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Petroleum Geology of Kirthar Sub-basin and Part of Kutch Basin

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ABSTRACT

Synthesis of data and mapping of lithofacies in Kirthar sub-basin and part of Kutch basin indicates that the partially producing Kirthar sub-basin had sedimentary environments conducive to growth and preservation of organic matter, maturation, generation and accumulation of hydrocarbons. Source-Reservoir-Seal trilogies exist within Late Mesozoic-Tertiary sedimentary sequence in onshore and offshore areas of the Kirthar sub-basin and Kutch basin.

INTRODUCTION

The study area lies between latitude 23° to 28° north and longitude 66° to 70° east, and occupies about 198,960 square kilometres of Indus onshore and offshore basin. It is divided into four physiographic/tectonic features, Kirthar and Karachi depressions, Sind platform, and Indus offshore (Figure 1).

The oil explorers have been looking for hydrocarbons in the area for the past 4 decades, and their efforts have resulted in the discovery of more than 38 oil and gas fields and about 34,000 line kilometres of multifold seismic coverage (Figure 2).

Although in the past, regional geological studies were carried out by Stanvac (1958-59), Sun Oil (1959-65), Hunt Oil (1958-59) and Tidewater (1961), but their interpretation may not be valid now in the face of recent exploration activity of UTP and OGDC. This warrants the reconstruction of regional geological framework for better understanding of the petroleum geology of the area.

The present paper has the main objective of synthesizing the regional setting of Cretaceous to Miocene formations and evaluating petroleum potential of the Kirthar sub-basin and a part of Kutch basin. In this context various thickness, lithofacies, ratio, and isogeothermal maps and regional correlation diagrams with oil and gas window are prepared based on the data pertaining to 66 selected wells and surface sections (Figure 3). The lateral extent, geometry and lithologic variations of the formations have been interpreted through the study of well logs, surface sections, geological reports and personal observations of the region. In certain wells the thickness and other stratigraphic information of various geological formations have been corrected with the help of wireline data. This synthesis is based on information in HDIP's reports entitled "Sedimentary patterns and oil and gas prospects of southern Indus basin" (1985), and "Petroleum zones of Pakistan" (1987).

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GENERALIZED STRATIGRAPHY

Exposed rocks in the sub-basin include Precambrian basement and Mesozoic to recent sedimentary rocks (Figure 4).

Triassic to Tertiary rocks have been drilled in the platform region of the sub-basin (Figure 5). Out of these, Cretaceous and Tertiary strata have been studied in detail.

The sedimentary fill is of varying thickness averaging about 5,000 metres with a maximum of about 10,000 metres in deeper part of the sub-basin (Figure 6).

Triassic

The Triassic rocks comprise shale and sandstone deposited in shallow marine environment.

Jurassic

The Jurassic rocks consist of shallow marine limestone in the upper part and clastics in the lower part.

Cretaceous

The Cretaceous sediments range from shales deposited in deep depressions overlain by bar-type sands in the basal part, through deep and shallow marine limestones, into thick sandstones in the upper part.

Paleocene

The Paleocene rocks are mostly shallow water clastics capped in most places by limestones. The environment of deposition ranged from fluviatile to deltaic and shallow

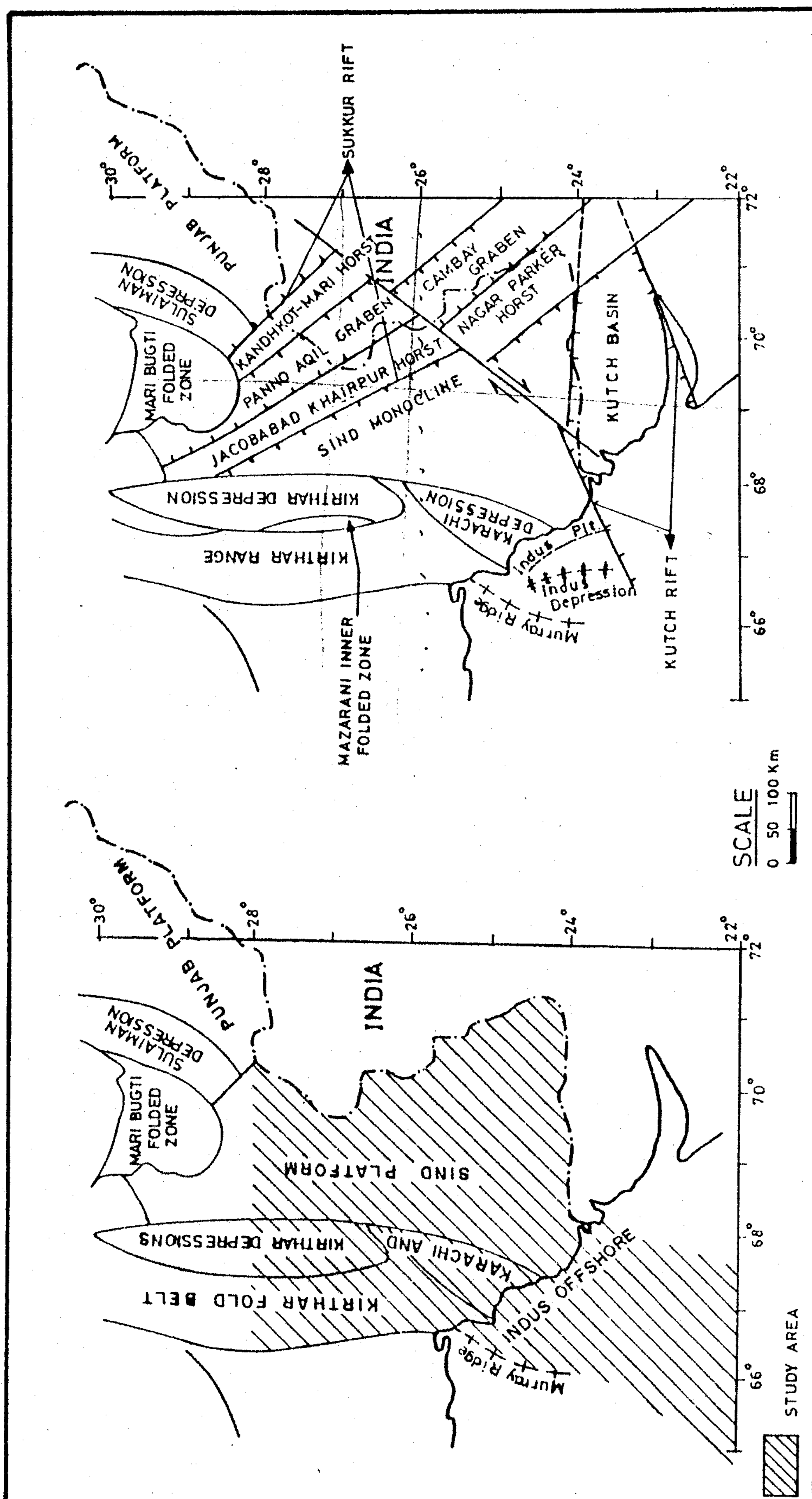


Figure 1—Location of study area showing physiographic/tectonic features and petroleum zones (Modified after Raza et al, 1987 and Abid & Siddiqui, 1984).

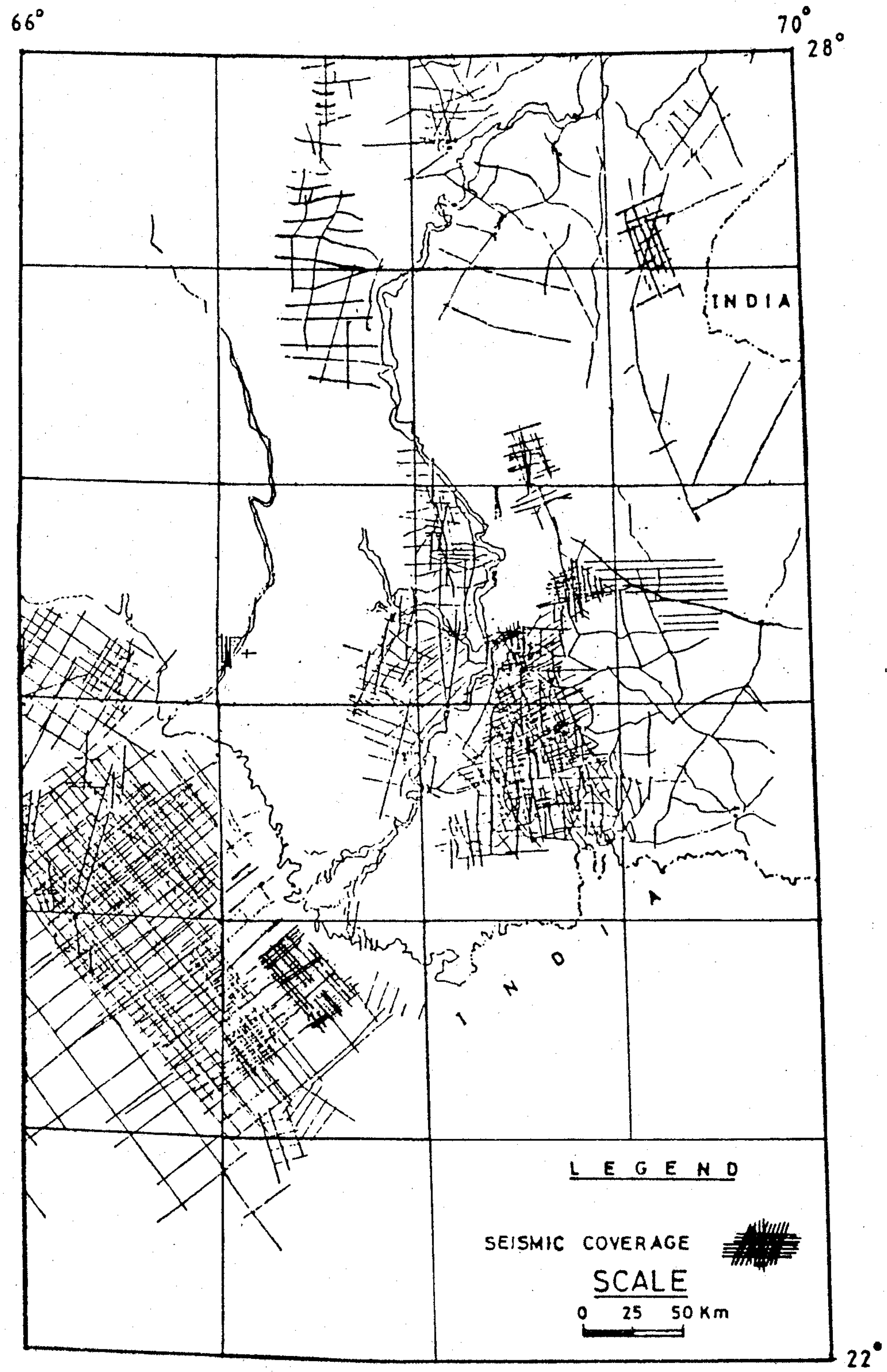
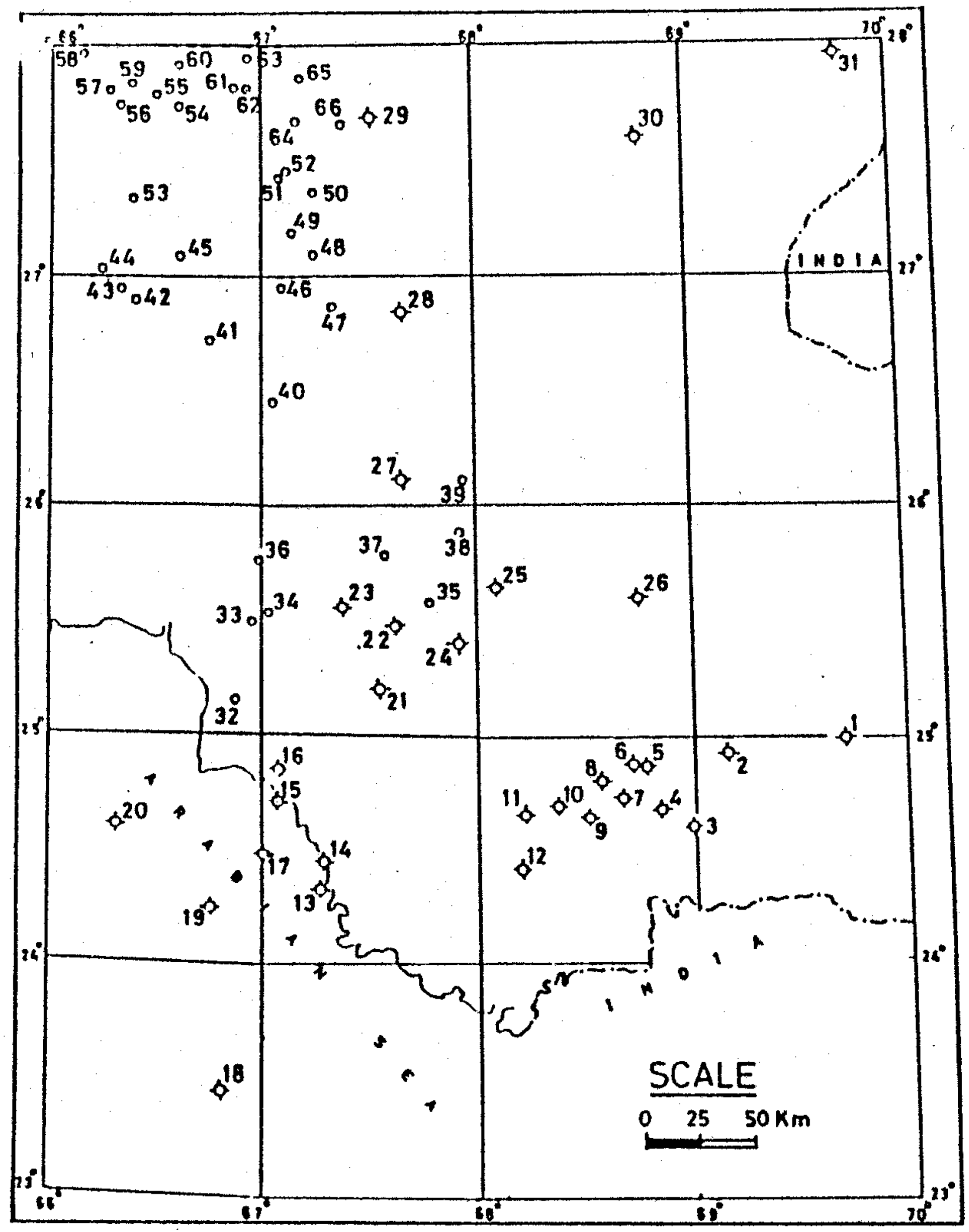


Figure 2—Multifold seismic coverage map, 1969–84 of Kirthar sub-basin (After Ali and Ahmed, 1985, unpub.).



Ref.No.	Well	Ref.No.	Well	Ref.No.	Surface Section	Ref.No	Surface Section
1.	Nabisar-X-1	21.	Sari Singh-1	37.	Kirthar Range	54.	Chor Jhal
2.	Digh-X-1	22.	Benir-1	38.	Ranikot area	55.	Jhek River
3.	Badin-X-1	23.	Kand-1	39.	Chat Nala & Bara Nai	56.	East of Nal in Igneous Complex
4.	Patar-1	24.	Sunbak-1	40.	Khunde Range	57.	Oosteri Nala
5.	Talhar-X-1	25.	Lakhra-1	41.	Khutti Jhal	58.	Gidar Dhor
6.	Laghari-1	26.	Dasori-1	42.	Tibbi River Valley	59.	Gameshi Nala
7.	Tarai-1	27.	Badhra-1	43.	Dhobi Jhal	60.	Kan Range
8.	Khaskheli-1	28.	Phulji-1	44.	Khuli Mountain	61.	Near Goru(Upper Nar River)
9.	Golarchi-1	29.	Mazarani-1	45.	Bohunbar	62.	Khori River
10.	Damiri-1	30.	Khairpur-1	46.	Kareji & Gaj River	63.	Near Confluence of Mula & Nar Rivers
11.	Mirpur Batoro-X-1	31.	Mari-X-1	47.	Eastern Gaj River	64.	South of Karkh (Photo Section)
12.	Jati-1		**Surface Section**	48.	Khurbi Nala	65.	Sund Area (Photo Section)
13.	Daboo Creek-1	32.	Pabuni Chowki	49.	Panwari Area	66.	South of Khenji River
14.	Patiani Creek-1	33.	Samalji Trail	50.	Wannahar Nala		
15.	Korangi Creek-1	34.	Pab Mountain	51.	Sanwar Area (Photo Section)		
16.	Karachi-2	35.	Kambhu Range	52.	Sanwar Area North (Photo Section)		
17.	Karachi South A-1	36.	Pab Range, Uthal to Shah Naran's Tomb.	53.	Hills North and South of Wadh		
18.	Indus Marine A-1						
19.	Indus Marine B-1						
20.	Indus Marine C-1						

Figure 3—Location of wells and surface sections

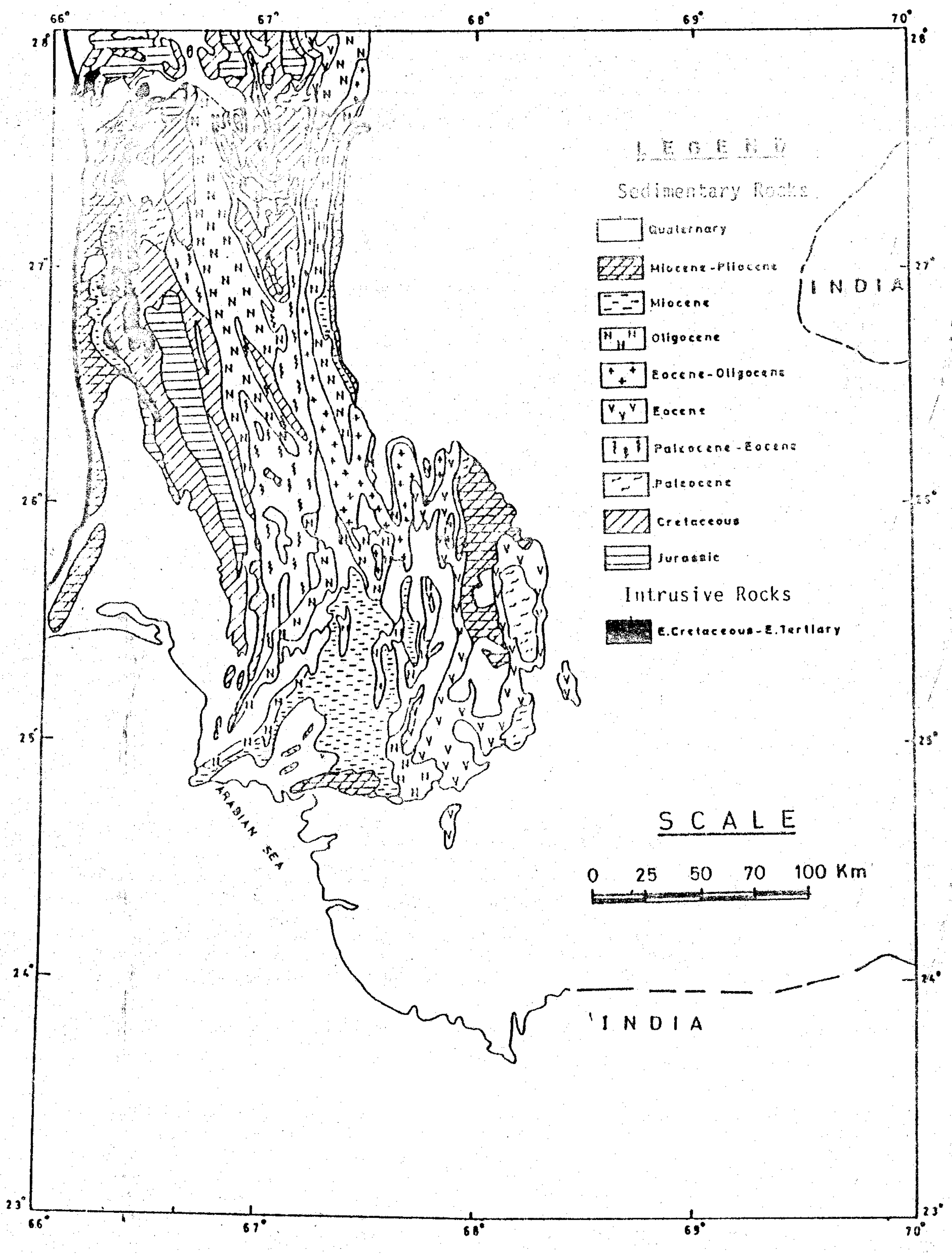


Figure 4—Geological map of Kirthar sub-basin (After Bakr and Jackson, 1964, simplified).

