The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

SMR/1839-1

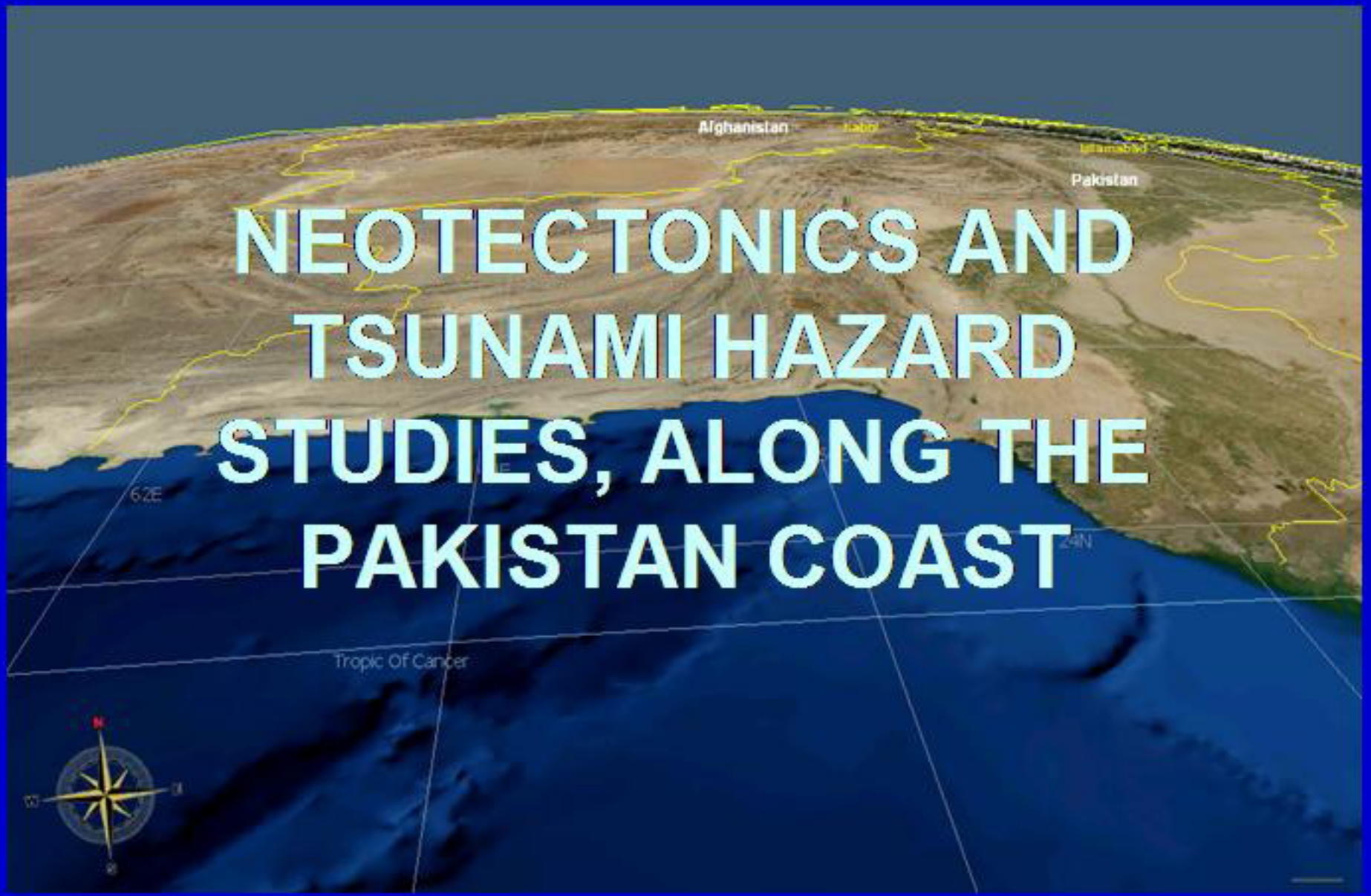
Workshop on the Physics of Tsunami, Hazard Assessment Methods and Disaster Risk Management (Theories and Practices for Implementing Proactive Countermeasures)

14 - 18 May 2007

Neotectonics and Tsunami Hazard Studies, along the Pakistan Coast

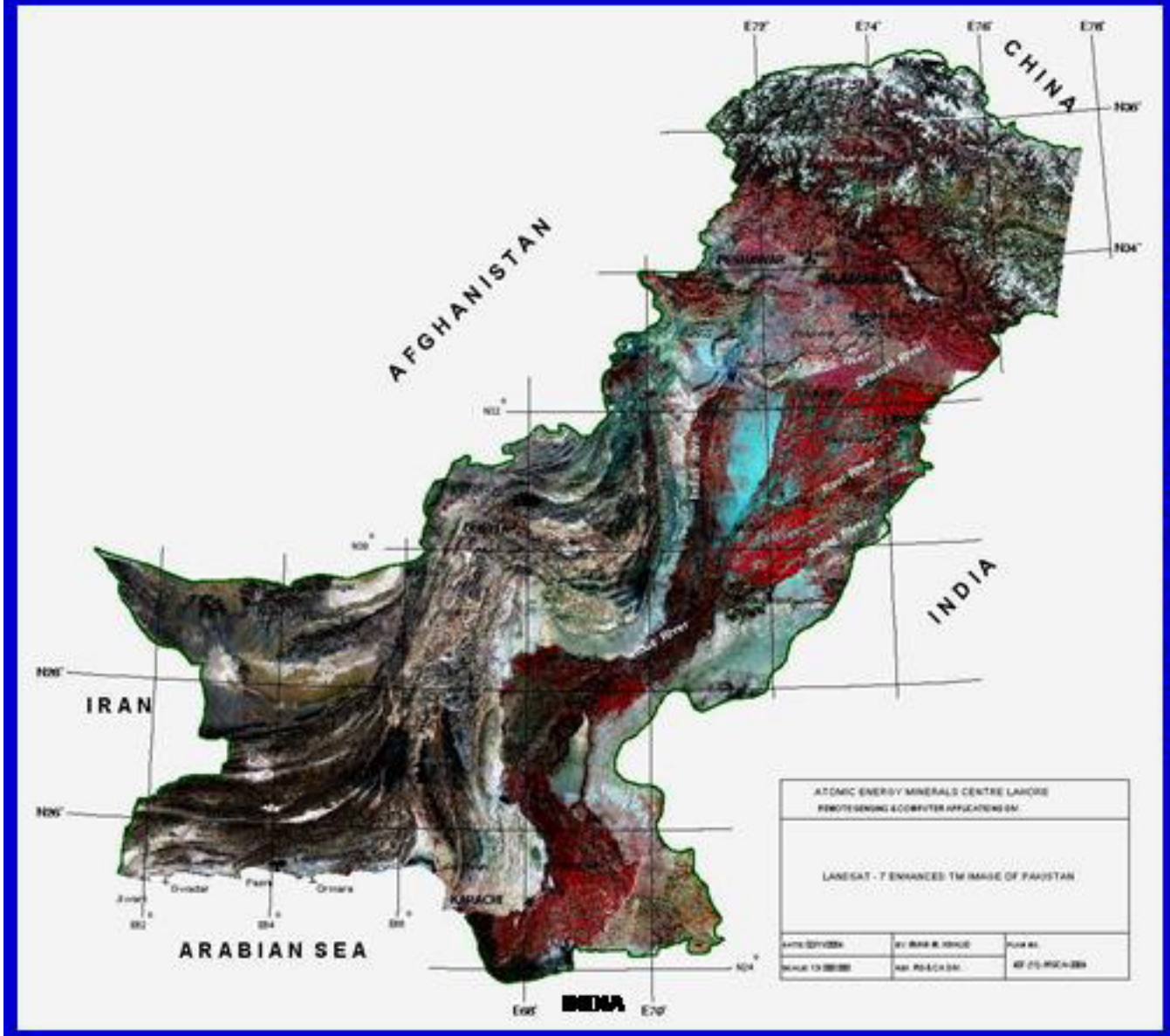
Javaid HUSSAIN

Atomic Energy Minerals Centre
Lahore, Pakistan



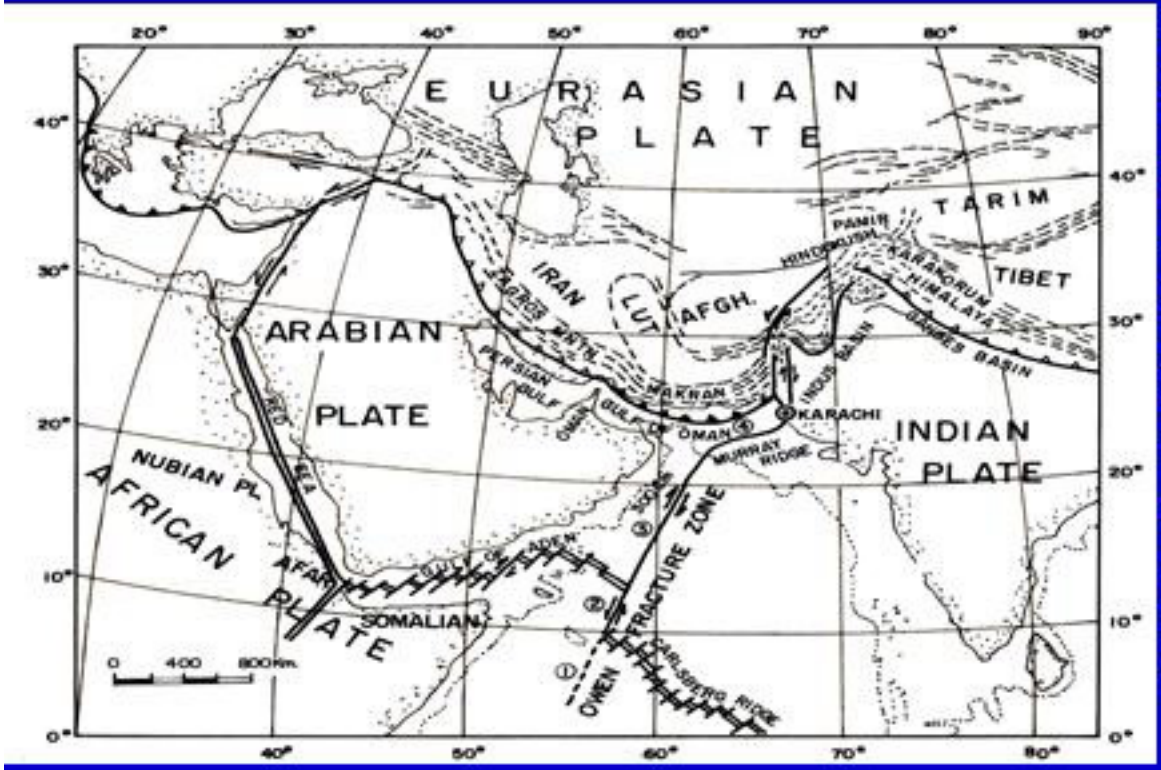
NEOTECTONICS AND TSUNAMI HAZARD STUDIES, ALONG THE PAKISTAN COAST

PAKISTAN



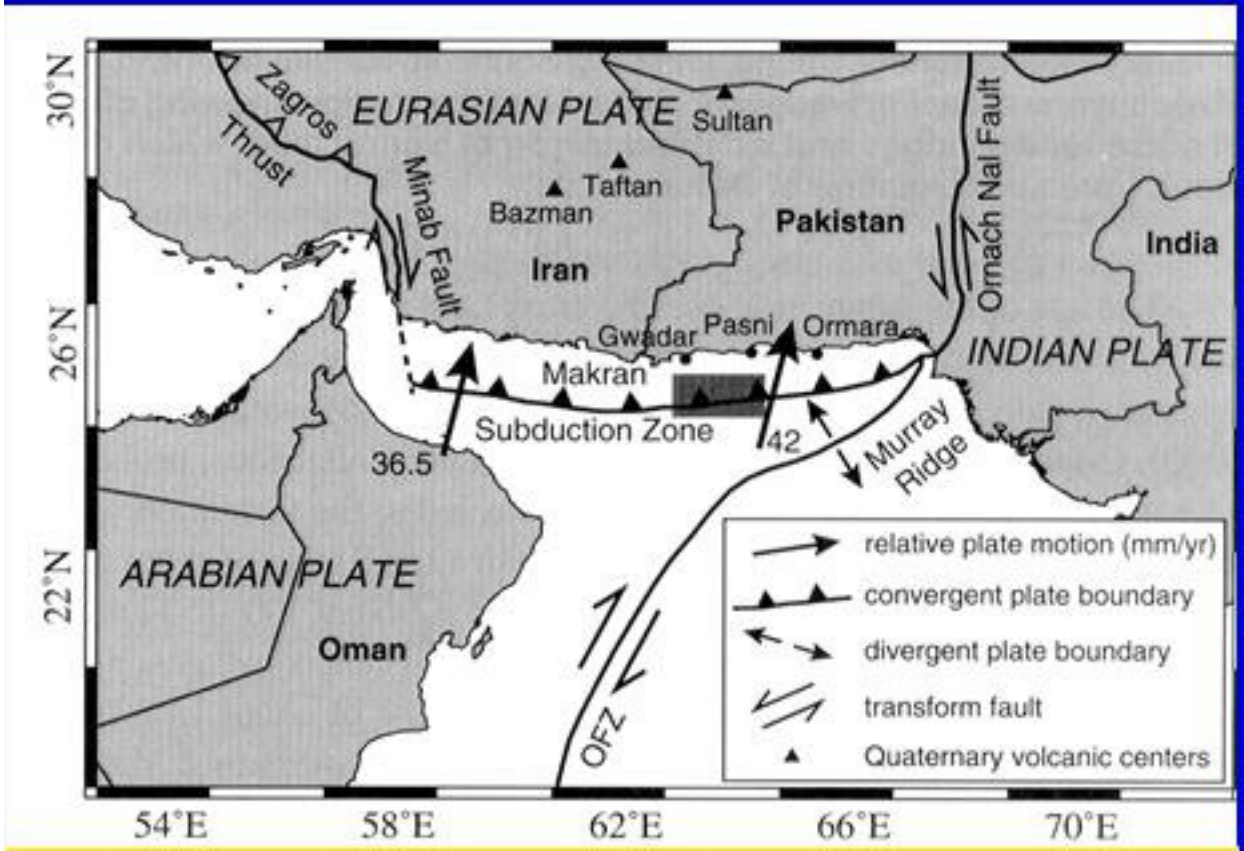
More than 700 km long Coast.
Biggest city of the country Karachi is located at the Coast.
Development of new ports, Gwadar completed, Sonmiani proposed
Major towns along the Makran coast are, Ormara, Pasni, Gwadar and Jiwani

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

GEOTECTONIC SETTING (CONTD)

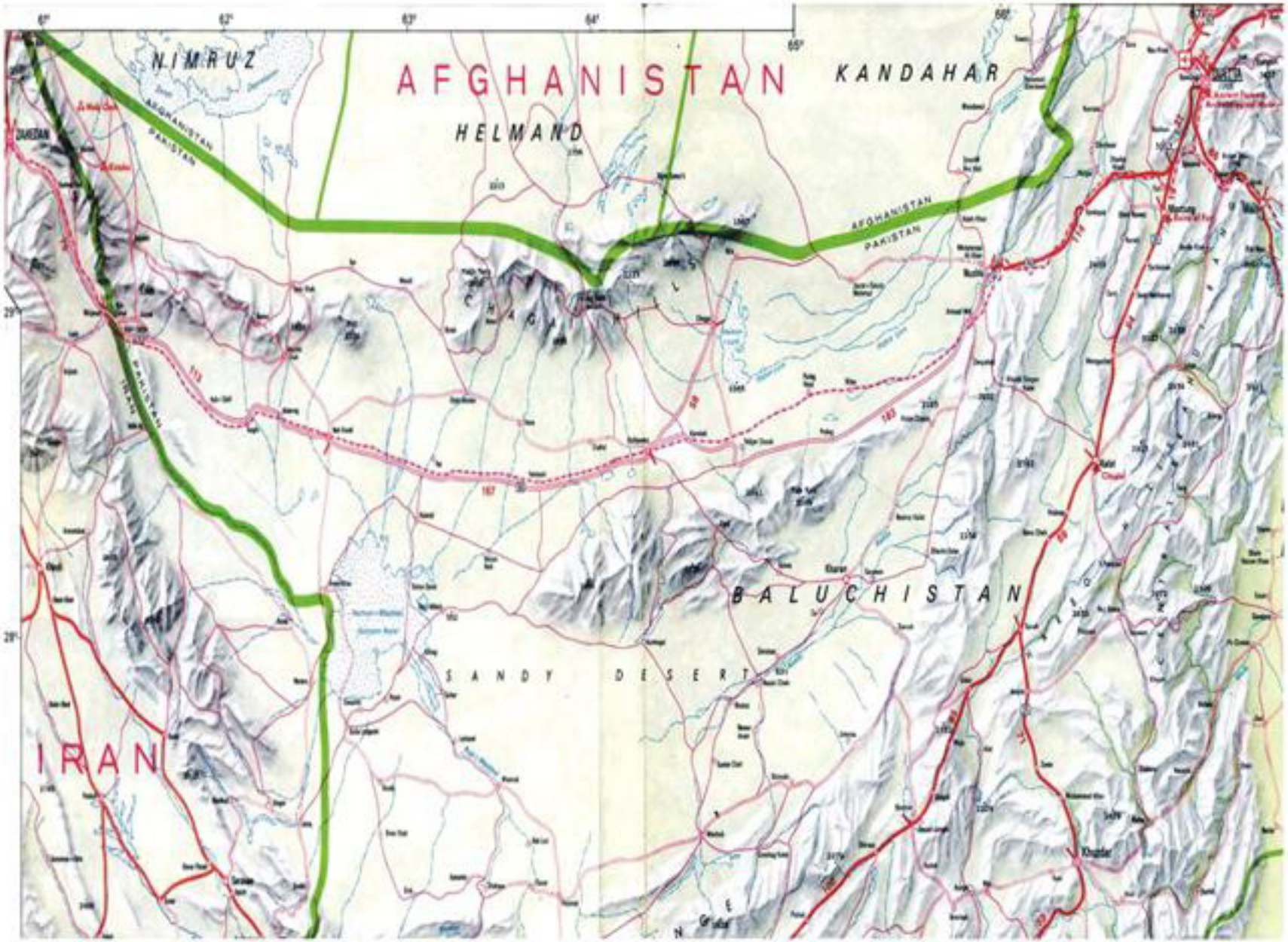


Simplified map of present day plate tectonic Framework of Arabian-Indian-Eurasian Convergence zone. Dark shaded rectangle is Area covered with swath mapping during cruise SO 123. Arrow indicate rate and direction of Convergence.

The subduction and resulting geological features constitute a tectonic province, called as Makran. 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.

Western limit of Makran is Minab Fault in Iran that joins it with Zagros thrust & fold belt.

The accretionery wedge of sediments developed between burried offshore trench & deformed Chagai Arc.

