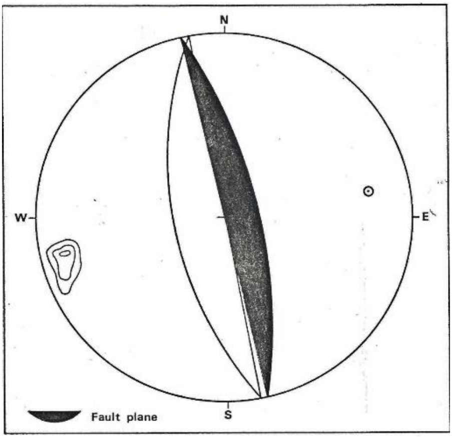

Figure 12: Stereographic representation of the normal fault planes at Poshat.

The level (A) occurs along the southeastern part of the peninsula. The best terrace sequence is exposed in this level, consisting of a fossiliferous pebbly beach 1 m thick which rests on Tertiary clay and is overlain by 7.50 m of grey, coarse to medium grained sandstone, capped by a fine grained, cross-bedded sandstone. The beach contains various fossil marine shells such as large pectens in growth position, large oysters and bivalves. Its surface level is 12.50 m above present sea level. It is thought to correspond to levels T1 and T2 (*Figure 14*) of page et al., (in press).

An extensive assemblage of flakes, blades and bladelets, microlights and some other artefacts was found on the surface of this terrace by Vita-Finzi (in press). He believes that the artefacts date from the 4th to early 3rd millennia BC.

The main terrace level (B) occupies the central and eastern part of the Konarak peninsula. Here, the marine deposits consist mainly of a light grey, well-rounded, medium to coarse grained, well-bedded occasionally laminated sandstone 3.6 m thick, resting unconformably on Neogene sediments. In some places the beach deposits are covered by 3.5 m of superficial deposits which include fossil sand dunes. The surface level of this terrace is 22 m above present sea level and corresponds to levels T3 – T5 of page et al. (in press).

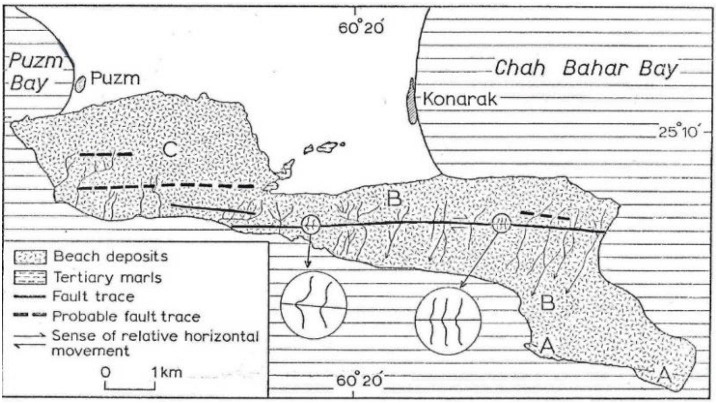

Figure 13: Distribution of faults in the Konarak peninsula.

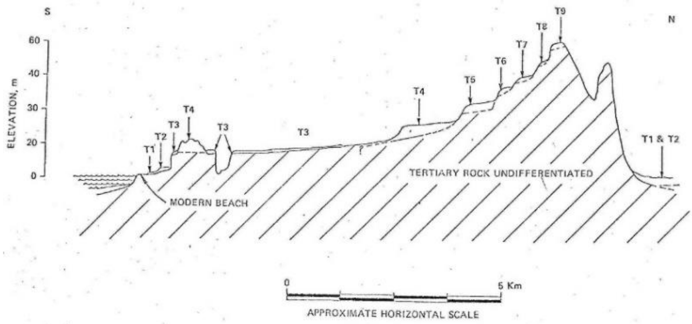

Figure 14: Schematic section of the Konarak peninsula (after page et al., in press)

The Neogene sediments are marly to shaly and blue-green in colour, but mainly white when weathered. They contain interbedded sandstone members. The marl is gypsiferous and although it is poorly consolidated it is exposed in cliff sections capped and protected by the fossil beach deposits. The contact between the Neogene sediments and the terrace capping is very well exposed in the extreme northern part of the peninsula where headwater stream erosion and slumping have occurred. An angular unconformity can be seen between the beach deposits and the underlying Neogene rocks there. The beach deposits dip 3° to 6° towards the south and the Neogene sediments dip 10° to 15° southwards.

Long, straight scarps are prominent in the main terrace level. In the central part of the main terrace a 10 m high scarp runs from east to west and is parallel to the peninsula for about 7 km (*Figure 13*). Numerous small streams cross this fault. Using aerial photograph analysis, a very slight horizontal component of right-lateral displacement amounting to less than one fifth the dip component can be detected in several localities along this fault. The scarp is much reduced in its vertical separation at its western end.

The highest level (C) is located in the north-western part of the Konarak peninsula, and numerous deeply weathered artefacts of Middle Paleolithic type found on its surface by Vita-Finzi and Ghorashi (1978). In this area the tilted Neogene rocks have been eroded and exposed as stripped structural surfaces. Terrace levels T6 to T9 proposed by Page et al. (in press) are located in this area.

