

Letter Section

A SHALLOW SEISMIC REFLECTION STUDY OF THE GULF OF KUTCH, NORTHWEST INDIA — OBSERVATIONS ON ITS STRUCTURAL EVOLUTION

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Abstract

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A study of echosounding (678 line km) and shallow seismic reflection (180 line km) records of the E–W trending Gulf of Kutch, India showed the following features: The gulf margins in the east, and partly in the southeast and northwest are covered with 2–5 m thick acoustically transparent clays. A U-shaped ENE–WSW or E–W channel of 25 km maximum width characterised by uneven topography occurs in the centre of the gulf, this channel being flanked by steep scarps about 10–14 m high. Additionally, about 40 m of thick dead-coral rocks dated at 10,000–13,000 yrs B.P. occur as currently submerged high standing blocks in the axial part of the gulf, and finally, three subbottom reflectors were located at depths of 4–10 m, 10–18 m and 18–20 m.

The uneven topography of the U-shaped channel and the even topography of the gulf margins characterise the different energy regimes of the seabed. The correlation of steep scarps with a known fault helped in identifying two ENE–WSW or E–W trending parallel faults along the gulf. Correlation of onshore well-log lithology (near Kadach 75 km from the study area) with subbottom reflectors revealed a comparable sequence, this sequence consisting of sandstone, brown clays and limestones. The relict corals are submerged due to subsidence of the bedrock between the faults on which the corals grew. A regional fault across the margin, connecting the Saraswati Valley of the continental slope with the relict Saraswati River onshore through E–W faults downthrowing towards the north of the shelf and the gulf is proposed. The signatures of the tectonics are imprinted in the coastal morphology of the gulf.

The channel scarps and the coral rocks are interpreted to be the result of faulting and subsidence of the bedrock between the two ENE–WSW or E–W trending faults.

Introduction

The Gulf of Kutch (Fig.1) is an E–W trending embayment about 125 km long and 50 km wide along the northwestern coast of India. Coral limestones and reefs, and raised beaches and oyster beds are found along the coasts of the gulf (Srivastava, 1965). The presence of these features about 180 m above sea level on the peninsula adjacent to the gulf is considered to be due to the vertical displacement of the

faulted blocks (Srivastava, 1965) and marine transgression in the Pleistocene (Lele, 1973). A clear picture of these events emerges once the interplay between the morphology, waves and currents, and evolution of the gulf has been revealed.

During the second cruise of R.V. *Gaveshani* in 1976 about 678 line km of echosounding records and 180 line km of shallow seismic (Boomer source) reflection analog records along fifteen profiles across the gulf were