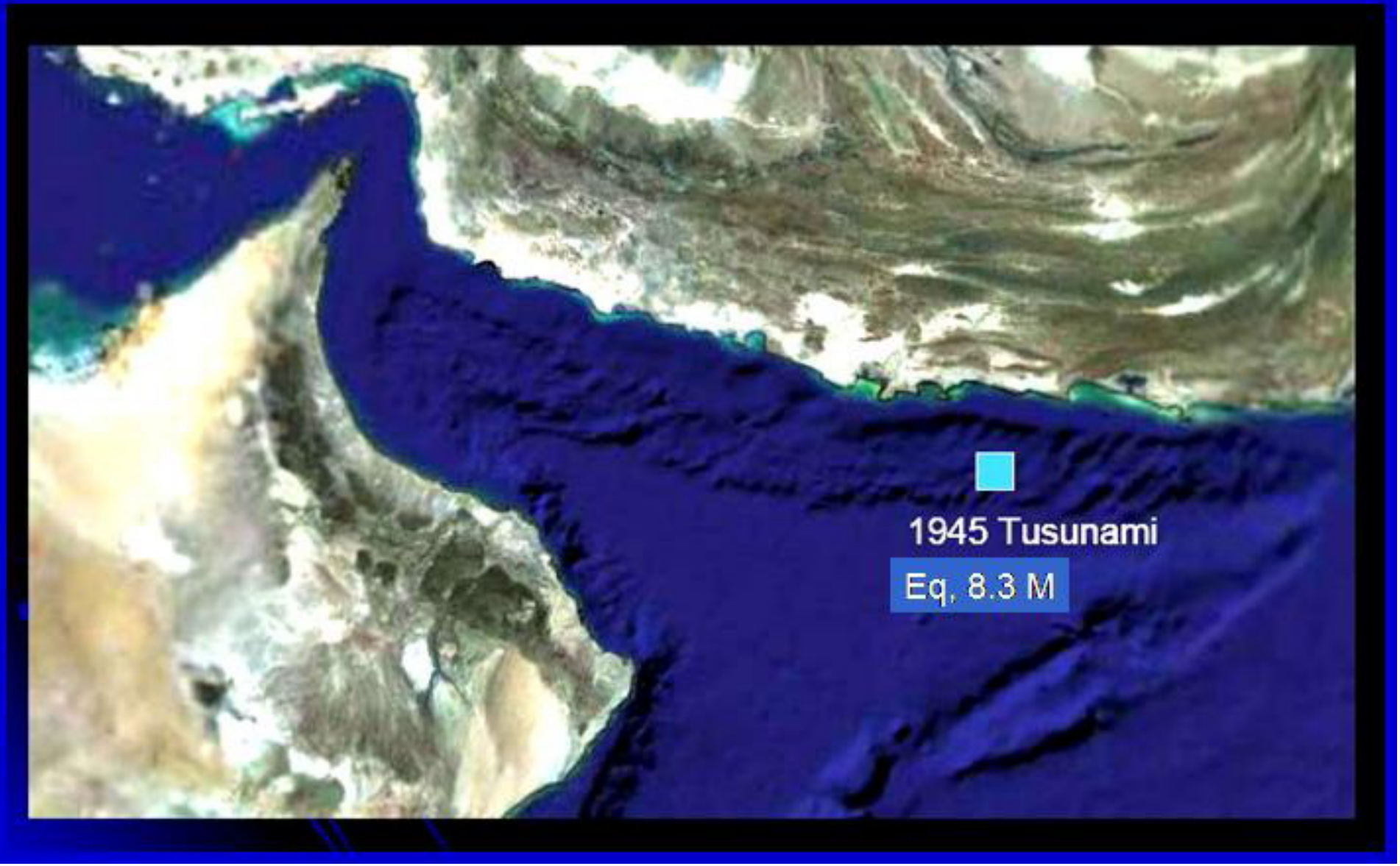

NIMRUZ
AFGHANISTAN
KANDAHAR
HELMAND
AFGHANISTAN
PAKISTAN
AFGHANISTAN
PAKISTAN
BALUCHISTAN
SANDY DESERT
IRAN

GEOTECTONIC SETTING (CONTD)

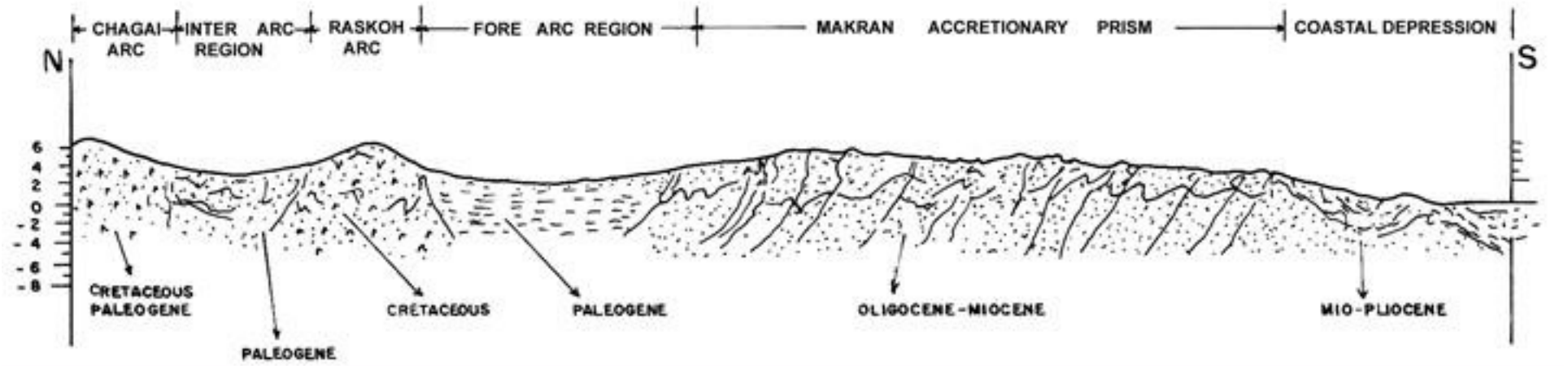
VOLCANIC PLUG

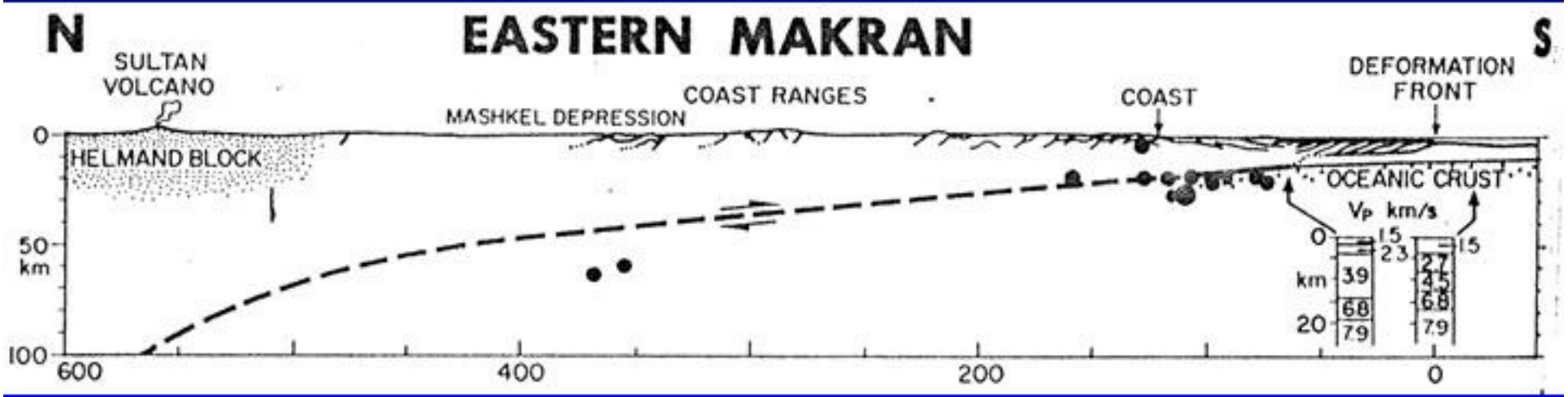
VOLCANIC SPINE

GEOTECTONIC SETTING (CONTD)

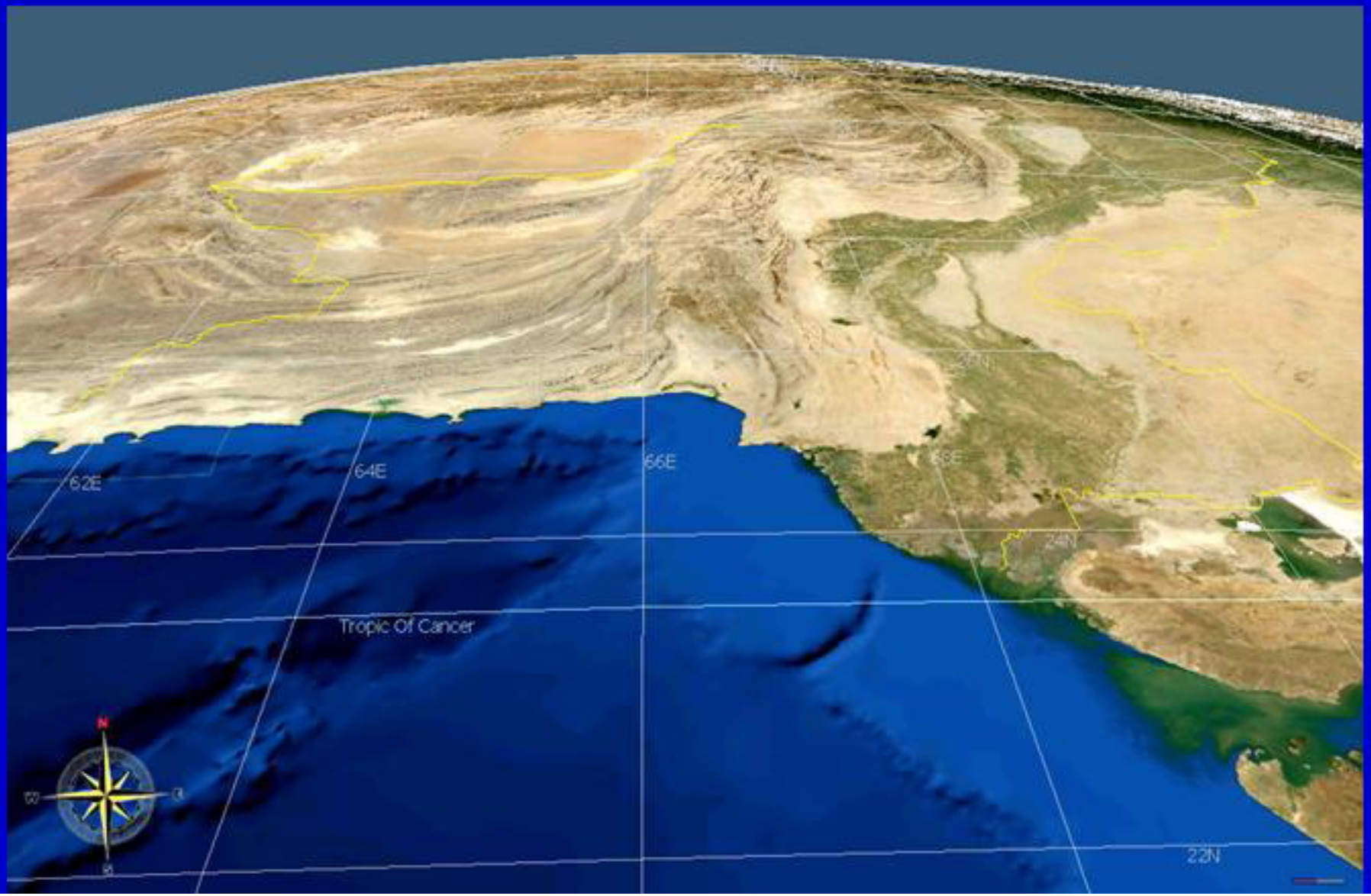


GEOTECTONIC SETTING (CONTD)

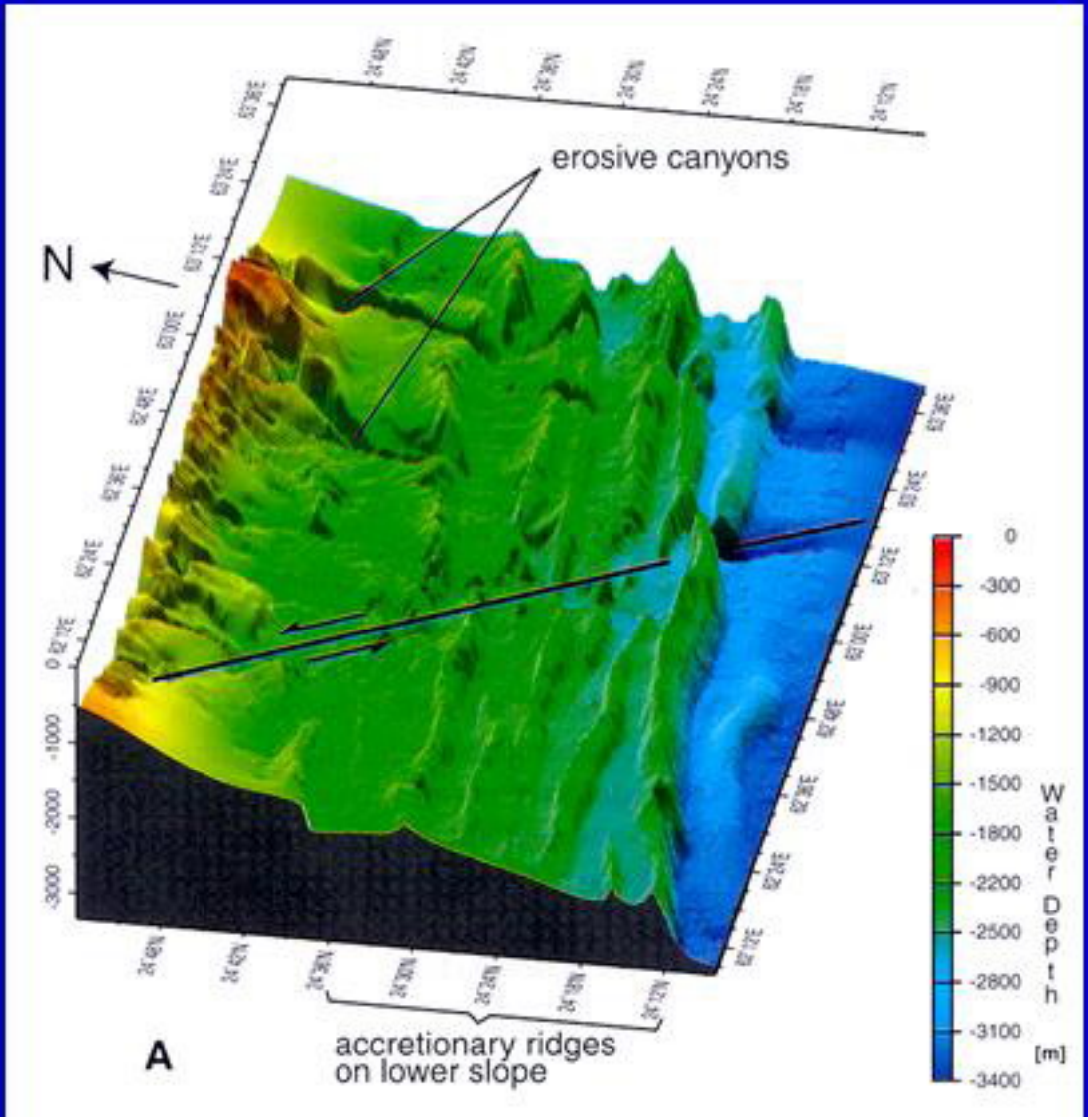




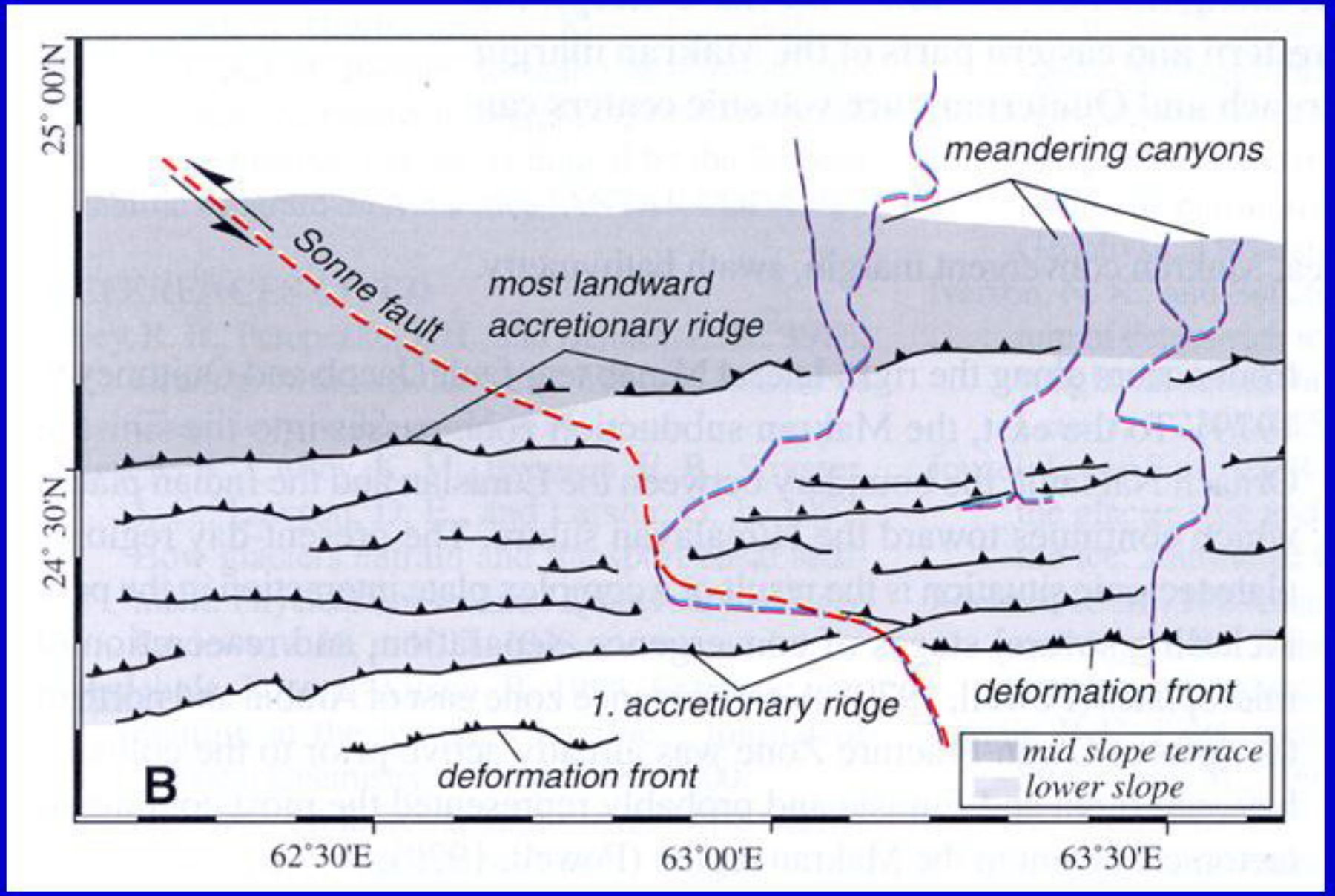
GEOTECTONIC SETTING (CONTD)



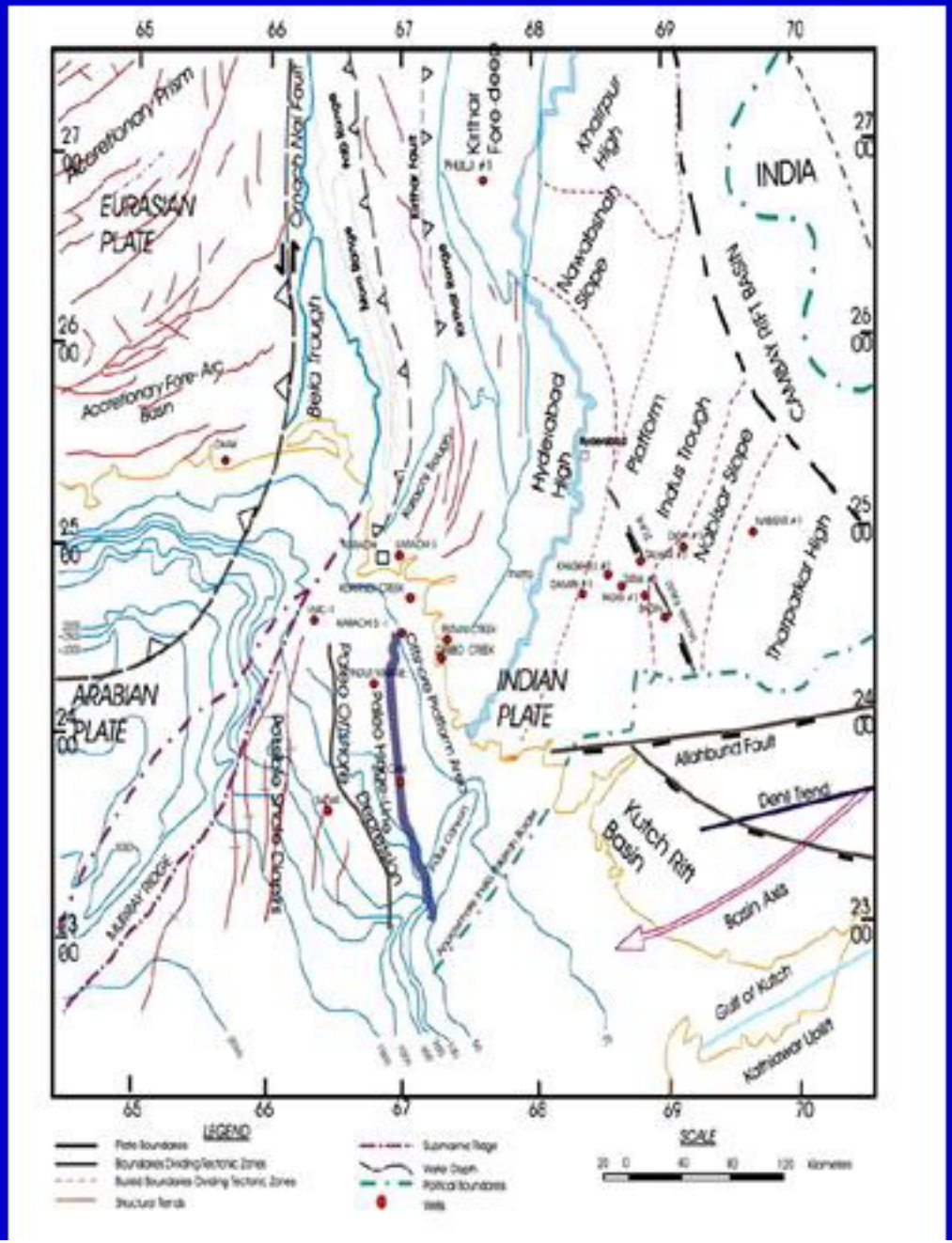
GEOTECTONIC SETTING (CONTD)