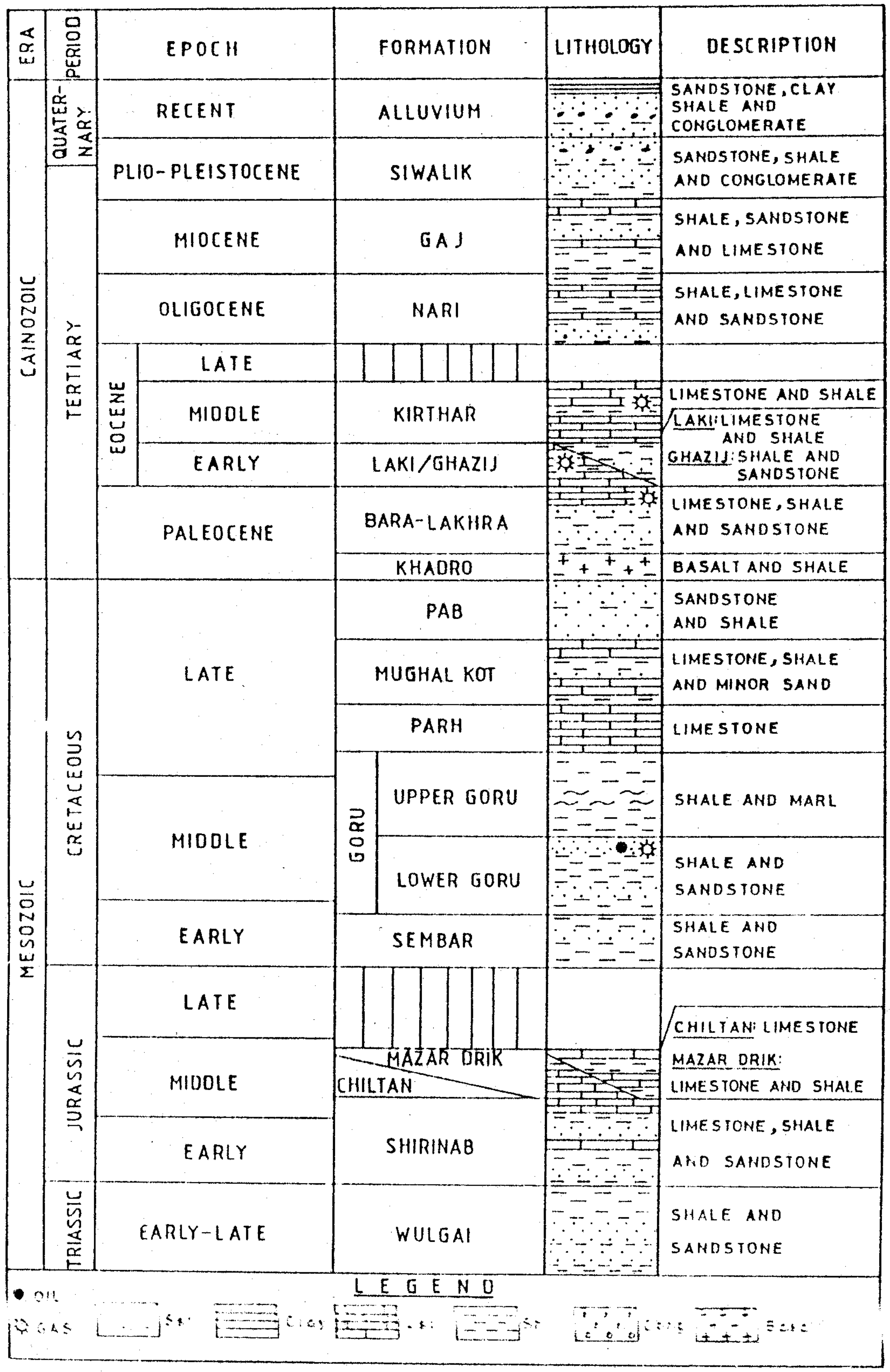


Figure 5—Generalized stratigraphy of Kirthar sub-basin.

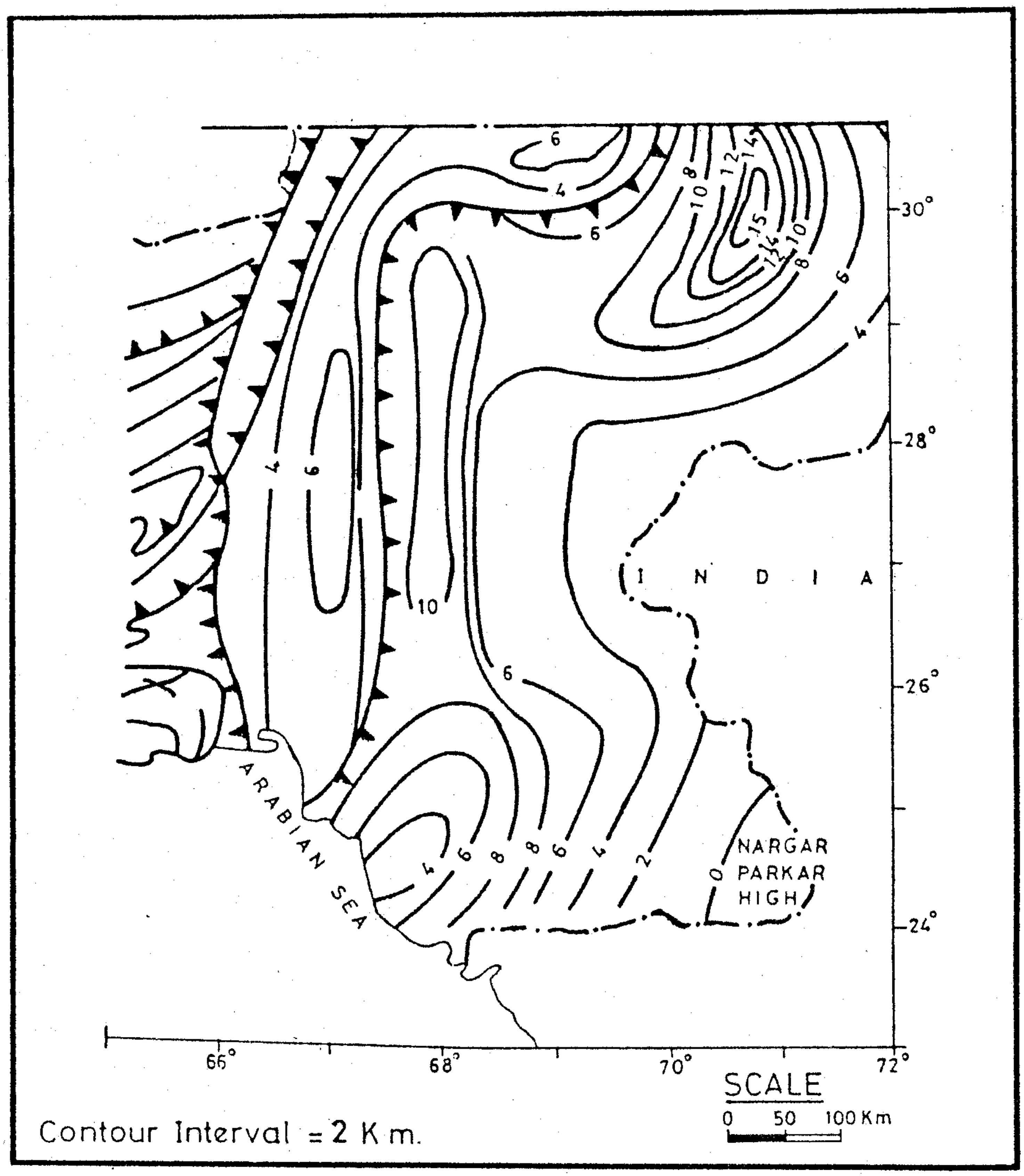


Figure 6—Thickness map of total sedimentary fill of Kirthar sub-basin (Kemal et al, 1982, modified).

marine. Deep marine strata are of limited occurrence, basaltic material dominates the basal part.

Eocene

The Eocene strata are mainly shallow marine shale and limestone. Deep water sediments (shale and fine-grained sandstone) are of limited extent and section in general becomes more calcareous upward.

Oligocene

Rocks of Oligocene age are shallow water limestones and clastics. In general the sequence becomes more clastic upward.

Miocene

The Miocene strata are of limited occurrence. They consist dominantly of shale deposited with subordinate limestone and sandstone. The rocks are both of shallow and deep marine origin.

Plio-Pleistocene

Plio-Pleistocene rocks consist of coarse to fine clastics and represent non-marine deposition onshore.

TECTONIC ELEMENTS AND STRUCTURAL STYLES

The Kirthar sub-basin is the southern segment of Indus Extra-continental Trough Downwarp basin, which is developed on Indian plate. The sub-basin has been affected by the following tectonic events happening in and around it since Early Jurassic time: (1) Fragmentation of Indian plate from Gondwana, (2) Northward movement of the Indian plate with anticlockwise rotation, and (3) plate collision.

The above mentioned events led to the creation of the following features: (1) Horsts and garbens in the southeastern part of the Indian plate due to rifting, (2) Foldbelts and depressions near the plate edge as a consequence of collision, and (3) Extinction of Tethys sea as a result of completion of plate invasion.

In the study area the following tectonic elements/potential petroleum zones are recognized (Figure 1): (1) Kirthar and Mazarani folded zones, (2) Kirthar, Karachi and Indus offshore depressions, and (3) Sukkur rift, Sind monocline, Indus offshore platform and Kutch rift.

The structural styles observed in each tectonic element/ petroleum zone are discussed below:

Kirthar and Mazarani Folded Zones

The structures in the Kirthar zone are large NNW-SSE oriented narrow and elongated anticlines made up of Mesozoic-Neogene sediments (Figure 7). Some of the target horizons e.g. Jurassic, Cretaceous, Paleocene and Eocene are exposed over these structures which grade the zone below depressions and platform at least for the time being when plenty of structures are available for drilling in the latter zones.

The Mazarani zone contains a N-S trending large and narrow anticlinal uplift. The main structures in the zone include Mazarani composite anticline and a southern updip inclined towards Kirthar depression (Figure 7). The Mazarani anticline is elongated and asymmetrical. Its eastern flank is steep and faulted. Gas and condensate have already been discovered in this anticline. Oil can be expected on its lower side and in structurally low anticlines in its vicinity.

Kirthar, Karachi and Indus Offshore Depressions

The Kirthar depression is covered by Quaternary alluvium. The available seismic data do not indicate significant structuring but the possibilities of some basement involved anticlinal features cannot be ruled out. The greater thickness of sediments in the depressions, which is a discouraging factor from exploration point of view, may provide maturation to younger rocks, especially Eocene oil shales.

The Karachi depression has a large number of structures in its eastern part, where the anticlines are small to large, asymmetrical with steep eastern flanks and gentle western limbs (Figures 7, 8). The anticlines in the northern part of the depression are comparatively simple. The western part is devoid of well formed anticlines.

A large number of anticlinal structures have been seismically delineated in the Indus offshore depression. The structures in the main depression trend NW-SE. Near Murray ridge the trend of structures changes to N-S. Some of the structures are faulted along their eastern limbs. Good gas shows were encountered in Pak-Can-1 from Miocene sandstones.

Sukkur Rift, Sind Monocline, Indus Offshore Platform and Kutch Rift

The Sukkur rift comprises a graben (Pano Aqil) bordered by two horsts (Mari in north and Jaccobabad-Khairpur in south). The feature represents fracturing of the platform under rotational compression giving rise to a graben flanked by two horsts. The graben was formed during Cambay rift phase (L. Cretaceous) and is a continuation of the India's oil and gas producing Cambay graben (Figure 1). The graben holds good prospects for liquid hydrocarbons if suitable traps are delineated by seismic survey. The two horsts contain large domal structures which have produced gas from Eocene carbonates (Mari and Khairpur). The Mari horst extends into India's Jaisalmer basin which is also gas producing. The Khairpur dome (Figure 9), according to this study, is a fault block developed due to a younger transverse fault along some old trend. Further work is essential to identify such patterns and to correlate them with the distribution of methane content in some fields in the area.

Sind monocline contains an oil producing area of fault traps (Badin) and a large anticlinal uplift (Lakhra). The traps in Badin area form good closures against faults

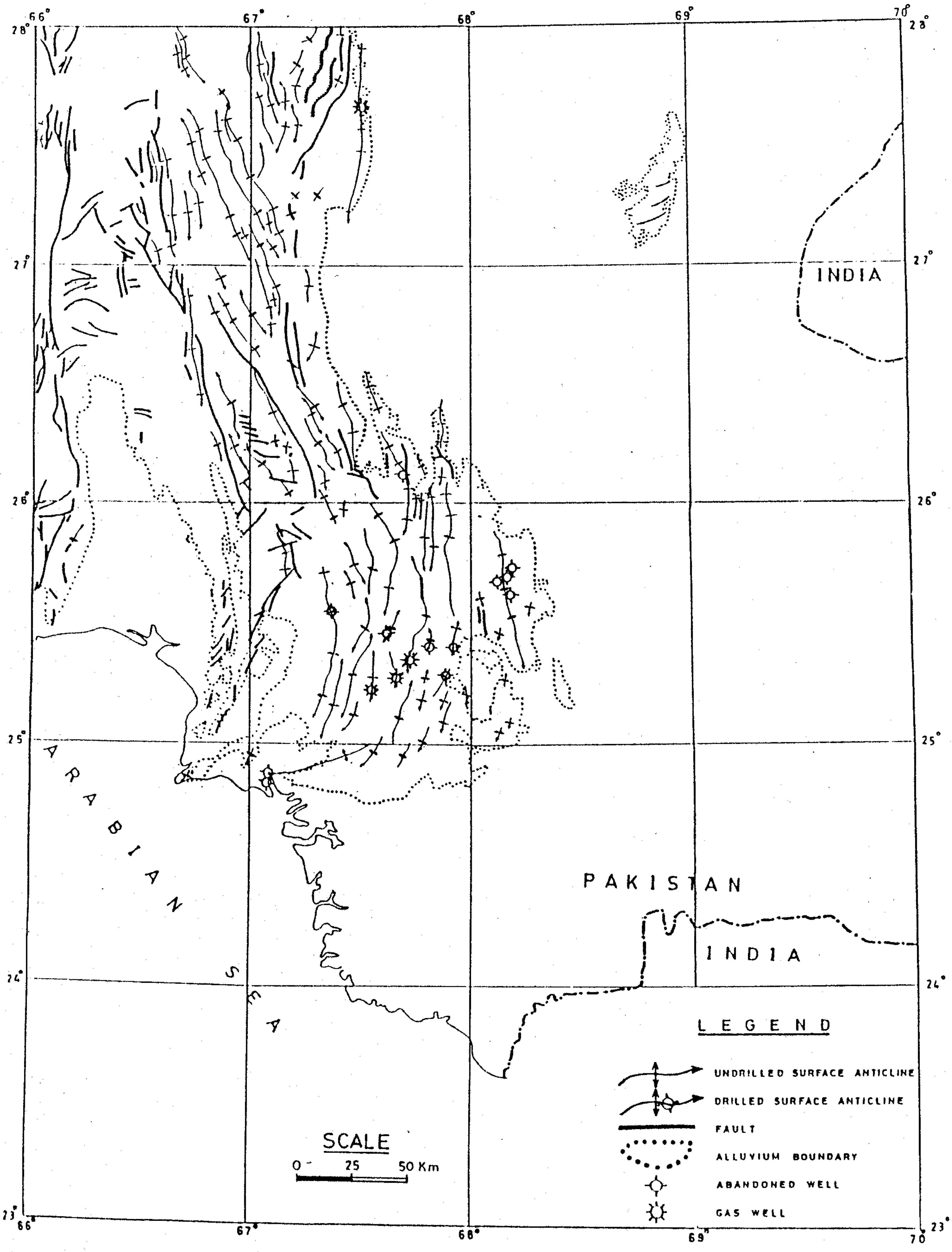


Figure 7—Structural map of Kirthar sub-basin showing surface anticlines.

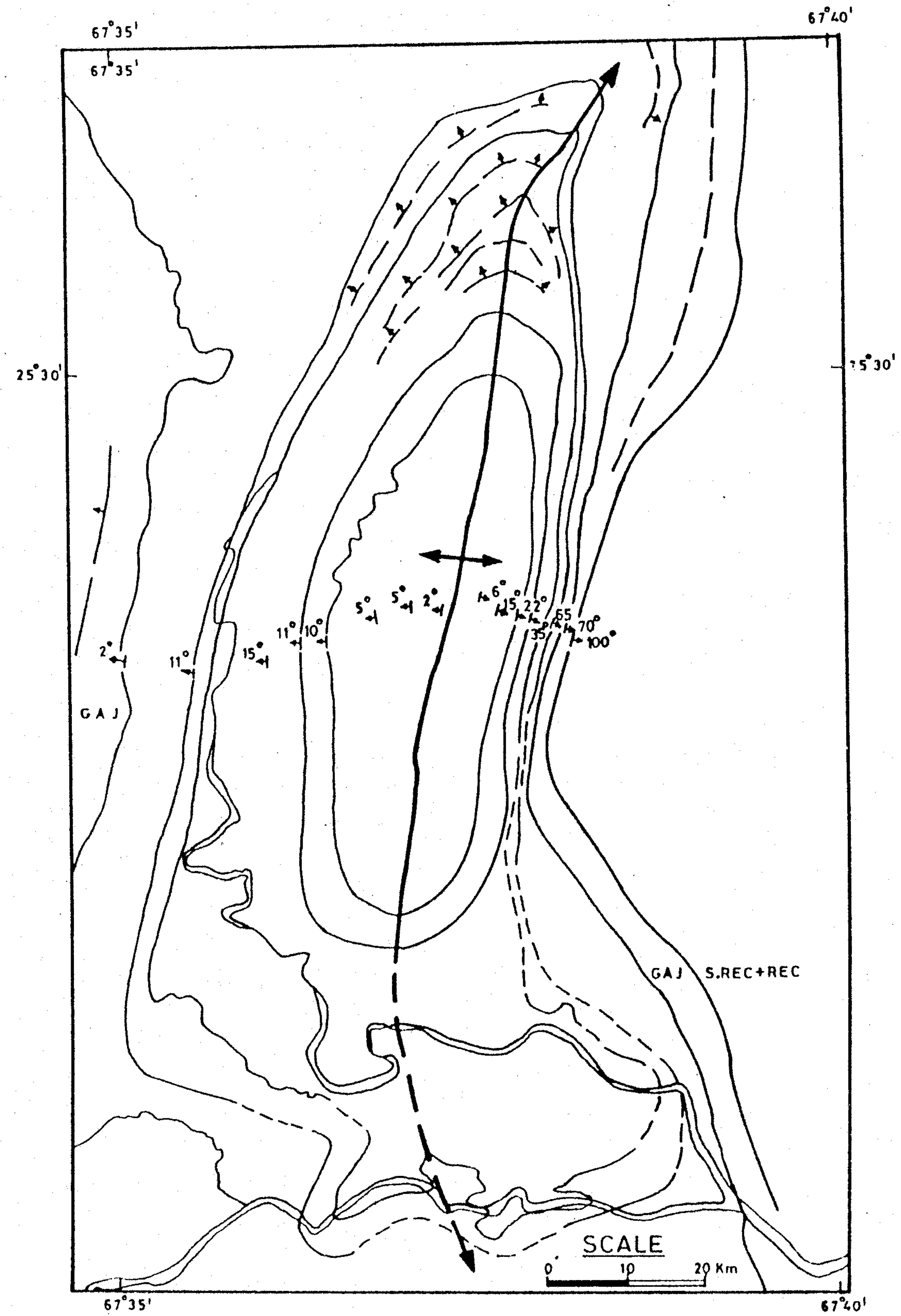


Figure 8—Structural style in Karachi depression (Benir structure, source: O.D.G.C., slightly midified).

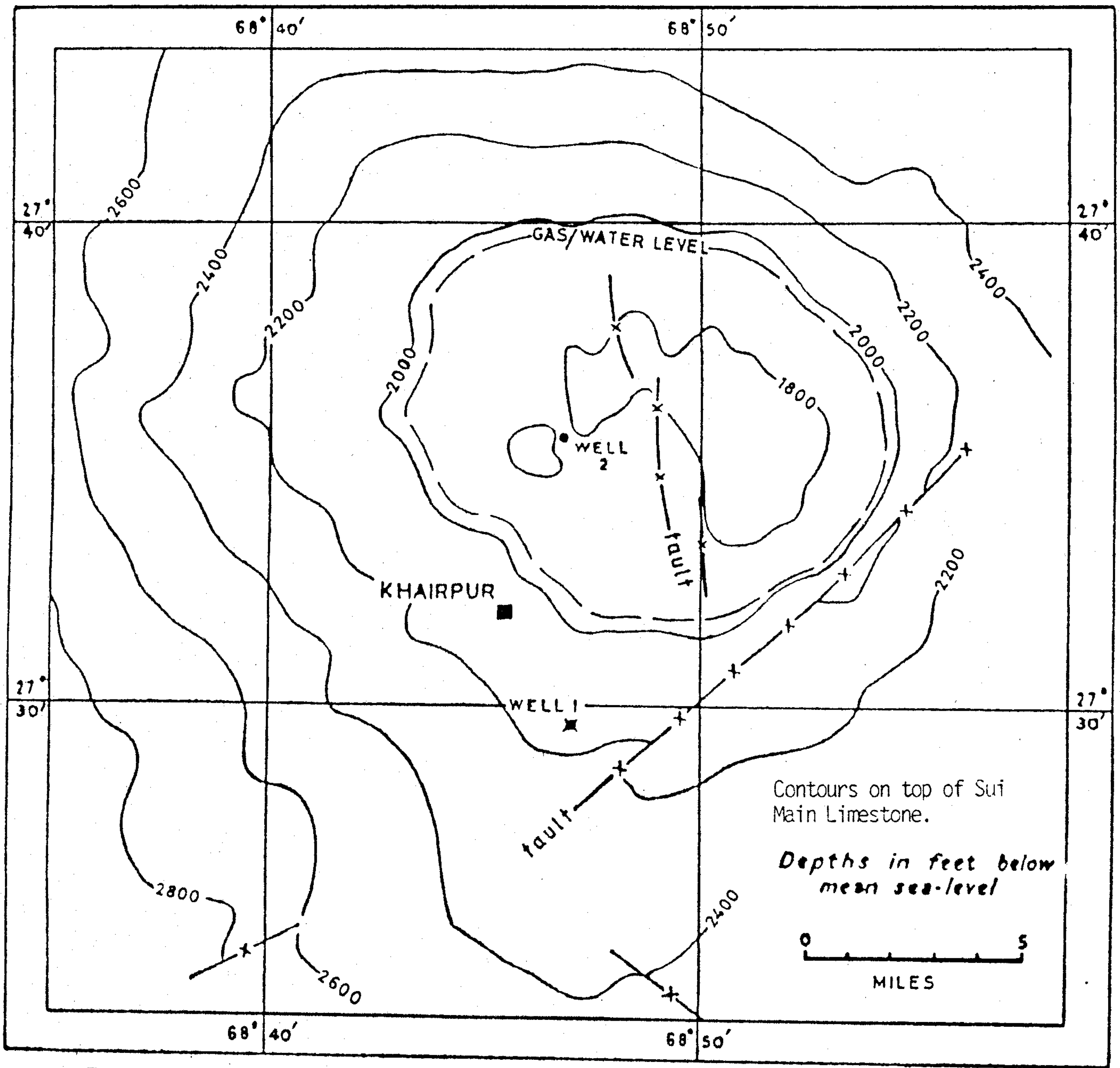


Figure 9—Structural style in Sukkur rift (Khairpur structure, after Tanish, Stringer and Azad, 1959).