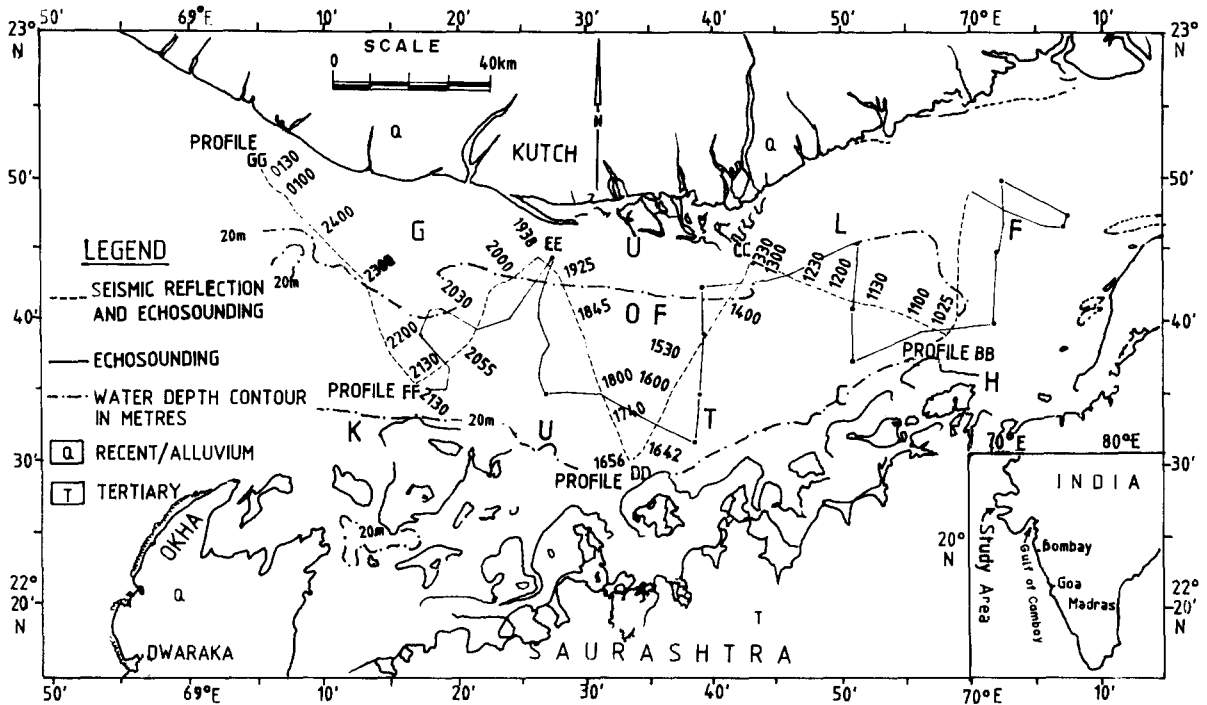


Fig.1. Gulf of Kutch, onshore geology and echosounding and seismic lines.

collected (Fig.1). They are utilised here with the aim of understanding the subsurface features, geology and tectonics of the gulf.

Previous studies

Previous studies on sediment samples and the bathymetry and currents of the gulf indicate that (1) the gulf seabed is characterised by a rugged bathymetry with steep, 6–32 m high scarps (Wagle, 1979), (2) dead-coral rocks dated at 10,000–13,000 yrs B.P. (R.R. Nair, pers. commun., 1987) and (3) high tidal currents of 3.1–5.9 kn occurring in the centre of the gulf (Naval Hydrographic Office, 1976).

Methods

Echosounding and seismic reflection profiling across the Gulf of Kutch (Fig.1) were carried out with a Kelvin and Hughes Model MS-45 echosounder with an operational frequency of 30 KHz, and a Huntec Hydrosonde Mark 2A system with a Boomer ED5 source,

recorder and analog receiver and hydrophone. The boomer was mounted on a catamaran and the hydrophone was towed at about 5 kn around 30–40 m from the vessel to avoid noise from the wake. Recording was carried out at a sweep time of 125–250 ms, and the filters were operated at 1153 Hz and 1791 Hz. Navigation was performed with a S and X band radar (Decca Mark 80309A) onboard R.V. *Gaveshani* (range 48 n mi). The analog echosounder records were digitised and corrected for tidal variations in order to prepare the seismic profiles. Depths and thicknesses estimated from the seismic records are based on sound velocities of 1.5 km/s.

Bathymetry, lithological sequences and morphology

The water depths range from 10 to 55 m, the deeper areas (> 20 m) occurring along the axial part of the gulf along which E–W flowing high tidal currents prevail (Naval Hydrographic Office, 1976). Examination of the profiles re-

vealed a thin layer (2–5 m) of acoustically transparent sediments, inferred as a clay layer. This layer occurs on profiles DD–EE (1656–1720 and 1830–1915) and FF–GG (0050–0130) (Fig.2) and is confined to the eastern, south-eastern and northwestern margins of the gulf. Besides the clays, three prominent subbottom reflectors at depths of 4–10 m, 10–18 m and 18–20 m are identified. The subbottom reflectors on profiles FF–GG (2345–2245) (Figs.2 and 3E), EE–FF (2000–2055) (Fig.2) dip towards the south. Lack of subbottom penetration farther south indicates that the reflectors are at greater depths, or due to a different lithology.

Srivastava (1965) reported thin Tertiary sediments resting on Upper Cretaceous–Lower Tertiary basaltic lavas in a well log near Kadach (21°21'N, 69°55'E). Correlation between this log and the subbottom reflectors in the Gulf of Kutch suggests that the two sedimentary sequences are lateral equivalents, the sequence consisting of sandstone, brown clays and limestones. The dipping reflectors could be lithified beds within the Upper Tertiary. The shallow levels of the Deccan Basalts are also reported in the Gulf of Kutch (Gopala Rao et al., 1978).