The rectilinear character of some of the marine platforms, particularly the northern margins of the main terrace level, suggests that this platform is fault-bounded.

Several ^{14}C dates have been reported from the Konarak peninsula. Samples of oyster and barnacle from the beach near the 10 m high scarp gave ^{14}C ages of 22085^{+390}_{-410} . (UM-1147) and 24585^{+770}_{-850} (UM-1146) years BP respectively (Vita-Finzi and Ghorashi, 1978). None of the samples showed signs of recrystallization or contamination. Two other ^{14}C dates have been reported from this surface by Page et al. (in press). They were: 25,675 ± 850 and 26,430 ± 910 years BP. Page et al. regarded these as minima, and went on to obtain ages of 138,000 ± 12,000 and 156000^{+54000}_{-24000} years BP by the Th/U and Pa/U method. It remains to be seen which of these two sets of results represents the correct limiting age for the faults in the terrace, but the samples used for dates UM-1146 and UM-1147 were of sufficiently high quality to inspire a fair measure of confidence.

Goksar Terrace

This terrace is located on the northern side of the fishing village of Goksar. It is approximately 120 km east of Jask and 150 km west of the Konarak peninsula. The terraces cover an area of about 80 square kilometers and extend up to 8 km inland and 10 km parallel to the coast. The Goksar terrace is one of the most complicated marine terraces exposed along the Makran coast, and consists of a group of irregular, highly eroded flat-topped and in some places tilted hills.

The beach deposits at Goksar are composed mainly of sandstone and lumachelle beds. The rocks are dark grey, thin-bedded, medium-grained, well-sorted, and cross-bedded in some places.

The rocks when freshly exposed are brown and mostly porous, pebbly, and difficult to break. The beach contains various species of fossil marine shells such as gastropods, Pecten, and oysters.

The Goksar terraces exhibit at least three major levels, the highest of which is highly eroded and lies in the west.

In a cliff northwest of Goksar village the beach deposits are composed mainly of two units. The lower unit consists of a light, greenish grey, fossiliferous silty sand 4 m thick overlain by 1 m of medium-grained, brownish, fossiliferous sandstone. Both units dip very gently towards the south. The beach is about 20 m above High Water mark and rests on dark, gypsiferous Neogene marls. No clear bedding has been observed in the Neogene deposits in this section.

Several prominent west-east lineaments pass through the Goksar terraces (*Figure 15*). Some of these features can be seen on the surface of 20 m level (here called Goksar 1) and are very similar to those of the Gavatre terrace and eastern Konarak peninsula. It has not been possible to trace these lineaments in the field.

There is another lineament north of Goksar village (Goksar 2). This forms the margin of a very straight marine terrace where 1.6 m of beach deposits rest on the Neogene sandy marl. The marine deposits are gypsiferous, and a fossiliferous horizon 40 cm thick can be seen on top of the section. Various species of fossil shells such as gastropods, Pecten, and oyster are preserved in this horizon but the shells have been recrystallized to calcite.

The highest level of the Goksar terraces is located in the northern part of the area. The beach deposits in this section include a horizontally bedded sandstone 6.70 m thick which is overlain by 6 m of medium to coarse-grained, cross-bedded fossiliferous sandstone. The top unit contains numerous fossil oyster shells. The whole sequence rests on the Neogene greenish-grey, sandy marls. Because of the steep slopes and the covering of blocks which have fallen from the cliffs surrounding the terrace levels, contact between the beach deposits and the Neogene rocks are not very well exposed.

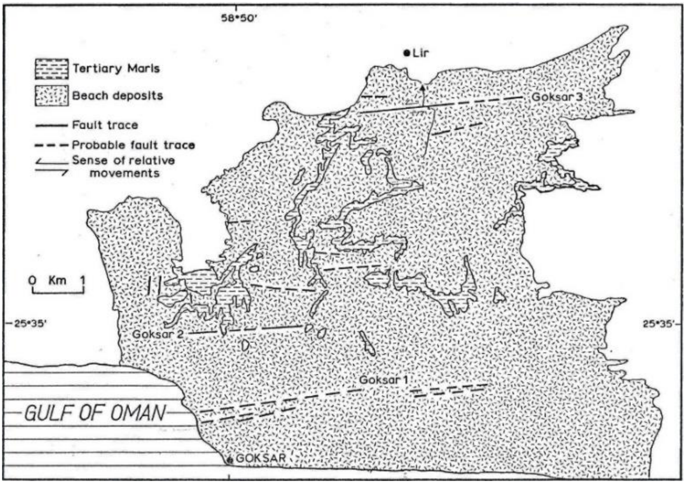

Figure 15: Distribution of faults in the Goksar marine terraces.

In the extreme northern part of the Goksar marine terraces south of the village of Lir, a transcurrent fault (Goksar 3, in *Figure 15*) cuts through the beach deposits. The fault trace is clearly visible both on vertical aerial photographs and in the field for about 3 km (*Figure 16*). Several stream courses have been displaced by this fault. There is some indication both from the air and on the ground that motion along this fault is almost purely left-lateral.

Samples of oyster from the faulted beach have been collected for dating but the result is not yet available.

