# Makran coast: A potential seismic risk belt

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ABSTRACT: *The Makran coast is located along an active plate boundary lying in the offshore region where Arabian plate is being actively subducted northwards beneath Afghan and Lut blocks. The active margin of Makran Coast remained a site of earthquakes throughout the historical and modern times. This scenario warrants a seismotectonic analysis of the Makran coastal areas to asses risk factors both for human settlements as well as important civil structures. The reconnaissance seismotectonic studies along the Makran coast resulted in the identification of a number of seismites of Holocene times associated with capable faults. The instrumental and historic seismicity catalogue reveals that the Makran coast active margin is marked by low seismicity presently clustered in the south of Pasni. The infrequent large events occurred all along the Makran coast. The event of 1945 (magnitude 8.1) with shallow depth of 25 km located near Pasni caused ground ruptures, modification of landscape, rock falls, liquefactions, fire and 5 to 10 m high tsunami.*

*The Makran coastal areas are divided into seven seismotectonic zones. The Makran coastal belt falls within one of these zones, in which main seismogenic structures are subduction related thrusts. A number of capable faults have also been recognized. The studies indicate significant seismic risk to the coastal areas. Presently the stresses are indicated to be accumulating in Gwadar area. It is therefore suggested that sites for important civil structures should be selected on the basis of geological and seismotectonic studies. The antiseismic design parameters for each structure should be adopted as per international codes and criteria for seismically active areas.*

## INTRODUCTION

The coastal areas of Makran remained site of some catastrophic earthquakes both in historic times and in recent past. The large events caused ground ruptures, modification of landscape, rock fall, liquefaction and also brought about fire and tsunami. This scenario warrants an evaluation of seismic potential of the Makran coast to minimize the loss of life and property.

The developed countries have regulatory commissions, which provide criteria to evaluate seismic potential of an area or a specific site. The site exclusion criteria of all the regulatory commissions of the world state that if a site for important civil structure is located on or in the close vicinity of a capable fault, it should be excluded. Based on geological, geophysical, geotechnical and seismological data, a fault is considered to be capable if it shows past movement of a recurring nature within upper Pleistocene and Holocene time (IAEA, Safety Guide, 1991). Any fault, which has a structural relationship to a capable fault in such a way that movement of one may cause movement of the other, will also be taken as capable. If the maximum potential earthquake associated with some buried seismogenic source is sufficiently large and is located at a depth which can cause surface faulting will also be classified as

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capable. In the absence of any regulatory commission for seismic hazard assessment in Pakistan, the IAEA guideline was used for the present study. The present work is of regional reconnaissance type. It includes identification of major capable faults along Makran Coast from Agor in the east to Jiwani in the west. This paper also discusses the seismic potential of Makran Coastal belt.

## GEOTECTONIC SETTING

South-western Pakistan has an important geotectonic setting where Eurasian, Arabian and Indian plates are interacting. In the west the oceanic floor of the Gulf of Oman is actively subducting northwards beneath the Afghan and Lut blocks of Eurasia forming a continental margin (Farhoudi & Karig, 1977). The subduction and resulting geological features constitute a tectonic province, called as Makran (Fig. 1). The eastern limit of Makran is the sinistral Ornach-Nal Fault (ONF), which is a southern extension of the Chaman fault: a boundary between Indian and Eurasian plates. Southwards in the offshore region, the ONF extend as northeast trending Murray ridge, which is a volcanic ridge of sea mounts (White, 1983). Further to the south, the boundary between the Arabian and Indian plate is represented by the Owen Fracture Zone. The triple junction is located to the south of Sonmiani bay.

The Minab Fault system in Iran joins the western edge of Makran with Zagros fold and thrust belt. The structures along dextral Minab fault are broken and rotated (Farah et al., 1984). The Afghan and Lut blocks of Eurasia are separated by the Sistan suture (Bryne et al., 1992) (Fig. 1).