GEOTECTONIC SETTING (CONTD)

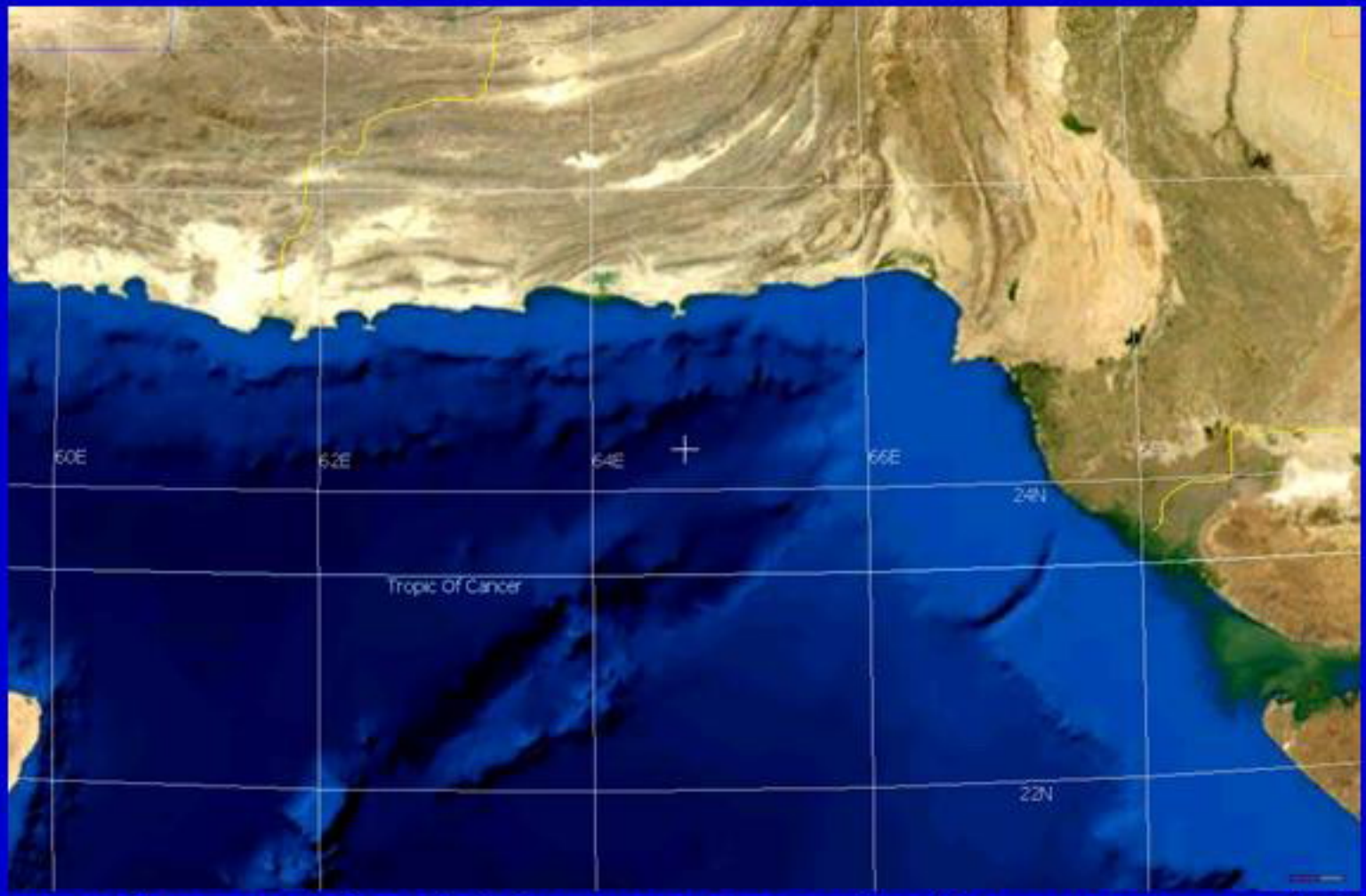


PAKISTAN OFFSHORE (CONTD)



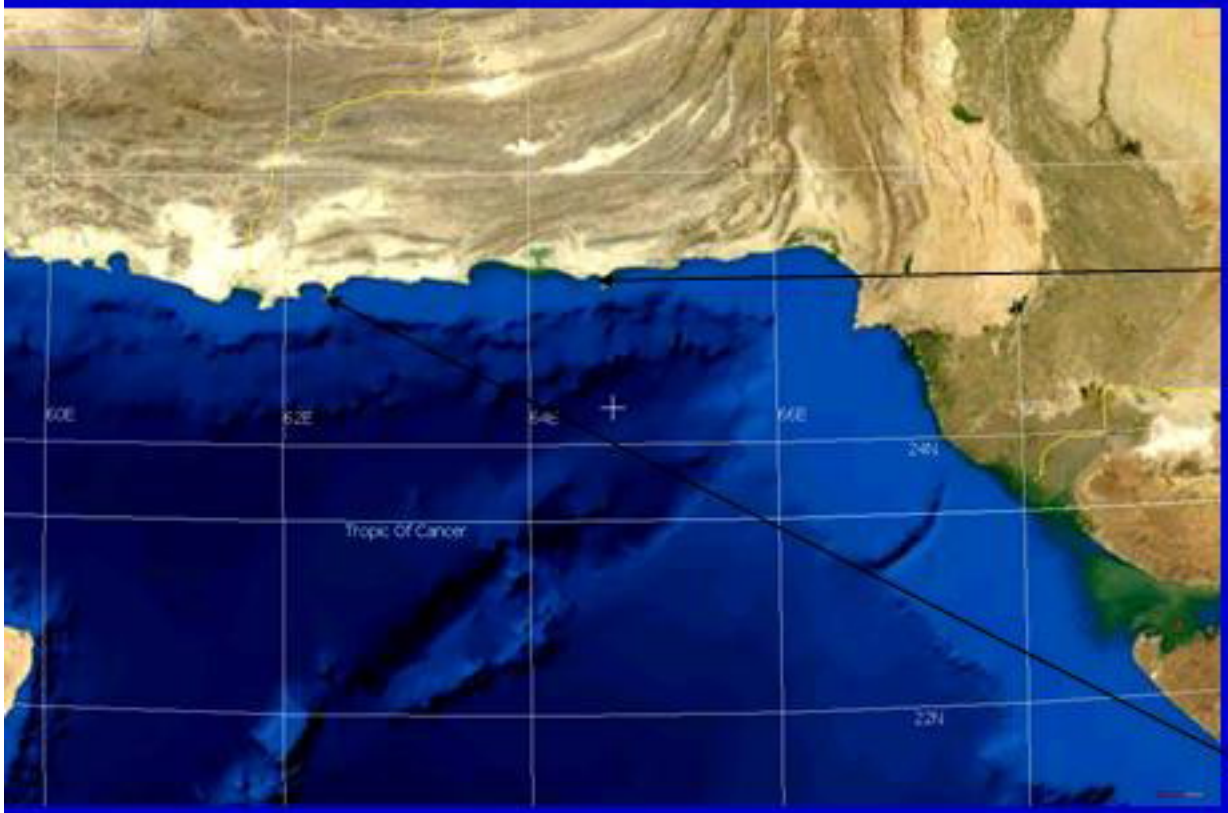
In the east Kutch Rift is active Feature of Indian Plate however Major active structures do not Extend in the Arabian sea

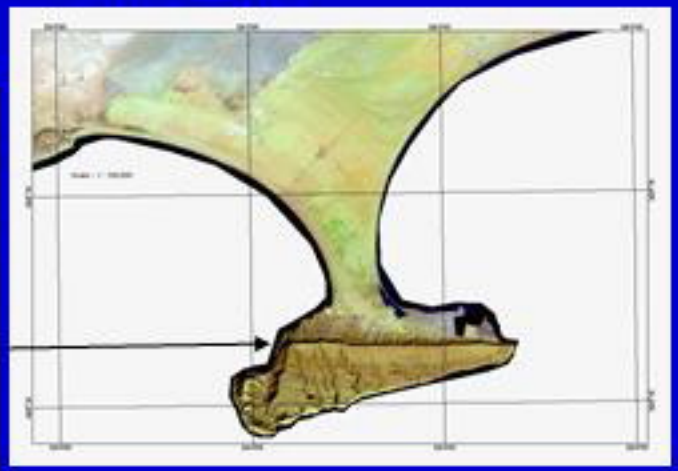
MAKRAN OFFSHORE (CONTD)

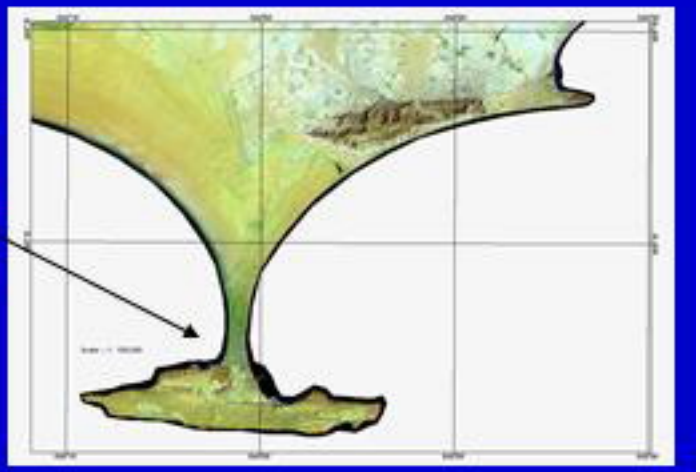


Eastern 200 km crenulated deltaic coast is gullied by numerous tidal creeks. In This part coast is approx. NS in the central part coast is EW and in the west Of Karachi it sharply turn to the north, than it takes a arcuate shape to become EW In Makran, the western coast line is more or less is controlled by tectonic

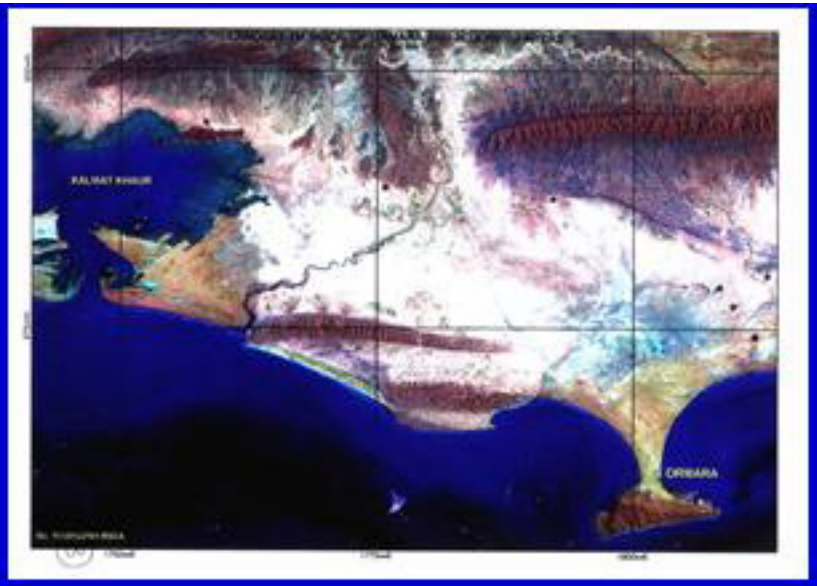
MAKRAN OFFSHORE (CONTD)

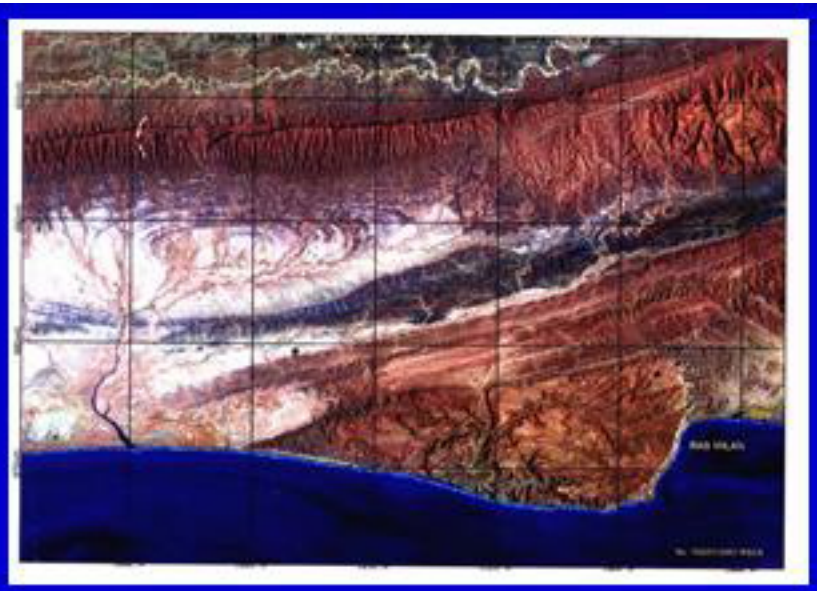


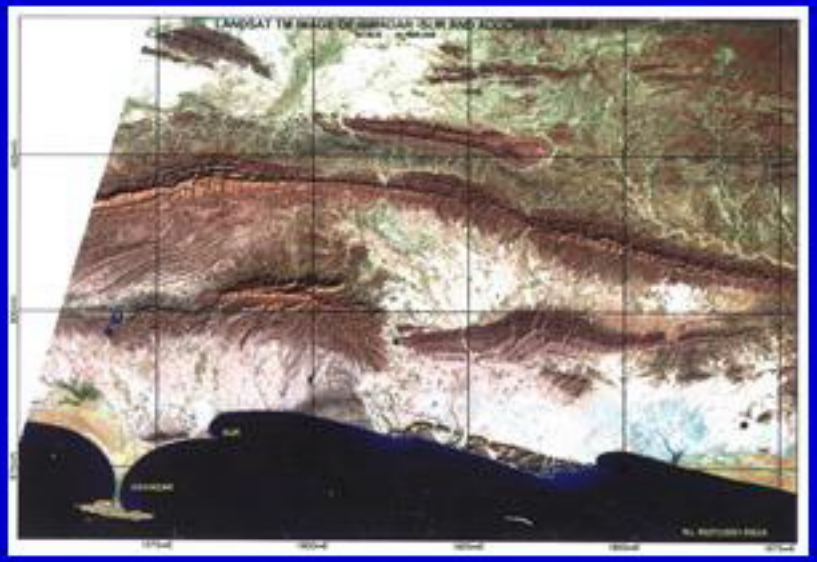


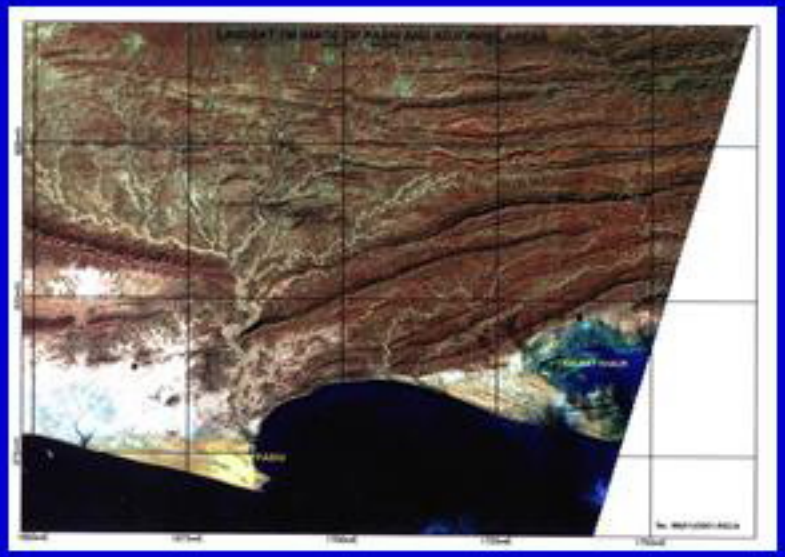


Makran coast is generally regular
However it is indented at places and
Have two hammer head shaped
Projections at Ormara and Gawadar



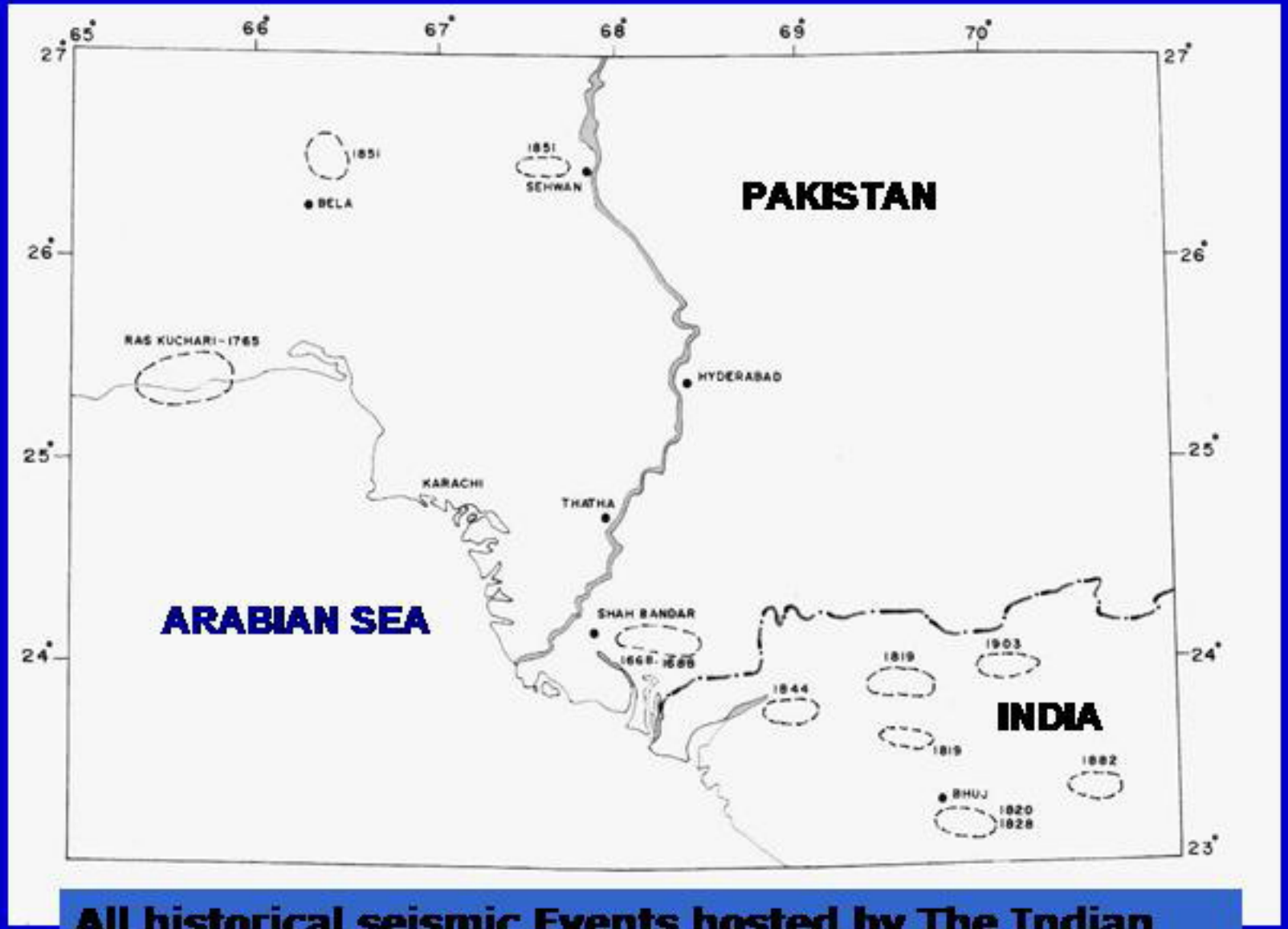






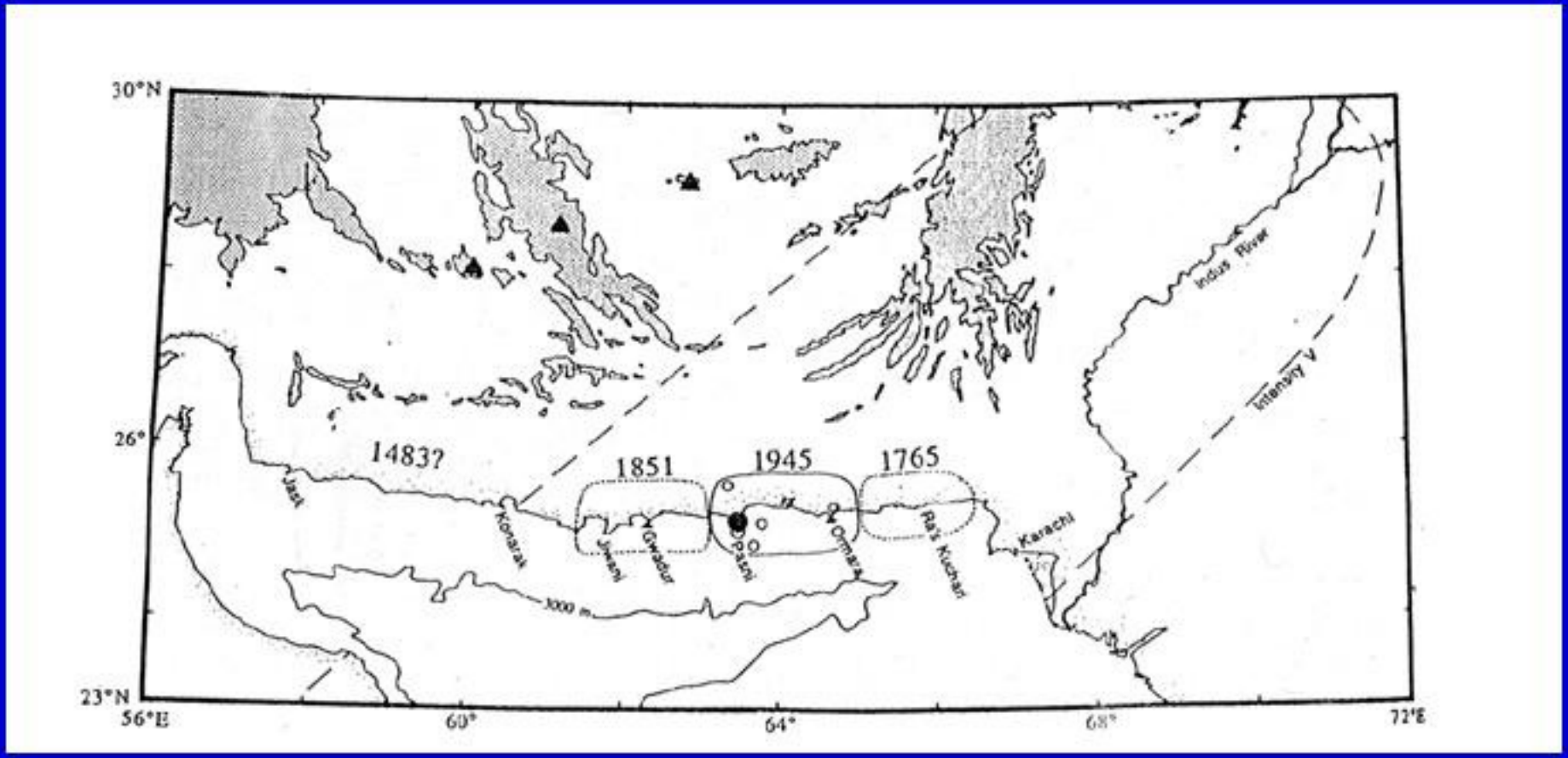
Generally the Makran Coast is comprised of 15 meters to 65 meters high Rocky cliff standing above a very narrow beach. Above the cliff a coastal Plain extends all along the Coast. The portion of beaches devoid of cliff are Prone to tsunami invasion

