

Past sea level changes along the western continental margins of India: evidences from morphology of the sea bed.

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The Holocene transgression, considered to be one of the latest episodes of sea-level fluctuations, has evoked considerable interest in varied disciplines of earth sciences. The episodic nature of the transgression is by now widely accepted and it is agreed that this has naturally led to distinct still-stands formation where the sea-level either remained static or even regressed a little temporarily. Such phenomena may have evidently left behind some signatures which can provide insight into the nature of these fluctuations.

Various direct and indirect palaeo sea-level indicators - having their advantages and disadvantages - have been identified with transgressive, regressive or still-stand conditions include specific biological indices of corals, molluscs, ooids, foraminifers, etc. and certain geomorphological features such as submarine terraces, reefs, notches, raised marine deposits, beach rocks and buried channels, etc.

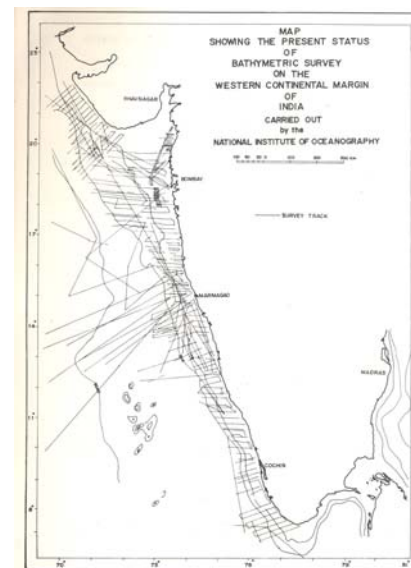
Glacio-eustatic sea-level fluctuations, along with relief, lithology, sedimentation, tectonic movements etc., have governed depositional and erosional patterns and thereby, topography of the continental shelf.

The continental shelves world over are marked by the presence of a variety of geomorphological features that are the net result of, along with other factors, prevailing hydrodynamic and sedimentological regimes and the Pleistocene sea level fluctuations. While the indications of higher than present-day sea level stand in the past are provided by shoreline features such as terraces, beach rock, grape stone, oyster beds, miliolites etc., the data on lower sea level stands than present have to be inferred from submerged geomorphic features like submerged terraces, buried channels at times or sedimentary facies such as oolitic sands, or coral / algal reefs. These often provide important clues about palaeo-environments.

Geomorphic features such as terraces, buried channels and reefs are the net result of various processes that have operated during sub-aerial or submarine conditions over a period of time. In other words, they can be considered as indicators of spatio-temporal variations that the seafloor has witnessed.

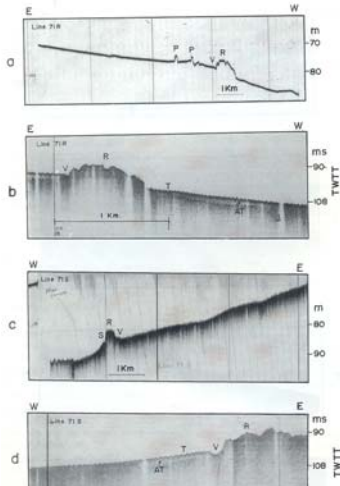
The topography of the continental shelves is

mainly governed by depositional and erosional processes which occur during glacio-eustatic sealevel fluctuations. Other factors involved, directly or indirectly, are the original relief, lithology, sedimentation, tectonic movements and climatic changes. The majority of the continental shelves world-wide have been affected to a considerable extent by Pleistocene glaciations (Emery, 1968). The rate of sea-level rise has varied frequently and the sea-level still stands produced wave-cut terraces and platforms. In other words, the surface of a terrace can be accepted as a reasonable record of former sea level (Sirkin et al., 1990).



National Institute of Oceanography (NIO) launched a systematic regional geological and geophysical surveys in 1976 to map the continental margin of India involving about 75,000 km of echo sounding, side-scan sonar and sub-bottom profiling on tracks about 20 km apart along with sediment sample collection. These provided basic information on topography, geology, sediment distribution, geochemistry and palaeontology especially from the continental shelf of India in about a decade's time. These information, in turn helped in understanding the processes that controlled the evolution of the margin, in the fields such as Holocene sealevel fluctuations, palaeo-climatic variations etc. While equipment like echo sounder provides the vertical section of the seabed, sub-bottom profiler (shallow

seismic) provides the penetration and side-scan sonar provide the plan view of the seafloor. Coupled with surficial sediment samples from the selected location, the integrated information provide the three dimensional view of the features of the seafloor.



