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Pakistan Offshore: An Attractive Frontier

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ABSTRACT

Due to poor exploratory effort the offshore sedimentary basins of Pakistan still remain as frontier basins. Hydrocarbon occurrence in Pakistan offshore can be explained by (1) adequate thickness of marine sediments, (2) favourable tectonics and basin analogies, (3) hydrocarbon seeps/shows, and (4) favourable results of field and laboratory investigations in the adjoining coastal areas. The size of the hydrocarbon resource is estimated to fall between 14-16 billion barrels of oil (or equivalent gas). The single most reason of non-discovery of this hidden wealth is lack of exploratory effort.

INTRODUCTION

A vast but underexplored offshore area of Pakistan measuring approximately 240,000 sqkm is situated in the south of the country between longitude 61° 45' and 68° 10'. In general, till now, only area of neritic depth has been the focus of exploration.

The offshore sedimentary area of the country is conveniently divided by the Murray Ridge, which is an expression of the plate boundary, into (1) Indus offshore basin and part of the Kutch basin and (2) Makran offshore basin.

Tectonically, 3 plates namely, Indian, Arabian and Eurasian seem to interact directly to shape the sedimentary basins in Pakistan offshore. A fourth plate (African plate) has also contributed in the evolution of these basins in the past (Figure 1).

No oil or gas field has been discovered so far in Pakistan offshore. Wildcats have been few and holes reaching prognosticated reservoirs rare. Therefore, the present assessment of the hydrocarbon potential has been focussed on thickness of sediments (Figure 2) and basic elements like geology, basin and sediments type, seeps/shows, source and maturation, reservoir, seal, trap, migration, etc. Formation pressure hazard which apparently is a hindrance to exploration is also briefly accounted for.

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INDUS OFFSHORE BASIN AND PART OF KUTCH BASIN

The area between Murray ridge and the Indian border constitutes this sedimentary region which comprises three main petroleum zones (Figure 3). One active and some passive submarine canyons have been distributing clastic sediments over shelf and shelf slope since plate collision (Late Oligocene/Early Miocene). Many drainage mouths of the Indus river characterise the coastal or deltaic part of the area and bear record of the shifting clastic sediment supply since post-plate collision time.

Structurally the area consists of (1) a half-graben which is extension of Kutch Basin; (2) a platform area which is commonly considered a prolongation of the onshore Sind monocline but according to the present study it may well be a part of the Kutch basin as there is a similarity of sedimentary rocks encountered in Creek wells with the stratigraphy of the Kutch basin, more work is required to prove this correlation; and (3) a deep de pression which appears to be linked with the belt of onshore depressions, this area is severely faulted by sinuous and gravity growth faults (Figures 4-6). The southwestern margin of this depression is bounded by a gentle uplift running parallel to the axis of the deep. Huge diapiric features are developed in the west of the depression towards Murray ridge (Figure 7).

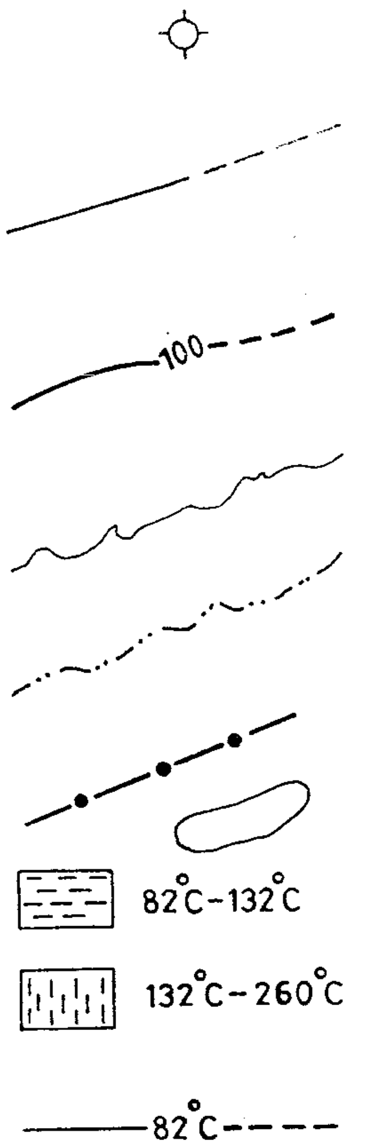
The fault patterns (Figure 8) fit in the regional tectonic setting resulting from northward flight of the Indian plate and subsequent rifting in its southeastern part.

The geology of the coastal region is shown in Figures 9a&b and the stratigraphy is depicted in Figures 10 and 11. The summary of pre-requisites for the occurrence of hydrocarbons is given below which is further highlighted in Lithofacies Analysis and Prospects parts of the paper.

A number of source rocks have been considered in the area, namely, the shales of Sembar and Goru (Cretaceous), Bara (Paleocene), Laki (Eocene), Nari (Oligocene), Gaj or equivalent facies (Miocene) and the limestones of Mughalkot (Cretaceous). Hard geochemical data from Kirthar Range (Seemann et al, 1988) indicates organic richness i.e. above average TOC values in samples from Sembar, Goru, Pab, Dunghan, Ghazij and Nari formations in onshore southern Indus basin. Gas shows were reported from the Eocene-Cretaceous section in Sun Oil wells.

LEGEND

FIGURES 1-54



WELL SECTION

LITHOLOGIC BOUNDARY
(Dashed where inferred or projected)

ISOPACH INTERVAL
(Dashed where inferred or projected)

OFFSHORE BOUNDARY

INTERNATIONAL BOUNDARY

PAKISTAN OFFSHORE LIMIT

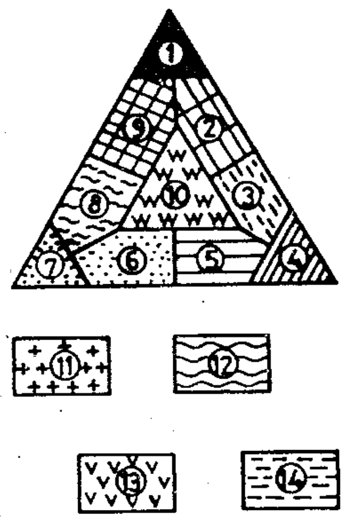
SEISMICALLY DELINEATED STRUCTURES

OIL AND GAS (Oil window)

GAS / CONDENSATE (Gas window)

OIL AND GAS WINDOW
(Dashed where inferred or projected)

FACIES DESCRIPTION



1. > 80% Lst.
2. 50-80% Lst.,Sh. > Sst.
3. 50-80% Sh.,Lst. > Sst.
4. > 80% Sh.
5. 50-80% Sh.,Sst. > Lst.
6. 50-80% Sst.,Sh. > Lst.
7. > 80% Sst.
8. 50-80% Sst.,Lst. > Sh.
9. 50-80% Lst.,Sst. > Sh.
10. Sst.,Lst. & Sh. < 50% each.
11. > 80% basalt
12. 50-80% basalt,Sst. > Sh.
13. 50-80% basalt,Sh. > Sst.
14. 50-80% Sh, Sst. > basalt

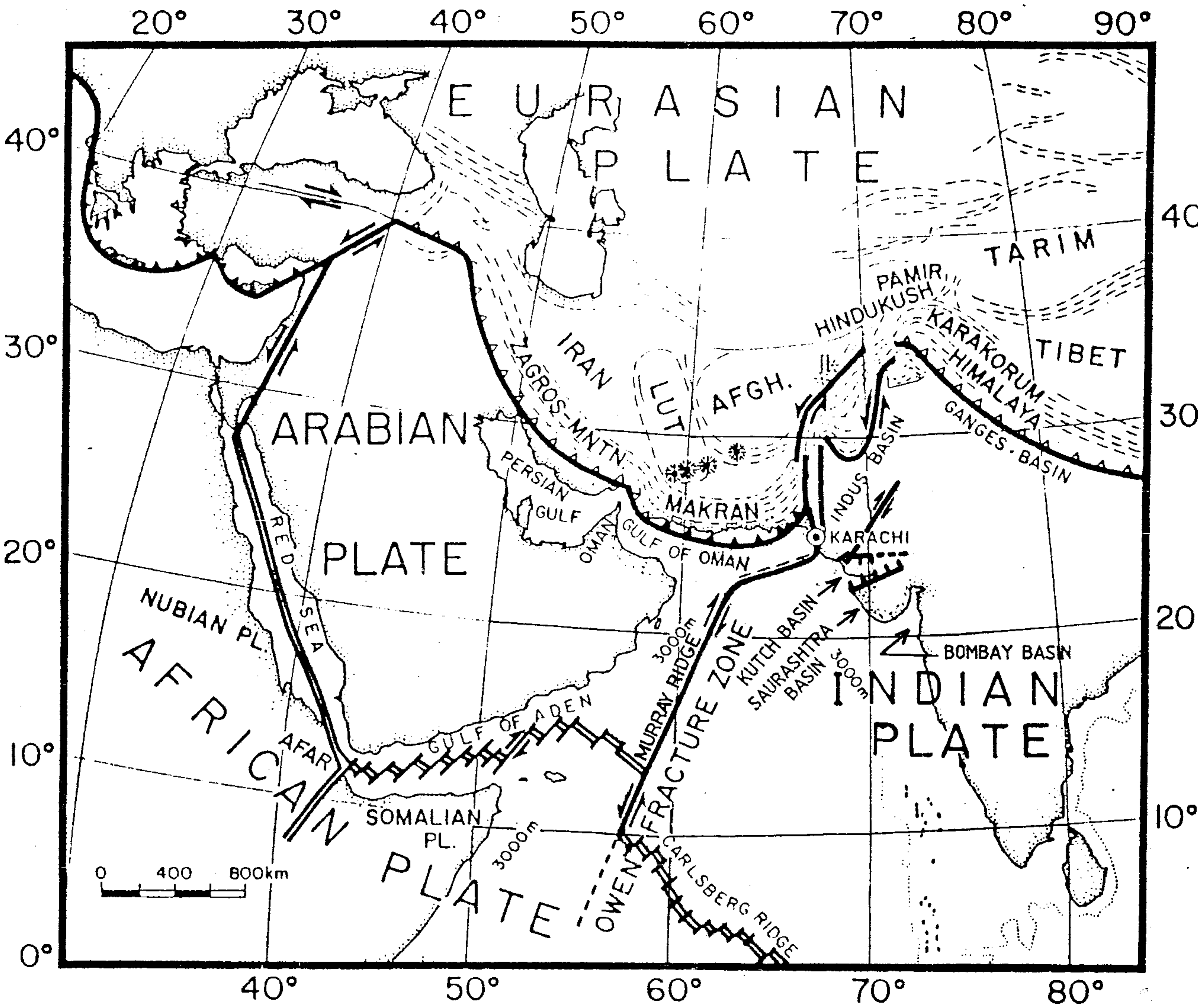


Figure 1— Regional tectonic setting showing the location of Makran, Indus and Kutch basins (after Jacob and Quittmeyer, 1979, modified).

Wintershall wells also encountered gas shows in Miocene. OGDC's Pakcan-1 was an offshore-wise uneconomical gas discovery in Miocene.

The geothermal gradients range from 1.5°C/100m to 3°C/100m (Figure 12). The oil window is estimated to fall in the general depth range of 2200-4500 metres (Figure 13).

The sands of Miocene age are proven reservoirs in the Indus offshore basin. Some Eocene probably reefal carbonates picked on seismic can prove to be the best accumulators of hydrocarbons. Towards the coast, at shallow depths, the sandstones of Goru and Pab (Cretaceous), Bara (Paleocene) and limestone of Laki and Kirthar (Eocene) which are established reservoirs in the Indus onshore basin are expected to be potential accumulators.

The presence of gas shows and the occurrence of hydrocarbons in the nearby areas is taken as a strong evidence for migration (Table 1).

There is no dearth of impervious strata in the sedimentary column. The reservoir formations have either their own sealing shales, or that of the overlying formations.

Both structural and stratigraphic traps have been identified on seismics. Fan and deltaic plays in post-plate collision deposits are also worthy of exploration.

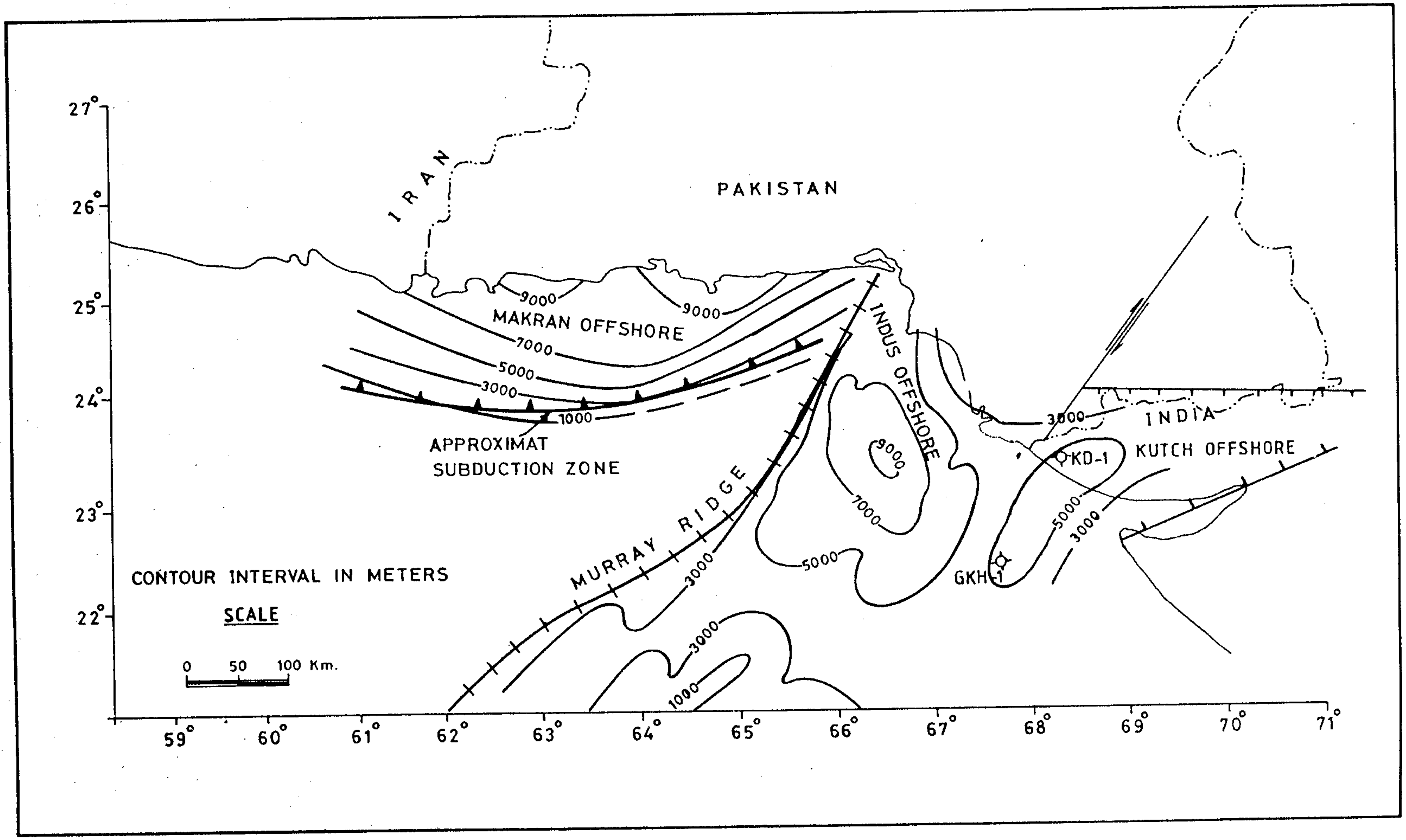


Figure 2— Total sediment thickness map of Indus-Kutch (after Coumes and Kolla, 1984, modified using an average velocity of 3200 m/see) and Makran using seismic profiles.

Table 1. Summary of drilling activity in the study area (after Qadri, 1984, modified).

Company	Well name	Year	Whether objective was reached	T.D. (below MSL) in metres	Remarks
Hunt	Dhak-1	1956	No	2562 (-2556)	Abandoned at shallow depth due to the stucking of the pipes which was attributed to an earthquake.
	Dhak-2	1956-57	No	4454.1 (-4448)	Abandoned due to fishing. Bit stuck while running into the hole.
Marathon	Garr Koh-1	1975	No	3622.7 (-3569)	Abandoned due to structural complexities
	Jal Pari-1A*	1976-77	No	2007 (-1987)	Abandoned due to extremely high formational pressure.
PPL	Karachi-1	1956-57	No	3035 (-2975)	Abandoned due to stucking of the pipe.
	Karachi-2	1959	Yes	3946.3 (-3886)	Dry, plugged and abandoned.
Sun Oil	Dabbo Creek-1*	1964	Yes	4354.1 (-4335)	Minor gas shows. Plugged and abandoned.
	Korangi Creek-1*	1964-65	Yes	4139.8 (-4124)	Gas shows in Paleocene-Eocene section. Plugged and abandoned.
	Patiani Creek-1*	1964	Yes	2659.2 (-2643)	Gas shows in upper part of Mughalkot. Plugged and abandoned.
Wintershall	Indus Marine-A1*	1972-73	Partially	2841.2 (-2831)	Abandoned for technical reasons after kicking.
	Indus Marine-B1*	1972-74	Partially	3804.2 (-3793)	Abandoned for technical reasons after kicking.
	Indus Marine-C1*	1975	No	1942 (-1932)	Formation pressure required mud weight greater than the fracture gradient at the bottom. Plugged and abandoned.
Husky	Karachi South-A1*	1978	No	3353 (-3343)	Tops of formations were found lower than expected. Abandoned.
OGDC	PakCan-1*	1985-86	Yes	3701	Non commercial gas discovery in Miocene. Plugged and abandoned.
Occidental	Sadaf-1*	1990	Yes	3981	Dry, plugged and abandoned.

* Offshore Wells.

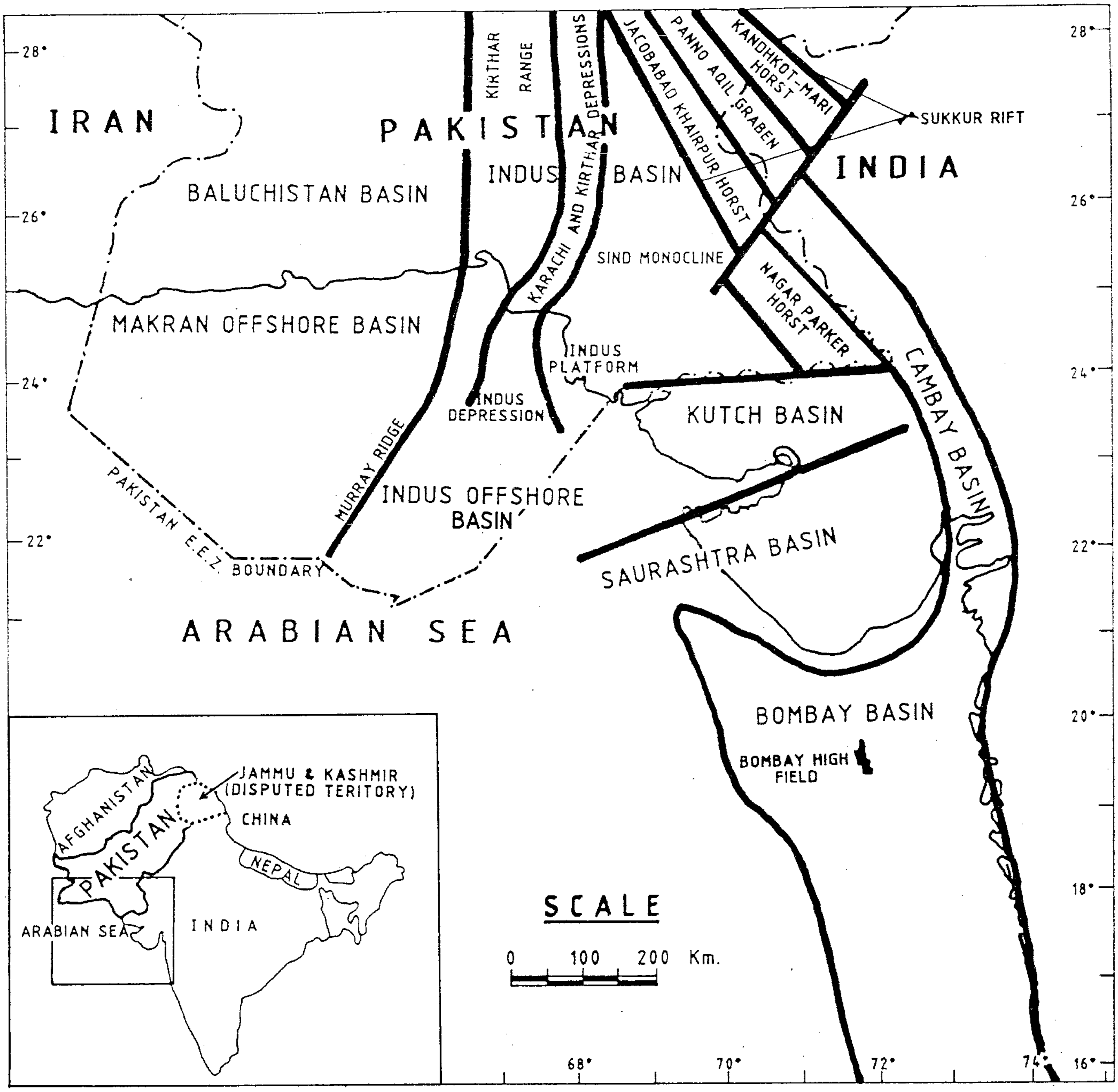


Figure 3— Location of study area with petroleum zones (after Raza et al, 1990 and Abid & Siddiqui, 1984, modified).

Lithofacies Analysis

Sembar Formation.— The formation is composed mainly of shale with subordinate sand/silt. The amount of sand may increase westward due to proximity of the feeding area, enhancing the possibilities of development of sand reservoirs in the western areas (Figure 14). The shales should be good source rocks as, firstly, these are proven source of hydrocarbons in Badin area (TOC upto 3%), and secondly, there is evidence of maturation of these shales throughout the area under discussion (Figure 15).

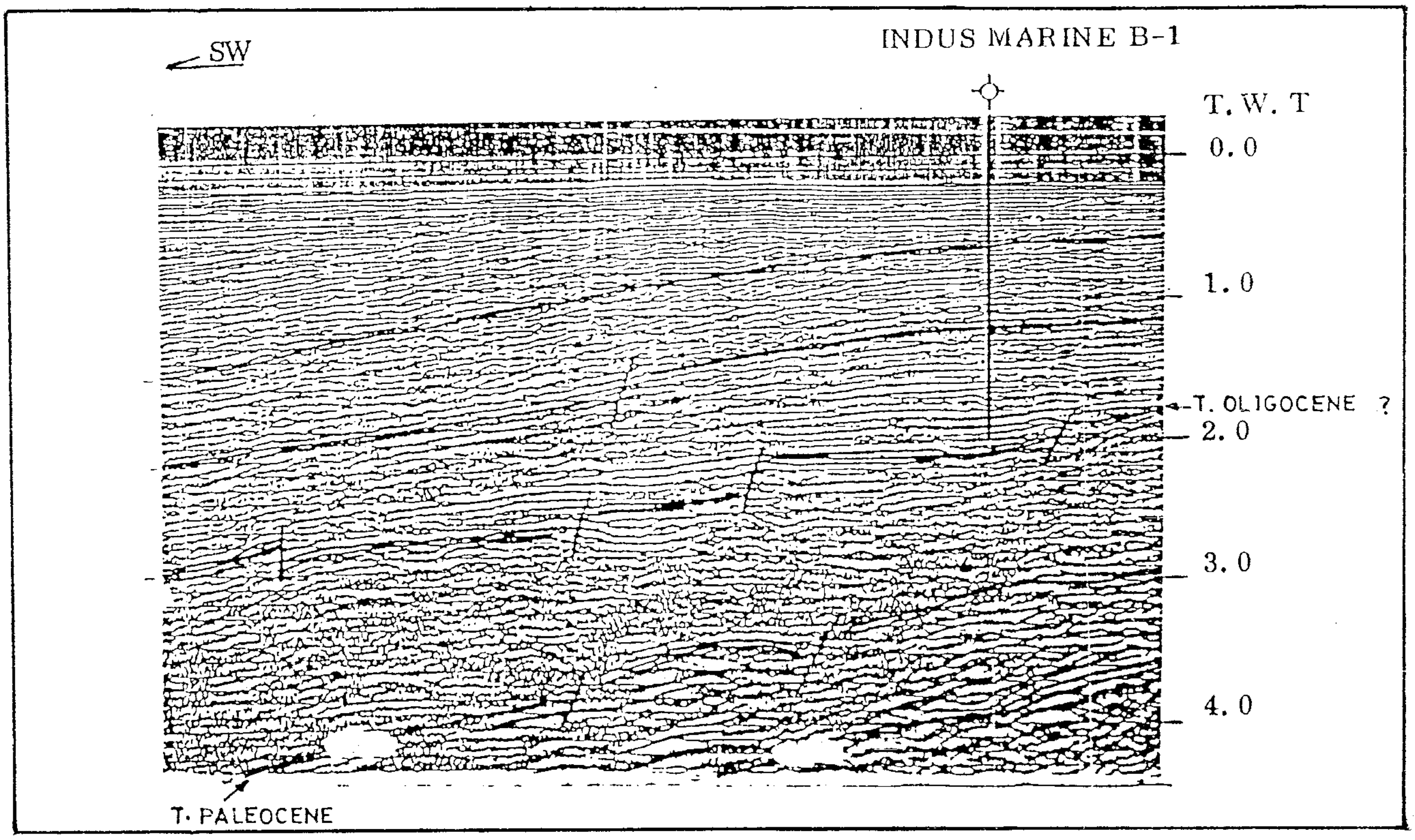


Figure 4— Profile along line A showing normal faults at different stratigraphic levels (source: Wintershall, modified). For location see Figure 32.