HISTORICAL EVENTS OF EASTERN COASTAL AREAS



All historical seismic Events hosted by The Indian plate are Located on land and No historical document Contain evidence of Tsunami

HISTORICAL GREAT EARTHQUAKE OF MAKRAN COASTAL AREAS, PAKISTAN



The historical catalogue Records four large events Along Makran Coast but No tsunami information is Available

SEISMICITY OF COASTAL AREAS

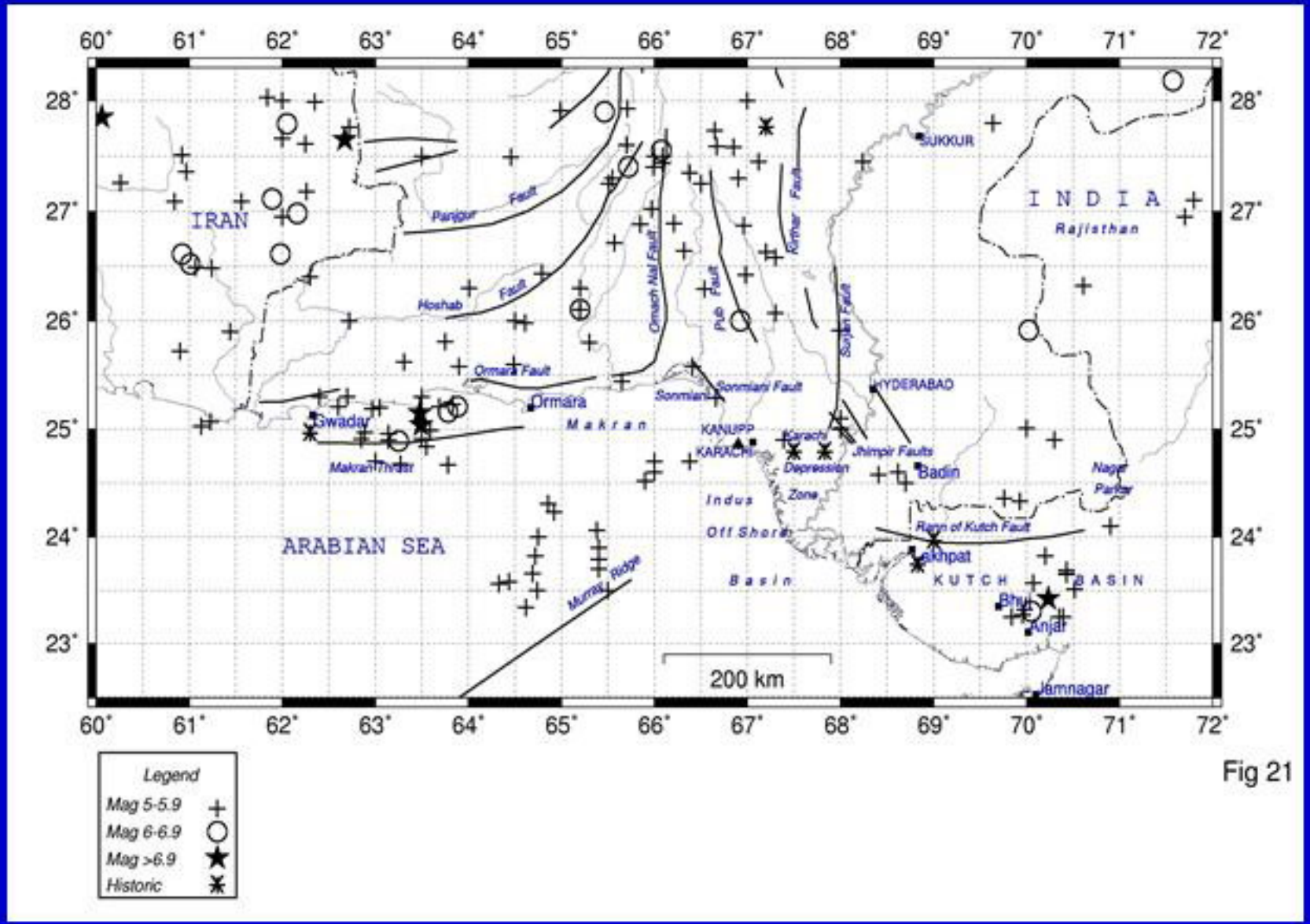
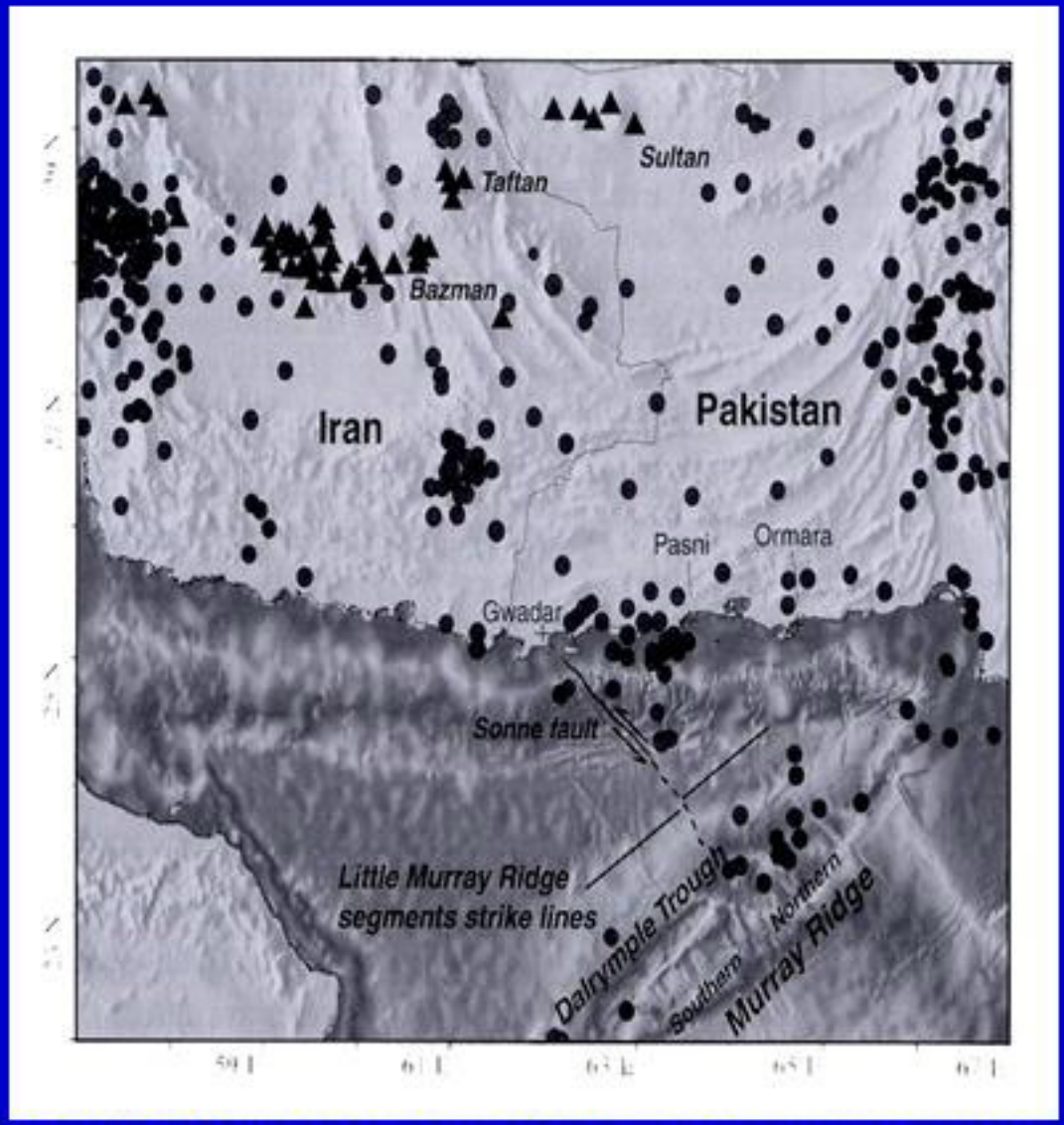


Fig 21

SEISMICITY OF MAKRAN COAST



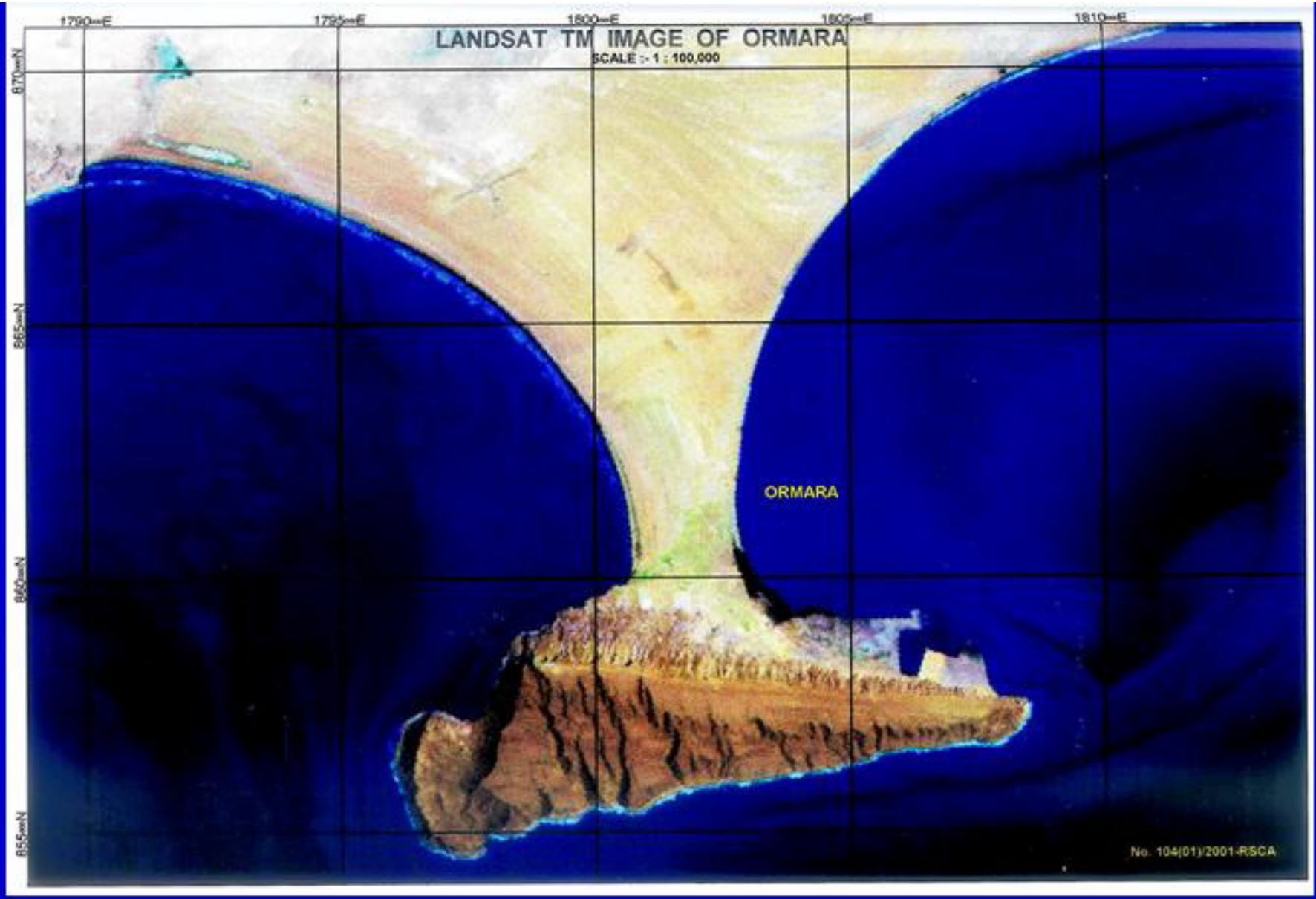
Frequency of events is higher in eastern Makran as ormara plate is moving at a faster rate.

SENIOR CITIZENS GIVING INFORMATION ABOUT THE GREAT EVENT OF 1945

The detail of the tsunami was gathered by interviewing the 50 nos. of senior Citizens who observe the event.

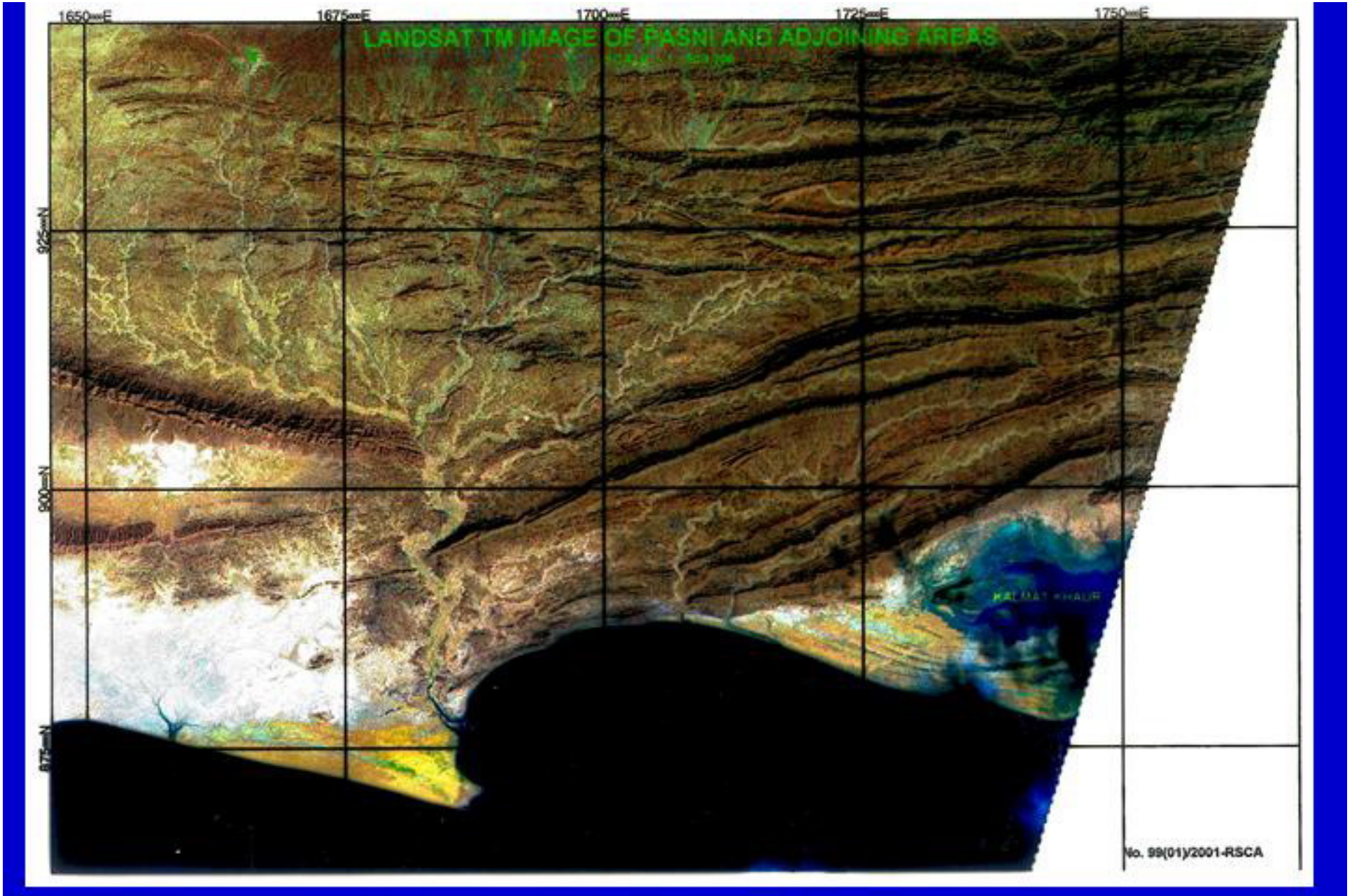
DAMAGE CAUSED

- 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 areas of Makran was thinly populated and majority of the population use to live in huts made up of date tree branches and in mud houses as such the loss of life and property was minimum as compared to the size of the event.