At water depths of greater than 20 m a number of scarps (10–14 m high) are observed along profiles BB–CC (1200–1330), CC–DD (1330–1645), DD–EE (1656–1924), EE–FF (2015–2100) (Figs.2 and 3B) and FF–GG (2215–0100) (Fig.3A). Some of these delimit a U-shaped channel along the gulf with a maximum width of approximately 20–25 km in the west and 15 km towards the east. The maximum depth is around 50–55 m. The channel is bifurcated along the axial part of the gulf as the result 38–40 m thick mounds rising with steep gradients (maximum 23:1) to approximately 10 m below sea level (profile EE–FF, Figs.2 and 3B) and underlain by an updomed reflector. The topmost reflector outcrops at the probably fault-controlled scarps, and a sharp contact between the two reflectors is seen on profile FF–GG (2300–2315, Fig.2).

A rugged reflector of limited extent and representing a sequence with a maximum thickness of around 38–40 m (profile DD–EE,

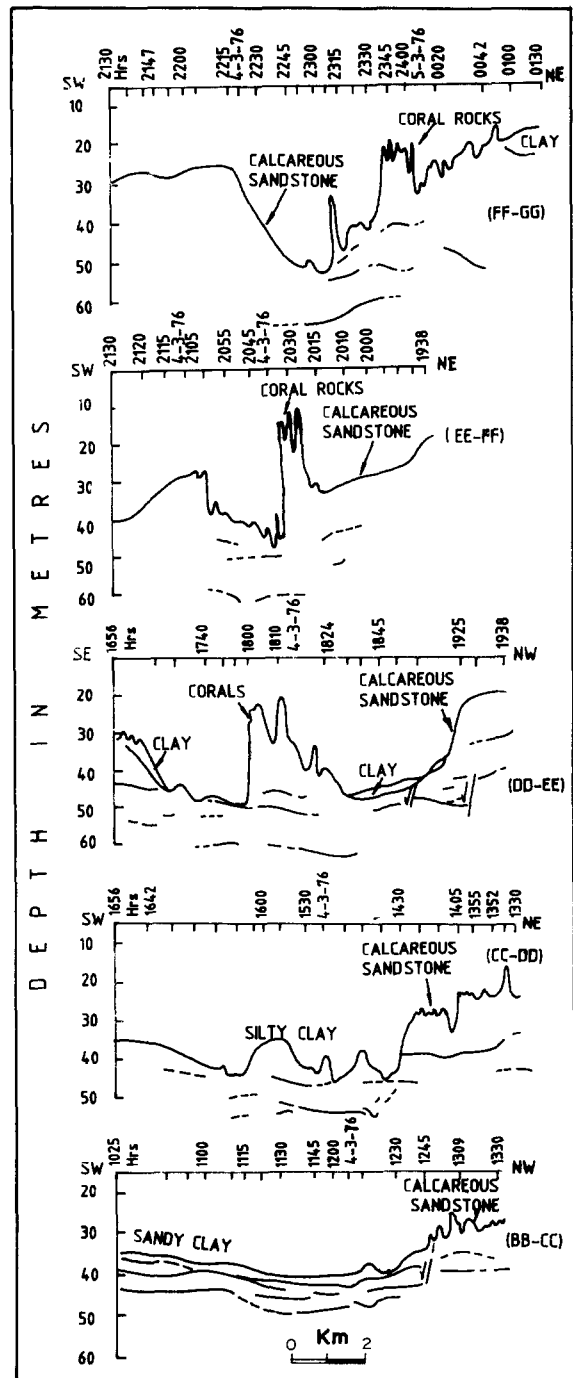


Fig.2. Interpreted shallow seismic reflection records showing the U-shaped channel bounded by scarps and the more gentle bathymetry developing towards the east.