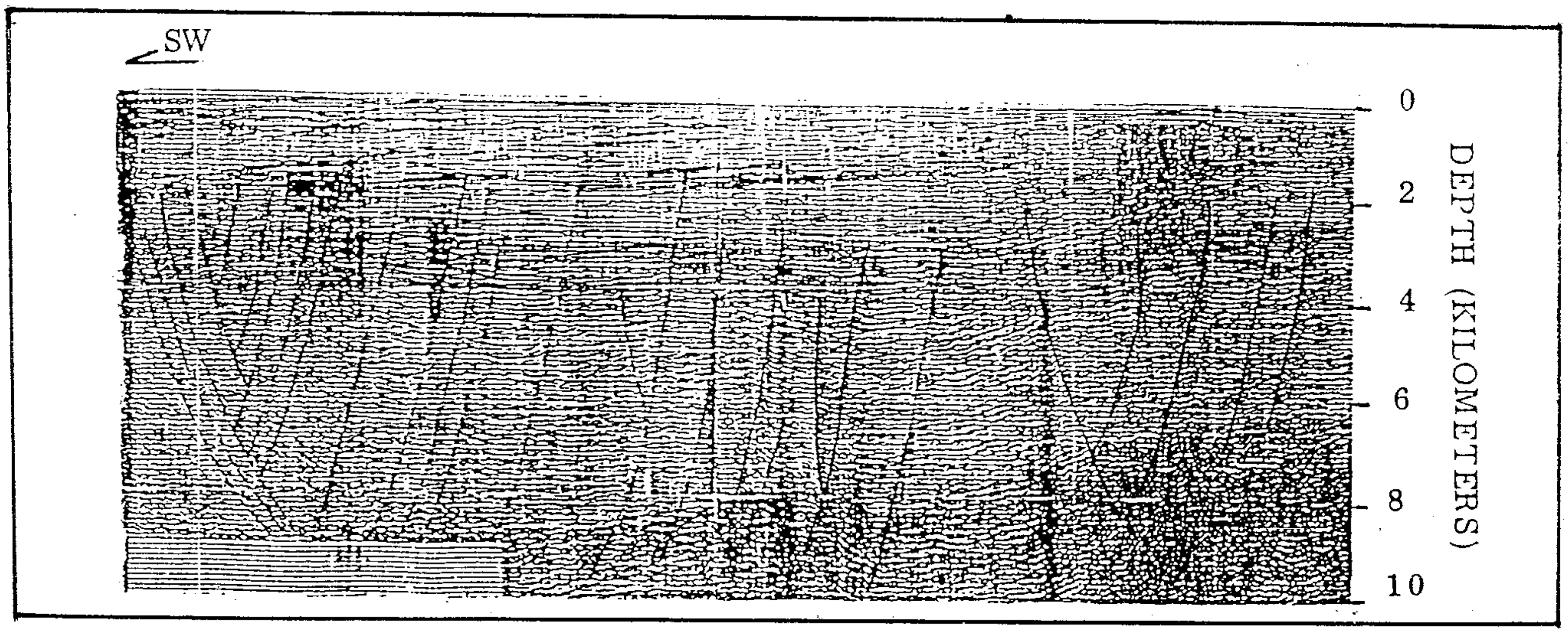


Figure 5— Profile along line B showing highly faulted section. The faults are normal, down-to-the basin type (Source: Phillips). For location see Figure 32.

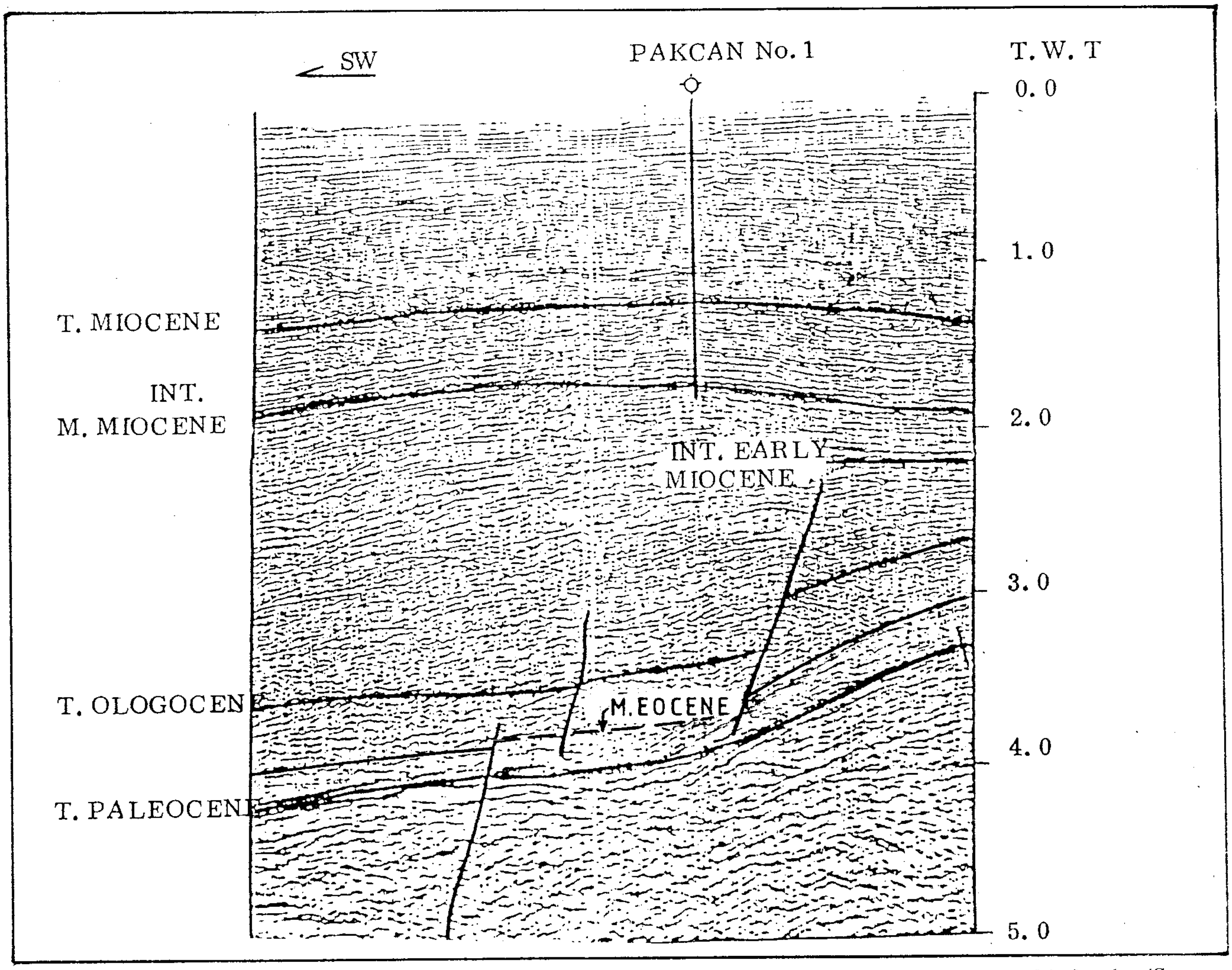


Figure 6— Profile along line C showing development of normal/growth faults at various stratigraphic levels. (Source: OGDC-NORAD, modified). For location see Figure 32.

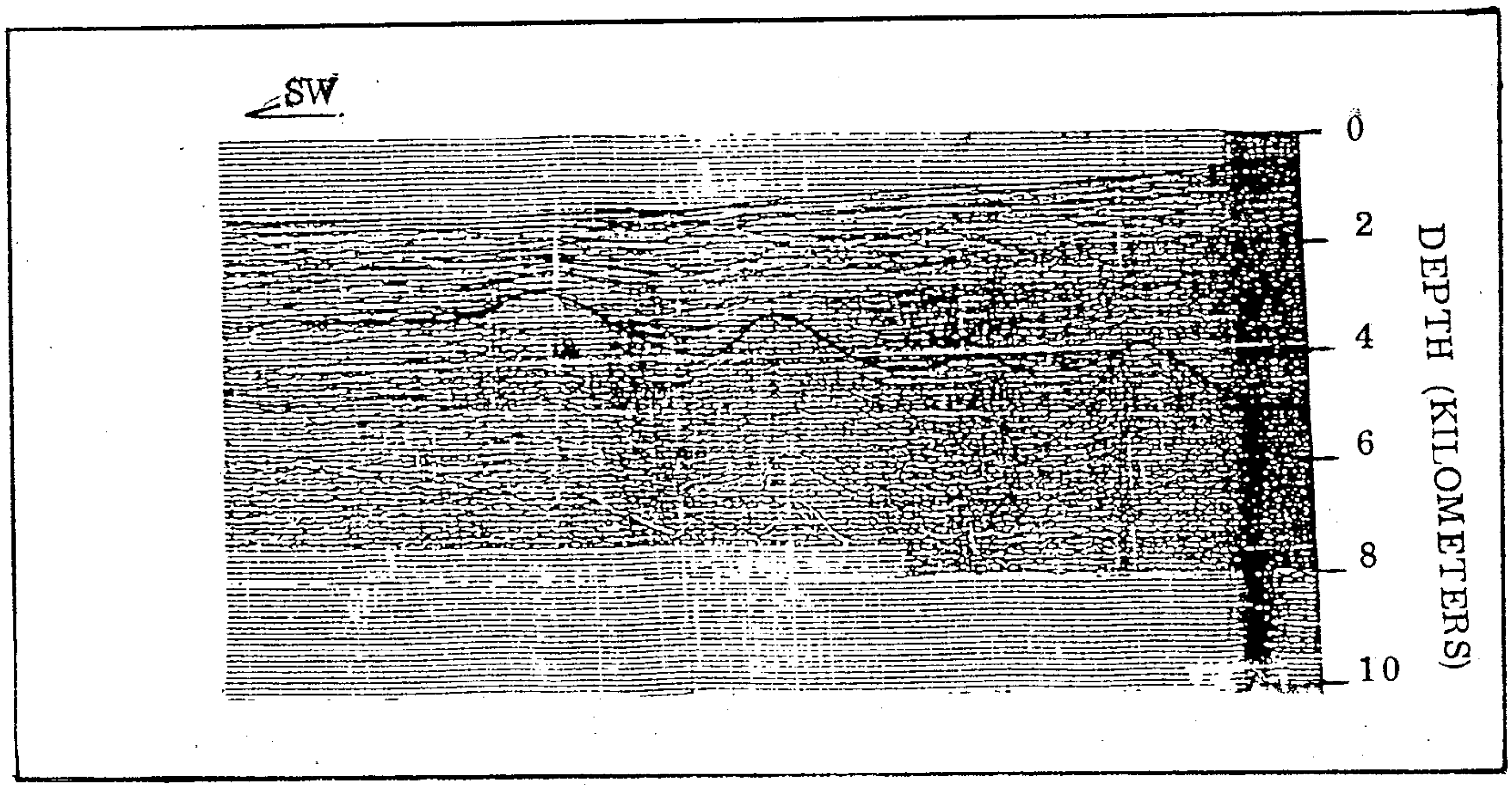


Figure 7— Profile along line D showing assymmetric folds developed due to shale diaprism (Source: Phillips). For location see Figure 32.

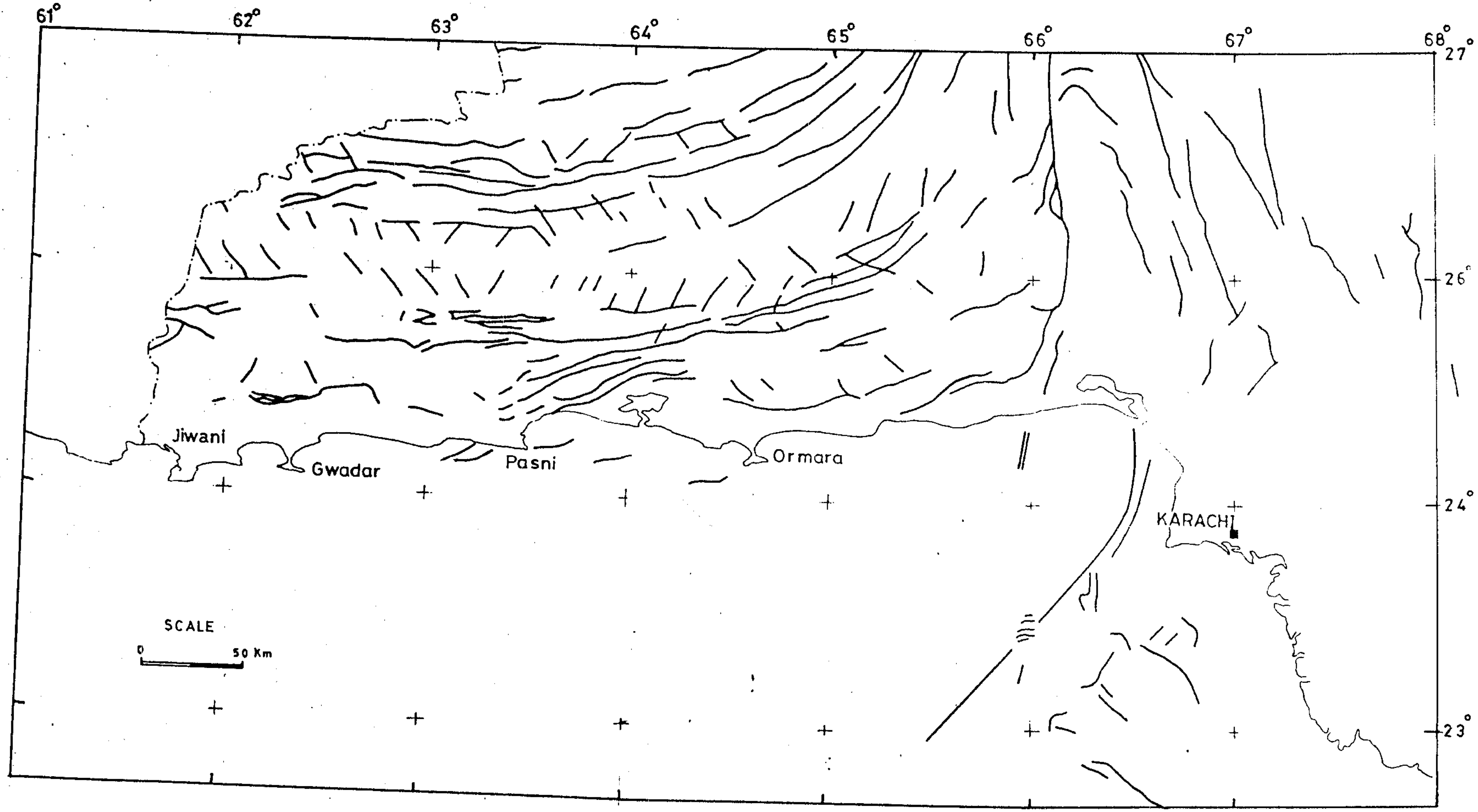


Figure 8— Map showing fault trends in offshore/onshore regions (after Bakr and Jackson, 1964, modified).

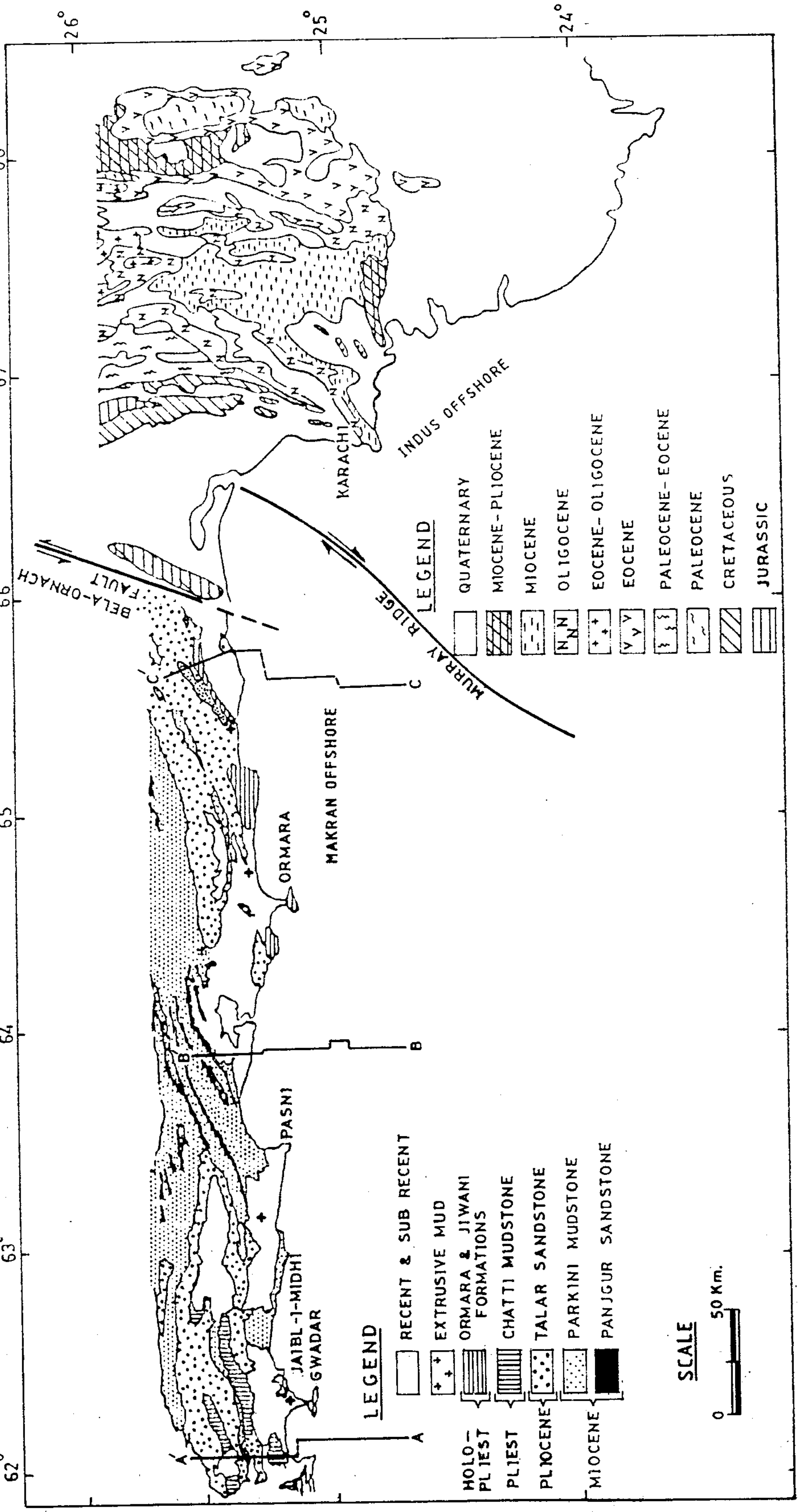


Figure 9a— Geological map of Indus coastal region (after Bakr and Jackson, 1964, simplified), and Makran coast (after J.A. Crame, 1984).

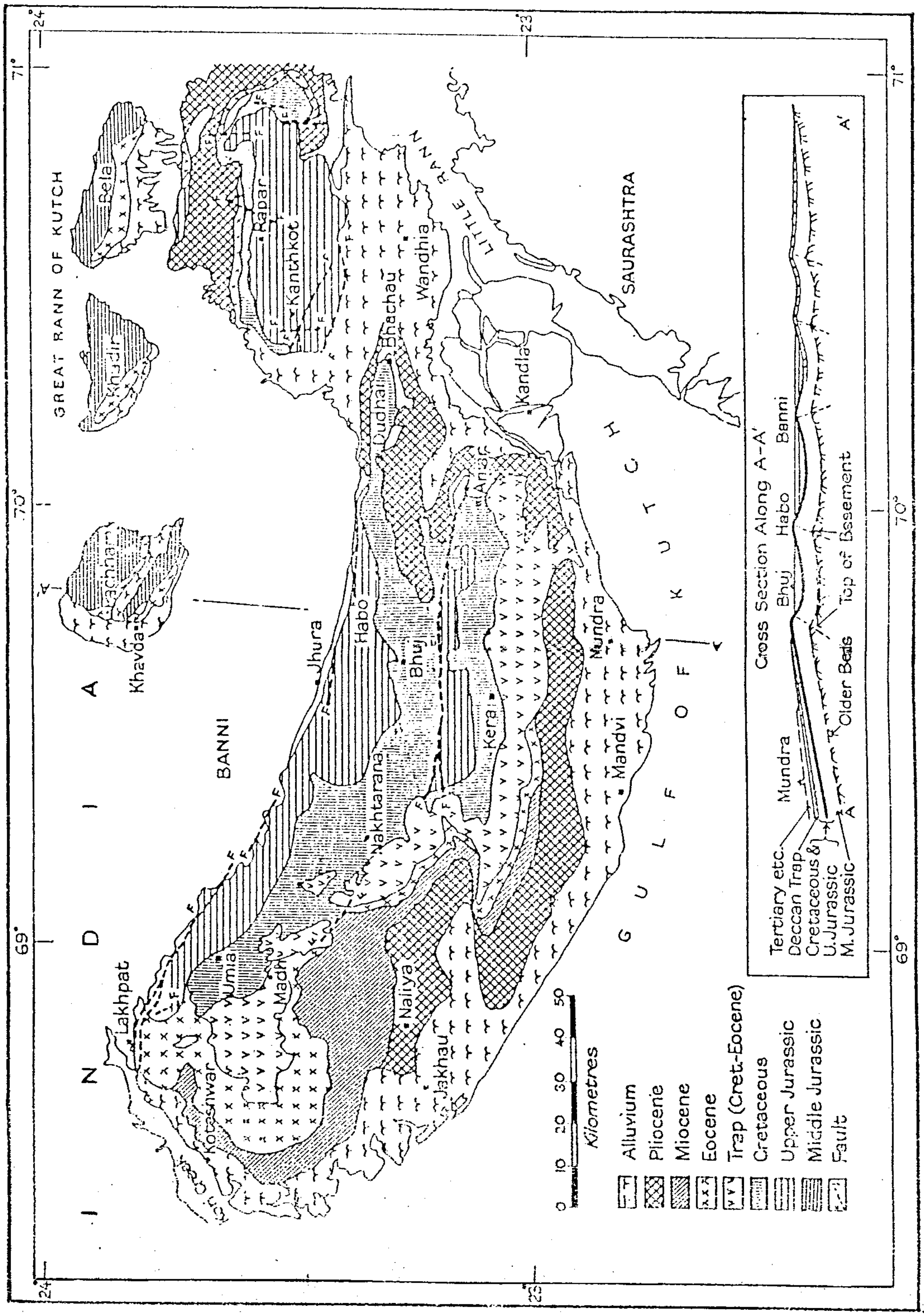


Figure 9b— Geological map of Kutch basin (after Brown and Dey, 1975).

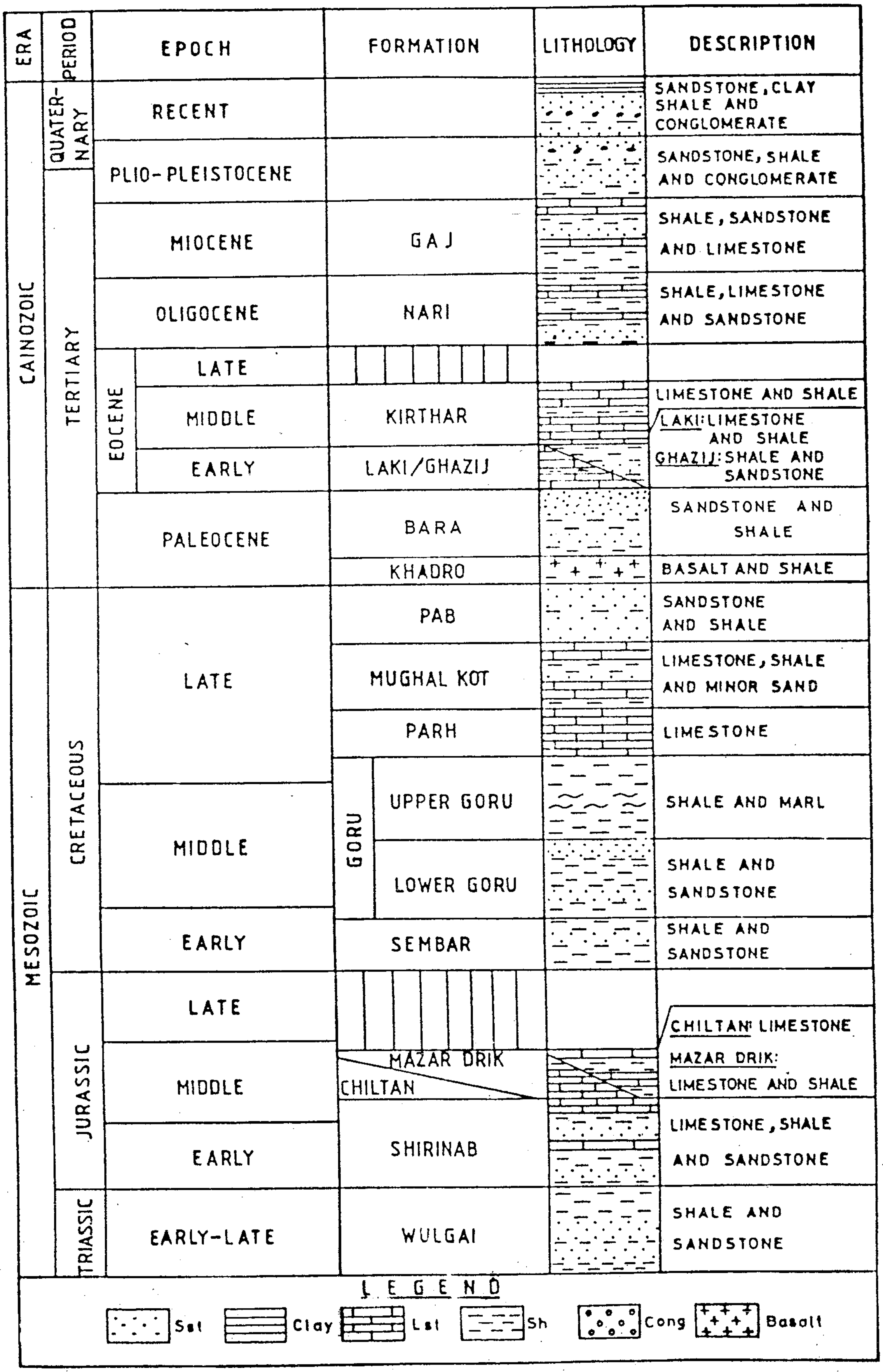


Figure 10— Generalized stratigraphy of offshore Indus basin.

AGE	KUTCH BASIN			CAMBAY BASIN		
	LITHOLOGY	ENVIRONMENT	EVENTS	LITHOLOGY	ENVIRONMENT	EVENTS
PLIOCENE	Sandstone/Conglomerate/ Minor Shale (1000 ft.)	Deltaic	Regression, Major Tectonic Movement	Sandstone /Shale/ Conglomerate (3500 ft.)	Fluvio-Deltaic to Marine	Regression, Major Tectonic Cycle
E. MIOCENE	Shale/Limestone/ Siltstone (660 ft.)	Shallow Marine	Transgression			
OLIGOCENE	Limestone/Shale (126 ft)	Shallow Marine	Regression, Tect. Cycle Transgression	Shale/Sandstone/ Limestone (600-900 ft.)		Oscillatory; Transgression/ Regression Cycles
L. EOCENE			Regression, Tect. Cycle		Marine /Deltaic	
M. EOCENE	Limestone/Minor Shale (185 ft.)	Shallow Marine	Transgression	Sandstone/Siltstone/ Shale/Coal (600-900 ft)		
E. EOCENE	Shale/ Limestone (135 ft.)	Shallow Marine	Regression Tect. Cycle Transgression	Black Shales (1500-4500 ft.)	Marine/ Prodeltaic	Transgression
PALEO CENE	Laterite/Tuff/Fe.Clay/ Sand St. (163 ft.)	Continental	Erosion/Peneplanation	Vol. Congl./Trap Wash /Fe. Claystone (60-4000 ft.)	Fluvial/Lacustrine	Graben Formation
L. CRETACEOUS	Deccan Trap; Basalt Flows (1500 ft.)	Terrestrial	Maj. Tect. Movement & Volcanicity	Deccan Trap (3000 ft.)	Terrestrial	Uplift / Erosion / Volcanicity Maj. Tect. Cy.
E. CRETACEOUS	Sandstone/Shale/ Ironstone (3500 ft.)	Deltaic	Regression	Felds. Sandstone (? 3000 ft.) ? ? ?	Fluvial / Deltaic	Rifting
U. JURASSIC	Sandstone /Shale (2000 ft.)	Shallow Marine				
E.-M. JURASSIC	Limestone/Shale (2500 ft.)	Shallow Marine	Regression Transgression			
LATE TRIASSIC	Arkosic Sandstone (150 ft)	Continental	Rifting			
PRE-MESOZOIC						
PRECAMBRIAN BASEMENT	Granite/Metamorphics			Granite		

ABBREVATIONS: Maj.-Major Tect.-Tectonic Vol.-Volcanic Fe.-Ferruginous Felds.-Feldspathic Congl.-Conglomerate Sd. St.-Sandstone

Figure 11— Generalized stratigraphy of kutch and Cambay basins (after Biswas, 1982).