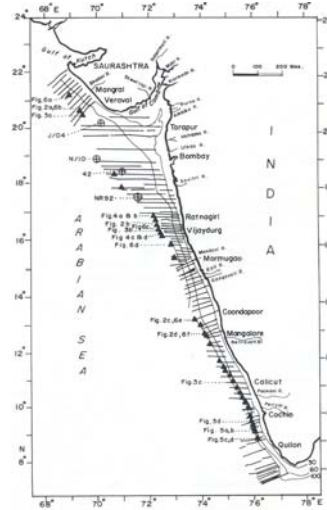
The western continental shelf of India is dotted with numerous conspicuous positive bathymetric features such as sand waves, coral reefs, coral banks, submerged platforms, sand ridges etc and submarine geomorphic features such as terraces and pinnacles.

The sediments on the western shelf can broadly be classified into three facies: (1) beach and near- shore sands, of modern age, extending to 5-10 m water depth, followed by (2) recent terrigenous silts and clays, extending roughly up to 60 m water depth on the middle shelf, and (3) relict, carbonate-rich, medium to coarse grained sediments, containing shells and skeletal fragments of various organisms and a variety of limestones occurring on the middle and outer shelf.

On the western shelf of India, the middle and outer shelf environment, beyond 60 m depth, is uneven and is characterised by the presence of relict carbonate-rich sediments and a variety of limestones. It is marked by a variety of geomorphic features. More than 200 prominent reefal structures between water depths of 38 and 136 m have been delineated caused by positive relief and believed to be due to biohermal growth. These reefs occur seaward of the inner shelf - outer shelf transition zone, as numerous peaks, pinnacles and protuberances of different heights. The height varies from <1 m to 14 m. In shallow environs, often the reefs are buried below 5 - 10 m thick sediments.

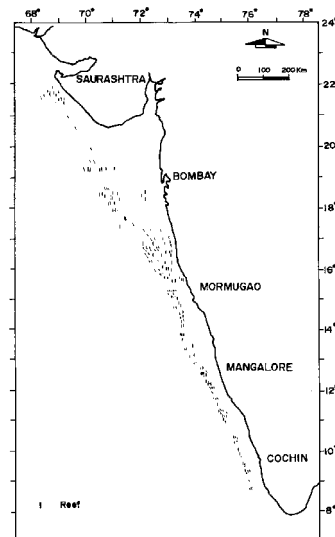
Based on echograms it has been observed that the reefs occur in various forms such as incipient or poorly developed, with a very low height in the form of a scarp, in isolated pinnacle forms or very well developed with

heights of 3 - 4 m, at times exceeding 14 m. It may be a single reef for tens of kilometres or a series of 2 - 3 or more coalesced reefs in succession leading to a reefal structure.



The distribution of reefs on the shelf is not uniform which perhaps may imply that conditions conducive for reef growth have not prevailed throughout the shelf uniformly. It is interesting to note that between Bombay and Mormugao, where the shelf is relatively broader, reefs occur abundantly on the middle and outer shelf. On the other hand, south of Mormugao, where the shelf is relatively narrow, they are only sparsely present and only on the outer shelf.

Submerged coral reefs may be defined as reefs that were established in relation to a pre-existing sea-level lower than present sea-level and occur at depths greater than that commonly associated with vigorous growth of reef building, hermatypic corals (Macintyre, 1971).



Dredge samples collected from the shelf edge reefal structures, mainly from south and off Ratnagiri and off Mangalore, where they are abundant, comprised of dead corals together with algal, biohermal and coralline limestones etc., at times associated with molluscan and other shells. Further, the radiocarbon dating of some of these samples indicates that they are of early Holocene age.

Seismic data reveal the occurrence of buried reefs off Saurashtra and Ratnagiri, indicating a possibility that shelf edge reefs might have formed initially at those locations but were either poorly developed or buried subsequently during the Holocene transgression. The reef growth appears to be prolific on the shelf between Ratnagiri and Quilon with the possible exception of the shelf between Mormugao and Coondapoor. Such massive reef growth must have been due to favourable environmental circumstances at that time. The massive shelf edge reefs perhaps also indicate shelf edge subsidence during the pre-Holocene.