In the end, it can be said that, on the basis of aerial photographic interpretation and field studies several faults and lineaments have been identified on fossil beaches along the Makran coastal plain. Faults ranging in length from a few hundreds of meters to some kilometers can be recognized. Some of the lineaments could not be detected on the ground (for example at Gavatre); others, as at Poshat and Konarak, represented very striking topographic features.

The faults observed on fossil beaches are mainly normal. They do not show any simple trend. In addition, the rectilinear character of the northern flank of the terraces at Jask, Puzm, Konarak and Bris is very conspicuous and is easily recognizable on aerial photographs.

Figure 16: Faulting on marine deposits at Goskar 3. View from west.

In this photo-mosaic interpretation of Iran, Pakistan and Afghanistan Wellman (1966) charted this feature as a single, major coastal fault which was subsequently named the Makran coast fault by Berberian (1976).

Three ^{14}C dates have been reported by Vita-Finzi (1975) and Vita-Finzi and Ghorashi, (1978) from the terrace at Jask: 22,960 ± 400; 25,190 ± 640 and 19165^{+365}_{-380} years BP (HAR-1097, 1115, and UM-1159). Radiocarbon dates of 34,310 ± 3,000; 28,010 ± 1,660; 32,680 ± 2,550 and 26,025 ± 1,050 years BP were obtained from Jask by Page et al. (in press). Like those of Konarak they regarded as minima, and Pag et al. turned to U-series dating. The results were in the region of 130,000 years. These dates, when related to the height of the Jask terrace (c. 6 m) led Page et al. to suggest that beach had been stable since the Pleistocene period.

In the eastern Makran, the Bris terrace lies 50 m above sea level. The straightness and height of its northern margin is also peculiar. Three ^{14}C dates have been reported from Bris (Vita-Finzi and Ghorashi, 1978). They are 24,400 ± 1,250; 27990^{+875}_{-980} and 28560^{+525}_{-560} years BP (MC-1579, UM-1145 and UM-1160 respectively). The $\delta^{13}C$ values for the three samples corroborates the evidence for no recrystallization obtained by x-ray diffraction and thin-section analysis (see *Table 3*).

As we have seen, the available dates for the platforms under discussion lie within 20,000 – 30,000 years. A possibility which springs to mind is that this coastal zone as a whole was block faulted and uplifted during this period. In addition, there is some evidence of localized transcurrent movement and faulting dates from the last 5,000 years or so. Only a massive application of radiocarbon dating in conjunction with further field studies will help us to establish the validity of these conclusions.

Vertical movements

As previously noted, the presence of marine terraces in different elevations along the Makran coastal plain both in Iran and in Pakistan has for over a century been ascribed to recent uplift and tectonic forces (for the lication and elevation of marine terraces see *Figure 17*).

Blanford (1876) found a "sub-recent shelly limestone" on the coast of southern Iran and stated that at Jask it formed a cliff about 6 m high. Pilgrim (1908) used the term "littoral concrete" and identified this feature as a raised beach. Falcon (1947) later described some of the terrace levels and their composition, and noted that marine terraces formed a series of low plateaux between Gohort and Gavatre. These plateaux were capped by raised beach deposits mainly of rust-colored shelly sandstone resting on a wave-cut platform. Falcon (1947) recognized the following levels along the Iranian Makran coastal plain.

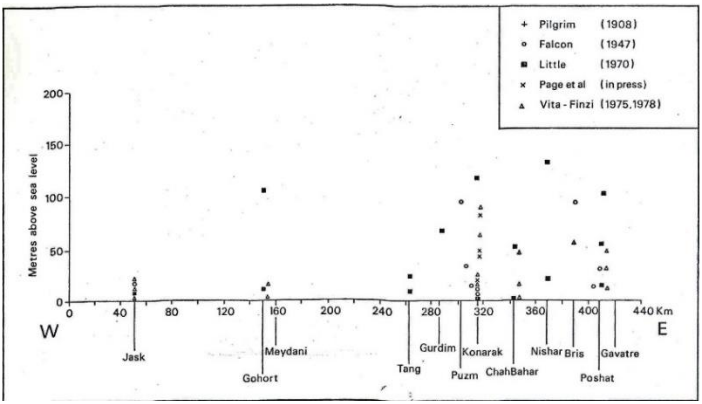

Figure 17: Elevation of marine terraces between Jask and Gavatre according to various authers.

1. At 250 – 300 feet (c. 76 – 90 m) - exposed south pf Puzm, near Bris and Poshat, and with relics some distance.
2. 100 feet (c. 30 m) terraces between Puzm and Konarak, Poshat and Pasabandar.
3. 50 feet (c. 15 m) terraces between Puzm and Bris and Gavatre. Falcon (1947) concluded that movement had been spasmodic.

Before the advent of radiometric dating the age of marine terraces was difficult to specify, as their faunas were similar to those now living in the area. For example, Pilgrim (1908) assigned his "littoral concrete" to Recent or sub-Recent times.