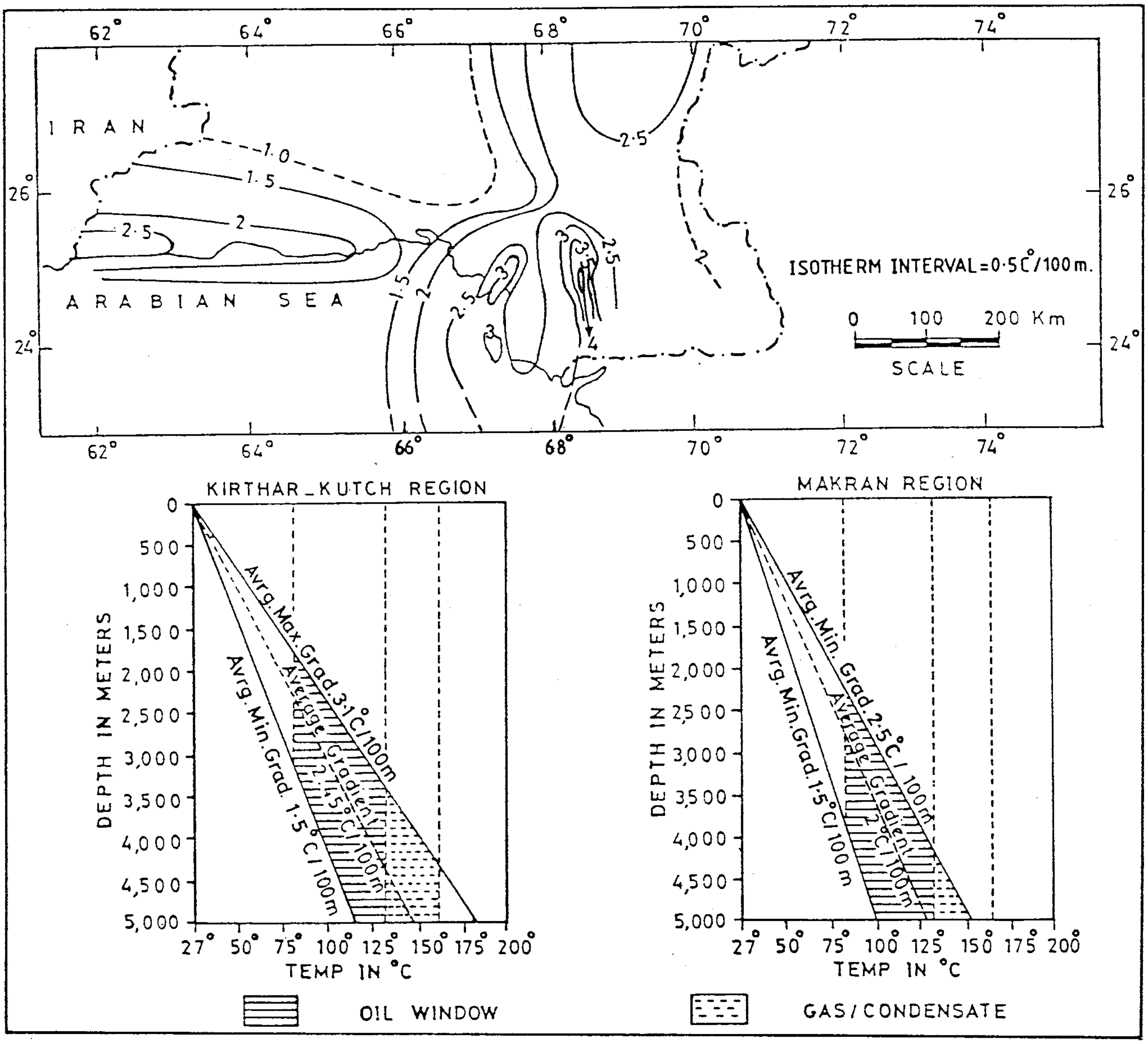


Figure 12— Geothermal distribution in Indus, Kutch and Makran basins (after Khan and Raza 1986, modified).

The thickness estimation is shown in Figure 11, the thickness increases toward southeast.

Lower Goru Formation.— The formation is composed of shale and sandstone. The sand content shows an increasing trend towards southeast (Figure 16). The shales in the western part are within the range of oil window and may act as source rocks. The sand/shale ratio of oil producing Badin area seems to persist in the southeastern offshore areas, enhancing the reservoir possibilities in these areas.

The thickness increases toward northeast and southeast.

Upper Goru Formation.— It is composed dominantly of shale. Among the subordinate lithologies, carbonates show an increase in thickness in the west (Figure 17).

The shales of the formation may act as cap rock as is the case in oil and gas producing Badin area.

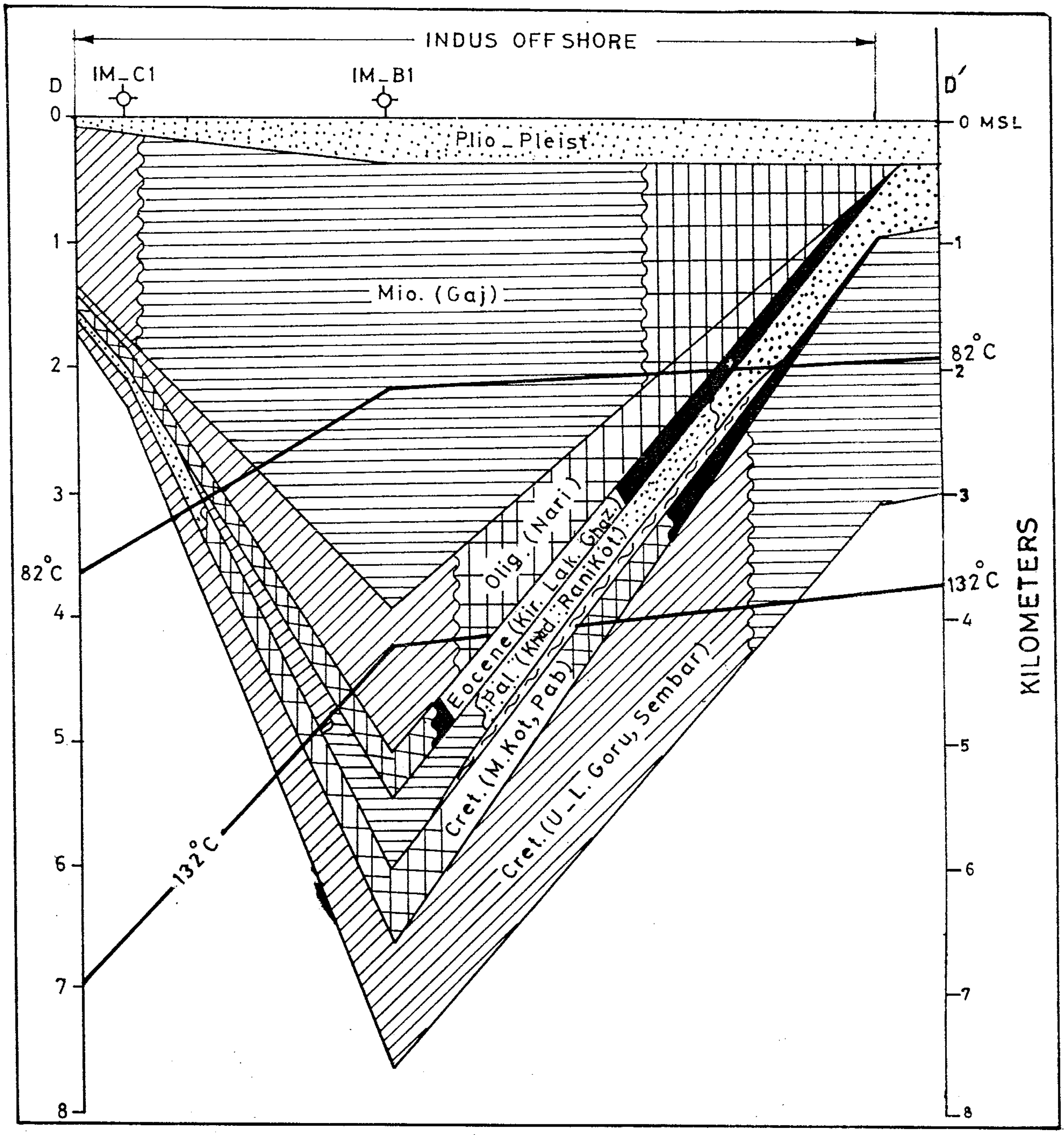


Figure 13— Schematic cross-section along line DD', Indus basin, with oil and gas window. For location see Figure 14.

The thickness follows almost the same trend as underlying Lower Goru formation.

Parh Formation.— It is exclusively represented by limestone lithology (Figure 18). Its distribution is restricted in the northwestern part of the area, where it is thinly developed. Apparently, it does not hold any source or reservoir potential due to compactness.

Mughal Kot Formation.— The formation is composed dominantly of limestone with subordinate shale. The shale content improves in the northwest (Figure 19). The

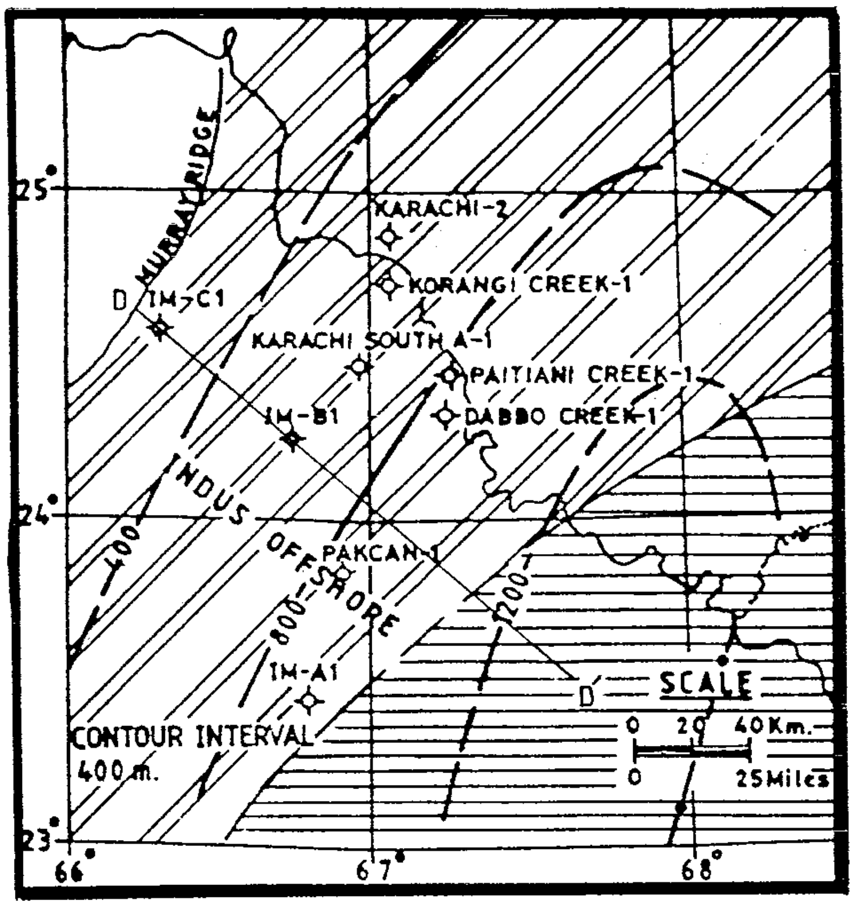


Figure 14— Thickness and lithofacies map of Sembar formation (after Raza et al, 1990, modified).

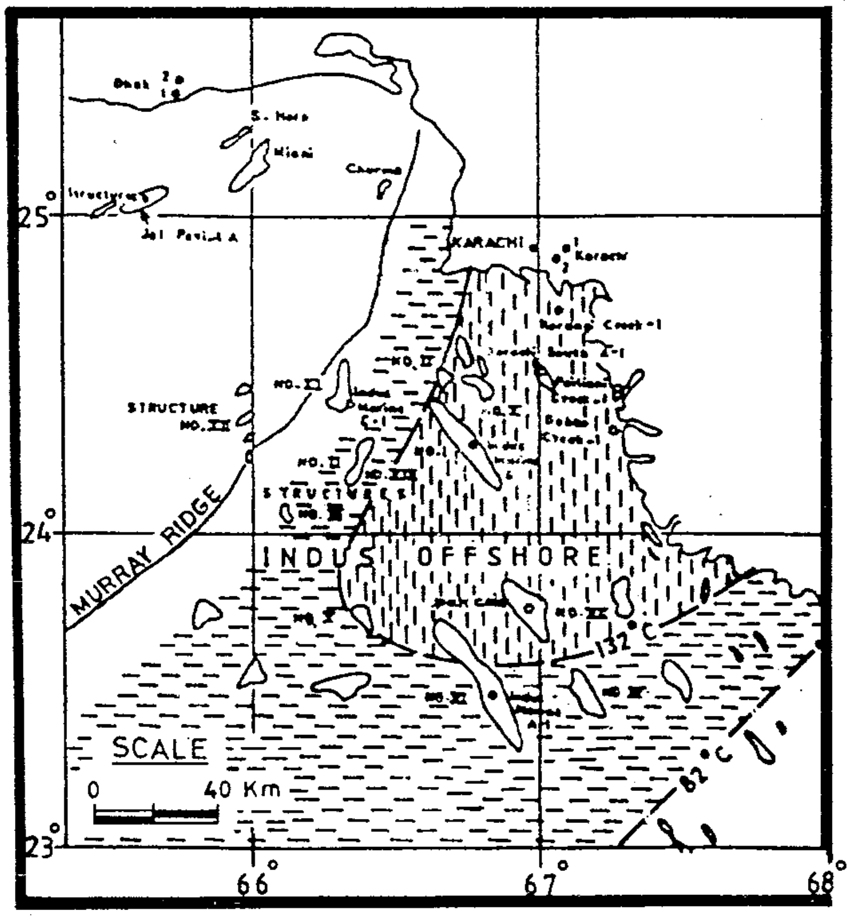


Figure 15— Oil and gas window in Sembar formation with seismically delineated structures. (The structures are not mapped on Cretaceous level).

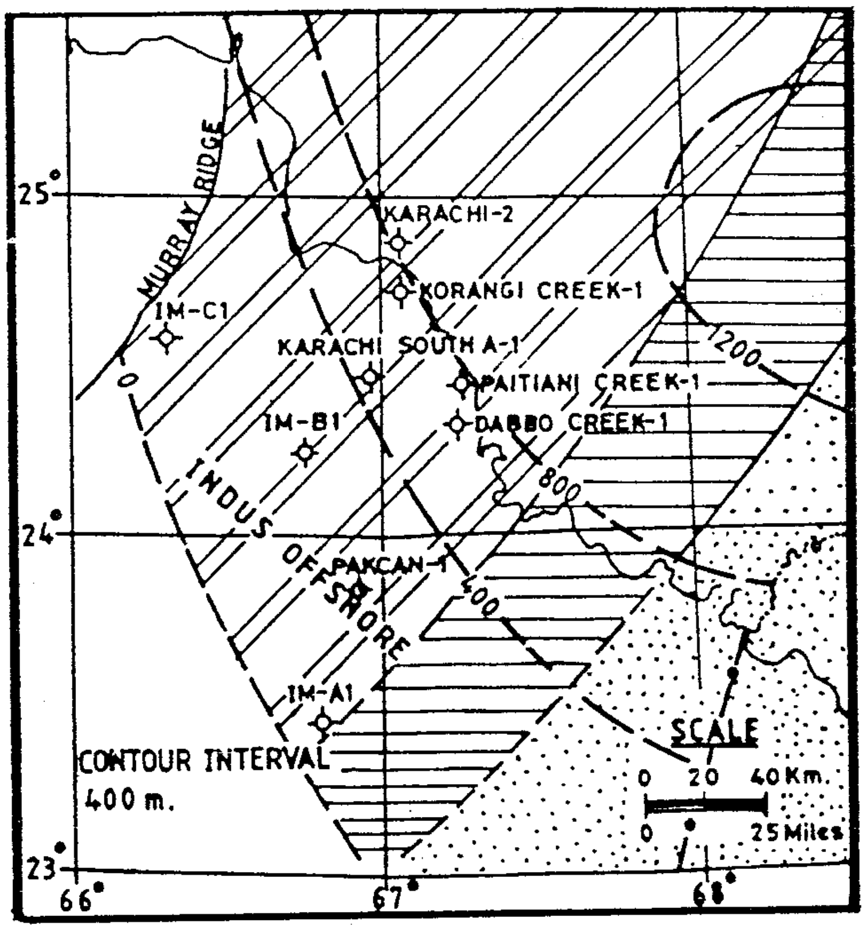


Figure 16— Thickness and lithofacies map of Lower Goru formation (after Raza et al, 1990, modified).

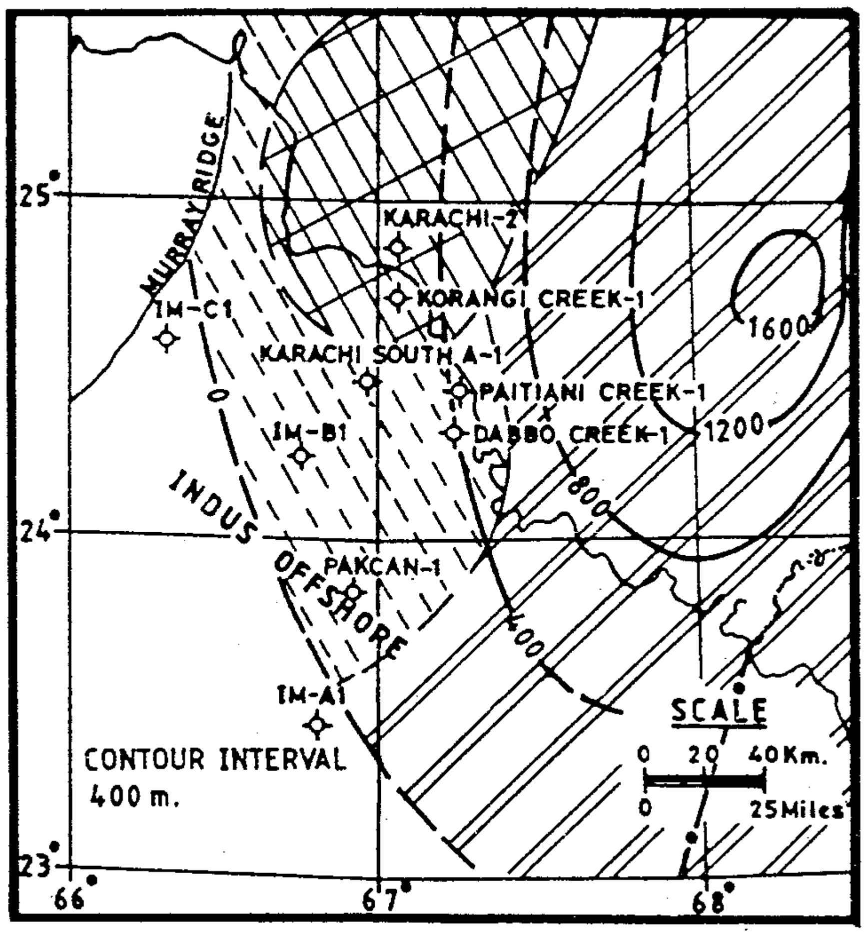


Figure 17— Thickness and lithofacies map of Upper Goru formation (after Raza et al, 1990, modified).

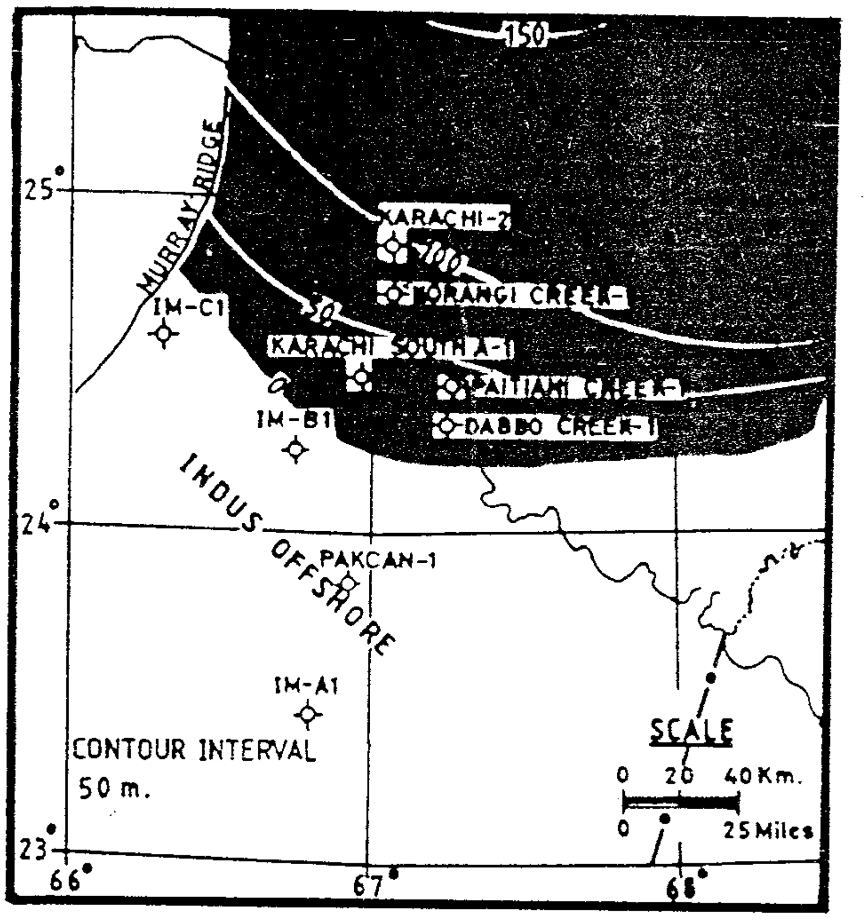


Figure 18— Thickness and lithofacies map of Parh formation (after Raza et al, 1990, modified).

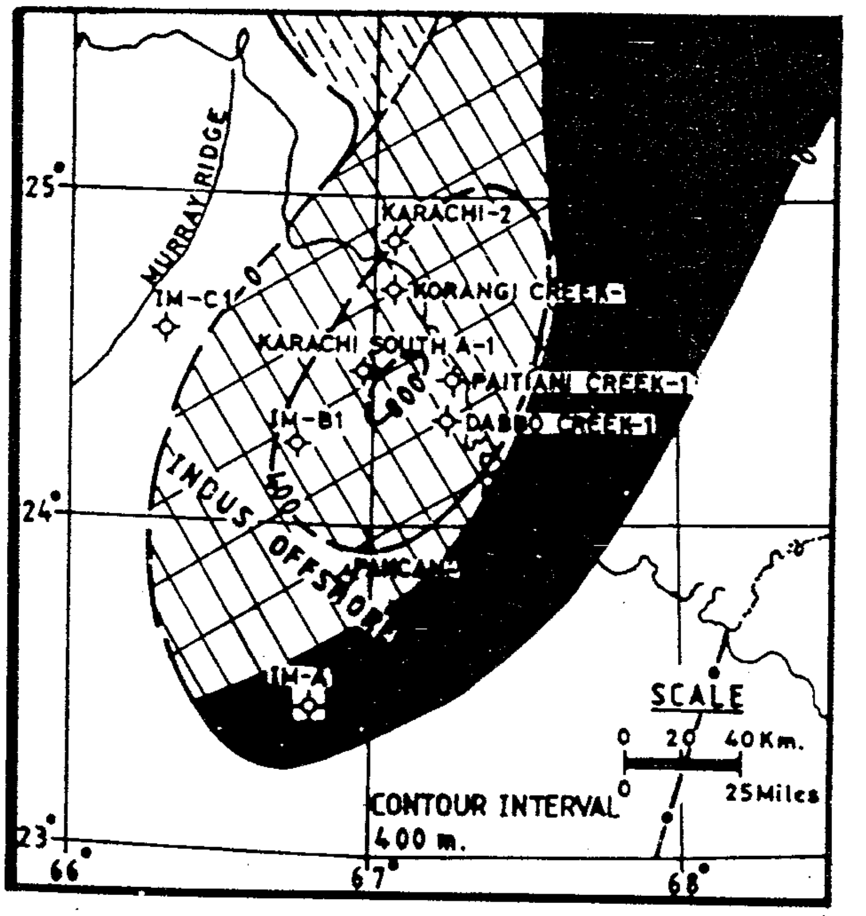


Figure 19— Thickness and lithofacies map of Mughal Kot formation (after Raza et al, 1990, modified).

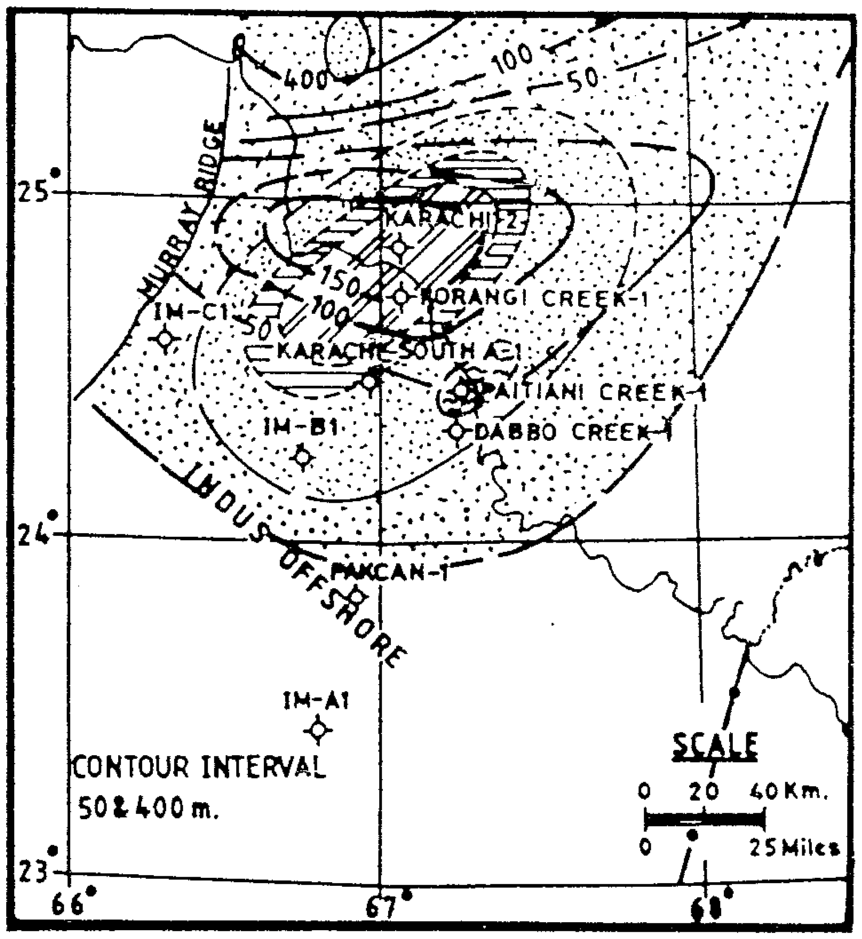


Figure 20— Thickness and lithofacies map of Pab formation (after Raza et al, 1990, modified).