(Figure 10). Two sets of faults indicating two different episodes of rifting, are developed in pre-Tertiary sediments. The first set of faults is associated with Early Cretaceous Kutch rift phase and the second set is a consequence of Late Cretaceous Cambay rift phase. These two phases are well recorded in Khaskheli structure (Figure 11).

The Indus Offshore platform is offshore extension of the Sind monocline and exhibits similar structural style of fault traps of Cretaceous age (Figure 12). The Indus offshore platform, coastal region east of Karachi and part of offshore depression are affected by the Kutch rift and share the prospects of the Indian Kutch basin where some oil and gas discoveries have been made in Tertiary reservoirs. Since the subsurface stratigraphy of the area is not known from drilling in Pakistan, the stratigraphy of the Kutch basin across the border is shown in Figure 13.

SEDIMENTARY PATTERNS AND PETROLEUM POTENTIAL

Petroleum potential of various formations occurring in Kirthar sub-basin has been evaluated by analysing the development and distribution of lithofacies in a chronological sequence. The results are as follows.

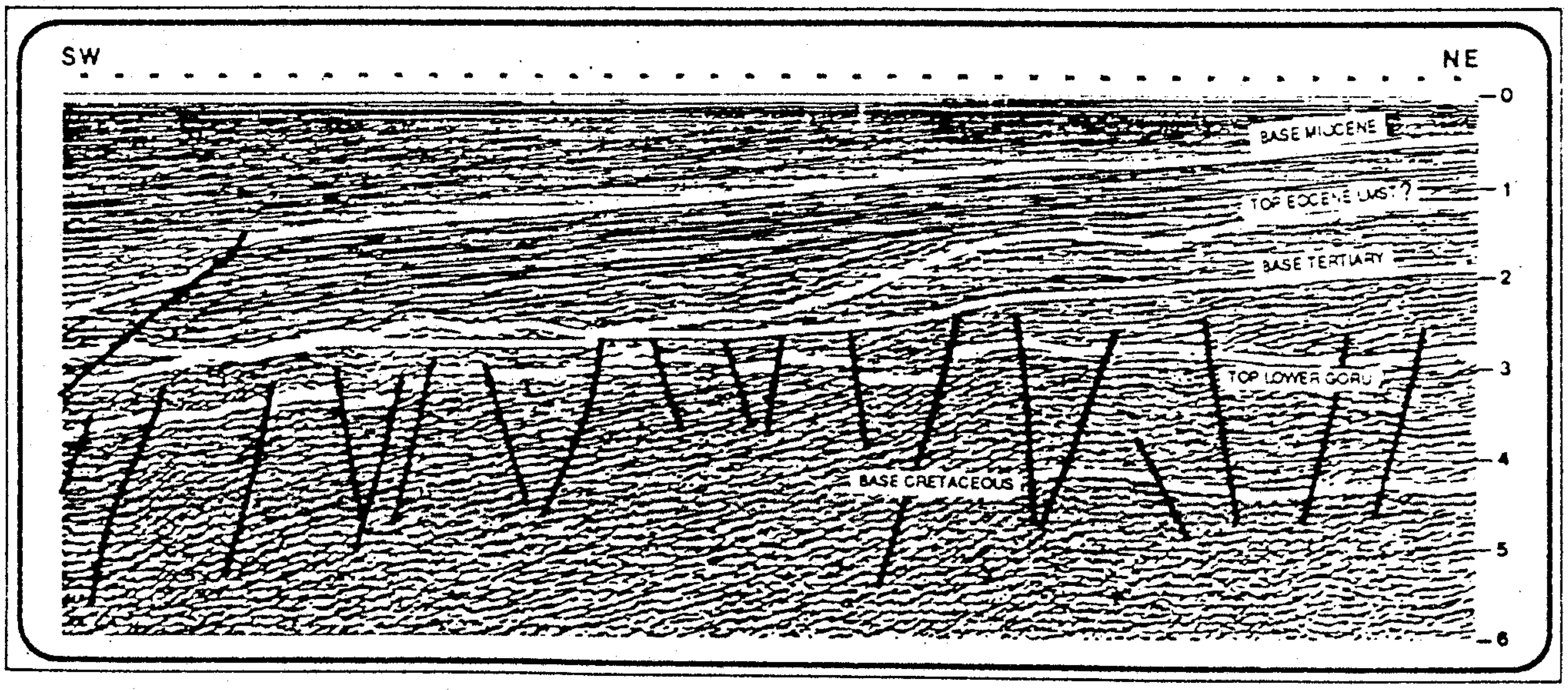
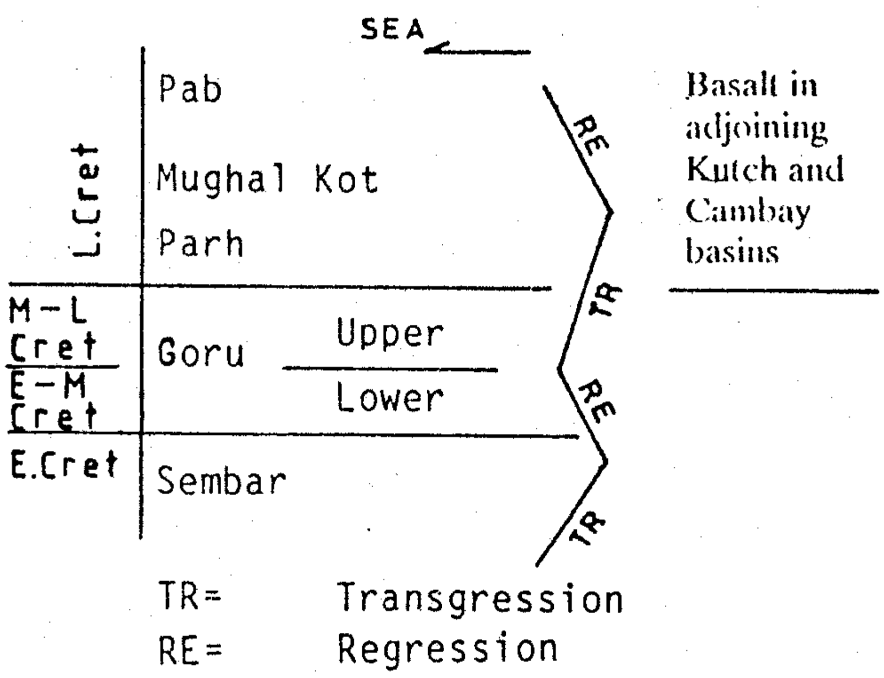


Figure 10—Development of Cretaceous fault traps in Sind monocline (after Soulsby and Kemal, 1988).

Cretaceous

The Cretaceous period was a time of tectonic instability in the region. The northward movement of the Indian plate generated compression, whereas accompanying anti-clockwise rotation produced tension. As a result, eastern shield was raised, the basin experienced intense subsidence, the platform was split into grabens and horsts at places and the southeastern area (Cambay and Kutch) witnessed volcanic activity.

The above mentioned tectonic setting proved ideal for widespread deposition of sediments exhibiting a variety of facies. The Cretaceous sediments in the sub-basin are divided into the following formations which are developed in most of the area except in adjoining Cambay and Kutch basins where Late Cretaceous is represented by basalt.



Sembar formation

Distribution.— The Sembar formation is present over most of the study area with the exception of Khairpur horst and the northern limit of Kirthar range (Figure 14).

Present day information reveals that the Sembar strata were deposited in a broad sedimentary basin which probably extended from the Indian shield in the east upto Bela-Ornach fault system in the west, and from Kutch area on the south to Sulaiman region in the north.

Thickness.— The thickest section of Sembar formation appears to occur between Dabbo Creek and Jati wells along a north-south trend. The formation within this area approaches more than 1200 metres in thickness. Eastwards, the formation becomes thinner and at the same time more sandy, which may indicate onlap deposition over a raised area. The Sembar sediments are also thin in Kirthar range. The thinning may be due to reduced sediment intake from the source area in the east.

Lithology and Lithofacies.— The Sembar is composed entirely of clastic rocks, mostly shale with lesser quantities of sandstone and siltstone. The sand content increases slightly in the southeastern part of the distribution area due to proximity of the source area. The Karachi depression, Kirthar ragne, Kirthar depression and northern part of Sind monocline being away from the source received only the finer clastics.

Petroleum Potential and Reservoir Facies.— Geochemical studies of the Sembar formation in Stanvac and Union Texas wells have rated this formation as good

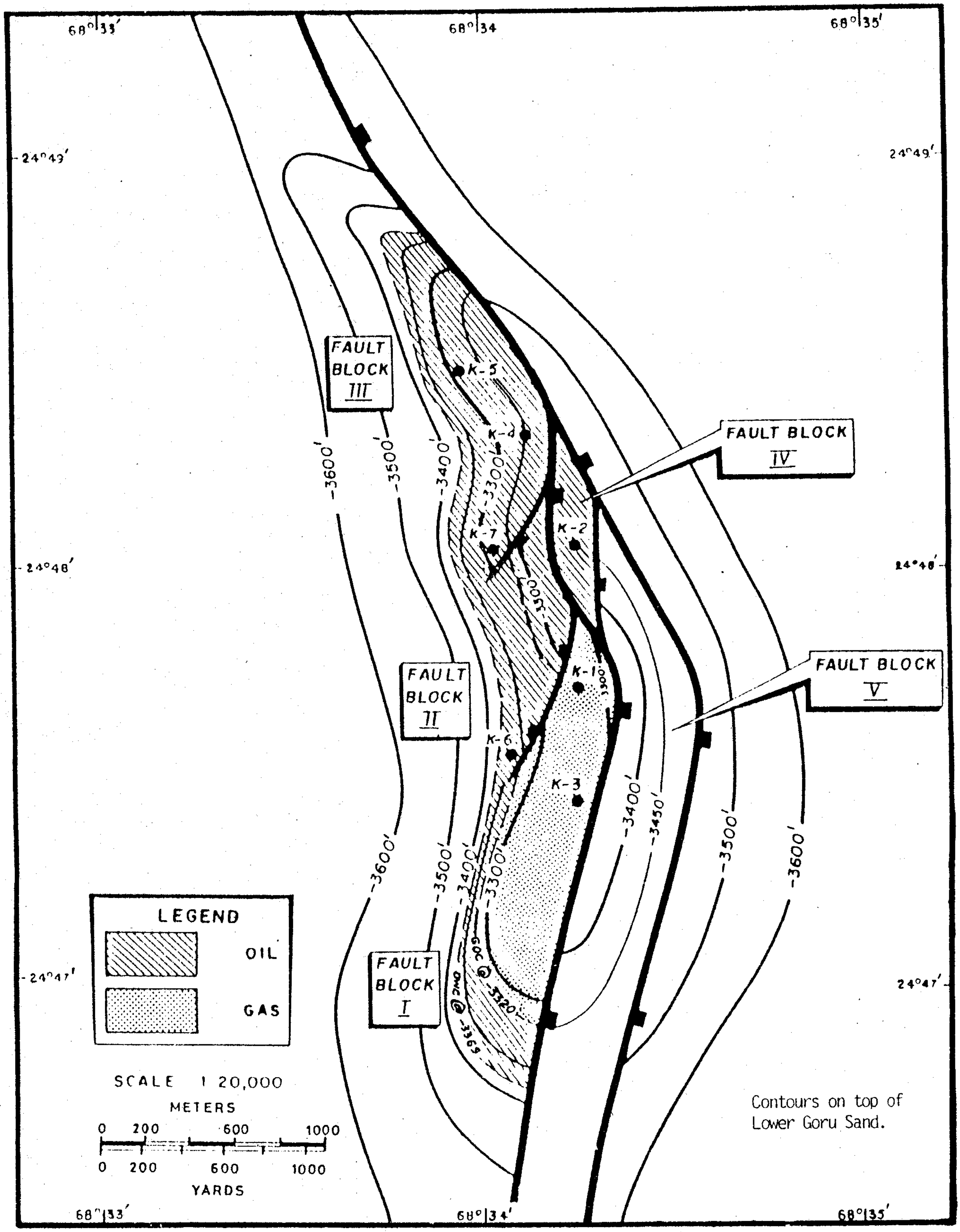


Figure 11—Structural style in Sind monocline (Khaskheli, after Saeed and Ashton, 1982).

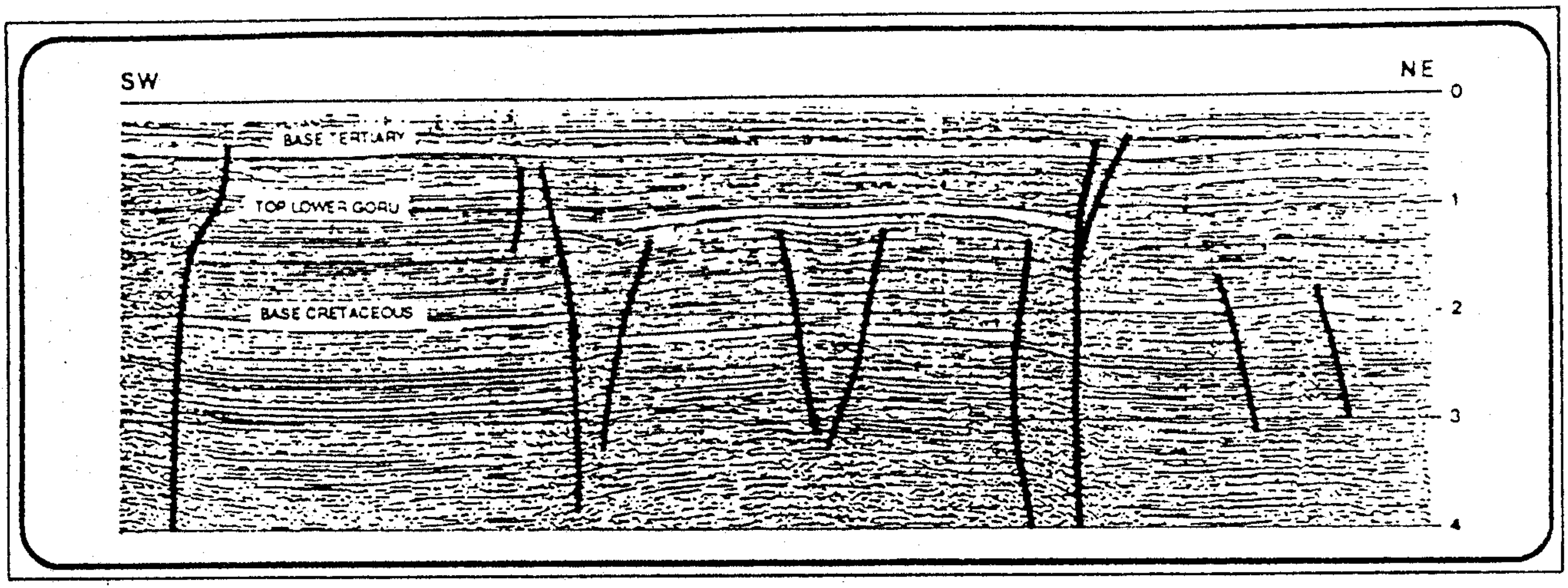


Figure 12—Cretaceous fault traps recognised on offshore Indus platform (After Soulsby and Kemal, 1988).

source rock (TOC upto 3%). Geochemical analysis of samples from Kirthar range (Figure 15, Table 1) carried out by Hydrocarbon Development Institute of Pakistan (HDIP) and Bundesanstalt fuer Geowissenschaften und Rohstaffe (BGR) in 1989 also indicate good source rock potential (TOC:0.83%, VR:0.87). The geothermal gradient study by Khan and Raza (1986) and the present work indicate that the formation, in the subsurface, is within the oil and gas window (Figures 16, 17, 18).

Sandstone of Sembar formation has generally low porosity, but some indirect evidence of good porosity is provided by the production of large quantities of water in Badin and Digh wells during DST. Sembar reservoirs with the highest sand concentration would lie around Patar-Badin and Kutch areas.

Lower Goru Formation

Distribution.— Like Sembar, the Lower Goru sediments are also the most widely distributed of Lower Cretaceous strata. It extends from Kutch on the south to Sulaiman region in the north. The east-west extent is probably from Jaisalmer to some distance upto Bela-Ornach fault system (Figure 19).

Thickness.— The thickest deposit known so far has been drilled in Khaskheli well on Sind monocline where the thickness of the formation is 1562 metres. The thickness rapidly decreases towards east and only 386 metres of the strata are encountered in Nabisar well. The rapid decrease in the thickness may be due to the combined effect of the following two factors: (1) Post-Goru erosion as evident from the presence of unconformity between Cretaceous and Paleocene strata in Nabisar, Digh & Badin wells, and (2) At the time of deposition of Lower Goru the Sind monocline was a westward dipping platform. The sediments gradually thin out elsewhere in the basin.

Lithology and Lithofacies.— The Lower Goru in eastern part of Sind monocline is a dominantly fine to coarse grained sandstone facies interbedded with shale/siltstone. The sequence laterally grades to siltstone and shale in the west. The zone of facies change from sand to shale in Sind monocline is distinctly marked.

Petroleum Potential and Reservoir Facies.— The petroleum potential of Lower Goru in Sind monocline seems to be high especially in view of the discovery of oil in sandstone reservoir at Khaskheli, Laghari, Nari, Turk, Tando Alam, South Mazari and Tajedi wells and gas at Golarchi and Sonro wells. The sandstone facies of prograding delta-front is widely distributed in the subsurface of the sub-basin. The facies with 2 to $\frac{1}{2}$ sand/shale ratio, which is considered as ideal reservoir-source combination is developed on a vast area of Sind monocline and may also occur in the eastern part of Karachi depression and offshore area where the shales are within oil and gas window (Figure 20). The shales of Lower Goru in Kirthar range show good source rock potential (Table 1, TOC:1.72%, VR:1.27).

Upper Goru Formation

Distribution.— Upper Goru occurs on a fairly vast area of the sub-basin. It extneds from east of the study area and beyond, upto Bela-Ornach fault system in the west and from Sulaiman sub-basin in north to the present day offshore area and Kutch basin in the south (Figure 21).

Thickness.— The maximum thickness of 2008 metres of Upper Goru was encountered in Damiri well. It is

AGE	KUTCH BASIN: LITHOLOGY	KUTCH BASIN: ENVIRONMENT	KUTCH BASIN: EVENTS	CAMBAY BASIN: LITHOLOGY	CAMBAY BASIN: ENVIRONMENT	CAMBAY BASIN: 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.)	Marine / Deltaic	Oscillatory; Transgression / Regression Cycles
L. EOCENE			Regression, Tect. Cycle			
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
PALEOCENE	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 13—Generalized stratigraphy of Kutch and Cambay basins (After Biswas, 1982).

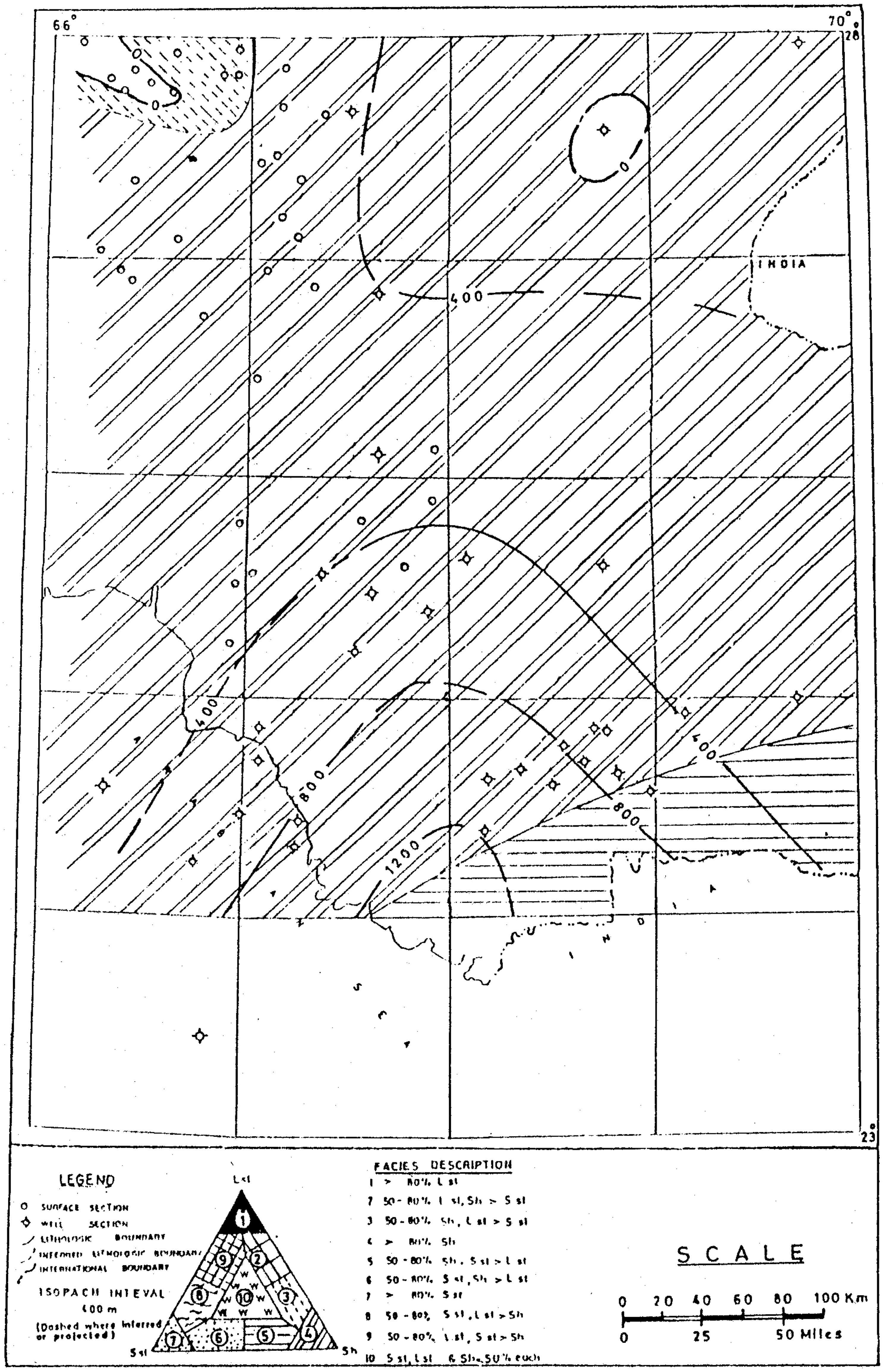


Figure 14—Thickness and lithofacies map of Sembar formation.