The first attempt to apply radiocarbon dating to the beach deposits was made by Little (1970). He described 10 terraces along the Makran coast. His interpretation for the Jask, Gohort, Meydani, Gurdim, and Bris-Nishar terraces was based on vertical aerial and oblique photographs. Little reported the following levels of raised beach deposits along the Makran coastal plain:

1- The Jask terrace as the most western low marine terrace level, at about 14 to 8 feet (c. 4 to 2 m) above sea level.
2- Approximately 100 km east of Jask, three major tarrace levels from about 20 to 30 feet (c. 6 to 9 m) level up to a few hundred meters above sea level near Gohort.

3- Three major elevations of the Meydani terraces occurring about 10 km east of Gohort, with a prominent north-south lineament in the central portion of the Meydani area and attributed to faulting.
4- The Tang terraces, approximately 75 km east of the Meydani terraces 20 to 30 feet (c. 6 to 9 m) above sea level. Several lineaments on these terraces indicated faulting.
5- The Gurdim terraces, a flat-topped platform 18 km long, parallel to the coast, 2 to 3 km wide and surrounding by wave-cut cliffs 180 to 196 feet (c. 55 to 60 m) high.
6- The Konarak terraces, divided in to two major sections, a northwestern area, and the major flat terraces are to the east. This is dominated by two levels, one at about 210 feet (c. 64 m) and the other at about 165 feet (c. 50 m). The highest level on this terrace attains 234 feet (c. 74 m) above sea level. Long, straight scarps ranging from a few centimeters high to about 10 m on these terraces were interpreted as faults.
7- A series of high platforms in the inland part of Chah Bahar ranging from 115 feet (c. 35 m) to a maximum of 820 feet (c. 250 m) above sea level, which Little called the "Tis terrace levels".
8- The Chah Bahar terraces, rangin in height from about 180 feet (c. 55 m) in the east to about 10 feet (c. 3 m) in the west near the town of Chah Bahar.

9- The coastal zone between Bris and Nishar, dominated by a raised beach 56 feet (c. 17 m) above sea level.
10- Finally, 6 km west of the Iran-Pakistan border, the flat topped Gavatre plain rises abruptly to more than 328 feet (c. 100 m) above the flat coastal plain. Little found three wave-cut levels on the Bris – Gavatre headland at elevations of 328 feet (c. 100 m), 164 feet (c. 50 m) and 56 feet (c. 17 m).

The dates reported by Little (1970) showed no simple correlation between the present elevation and the age of the marine terraces (*Table 1*). For example, two ^{14}C dates were reported from Konarak: one, which has already been mentioned, of 30,500 ± 1,800 yr BP (I-4321) for the surface capping at the 105 m level, and one of 31,850 ± 1,550 yr BP (I-4062) for the top of a 4.6 m scarp on the lowest of the terraces. In addition, he obtained two ^{14}C ages from Gavatre, near the Pakistan border: one of 5780 ± 115 yr BP (I-4064) for a deposit capping a 24 m terrace, and one of 23,660 ± 650 yr BP (I-4061) for a similar deposit on a terrace 1.5 m above sea level. At Gwadar, in Pakistan, he obtained a date of 28,750 ± 1,300 yr BP (I-4320) on material at a height of about 122 m, and one of 20,400 ± 450 yr BP (I-4063) on a sample at about 61 m.

Although Little (1970) was familiar with the risks of sample contamination, discrepancies between the height and the age of the terraces led him to the conclusion that uplift and warping, as well as faulting, had caused different degrees of tectonic movements along the Makran coastal plain. Thus, he suggested that tectonic activity in this region had been most pronounced between 30,000 and 20,000 BP.

In order to evaluate the rate of uplift along the Makran coastal plain of Iran and Pakistan Page et al. (in press) collected shell samples for radiometric age determinations from beach deposits at Jask and Konarak. Nine terraces were identified on the south side of the Konarak peninsula by Page et al. (in press, see above, *Figure 14*). In their view, the lowest two terraces (T1 and T2) occurred as small remnants along the southeast side of the peninsula. Terrace T3 was the most extensive terrace and covered most of the southeast part of the Konarak terraces. The fourth terrace (T4) had a form similar to terrace T3. The fifth terrace (T5) extended across the eastern part of the headland in a narrow strip. Terraces T6 to T9, located on the southwest part of the peninsula, did not have a large areal extent, and were not investigated by Page et al.

Table 1: Age and elevation of fossil beach deposits reported by Little (1970)

Location	Elevation	^{14}C age	Lab. No.
Gwadar*	c.400 ft (122 m)	28 750 ± 1300	I-4320
Konarak	344 ft (104.8 m)	30 500 ± 1800	I-4321
Chah Bahar	c. 300 ft (91.4 m)	> 39 900	I-4325
Gwadar*	c. 200 ft (61 m)	20 900 ± 450	I-4365
Gavatre	80 ft (24 m)	57 80 ± 115	I-4064
Chah Bahar	60 ft (18 m)	31 050 ± 950	I-4324
Konarak	15 ft (4.6 m)	31 850 ± 1550	I-4052
Gavatre	5 ft (1.5 m)	23 600 ± 650	I-4061

* = in Pakistan Makran

It is widely accepted (Thurber et al.,1972, see above, P. 84) that ^{14}C ages on shell greater than 20,000 years should be treated as minima. This assumption induced Page et al. (in press) to treat dates greater than 20,000 as minima and to use uranium-series dating as a means of confirmation (*Table 2*) even where there was no positive evidence of contamination. In addition, Page et al. (in press) discarded one of the Th/U dates merely because it did not fit the stratigraphical field relationships. The age in question – 76,000 ± 12,000 yr – had been determined on barnacles and clams from the surface of terrace T5.