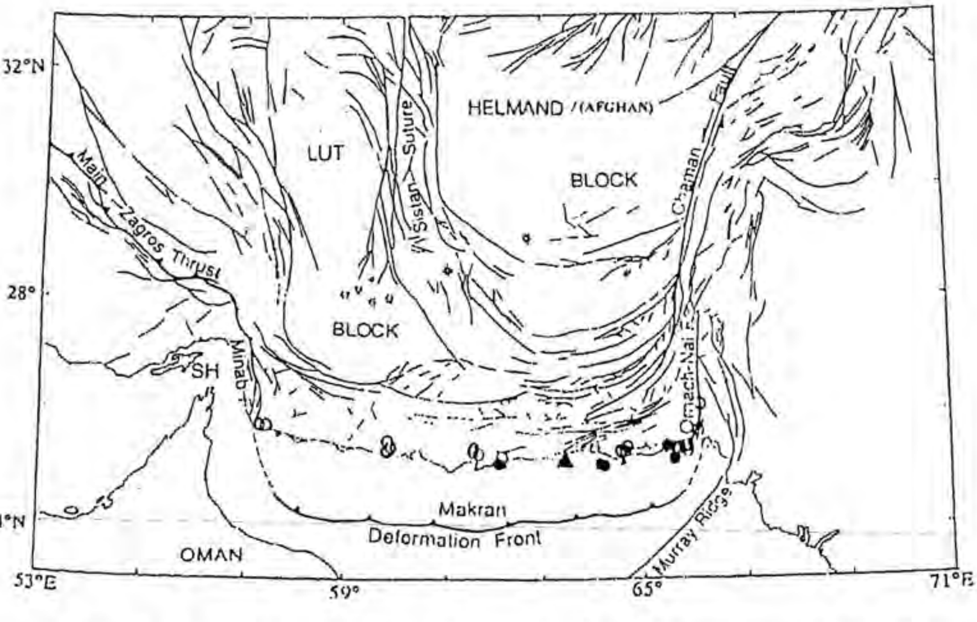


Fig. 1: Faults (Solid Lines) and Major Tectonic Features of Makran Subduction Zone. Abrabian Plate being subducted beneath Eurasian Plate along Deformation Front (Teeth on Overriding Plate), Epicenter of 1945 Great Earthquake is shown as Solid Triangle. Mud Volcanoes along the Coast are shown by open circles; Those activated by 1945 event are shown as solid circles. Calc-Alkaline Volcanoes are shown by concentric, radiating spokes. Lut and Helmand Blocks are older Micro Continental Fragments separated by Sistan Suture Zone. SH is strait of Hormuz. (After Byrne et al., 1992).

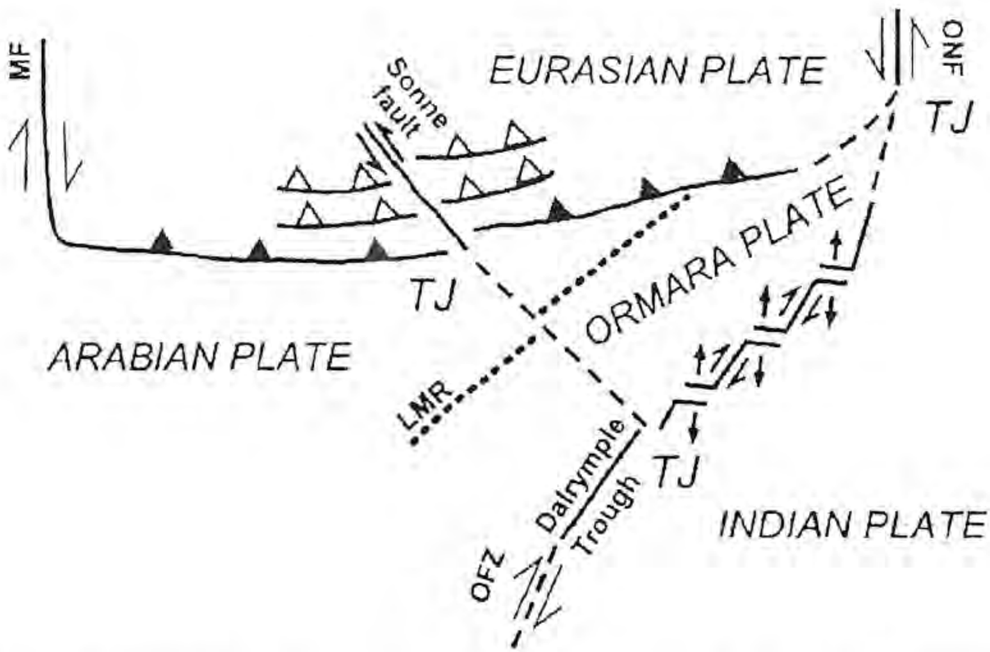


Fig. 2: Plate Tectonic sketch indicating position and framework of newly indentified Ormara Plate, ONF is Ornach Nal Fault, OFZ is Owen Fracture Zone, TJ is Triple Junction LMR is little Murray Ridge. (After Flueh et al., 1997).

Makran is an EW trending prism developed as a consequence of ongoing subduction since Cretaceous. The arc - trench gap is unusually large and the deformed Andean - type andesitic Chagai arc remained active up to Quaternary (Farah et al., 1984). The accretionary wedge of sediments developed between buried offshore trench and its large part is lying over mobile oceanic Arabian plate dipping at shallow angle (White, 1979., Quittmeyer et al., 1979). The subducting lithosphere is broken along large basement faults perpendicular to trench, dividing the plate into variously dipping digitate segments (Marzouk & Sattar, 1993, Kazmi & Jan, 1997).

The structural interpretation of Makran offshore is given by Flueh et al., 2000, based upon seismic, gravity and magnetic surveys. In the offshore region there is no distinct trench due to thick sedimentary cover and deformation is taking place along steeply dipping thrusts. A northwest trending sinistral fault (named as Sonne fault after the Survey Vessel) cuts across the entire wedge, offsetting offshore ridges up to 10 km. In the southeast it has displaced little Murray ridge, an old basement high in abyssal plane. On the basis of the nature of fault and difference of seismicity in eastern and western Makran, it is identified as plate boundary of a micro - plate named as Ormara plate (Flueh et al., 2000). The micro plate is triangular shaped with northern Murray Ridge and east Makran subduction zone at other edges. It forms triple junctions at each corner marked by higher seismicity (Fig 2). The Ormara microplate is dipping at shallower angle than Arabian plate and convergence close to Minab fault is 36.5 mm/yr while it is 42 mm/yr in the eastern most Makran. The Ormara plate covers the whole of Pakistani Makran (Bryne et al., 1992).

The fore-arc basin sediments are dominated by mudstone and subordinate sandstone, which have been deformed and piled up at the subduction margin. About 5-7 km thick horizontally deposited pile of sediments in the abyssal plain is abruptly deformed shoreward, and thicking of sediments is caused by large scale underplating in which decollement increases to north (Platt et al., 1985). The thrust faults extend down to oceanic basement, forming basal decoupling (White, 1982).