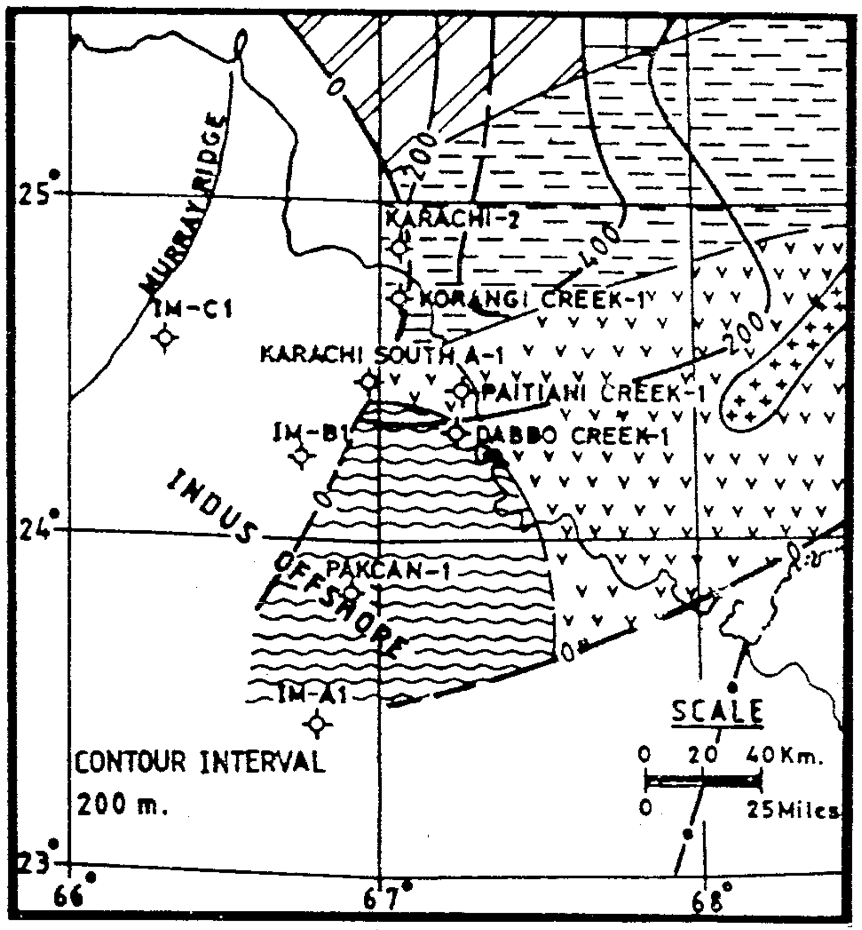


Figure 21— Thickness and lithofacies map of Khadro formation (after Raza et al, 1990, modified).

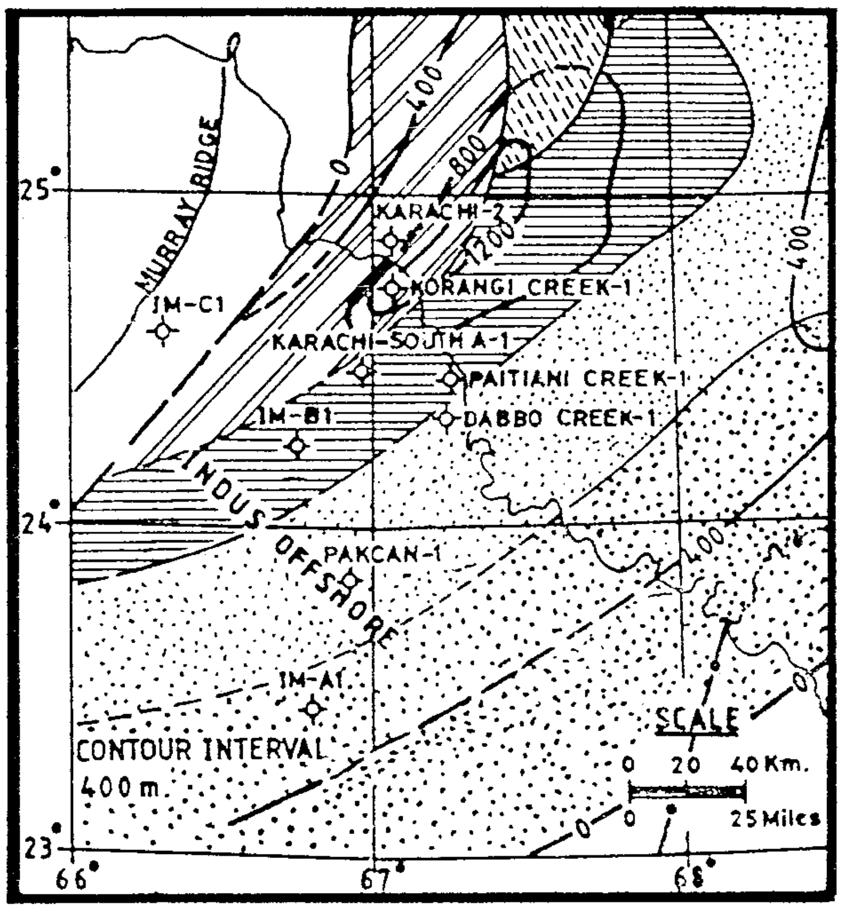


Figure 22— Thickness and lithofacies map of Bara formation (after Raza et al, 1990, modified).

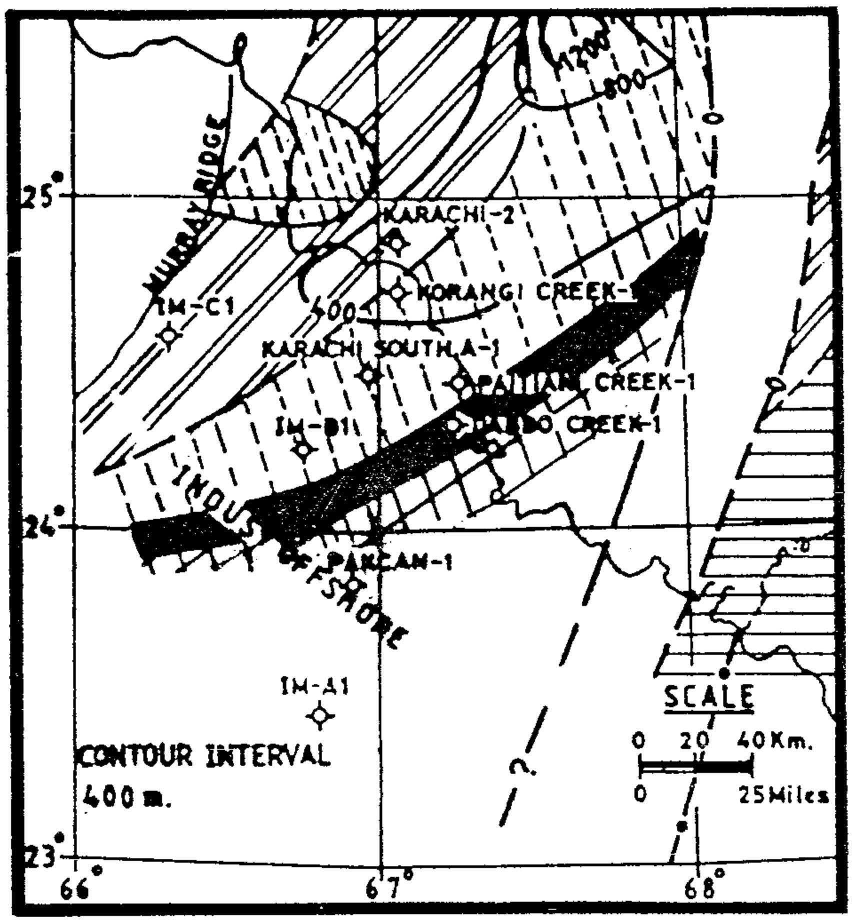


Figure 24— Thickness and lithofacies map of Laki/Ghazij formation (after Raza et al, 1990, modified).

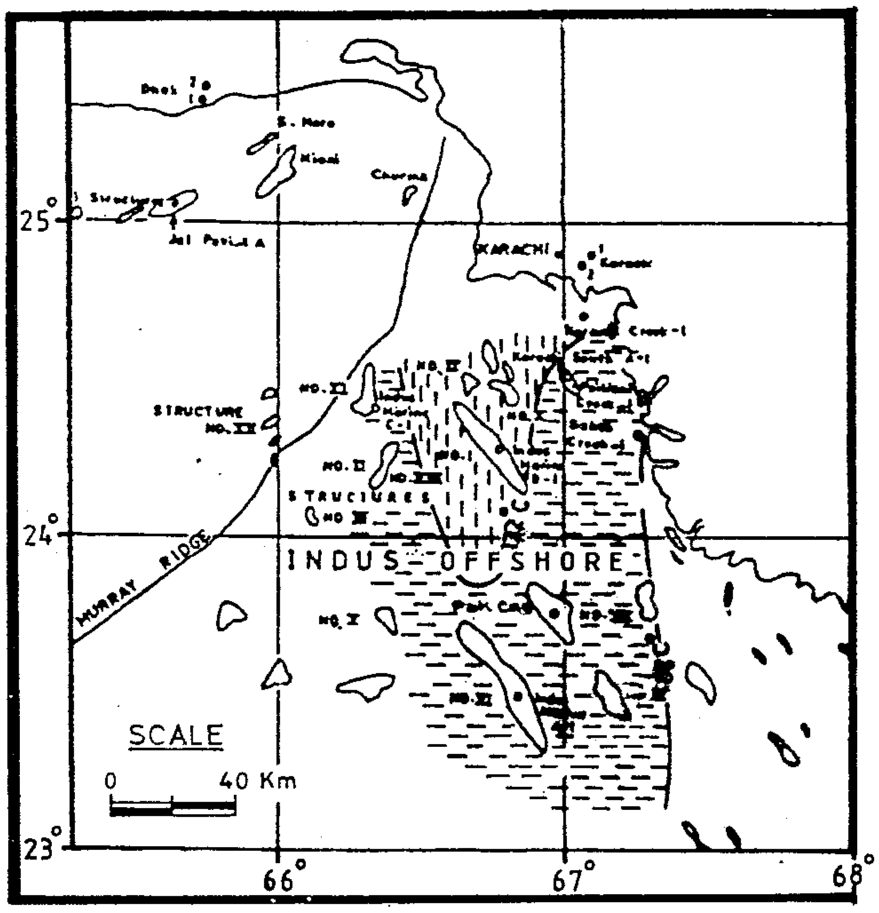


Figure 23— Oil and gas window at the base of Bara formation with seismically delineated structures (Some of the structures are mapped at Paleocene level).

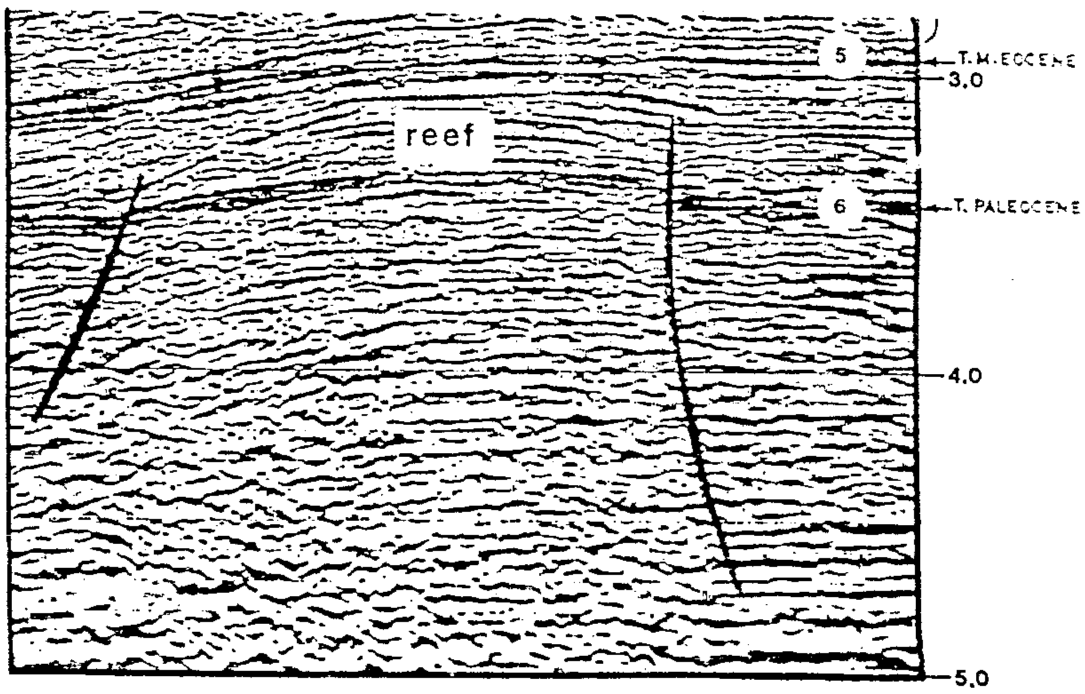


Figure 25— Profile along line H showing probable reef build up at Eocene level (source: OGDC-NORAD, 1983, modified). For location see Figure 32.

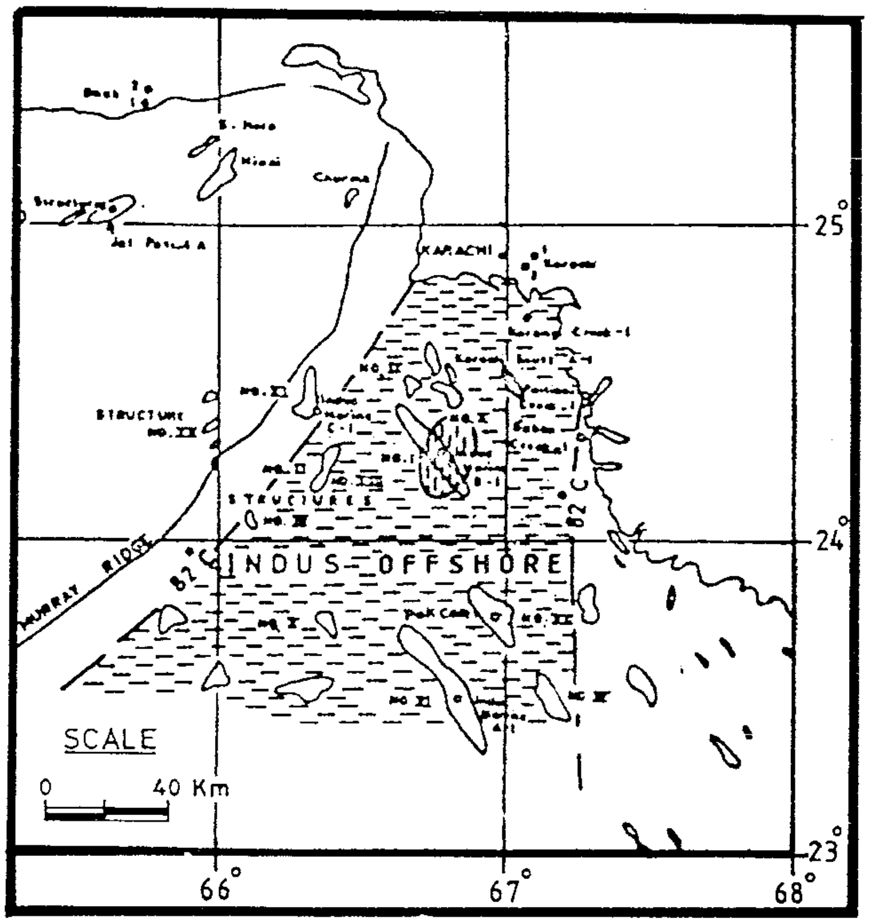


Figure 26— Oil and gas window at the base of Laki/Ghazij formation with seismically delineated structres (Few structures are mapped at Eocene level).

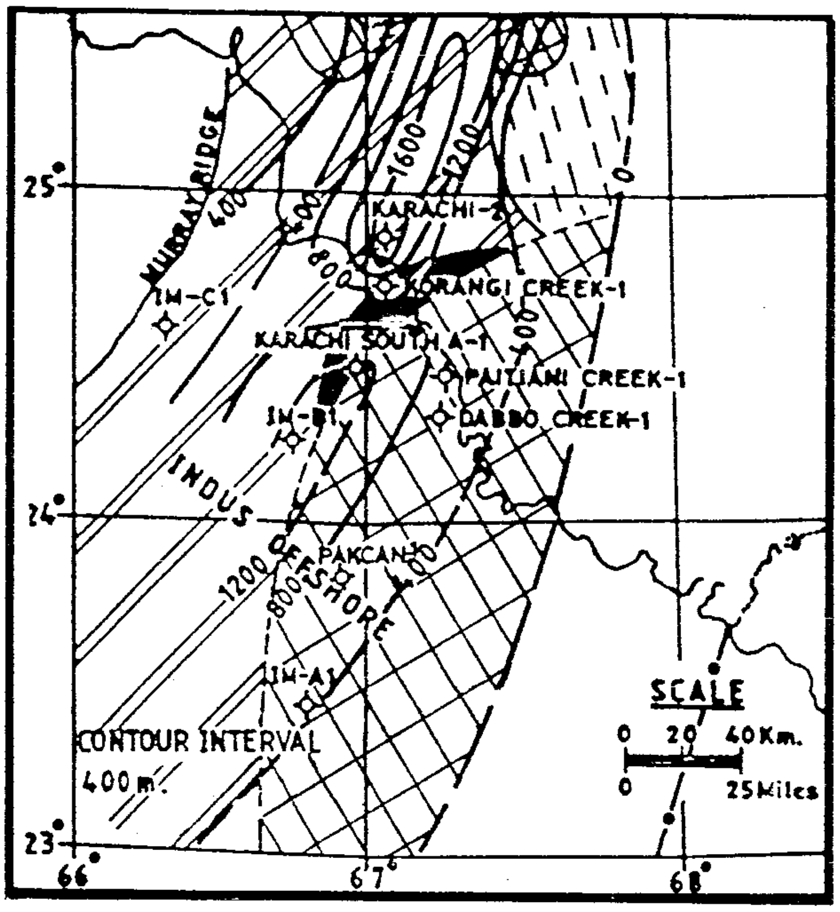


Figure 28— Thickness and lithofacies map of Nari formation (after Raza et al, 1990, modified).

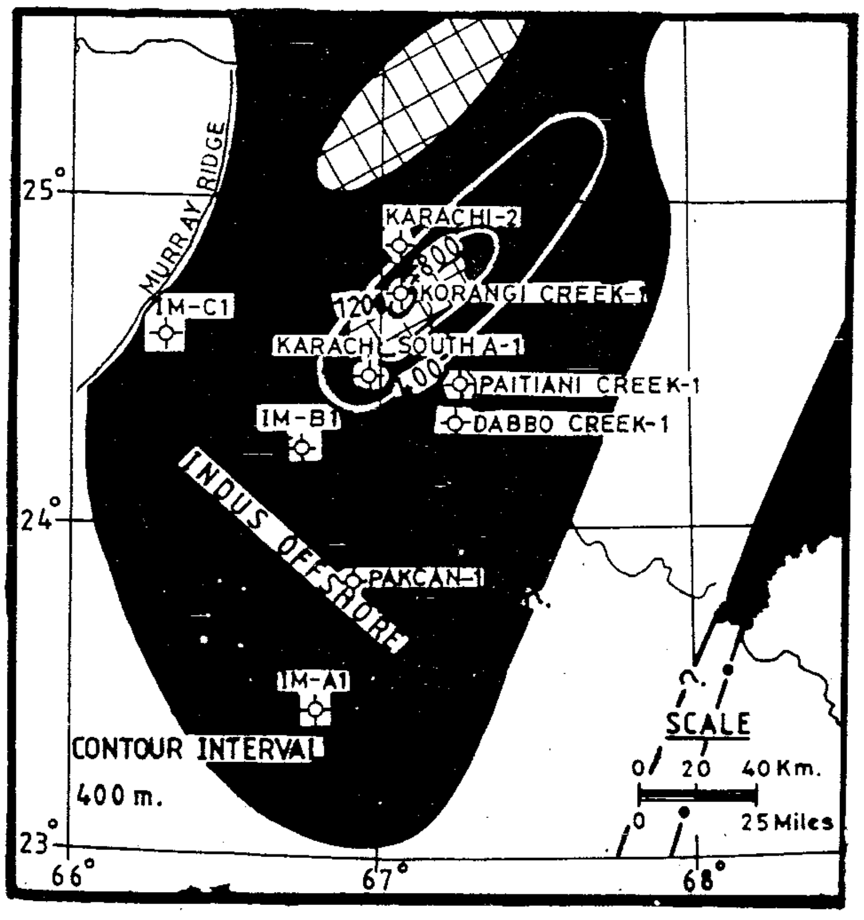


Figure 27— Thickness and lithofacies map of Kirthar formation (after Raza et al, 1990, modified).

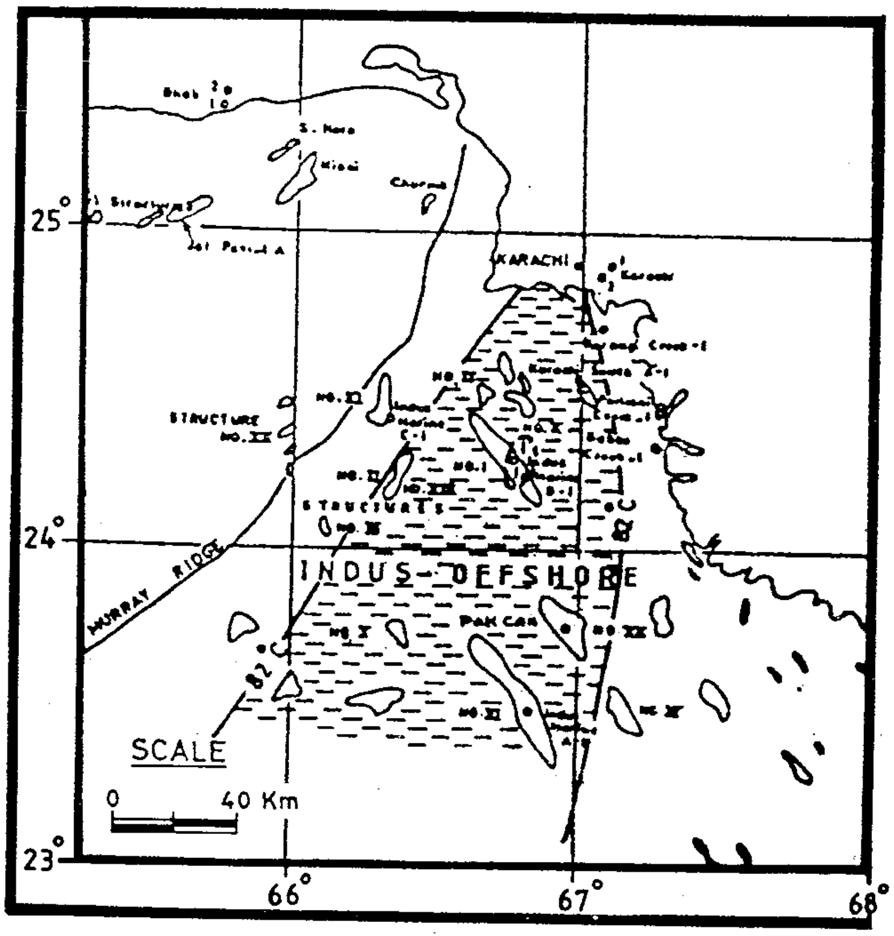


Figure 29— Oil and gas window at the base of Nari formation with seismically delineated structures (Most of the structures are mapped at Oligocene level).

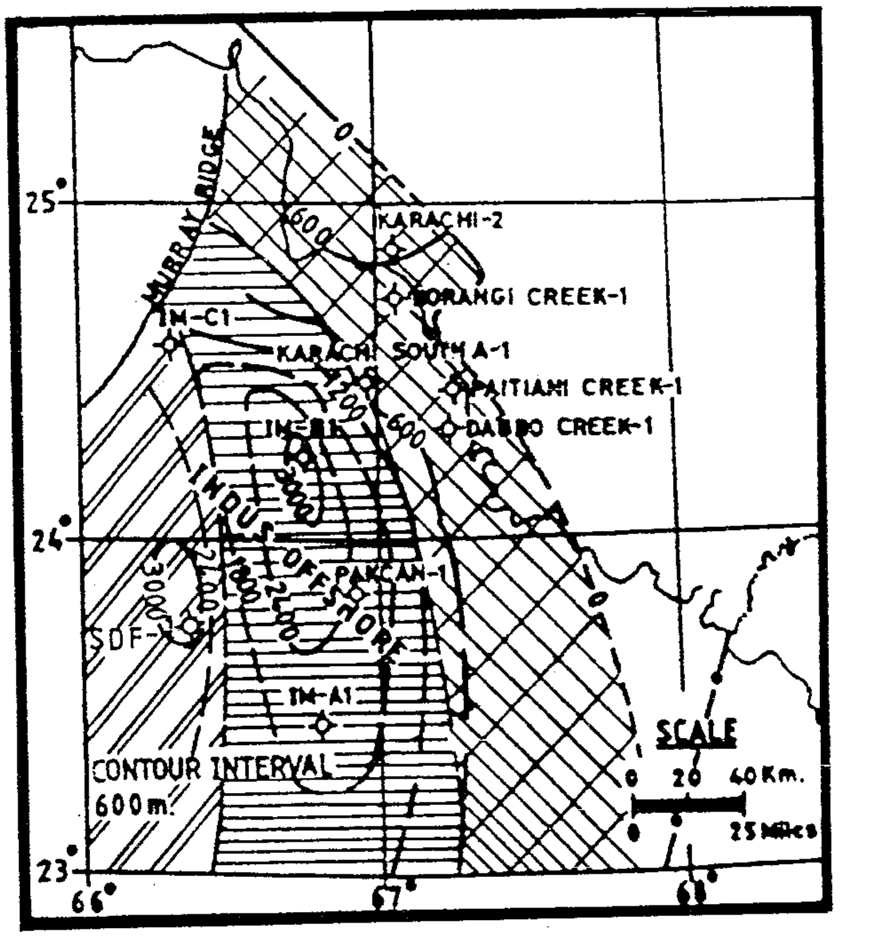


Figure 30— Thickness and lithofacies map of Gaj formation (after Raza et al, 1990, modified).

formation is restricted to Indus basin, the depocentre being around Karachi South A-1 and Patiani Creek wells. The formation may hold some source-reservoir potential in the coastal area where shale content improves, though there is no available evidence so far to prove it.