At all events, after allowing for eustatic fluctuations using Flint's (1971) curve (*Figure 18*) Page et al. (in press) found that long-term average rates of uplift ranged between 0.1 and 0.2 cm/yr; using Clark's (1977) curve, the values ranged between 0.01 and 0.18 cm/yr. In either case, rates of uplift increased eastwards to a maximum value for the Holocene of 0.18 cm/yr at Ormara, in Pakistan. Page et al. (in press) inferred that episodic uplift along the Makran coast had resulted from large-magnitude earthquakes, and they ascribed such movements to faulting. Using the measured uplift rate at Ormara of 0.1 – 0.2 cm/yr and uplift of 2 m for the Pasni earthquake, they suggested a recurrence of 1000 – 2000 years for such an earthquake (M 8.3) for this coast, and they concluded that the rates of uplift along the proposed subduction zone off the Makran coast were comparable with those on uplifted coasts in other parts of the world.

Table 2: Dates of shell samples reported by Page et al. (in press)

Location	Sample	^{14}C (yr BP)	^{14}C corrected for $^{13}C/^{12}C$	$^{230}Th/^{234}U$ (yr BP)	$^{231}Pa/^{235}U$ (yr BP)
PAKISTAN					
Ormara					
Alluvial fan	O-1 (oyster)	> 37,000			
Tombolo	O-2 (clams)	2,710±135			
KONARAK					
Tombolo	K-4 (clams & gastropods)	5,520±165	5,935±165		
Tombolo	K-6 (clams)	5,880±320	6,255±320		
Terrace 2	K-10 (clams)	5,190±120	5,595±120		
Terrace 2	K-11 (gastropods)	5,330±120	5,795±120		
Lagoon	K-12 (clams)	5,280±160	5,700±160		
Terrace 3	K-8		25,675±850*	138,000±12,000	156000^{+54000}_{-24000}

	(barnacles)			
Terrace 3	K-9 (clams & barnacles)	26,430±910*		
Terrace 5	K-3 (clams & barnacles)		76,000±12,000**	
<u>JASK</u>				
Terrace dep.	J-1 (clams & oyster)	34,310±3,000*	133,000±13,000	140000^{+80000}_{-32000}
Terrace dep.	J-2 (shell fargs)	28,010±1,660*		
Terrace dep.	J-3 (shell frags)	32,680±2,550*		
Terrace dep.	J-4 (shell frags)	26,025±1050*	136,000±14,000***	114000^{+80000}_{-20000}

* ^{14}C date minimum.
** Insufficient material for a ^{231}Pa/^{235}U check; date not considered reliable.
*** Possible extraneous ^{230}T/&^{231}Pa contamination; date may be too old.

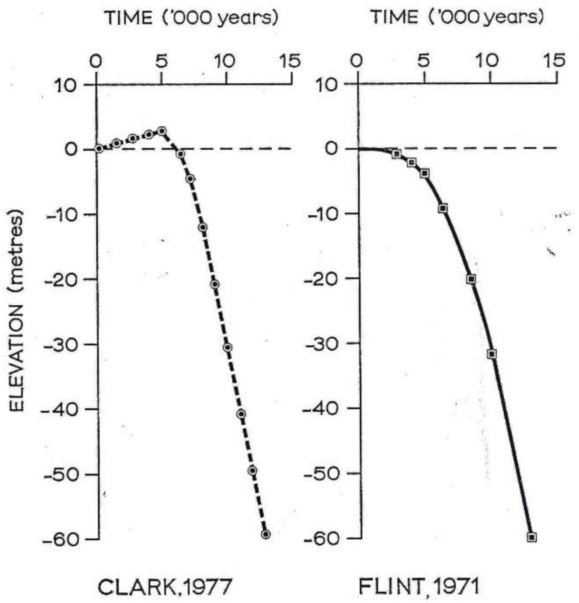

Figure 18: left, sea-level curve for parts of zone III of Clark (1977) that were distance from Pleistocene ice margin; right, global sea-level curve after Flint (1971).

To establish the extent of differential vertical movements datable material was collected from fossil beaches at a variety of locations and heights by Vita-Finzi (1975) Vita-Finzi and Ghorashi (1978) along the south coast of Iran both in the Zagros and in the Makran. Seven sites between Bandar-e-Lengeh and Bris were studied by Vita-Finzi. The first section in the Zagros is located about 42 km east of Bandar-e-Lengeh. He obtained an age of 4600 ± 100 yr BP (MC-1099) for this beach at about 4 m above sea level. The next two sections in this zone are located approximately 12 km west of Bandar Abbas. The beach deposits contained different species of marine shells in good condition. A sample of Turritella fultoni, 1.40 m above High Water, gave an age of 3500 ± 100 yr BP, and a similar sample at an elevation of 3.9 m gave an age of 4950 ± 110 yr BP (MC-1574 and 1572). Thin sections showed no obvious sign of recrystallization and X-ray analysis indicated aragonite with a very small trace of calcite for both samples. The other dates obtained in the survey have already been reviewed.