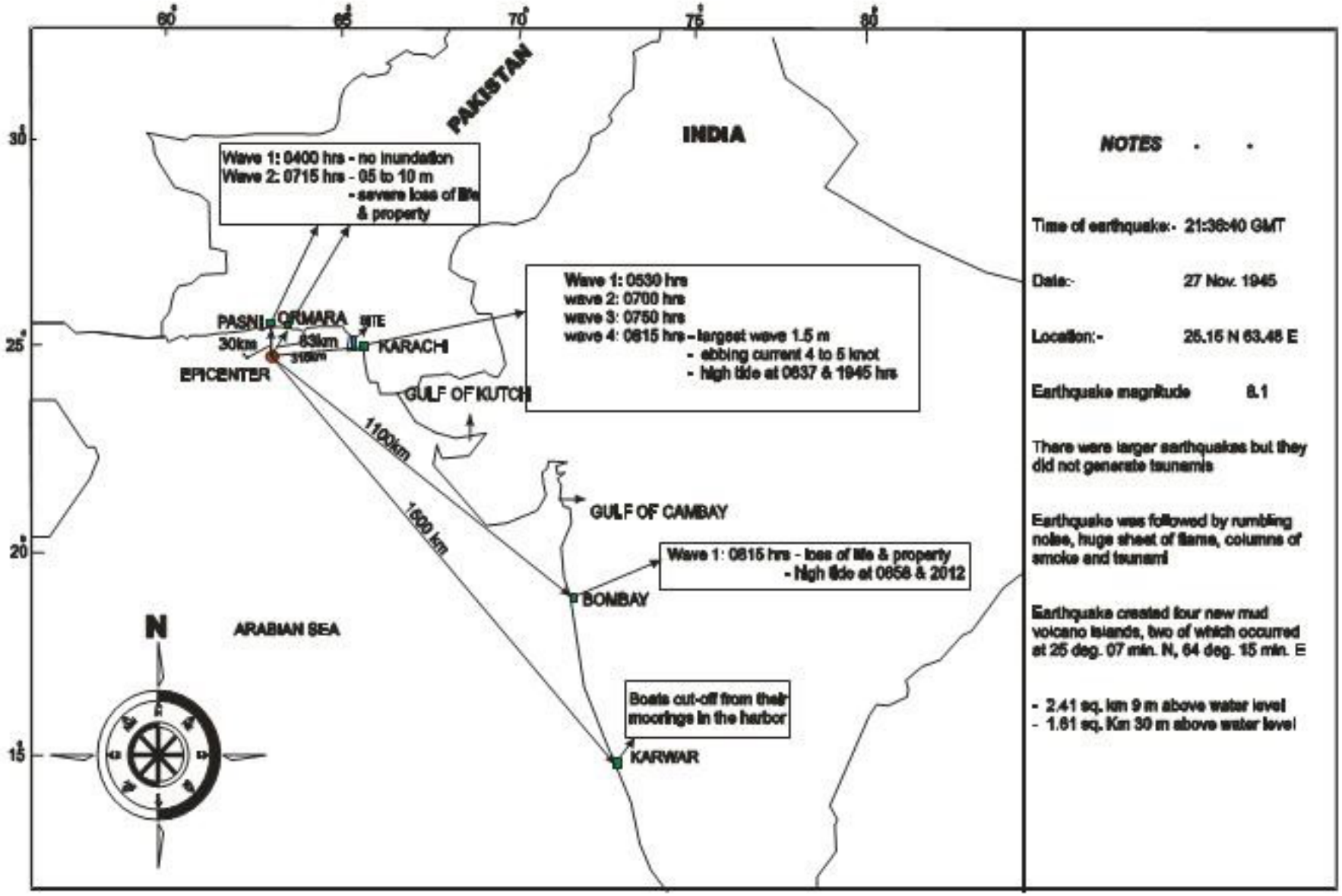


The tsunami height was 5 meters in ormara. It was estimated from the height of a tree which was submerged under water. The tsunami swap over the tombolo And effected an area of 10 km along the coast

Ground rupture in coastal plain north of Ormara town caused by the Great event of 1945. Man pointing toward the direction of rupture.

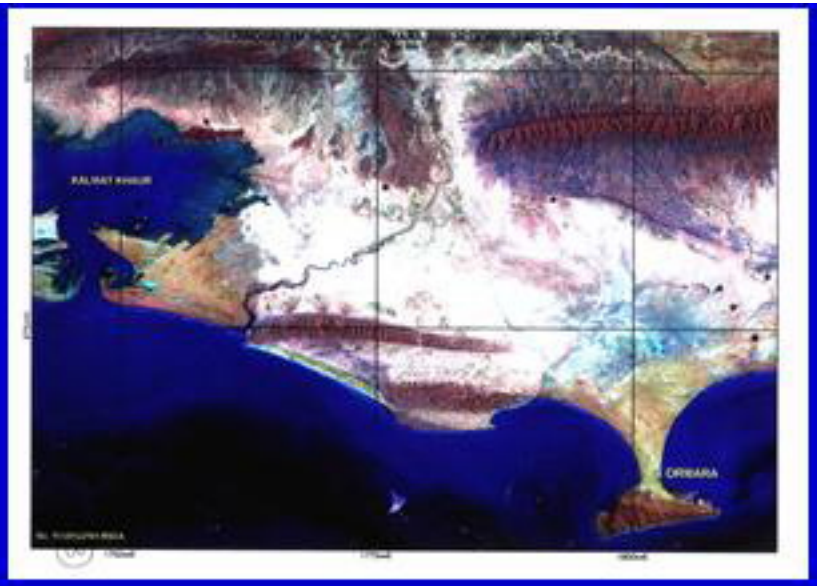


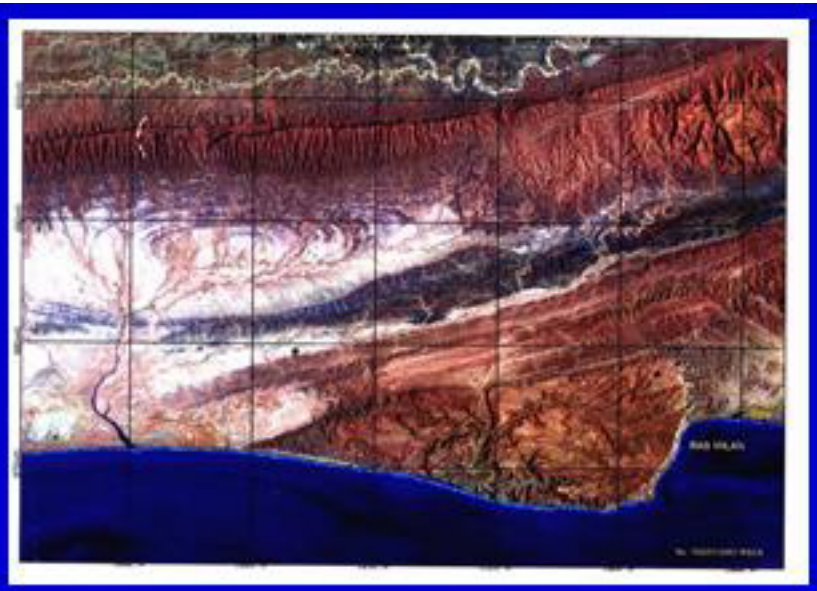
A fishing boat was hanged by tsunami over 10 m high minaret of a mosque in Pasni town indicating that the height of the tsunami was approx. 10 m in Pasni area

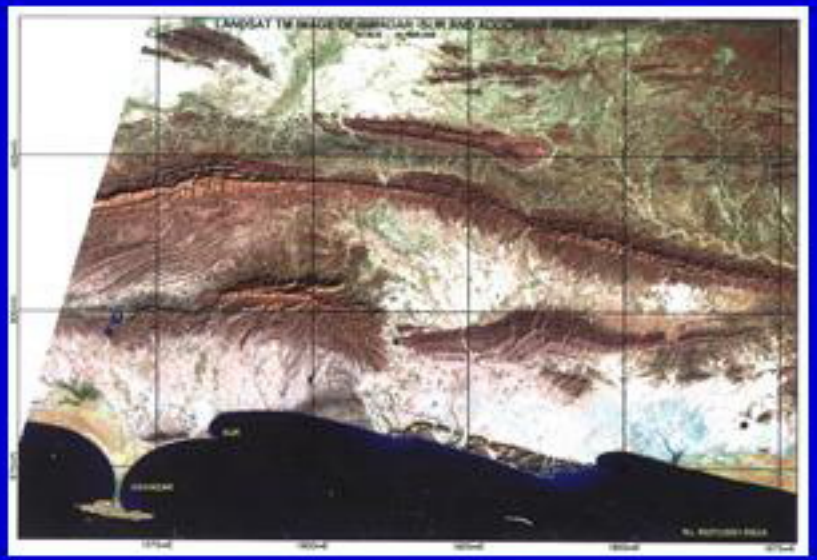


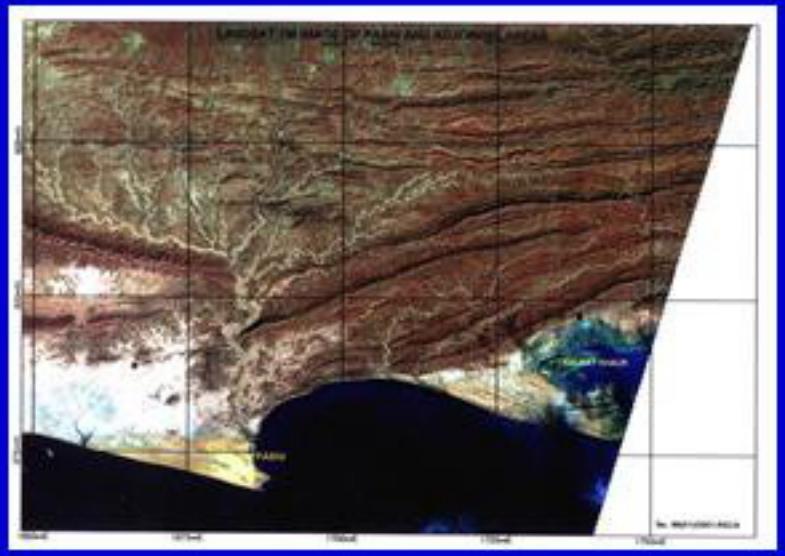
TSUNAMI GENERATED BY THE NOVEMBER 1945 EVENT IN THE ARABIAN SEA

(Modified after T.S Murty 1999)

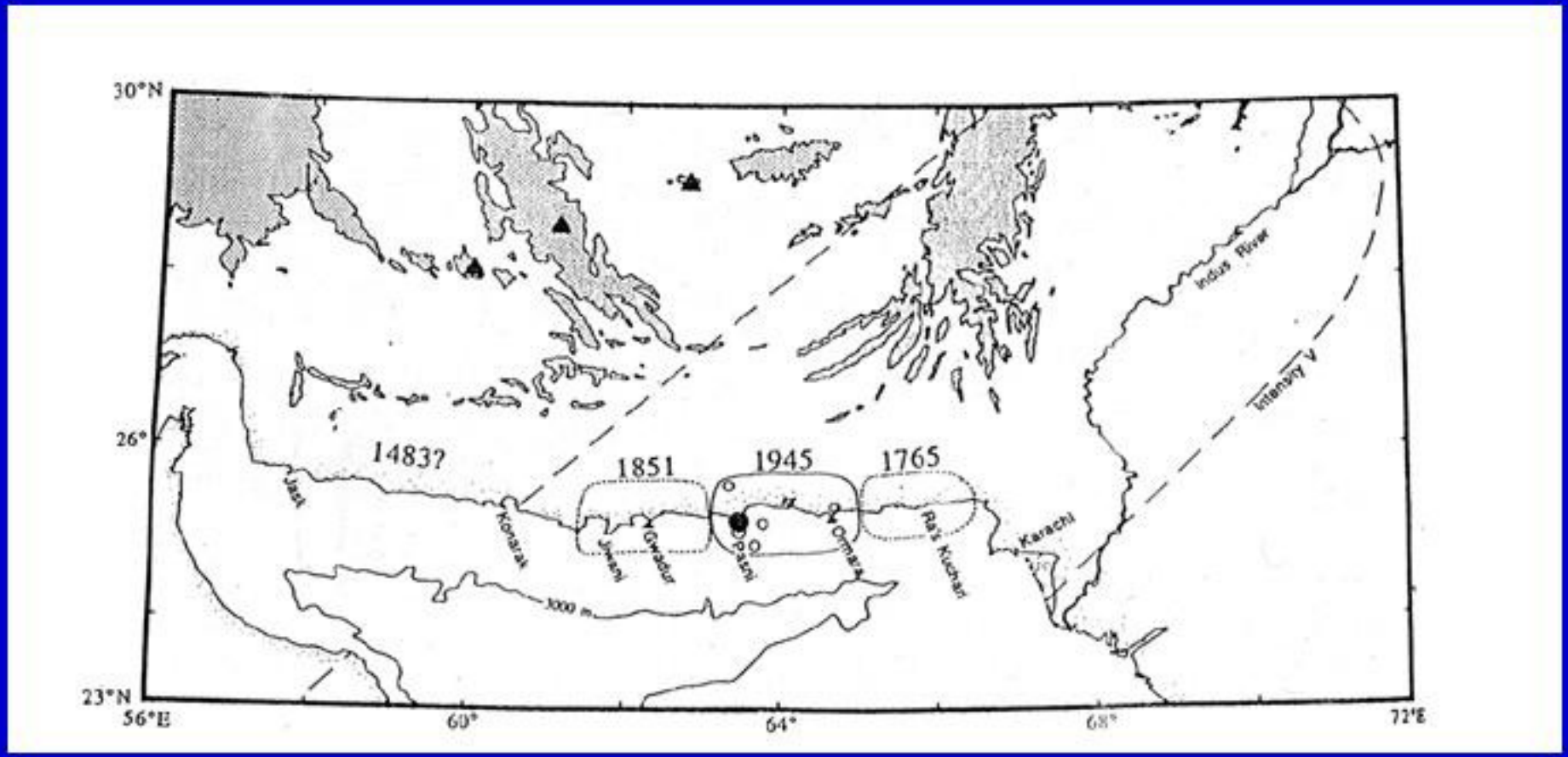




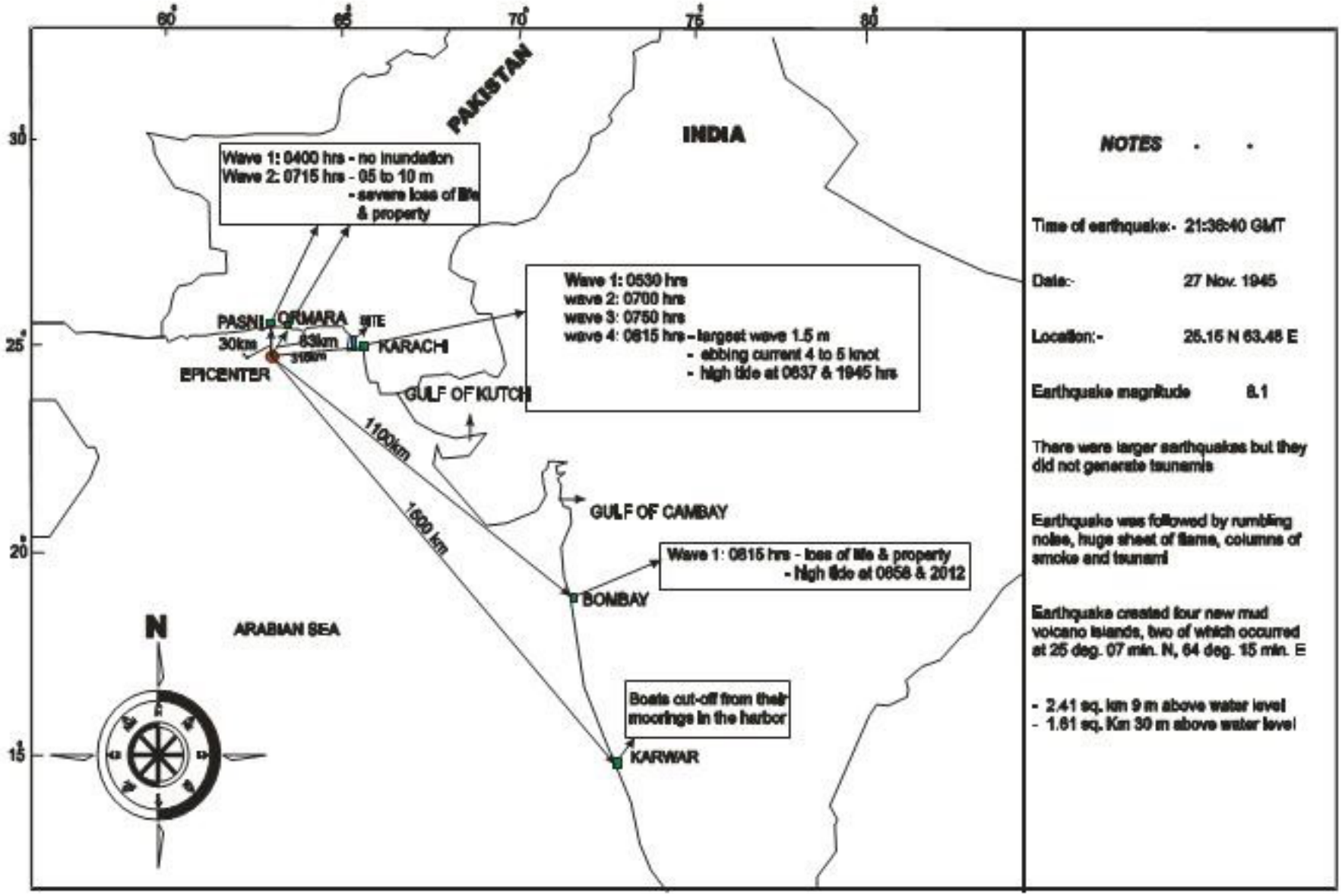




Tsunami could not invade the cliffy coast and it only ran over low lying Beaches. Interestingly Tsunami did not cause life loss as local people were Aware of the tsunami and they had taken refuge over high lands before the Tsunami hit the area.



The rupture occurred in a radius of 80 to 150 km. the propagation of slip was in SSE direction. Seven meters displacement at a dip of 7 degree will cause 1 meter vertical offset at the ocean floor.