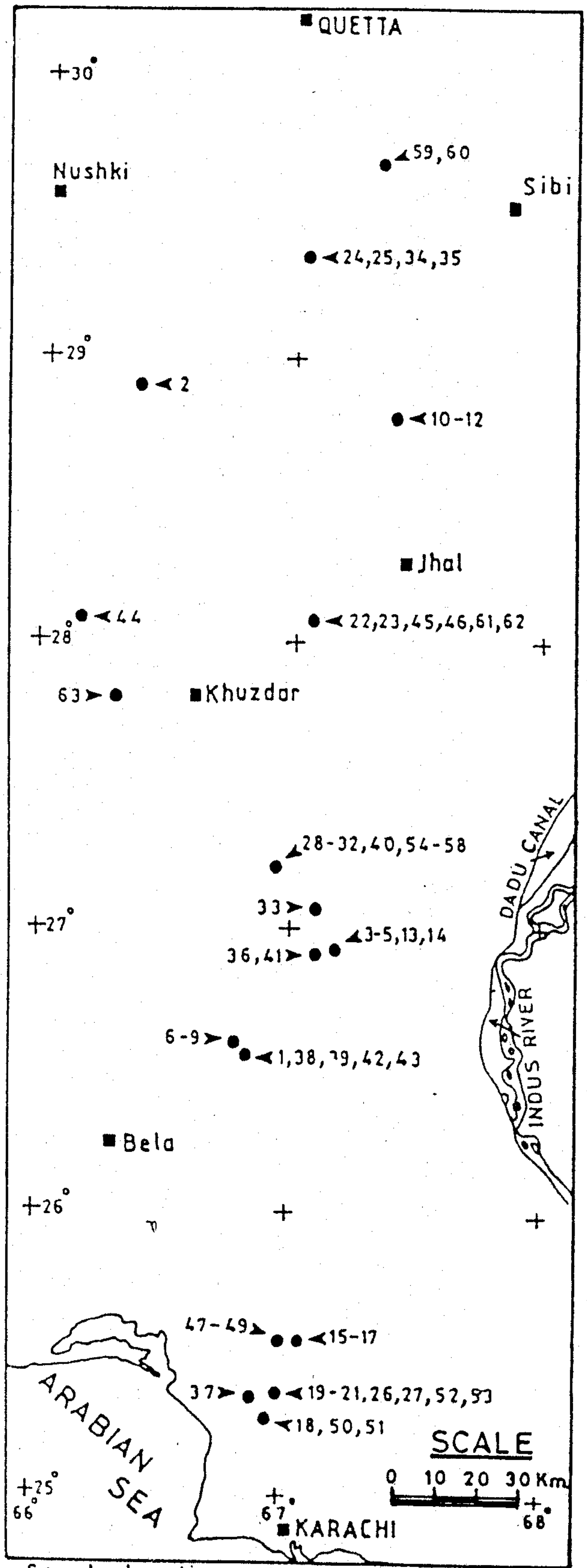


Figure 15—Map showing location of geochemically analysed samples (Results in Table 1, p. 49).

restricted to a narrow and elongated, north-south trending area in Sind monocline. The sediments thin out rapidly towards east and only 239 metres of deposit has been reported in Patar well. Elsewhere, the thickness decreases gradually.

The truncated strata against zero line in the east is related to Cretaceous rifting. The western zero contour line extending north-south from Kirthar range to offshore area represents probable depositional limit of the sediments.

Lithology and Lithofacies.— The Upper Goru consists dominantly of shale or mudstone, frequently calcareous, and range in colour from black to grey and rarely maroon. Sand is rare and locally limestone forms a significant percentage of the formation. The limestone is thin bedded, and in shades of grey. Both fauna and lithology indicate deep marine conditions.

The Upper Goru in Sind monocline and in the major part of the Kirthar range and offshore region is dominantly shale or mudstone with subordinate limestone/marl/sandstone. The sandstone is restricted to the southeastern corner of the study area. A dominant limestone facies with subordinate shale has been developed in Kirthar depression, Karachi depression, southern and eastern parts of the Kirthar range and northeastern part of the offhsore region.

Petroleum Potential and Reservoir Facies.— A rare amount of sandstone is developed in the eastern and southern parts of Sind monocline. Such amount of sand may not act as ideal reservoir. However, Upper Goru can serve as cap rock over the underlying formation in the sub-basin. It can also act as source rock (Table 1, TOC: 2.55%, VR:1.51).

Parh Limestone

Distribution.— The Parh has little areal extent east of Khaskheli and south of Dabbo Creek wells. In the north, it is absent in Khairpur, Mazarani and Mari wells (Figure 22).

Thickness.— The maximum accumulation of Parh is believed to be in the northern limit of Kirthar range where it amounts to more than 450 metres in a narrow elongated north-south depression. This great thickness of Parh may be the result of uplifts in south and east associated with Cretaceous rifting. Elsewhere, the Parh is generally thin.

The zero line in the east and west represents erosional limit of the formation. The zero line elsewhere in the sub-basin marks probable depositional limit of the formation.

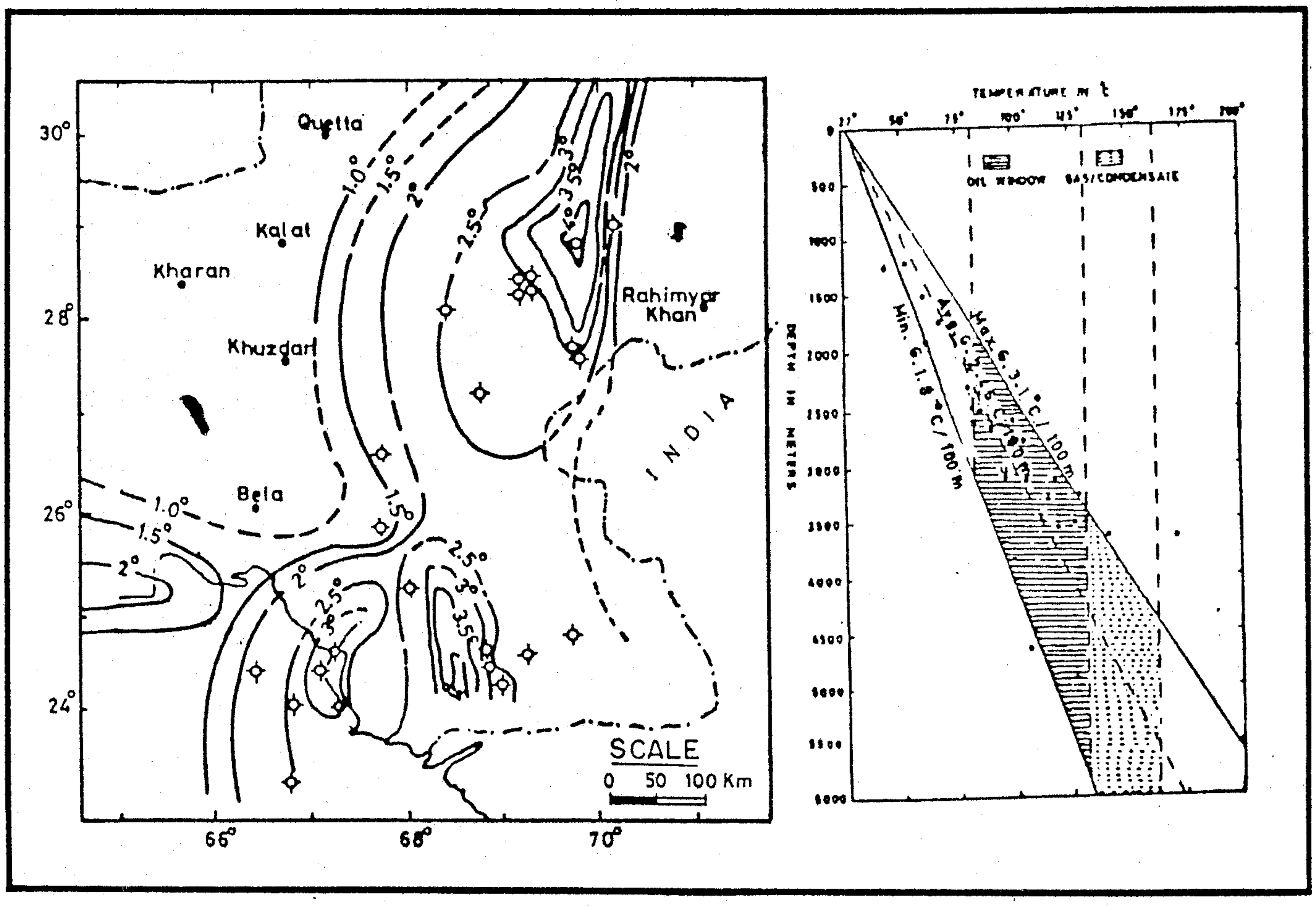


Figure 16—Isothermal map of Kirthar sub-basin alongwith graph showing regional geothermal gradients (after Khan & Raza, 1986).

Lithology and Lithofacies.— Parh is lithologically the most uniform unit in the Cretaceous section. It is mainly in limestone facies. The limestone is in light shades of white, pale, grey and tan, fine grained and Globotruncana-bearing. Porcellaneous texture and conchoidal fracture are characteristics of this formation. Both lithology and fauna clearly indicate it to be a deep water deposit.

Petroleum Potential and Reservoir Facies.— Except for Giandari well in the north (outside study area) which produced 18,200 m^3 gas in a DST, no oil or gas show has been found in the Parh limestone in the subsurface and no surface seeps are known. Abundant organic life was present during its deposition but silled basin necessary to preserve organic matter is not known to have existed. The argillaceous content and compact nature of the limestone have resulted in a very low primary porosity. As a reservoir the formation would have to depend on the development of secondary porosity.

Mughal Kot Formation

Distribution.— It extends roughly from Indus Marine A-1 well in the south to beyond latitude 28° north. It is limited to west of Mirpur Batoro and Dasori wells in the east and has its western boundary of deposition in the Kirthar range which extends southwards in the offshore region (Figure 23). The formation, as compared to the underlying Parh formation, has more restricted distribution in the east and west and is more widely distirbuted in the southern and northern parts.

Thickness.— The formation is generally thin throughout the sub-basin except in the offshore area where more than 800 metres of sediments are expected to be accumulated in a northeast-southwest elongated area. This increase in thickness is the result of a sag in the southeastern part of the area connected with the Cretaceous rifting.

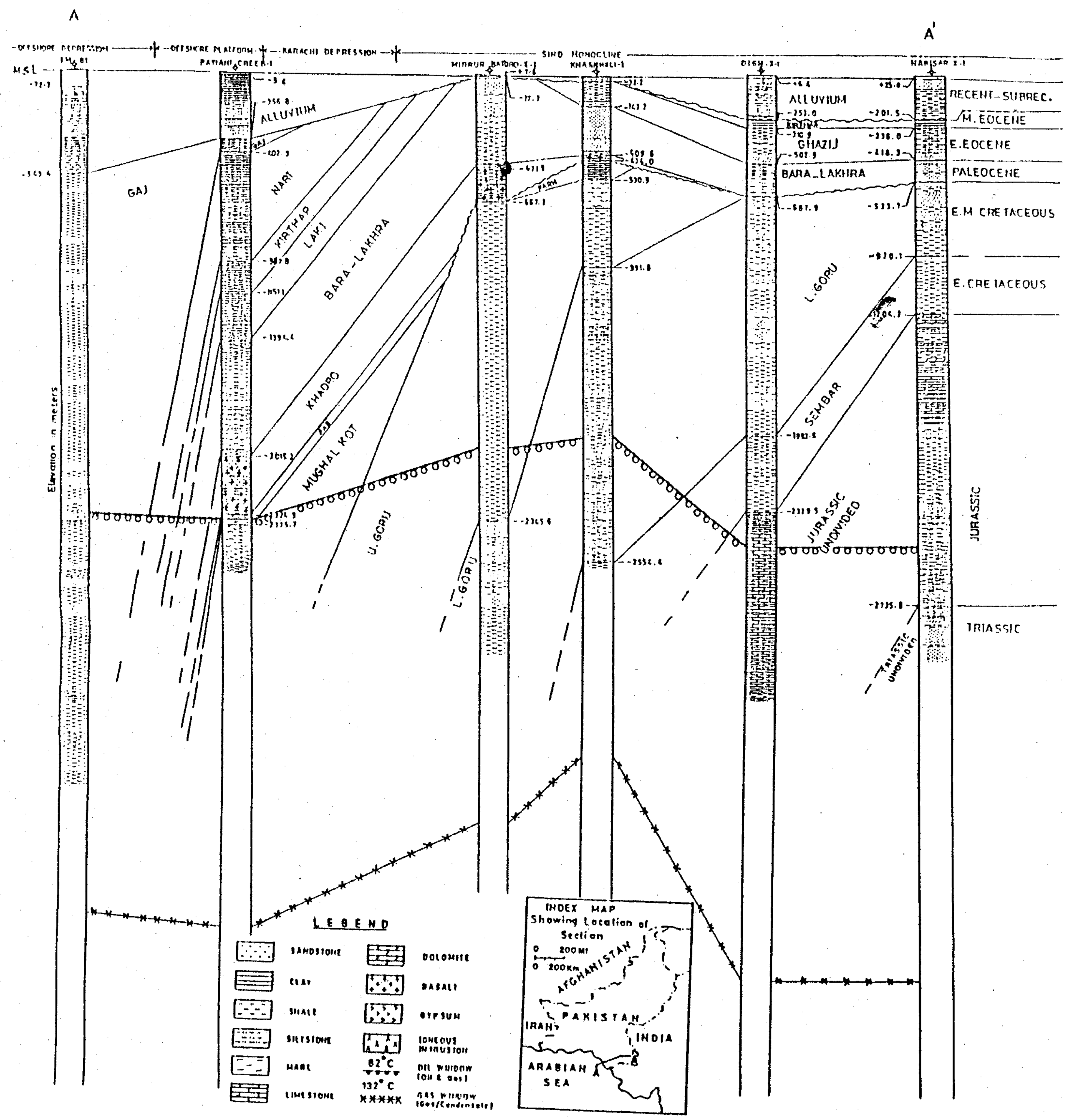


Figure 17—Stratigraphic correlation across offshore depression and platform, Karachi depression and Sind monocline, with oil and gas window.

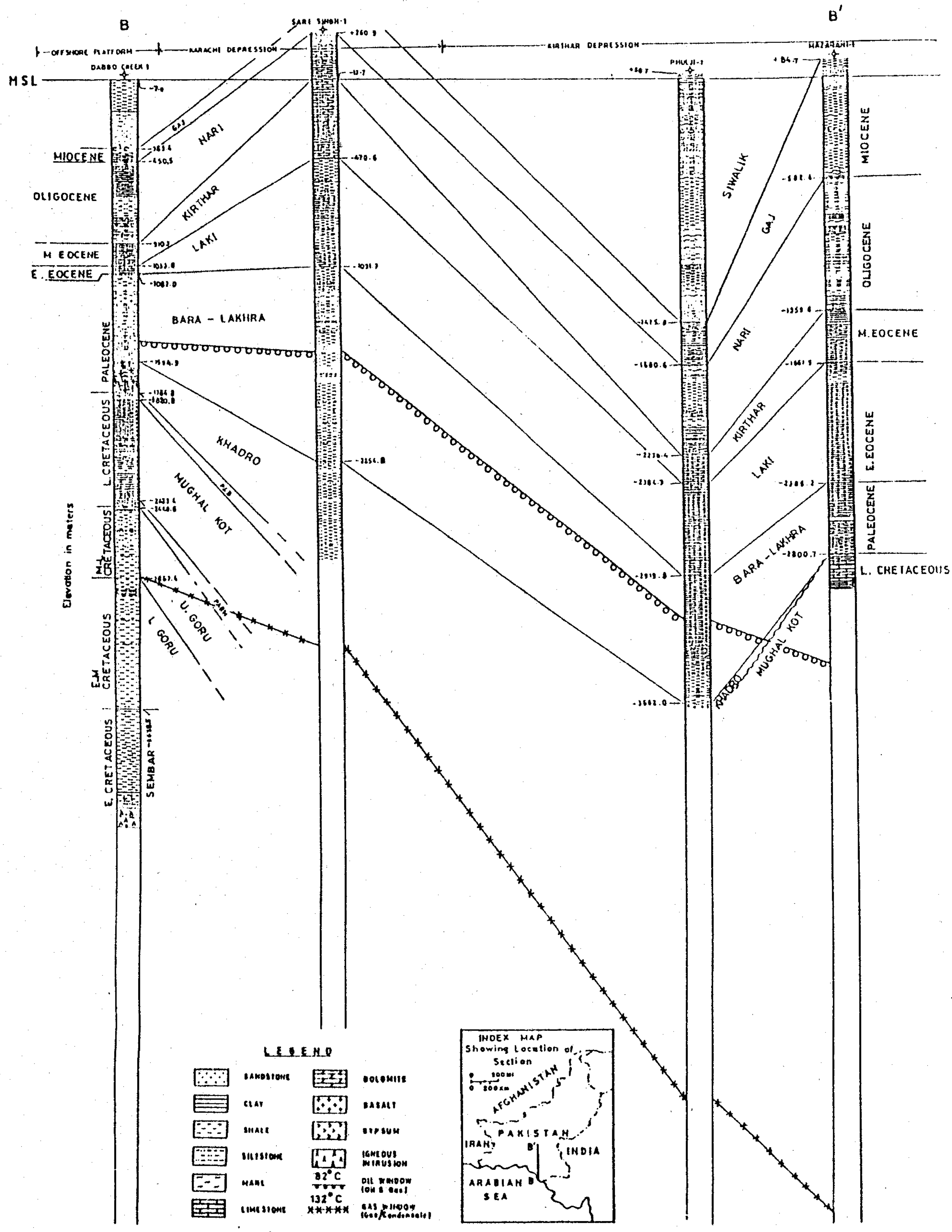


Figure 18—Stratigraphic correlation across offshore platform and Karachi and Kirthar depressions, with oil and gas window.

Table 1. Geochemical analysis of surface rock samples from Kirthar range. (For location of samples, see Figure 15)

Age	Formation	Sample Number	Lithology	TOC	VR	HI	Age	Formation	Sample Number	Lithology	TOC	VR	HI	Age	Formation	Sample Number	Lithology	TOC	VR	HI
OLIGOCENE		1	Sh	0.28	0.94	-	PALEOCENE	Lakhra	22	Lst	0.42	-	-	CRETACEOUS	Goru	43	Lst	0.07	2.06	-
		2	Sh	0.86	0.38	116			23	Lst	0.14	1.32	-			44	Sh	0.57	1.47	-
EOCENE	Kirthar	3	Lst	1.36	0.73	824			24	Sh	1.05	1.13	208			45	Sh	0.23	1.86	-
		4	Lst	2.09	0.73	756			25	Sh	1.19	1.01	210			46	Lst	0.17	1.69	-
		5	Lst	2.08	0.71	611	CRETACEOUS	Pab	26	Sh	1.57	1.09	< 50			47	Sh	3.47	1.06	49
		6	Sh	0.77	1.18	-			27	Sh	1.72	1.07	< 30			48	Sh	0.67	1.23	-
		7	Sh	0.48	1.24	-		Mughal Kot	28	Sh	0.64	1.03	109			49	Sh	0.52	1.19	-
		8	Sh	0.53	1.44	-			29	Sh	0.72	1.27	97			50	Sh	0.31	1.55	-
		9	Sh	0.42	1.42	-			30	Sh	1.28	1.26	< 50			51	Lst	2.15	1.49	60
		10	Lst	6.10	0.76	600			31	Sh	1.02	1.27	88			52	Sh	0.57	1.16	-
		11	Lst	7.79	0.76	603			32	Sh	0.97	1.29	52			53	Lst	3.48	1.13	66
		12	Lst	9.75	0.76	617			33	Sh	0.58	1.04	< 70		Lower Goru	54	Sh	0.59	1.22	< 85
	Ghazij	13	Sh	6.89	0.65	398			34	Sst	0.27	0.81	-			55	Sh	1.29	1.15	47
		14	Sh	6.43	0.66	480			35	Sh	0.41	-	-			56	Lst	1.21	1.27	< 66
		15	Sh	0.38	1.70	-			36	Sh	0.89	1.31	56			57	Lst	1.03	1.18	< 50
		16	Sh	0.32	1.68	-			37	Sh	0.57	1.23	-			58	Sh	1.72	1.27	< 70
		17	Sh	0.35	1.68	-		Parh	38	Lst	0.08	-	-		Sembar	59	Silt.St	0.23	-	-
		18	Sh	0.61	1.17	-			39	Lst	0.11	-	-			60	Lst	0.31	-	-
		19	Sh	1.11	1.04	90		Upper Goru	40	Lst	0.39	-	< 128			61	Sh	0.83	-	-
		20	Sh	0.99	0.99	< 121			41	Sh	2.55	1.51	71			62	Sh	0.59	-	-
		21	Sh	1.04	1.06	96		Goru	42	Sh	0.08	2.0	-			63	Sh	0.32	0.87	-

Data source: HDIP-BGR.