The dates (*Table 3*) reported by Vira-finzi along the Makran coast tend to support the argument that differential movement has occurred along the Makran coast. In other words, the dates indicate a progressive eastward increase in the elevation of beds in the 20,000 – 30,000 years range. Although the displacements do not indicate a continuous and uniform movement in this region, after correcting for eustatic change on the basis of Flint's curve (1971), Vita-Finzi (in press) obtained mean rates of uplift of about 0.15 cm/yr for the area west of Bandar Abbas, 0.25 cm/yr at Tujak, and 0.35 cm/yr between Jask and Bris along the Makran coast.

Table 3: ^{14}C dates reported by Vita-Finzi and Ghorashi (1978)

Location	Elavetion	Sample no.	Lat. & Long.	Leach %	^{14}C age (yr BP)	δ13 %	Lab. No.
Sheikh Jalal	1.40 m	76/1	27°09'N, 56°09'E	20	3500±100	n.d.	MC-1574
	3.90 m	76/4 A	27°09'N, 56°09'E	20	4950±110	n.d.	MC-1572
-------	4 m	IBR1	27°47'N, 55°10'E	20	4600±115	n.d.	MC-1099
Tujak	3.6 m	ET1a	26°01'N, 57°14'E	10	1940±45	n.d.	SRP-1258
	8 m	T1	26°01'N, 57°14'E	30	4200±90	+1.68	HAR-1754
	8 m	T1	26°01'N, 57°14'E	70	4300±80	+1.60	HAR-1766
	8 m	T3	26°01'N, 57°14'E	20	4180±120	n.d.	MC-1576
	11.8 m	ET2a	26°01'N, 57°14'E	10	3310±85	+0.79	UM-1268

	11.8 m	ET2b	26°01'N, 57°14'E	10	2923±40	n.d.	SRP-1257
	28.6 m	ET3x	26°01'N, 57°14'E	10	6155±155	+0.83	UM-1255
	28.6 m	ET3b	26°01'N, 57°14'E	10	6105±95	+0.46	UM-1269
Jask	5.5 m	Jask I	25°38'N, 57°46'E	30	22,960±400	+1.30	HAR-1097
	5.5 m	Jask I	25°38'N, 57°46'E	70	25,190±640	+1.40	HAR-1115
	6 m	Jask1 G	25°38'N, 57°46'E	10	19165^{+365}_{-380}	+0.12	UM-1159
East Jask	2 m	E. Jask1	25°39'N, 57°46'E	10	6615±125	n.d.	UM-1150
	2 m	E. Jask2	25°39'N, 57°46'E	10	4870±100	+0.09	UM-1151
Konarak	22 m	K76C (B)	25°19'N, 60°23'E	15	24585^{+770}_{-850}	-0.59	UM-1146

	22 m	K76C (O)	25°19'N, 60°23'E	15	22085^{+390}_{-410}	-1.52	UM-1147
Chah Bahar	18.20 m	CBI (U)	25°16'N, 60°37'E	30	29,980±900	+0.51	HAR-1755
	18.20 m	CBI (U)	25°16'N, 60°37'E	70	>35,000	+0.51	HAR-1767
	16.65 m	CBI (L)a	25°16'N, 60°37'E	20	28,750±1950	n.d.	MC-1577
	16.65 m	CBI (L)b	25°16'N, 60°37'E	15	27850^{+670}_{-730}	O.∞	UM-1148
Lifar	45 m	CB2 (U)	25°15'N, 60°50'E	20	30,000±2400	n.d.	MC-1580
	45 m	CB2 (L)	25°15'N, 60°50'E	30	30,000±1000	+0.30	HAR-1757
	45 m	CB2 (L)	25°15'N, 60°50'E	70	32,400±1500	+0.42	HAR-1769
Bris	50 m	Bris 1B	25°11'N, 61°11'E	20	24,400±1250	n.d.	MC-1579

	50 m	Bris 1C	25°11'N, 61°11'E	15	279990^{+875}_{-980}	+0.06	UM-1145
	50 m	Bris 1G	25°11'N, 61°11'E	10	28560^{+225}_{-560}	-0.59	UM-1160
Pasabandar	65 m?	PPA	25°09'N, 61°13'E	10	20,555±245	+0.83	UM-1256

From the foregoing accounts, it is evident that marine terraces provide valuable information on the nature and magnitude of structural deformation undergone by the Makran coast during Quaternary times. But whether existing models are compatible with the results is another question.

For example, in contrast to Page et al. (in press), who suggest that the eastward increase in the height of the marine terraces is due to an east-west-trending active subduction zone, Vita-Finzi (perss. Comm.) states that there is no reason for expecting greater uplift to the east as a consequence of such a mechanism, and every reason for equating the proposed low angle of subduction with minimal uplift throughout. He also of argues that, rather than being a direct consequence sea-floor spreading, the observed tilting might be a secondary effect of Himalayan uplift.