The coastal areas of Makran represent relatively broader synclinal outliers with lower frequency of faulting as compared to the northern and central Makran, where folds are narrow, elongated, and have higher frequency of faulting. At the eastern limit of Makran, a 30 to 60 km wide zone of fold and thrust belt between Pab fault and ONF is a product of oblique collision of Afghan block and India. This belt is underlain by relatively thinner, transitional or oceanic crust covered by 10 km thick sediments, forming an imbricate zone of thrusts and napes (Kazmi & Jan, 1997). The ONF at its northern terminus is marked by a number of faults, which are curved, convexing to north and form the Khuzdar knot (Sarwar & Dejong, 1979).

In Agor area the northeast directed structural trends gradually swing to the west to become more or less east-west in the Ormara area. The north-trending faults of Agor area join ONF in the north. A number of strike slip faults cut obliquely the strata along the coast, while thrusts are parallel to the regional strike. The conjugate sets are well exhibited in the sandstone of Hinglaj Formation while in younger Gwadar and Jiwani Formations no appre-

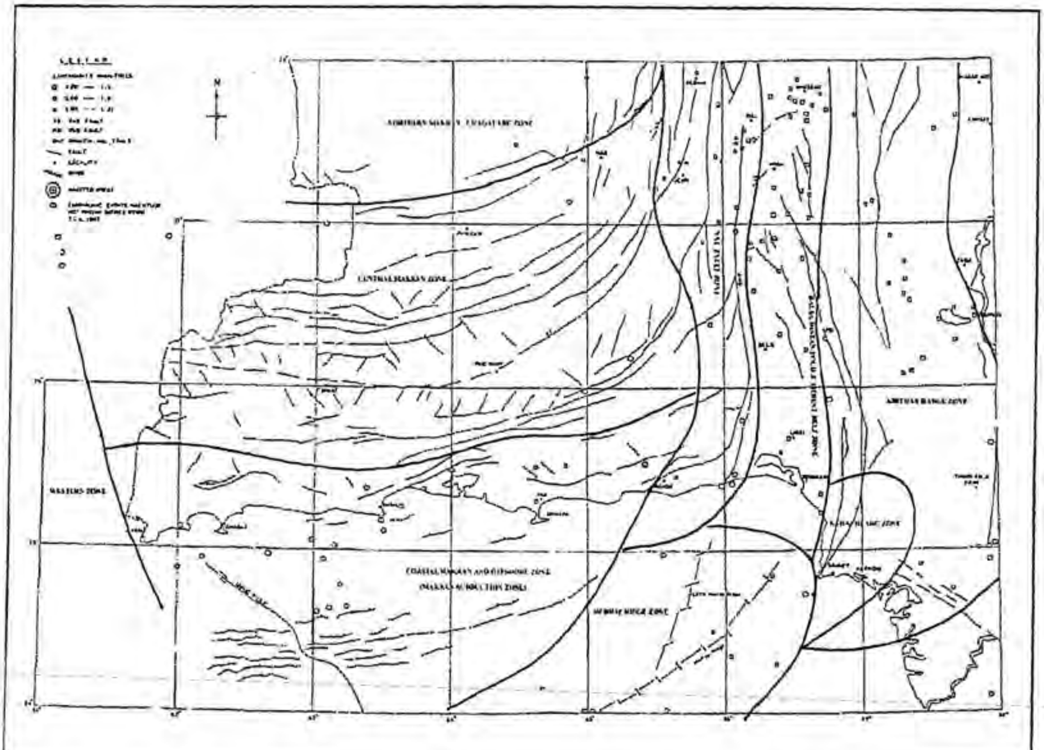

Fig. 3: Tectonic map of coastal areas of Pakistan showing distribution of Earthquakes (USGS Data 1900-2000) and proposed Seismotectonic Zones.