Pab Formation.— The formation is composed dominantly of sandstone. A shale dominated sequence is encountered in western coastal area (Korangi Creek and Karachi Wells). The distribution of the formation is restricted to Indus basin. The thickness of the formation increases northward (Figure 20). Source-reservoir possibilities exist within the formation although there is no direct evidence of occurrence of hydrocarbons uptil now.

Khadro Formation.— The formation is composed of intercalations of clastics and basalt. The formation is restricted to the south eastern part of the Indus basin where it is thinly developed (Figure 21). Apparently, the formation does not hold any hydrocarbon potential.

Bara Formation.— The formation is composed dominantly of shale in the northern part and sandstone in the southern part (Figure 22). The thickness of the formation increases toward north. Lithologically, the formation seems to hold hydrocarbon potential. Some gas shows were encountered in Dabbo Creek-1 and Korangi Creek-1. The formation is within oil window in most of the area (Figure 23).

Laki/Ghazij Formation.—The formation is composed of limestone and shale which vary in percentage in different parts of the basin (Figure 24). The thickness increases toward coastal region. The formation holds good hydrocarbon source-reservoir potential in the south and southeastern parts where carbonates including probably reefs are better developed (Figure 25). The formation is within oil window in most of the area (Figure 26).

Kirthar Formation.— The formation is composed dominantly of limestone with subordinate shale (Figure 27). The thickness increases northward. The carbonates of the formation can form good reservoirs. Gas shows were encountered in Karachi-1.

Nari Formation.— The formation is composed of limestone and shale with subordinate sandstone. The depocentre is in offshore depression (Figure 28). The formation holds good reservoir potential in carbonates/sandstones. Gas shows were recorded in Dabbo Creek-1, Patiani Creek-1 and Karachi-1. The formation is mature mainly in offshore depression (Figure 29).

Gaj Formation.— The formation is composed of limestone and shale with subordinate sandstone. The depocentre lies in offshore depression (Figure 30). Noncommercial gas has been discovered in sand facies equivalent in age of Gaj formation. Oil window covers some parts of the formation in the offshore area.

Prospects

The Indus offshore basin is the southern offshore extension of the Indus basin and comprises approximately 20,000 square km area of the continental shelf. Many international oil companies have conducted seismic surveys in the area (Figure 31). These companies include Sun Oil (1962-63), Wintershall (1969-74), Husky (1976-78), Phillips (1977) and Oxy (1987-88). In 1982, the structures marked earlier by Wintershall were reinvestigated with the help of Norwegian Government (OGDC-NORAD, 1983).

More than 30 structures were seismically delineated as a result of activities of the above-mentioned companies (Figure 32). In addition to these conventional traps, exploration directed towards reefal build-ups, fan and deltaic plays should also yield interesting results.

Ten wells have been drilled so far in the offshore and coastal region. Although none of the wells was a producer, yet some gas shows in the Tertiary and Cretaceous in some

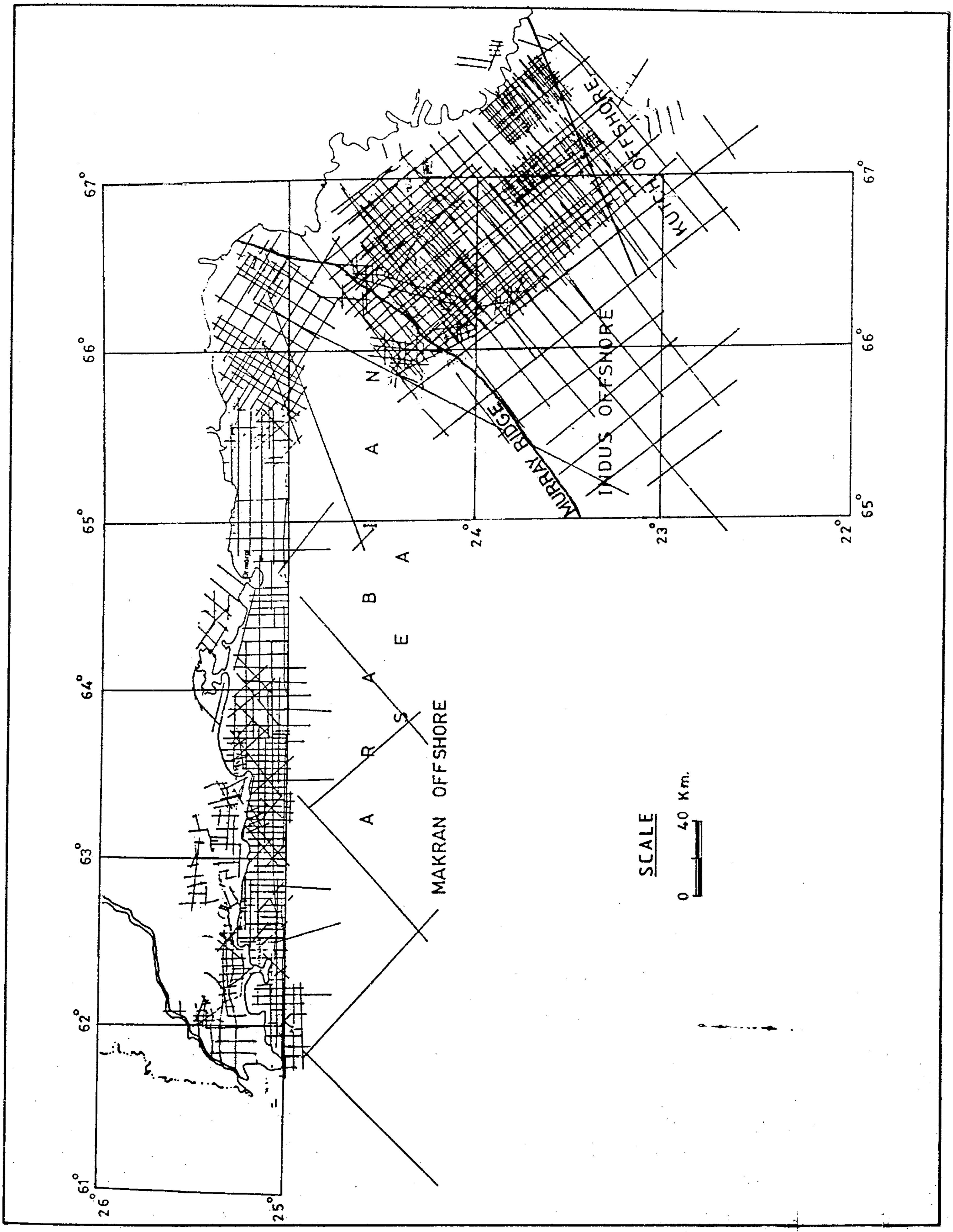


Figure 31— Multifold seismic coverage map (after Ali and Ahmad, 1985, modified).

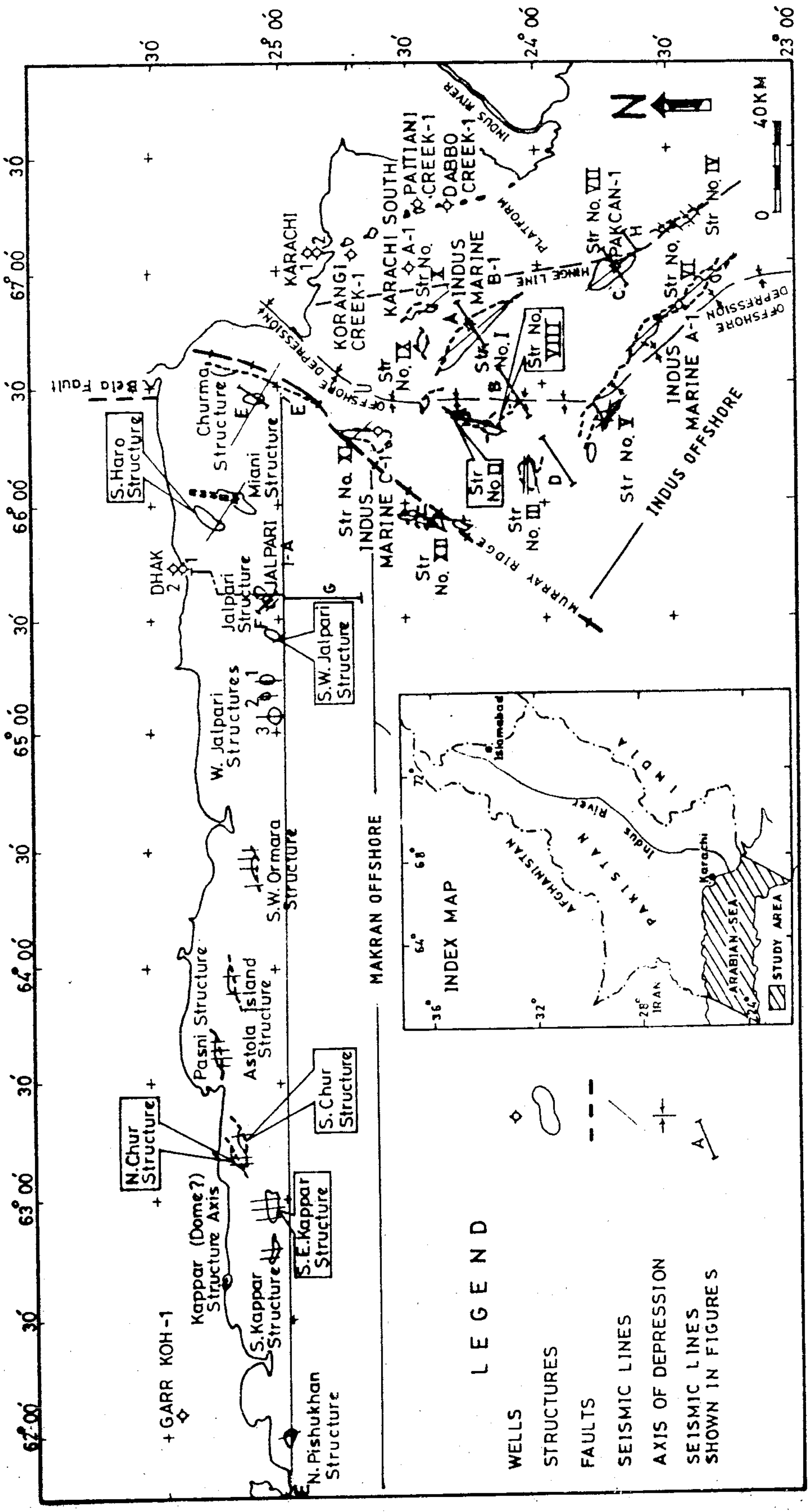


Figure 32— Map showing seismically delineated structures. (after Raza et al, 1980, modified).

of the wells indicate the occurrence of hydrocarbons in the area (Table 1). The OGDC's PakCan-1 could well have been a small but commercially exploitable gasfield if located onshore. The onshore discoveries of Sari and Hundi gasfields in Karachi depression and oil and gas discoveries of Badin area in Sind monocline provide indirect evidence of the prospectivity of the Indus offshore basin.

Recent failure of Oxy's Sadaf-1 drilled to test deltaic play might temporarily delay further exploration in the area. But in view of the worldwide pattern of exploration and discoveries in areas of unproven potential, drilling of one well is not enough. Moreover, Wintershall, OGDC and Oxy all have drilled for Miocene target, any future campaign should consider older targets as well.

The distribution and intensity of geopressures in offshore Pakistan is predicted through seismic and drilling data. It is indicated that except for the area close to Murray ridge which is a zone of high geopressure, the rest of the basin is relatively low pressured at shallow depth. Majority of structures are found at hydrostatic pressure gradient between 1400 to 2700 m depth (Figure 33). The formation pressure distribution of 15 MPa, 25 MPa, 50 MPa and 75 MPa at various depths is shown in Figures 34-37. A classification of structures falling in the range of hydrostatic, moderate and intense geopressures at variable depths is given in Figure 38.

The stratigraphy of the Kutch basin is shown in Figure 11. The basalt which forms a basement in India's Cambay and Kutch basins trends to thin out and may even be absent in Pakistani part of the Kutch basin. Cretaceous sands here may form promising reservoirs. Both structural and stratigraphic traps can be expected. According to Biswas (1982) good Tertiary and Lower Cretaceous prospects exist in offshore area of Kutch basin where mainly stratigraphic prospects are expected.

Rift basins of the Indo-Pak offshore and coastal region came into existence during northward flight of the Indian plate as a consequence of the tension generated by the anticlock-wise rotation of the moving plate. These basins were developed one after the other, Kutch basin being the oldest (Early Jurassic). India's Kutch basin which has some oil and gas indications in wells extends into Pakistan and shares the prospects with it. South of the Kutch basin lies India's Saurastra basin. Further south is located the largest oil-producing basin of the sub- continent, the Bombay offshore basin, which includes world class giant, the Bombay High. Bombay offshore basin is linked onshore with India's oil and gas-producing Cambay basin which further extends into Pakistan's Panno Aqil graben (Figure 3). It amy be noted that although Bombay High field is located physically rather close to the Indus offshore basin, it is situated in a totally different geological province.

MAKRAN OFFSHORE BASIN

The Makran offshore basin occupies the western part of the offshore region of Pakistan, between Murray ridge and Iranian border. It is a fore-arc subduction basin with known sedimentary history dating back to Early Miocene (Figure 39). Sedimentary thickness in the basin is quite adequate for reaching maturity of the potential source rocks (Figures 2, 40). The potential reser voirs are only sandstones. Fairways of hydrocarbon migration from deeper source are commonly associated with active subduction. A large number of gas seepages associated with spectacular mud volcanoes present all along the Makran coast provide indication of hydrocarbon generation and migration. Both structural and stratigraphic traps should form objective of exploration.

Only one petroleum zone is recognized within the offshore limits of the basin (Figure 3). The structural expressions are oriented in the direction of subduction (Figure 8). Some structural features in the eastern part of the basin can be attributed to mud diaprism and local stresses associated with subduction and transform movement (Figures 41-42).

Seismic Stratigraphic/Lithofacies Analysis

Hoshab Formation.— The Hoshab formation is the oldest known sedimentary unit (Early Miocene). It is exclusively composed of abyssal shale which is probably uniformly distributed all along the basin (Figure 43). The preliminary source rock studies on onshore surface samples by HDIP have indicated presence of category II-III organic matter. The TOC ranges between 0.25% to 0.47% which is rather low but could be the result of existence of a deeper zone of oxidization.

Panjgur Formation.— The formation comprises abyssal to lower slope shales and turbiditic sands. The unit is distributed throughout the basin. The lithofacies map with thickness computed from regional cross-section based on seismic profiles indicate an increase in thickness toward the coastline (Figures 44-48).

The formation is within oil and gas window (Figure 49), the shales are potential source rocks (TOC of onshore surface samples ranges from 0.66% to 5.62%, Alam, 1986). The sandstones of the unit are ranked as good reservoirs (porosity of onshore surface samples ranges from 10 to 20 percent).

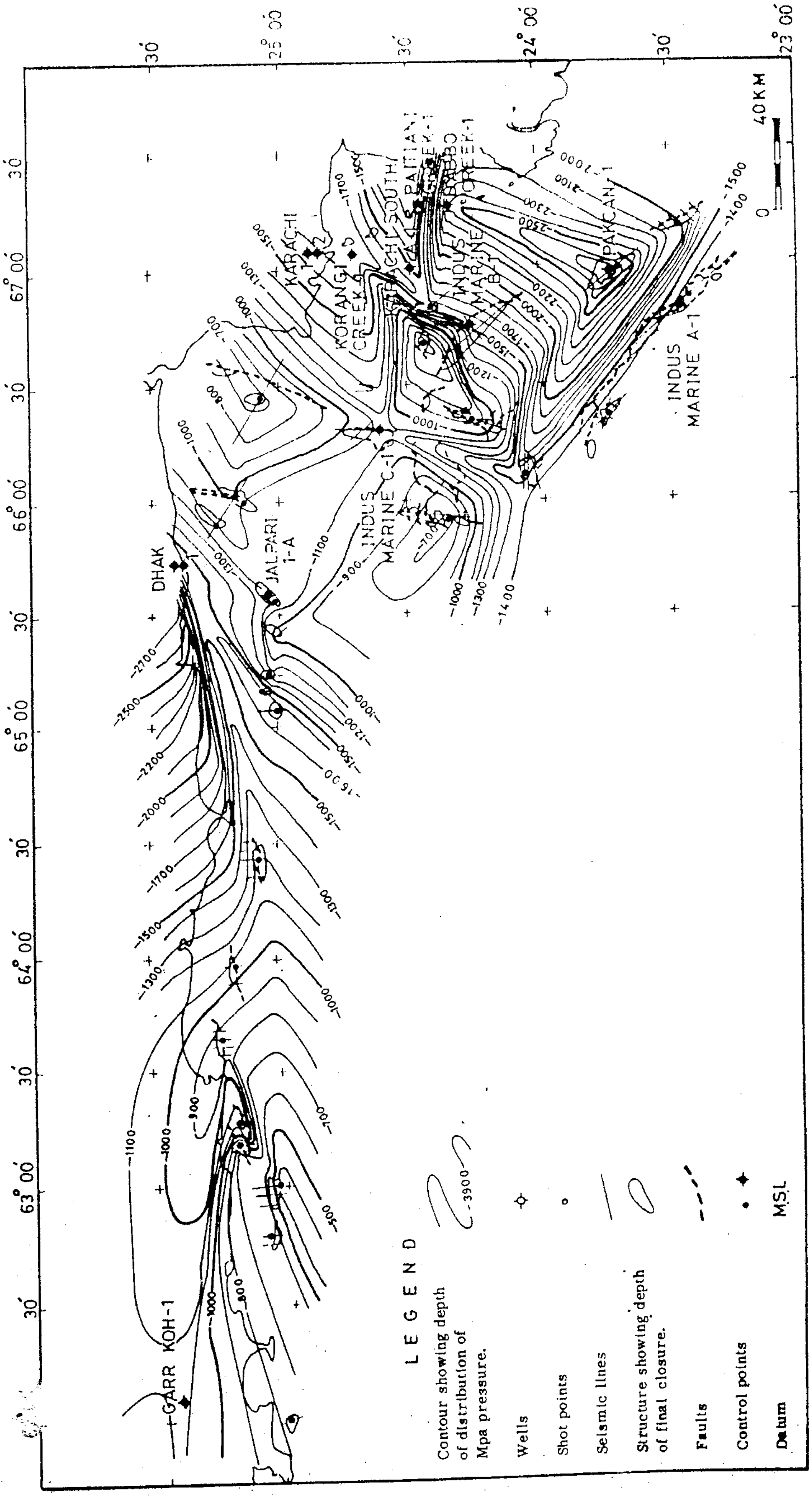
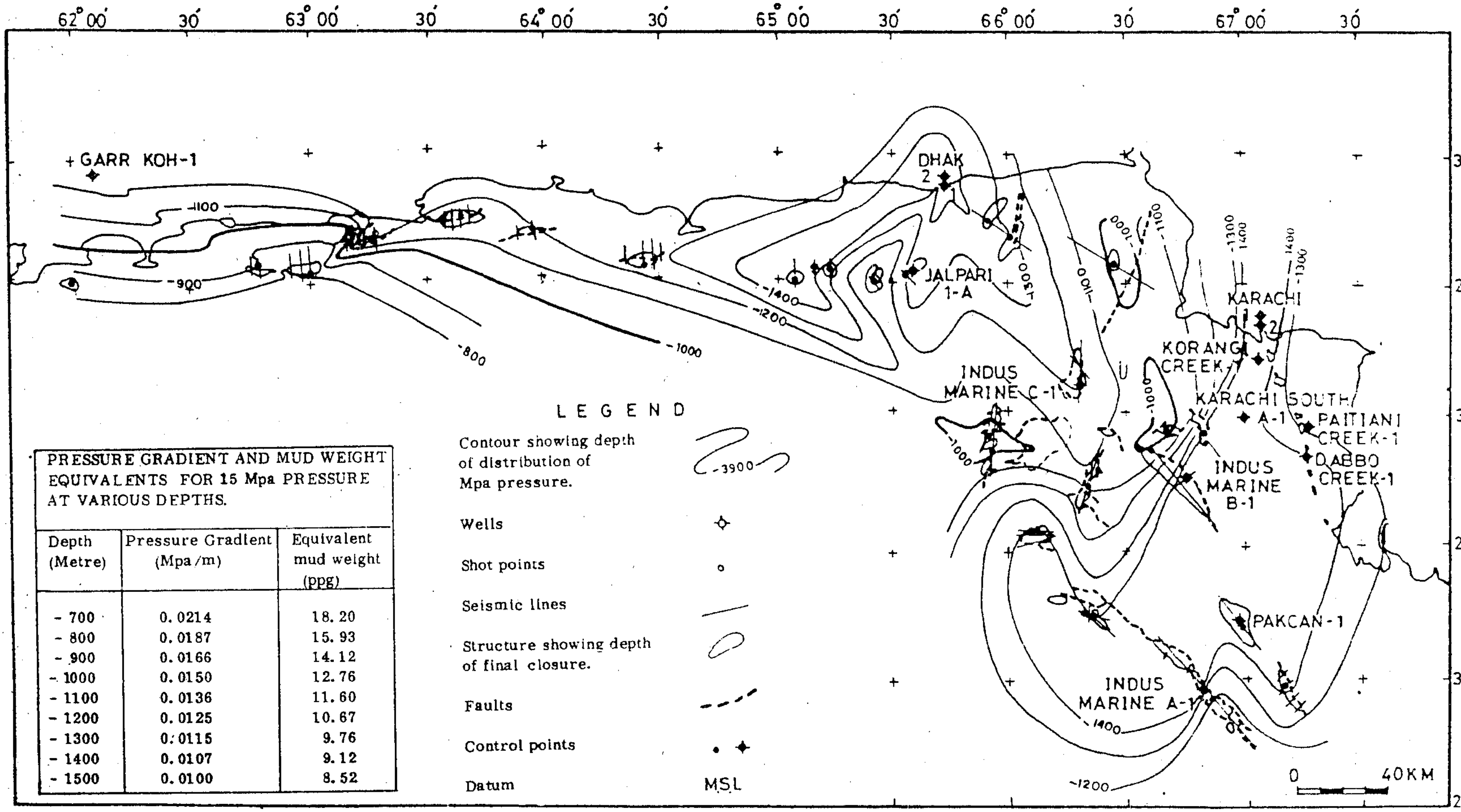


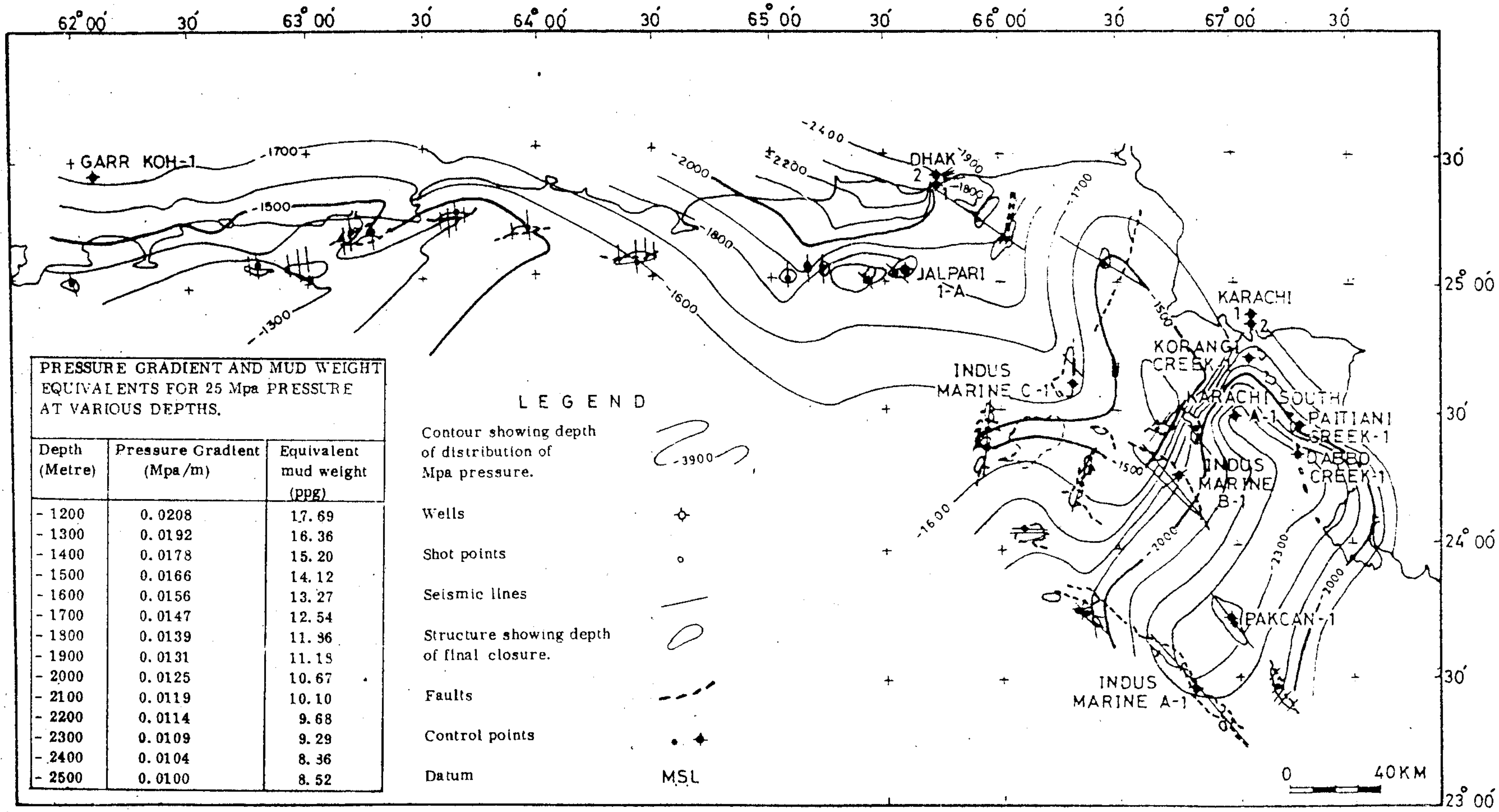
Figure 33— Drilling/seismically predicted hydrostatic formation pressure distribution at various depths. (after Raza et al, 1980, modified).



PRESSURE GRADIENT AND MUD WEIGHT EQUIVALENTS FOR 15 Mpa PRESSURE AT VARIOUS DEPTHS.