As a summary in this section, it can be stated that, the character and chronology of late Cenozoic deformation in S.E. Iran have revealed a complicated pattern which is somewhat inhomogeneous. This may have been controlled in part by lithological and structural variations. At all events, our provisional chronology for the Iranian Makran indicates that the earth's crust in the area has been subject to widespread faulting at least since the Early Tertiary. This faulting is manifested not only in the rupture of beds along individual structures but also as differential, large-scale, block-faulting along the coast.

The area has not yet received adequate attention from geophysicists, without whose assistance major structural problems will never be solved. What geophysical information on the Makran and the Gulf of Oman is available will be briefly reviewed in the next chapter before any attempt is made to interpret the record of late Cenozoic deformation.

Conclusion

Let us now briefly examine the suggested structural models for the Makran and adjoining areas in the light of the evidence obtained in this study. The region is particularly interesting in the context of current debates about continental drift, plate tectonics and sea-floor spreading and the importance of relative vertical and horizontal movements in crustal history, and it is all the more unfortunate that the geophysical and seismological data should still be inadequate for more than a preliminary assessment.

We may begin our narrative with Carey (1955), who used the 'orocline concept' to explain the arcuate shape of the Iranian-Baluchestan-Himalayan ranges. The concept appeared to be supported by palaeomagnetic work in Deccan, the results of which fitted the suggestion that the imagined crustal splitting, which in Carey's diagram extended to the Makran, took place in late Cretaceous and early Tertiary times. Later work by the Hunting Survey Corporation (1960), however, showed that the general pattern of tectonic stress in the

Baluchestan region and its symmetrical structure did not confirm with those postulated by the 'orocline concept'.

The Geology of the Makran was then interpreted in terms of geosynclinal theory by the same group of workers (Hunting Survey Corporation, 1960). They showed that the Baluchestan geosyncline had probably originated during the early Paleozoic as a broad depression of relatively simple shape with a medial axis more or less parallel to the present mountains of southern Iran and Baluchestan. Thousands of meters of shallow-water sediments accumulated in the continually subsiding basins. From Jurassic times, structural ridges and welts began to form and this process reached a peak during the Pleistocene Himalayan orogeny. In 1969, S. Sirtujuddin Ahmed discussed the structural history of the Makran both in Iran and Pakistan along similar lines. This kind of interpretation is difficult to test by reference to the faulting record, and all one can say at this stage is that it is neither compatible nor incompatible with the neotectonic evidence.

In 1974, Stoneley then expressed his views on the position of the suture line between the former Eurasian and Gondwana crustal elements based on the geological relationships between the two zones. In southern Iran he charted the southern Tethys suture at the foot of the northern continental slop of the Gulf of Oman, and went on to suggest that the spur of the Arabian shield extending eastward to the Oman coast could be regarded as a southern continental margin that had not yet collided with Eurasia. Instead, the Zagros crush Zone was represented to the west by the line of collision between the Gondwana Arabian continental and Eurasia.

In contrast, Stocklin (1968, 1974, 1977) demonstrated that some stratigraphic units of Early Cambrian to Middle Triassic age in Arabia and northern Africa could be traced through Iraq, Iran and in to Soviet Central Asia. For example, except for a partial change from evaporates to dolomite, Infra-Cambrian epicontinental deposition seems to have been continuous from the Zagros area across the later thrust line to the Soltanieh Mountains in central and north Iran. This continuity is supported by biogeographical considerations. This fact led Stocklin to the belief that, during the Paleozoic until the Triassic, Iran formed part of a continuous, undivided Arabian-Iranian platform, and hence of Gondwanaland. Stocklin (1974) suggested that if any substantial separation between Gondwana and Eurasia existed in the Paleozoic, it must have been north of Iran.

In 1976, White and Klitgord carried out a geophysical survey in the Gulf of Oman and reported a series of lightly folded sediment ridge aligned parallel to the Makran coast. They stated that the Gulf of Oman lay in a region of compression between the Arabian and Eurasian plates, and concluded that the deformed sediments in the Makran fold belt represented a thick pile of sediment scraped off the top of a subducting plate.

In 1977, Farhoudi and Karig, on the basis of a review of the literature, compared the features of the Makran with those of active arcs. Normal faulting in island arc-trench systems had been reported by various workers (Ludwig et al., 1968 ; Stauder, 1968 ; Katsumata and Sykes, 1969 ; Fitch, 1970 ; Kanamori, 1971 ; Abe, 1972a , 1972b ; Caldwell et al., 1976) and explained in terms of bending of the lithosphere just before it plunges beneath an island arc, the argument being that, in a bending plate, the upper part is placed under tension whereas the lower part is under compression (Caldwell et al., 1976). By analogy with well documented areas, Farhoudi and Karig (1977) showed that the northward increase in the age of the sediments, their deformation, and the elevation of the ranges as well as that of large subsiding basins flanked to the north by active volcanoes, all fitted in to such a scheme. Arc systems were again invoked by Farhoudi (1978) in his interpretation of the Zagros region in terms of collision and subduction.