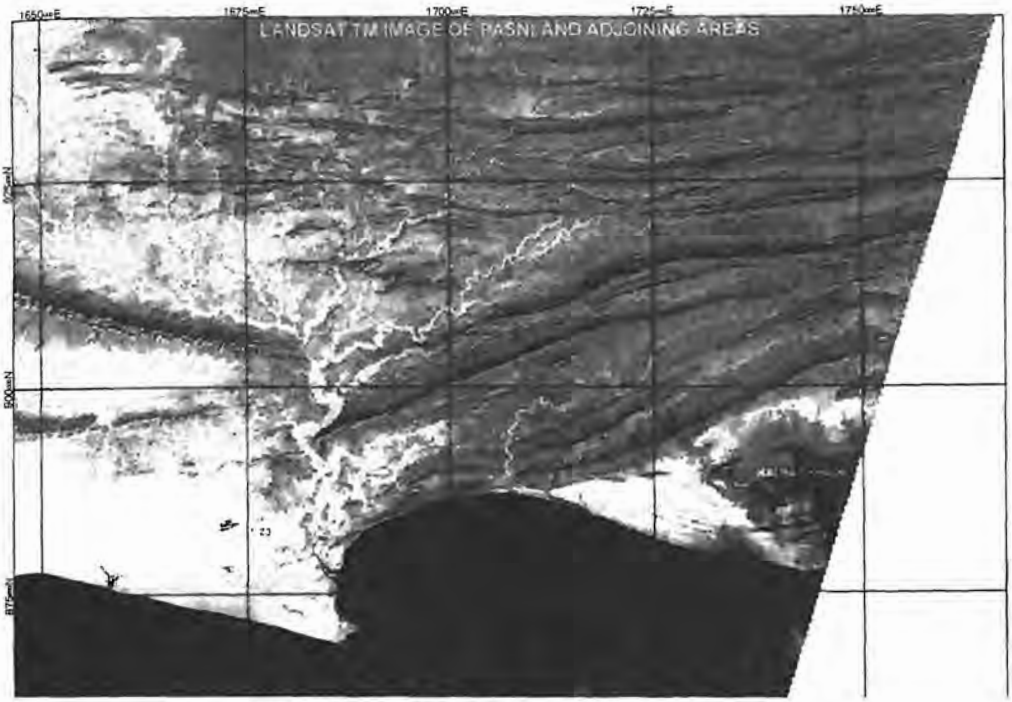


Fig. 4. Landsat TM image of Pasni and adjoining areas.

ciable movements are recorded. The Ras Melan area is not intensely deformed. The areas to the north of Ormara and Pasni towns are folded and anticline limbs are often faulted. Similar structural style is observed in the Gwadar area (Fig 3 & 4).

The coastal areas are mainly occupied by Miocene to Recent strata, with mudstone, sandstone, siltstone as major lithologies. The Recent deposits are represented by alluvial fans, mud flats and aeolian sands.

## SEISMICITY

The Makran margin is marked by low seismicity as compared to the other active margins of the world. The shallow dipping subduction zone does not show a well-developed benioff zone (Farhoudi & Karig, 1977).

In the text the term great is applied to those earthquakes which have surface wave magnitude of 7.8 or greater. The events with magnitude 7 to 7.8 are termed as large and those with magnitudes 6 ~ 6.9 are called as moderate

## Historical record

The Makran coast remained a remote and sparsely populated area. The historical record is not well-documented and covers only large earthquakes that occurred not in the distant past. The historical catalogue reliably records five large earthquakes in Makran, which might have ruptured the plate boundary (Byrne et al., 1992). The historical data is obtained from catalogue of Oldham (1882), Quittmeyer & Jacob (1979) and Byrne et al., (1992).

i. *Western Makran, 1483:* It is the only event which occurred in western Makran and affected the Strait of Hurmus. The specific location of the event is not known.

ii. *Ras Kuchari, 1765:* The earthquake jolted Agor – Ras Malan area and probably was associated with the eastern terminus of Makran subduction zone.

iii. *Gwadar, 1851:* The seismic event of westernmost Pakistani Makran affected the towns of Gwadar and Jiwani. The causalities and loss of property are not documented. The event was probably related with thrust system of the subduction zone.

iv. *Gwadar, 1864:* The event occurred in the same area which was effected by the event of 1851. It is supposed that the event was associated with the same rupture zone responsible for the event of 1851 (Byrne et al., 1992).

v. *Northern Makran, 1914:* The epicentre of the earthquake is not exactly known. It occurred in the northern Makran at a depth of 60-100 km. The rupture was in the down going slab.

The historical record reveals that infrequent large events occurred in Makran. The distribution of the events is asymmetric both in terms of time and space, however, all major events occurred in Pakistani Makran and were associated with the frontal deformation zone of Makran accretionary prism, except the event of 1914 which occurred in the northern Makran.

## Instrumental seismicity

The catalogue of seismic events in the region stretching between latitude 24° to 28° N and longitude 61° to 68° E was obtained from National Earthquake Information Centre (NEIC) of United States Geological Survey (USGS) and International Seismic Summary (ISS). Some events have been incorporated from Byrne et al., 1992 and Quittmeyer & Jacob 1979.

The catalogue was completed after the installation of world-wide standard seismic network (WWSSN) in 1963. The high magnification seismic stations are not present in the region hence the record of the events below magnitude 4 is not available. The epicentral locations and respective magnitudes are depicted in Fig. 3.

In eastern Makran 48 epicentres are located between longitude 65° 5′ to 67° E and latitude 25° 25′ to 28° N. Generally Magnitude of 20 events ranges from 4 to 4.9 while 25 earthquakes are of magnitude 5 to 5.9. The events are shallow and located near Besima, Jebri, Nal, Khuzdar, Sonmiani and Agor. A few shallow earthquakes of magnitude 6 to 6.9 occurred near Jabri and Nal.

The northern Makran is marked by 2 seismic events of magnitude up to 5.9 with intermediate depth. The central Makran area lying between latitude 25.7° to 27° N is relatively stable and 3 events of magnitude less than 5 are located.

In the western Makran a NNW-trending zone of seismicity extends northward at longitude 61.5° E and latitude 20.5° to 27.3° N. In late seventies frequent shallow seismic events, up to magnitude 5.9, were recorded in this zone.

In Pakistani Makran, shallow and low seismicity areas form a band along the coast. The large historic events and great event of 1945 also falls within this seismic zone. The epicentres are clustered in offshore area near Pasni. Some epicentres are located along Murray ridge.

The great earthquakes of November 27, 1945 at 2156:55:02 UT (universal time) occurred near Pasni. The NEIC located the epicentre at 63° E and 24.5° N while Quitmeyer & Jacob (1979) and Byrne et al., (1992) placed the event at 63° 48′ E and 25.15° N. The magnitude given by Byrne et al., 1992 is 8.1 while NEIC records show 8.3. The large after shock of magnitude 7.3 occurred in 1947. Byrne et al., 1992 presented a detailed analysis of the event. The thrust related event had nodal plane striking at 236° and dipping at 7° due north. The rupture propagated in SEE direction. The duration of the event was 56 sec. Ground rupture was caused within a radius of 80 to 150 km with an average slip of 6 to 7 m. Other than severe shocks, the great event caused ground ruptures, modification of landscape, and reactivation of mud volcanoes, rock falls, slumping, liquefaction, fire and tsunami. The coastal area was thinly populated and the people used to live in huts made up of date tree branches and in mud houses as such the loss of life and property was minimum for the size of the event.