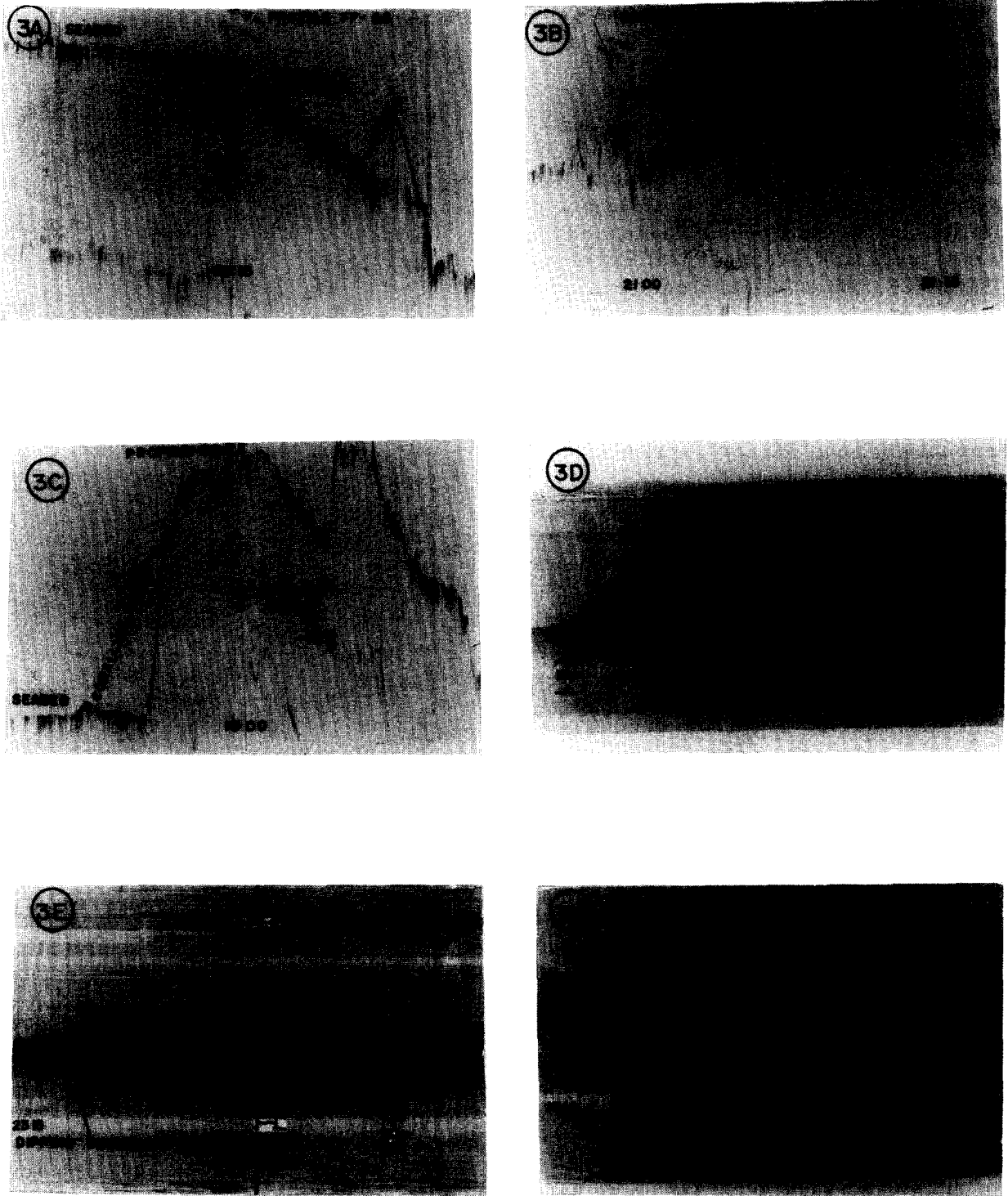


Fig.3. Typical echograms and seismic reflection records. A and B. Scarps of around 14 and 10 m height respectively. C. Highly irregular bathymetry of the seabed. Thickness of coralline rocks is around 38–40 m. D. Contact between an essentially flat-lying reflector and the overlying uneven coralline rocks. E. Undulating S-dipping subbottom reflector. F. Layered subbottom reflectors.

1755–1824, Figs.2 and 3C) is identified as being due to coralline rocks dated at approximately 10,000–13,000 yrs B.P. Indeed, Hashimi et al. (1978) have dredged corals just in this vicinity. Further, on the basis of this rugged characteristic and the acoustic response, similar rock types also occur in several other locations (profiles CC–DD (1330–1600) and EE–FF (2040–2015)) (Figs.2 and 4).