TSUNAMI GENERATED BY THE NOVEMBER 1945 EVENT IN THE ARABIAN SEA

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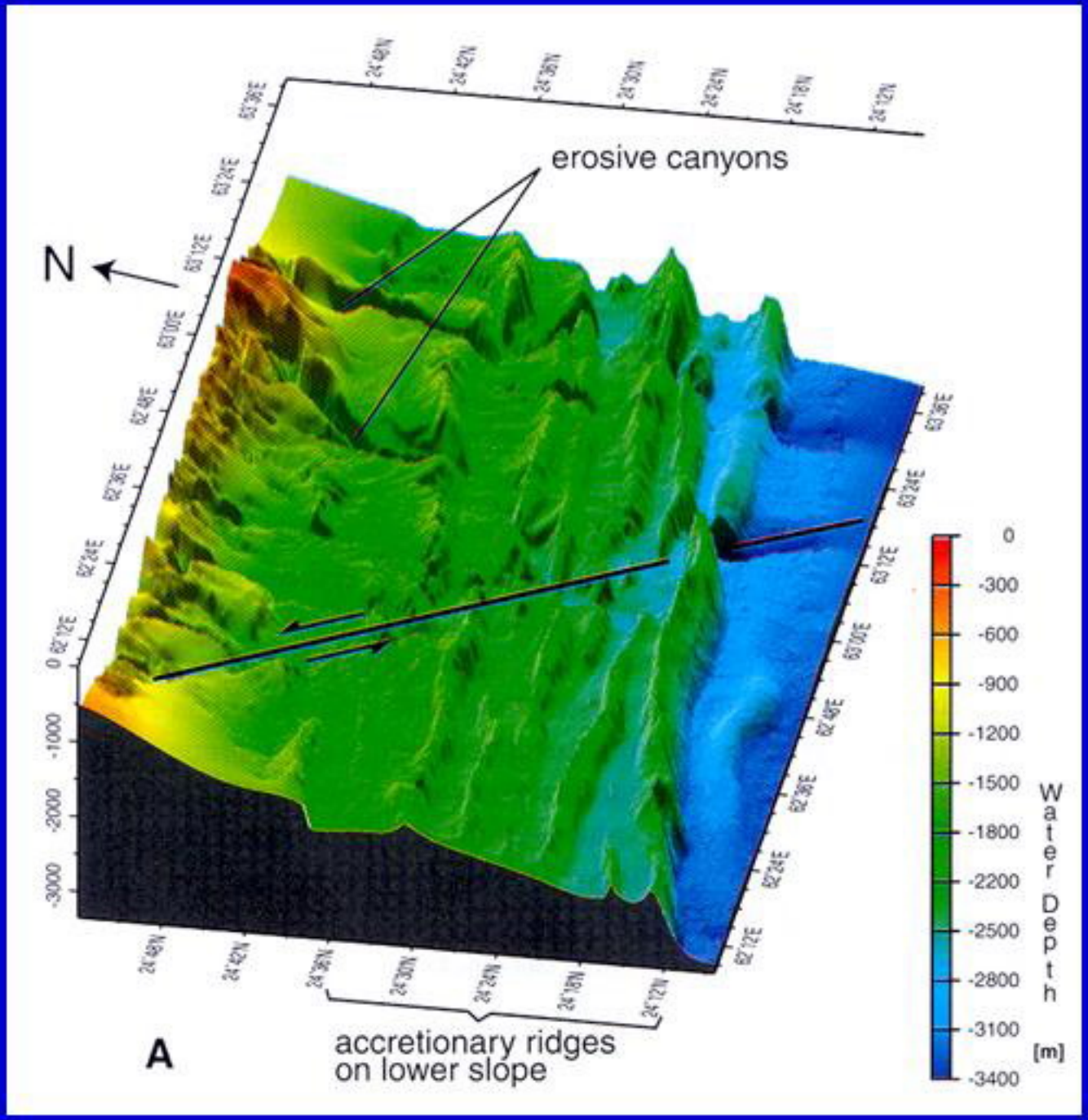
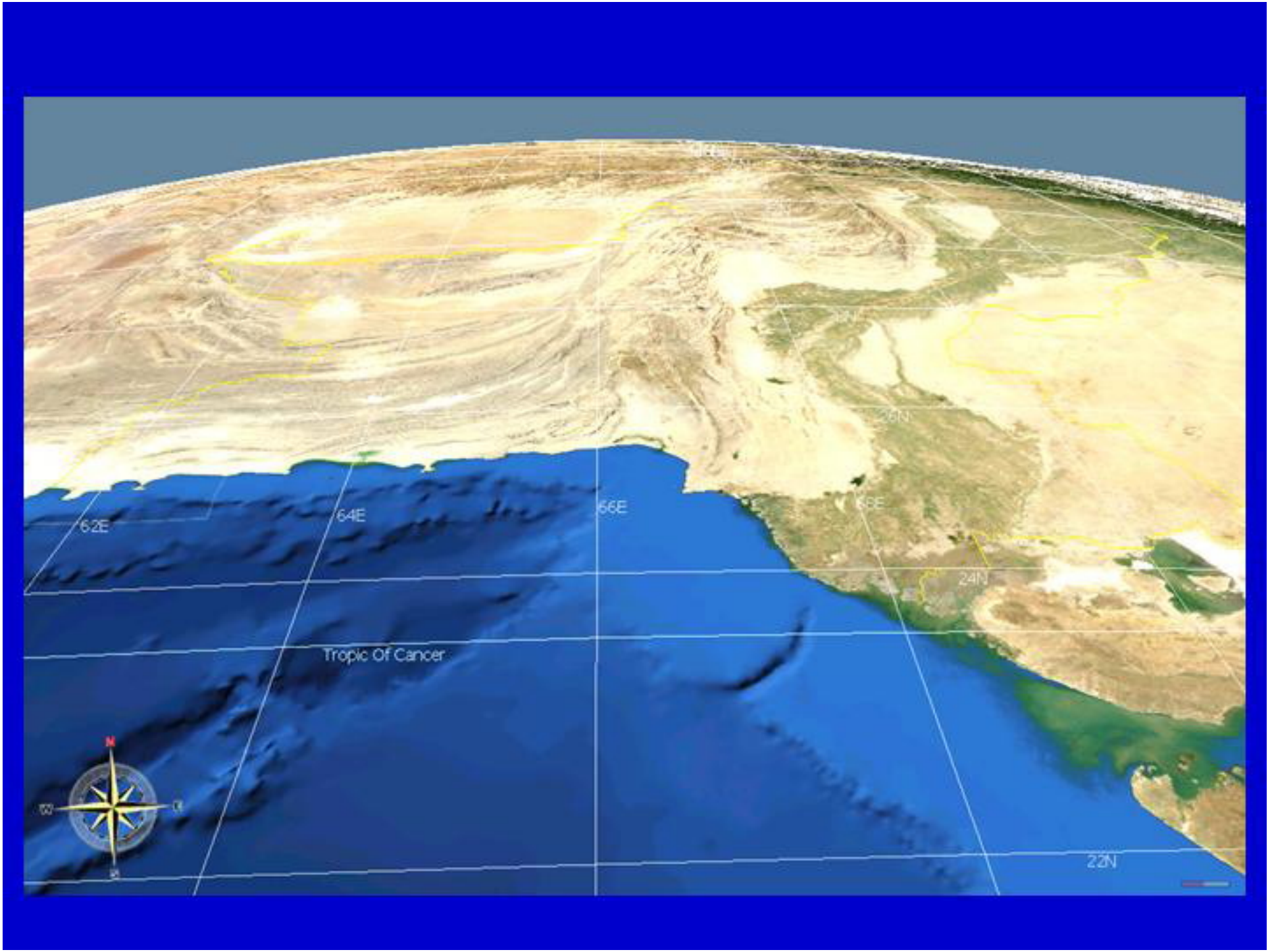
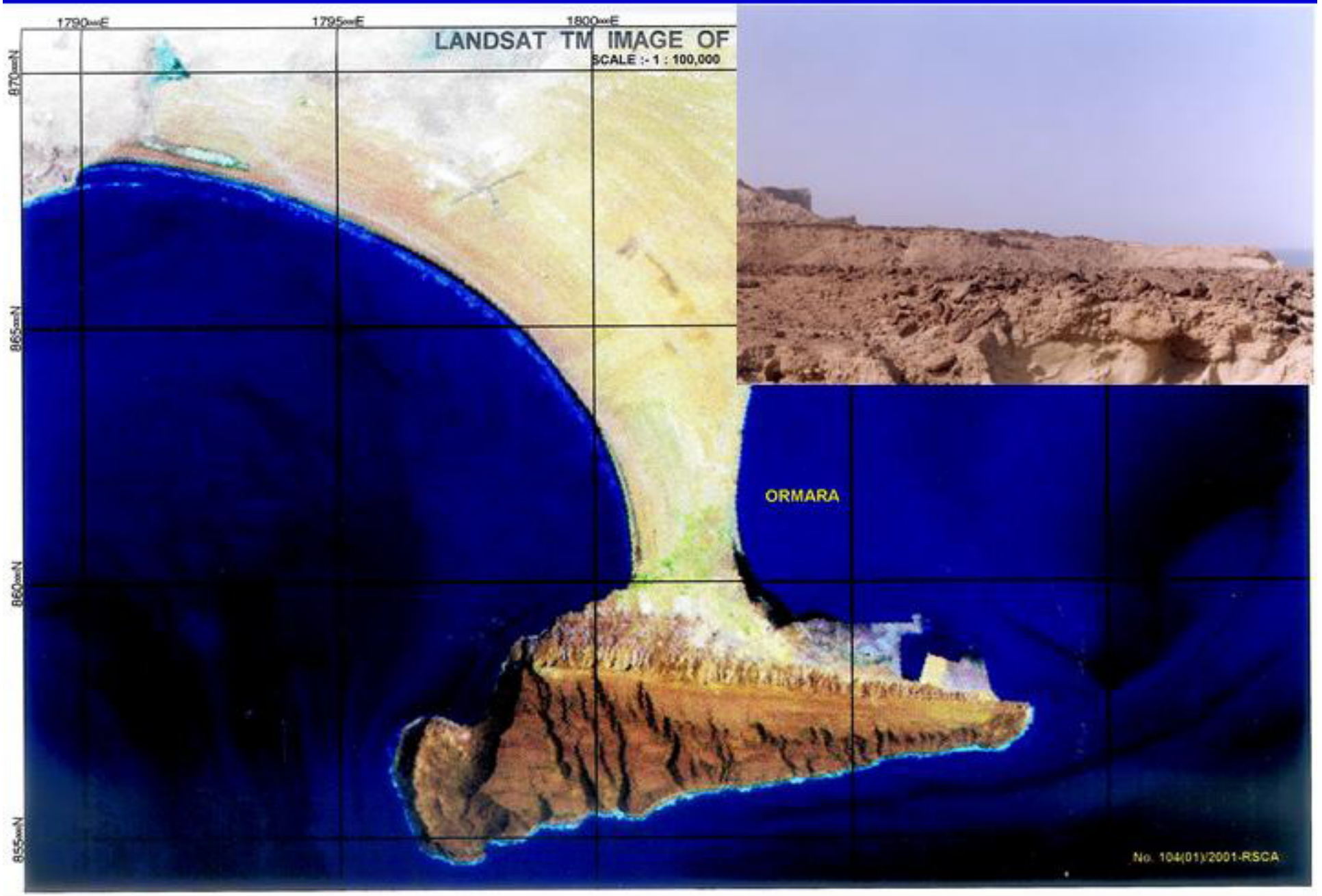

erosive canyons
N
A
accretionary ridges
on lower slope
Water Depth
[m]
0
-300
-600
-900
-1200
-1500
-1800
-2200
-2500
-2800
-3100
-3400
0
-1000
-2000
-3000


62E
64E
66E
24N
Tropic Of Cancer
22N

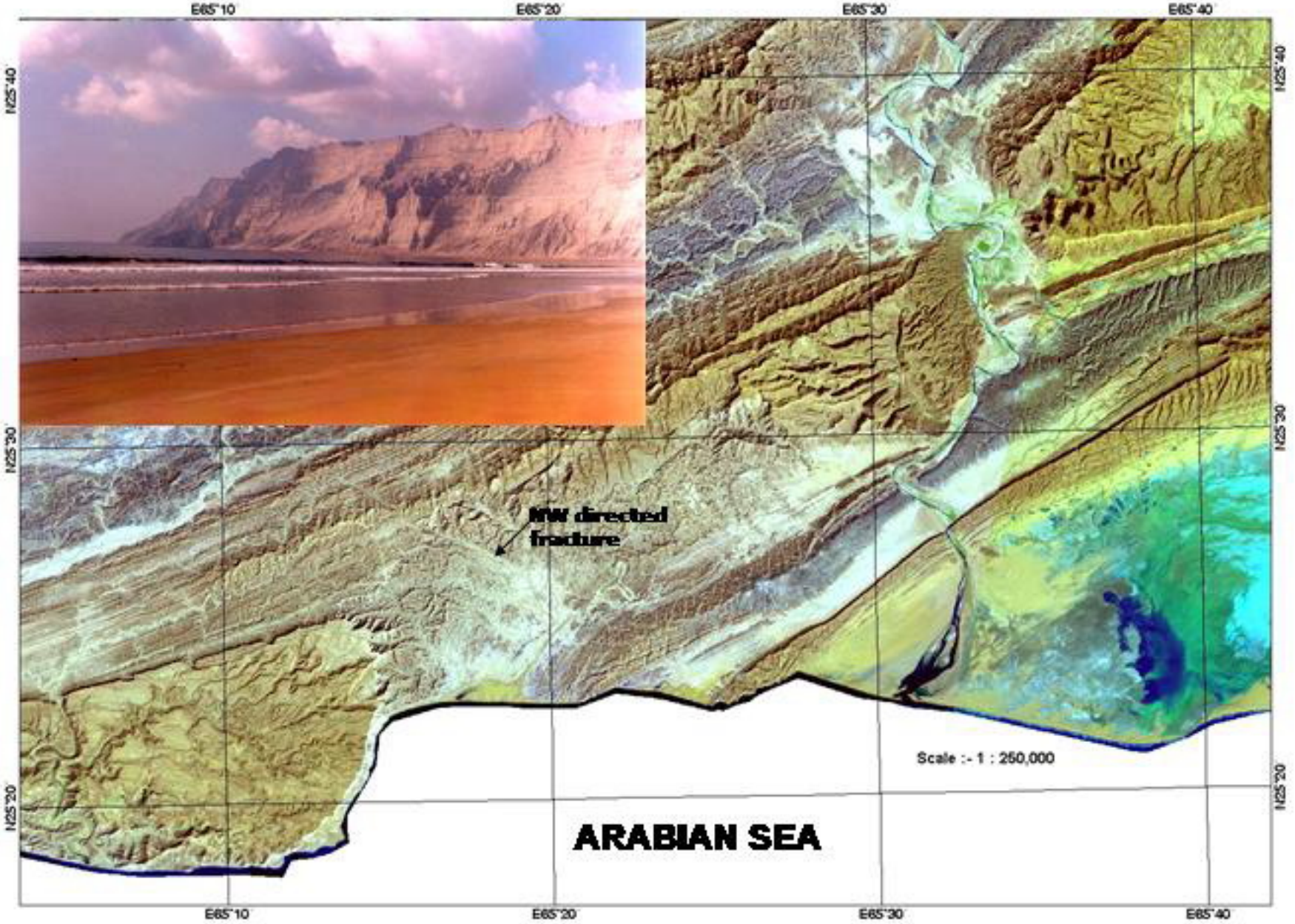

1790mE
1795mE
1800mE
870mN
865mN
860mN
855mN
LANDSAT TM IMAGE OF
SCALE :- 1 : 100,000
ORMARA
No. 104(01)/2001-RSCA

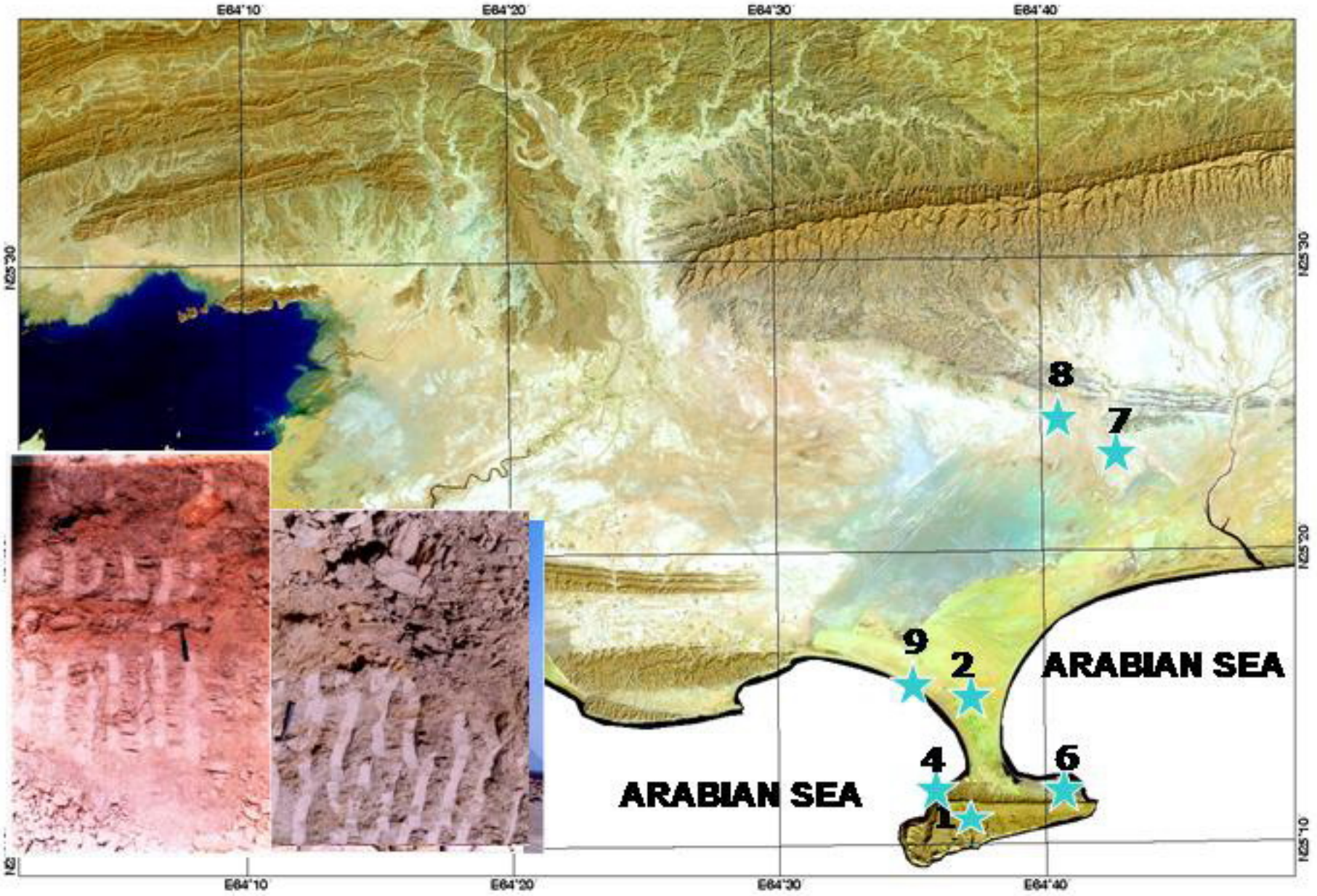
Major Tsunamis in South Asia

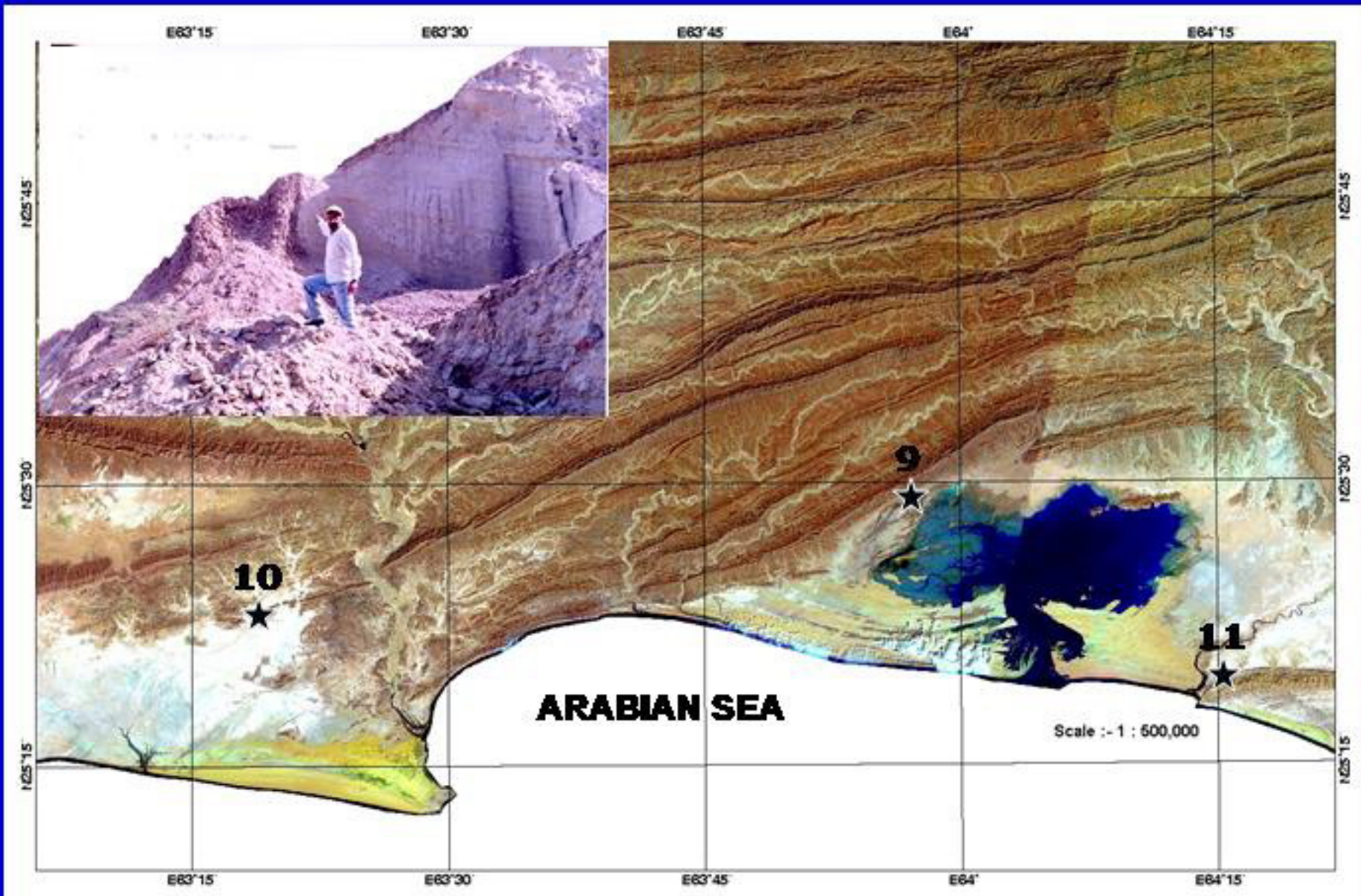
Date	Location
1524	Near Dabhol, Maharashtra
02 April 1762	Arakan Coast, Myanmar
16 June 1819	rann of kachchh Gujrat
31 October 1847	Great Nicobar Island
31 December 1881	Car Nicobar Island
26 August 1883	Krakatoa volcanic eruption
28 November 1945	Makran coast Balochistan