The maximum depth at which these reefs occur i.e. -136 m is interesting. It is assumed that the world wide maximum of the glacioeustatic regression during the last glacial epoch reached only -120 to -130 m (H. Bruckner, pers. Comm.). The onset of reef growth presently at around -136 m water depth may testify to a subsidence of several meters. This is well possible since the Konkan Coast is believed to be subsiding (Bruckner, 1989).

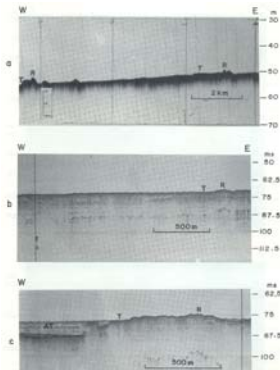
It is easy to conclude that generally pre-existing topographic highs played a dominant role in the onset of a reef. It is, therefore, concluded that the western shelf of India also had favourable geomorphic features such as terraces, scarps or other topographic highs and/or coralline/hard substrate in pre-Holocene time.

Submerged coral - algal reefs are enigmatic as indicators of former sea-levels as one school of thought accepts them to be a sea-level indicator, but other groups do not favour them as a sea-level indicator *per se*. Carter et al. (1986) have described several submarine shorelines features including drowned reefs. They have observed that the common level of reef growth can be taken as a former sea-level particularly where the platforms from which the reefs growth is associated with sediment wedges. We have, however, considered them to be indicator of sea level and given the still stand derived from the occurrences of reef below.

Terraces

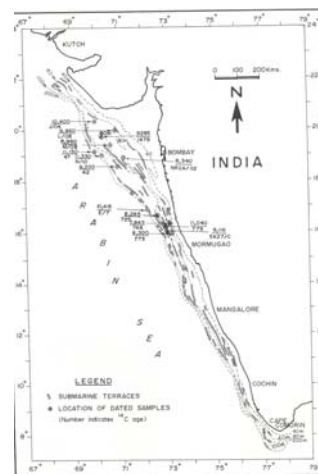
Detailed analyses of echograms and corresponding sonographs and shallow seismic profiles of the continental shelf reveal unique geomorphic features: a series of fiat, extensive platforms in the middle and outer shelf amidst an uneven and rough topography. The

profiles display a suite of well developed terraces. However, only some terraces are regionally extensive while others occur locally. Most of the profiles show 2-4 terraces whereas some record as many as six terraces. Submarine terraces have been reported from continental margins throughout the world. The presence of terraces has also been reported on the western continental shelf of India



In general, most of the terraces of the western shelf are seafloor features and are characterised by hard, smooth surfaces apparently devoid of large irregularities; but, in places, the smooth surfaces are dotted by 1-2 m high sharp peaks/pinnacles and shallow erosional depressions. Morphologically, these are relatively flat, gently inclined surfaces having widths of several hundred meters with prominent scarps at the shoreward end. These are commonly found in the middle and outer shelf.

The terraces generally occur at depths ranging from 35 to 140 m, i.e., from the outer fringe of the inner shelf to the shelf break, however, the terraces are more prominent between 50 and 115 m water depth, Though some of these are discontinuous, they extend over several kilometres along the shelf.



The submarine terraces can be broadly categorized based on their geomorphic features, lithological characteristics and present location on the continental shelf into: (1) wave-cut terraces, (2) coral/algal reef-

induced terraces and (3) palaeo- beach/barrier terraces.

Wave-cut terraces

Morphologically, these are relatively flat, gently inclined surfaces having widths of several hundred meters with prominent scarps at the shoreward end. These are commonly found in the middle and outer shelf.

Coral/algal reef-induced terraces

These terraces are either backed by a well pronounced reefal-ridge towards the shore end or are bounded in between two ridges. These are a few hundred meters wide and occur mostly on the outer shelf i.e., beyond 70 m water depth which are very well confirmed by seismic profiles. The terrace bordered by a ridge on the shore end probably represents the seaward reef flat formed due to wave action during still stand.