Because the scarps and highly irregular topography occur at water depths greater than 20 m where currents of 4–5 kn prevail (Figs.1 and 2), it seems likely that the U-shaped channel between the scarps is partly the result of current scouring. The scarps and the channel are continuous from west to east although in the east of the gulf more even bathymetry and more laterally continuous stratigraphy appear to be due to increased sediment cover

and partial burial of the corals. This partial cover of the channel to the east (profile BB–CC) (Fig.2) could be due to strength differences between the currents in the west and the east, and after formation the channel would then have been partially covered due to a lowered sea level.

The south and southeast dips of the subbottom reflectors on profiles CC–DD, DD–EE, EE–FF and FF–GG are similar to the dips observed in Tertiary rocks onshore (see also Fig.3F). They occur in a nondepositional region of the channel, and the deepest reflector at about 20 m below the sea bed (profiles FF–GG and EE–FF) also demonstrates this dipping attitude. The presence of thick corals overlying the dipping reflectors can be attributed to (1) the growth of corals in the axial part of the gulf which could not keep pace with

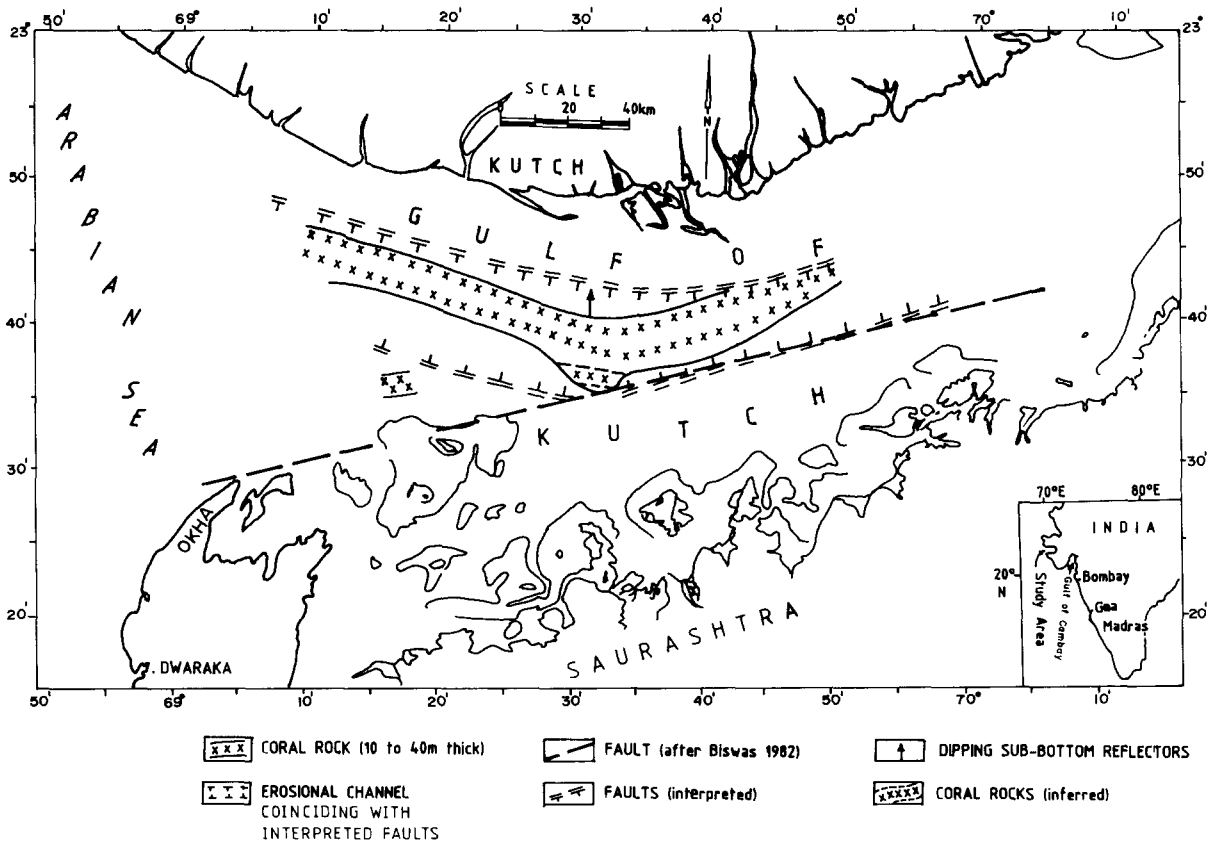


Fig.4. Structural elements of the Gulf of Kutch. Note the location of the erosional channel and the major faults delineating the Kutch Basin.

sea-level rise, and the subsequent partial erosion of these corals due to changing sea levels and currents, or (2) coral growth in shallower regions in the past which then subsided to the present level seen in the profiles.