The details of damage were gathered by the authors through intensity survey by interviewing more than 50 eyewitnesses. The event caused about 5 cm wide rupture in football ground of Pasni town. Warm water oozed out of the rupture. The ground was also ruptured in Ormara town. A terrace was raised up to two meters near Ormara and shoreline receded at Ras Basol due to uplifting of the beach. A piece of land subsided in the east of Ormara. The higher spouting of mud and gas was reported from mud volcanoes near Ormara and some extinct mud volcanoes were reactivated. Four mud Volcano Islands emerged in sea between Ormara & Pasni. A new mud volcano emerged at Gwadar (Hunting Survey Corporation, 1960). Extensive rock falls, slope failures and landslide / debris flow occurred all along the coast. A part of Pasni town was submerged with submarine slide resulting in 100 m landward shift of coastline.

The trans-oceanic cable between India and England broke at eight places due to offshore slumping (Byrne et al., 1992). Liquefactions occurred near Ormara, Hud villages and along sandy shores. In the east of Ras Malan, large volumes of natural gas escaped from mud volcanoes, which caught fire. Widespread tsunami was generated which hit the coastal areas after two hours of the first shock. The height of tsunami was about 5 m at Ormara as estimated from height of tree, which was reported to be submerged. A fishing boat was hanged over a minaret of a mosque in Pasni town, which indicates that the tsunami was about 10 m high. It was 1.5 m high in Karachi (300 km from the epicentre), about 2 m near Bombay (1100 km from the epicentre). The high tides were noticed in Muscat (Bryne et al., 1992). It is anticipated that any great event in future may create similar catastrophic scenario.

## NEOTECTONICS

Earthquakes trigger ground motion, which is recorded by the rocks or unconsolidated sediments as permanent deformational feature. The documented historical and instrumental records of seismic events cover only a short span of past as compared to repeat time of many seismic events. The study of deformational features recorded by the late Pleistocene and Holocene sediments is the only way to unearth the seismic past.

The C14 dating of two samples of terrace sediments from Gwadar revealed 20,000 and 30,000 yrs respectively. The samples of unconsolidated sediments from adjacent Irani Makran (Gwater and Chah Bhar) indicate ages of 5000 yrs and 15000 yrs (Kazmi & Jan, 1997). The Makran coastal areas have the same tectonics set up, hence all the cover sediments along the coast may fall in a similar range of age. The stratagraphic committee of Pakistan assigned late Pleistocene age to the younger most Jiwani Formation while Raza et al., 1991 suggested Holocene age for the Jiwani Formation. The present neotectonic studies include investigation of deformational features in Jiwani Formation and overlying loose sediments.

*Agor area:* Fractured Jiwani Formation (Fig. 5, feature 1) at Agor, mud volcano of Chandra Gup, NE-trending lineament along Drabi Kaur, and abrupt truncation of Hinglaj Formation against alluvium along a lineament in NE of Agor. The faults in the east of the Agor village which have associated epicentres are classified as neotectonic features of Agor area.

*Ras Malan – Buzi Pass area:* Uplifting and folding of Jiwani Formation at Ras Malan (Fig. 5, feature 2), and NE-trending fault in the Jiwani Formation near Buzi Pass (Fig. 5, feature 3) are the seismites recognized in the area.

*Maniji Kaur area:* The course of Maniji Kaur follows a regional thrust and neotectonic features like cracks and shearing in the alluvium are observed (Fig. 5, feature 4). The fault probably joins the


Fig. 5. Landsat TM image of Ras Milan and adjoining areas.

inferred fault along the mud volcanoes in Mor Pati area.

*Dadigor Kaur area:* The ENE trending thrust and NE trending sinistral fault, interpreted from the image cut through the alluvium are recognized as the neotectonic features.

*Ormara area:* The 427 m high Ormara mesa with fractured and sheared Jiwani Formation at the top is itself a neotectonic feature (Fig. 6, feature 5). A set of EW trending minor faults at the northern slope of mesa constitutes a south dipping reverse fault zone (Fig. 6, feature 6). The ridges facing towards mainland form topographic steps along these faults. The Gwadar formation is abruptly truncated against alluvium along most of the landward side faults. The presence of the faults in the alluvium is confirmed by shallow reflection seismic survey at three places. The thrust faults of Ras Malan area may be bounding the mesa in the sea as inferred from the bathymetric map. It indicates that the fault bound Ormara mesa is an active feature.

The tilting and fracturing of Jiwani Formation of Pleistocene age, uplifting of a terrace during the great event of 1945 and presence of five distinct terrace levels indicate that seismic events are involved in their development. The pebbles in the conglomeratic facies of Jiwani Formation are broken along NE-trending fractures. In the western Ormara Bay Recent sand interbedded with clay layers is tilted $30^0$ due east and a terrace near Bros Panjak is tilted due north (Fig. 6, feature 7 photo 1). Some shear

Photo 1. Tilted beach sand interclated with clay at west bay Oramara.