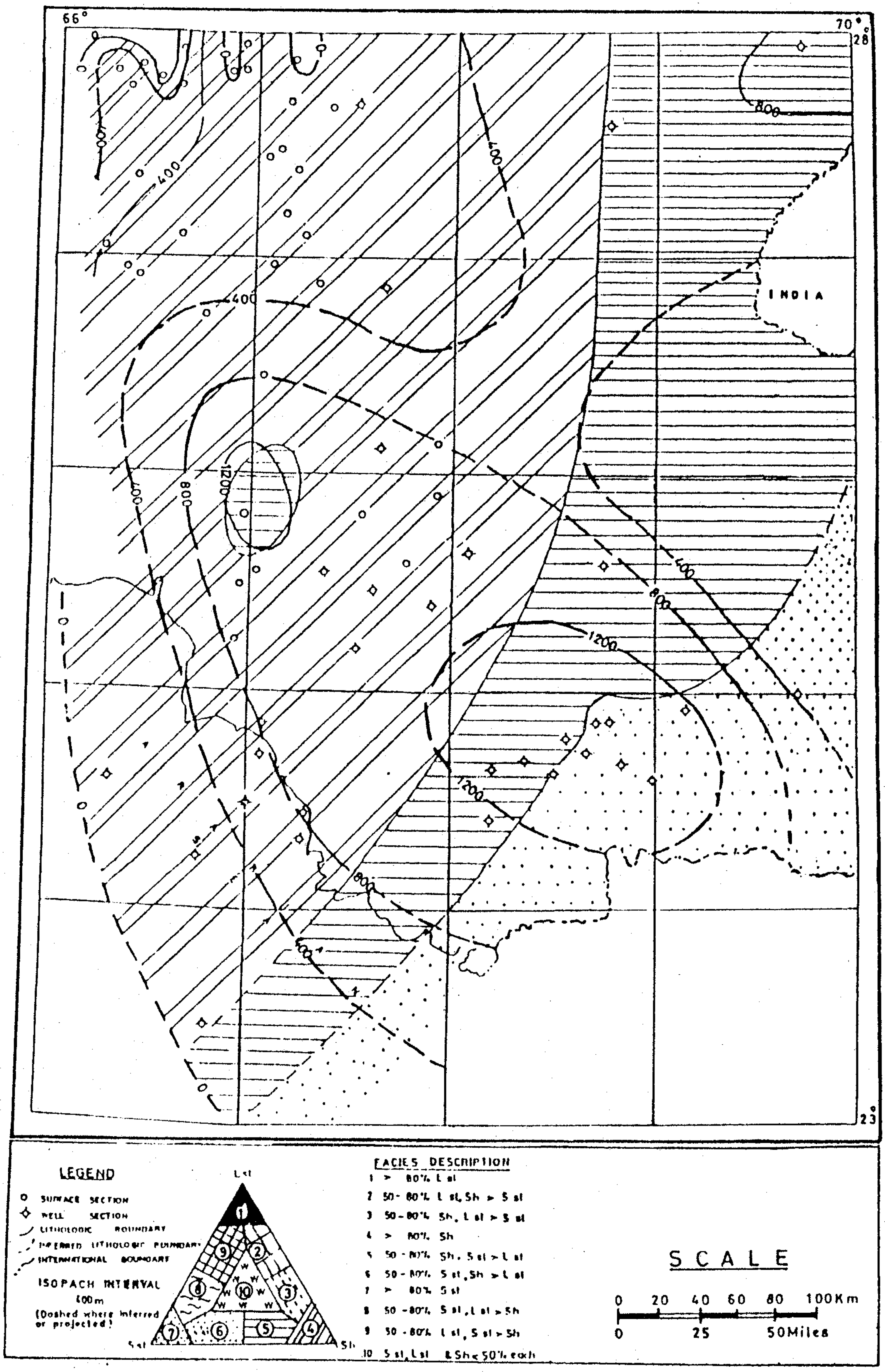


Figure 19—Thickness and lithofacies map of Lower Goru.

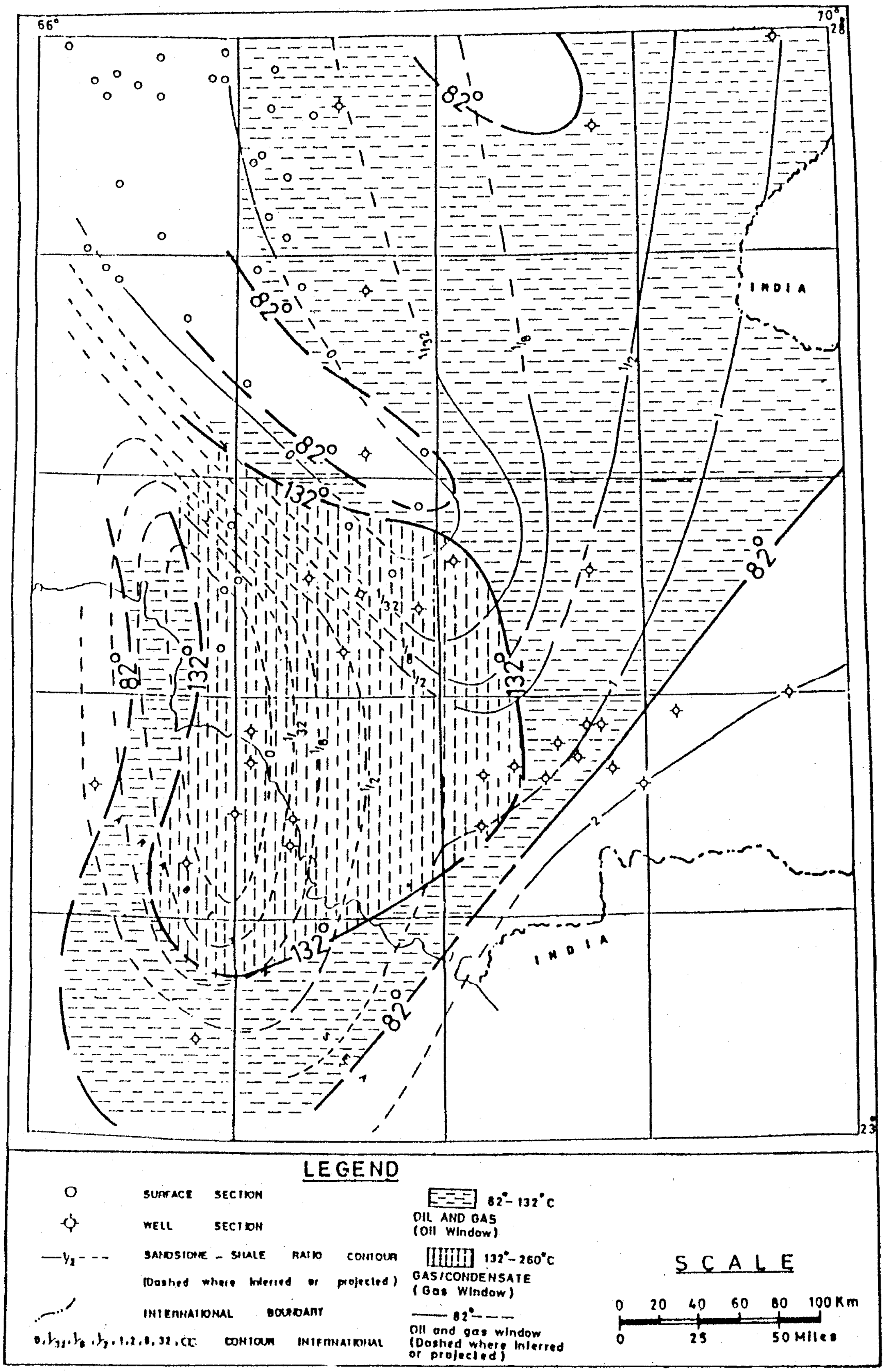


Figure 20—Sand-shale ratio map of Lower Goru with isogeotherms at the base.

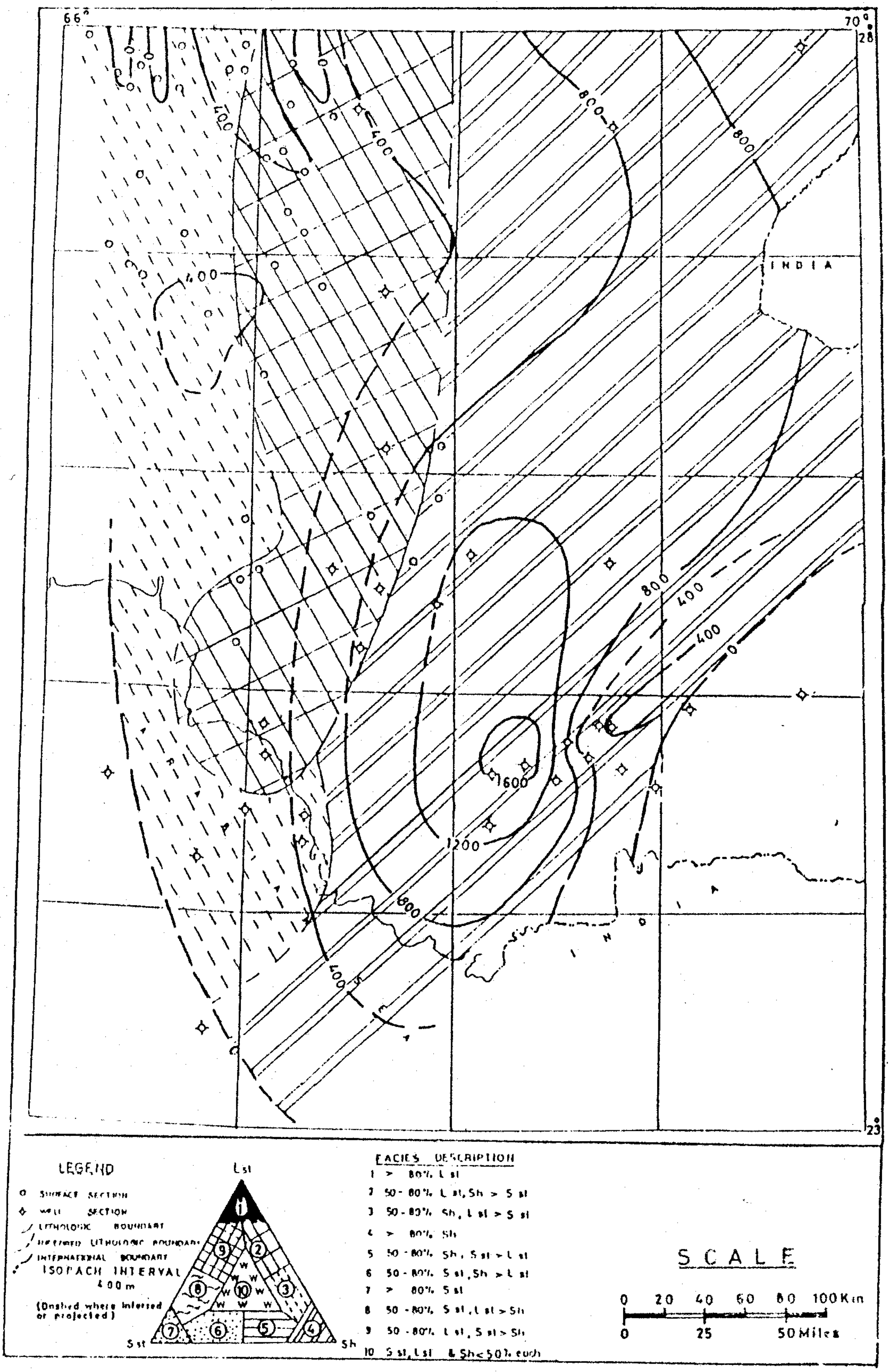


Figure 21—Thickness and lithofacies map of Upper Goru.

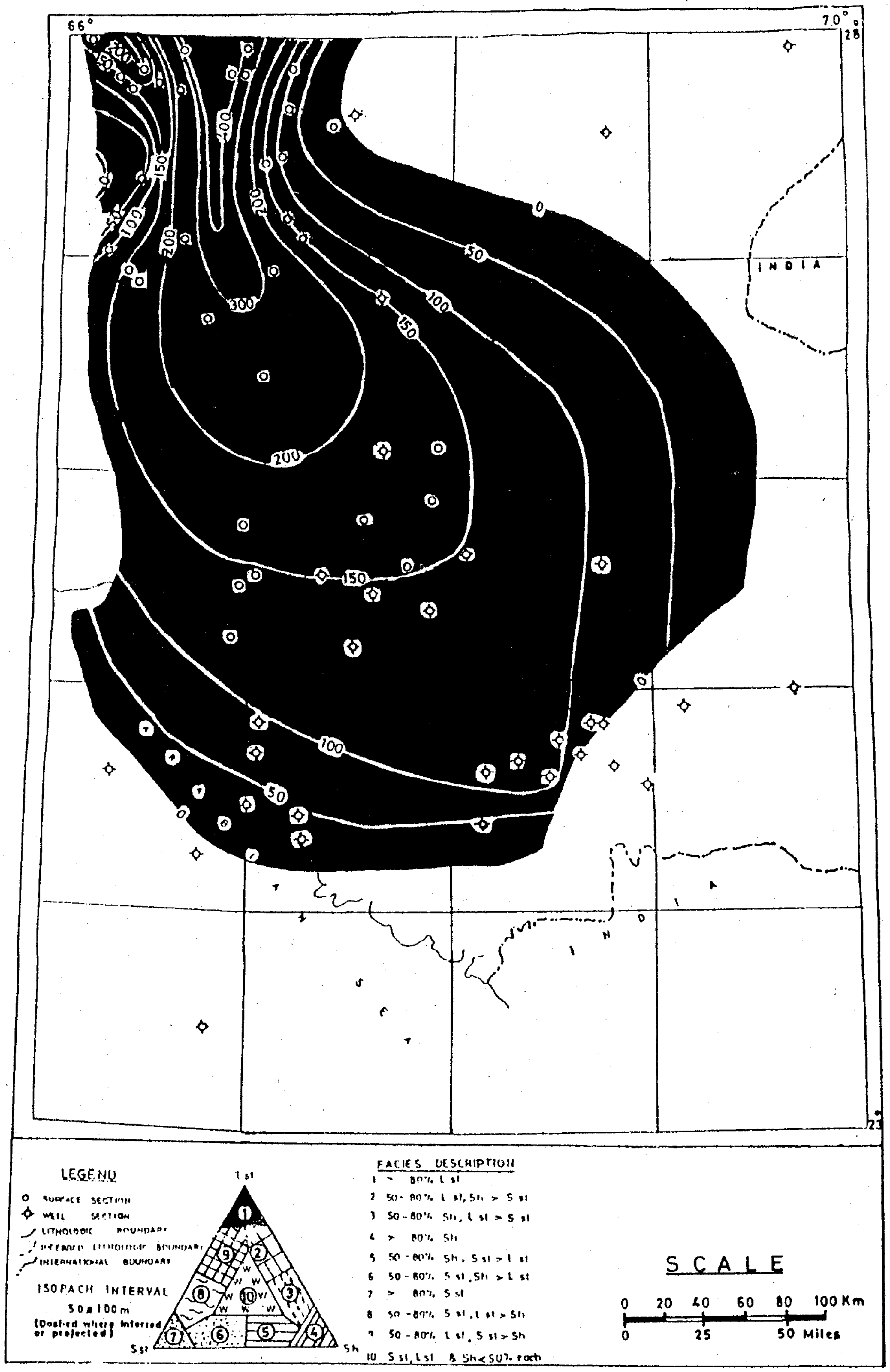


Figure 22—Thickness and lithofacies map of Parh limestone.

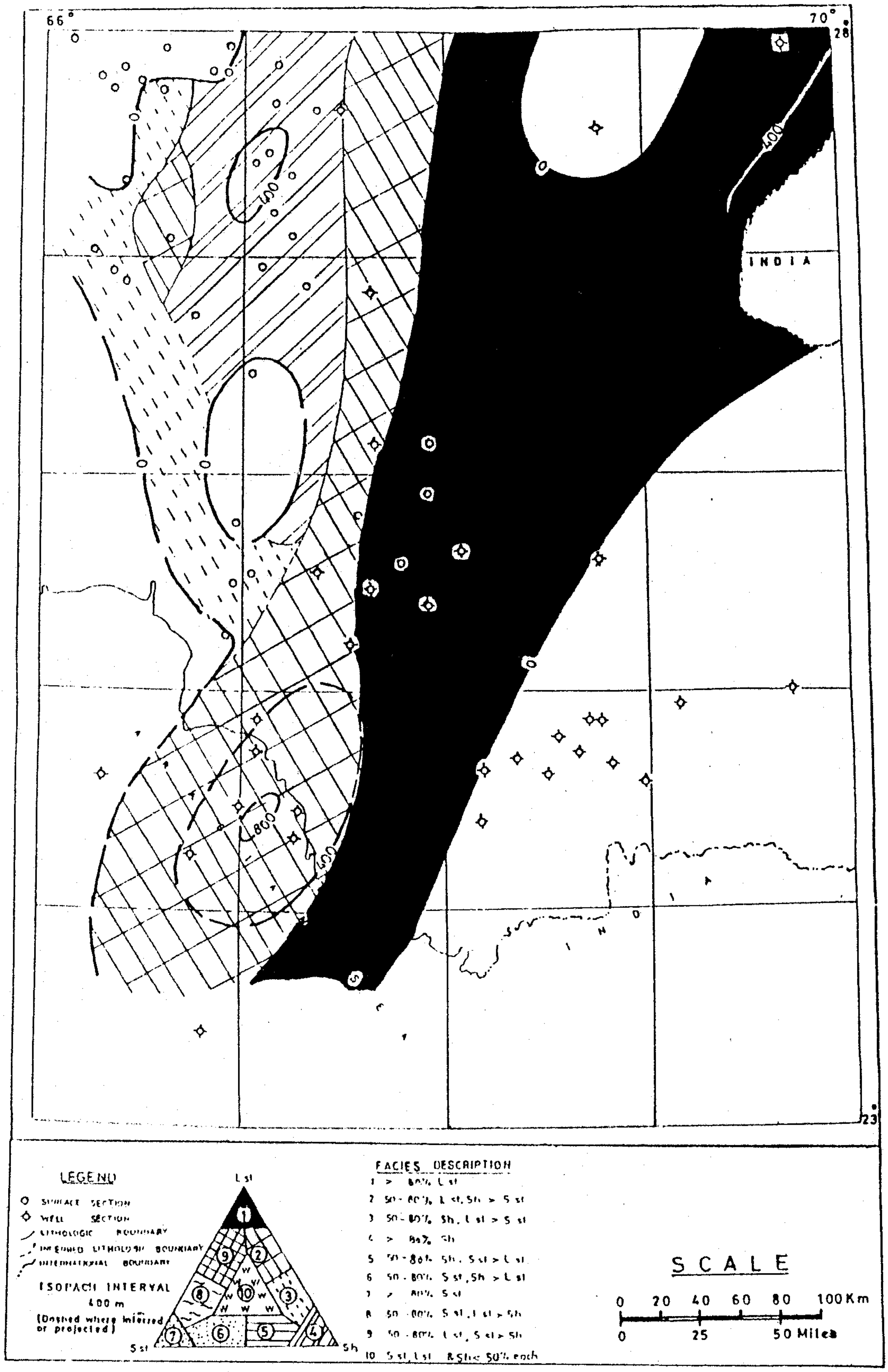


Figure 23—Thickness and lithofacies map of Mughal Kot formation.

The absence of the formation in the central and northern parts of the Kirthar range and northern part of the Sind monocline is considered to be the result of non-deposition. The zero line in the east and west reflects the depositional limit of the formation.

Lithology and Lithofacies.— The Mughal Kot formation is lithologically a heterogeneous unit, comprising dominantly grey argillaceous limestone/marl with subordinate grey shale and rare amount of sandstone in Sind monocline, Karachi and Kirthar depressions and offshore area. In Kirthar range, it consists of grey silty and calcareous shale with subordinate argillaceous limestone/marl.

Petroleum Potential and Reservoir Facies.— Gas shows were recorded from the formation in Patiani Creek-1 and Dabbo Creek-1. In the adjoining Sulaiman sub-basin, oil seepage at Mughal Kot and gas discovery at Jandran also indicate petroleum generation potential of the formation. Indications of silled conditions suitable for generating petroleum were present in Karachi depression. The formation shows good source rock characters and is within oil window in offshore platform and Karachi depression (Figure 17). The geochemical analysis of samples from Kirthar range indicates good source rock potential (Table 1, TOC:1.28%, VR:1.26).

The carbonate reservoir facies is developed more or less in the entire sub-basin. Soruce-reservoir-seal trilogy may exist in the western part of Sind monocline, Kirthar and Karachi depressions and offshore region.

Pab Sandstone

Distribution.— The Pab is limited to the west of Mirpur Batoro and Dasori wells, it may extend some distance south of Dabbo Creek-1 and Indus Marine B-1 wells. In the north it is absent in Khairpur and Mazarani wells and northern part of Kirthar range. In the west it extends upto the Bela-Ornach fault system (Figure 24).

Thickness.— The thickest section of Pab has been accumulated in the southern part of Kirthar range where more than 1280 metres of strata was deposited in a narrow northeast-southwest oriented depression.

In the Karachi depression the Pab was deposited in excess of 169 metres in an east-west oriented broad depression. This might have been the result of an uplift in the south originated during Pab time.

Another depocentre has been observed in the northern part of Kirthar range, where more than 981 metres thick Pab has been deposited in a north-south oriented depression. This depression is also believed to be the result of an uplift from east and west during or prior to the deposition of Pab strata. It is apparent that the uplifts originated during or prior to Pab deposition in the north and south have resulted in some subsidence on Sind monocline in the east and Kirthar range in the west.

The zero line represents depositional limits of the formation across Khairpur high and Kirthar depression in the northern part of the study area. The south and southeastern extent of deposition is marked in offshore region and eastern part of Sind monocline.

The truncated strata against the zero line running roughly north-south in the northern part of Kirthar range is considered to be the result of post-Pab erosion. The zero line against the truncated strata on the east continues to reveal the concept of truncating pre-Tertiary shelf dipping west from the Indian sheild as a consequence of plate movement.

Lithology and Lithofacies.— The Pab is light grey, light tan to brown, quartzitic, fine to coarse grained, hard to soft sandstone. It is occasionally conglomeratic and quite often cross bedded. Thin intercalations of dark grey shale are common and in the south it locally contains interbeds of argillaceous limestone. Sandstone accounts for most of the lithology. Locally in the south, the sandstone grades into shale. In Korangi Creek-1 and Karachi-2 wells drillled in the Karachi depression, the Pab as a sandstone is not present. It is possible that the shale encountered in the Upper Cretaceous strata in these wells, is a basinwards shale facies of Pab derived from east-west sources. A lateral gradation of sand to shale facies from east to west has also been observed in the northern part of Kirthar range.