Palaeo-beach/barrier terraces

These are very extensive flat surfaces with an average width of about 2 to 4 km, and lie between 60 and 70 m below the present sea level. They are either backed by a broad rounded ridge or they lie on the landward side of a ridge

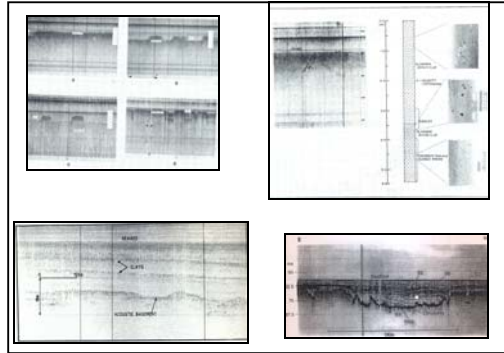
The depositional environment on the western continental shelf during the Holocene is characterized by shallow water conditions. Radiocarbon age determination of the ooid grains, oolitic limestones and the algal limestones suggests that the terraces on the western continental shelf between Bombay and Karwar are of Holocene age, and that the irregular topography of the outer shelf resulted during the Holocene transgression. Thus the submarine terraces on the shelf must have also been formed during the late Pleistocene to mid-Holocene still stands of the sea level. Radiocarbon dates of surficial samples comprising of algal, oolitic and coralline limestones (Nair and Hashimi, 1980; Rao and Nair, 1992) collected from the terraces and/or in their vicinity suggest that the innermost terrace along the shelf (55-60 m) is of 7845 yrs B.P. and the outermost terrace on the shelf is around 11,150 yrs B.P.

An additional interesting aspect of these terraces, especially those off the central and southwest coast (terrigenous province), is the possibility that they may be sources of placer deposits of economic heavy minerals analogous to those found on the recent beaches along the west coast of India.

Inferences from Shallow Seismic Profiles

The shallow seismic profiles also provide critical information to infer and understand sub-surficial features of the seafloor. The reflectors represent the periodic features, similar to the tree rings, each one representing the change in sedimentation pattern. Based on nature and characteristic of the reflector, it is possible to infer the cycle of hiatus, aerial, sub aerial erosion, subsequent sedimentation based on the profile. The profile may also indicate presence of gas in some favourable conditions,

if present in the upper sediment column



Implications for sea level change studies on the western shelf of India

Merh (1992) while reviewing Quaternary sea level changes along India's coasts observed that the Last Glacial Stage was a period of regression when the sea level went down to almost -150 m. With the advent of the Holocene, the sea started rising again; as for the western continental shelf of India, the sea level reached its maximum during 4000 - 6000 yr B.P. The rise, as believed was not episodic but with several variations and still stands.

The still-stands inferred for the western shelf of India from the presence of submerged reefs are spatial. It is difficult to assign any dates to these still-stands at present. In fact the paucity of dates from the shelf is a major hindrance in attempting a meaningful reconstruction of palaeohistory of the area. Depending on integrated data analysis of geomorphology and shallow seismics of limestone terrain and its petrography, SEM studies and radiocarbon dates, they have inferred subsidence of the area after 11,900 years BP by about 40 m. Similarly, Bruckner (1989) has reported subsidence of the Konkan coast around the same period. Tooley, (1993) has advocated six sea level zones based on geoidal lows and highs and predicted sea level curves for last 6000 years according to which the northern part of the western shelf of India is emerging while the coastlines of the southern shelf are of submerging.

From our studies it is clear that the reefs, which are nearly parallel to the present day shoreline, represent the still-stand stages developed during transgression in the late Holocene. However, it is possible that some of these stand-still signatures could be remnants of earlier interaction of sea-level transgression on pre-existing topography or tectonic event. Shelf edge reefs observed between 140 and 85 m water depth off western India have been reported by Vora et al. (1996) wherein it is concluded that these reefs reflect the late Pleistocene shoreline. In continuation, these still-stands provide the next step in the reconstruction of palaeo-shorelines successively towards the shore.

Comparison of inferences from the reefs and terraces

Based on the frequency distribution of reef depths, we propose still-stands on the western shelf of India at depths of 38-40 m, 48-50 m, 65-69 m, 78-81 m, 90-92 m, 94-95 m, 98-100 m, 105-106 m, 114-116 m, 119-120 m and 135-136 m. Similarly, the terraces present on the western shelf are prominent at about six levels, i.e. 55-60 m, 65-70 m, 75-80 m, 85-90 m, 95-100 m and 110-115 m. It may be observed that though there is some variations in depth range of still stand observed from two different geomorphic features, they do make a point clear that they can be relied up on to reconstruct the sea level history for western shelf of India.

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