Depth (Metre)	Pressure Gradient (Mpa /m)	Equivalent mud weight (ppg)
- 700	0.0214	18.20
- 800	0.0187	15.93
- 900	0.0166	14.12
- 1000	0.0150	12.76
- 1100	0.0136	11.60
- 1200	0.0125	10.67
- 1300	0.0115	9.76
- 1400	0.0107	9.12
- 1500	0.0100	8.52

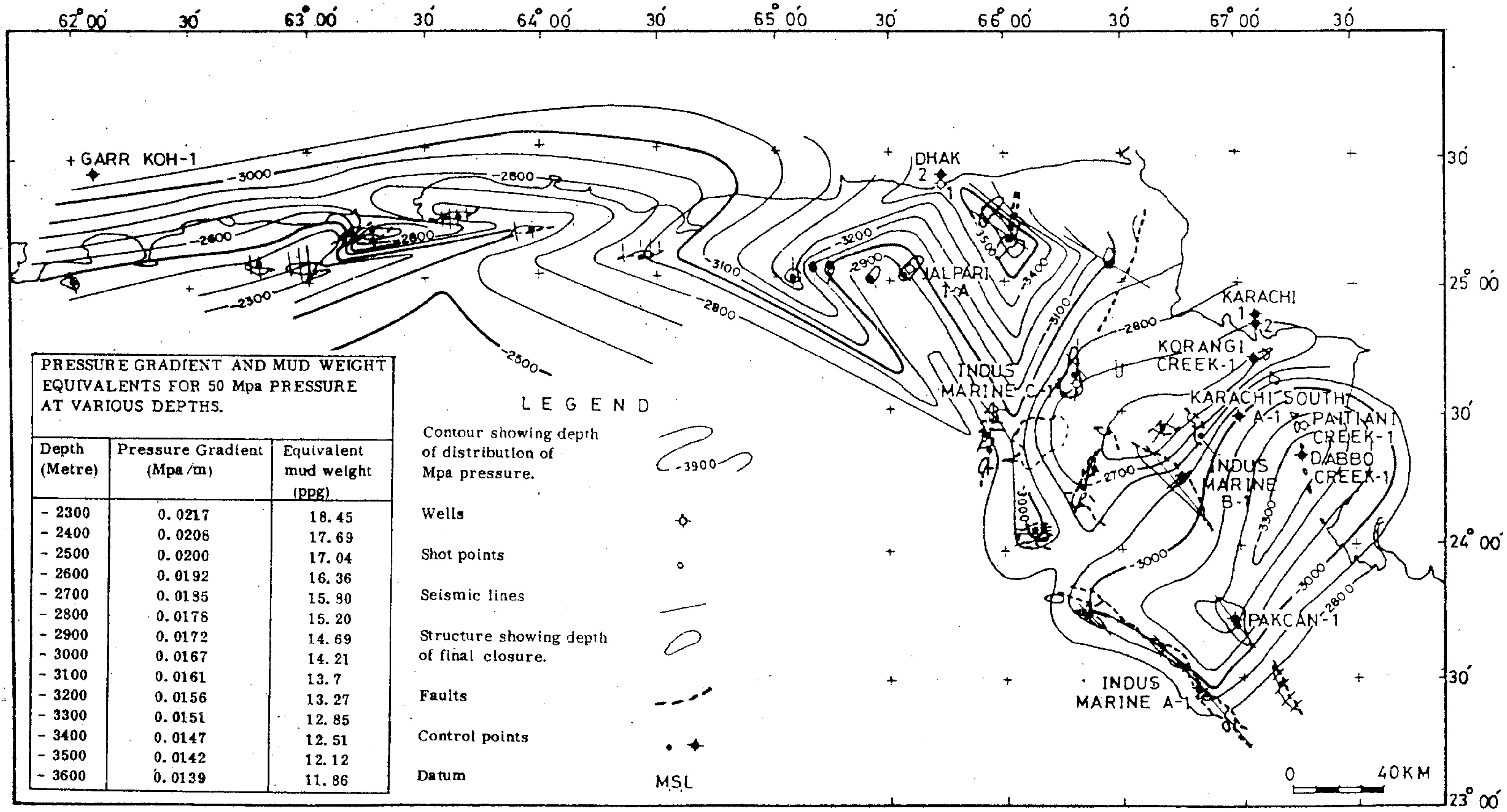
Figure 34— Drilling/seismically predicted formation pressure distribution of 15 MPa at various depths (after Raza et al, 1980, modified).



PRESSURE GRADIENT AND MUD WEIGHT EQUIVALENTS FOR 25 Mpa PRESSURE AT VARIOUS DEPTHS.

Depth (Metre)	Pressure Gradient (Mpa/m)	Equivalent mud weight (ppg)
- 1200	0.0208	17.69
- 1300	0.0192	16.36
- 1400	0.0178	15.20
- 1500	0.0166	14.12
- 1600	0.0156	13.27
- 1700	0.0147	12.54
- 1800	0.0139	11.86
- 1900	0.0131	11.18
- 2000	0.0125	10.67
- 2100	0.0119	10.10
- 2200	0.0114	9.68
- 2300	0.0109	9.29
- 2400	0.0104	8.86
- 2500	0.0100	8.52

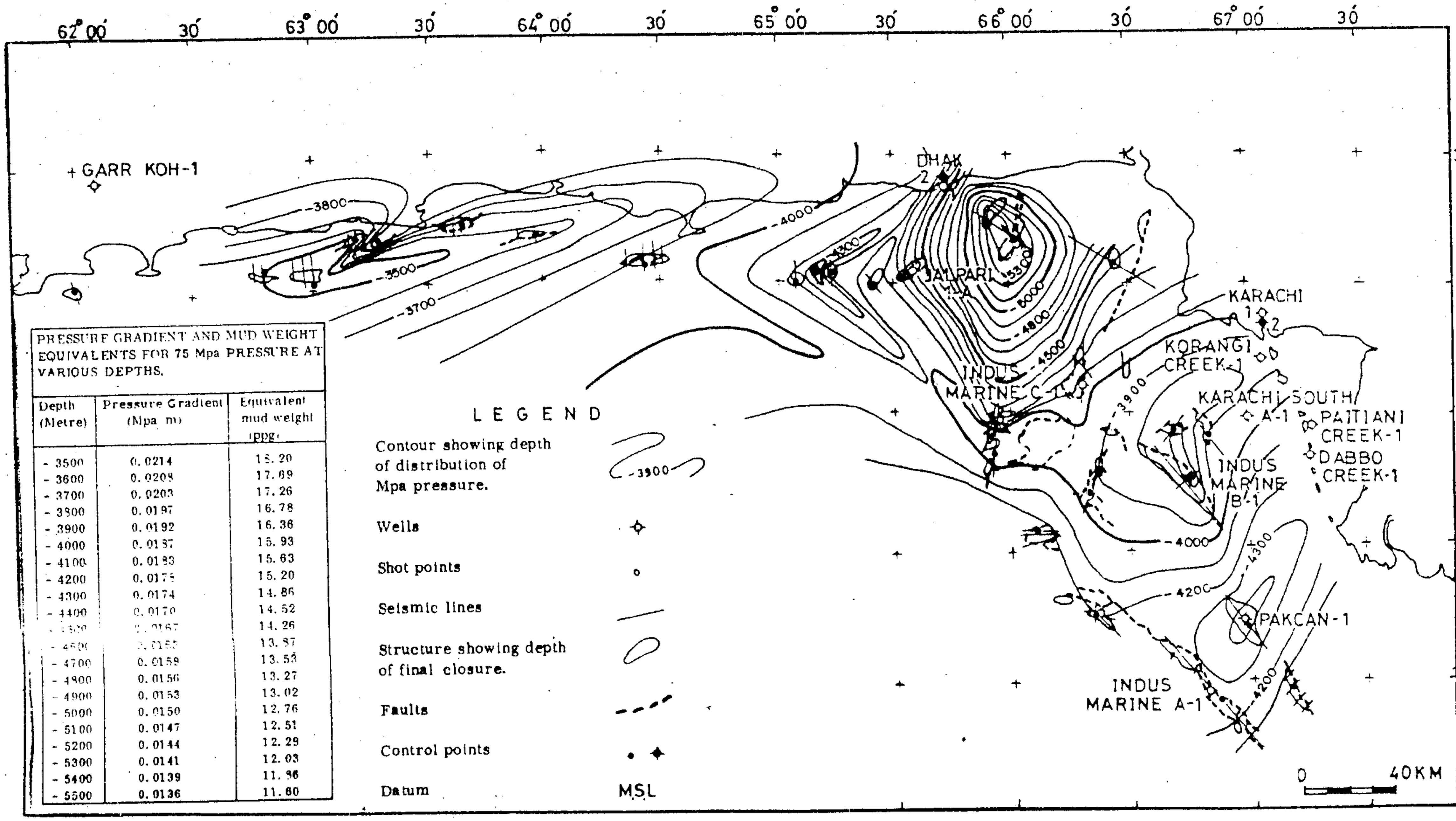
Figure 35— Drilling/seismically predicted formation pressure distribution of 25 MPa at various depths (after Raza et al, 1980, modified).



PRESSURE GRADIENT AND MUD WEIGHT EQUIVALENTS FOR 50 Mpa PRESSURE AT VARIOUS DEPTHS.

Depth (Metre)	Pressure Gradient (Mpa/m)	Equivalent mud weight (ppg)
- 2300	0.0217	18.45
- 2400	0.0208	17.69
- 2500	0.0200	17.04
- 2600	0.0192	16.36
- 2700	0.0185	15.80
- 2800	0.0178	15.20
- 2900	0.0172	14.69
- 3000	0.0167	14.21
- 3100	0.0161	13.7
- 3200	0.0156	13.27
- 3300	0.0151	12.85
- 3400	0.0147	12.51
- 3500	0.0142	12.12
- 3600	0.0139	11.86

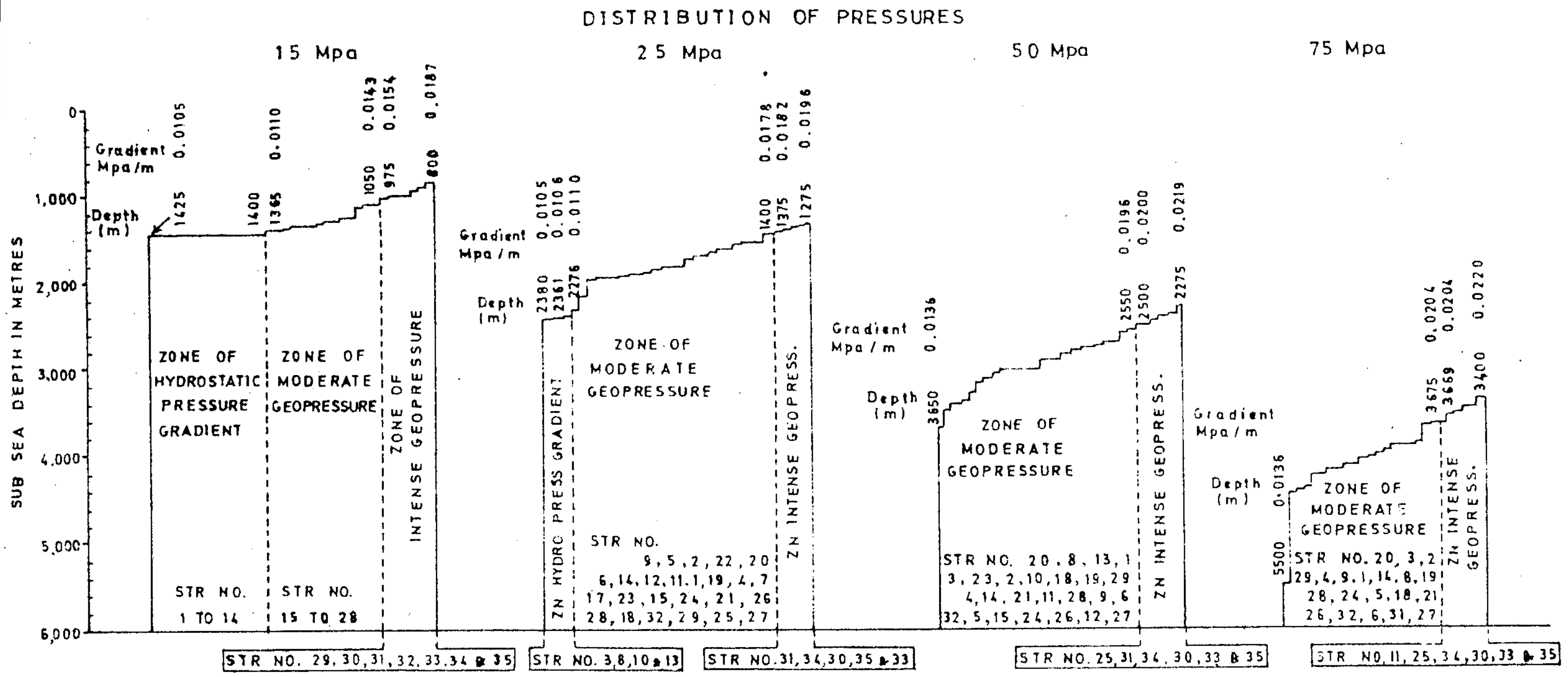
Figure 36— Drilling/seismically predicted formation pressure distribution of 50 MPa at various depths. (after Raza at el, 1980, modified).



PRESSURE GRADIENT AND MUD WEIGHT EQUIVALENTS FOR 75 Mpa PRESSURE AT VARIOUS DEPTHS.

Depth (Metre)	Pressure Gradient (Mpa m)	Equivalent mud weight (ppg)
- 3500	0.0214	18.20
- 3600	0.0208	17.69
- 3700	0.0203	17.26
- 3800	0.0197	16.78
- 3900	0.0192	16.36
- 4000	0.0187	15.93
- 4100	0.0183	15.63
- 4200	0.0178	15.20
- 4300	0.0174	14.86
- 4400	0.0170	14.52
- 4500	0.0167	14.26
- 4600	0.0163	13.97
- 4700	0.0159	13.58
- 4900	0.0156	13.27
- 4900	0.0153	13.02
- 5000	0.0150	12.76
- 5100	0.0147	12.51
- 5200	0.0144	12.29
- 5300	0.0141	12.03
- 5400	0.0139	11.86
- 5500	0.0136	11.60

Figure 37— Drilling/seismically predicted formation pressure distribution of 75 MPa at various depths. (after Raza at el, 1980, modified).



NOMENCLATURE

1. W. JALPARI NO. 3	7. DHAK -1	13. DABBO CREEK - 1	19. W. JALPARI - 1	25. ASTOLA ISLAND	31. STR. IX
2. W. JALPARI NO. 2	8. DHAK - 2	14. STR. V	20. S. HARO & MIANI	26. STR. II & VII	32. STR. XII
3. STR. VII (PAKCAN-1)	9. STR. VI (IM-AI)	15. KARACHI - 1	21. S. W. ORMARA	27. PASNI	33. S. KAPPAR
4. STR. III	10. KARACHI SOUTH A - 1	16. KARACHI - 2	22. PAITIANI CREEK - 1	28. S. W. JALPARI	34. N. PISHU KHAN
5. STR. IV	11. STR. I (IM-BI)	17. JALPARI (I-A)	23. GARR KOH -1	29. CHURMA	35. S. E. KAPPAR
6. STR. X	12. KORANGI CREEK - 1	18. SOUTH CHUR	24. STR. XI (IM - CI)	30. N. CHUR	

Figure 38— Formation pressure histogram showing classification of structures falling in the range of hydrostatic, moderate and intense geopressure.

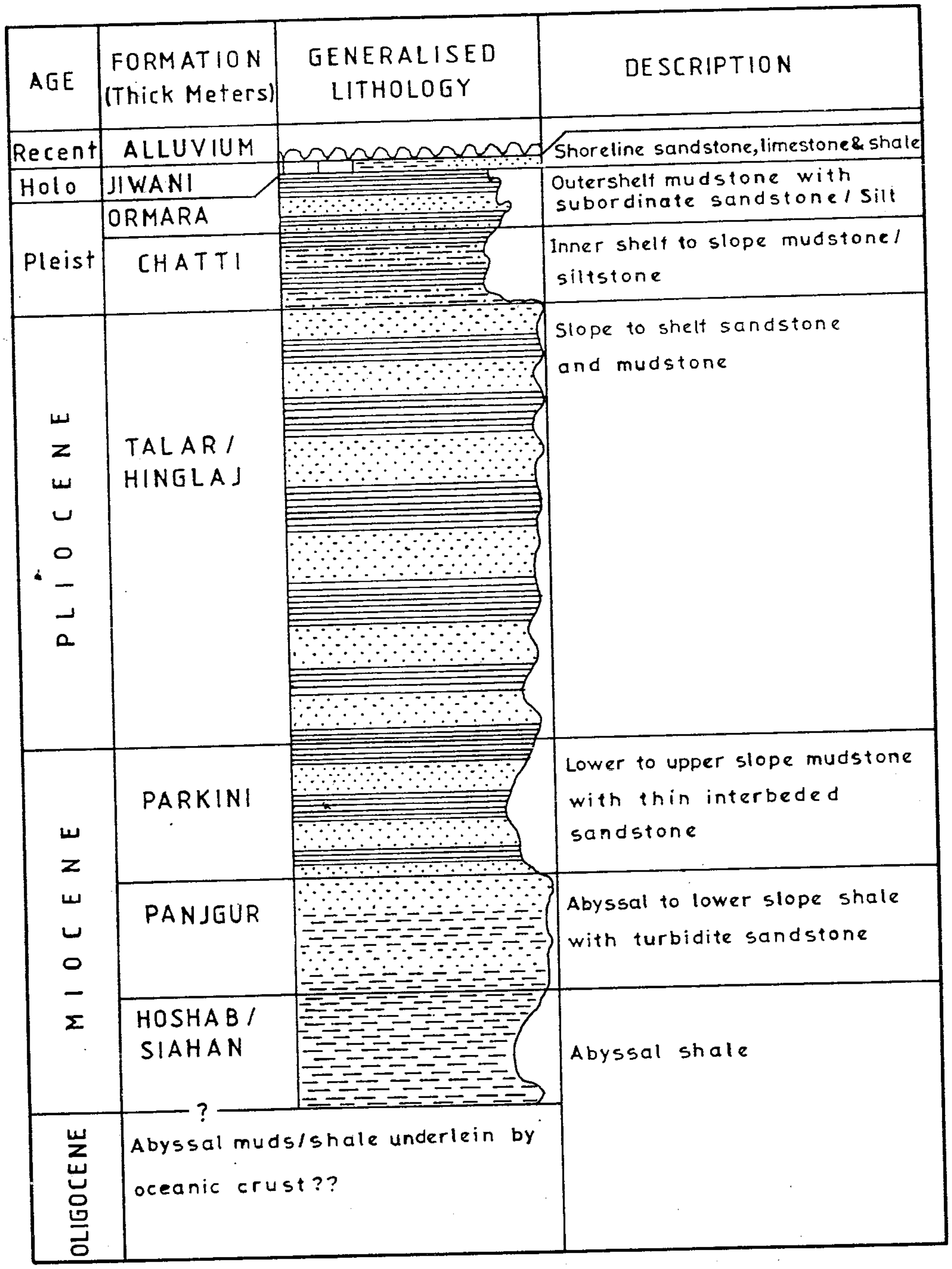


Figure 39— Generalized stratigraphy of Makran offshore. (after Harms et al, 1982, modified).

Parkini Formation.— The formation consists of thick slope mudstones with thin interbeds of sandstone. It is less widely distributed than the underlying Panjgur formation. The thickness increases toward the coast (Figure 50).

The formation is within oil and gas window in most of the area (Figure 51). The muds are rated as good source rocks, TOC of onshore surface samples ranges from 0.46% to 0.98% (Alam, 1986). The thick muds can also serve as excellent seal over the Panjgur sandy accumulators.

Talar/Hinglaj Formation.— The formation is composed of slope to shelf sandstones and mudstone rythms of several

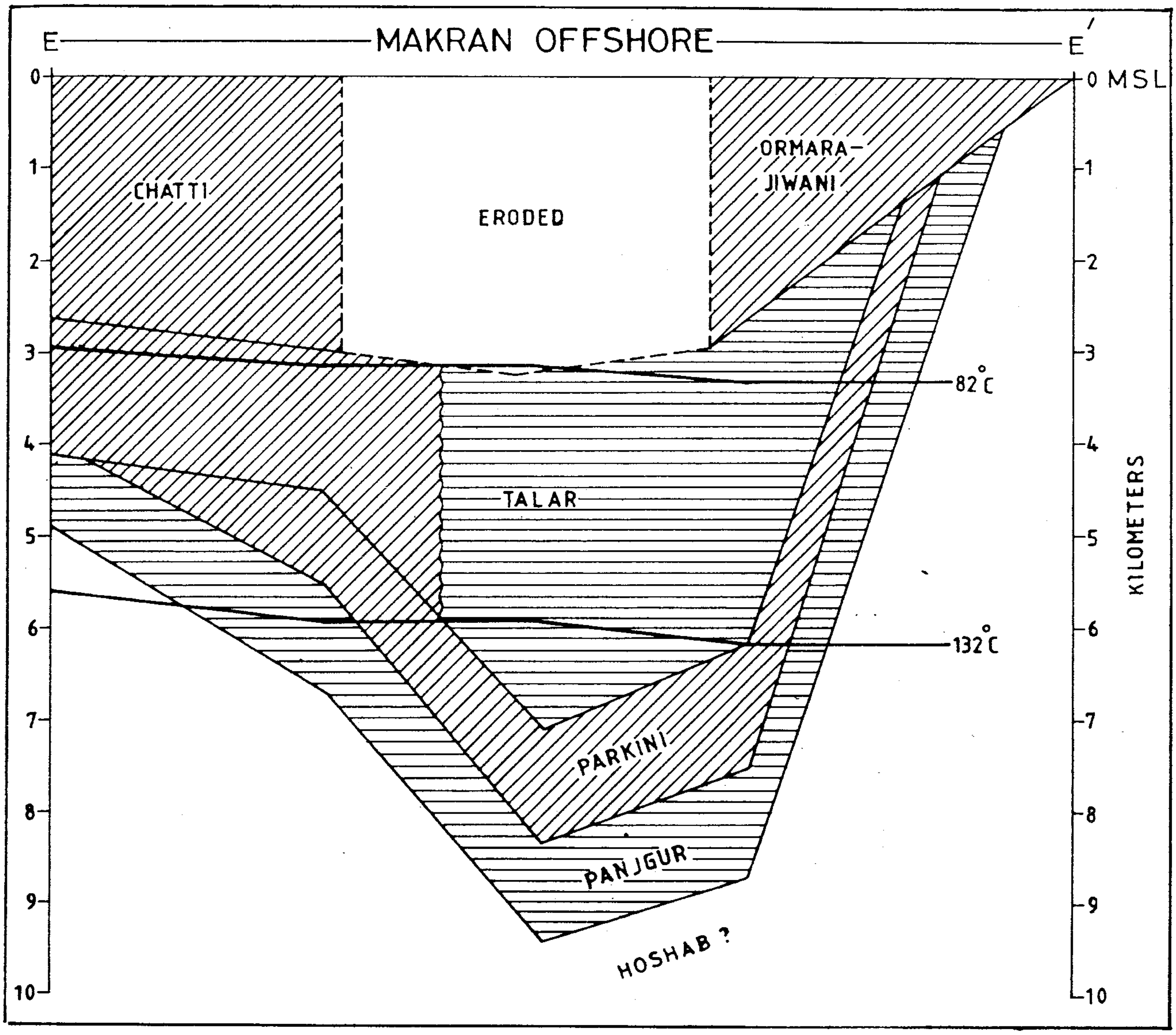


Figure 40— Schematic cross-section along line EE', Makran, with oil and gas window. For location see Figure 32.

hundred metres alongwith subordinate packets of conglomerate. The formation is more widely distributed than the underlying Parkini formation in some parts of the basin. The depocentre lies in the middle of the basin. The dominant sand facies grades into a dominant mud facies when traced from north to south (Figures 45-48, 52).

The formation is within oil window in most of the area (Figure 53). The TOC of onshore surfacce samples (shelf facies) ranges from 0.33% to 0.57% (Alam, 1986). The sands exhibit excellent reservoir properties. High porosity, traceable regional facies changes, adequate thickness and source-reservoir-seal trilogy make the formation an interesting objective of exploration for stratigraphic traps (Figures 45-48, 52).

Chatti Formation.— The formation consists of shelf to slope calcareous mudstone-siltstone. The unit is developed only in the western part of the basin, where it is widely distributed (Figures 45-46, 54). The thick accumulation of Chatti muds have probably obscured the present day trench (Figure 2).

Ormara Formation.— The formation is composed of mudstone/sandstone/siltstone. It conformably overlies the

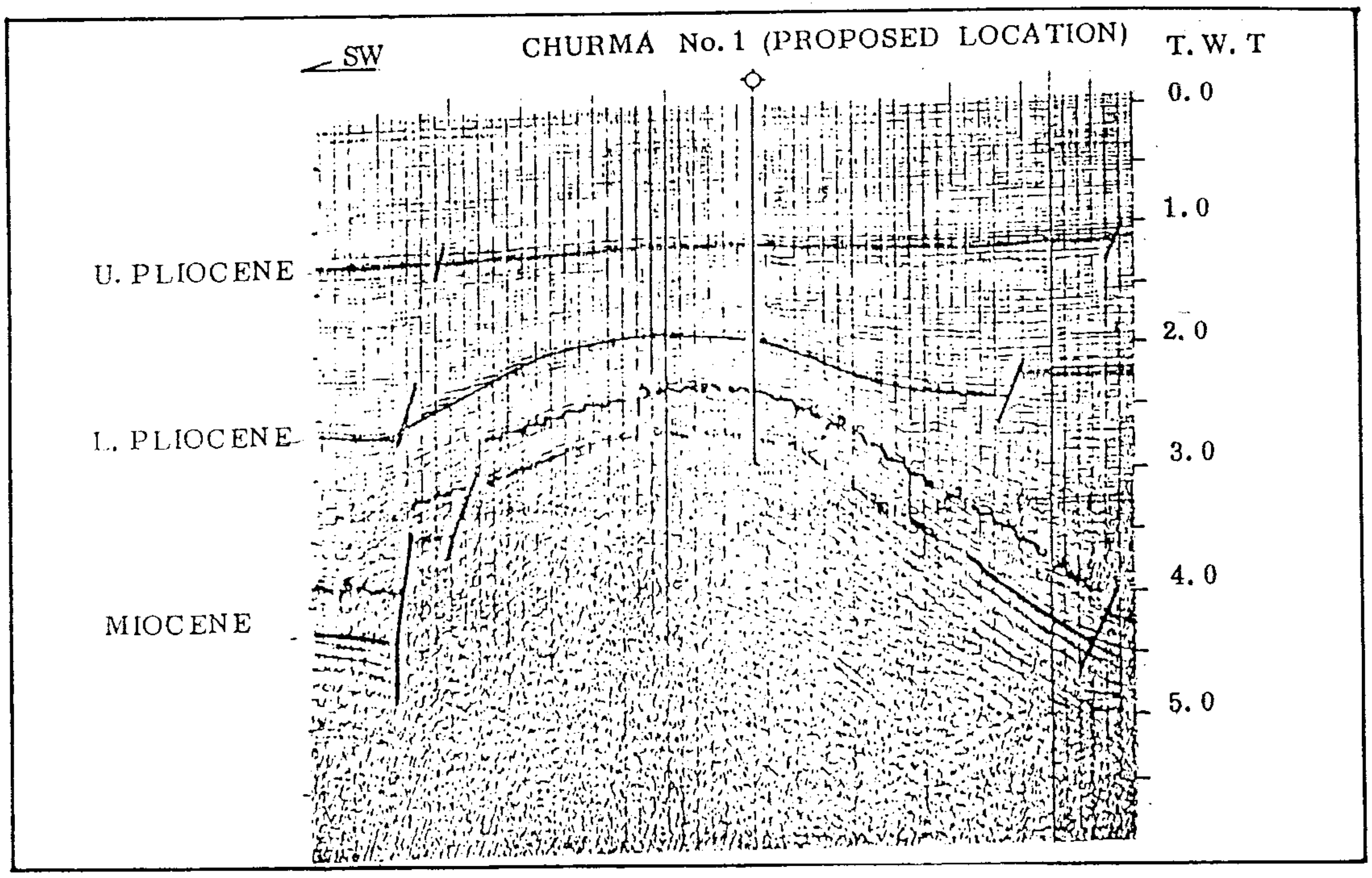


Figure 41— Profile along line E showing structure developed either by local stressess related to Las Bela fault or by deep-seated core of mobile mud or combination of the two (Source: Marathon). For location see Figure 32.