Petroleum Potential and Reservoir Facies.— The Pab is mainly a quartzitic sandstone having no petroleum source potential, but could be a good reservoir (Table 2). Its reservoir potential is amply proved by the following petroleum occurrences in the adjoining Sulaiman sub-basin: oil seepage at Mughal Kot, gas seepage at Zindapir and gas discoveries at Dhodak, Rodho and Pirkoh. The sandstone facies of Pab is developed on a vast area of the sub-basin. The zone of lateral gradation combining probable potential source rock with excellent sand reservoir is believed to be developed in a northeast-southwest oriented area in the Karachi depression and

Table 2. Porosities of various reservoirs in Kirthar sub-basin

Age	Reservoir Formation	Lithology	Porosity (%)
M.Eocene	Kirthar	Lst	7 - 12
E.Eocene	Laki	Lst	5 - 12
Paleocene	Lakhra	Lst	8 - 12
Paleocene	Bara	Sst	15 - 20
L.Cretaceous	Pab	Sst	15 - 20
E-M.Cretaceous	Lower Goru	Sst	15 - 30

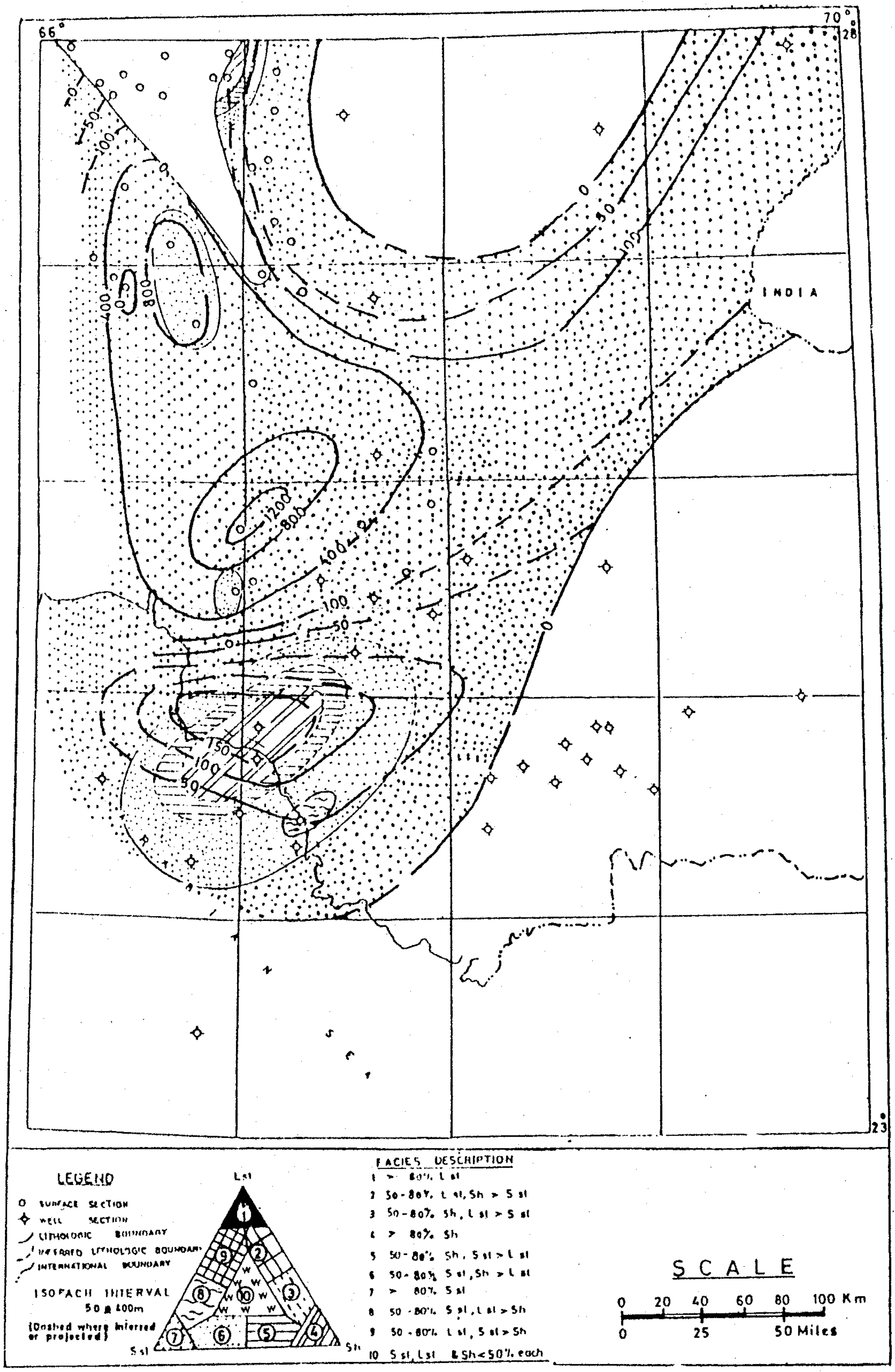


Figure 24—Thickness and lithofacies map of Pab formation.

offshore region where Pab is within oil window and is considered to be the prospective target for sandstone reservoir (Figures 17, 18). Geochemical analyses of shale samples from Kirthar range show good source rock potential (Table 1,TOC:1.72%, VR:1.07).

Probable Source-Reservoir-Seal Trilogy

Source	Reservoir	Seal
Mughal Kot (Limestone and shale)	Pab (Sandstone)	Khadro (Shale/basalt)
Mughal Kot (Limestone and shale)	Own limestone	Own shale or limestone
L.Goru (Shale)	Own sandstone	Own shale/ U.Goru(Shale)
Sembar (Shale)	L.Goru(Sandstone)	Upper Goru (Shale)

Paleocene

The Paleocene ushered a new sedimentary cycle. The Paleocene deposition commenced over Pab formation in downwarped areas where marine influence existed at the close of Cretaceous period. Some reshaping and redistribution of depressed and raised areas took place as a result of acceleration of northward plate movement accompanied by rapid sea-floor spreading of the Indian Ocean.

The Paleocene is represented by Khadro, Bara and Lakhra formations. The volcanic activity that commenced during Cretaceous time in adjoining Indian basin due to rifting extended into Early Paleocene when basalt oozed out from block faults and spread in the onshore and offshore areas of the sub-basin. The volcanic activity is restricted to Early Paleocene time as indicated by the presence of basalt in Khadro formation. The lava flows are predominantly basaltic in nature and range from fine to medium crystalline depending on the rate of cooling.

Khadro Formation

Distribution.— Khadro is the most restricted of Paleocene formations. It is mostly absent on Sind monocline, in the northern part of Kirthar range and Kirthar depression. It is also absent in the southern part of Kirthar range and western limit of Karachi depression, and has a very limited distribution in the offshore region (Figure 25).

Thickness.— Two depocentres of the formation occur in the study area. The southern one is in the Karachi depression, which received more than 500 metres of sediments and the other lies in the Kirthar range where the sediments attained a thickness of more than 600 metres in a north-south oriented depression. The truncated strata against the zero line in north of Kirthar range and Kirthar depression represent probable limit of erosion. The absence of formation in the eastern part of Sind monocline and south of Dabbo Creek well is probably due to non-deposition. The truncated strata against zero line in the west probably represents post-Khadro erosional limit. The absence of Khadro on locally developed uplifted areas in Kirthar range may also be the result of post-Khadro erosion.

Lithology and Lithofacies.— The formation consists of sandstone and shale with subordinate limestone. The sandstone is grey to brown in colour, poorly consolidated, ferruginous and calcareous. The shale is grey to brown, arenaceous, and sometimes contains thin limestone bands.

Some lava flows are present in the unit that are fine to medium crystalline and basaltic.

In the southern part, the Khadro is dominated by basalt with subordinate shale, sandstone and rare amount of limestone. In the southeast (Kutch basin) tuff has been reported from the Indian part of the Kutch basin. The amount of basalt decreases northwards and a dominant shale facies with subordinate sandstone and limestone has been developed in Kirthar range, Kirthar depression, Sind monocline and Karachi depression.

Basalt is present in most of the wells drilled in Sind monocline and Karachi depression.

Petroleum Potential and Reservoir Facies.— Due to volcanic activity during Khadro the petroleum potential of the formation is doubtful. However, it could act as a seal over Pab reservoir.

Bara-Lakhra Formation

Distribution.— It has a greater lateral extent in the east, north and south than the underlying Khadro formation. It is absent in the west in Kirthar range, Mari horst and part of offshore region and is locally absent in the northern part of Kirthar range (Figure 26).

Thickness.— The thickest accumulation of strata occurs in a narrow northeast-southwest oriented area from Karachi depression to offshore region. This area received

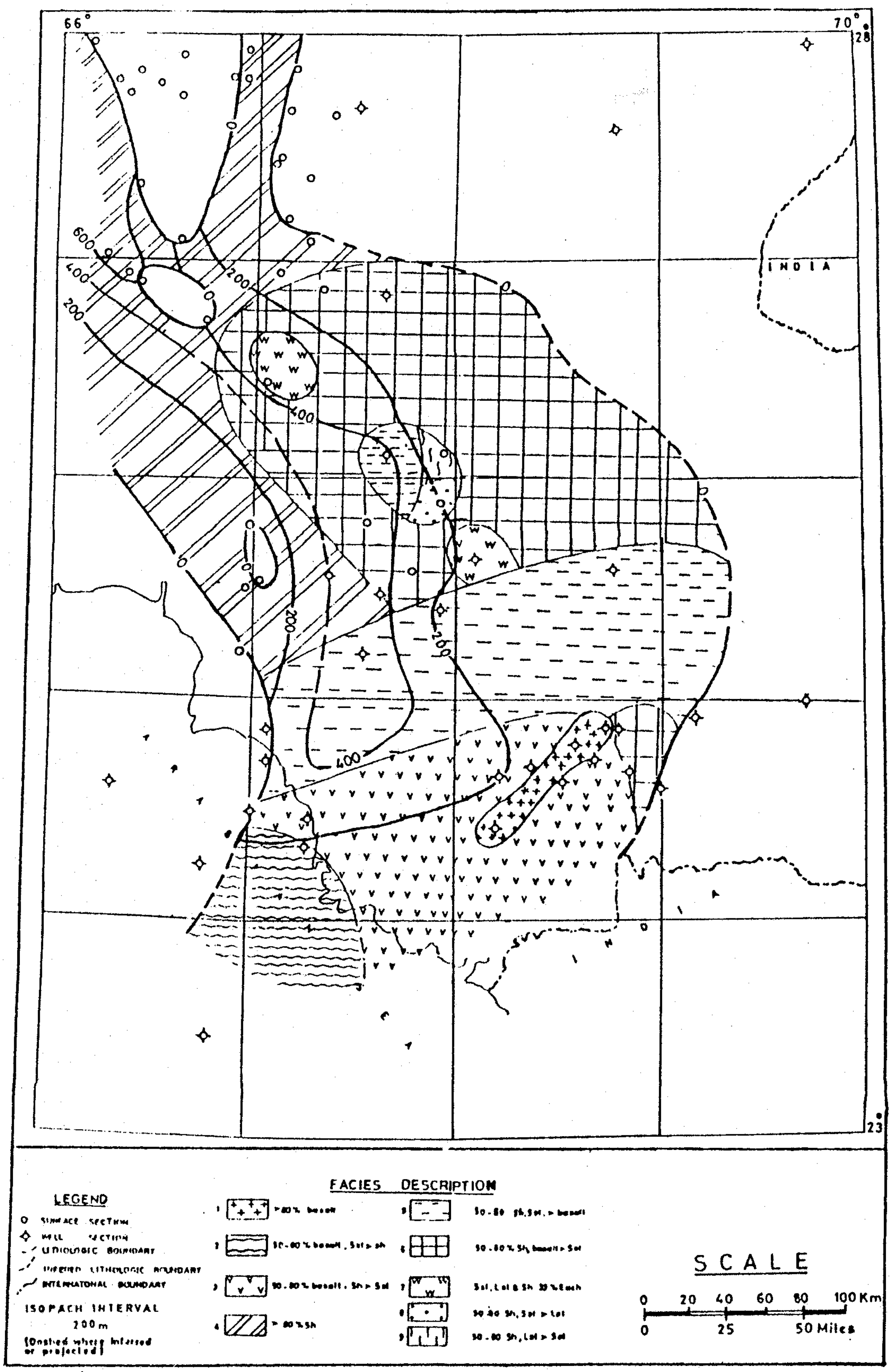


Figure 25—Thickness and lithofacies map of Khadro formation.

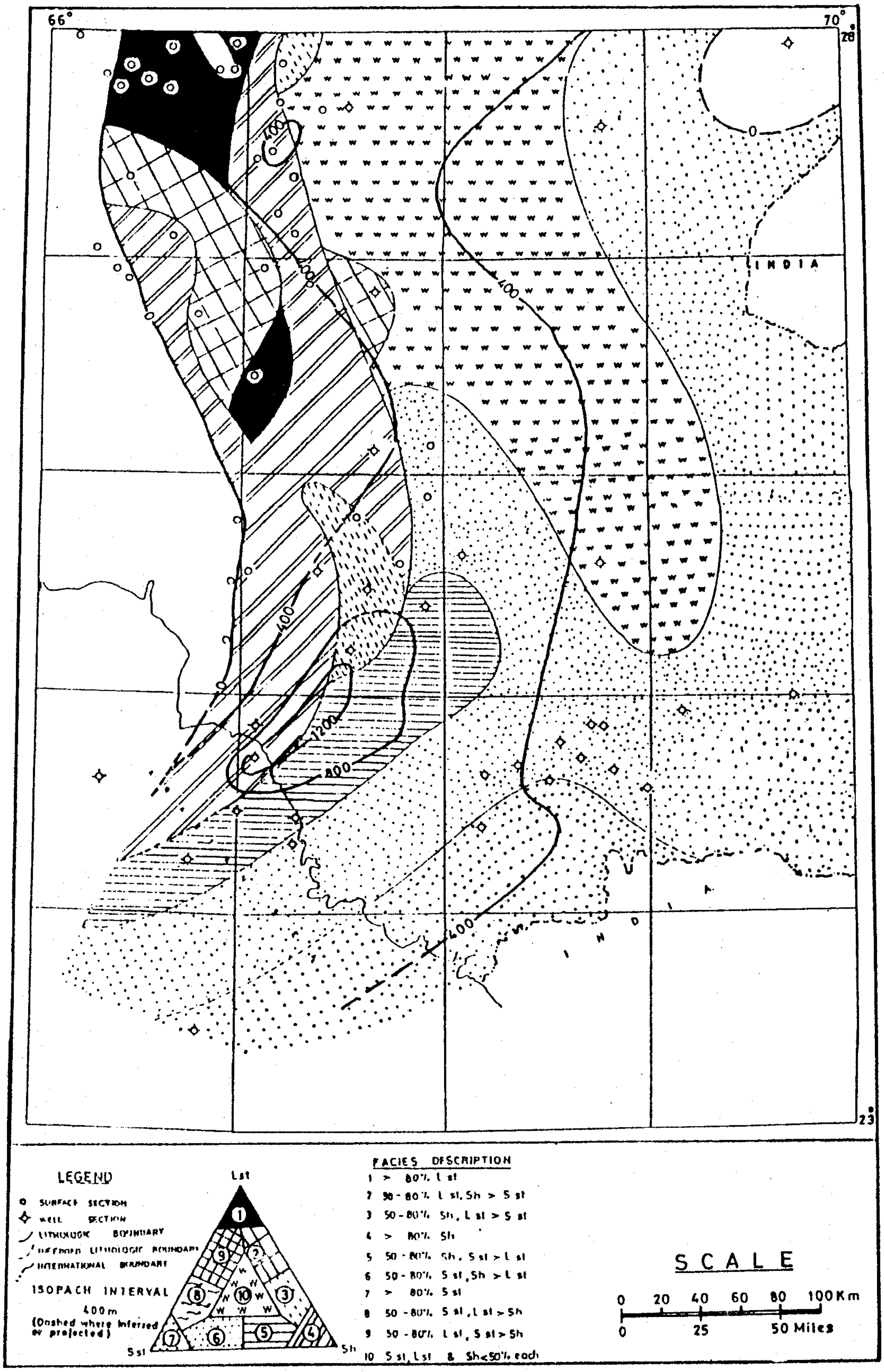


Figure 26—Thickness and lithofacies map of Bara-Lakhra formation.

more than 1300 metres of sediments. From the depocentre, the thickness decreases rapidly towards northwest, whereas the decrease in thickness is gradual in all other directions.

Lithology and Lithofacies.— The formation is very heterogeneous ranging from sandstone, shale to limestone. It is dominantly a coarse grained, grey to brown, usually ferruginous sandstone with subordinate shale in the east in Sind monocline. The amount of shale increases westward on the expense of sandstone and a dominant shale lithology with subordinate limestone and rare amount of sandstone extending from Kirthar range to Karachi depression and some of the offshore region has been developed. The shale is generally grey to brown, fissile and silty. In the northern part of Kirthar range the formation is dominantly a limestone which is generally grey, weathering brown, with interbeds of grey to brown shale.

Petroleum Potential and Reservoir Facies.— The formation is within oil and gas window in Karachi and Kirthar depressions and offshore region (Figures 17, 18, 27). Gas has been discovered at Sari, Hundi and Kothar. Traces of gas were recorded during DST in Dabbo Creek-1 and Korangi Creek-1.

The sandstone reservoir facies is distributed in Sind monocline and some of the area in Karachi depression, Kirthar depression and offshore region. The dominant sandstone unit in Sind monocline grades laterally into silty shale deposited under marine conditions in Karachi depression where source rocks may be developed. Shales of the Lakhra in Kirthar range show good source rock potential (Table 1,TOC:1.19%,VR:1.01).

The clastic/nonclastic ratio shows that formation has limited carbonate distribution in the area (Figure 28). The carbonate reservoir facies is located in the Kirthar and Karachi depressions and may act as potential target for exploration.

Probable Source-Reservoir-Seal Trilogy

Source	Reservoir	Seal
Lakhra (Shale)	Own limestone	Own shale
Bara(Shale)	Own sandstone	Own shale

Eocene

As a response to plate collision in Eocene the final regression took place during Middle-Late Eocene in northern part of the Indus basin; the seas transgressed over Cambay and Paleocene marine conditions persisted in Eocene over Kirthar sub-basin, where the southern areas became more depressed and submerged.

Eocene rocks are of considerable importance because they contain many oil and gas fields discovered in various parts of the Indus basin. In our study area Mari, Khairpur and Mazarani fields are located which have Eocene carbonate gas reservoirs. Rocks of Eocene age are widespread in the sub-basin. The Eocene section becomes thickest towards offshore region. The thickness decreases over unstable horst areas.

The rocks of Eocene are represented by Laki/Ghazij and Kirthar formations. These two formations are well exposed in the Kirthar range and are present in varying amount in the subsurface.

Laki/Ghazij Formation

Distribution.— The western boundary of the formation is marked in the Kirthar range. The offshore region appears to receive thin deposits during this period. Northwards, the formation extends into Sulaiman depression. It is absent in Mirpur Batoro, Damiri and Jati wells in Sind monocline (Figure 29).

Thickness.— The thickest sequence of Laki/Ghazij has been encountered in Benir-1 well in the Karachi depression, where it is 1328 metres thick. This area is adjacent to Kirthar range and it appears that probably a part of the Kirthar range was an uplifted area and acted as a source of sediment for Karachi depression.

The formation extends in the south in Kutch basin limits. It is absent at the eastern margin of Karachi depression and southeastern area of Kirthar depression.

Lithology and Lithofacies.— The facies equivalent of Laki limestone is the Ghazij shale. The Ghazij formation is well developed in the east in Sind monocline, in the eastern part of Kirthar range and roughly in the western part of Karachi depression and some of the offshore area. The Ghazij is dominantly a shale facies with subordinate sandstone and rare amount of locally developed limestone in the southeastern part of Sind monocline. The amount of shale decreases southward on Sind monocline. Towards north in Sind monocline the dominant shale facies is interbedded with subordinate limestone and rare amount of locally developed sandstone. Similar facies were developed in the western part of Sind monocline. The shale is generally grey to greenish grey, friable, calcareous, silty, and lacks stratification. The limestone is of grey colour, argillaceous and thinly bedded. The sandstone is grey, soft, ill sorted, fine to coarse grained and well stratified. In Kirthar range, Karachi depression and offshore area, the shale is greenish grey, pale, brown, and

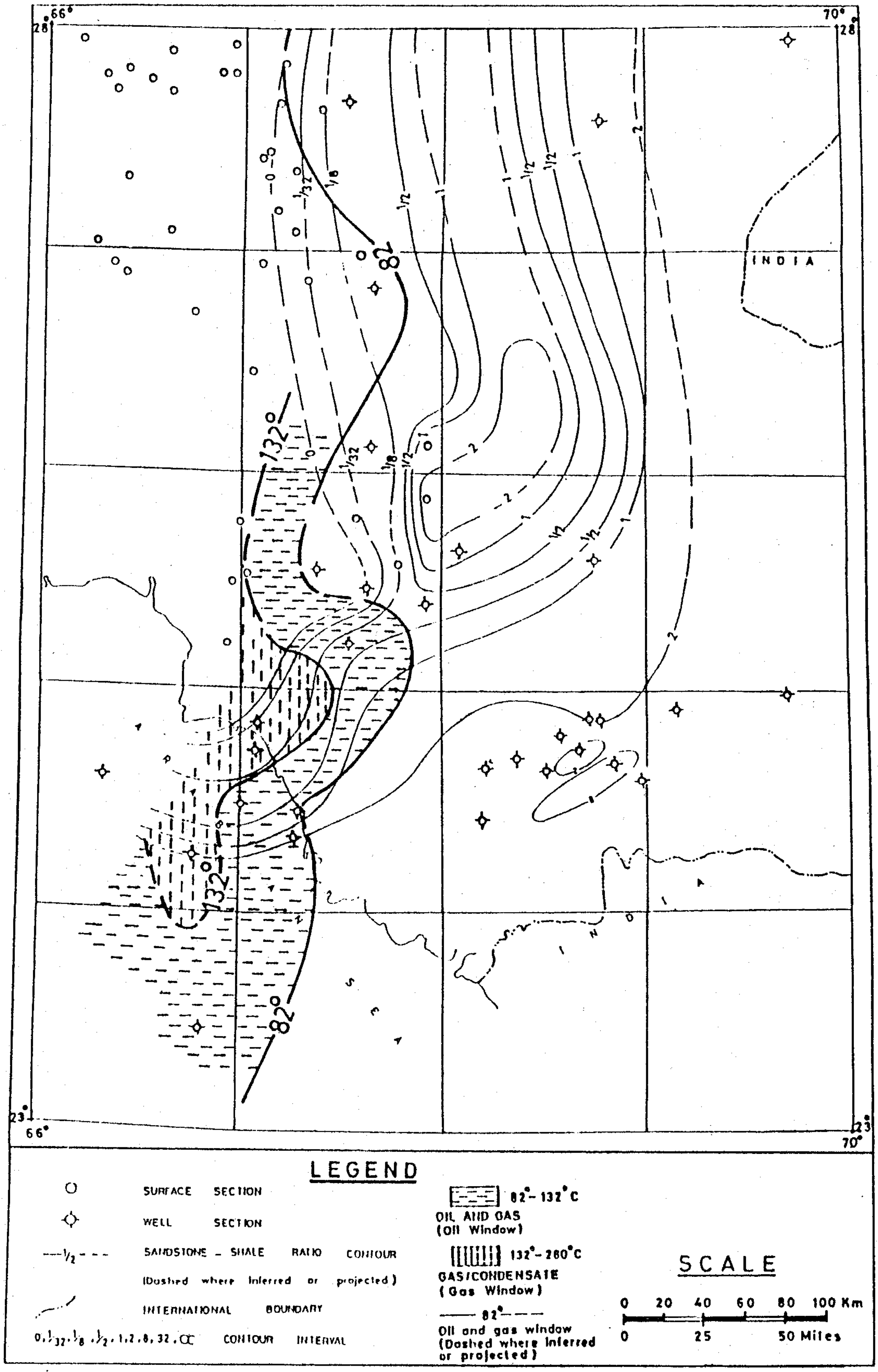


Figure 27—Sand-shale ratio map of Bara-Lakhra formation with isogeotherms.