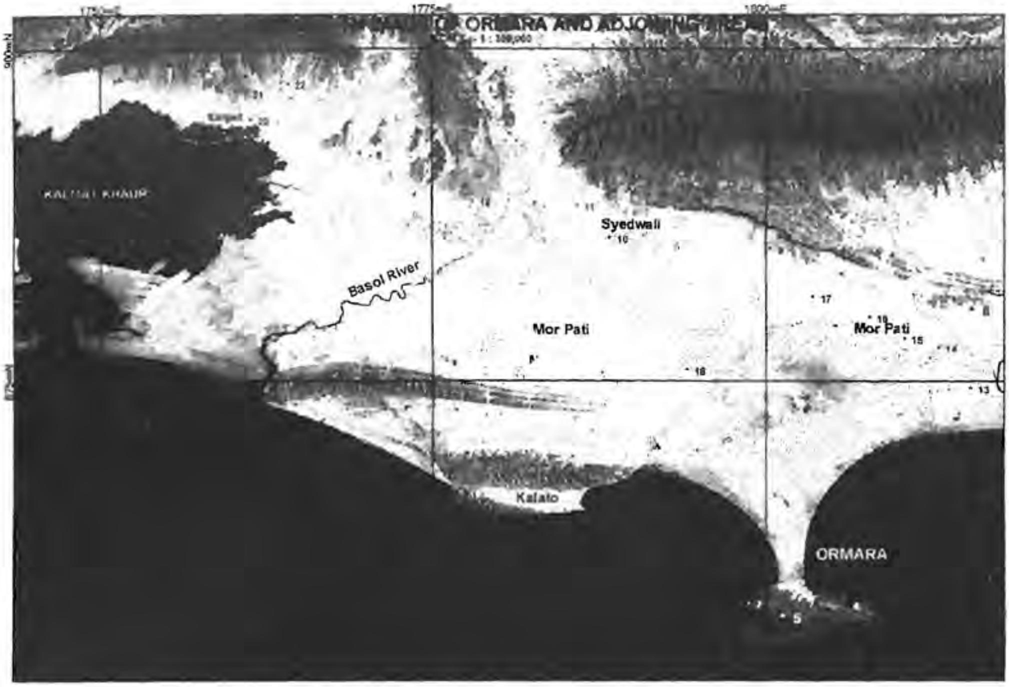


Fig. 6. Landsat TM image of Ormara and adjoining areas.

fractures of Gwadar Formation extend into the Recent cover sediments. Boulders of Jiwani Formation are entrapped in the clays of Gwadar Formation along a fault zone. All these neotectonic features clearly indicate that Ormara area remained active during the late Pleistocene times.

*Mor Pati area:* Along eastern tributary of Rach Kaur, Parkini mudstone member of Hinglaj Formation has a faulted contact with alluvium (Fig. 6, feature 8). The Hinglaj Formation is abruptly truncated against alluvium in the east of Landi Kaur (Fig. 6, feature 9). The westward extension of fault is interpreted from the satellite image. Near Syed Wali shearing and a geomorphic step is observed in the alluvium (Fig. 6, feature 10). Many neotectonic features (abrupt truncation, shearing, deflections of stream course) are observed in the area. These features are associated with a fault which runs at the southern limb of Gurad syncline (Fig. 6, feature 11). At the right bank of Basol River, a large older fan is abruptly truncated along a straight line, which may be the westward extension of the Gurad syncline thrust. A young fan is developing at the truncation (Fig. 6, feature 12). This scenario indicates the active nature of the fault. To the SE of Bal, the Gwadar formation is in contact with Recent sediments along a fault (Fig. 6, feature 19 photo 2).

The Mor Pati area hosts many active and extinct volcanoes (photo 3) aligned in a particular direction

Photo 2. Recent alluvial material faulted against Gwadar formn. Bal area, Camera faces SE.

Photo 3. Extinct mud volcano to the NE of Oramara town.

Photo 4. Tilted terrace in the north of Kalmat Khor, strata dips to the north, slope of the area is toward south, while tilt is toward east, frontal escarpment along fault, Camera faces toward north.

indicating the signature of a concealed fault (Fig. 6, feature 13,14,15,16,17,18). During the great event of 1945 extinct mud volcanoes were reactivated and pre-existing ones showed higher spouting of mud and gases.

*Kalmat Kaur area:* The area to the north of Kalmat Kaur is marked by a number of neotectonic features. A lineament along Kargari hill brings Hinglaj Formation against alluvium (Fig. 6, feature 20). Another lineament cuts through the Parkini mudstone of Hinglaj Formation and extends into the alluvium (Fig. 6, feature 21). A fault near Kargari is traceable in the Sub-Recent fan and alluvium (Fig. 6, feature 22). The shear fractures were also observed in the Sub-Recent sediments. Tilted terrace along a fault in the north of Kalmat Khur area indicates its active nature (photo 4).