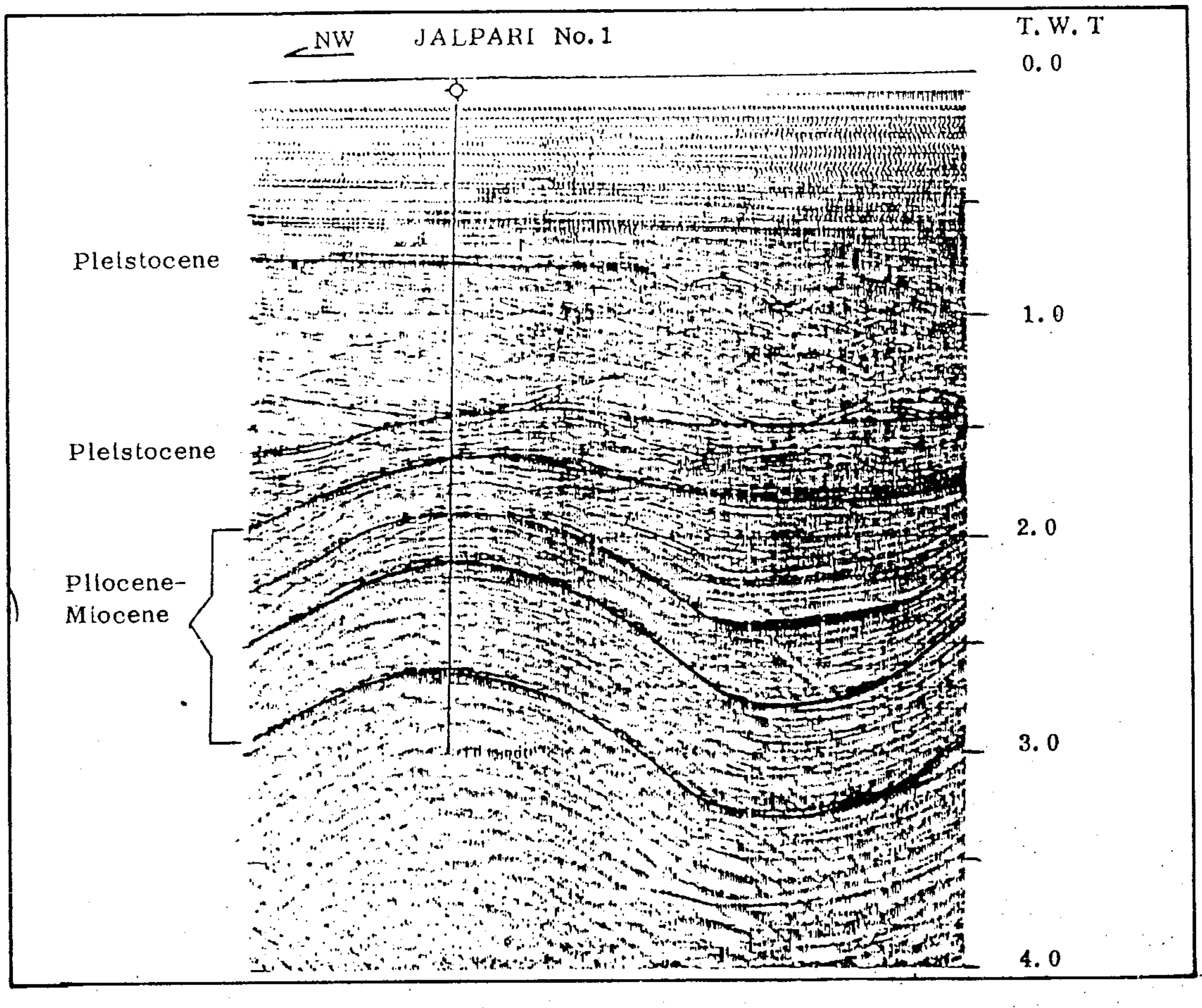


Figure 42— Profile along line F showing a fold developed by mud diaprism and buried by Late Pleistocene (Source: Marathon). For location see Figure 32.

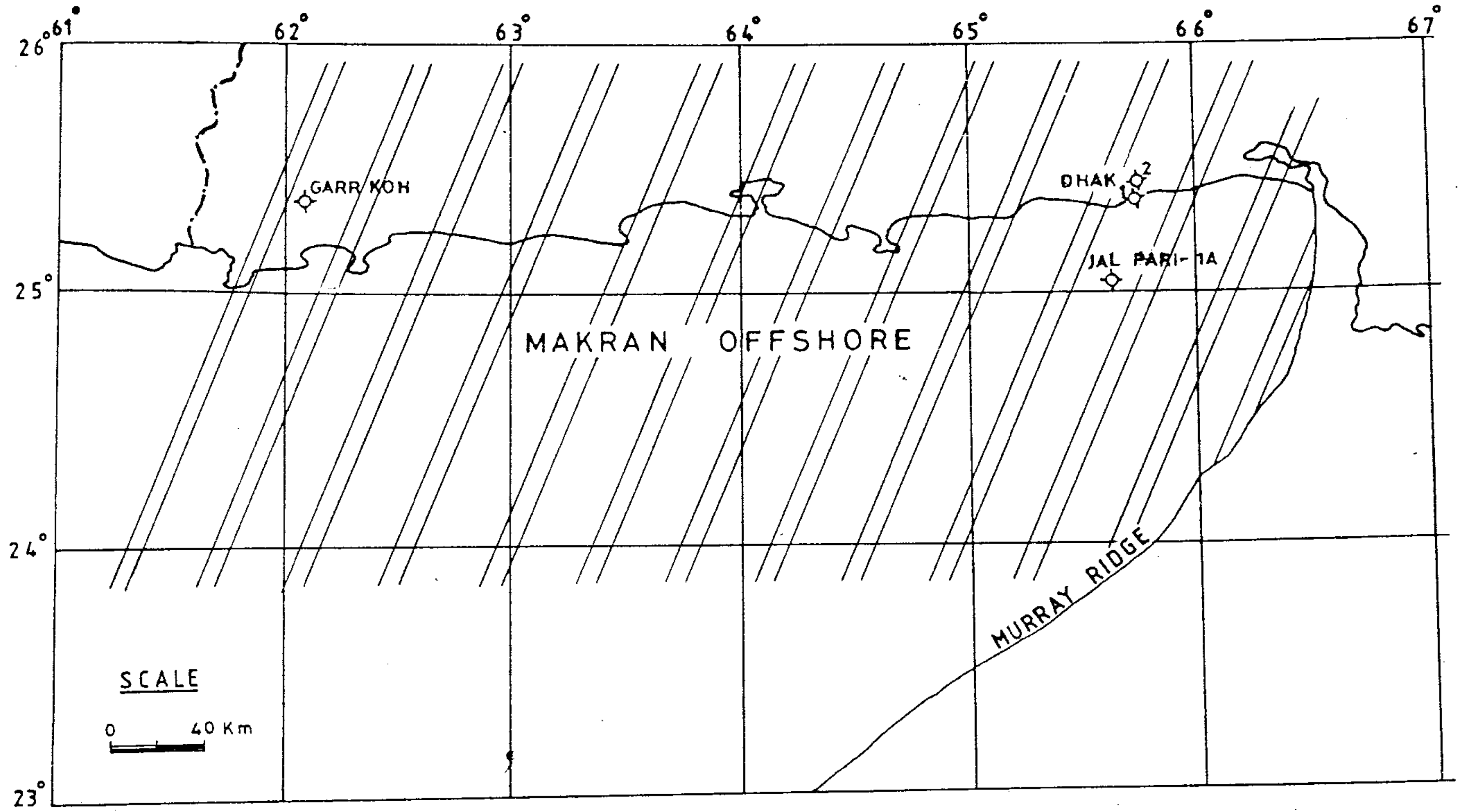


Figure 43— Lithofacies map of Hoshab formation.

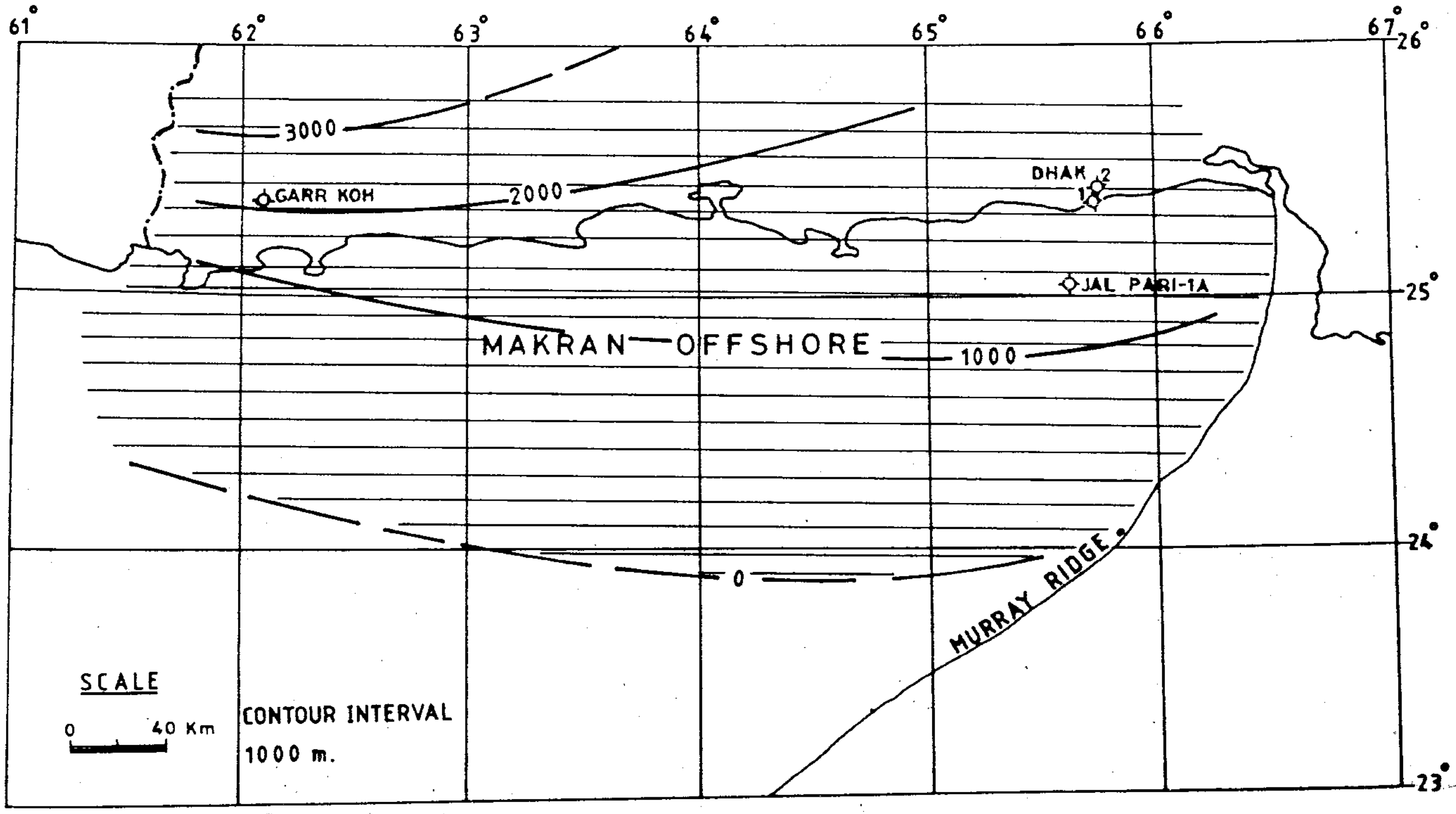


Figure 44— Thickness and lithofacies map of Panjgur formation.

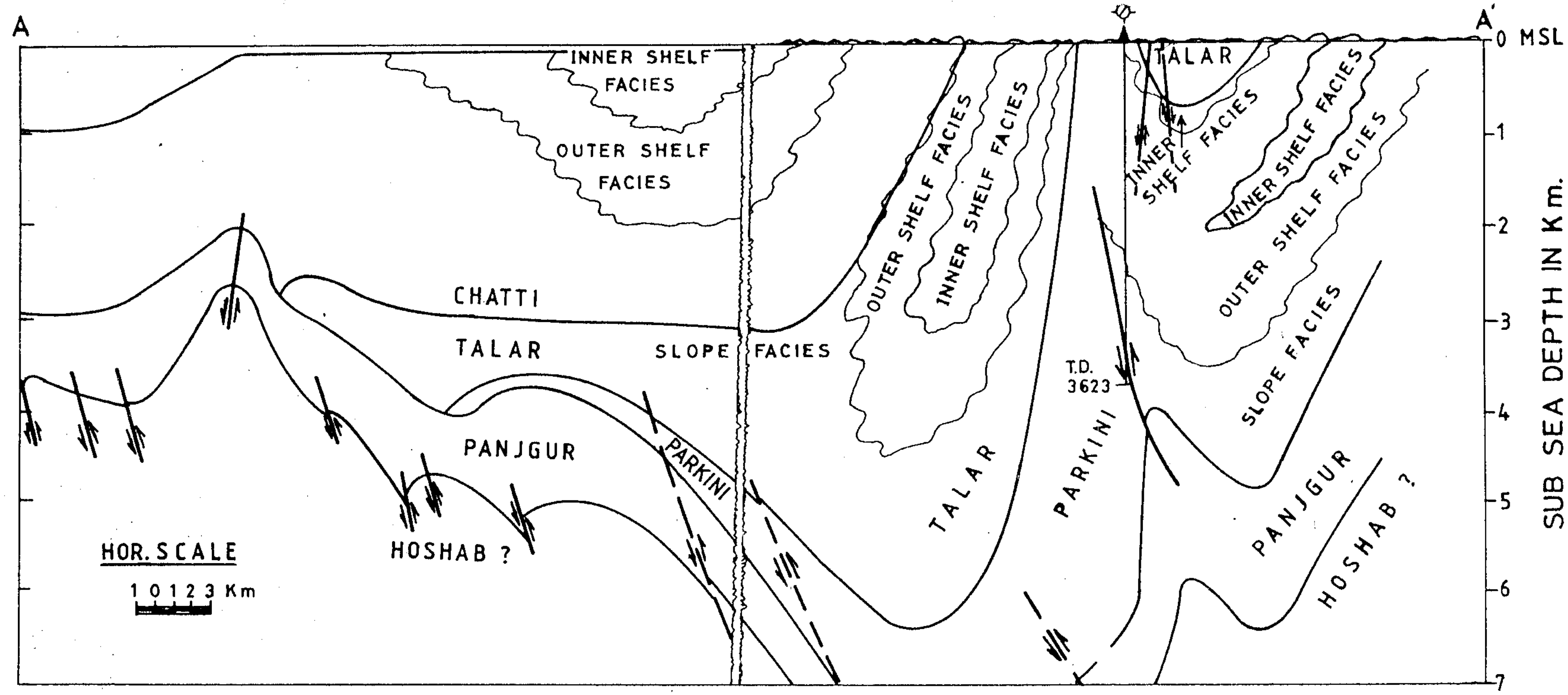


Figure 45— Structural cross-section along line AA', Makran, with facies distribution of different formations. (after Harms et al, 1982, modified). For lcoation See Figure 9a.

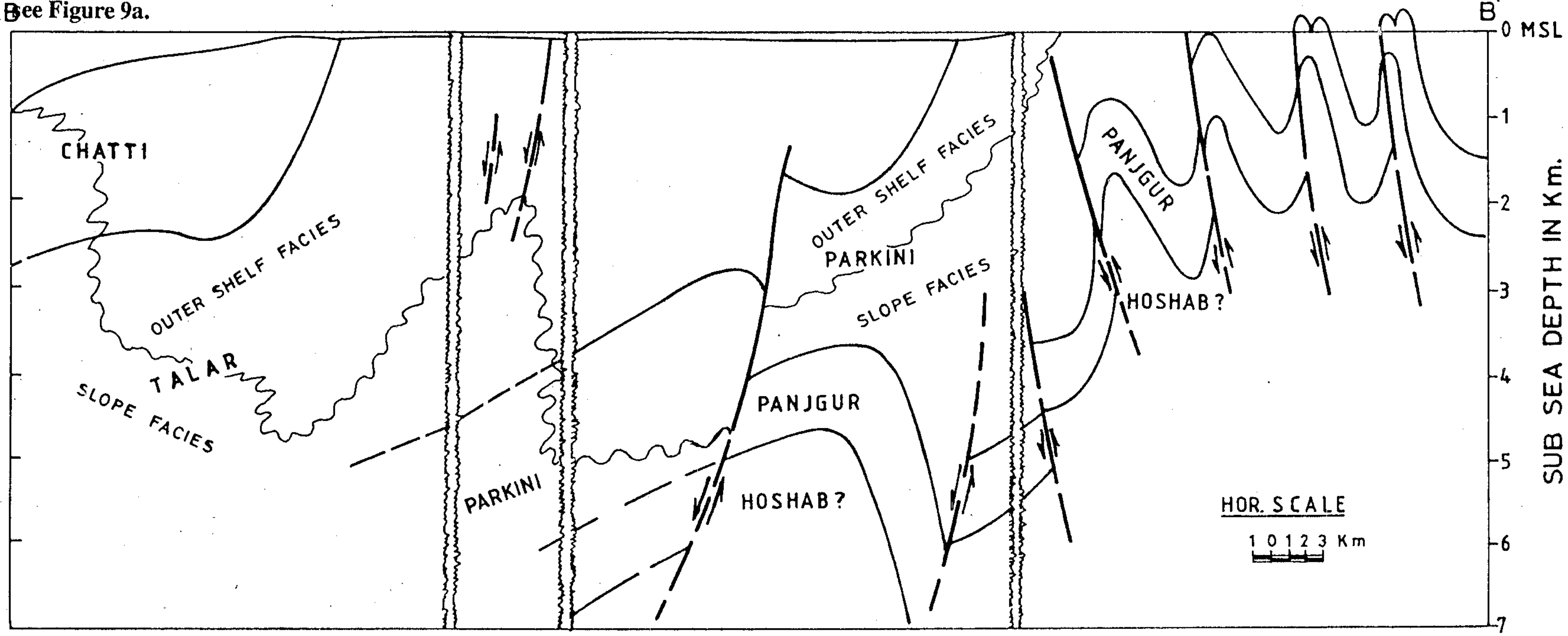


Figure 46— Structural cross-section along line BB', Makran, with facies distribution of different formation (after Harms et al 1982, modified). For location

Figure 46— Structural cross-section along line BB', Makran, with facies distribution of different formation [illegible] 982, modified). For location

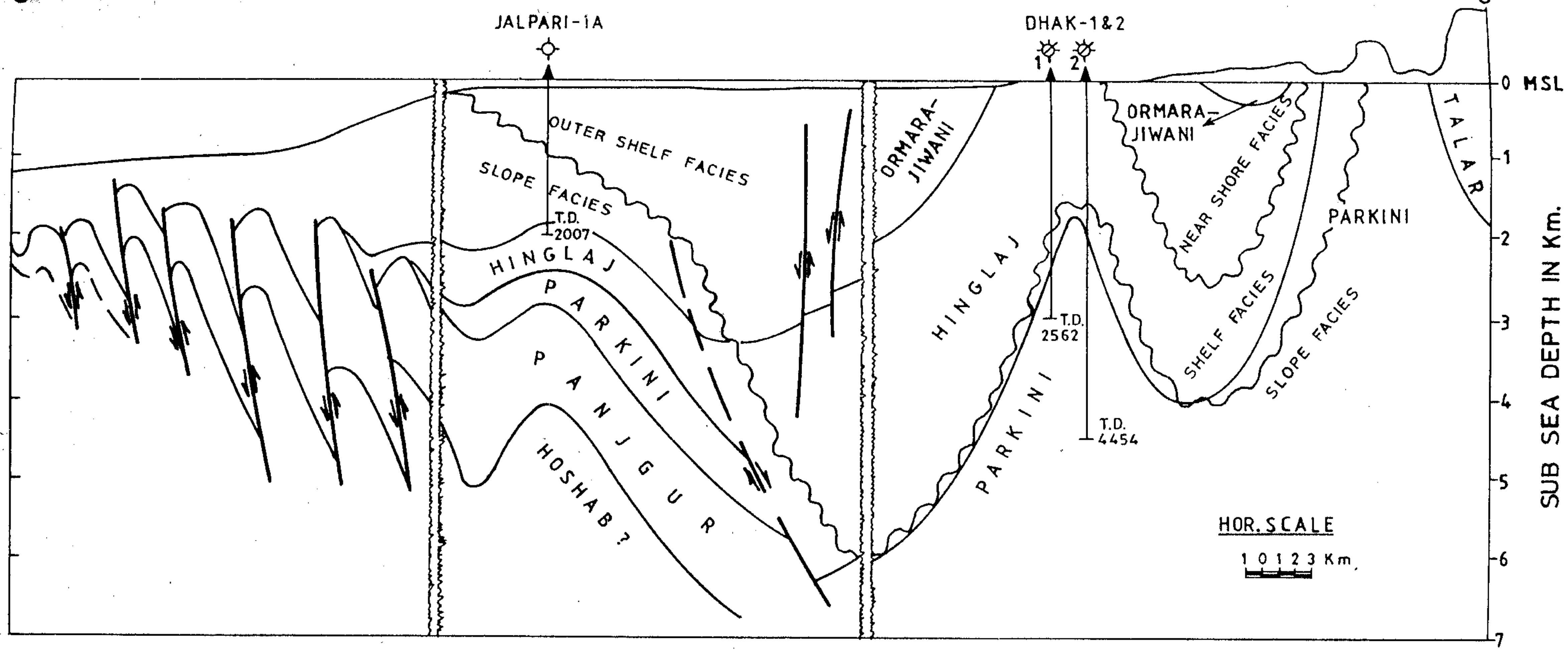
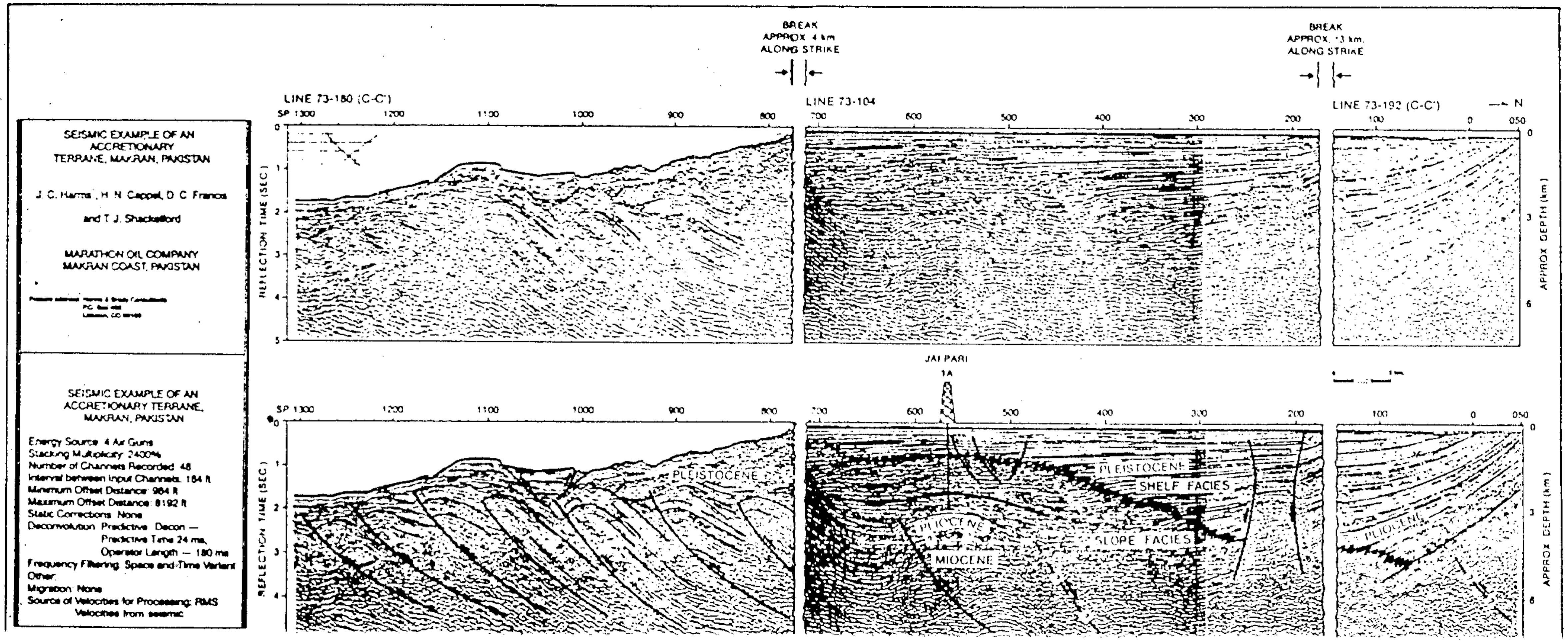


Figure 47— Structural cross-section along line CC', Makran, with facies distribution of different formations (after Harms et al, 1982, modified). For location see Figure 9a.