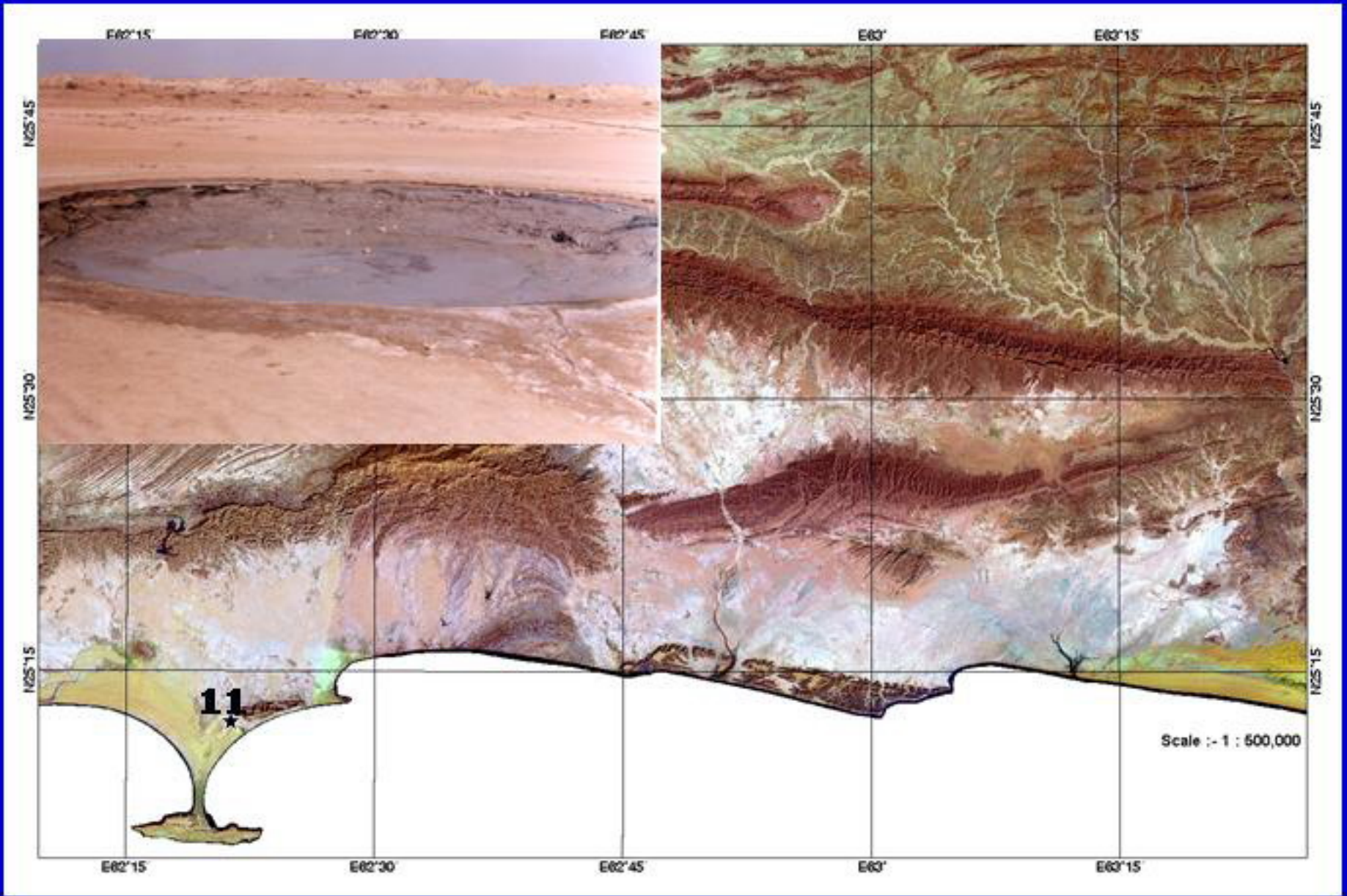
CARBON DATING OF THE SOME OF THE UPLIFTED COASTAL TERRACES (After Snead 1992)

LOCATION	ELEVATION IN METERS	14 CARBON DATING AGE
Gwadar	45	20,000
Gwadar	75	30,000
Gavater (Iran)	30	5,000
East of chah bahar (Iran)	15	15,000

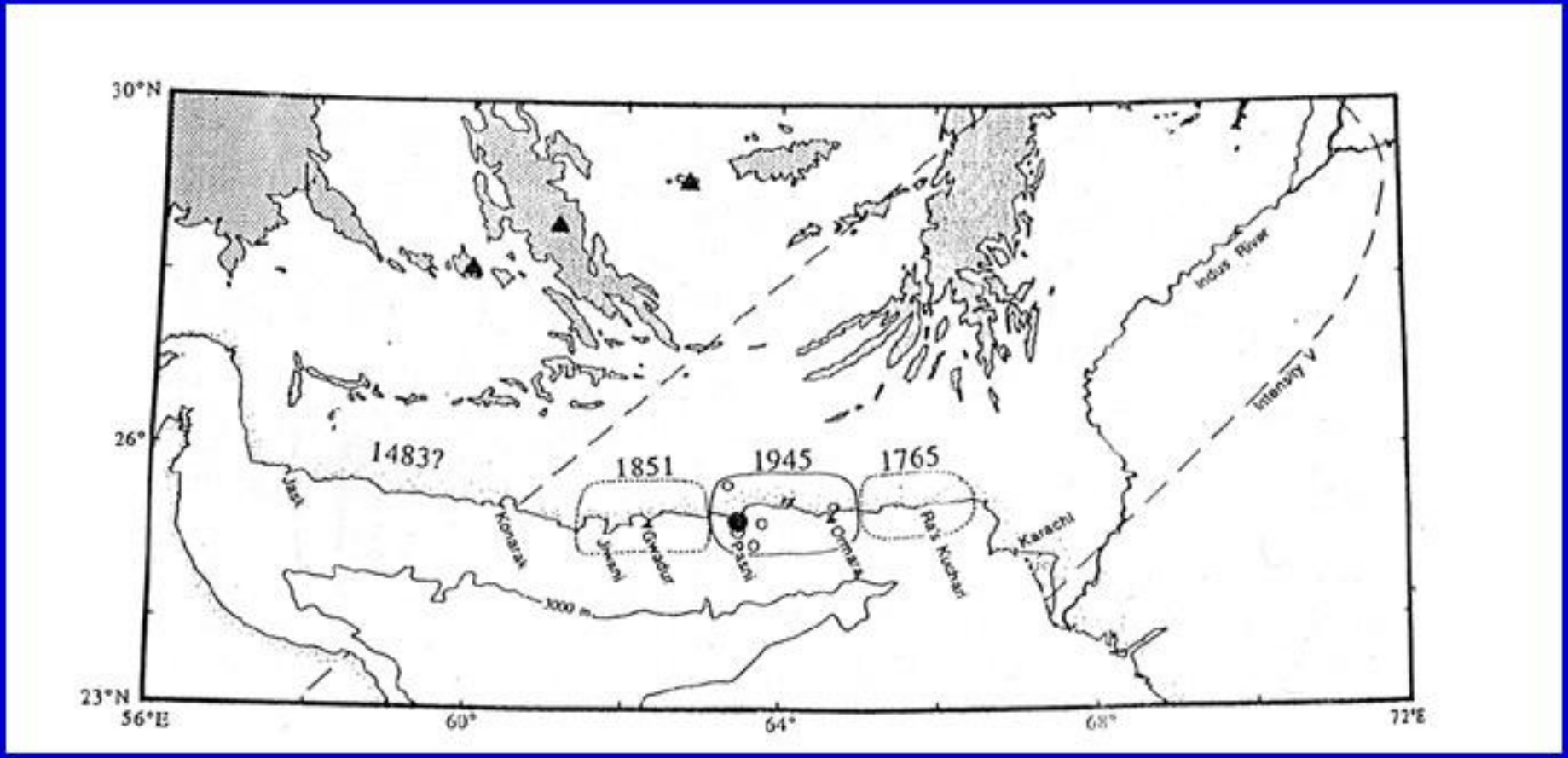

E65°10
E65°20
E65°30
E65°40
N25°40
N25°30
N25°20
NW directed fracture
Scale :- 1 : 250,000
ARABIAN SEA


E64°10'
E64°20'
E64°30'
E64°40'
N25°30'
N25°20'
N25°10'
8
7
9
2
4
6
1
ARABIAN SEA
ARABIAN SEA


E63°15'
E63°30'
E63°45'
E64°
E64°15'
N25°45'
N25°30'
N25°15'
9
10
11
ARABIAN SEA
Scale :- 1 : 500,000


E62°15'
E62°30'
E62°45'
E63°
E63°15'
N25°45'
N25°30'
N25°15'
11
Scale :- 1 : 500,000

HISTORICAL GREAT EARTHQUAKE OF MAKRAN COASTAL AREAS, PAKISTAN



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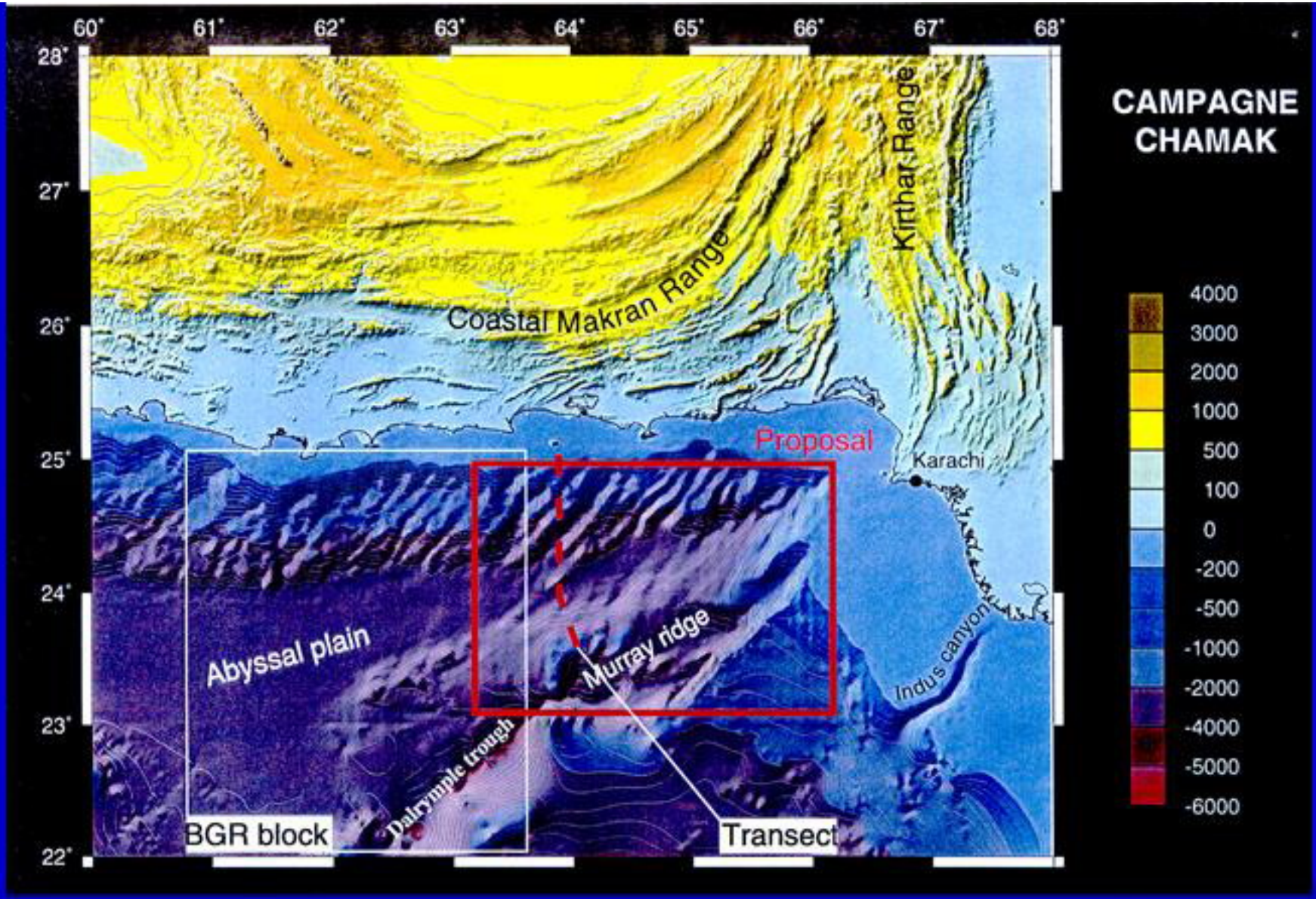
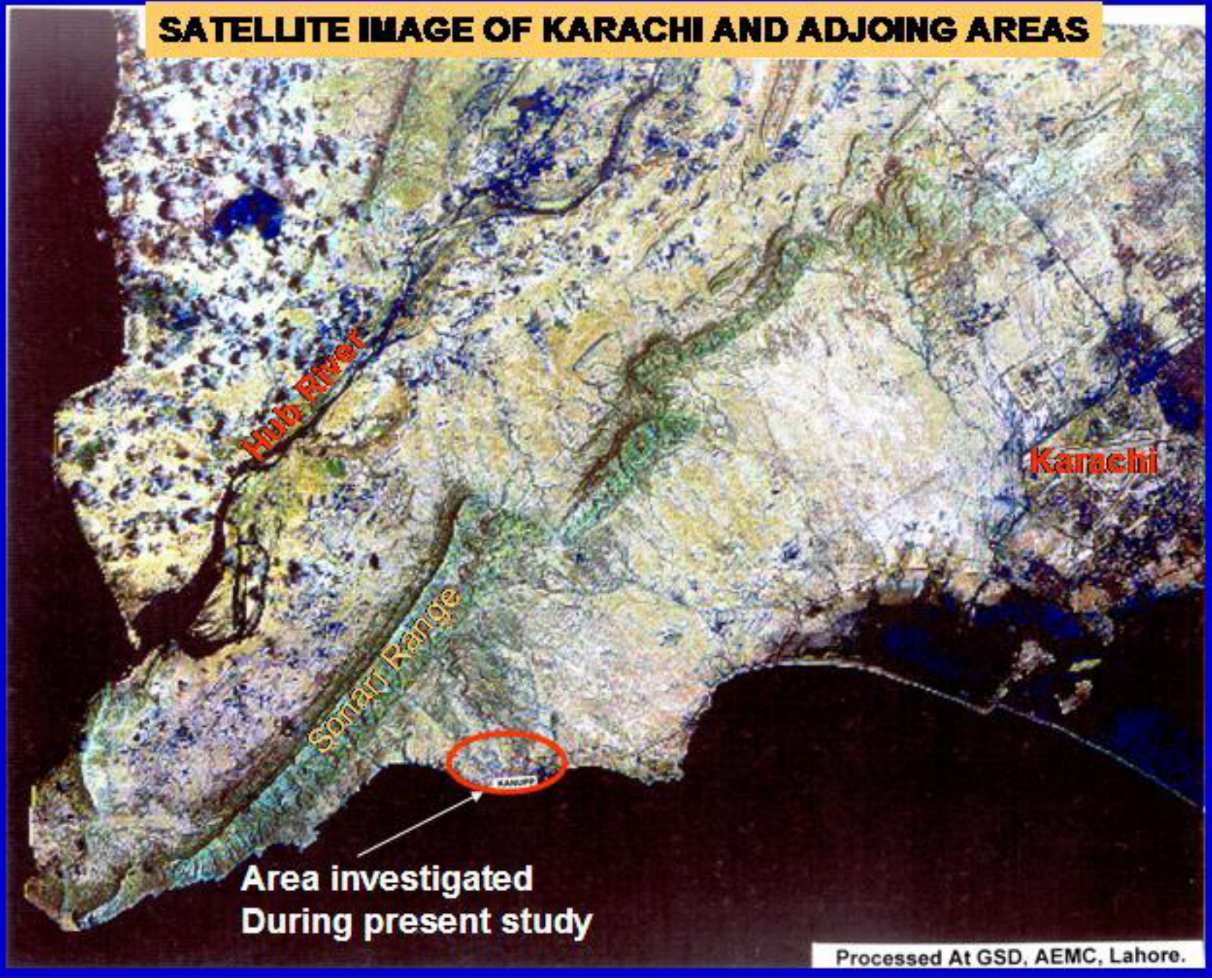
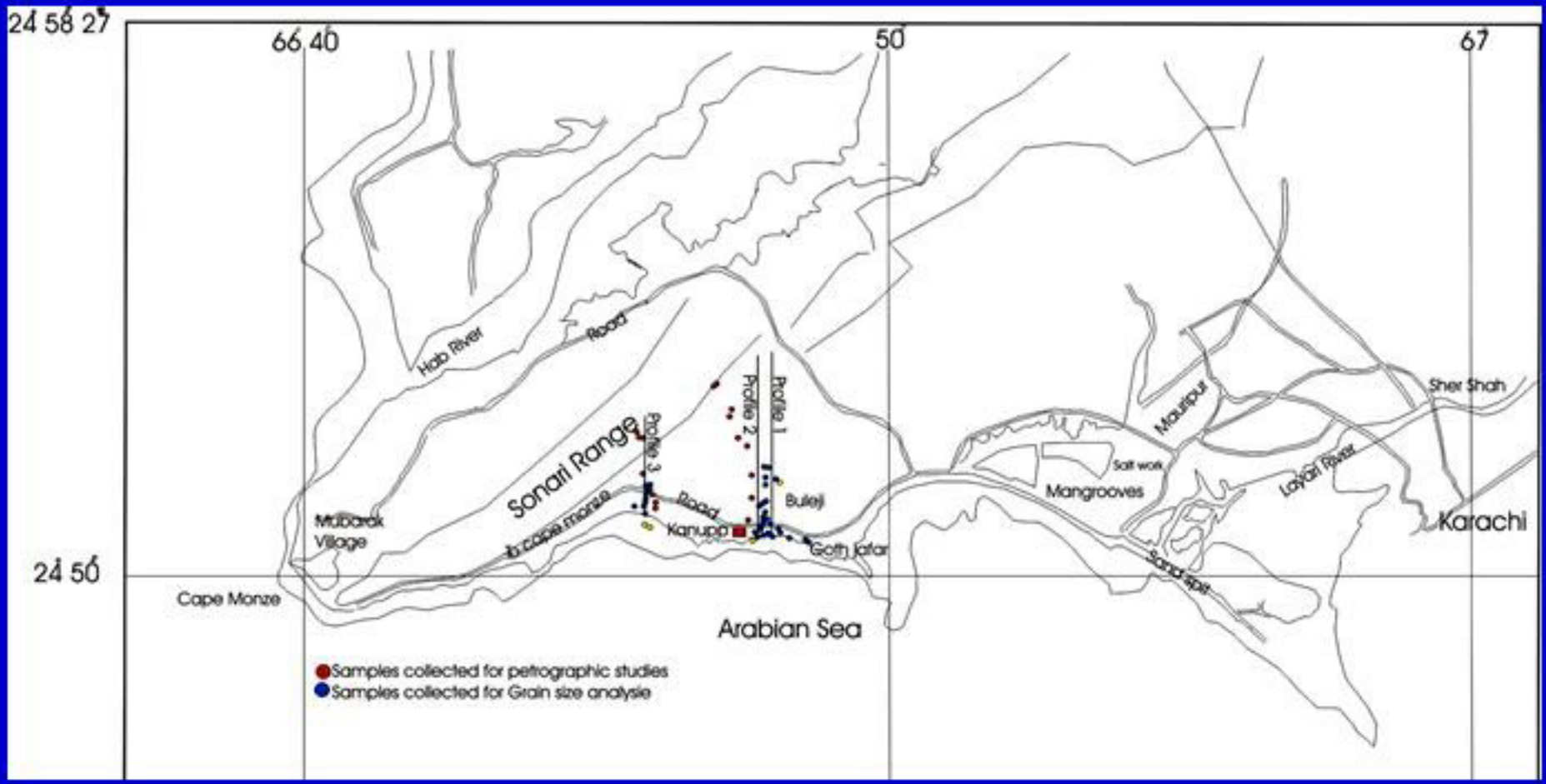


Another tsunamigenic source is offshore Murray Ridge. It is an extension of Chaman F It is marked by strike slip motion. The fault plane solution of two small events at the Margin of the ridge revealed normal sense of movement. Such event may generate small tsunami

SATELLITE IMAGE OF KARACHI AND ADJOING AREAS



MAP SHOWING THE LOCATION OF SAMPLES COLLECTED FOR GRAIN SIZE ANALYSIS AND PETROGRAPHIC STUDIES



LITHOLOG OF PIT 1 & 3

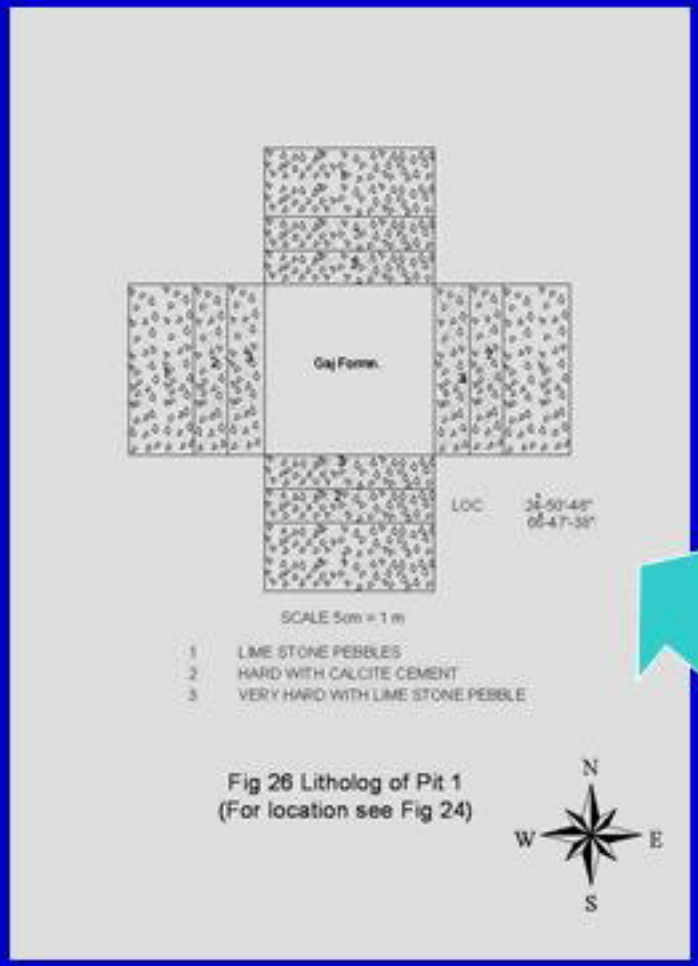
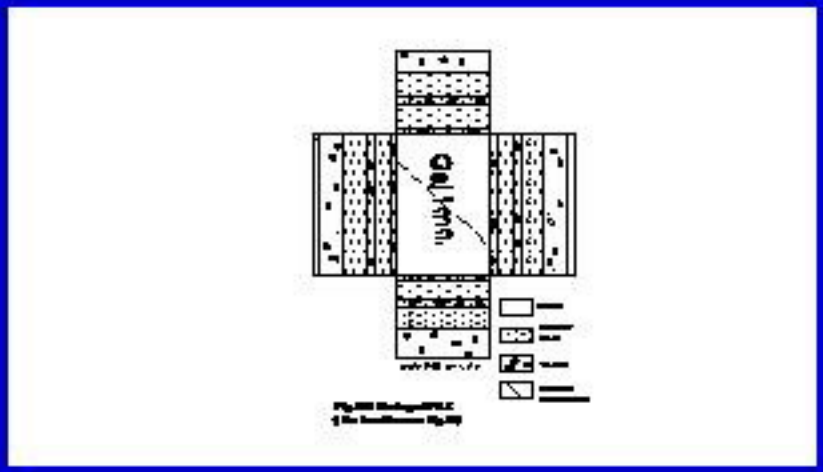