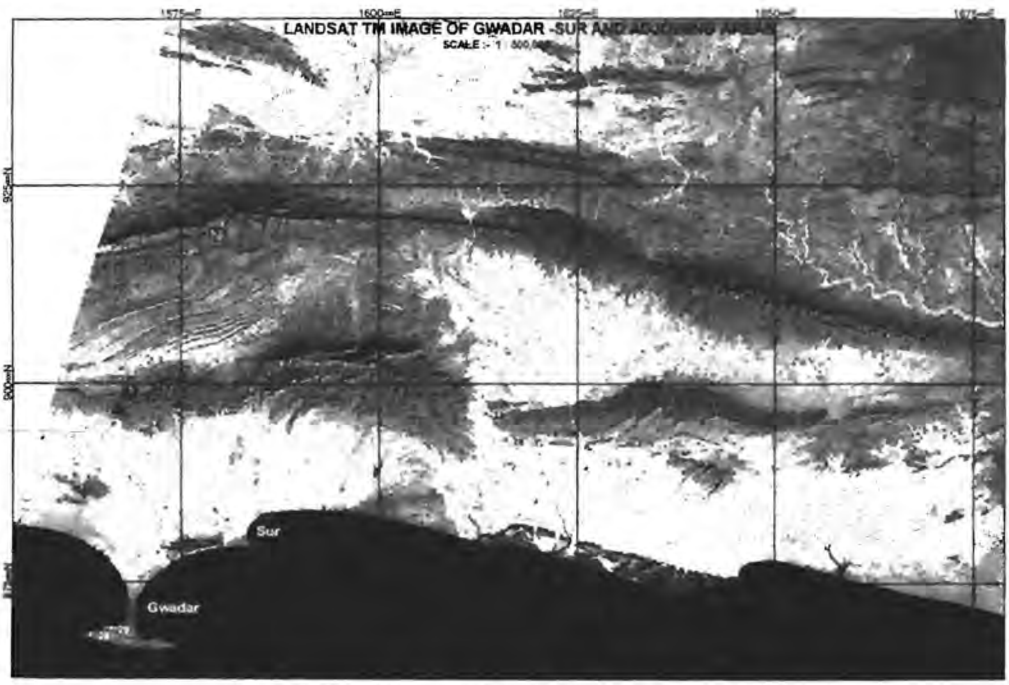


Fig. 7. Landsat TM image of Gwadar-Sur and adjoining areas.

*Pasni area*: The presence of seismites and neotectonic features shows that the Pasni area is seismically active. The neotectonic features observed in the area are, active fault of Kalmat Kaur which extends westward into the Pasni area, abrupt truncation of Gwadar Formation against alluvium (Fig. 4, feature 23), tilted terraces, offset in the Recent terrace material, cracks in alluvium forming concealed fault traces (Fig. 4, feature 24, photo 5) presence of seismicity along thrusts and the catastrophic event of 1945 confirms that the area is seismically active.

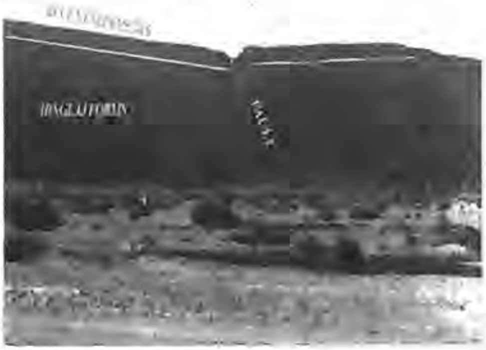

Photo 5. Recent terrace at the top of the Parkini mudstone of HInglag formn. offset by a reverse fault near Pasni.

*Gwadar area:* The seismites observed in the Gwadar area are Gwadar mesa, sheared Jiwani Formation (Fig. 7, feature 25, 29) at Gwadar, Sur, newly emerged mud volcano (Fig. 7, feature 26) and abrupt truncation of Gwadar formation against alluvium along NW trending fault (Fig. 7, feature 27, 28). The presence of these seismites indicates the seismically active nature of the area.

*Jiwani area:* Raised terrace, folding and faulting of Jiwani Formation of late Pleistocene age, faulting in the terrace along roadside from Jiwani to Guns suggest that the area has experienced tectonic activity in the post-Pleistocene time (photo 6).

Distribution of neotectonic features all along the Makran coast right from Agor in the east to the

Photo 6. Recent terrace offset along a normal fault in Gwadar firmn. along roadside between Guns and Jiwani.

Jiwani in the west, leads to the conclusion that the coast remained seismically active in the Holocene time.

## SEISMOTECTONIC ZONES

Quitmeyer et al., (1979) divided Pakistan in 15 zones on the basis of tectonics setup and associated seismicity. The Makran area falls in Makran zone, Murray Ridge zone and Ornach Nal Fault zone. In the present work the zones are subdivided into seven on the basis of instrumental data and seismotectonic analysis (Fig 3).

*Coastal Makran-Offshore zone:* Available fault plane solutions (Byrne et al., 1992) reveal that the seismicity of the region is mainly thrust-related. In the offshore region a narrow band of epicentres delimit the most seaward location of subduction and plate boundary. The focal depths of the events are shallow (around 20 km) and it gradually increases toward north (30 km along coast). This seismic pattern fits to the tectonic model of the area. The band of seismicity includes large and great events of both historical and modern times. It poses equal potential risk to civilization all along Makran coast. The plate boundary can rupture at any place to produce a large event, however, presently the stresses are being continuously released in the eastern part while it is accumulating in Gwadar area. The probability of future seismic event is higher in Gwadar area.

*Murray Ridge Zone:* Murray Ridge is a plate boundary marked by normal and strike slip fault-related shallow earthquakes of magnitude up to 7. A number of epicentres are located at triple junctions of Ormara micro-plate. The Agor, and Ras Malan area, can be affected by any large event in the northern part of the zone.

*Central Makran Zone:* The zone is marked by sparse seismicity, however, neotectonic feature are documented along faults (Kazmi & Jan, 1997). The focal depths are generally about 30 km, indicating that the seismicity is associated with the basal decollement. It can generate moderate size earthquakes.