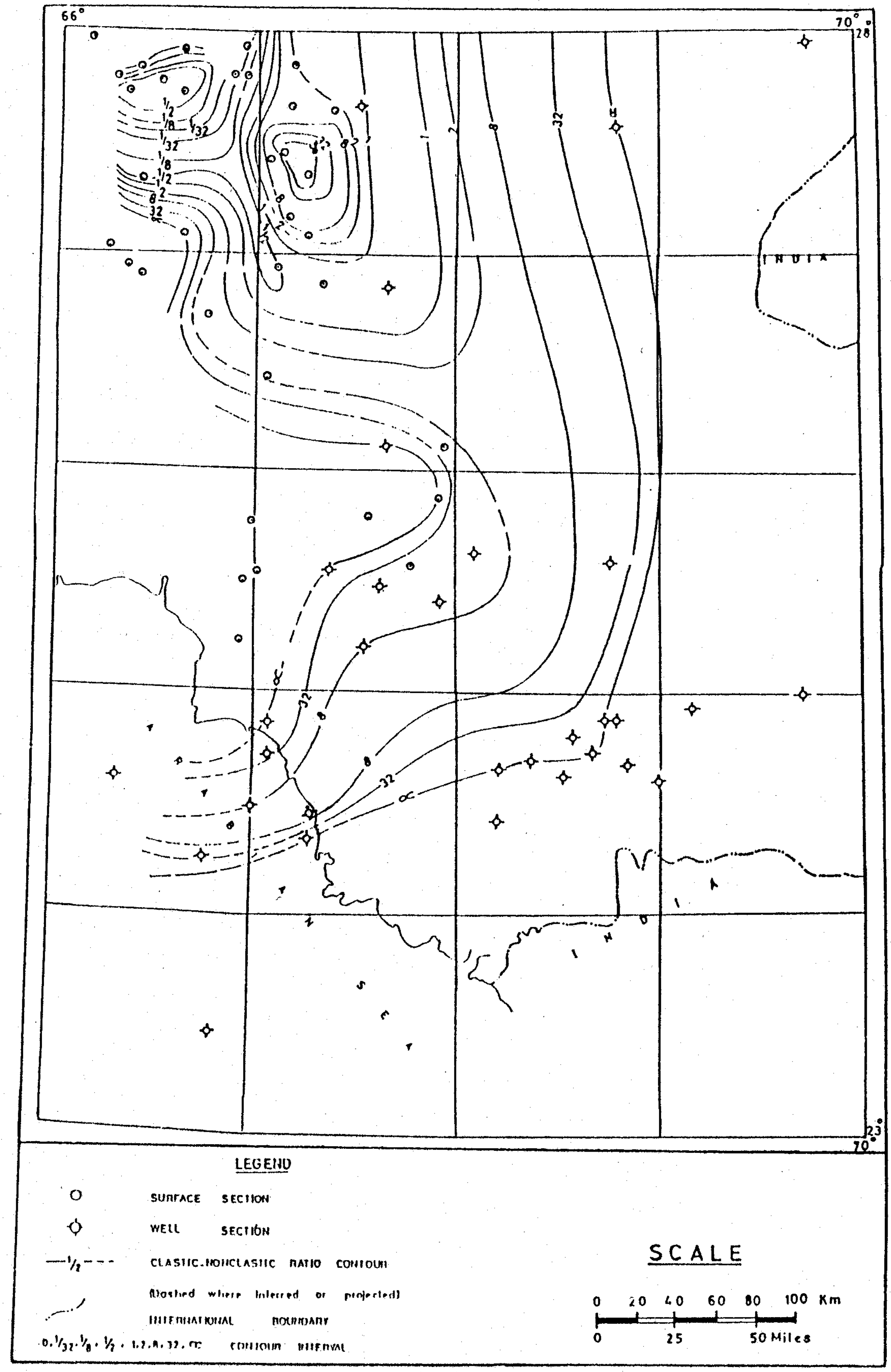


Figure 28—Clastic/nonclastic ratio map of Bara-Lakhra formation.

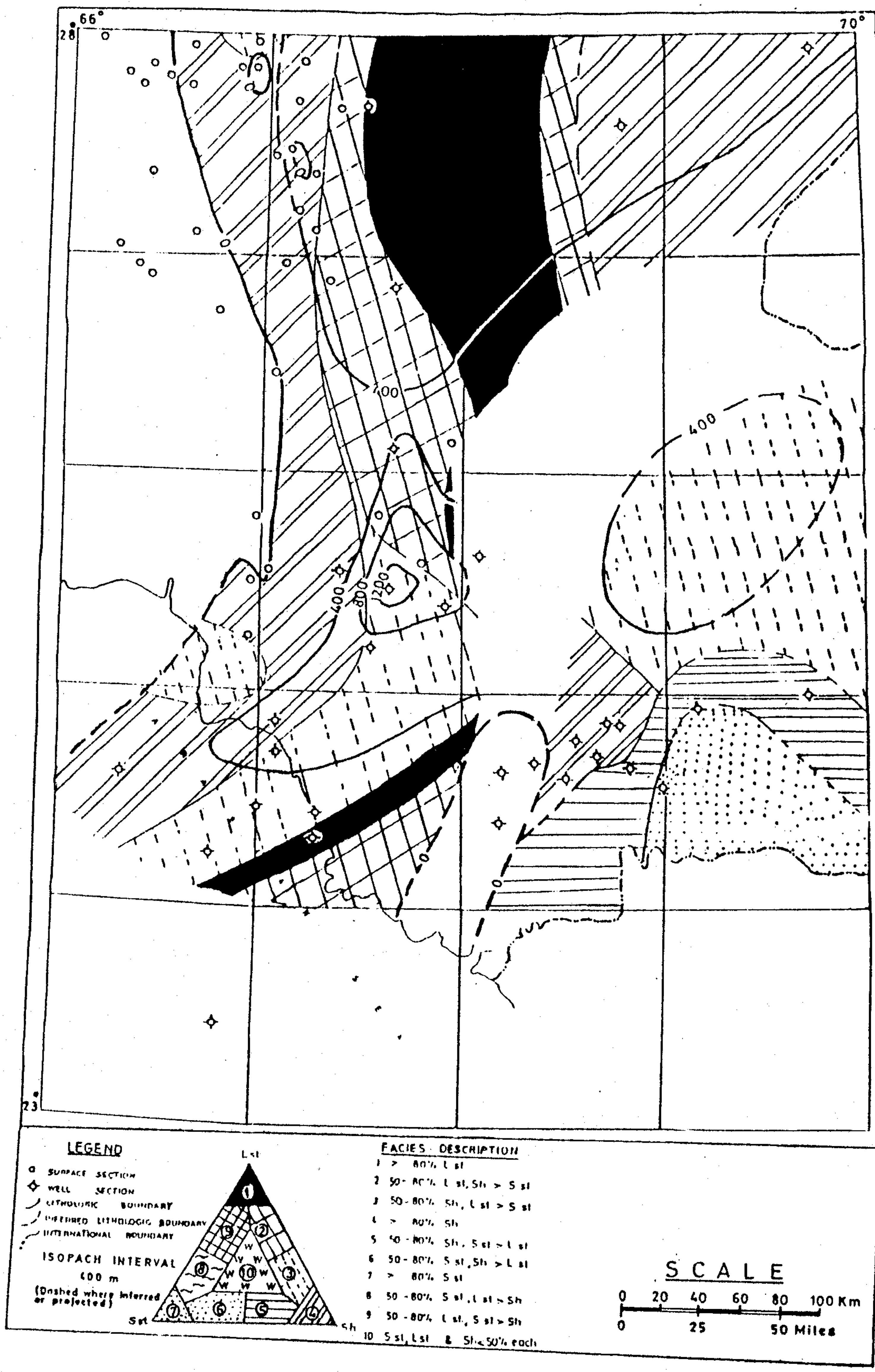


Figure 29—Thickness and lithofacies map of Laki/Ghazij formation.

contains intercalations of grey stratified limestone and grey fine grained sandstone. The formation contains a mixture of planktonic and smaller benthonic foraminifera which suggest it to be a shelf edge-slope deposit. The subordinate lithologies of the Ghazij i.e. limestone and sandstone are quite persistent in their distribution.

The dominant shale facies from the eastern and western boundary laterally grades into limestone and a dominant limestone facies with subordinate shale has been developed in Kirthar depression, northern and western part of Karachi depression which is termed as Laki formation. The limestone is mostly light brown to grey, crystalline, fragmental, fossiliferous, occasionally dolomitic with subordinate olive green to light grey, brown to dark brown, carbonaceous shale.

Petroleum Potential and Reservoir Facies.— Two oil shows have been obtained from Ghazij strata, one in Mari-1 well from thin interbedded limestone, and the other from calcareous shale in Sunbak-1 well. Gas has been found in Laki limestone in Mazarani-1 and Khairpur-2 wells.

Though essentially Ghazij is a shale facies, and a possible source rock, (Table 1,TOC:6.89%,VR:0.65) the interbedded sandstone and limestone can serve as reservoir in Sind monocline, Kirthar and Karachi depressions and offshore area.

The clastics/nonclastic ratio shows that the carbonate reservoir facies interbedded with shale are developed in Karachi and Kirthar depressions, northern part of Sind monocline and offshore area (Figure 30).

The carbonate reservoir facies is distributed in the major part of Karachi depression, Kirthar depression and northern part of Sind monocline. Development of reef is indicated on seismic data in offshore platform which could form excellent exploration target. The formation is within oil window in Karachi depression and offshore area.

Kirthar Formation

Distribution.— Kirthar has more restricted areal distribution in the east and has wider areal extent in the west and south than the underlying Laki/Ghazij formation (Figure 31).

Thickness.— Over 1200 metres thick Kirthar formation has been accumulated in the Karachi depression. This thickest section of Kirthar has been encountered in the Korangi Creek-1 well.

Probably more than 600 metres of Kirthar strata have been deposited in two separated depressions, one in the northern part of Karachi depression and the other in the central part of Kirthar range. The formation is generally thin elsewhere in the sub-basin. The absence of Kirthar strata in Sind monocline indicates probable erosion prior to the deposition of Siwalik.

The zero line in the west and offshore area represents probable depositional limits.

Lithology and Lithofacies.— The Kirthar is dominantly limestone facies with subordinate shale. The limestone is in light shades of white and grey, hard and massive, fossiliferous, and weathers in light brown colour. It is a typical shelf carbonate deposit. The shale is grey, brown, soft and calcareous.

The formation is mainly of Middle Eocene age, but in a part of Karachi depression the age and lithology extends into Early Oligocene with a small time hiatus in between.

Petroleum Potential and Reservoir Facies.— The Kirthar has yielded substantial quantities of gas in Mari wells. Gas shows have been encountered in Karachi-1 well. Oil shows have been found in Mari X-2 and Mazarani-1 wells. The reservoir characters of the limestone are well demonstrated by the Mari wells. Thickness of limestone unit is substantial and both primary and secondary porosity can be expected. Reef may be developed in shallow shelf waters and thus would form potential reservoir in the offshore area.

The limestone reservoir facies is developed in Kirthar and Karachi depressions, offshore area and Sind monocline.

Known oil shale occurrences in Sulaiman range may extend and adequately buried in Kirthar depression to act as source rock. Limestone and shale samples in Kirthar range show source rock potential (Table 1,TOC:9.75%, VR:0.76).

Probable Source-Reservoir-Seal Trilogy

Source	Reservoir	Seal
Kirthar (Shale and limestone)	Own limestone	Own shale
Laki/Ghazij (Shale)	Own limestone	Own shale

Oligocene

The end of Eocene period is marked by the partial uplift of the Himalayas and its associated mountains in the central part of the Indus basin.

The Oligocene sediments consist of Nari formation. This formation is exposed only in the western part of the study area.

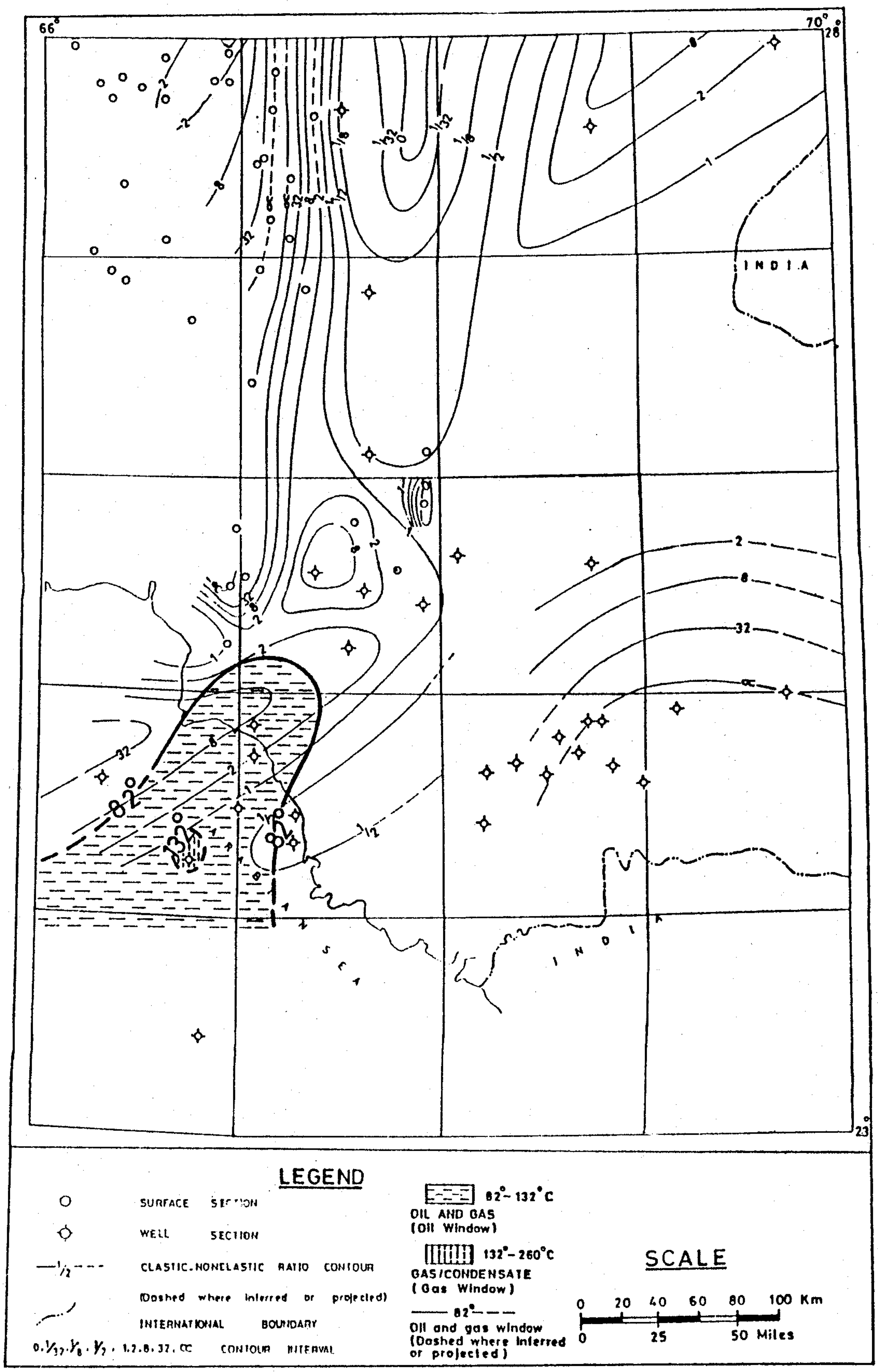


Figure 30—Clastic/nonclastic ratio map of Laki/Ghazij formation with isogeotherms at the base.

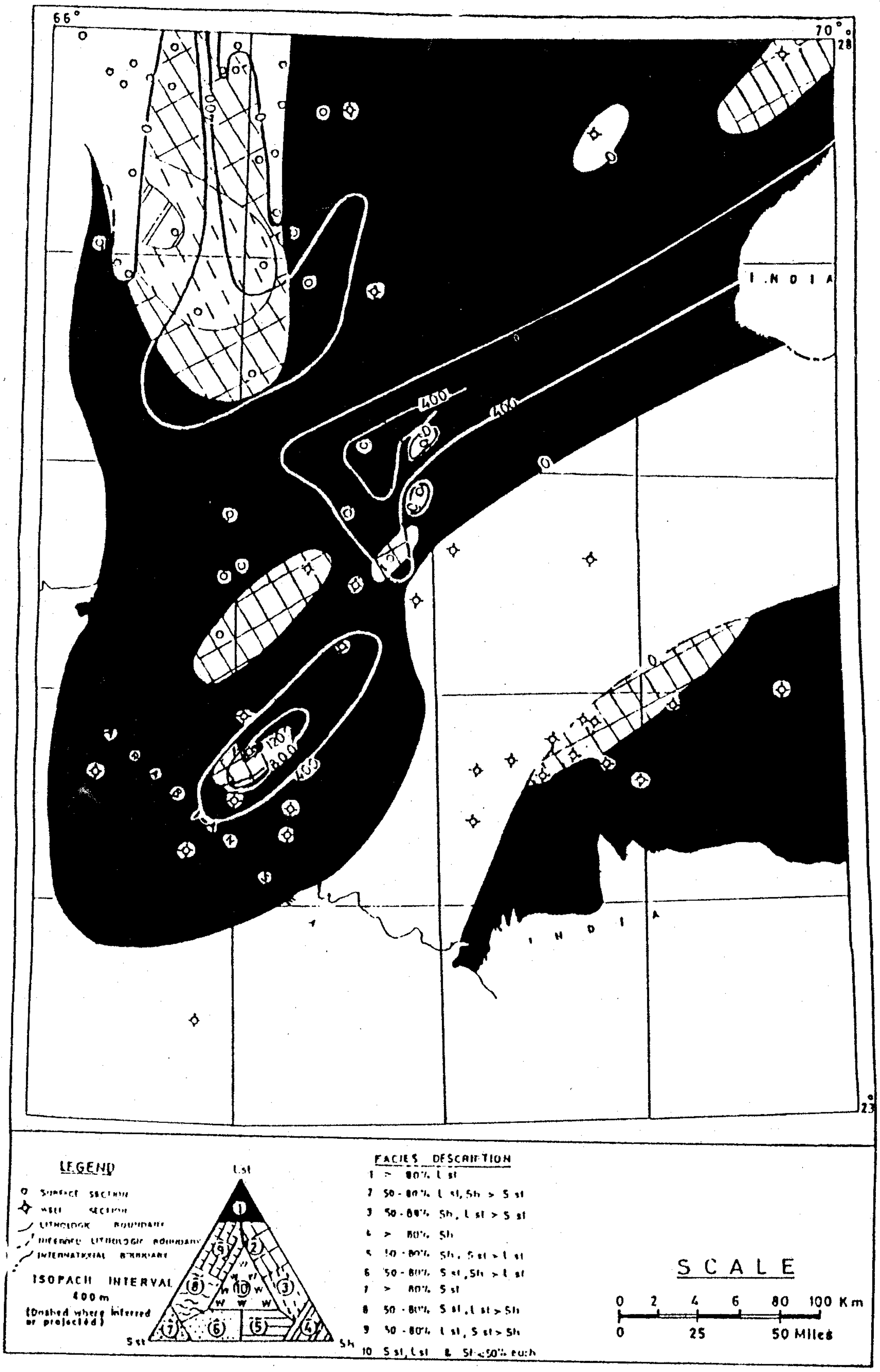


Figure 31—Thickness and lithofacies map of Kirthar formation.

The rocks of Oligocene age record a fundamental change in the sedimentation of the basin by the gradual replacement of limestone with clastics sediments. Prior to this the Karachi depression experienced marine influence during the deposition of calcareous, argillaceous facies of the formation, whereas northwards the ferruginous sandstone is believed to be deposited in fluviatile environment.

Due to the above mentioned uplift the basin was considerably reduced by the westward movement of the foreland shore with the result that Oligocene sediments in the study area are not present in the eastern part of Sind monocline.

Nari Formation

Distribution.— The Nari occurs in Kirthar and Karachi depressions and extends into offshore area. It is mostly absent in Kirthar range and almost completely absent in Sind monocline (Figure 32).

Thickness.— Oligocene sediments in certain areas of the basin are very thick, and it is apparent that the uplift at the time of Oligocene precisely delineated the Kirthar, Karachi and offshore depressions in the Kirthar sub-basin. The thickest section of the formation which is up to 1798m thick was encountered in Karachi-2 well drilled in Karachi depression. The absence of strata at some places in the northern part of Kirthar range and at the sub-division of Karachi and Kirthar depression is probably due to pre-Siwalik erosion. The zero line west of Kirthar range and in the offshore area represents probable depositional limit of the formation.