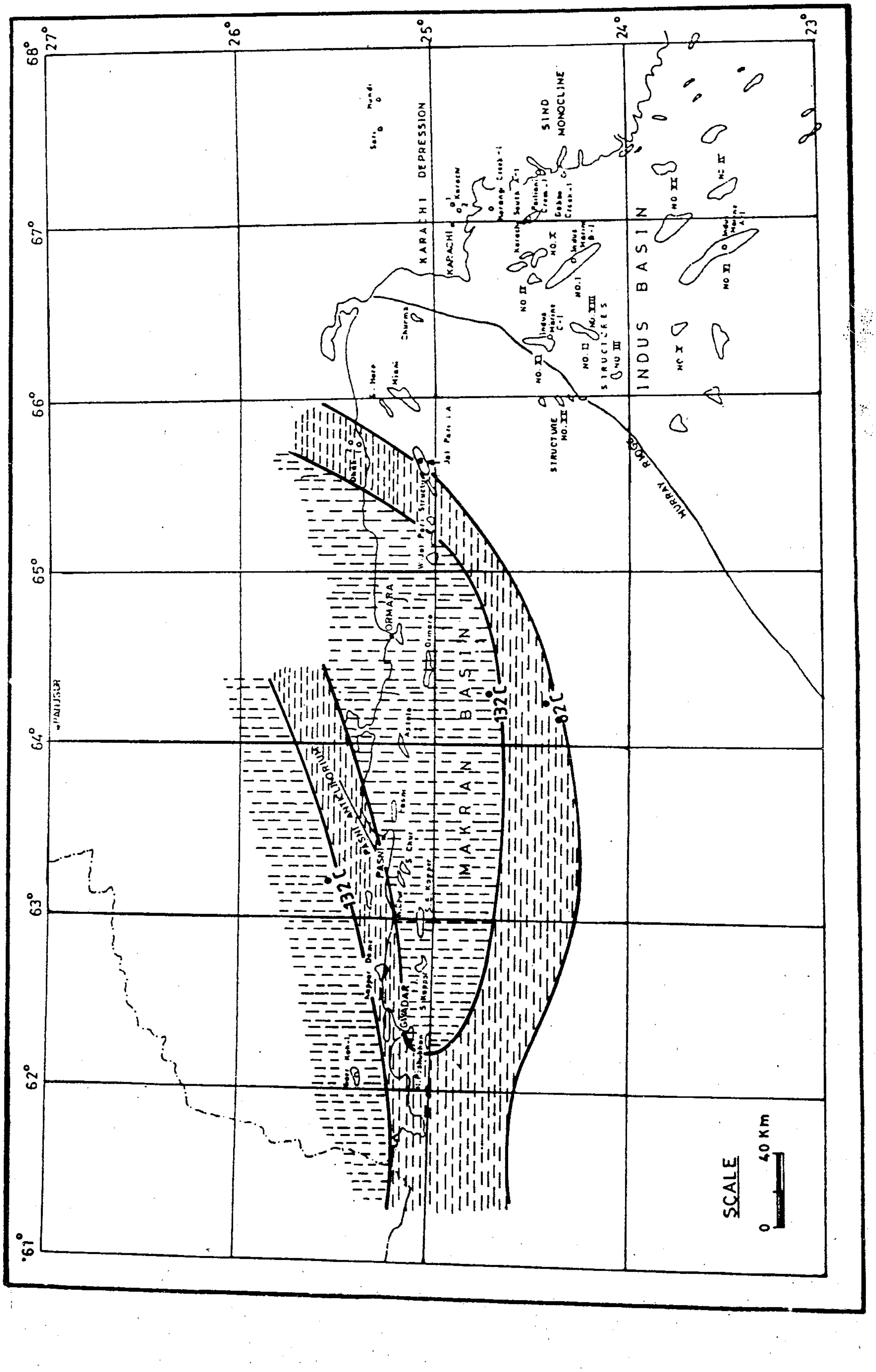


Figure 49— Oil and gas window at the base of Panjgur formation with seismically delineated structures (some of the structures are mapped at Panjgur level).

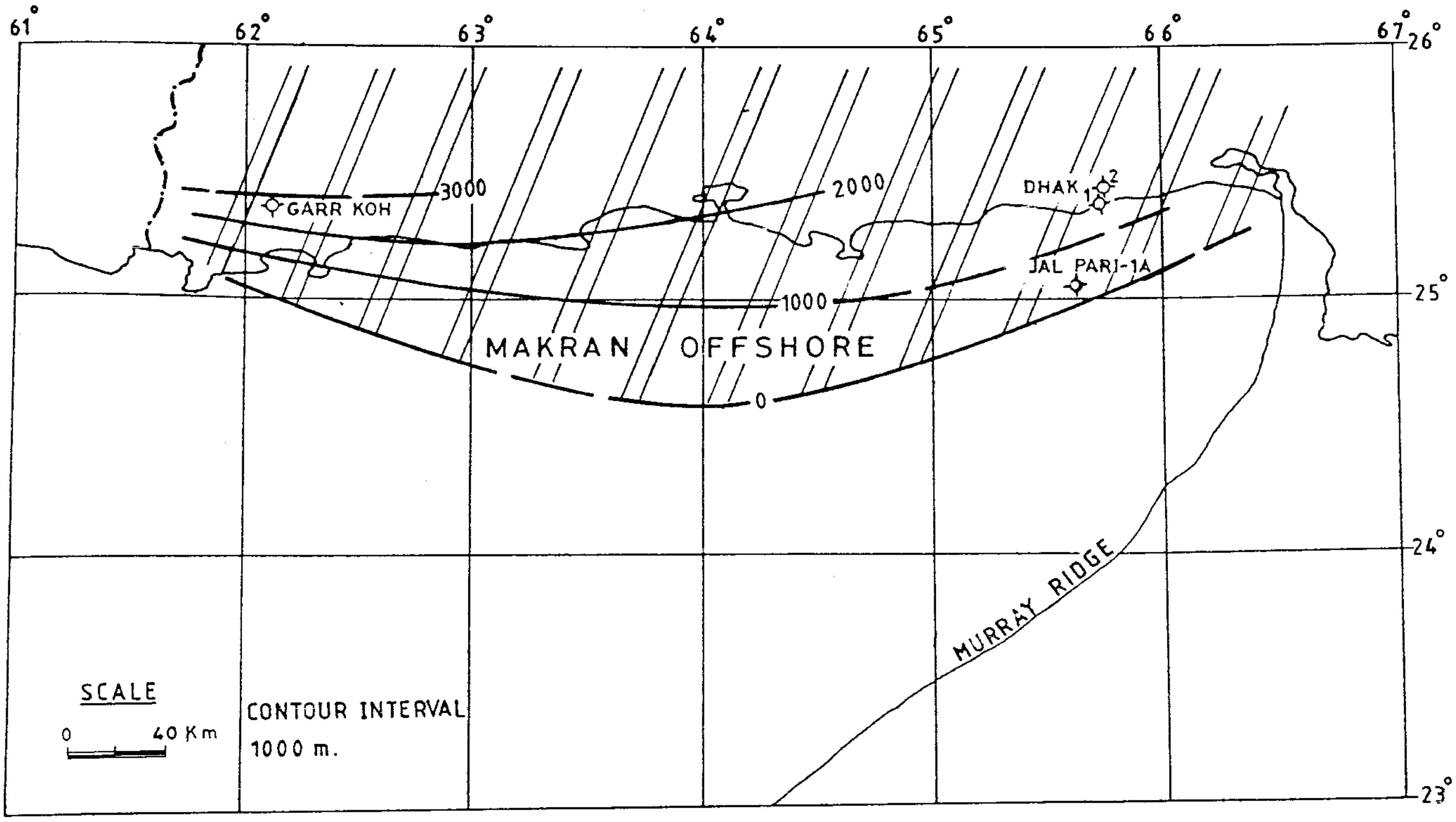


Figure 50— Thickness and lithofacies map of Parkini formation.

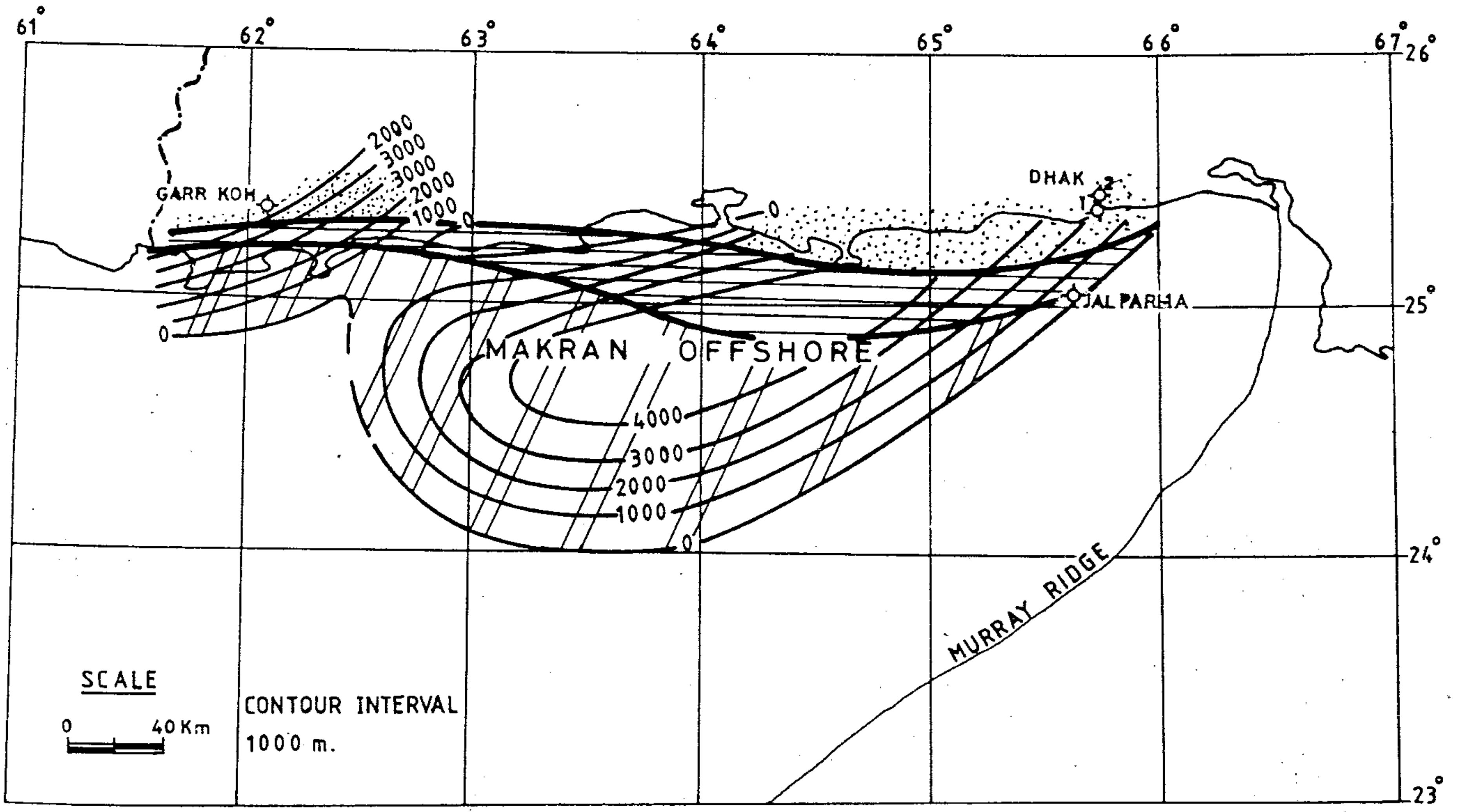


Figure 52— Thickness and lithofacies map of Talar/Hinglaj formation.

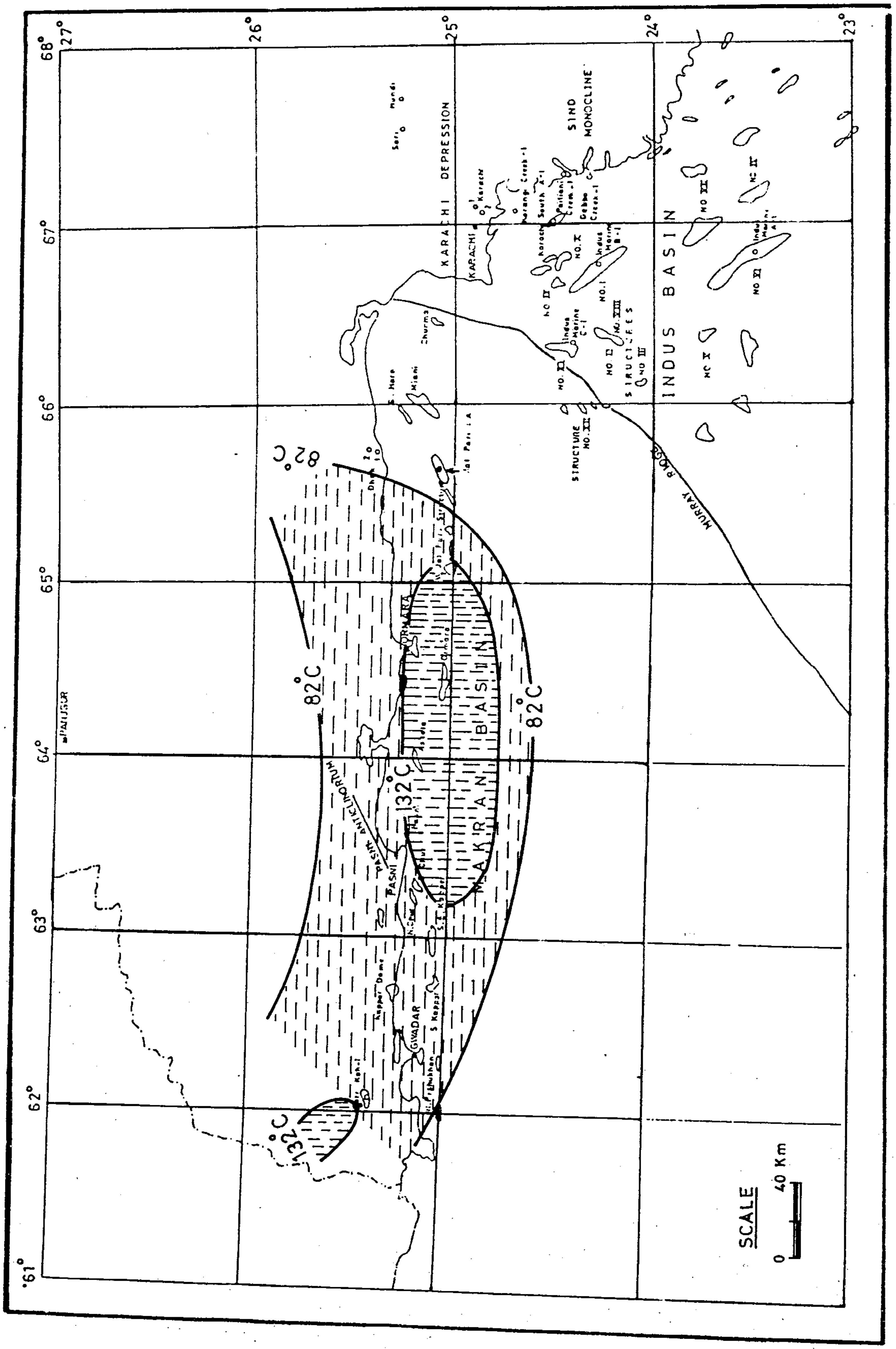


Figure 51— Oil and gas window at the base of Parkini formation.

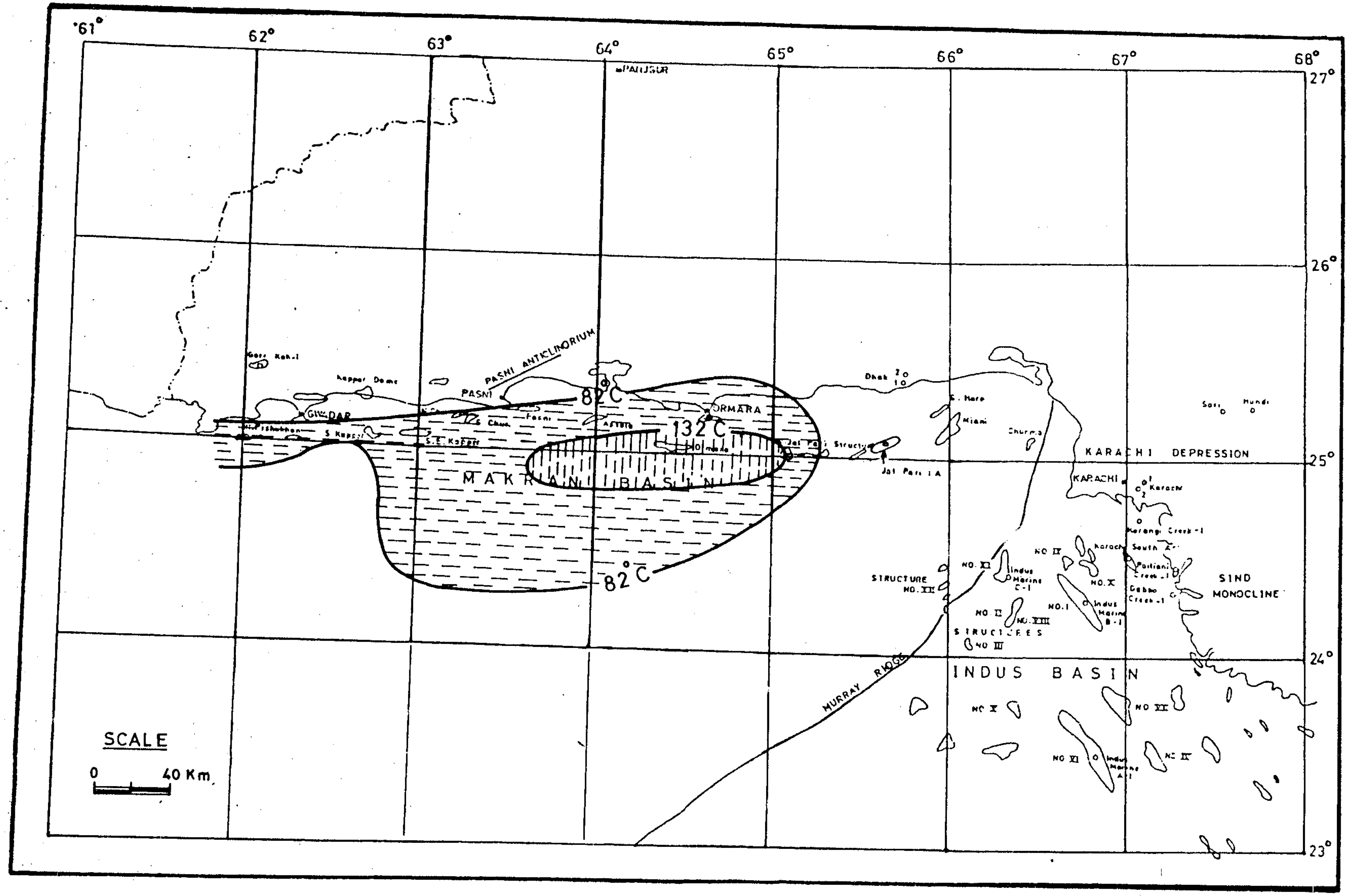


Figure 53— Oil and gas window at the base of Talar/Hinglaj formation with seismically dlineated structures (some of the structures are mapped at Talar/Hinglaj level).

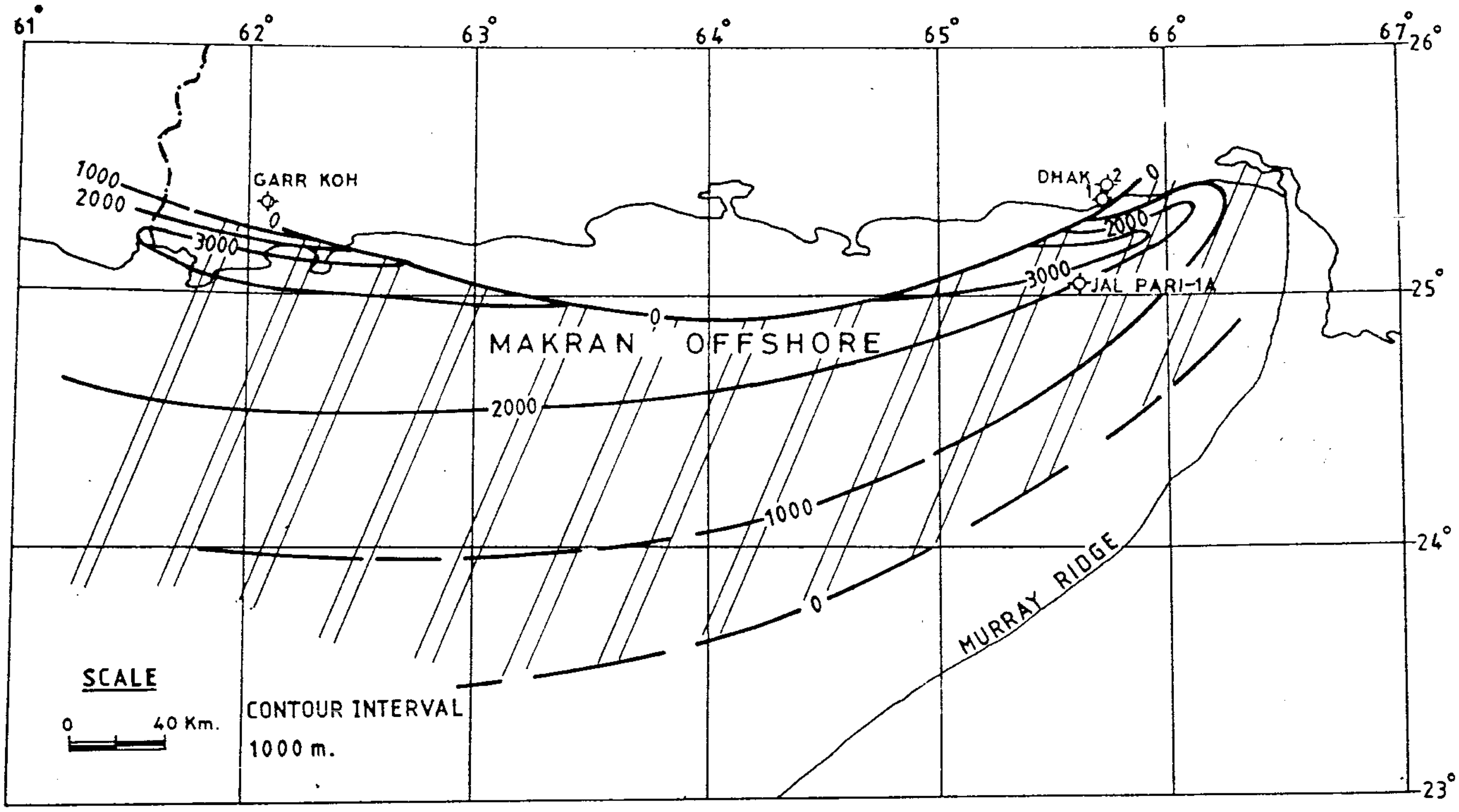


Figure 54— Thickness and lithofacies map of Chatti-Ormara- Jiwani formation.

Hinglaj formation in the east. Its development in the western part of offshore is doubtful (Figures 47-54).

Jiwani Formation.— The formation is composed of limestone, sandstone and shale. It is thinly developed in the east along the shoreline.

Prospects

The area has not received due attention from oil companies. Hunt Oil (1956) and Marathon (1973-77) carried out seismic surveys in the area. Shell International (1973) also performed reconnaissance work in the deep water covering Makran offshore (Figure 31).

About 24 structures have been located by seismic surveys (Figure 32). The structures are generally oriented East-West except near Murray ridge where axial direction changes to North-South. Generally, southern limbs of the structures are faulted. Stratigraphic traps may also exist in the offshore area within Talar/Hinglaj formation.

Four wells have been drilled to explore the hydrocarbon potential of the area, of these only one well has been attempted offshore (Table 1). None of these wells could reach target due to technical problems or high pressure. However, gas shows were encountered in Garr Koh-1 which was drilled off-structure and merits re-drilling (Figure 45).

Source rock and maturation studies indicate the possibilities of both oil and gas generation in the area. The gas-prone reputation of the area is perhaps due to the fact that deeper Panjgur accumulators are completely protected by thick Parkini muds through which only gas could escape.

Overpressures are developed in the area which are related to tectonics and sedimentation. Shale diaprism, rapid sedimentation and earthquakes could be the contributing factors to localised overpressuring (Figures 41-42). The areas west of Pasni anticlinorium and close to Murray ridge are suspect locations for over pressuring at shallow depth. Recent studies indicate that geopressures of high magnitude are restricted to a few localised areas which have been demarcated and the geopressures in most of the areas are within controllable limits (Figures 33-38).

HYDROCARBON RESOURCE

The following two methods have been applied to estimate the hydrocarbon potential of offshore region.

Volumetric Method

The Makran offshore basin is classified as Fore-arc Subduction Basin (Riva, 1983) and the Indus offshore basin falls in the category of Extra-continental Downwarp to Small Ocean Basin combined with Tertiary Delta basins (Klemme, 1980). Some of the producing analogues are: Talara and North Ceram (Makran); Assam- Bangladesh, Po, East Italy, Molasse, Ploesti (Indus); Missisippi, Mackenzie, Niger, Mahakam, Nile, Po, North Borneo (Indus Delta); and Sirte, Suez, Dnieper-Donetz, Tsaidam, Gulf of Siam, Central African grabens (Kutch). The minimum average for all the aforementioned types of producing basins is 90,000 barrels of oil or equivalent gas per cubic mile of sediment. A rough estimation using volumetric method based on the aforementioned analogues is given below:

Volume of sedimentary rocks. = 185,000 cubic miles

Average amount of recoverable hydrocarbons per cubic mile. = 90,000 barrels

Ultimate recoverable hydrocarbons. = 185,000 x 90,000
i.e. 16.6 billion barrels oil or equivalent gas.

Oil : gas ratio = 50 : 50
Potential oil = 8.325 billion barrels
Potential gas = 50 TCF

Geologic Analogue Method

To check the above estimation another procedure which is a modification of Hendricks Geologic-Analogue method (Hendricks, 1965) and based on the study of the estimated productive area and potential oil resources of subsea shelves and slopes of the world (Weeks, 1975), is applied and the results are as follows:

Moderately attractive nonbonanza class area = 58,000 sq mi

Effective productive area = 58,000 sq mi x 1.5%
= 870 sq mi
or 556,800 acres.

Per acre yield in the moderately attractive nonbonanza class = 25,000 bbl/acre

Ultimate recoverablel hydrocarbons = 14 billion barrels oil or equivalent gas.

In summary, the expected potential of ultimate recoverable hydrocarbons in offshore Pakistan would be in the range of 14 to 16 billion barrels. This figure, however is only an indicator of the likely potential and is based on most rough methods of estimation.

CONCLUDING REMARKS

Offshore region of Pakistan is filled with thick marine sedimentary rocks of varying lithologies, which commonly form source-reservoir-seal trilogies. Basins similar to Pakistan offshore basins have been mostly producing hydrocarbons. Although there is not a single discovery in this region, yet existence of thick sediments, seeps/shows in and around the region and suitable geotherms furnish positive evidence of occurrence of hydrocarbons. Surveys have also identified potential traps, both structural and stratigraphic. It is, therefore, imperative that the search for undiscovered hydrocarbons be accelerated by intensifying geological and geophysical investigation, including reprocessing of existing seismic using latest techniques and conducting more seismic surveys.

Special mention is made to the occurrence of thick turbidites (Panjgur) in Makran offshore and coastal onshore area. Turbidites are of special interest to petroleum explorer because their deposition takes place in oxygen deficient environment where supply of organic detrital is abundant. Sand reservoirs are located within turbidite sequence close to organic rich muds, hence migration comes handy and efficient. India's discoveries in Krishan-Godavari basin are attributed to the occurrence of turbidites (Rangaraju, 1988).

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