As their authors concede, none of these proposals is supported unambiguously by the field evidence. But those based on plate tectonics do at least offer scope for comparing predicted with observed deformation. According to Farhoudi and Karig (1977), for example, lithospheric banding occurs some 400 km north of the coast (*Figure 19*); it is therefore irrelevant to the present area. The only faulting indicated by these authors on the Makran is thrusting consequent upon subduction. And, as we have seen, thrust faulting is not characteristic of the coastal areas. We may therefore conclude that only in the Inner Makran is the pattern of faulting consistent with this model. There is of course the possibility that normal faulting was restricted to basin fills. But here again the field evidence, notably at Konarak, suggests that normal faulting was not confined to superficial deposits.

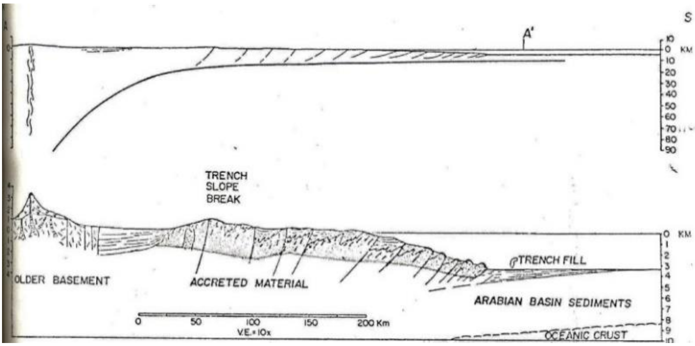

Figure 19: Schematic cross section of the Makran zone along Long. 60°E (after Fathoudi and Karig, 1977).

As regards interplate movements along the Minab Fault zone, Falcon's (1967, 1976) views that any transcurrent movements were followed by thrusting is supported by the field record. The rate of displacement indicated by the scanty data is c. 5.5m/6,000yr, that is c. 92cm/1000yr, for the Teleg fault. This is well within the rate of 5 cm/yr (that is 5,000cm/1000yr) indicated for northeastward movement of Arabia but only in that sense compatible with it.

Regrettably, the various models say little or nothing about the chronology of faulting, and therefore the data presented here cannot be used to choose between them on this basis. There is one conception, namely Farhoudi and Karig's (1977) suggestion that loci of deformation moved southward (that is trenchward) with time. In this respect along the field evidence could be deemed to correspond with the trench concept.

We may conclude that although the concept of plate tectonics has helped to focus attention on major structural lineaments, the pattern of faulting and the regional pattern of deformation of the Makran region and adjoining areas is not thereby fully explained. One can always make the evidence fit the theory: thus a possible explanation for the presence of normal faulting along the Makran coast and its absence in the Zagros is that in the latter the oceanic plate was completely consumed so that one continent collided with the other. But few would regard this kind of special pleading as particularly satisfying.

The concept of plate tectonics was of course established principally by studying oceanic plate boundaries. The seismicity of such boundaries is confined to a zone no wider than a few tens of kilometers (McKenzie, 1972), and therefore ridges, trenches and transform faults can be considered as lines on the earth's surface along which plates are produced, destroyed, or slide past each other. Continental tectonics is more complicated: for example, the epicenters in the

Mediterranean and in Iran in particular are distributed over a broad belt (McKenzie, 1972). Thus, in order to apply the idea of plate tectonics to a complicated area such as Iran, we are obliged to postulate a large number of independent plates. Alternatively, we can assume that continental regions behave plastically and that deformation is distributed over wide zones rather than concentrated on a few large faults (Molnar and Tapponnier, 1975).

Many of the problems can be resolved by additional field studies. In conjunction with detailed surface geological mapping, geophysical methods such as gravity, magnetic and seismic refraction both at sea and on land could be used to obtain more information about the nature of the floor of the Arabian Sea and the Gulf of Oman, and the extent of any sub-surface faulting that might be associated with regional seismicity. On a more modest plane, there are several locations where the geological evidence for faulting needs to be corroborated by geophysical techniques. Some 20 km west of Bandar Abbas several north-south lineaments are clearly recognizable on vertical photographs and can also be traced on the ground (*Figure 20*). The features are believed to be faults because they are extremely straight and continuous; they have led to the localized deposition of surface carbonates. A preliminary geophysical survey by the Geoinstitute of Belgrade (1976) ascribed the features to faulting, but its precise extent and character remains poorly understood. A similar set of lineaments, this time picked out by vegetation, is to be seen north of the Poshat marine terrace 5 km west of the Pakistan border (*Figure 21*).

It hardly needs to be stressed that dating of these features would add greatly to their value for structural interpretation. Again, most of the faulted marine terraces and alluvial fills discussed in earlier chapters require a far has hitherto proved possible if their chronological potential is to be fully realized. Some of these features, notably the beaches at Tujak, would also lend themselves admirably to instrumentation for the detection of present-day movement (King et al., 1975). Such studies are in any case crucial for the realistic evaluation of geological hazards in regions of potential population growth, or in areas in which it is proposed to construct factories, dams or atomic power plants whose disturbance could involve the risk of loss of life and capital. In other words, the benefits to be gained from further work would be immediate and practical.

Figure 20: Lineaments west of Bandar Abass.

Figure 21: Lineament north of the Poshat marine terraces.

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