Fig 26 Litholog of Pit 1
(For location see Fig 24)



GRAIN SIZE ANALYSIS

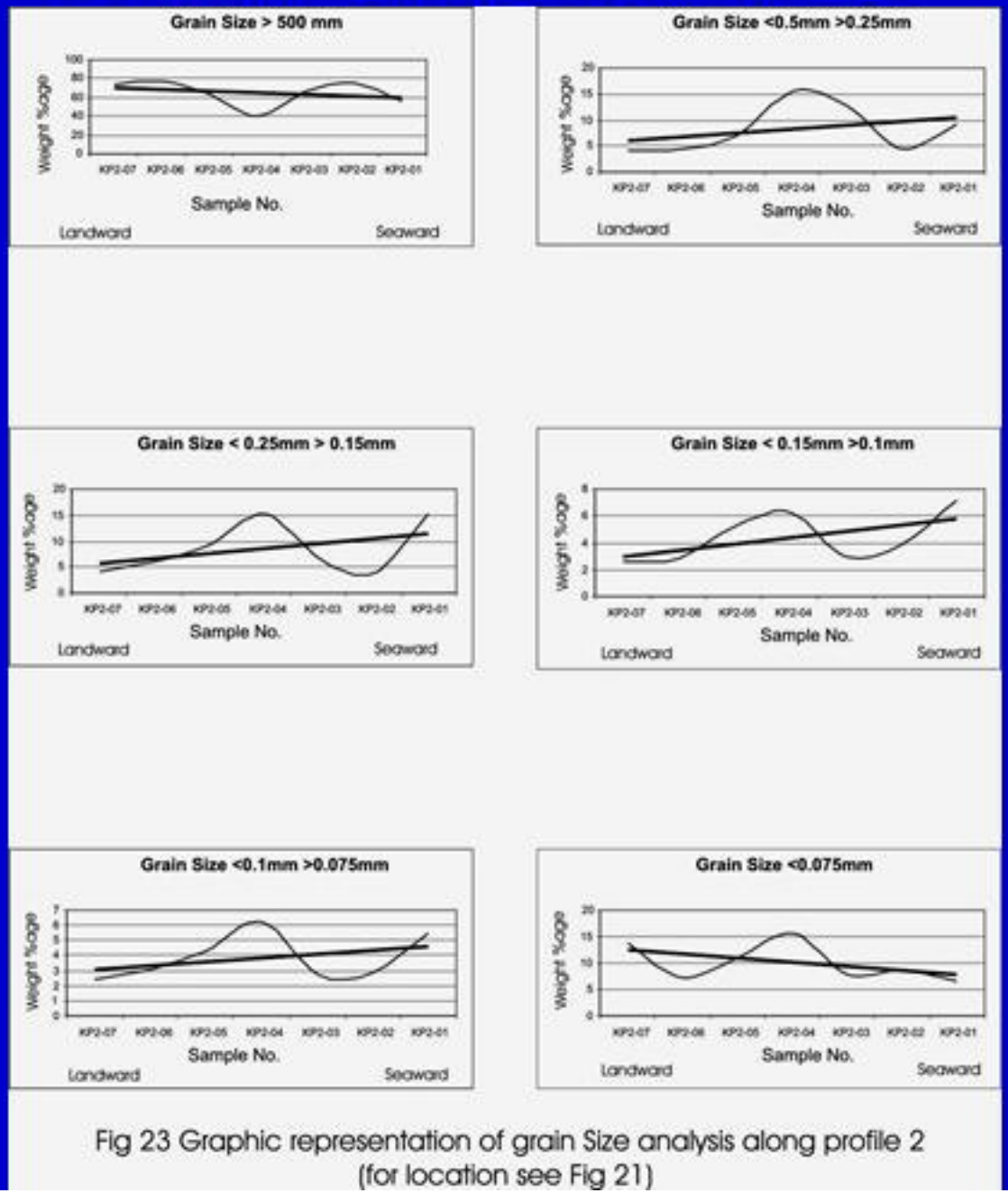


Fig 23 Graphic representation of grain Size analysis along profile 2
(for location see Fig 21)

RESULTS OF GRAIN SIZE ANALYSIS

- Apart from the general trend of seaward fining of the fractions, abnormality in the fractions trend was observed. Some reworking of the deposits probably also occurred between deposition and lithification and may be responsible for some of the variability in these trends because reworking would tend to move smaller grains preferentially.
- In alluvial fan facie such local grain size variation is not unusual.

RESULTS

- Pits dug for tsunami deposit study indicate that no such deposit occurs in the area under-investigation
- The absence of such deposit led to the conclusion that no salt water inundation happen.

PETROGRAPHIC ANALYSIS

- The petrographic analysis of rock samples and clasts/trench samples were carried out to decipher any petrographic similarities between two. The objective of this study was to confirm that the clasts/subrecent deposit samples have any similarity with the rock exposed in the near by Sonari Range.

Sr.No.	Sample No.	Composition	Accessories	Rock Name	Fossil
1	SRK-1	Calcite and Aragonite	Hematite/ Limonite, Quartz, Feldspar	Packed Biomicrite / Fossiliferous Limestone	Foraminifera, gastropods, some bivalves including molluscs and algae. Some ooids.
2	SRK-2	Calcite and Aragonite	Hematite, Quartz and Feldspar.	Sparse Biomicrite / Fossiliferous Limestone	Molluscs, gastropods, Foraminifera, echinoids and algae.
3	SRK-3	Calcite and Aragonite	Hematite/ Limonite, Quartz,	Sparse Biomicrite / Fossiliferous Limestone	Molluscs, gastropods, Foraminifera, echinoids and algae.
4	SRK-4	Calcite and Aragonite	Hematite/ Limonite,	Packed Biomicrite / Fossiliferous Limestone	Foraminifera, gastropods, some bivalves including molluscs and algae. Some ooids.
5	SRK-5	Calcite and Aragonite	Hematite/ Limonite,	Sparse Biomicrite / Fossiliferous Limestone	Molluscs, gastropods, Foraminifera, echinoids and algae.
6	SRK-6	Calcite and Aragonite	Hematite/ Limonite, Quartz,	Sparse Biomicrite / Fossiliferous Limestone	Molluscs, gastropods, Foraminifera, echinoids and algae.
7	Pit-2/1	Calcite and Aragonite	Hematite/ Limonite, Feldspar.	Sorted Biosparite	Foraminifera, algae and brachiopods.
8	Pit-2/2	Calcite and Aragonite	Hematite/ Limonite, Quartz	Packed Biomicrite	Brachiopods, foraminifera, bryozoans, algae and echinoderms.
9	Pit-2/3	Calcite and Aragonite	Hematite, Quartz and Feldspar.	Sparse Biomicrite	Coral, foraminifera, algae and echinoderms.
10	Pit-2/4	Calcite	Hematite/ Limonite, Quartz,	Sparse Biomicrite	Foraminifera, algae and echinoderms.
11	Pit-2/5	Calcite	-	Limestone	Non fossiliferous
12	Pit-2/6	Calcite	Hematite/ Limonite, Quartz and Feldspar.	Sorted Biosparite	Forminifera, algae and echinoderms.
13	Pit-2/7	Bioclast and Matrix	Hematite/ Limonite,	Sparse Biomicrite	Echinoderms, molluscs, brachiopods, foraminifera and algae
14	Pit-4/1	Bioclast and Calcite cement.	Hematite/ Limonite, and Feldspar.	Biosparite/ Grainstone	Foraminifera, bryozoans, echinoderms and algae.
15	Pit-4/2	Bioclast and Calcite cement.	Hematite/ Limonite, quartz and Feldspar.	Biosparite/ Grainstone	Bryozoans, Foraminifera, echinoderms and algae.
16	Pit-4/3	Bioclast and Calcite	Hematite/ Limonite	Sparse Biomicrite	Miliolids, Bryozoans, echinoderms, algae and peloids.
17	Pit-4/4	Calcium Carbonate	Hematite/ Limonite	Limestone	Non fossiliferous

COMPARATIVE PETROGRAPHIC STUDIES OF ROCK AND SUBRECENT/CLAST SAMPLES

RESULTS

- The comparative study shows that the samples of subrecent strata have the same mineralogy/Fossils as that of samples of near by Sonari Range.

ANGULAR UNCONFORMITY BETWEEN GAJ Fmn. AND HORIZONTALLY LYING SUBRECENT DEPOSITS

RESULTS

- **The horizontally lying cover sediments suggest that the area has not been subjected to the tectonic activity in the Holocene time.**

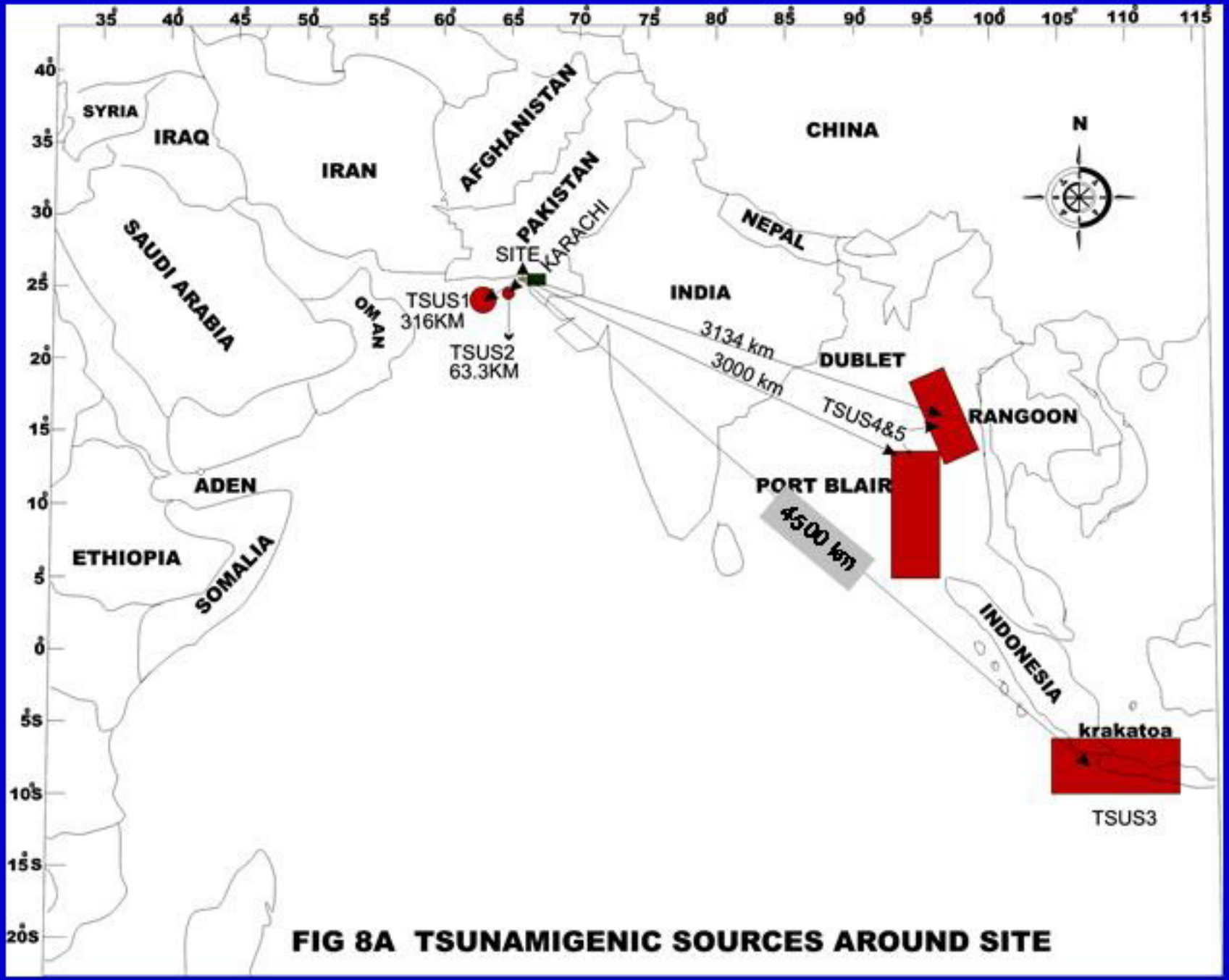


FIG 8A TSUNAMIGENIC SOURCES AROUND SITE

TSUNAMIGENIC SOURCES

REGIONAL SOURCES

- Tsunamigenic source 3 (TSU 3) occurred in Indonesia
- Tsunamigenic source 4 & 5 (TSU 4,5) occurred near Rangoon. These sources can not effect the area due to the presence of Indian landmass.

LOCAL SOURCES

- **Tsunamigenic source 1 (TSU 1) Makran Subduction zone.**
- **Tsunamigenic source 2 (TSU 2) Murray Ridge zone.**

TSUNAMI IMPACT OF TSU 3

- I.5 M TSUNAMI AT MADRAS
- 0.6 M AT NAGAPATTINAM
- 0.2 M AT ADEN
- IMPACT AT PAKISTANI COAST NOT DOCUMENTED

LOCAL TSUNAMIGENIC SOURCES

- TSUS 1 MAKRAN SUBDUCTION ZONE
- TSUS 2 MURRAY RIDGE

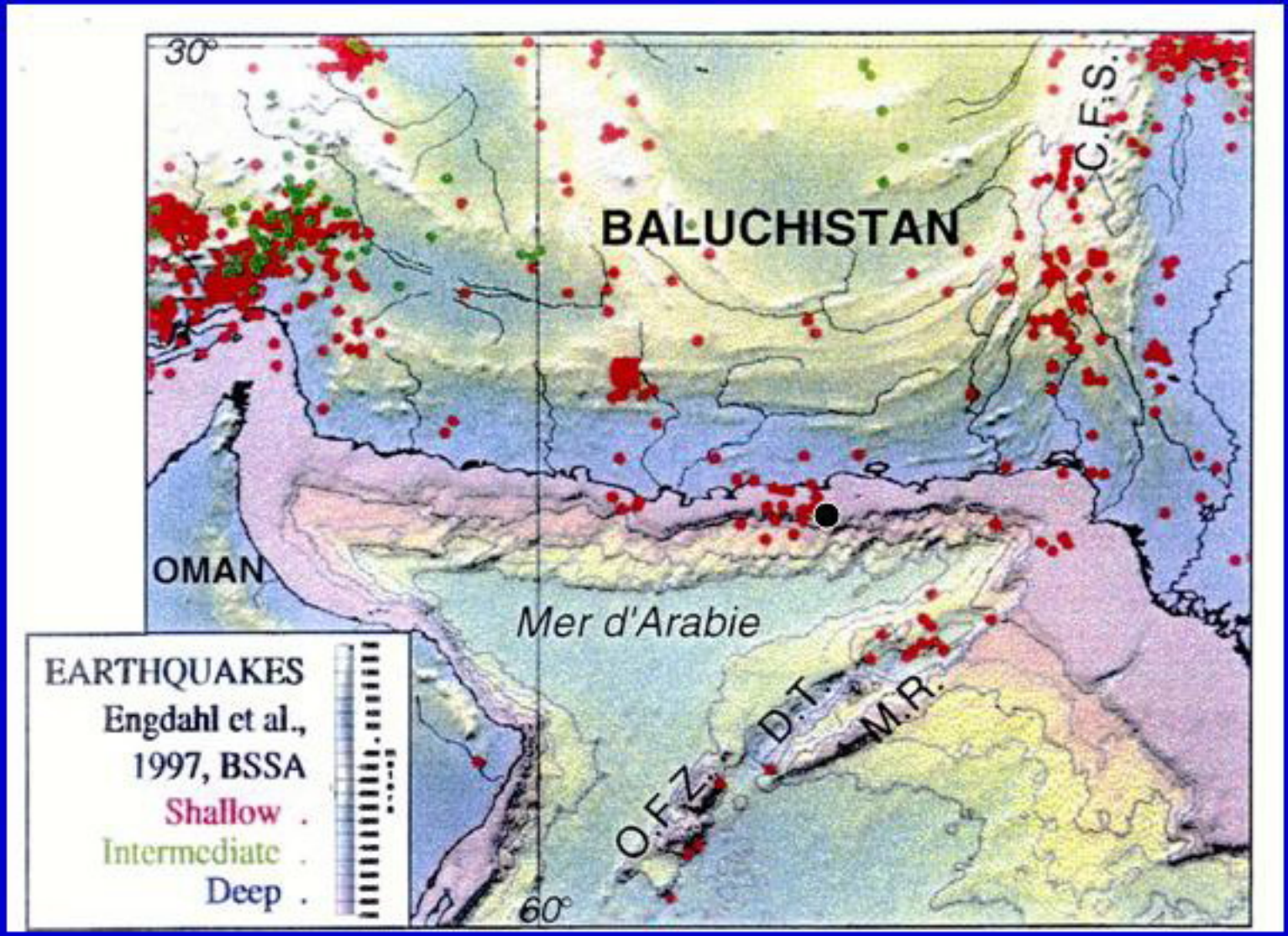
LOCAL TSUNAMIGENIC SOURCES(TSU 1)

- MAKRAN SUBDUCTION ZONE
- SITE OF LARGE (≥ 7) & INFREQUENT GREAT (≥ 7.8) EARTHQUAKES
- CAUSE IS SUBDUCTION OF ARABIAN PLATE BENEATH THE EURASIAN PLATE
- NOT ALL BUT A FEW EARTHQUAKES GENERATE TSUNAMI

THE TSUNAMIGENIC EARTHQUAKE OF 1945 OCCURRED IN ARABIAN SEA

- The great earthquakes of November 27, 1945 occurred near Pasni at 21:55:02 UT (universal time). The U.S.A National Earthquake Information Center (NEIC) located the epicenter at 63º E and 24.5º N. The magnitude of the event was 8.3. The large after shock of magnitude 7.3 occurred in 1947.

TSUNAMIGENIC EARTHQUAKE OF 1945



TSUNAMIGENIC SOURCE 2 (TSU 2)

- MURRAY RIDGE IS REPRESENTED BY SEA MOUNTS WITH STRIKE SLIP AND NORMAL FAULTING
- NO. KNOWN TSUNAMIGENIC ZONE ASSOCIATE WITH THIS SOURCE

CONCLUSIONS

- Tsunami hazard along Karachi Coast is fortunately rather remote due to the absence of tsunamigenic source
- The disaster tsunamigenic earthquake of 1945 occurred in the Arabian Sea south of Pasni town. The tsunami waves generated by this event hit the coast line of Hawks bay. The height of the tsunami wave was 1.5 m.
- Nevertheless if we take into account the similarity of the earthquake with that occurred on Nov 27th, 1945, as far as focal mechanism and epicenter are concerned, we should consider the future production of a large tsunami in the coastal areas of Makran as possible if the earthquake magnitude surpasses 7-8.

contd

- **Recognition of Neotectonic features all along the Makran coast confirms that Makran coast is active. Under the earthquake loading, parts of Makran are susceptible to permanent ground displacement and tsunami.**

CONTD.

- The tsunamigenic source (TSU 2) occurs in the west of Karachi area in the offshore region of the Arabian Sea.
- The historical records and the distribution of the earthquakes in the east of Karachi and the shape of the coast suggests that Karachi coastal areas are lying in low seismogenic / tsunamigenic zone

CONTD.

- The tsunamigenic source 3 occurs 4800 km away from the site at krakatoa (Indonesia). The source is well known for its tsunamigenic potential. In the past the disaster volcanic eruptions of August 26-27 1883 associated with this island jolted whole ocean basin and generate a tsunami that propagate across the entire ocean basin and hit the coast of India near to the Pakistani territory.
- It is inferred that if the event of such magnitude and intensity occurred in future, the Pakistani coast will be least effected due to the presence of Sri Lanka and southward extended Indian land mass.


THANKS