*Northern Makran-Chagai Arc Zone:* The northern Makran exhibits moderate seismicity of intermediate depth, with the exception of a large event of 1914. The event was related with normal fault at depth of 60-100 km (Quittmeyer et al., 1979., Byrne et al., 1992) caused by tension in the subducting plate. Keeping in view attenuation factor, the zone poses no significant seismic impact on coastal areas.

*Western Zone:* The NNW trending zone lies in Iran. Many seismic events are located in the zone. Fault plane solution of an event revealed dextral strike slip motion. The epicentres are aligned in the direction of Sistan suture lying to the north. It may be representing some basement fault. The zone is located about 100 km to the west of Gwadar and large event in the zone may cause damage in Jiwani and Gwadar areas (Byrne et al., 1992).

*Ornach-Nal Fault Zone (ONF):* Many shallow depth epicentres of moderate size are located along the 160 km long sinistral fault, majority of which are clustered at its northern terminus. Some epicentres are along the southern splays where the thrusts of Makran obliquely join the ONF. The terminus, intersection or union of faults are loci of earthquakes (Barosh, 1986) and it is evident from the seismic behaviour of ONF. Neotectonic feature are present all along the ONF (Quittmeyer et al., 1979, Kazmi and Jan, 1997). The zone can generate moderate size earthquakes, which may effect Agor and Ras Malan area.

*Baluchistan Fold and Thrust belt:* The zone lies between ONF and Pab Fault / Bela Fault to the east. Ongoing dragging along ONF is the main cause of seismicity in the zone. Generally, the seismicity is low with some moderate events. The Khuzdar Knot is very active as manifested by cluster of epicentres, but some epicentres are located near Sonmiani. The southern segment of the zone can generate moderate size earthquakes which may effect the Agor area.

*Capable Faults:* The Makran subduction zone and related thrust in offshore region are essentially capable. In the eastern Makran the thrusts to the east of Agor and Ras Malan are capable as neotectonic features are associated with these faults. Northeast trending fault near Buzi, Ras Melan, Maniji Kaur Thrust, NE trending faults of Dadigi Kaur, mud volcano fault of Mor Pati, Gurad syncline fault and northern back thrust of Ormara mesa are capable faults. In Kalmat Khur area, Kargari hill fault is active and capable. All strike slip faults, which cut across these capable faults, may act as sympathetic structures and hence, may be regarded as active.

The Pasni area is also marked by capable faults including Buzi fault, NNW trending fault at 64.75°E and 25.4° N, an east west trending fault in the same area and fault of Kalmat Khur extending into Pasni area. In the western Makran a fault near Guns is capable.

## PERMANENT GROUND DISPLACEMENTS

Under earthquake loading, permanent ground displacements like rockfall, slope failures, landslides and debris flow sometimes cause greater damage than the shocks of the event. The susceptibility to permanent ground displacement is assessed by geomorphology, lithology, hydrology, structure and neotectonics of the area.

The coastal areas of Makran are marked by mesas, butts, cliffs, and steep slopes particularly in Ras Malan, Agor, and Buzi, Pass, Ormara, Kalmat Khur, Gwadar and Jiwani areas. At most of these places competent strata overlie incompetent shales/ mudstones. The Recent sediments are mainly composed of boulder clasts, sand and clays. Climatic conditions are generally semi-arid, but well-developed drainage indicates that it receives heavy intermittent rainfall.

There are occurrences of nose and hollow structures and ill-sorted material at the slopes of Ormara mesa, land slide material in Gwadar and failed slopes with scars in Ras Malan and Buzi Pass. These phenomena can be triggered by earthquakes.

Rockfalls are common along the rocky coastline and along cliffs of hilly terrain of coastal areas. Meteoric water percolating through joint, lubricate clay lying under competent strata and squeezing of plastic stratum by loss of salts cause minor slips. This process is aided by gravity and side release joints forming wide-open rectangular/triangular block pattern. It is well exhibited in Ras Malan, Ormara Gwadar and Jiwani areas. Seismo gravitational phenomenon can cause rock falls in case of seismic event. Extensive rockfall is reported during the great event of 1945.

Subaqueous slides occur by slipping of unconsolidated sediments especially clay, silt and calcareous mud. Sometimes small-scale slides are represented only by bending of sediment at shoreline. Vibration and shocks can cause liquefaction in near shore Recent sediments. Tsunami and swells induced by earthquake may be a danger to property and life along the coast.

## CONCLUSIONS & RECOMMENDATIONS

Makran region is an active continental margin marked by low seismicity with infrequent large earthquakes. Most of the earthquakes are shallow, with thrust focal mechanism and located along subduction zone. The Makran coast has a history of large seismic events and a great event of magnitude 8.1 with shallow focal depth caused a widespread damage along the coast. Recognition of capable faults all along the coast confirms that Makran coast is active. Under the earthquake loading, parts of Makran are susceptible to permanent ground displacement and tsunami. The Makran coast falls within one seismotectonic zone and similar seismic risk is suggested for the coastal areas.

The site exclusion criteria for important civil structures in seismically active belts states that all sites located on or in close vicinity of capable faults should be excluded. Similarly sites should not be located on sympathetic fault of a capable fault. Sites near or close to the cliffs and steep slopes should be avoided. Sites should be preferably selected on competent rock units. Maximum possible tsunami height should be considered. Above all, site-specific peak ground acceleration should be assessed following guidelines of IAEA or some other country located in the seismically active area.

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