Lithology and Lithofacies.— The Nari is composed dominantly of clastics in the major part of the basin. The western part of its deposit consists dominantly of shale, whereas the eastern part has a dominance of carbonate facies. In the central part, a dominant sand facies has been developed. The limestone is pale, light brown and whitish grey, arenaceous and fossiliferous. Thin layers of dark grey shale and fine grained sandstone intercalate with the limestone. The sandstone is brown to grey, locally conglomeratic. The shales are in shades of brown, grey and pale, arenaceous to calcareous, clayey and at places ferruginous.

Petroleum Potential and Reservoir Facies.— Some gas shows have been recorded in Dabbo Creek-1 and Karachi-1 wells. Out of these Dabbo Creek was tested to find out the potential of gas shows but the result showed the absence of any commercial hydrocarbon.

Sandstone in Nari is commonly well sorted and loosely cemented and it could make an excellent reservoir.

The sandstone reservoirs are distributed in the major part of the sub-basin. The sandstone reservoir facies exists in the offshore and adjacent onshore area. The other deposits of sandstone reservoir facies have been developed in a north-south oriented area in Kirthar depression. The most prospective target for hydrocarbon exploration may exist in the offshore and adjoining onshore areas, which have sufficient overburden for the generation of hydrocarbon (Figure 33). Geochemical analyses of shale samples in Kirthar range indicate source rock potential (Table 1, TOC:0.86%, VR:0.94).

The carbonate reservoir facies which exists in the offshore area may act as prospective target for hydrocarbon exploration (Figure 32).

Probable Source-Reservoir-Seal Trilogy

Source	Reservoir	Seal
Older source, Nari (Shale and reefal limestone)	Nari(Sandstone and limestone)	Own shale-clay

Miocene

During the Miocene period the Oligocene basin was further reduced due to heavy load of detritus coming from the growing mountain ranges. This is shown by the fact that the rocks of this age are not as widespread as those of Oligocene.

The period also exhibits marine and fluviatile deposition. The change which commenced from the north in Oligocene time continued pushing the marine environments to the south throughout the Miocene period. This period represents the last marine environment onshore in the sub-basin. Rocks of Miocene age are represented by Gaj formation.

Gaj Formation

Distribution.— The Gaj occurs in two separate areas, one in the offshore and adjacent Karachi depression, whereas the other lies in the Kirthar range and adjacent Kirthar depression. The Gaj generally coincides with the eastern portion of the Nari distribution. It is mostly absent in the Kirthar range and Karachi depression (Figure 34).

Thickness.— The thickest accumulation of 3249 m is encountered in Indus Marine B-1 well located in the offshore area of southern Indus basin. This depression is oriented in north-south direction. The thickness rapidly

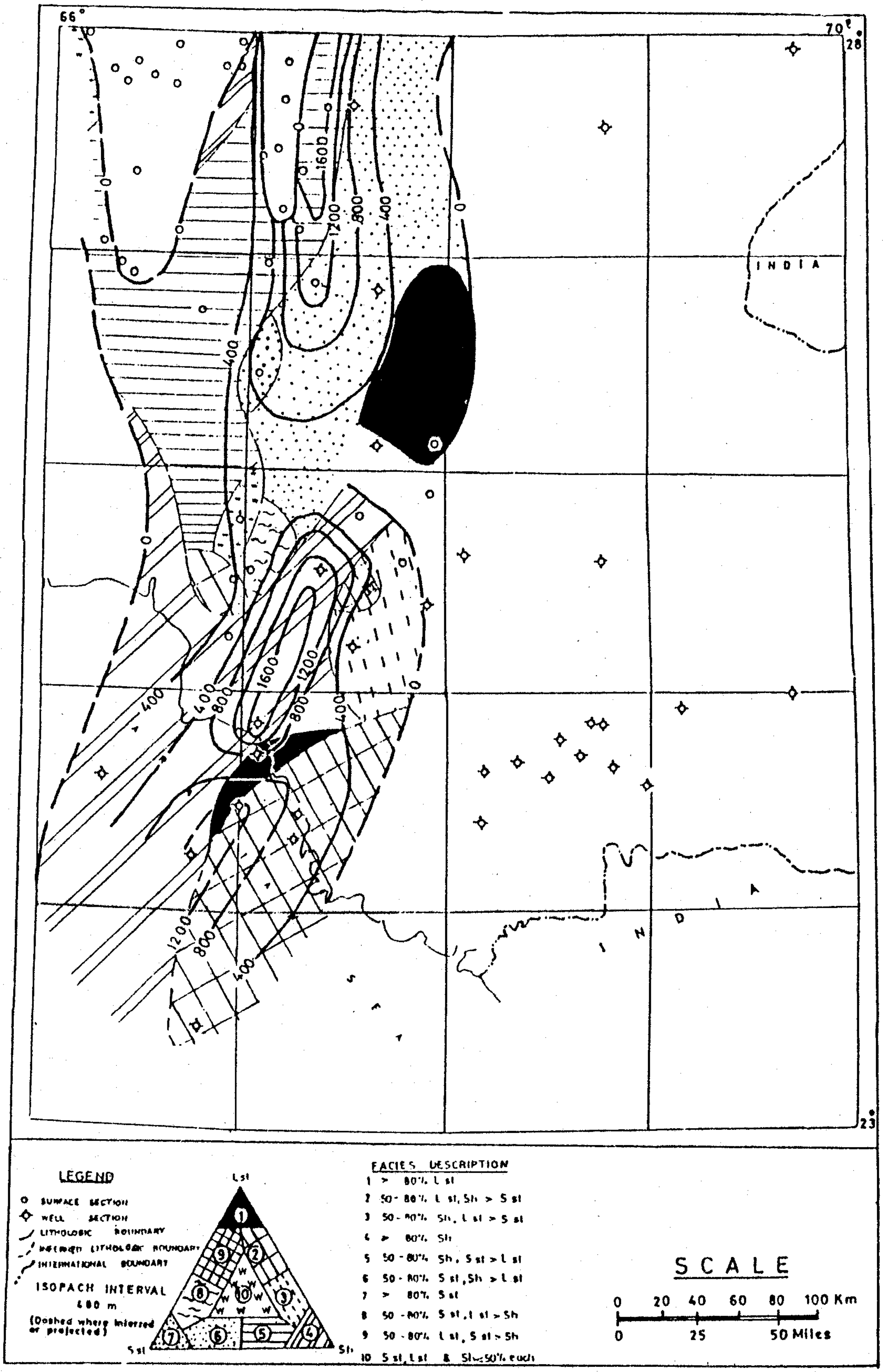


Figure 32—Thickness and lithofacies map of Nari formation.

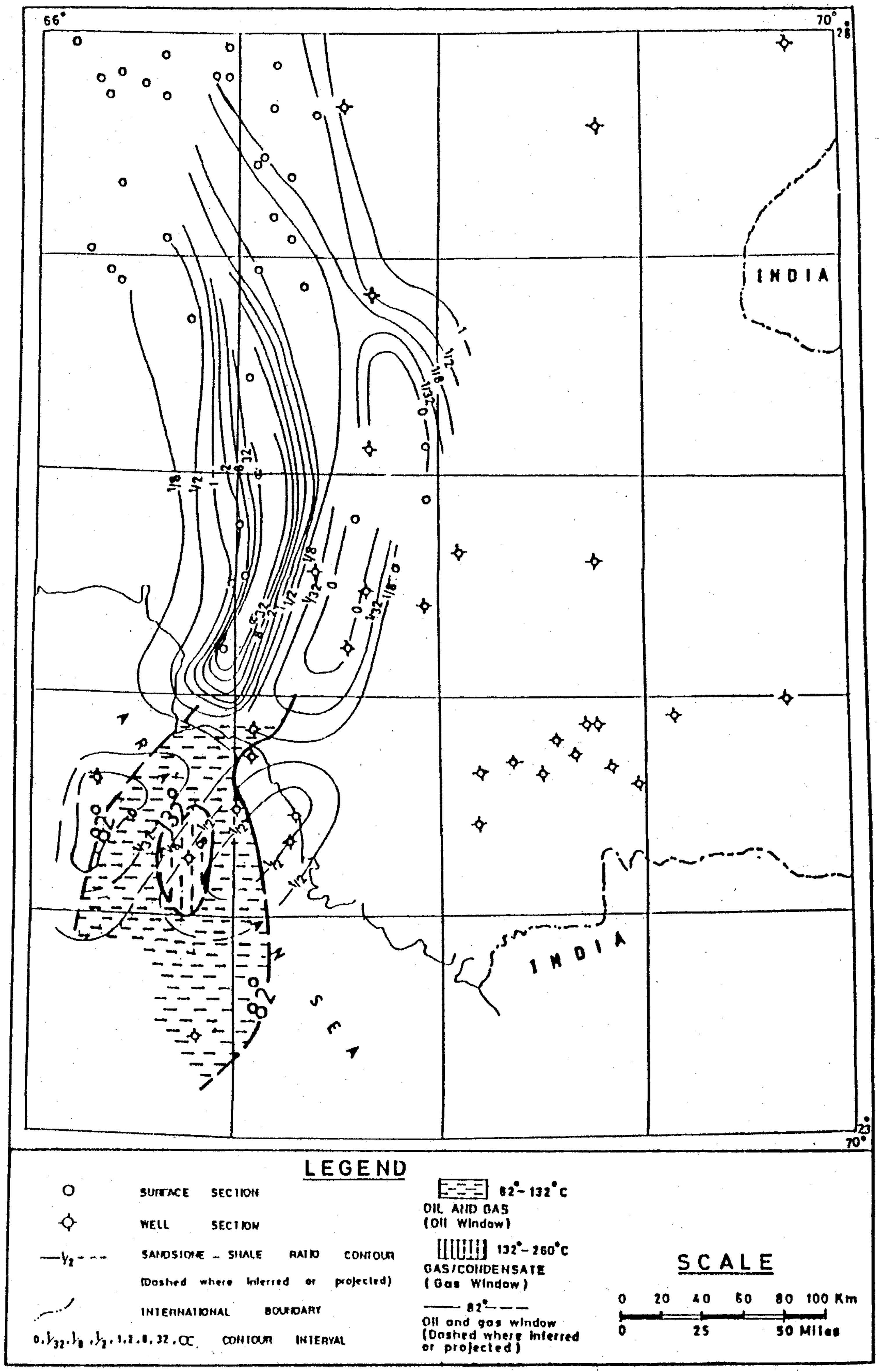


Figure 33—Sand-shale ratio map of Nari formation with isogeotherms at the base.

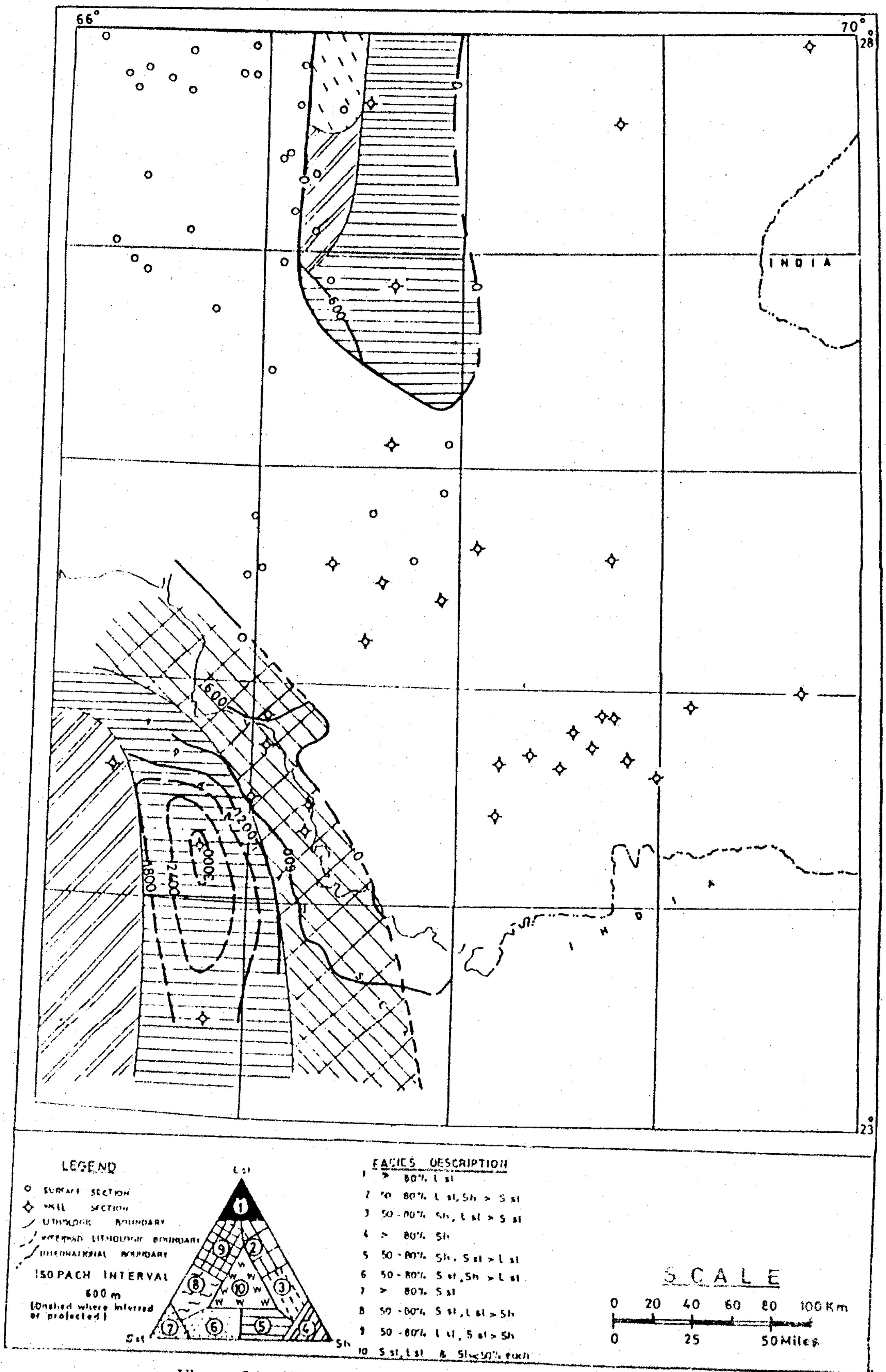


Figure 34—Thickness and lithofacies map of Gaj formation.

decreases towards east and west from the depocentre. The absence of Gaj strata in Karachi depression and Kirthar range is probably due to post-Gaj erosion, whereas its absence in Sind monocline is due to non-deposition.

Lithology and Lithofacies.— Clastic sediments dominate the lithology of Gaj formation. Deposition within Karachi depression consists mainly of carbonates with interbedded shale and rare amount of sandstone. This sequence is also encountered westwards in the Kirthar range and southwards in the offshore area. The dominant carbonate lithology decreases towards offshore and a dominant shale lithology with subordinate sandstone and rare amount of limestone has been deposited in west in offshore area.

The shale is variegated, greenish black, soft, silty to sandy. The sandstone is brown, greenish grey, calcareous, and cross bedded. The limestone is brown or yellowish white, argillaceous and fossiliferous.

Petroleum Potential and Reservoir Facies.— The unit holds no prospects for oil and gas onshore due to lack of overburden. Gas has been discovered in Pak-Can-1 in clastic equivalent of Gaj in offshore. Oil window covers some part of the formation in offshore depression (Figure 17).

Probable Source-Reservoir-Seal Trilogy

Source	Reservoir	Seal
Older source and own shale	Gaj(Sandstone)	Own shale-clay

STRATIGRAPHIC SETTING AND DEPOSITIONAL EVENTS

Two stratigraphic correlation sections have been prepared to demonstrate the stratigraphic setting of various formations in the area.

Section AA'(Figure 17) gives the stratigraphic correlation of Sind monocline to Karachi depression, offshore platform and offshore depression in east-west direction. The oldest rock which has been partially penetrated by Nabisar well in the eastern corner of Sind monocline is of Triassic age whereas the deepest well, Indus Marine B-1 in the west in offshore depression was abandoned in Gaj formation of Miocene age. Due to limited control the Triassic and Jurassic strata have not been correlated.

Several extensive cycles of marine transgressions and regressions occured in the area as response to rifting and northward movement of the Indian plate. Two main phases of tectonic instability have been recorded. The uplift associated with Cretaceous-Paleocene rifting has caused an unconformity. As a result, Middle to Late Cretaceous strata are missing in horst blocks in Sind monocline. The presence of Paleocene strata in all wells drilled in the alluvial plain of the basin reflects a remarkable subsidence of Sind monocline during Paleocene time.

The second cycle of regression probably occurred during Late Eocene-Early Miocene time which has also resulted in the creation of an unconformity and Late Eocene to Miocene strata are largely missing in Sind monocline. The wells drilled in the offshore platform have penetrated the Miocene to Late Cretaceous sediments.

Section BB' (Figure 18) correlates the stratigraphic sequence of Kirthar and Karachi depressions and offshore platform in north-south direction. The deepest well drilled in the offshore paltform is Dabbo Creek-1 which has penetrated a section of Miocene to Cretaceous strata. The well was probably abandoned in Early Cretaceous section. Metamorphosed limestone and siltstone/shale with associated igneous material were encountered in the basal part of Dabbo Creek well. This section is absolutely new in this area and can not be correlated with any well or surface section. However, in the Kirthar range in the west and Kutch area in the east igneous intrusions are present in the Cretaceous formations. Petrological studies of the cored interval in Dabbo Creek well by Sun Oil Company's Research lab in Richardson, Texas, U.S.A. (1985) concluded that metamorphosed rocks associated with igneous material represent a zone of igneous intrusions and it should be considered as effective basement for the offshore area.

Complete correlation of Cretaceous-Paleocene formations has not been done because the wells drilled in Karachi and Kirthar depressions were abandoned in Paleocene and Late Cretaceous strata. However, the following points can be derived: (1) A phase of uplifting is recorded in the northern part of the sub-basin where the Late Cretaceous Pab formation and Early Paleocene Khadro formation are absent in Mazarani well, (2) Maximum thickness of Bara-Lakhra is observed in Karachi depression. The facies changes from dominantly calcareous in the north to argillaceous-arenaceous in the south, and (3) The Laki formation is in limestone facies in the north and becomes more argillaceous southwards. It is also reduced in thickness in coastal region.

RESOURCE AND RESERVES

Using volumetric yield method of Weeks (1949) a preliminary estimate of the undiscovered hydrocarbon resources of the region has been made as follows:

Volume of sediments:	440,000 mi^3
Type of basin:	Extra-continental trough downwarp.
Recovery per cubic mile in analogous producing basins:	60,000 barrels
Estimate of resources:	440,000 x 60,000 = 26,400 million barrels
Petroleum potential:	High
Oil and gas ratio:	1:1
Total oil resource:	13 billion barrels
Total gas resource:	76 trillion cubic feet

The proven reserves so far discovered in the region are as follows:

Proven oil reserves: (Excluding a number of fields in Badin area)	85 million barrels
Proven gas reserves: (Excluding a nubmer of fields in Badin area)	9 trillion cubic feet

A comparison of the resource with proven reserves is enough to suggest that a lot of effort has to be done to tap a major part of the resource. The resource should, however, be taken as very rough.

CONCLUDING REMARKS

Northward movement of the Indian plate accompanied by anticlockwise rotation, resulting sea floor spreading and collision and bulldozing of the Indian plate against Eurasia were the major tectonic events which gave rise to local tectonics and influenced sedimentation in the sub-basin.

Geological setting of a sedimentary basin controls hydrocarbon migration and entrapment. The nature of sedimentary fill, pressure of fluid and growth of structures determine the path of fluid movement. The entrapment of moving fluid is dependent mainly on tectonics and variation in sedimentary facies. Generally, the following patterns of fluid movement are observed: (1) In interbedded sandstone-shale sequence, the movement is towards the basin edge, (2) In a thick shale infill, the fluid movement is directed vertically upward, and (3) The carbonates provide both vertical as well as edge-wise paths for the moving fluid. Observing this phenomenon and from the preceding appraisal of various maps and cross sections the following observations are made:

1. The sedimentary fill shows that through much geologic time, marine circulation of the basin was slightly restricted. The result was deposition of numerous shales with probable high organic content which may act as source bed for large amount of hydrocarbon.

2. Probable source rock with reservoir rock exists in Sembar, Goru, Mughal Kot, Pab, Bara-Lakhra and Kirthar formations of Cretaceous to Eocene age. It is postulated that during the active subsidence phase in Jurassic-Cretaceous time, hydrocarbon might have been generated in the deeper parts of the basin and sloping shelf, and the fairway of hydrocarbon migration would be vertically upward in deep depressions and updip on Sind monocline where they are presently found.

3. The present study indicates that in addition to onshore areas of the sub-basin, the rocks of Cretaceous-Oligocene age also fall within oil and gas window in offshore and adjoining Kutch basin, where Late Cretaceous-Palecoene sandstone, Eocene carbonate (including reefs) and Miocene sands can form reservoirs.

4. Rock deformation associated with rifting and collision might have resulted in formation of a large number of structural and stratigraphic traps in elevated as well as deeper part of the basin which may serve as potential exploration targets. During the rifting phase traps associated with faults are expected to be largely developed on Sind monocline and Indus offshore platform, whereas during the compressional phase large anticlines might have mainly developed in Karachi, Kirthar and offshore depressions and Kirthar and Mazarani folded zones.

5. Oil and gas pools of three different ages exist: (1) Cretaceous sandstone, (2) Paleocene sandstone and carbonate, and (3) Eocene carbonates. The known reservoirs of Cretaceous age lie exclusively on Sind monocline. The Paleocene reservoirs are located in Karachi depression and the Eocene reservoirs are restricted to the northern limits of Sind monocline and Kirthar depression. Both oil and gas are found in Cretaceous reservoirs, whereas Paleocene and Eocene reservoirs are gas-bearing so far as discovered.

6. The proven reserves excluding a number of oil and gas fields in Badin block are: More than 85 million barrels of oil and 9 trillion cubic feet of gas. The estimated resource (present study) consists of 13 billion barrels of oil and 76 trillion cubic feet of gas.

7. The sub-basin is a good example of petroliferous basin with sedimentary environments favourable for growth and preservation of organic matter and the maturation and generation of hydrocarbons. Although the area is receiving ever increasing attention of exploration companies, a lot remains to be done.

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