Tectonics

The Kutch Basin is a rift graben divided into one-sided horsts and half grabens bounded by steep faults (Biswas, 1982). An ENE–WSW trending deepseated fault onshore extends into the gulf (Fig.4) and coincides with the scarps which are thus believed to be an expression of this fault. Similar scarps occur on the northern side of the Gulf of Kutch (Figs.2 and 4) and could be an expression of another parallel fault. These two parallel ENE–WSW or E–W trending faults downthrowing towards the centre of the basin suggest subsidence of the axial area and thus an ENE–WSW or E–W trending graben structure.

(Kolla and Coumes, 1987) have shown the location of the Saraswati Valley in the upper slope region (1000–2000 m depth) off the Gulf of Kutch while Agrawal and Singh (1981) identified a major basement fault downthrowing to the north from seismic reflection profiles across the continental shelf off Okha. Additionally, Agrawal (1984) has identified the tectonically originated relict Saraswati river valley in Rajasthan which flowed into the Arabian Sea east of the Indus River (Agrawal, 1984) in a southeasterly direction during the pre-Holocene but which ceased to exist due to uplift in the south. These previous studies and the fault system in the Gulf of Kutch as proposed in this study indicate that a regional fault connects the Saraswati Valley, the fault system across the shelf and the gulf, and the relict Saraswati onshore river bed.

Hashimi et al. (1978) suggested that the relict coral growth dated at 10,000–11,000 yrs B.P. on the middle and outer continental shelf off the northwest coast of India is due to worldwide regression in the Pleistocene (Emery, 1968). Stoddart (1971) on the other hand noted a 1.0–1.25 cm/yr and a 0.03–0.08 cm/yr worldwide

rise in sea level during the last 8000–15,000 yrs B.P. and over the last 4000 yrs B.P. respectively. This sea-level rise would result in approximately a 20–66 m increase in water depth over the 10,000–13,000 yr old Gulf of Kutch coral colonies. However, uplift of the area has been proven (Srivastava, 1965; Lele, 1973) as an established phenomenon but despite this, water depths of 20–55 m occur along the axial part of the gulf which implies subsidence of the area. Quitt Meyer and Jacob (1979) showed that the Kutch area is seismically unstable and indeed, during the Kutch earthquake of 1819 the town of Sindre (24°N, 69°E) was inundated by the accompanying incursion of the sea. Merh (1980) suggested neotectonic activity and a tilting process throughout the Quaternary period resulting in gradual submergence (the Pliocene Dwaraka Beds) and emergence of the northern and southern coasts of the Saurashtra Peninsula respectively. Although this general occurrence of uplift cannot be questioned, the present evidence for subsidence in the area agrees with the subsidence of the northwestern continental margin of India and other areas of the Kutch and Saurashtra peninsulas. Even the present coastal morphology in the north and the south of the gulf resembles the Kutch Basin graben trend (Fig.4). Thus, the morphology of the coastline itself appears to be a manifestation of the tectonics in the region.

The subsiding northwestern continental margin of India with increasing sediment input from the Indus River in the north is perhaps the precursor for tectonic instability and subsidence along pre-existing zones of weakness in the Gulf.

Conclusions

(1) Study of echosounding and seismic reflection records in the Gulf of Kutch reveal significant bathymetrical features and sub-bottom reflectors, a graben structure and possible subsidence of the axial part of the gulf between two parallel ENE–WSW or E–W trending fault zones or zones of weakness.

(2) An ENE–WSW or E–W trending regional fault across the continental margin off Okha, the Saurashtra coast and the Gulf of Kutch and the adjacent onshore area is proposed.

(3) The faults which define the graben in the Kutch Basin control the important bathymetrical features, i.e., the scarps bounding the U-shaped channel and the regional tectonics may be seen in the E–W trend of the Gulf of Kutch.

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