Pakistan Journal of Hydrocarbon Research
Vol.11, (January 1999). p.37-50, 8 Figs., 3 Tables

Regional Trends in Porosity and Permeability of Reservoir Horizons of Lower Goru Formation, Lower Indus Basin, Pakistan

Fazal Ghani Khattak[1], Muhammad Shafeeq[1] and S. Manshoor Ali[1]

ABSTRACT

This paper addresses the porosity and permeability trend of the Lower Goru Formation in the Lower Indus Basin. For this study 149 wells were selected; however, only for 114 and 25 wells, the porosity and permeability data respectively were available. The highest values for porosity and permeability are 25.6% and 1280 millidarcy respectively. The regional trend shows that the eastern side of the Lower Indus Basin is more prospective from better porosity and permeability point of view.

INTRODUCTION

Most of the oil and gas production in the Lower Indus Basin comes from the deltaic and esturine sands of the Lower Goru Formation of the Early Cretaceous age. The Lower Cretaceous Sembar Formation is considered as the main source rock in the area, while Upper Goru Formation provides seal to complete the petroleum system.

This report focuses on the reservoir characteristics of the Lower Goru Formation with special emphasis on the changes in its porosities and permeabilities in relation to the sedimentry fill of the basin, facies variation and tectonic events.

The area under investigation is a vast sedimentry area. It consitutes the southeastern part of the Indus Basin. It has been divided into several physiographic units as from east to west follows Kirthar Slope and Platform, Kirthar Depression (sub-Kirthar Foredeep) and Kirthar Foldbelt (Figure 1).

STRATIGRAPHIC SUCCESSION

The generalized stratigraphic succession of the area is given in figure 2. The oldest exposed sedimentary sequence of the Lower Indus Basin consists of the Wulgai Formation of Triassic age. Triassic rocks of Wulgai Formation have also been encountered in Nabisar well (Figure 3). The depositional history shows that sediments deposited during Triassic period are mainly clastic sediments. Jurassic carbonate rocks are followed by deep water shale of the Sembar Formation of the Early Cretaceous age. These sediments in turn are overlain by sandstone of the Goru Formation. Facies relationship within the Mesozoic sequence is complicated as a result of local topographic variation. Towards the close of Cretaceous period basin growth slowed down and regional disturbance altered the pattern of deposition over large parts of the basin. Rift tectonics in the Cretaceous caused development of horsts and grabens structural features which gave rise to differential sedimentation. Several reports are available about the stratigraphy and depositional history of the area. Here the description of the lithological chararcteristics and facies distribution of the producing formation of the area, i.e., Lower Goru sandstone is given.

Goru Formation

The name Goru Formation was introduced by William (1959) for the upper part of Oldham's Belemnite Beds (1892). The type section is situated near Goru, a small village on the Nar River, the southern Kirthar Range (lat. $27^0$50'00" N, long. $66^0$54'00" E).

The Goru Formation at the type locality consists generally of interbedded limestone, shale and siltstone. The basal part is usually composed of very fine grained, thinly bedded and light to medium grey limestone with minor intercalations of shale. The interbedded shale and siltstone are grey, greenish grey, locally maroon, irregularly bedded, splintry, hard and calcareous at places.

Based on the well data the Goru Formation in the platform and foredeep has been divided into two units- the Upper and Lower. However, this division is difficult to be followed in the Kirthar foldbelt where usually the Goru Formation exhibits a homogeneous lithological characteristics.

The Lower Goru Formation is composed of sandstone with interbeds of shale.The sandy facies is dominated in the southern area of the platform (Figure 4). Sands of the Lower Goru possess excellent reservoir properties. Porosity ranges from 5 % to 40 % and permeabilities in many places exceed I darcy (Quadri & Shoaib, 1986). The Upper Goru is dominantly composed of shale or clay and marl and therefore could not act as potential and ideal reservoir, however, it can serve as a cap rock (Raza et al., 1990). The published data shows that the Lower Goru Formation attains maximum thickness mainly clastic sequence in Khaskheli well (Figure 5). The thickness decreases in all directions from Khaskheli well. However, there is a rapid decrease in thickness towards east.

Figure 3 shows that the sandstone of the Lower Goru Formation interfingers depositionally downdip with the Sembar deltaic foreslope shales which are a confirmed hydrocarbon source rock. Generally, decrease in reservoir quality occurs in Lower Goru Formation from east to west.

In order to analyse the relation of facies distribution of the Lower Goru Formation and porosity trends, the interpretation of the facies distribution of the producing Lower Goru Formation will be beneficial.

[1] Hydrocarbon Development Institute of Pakistan, Islamabad.

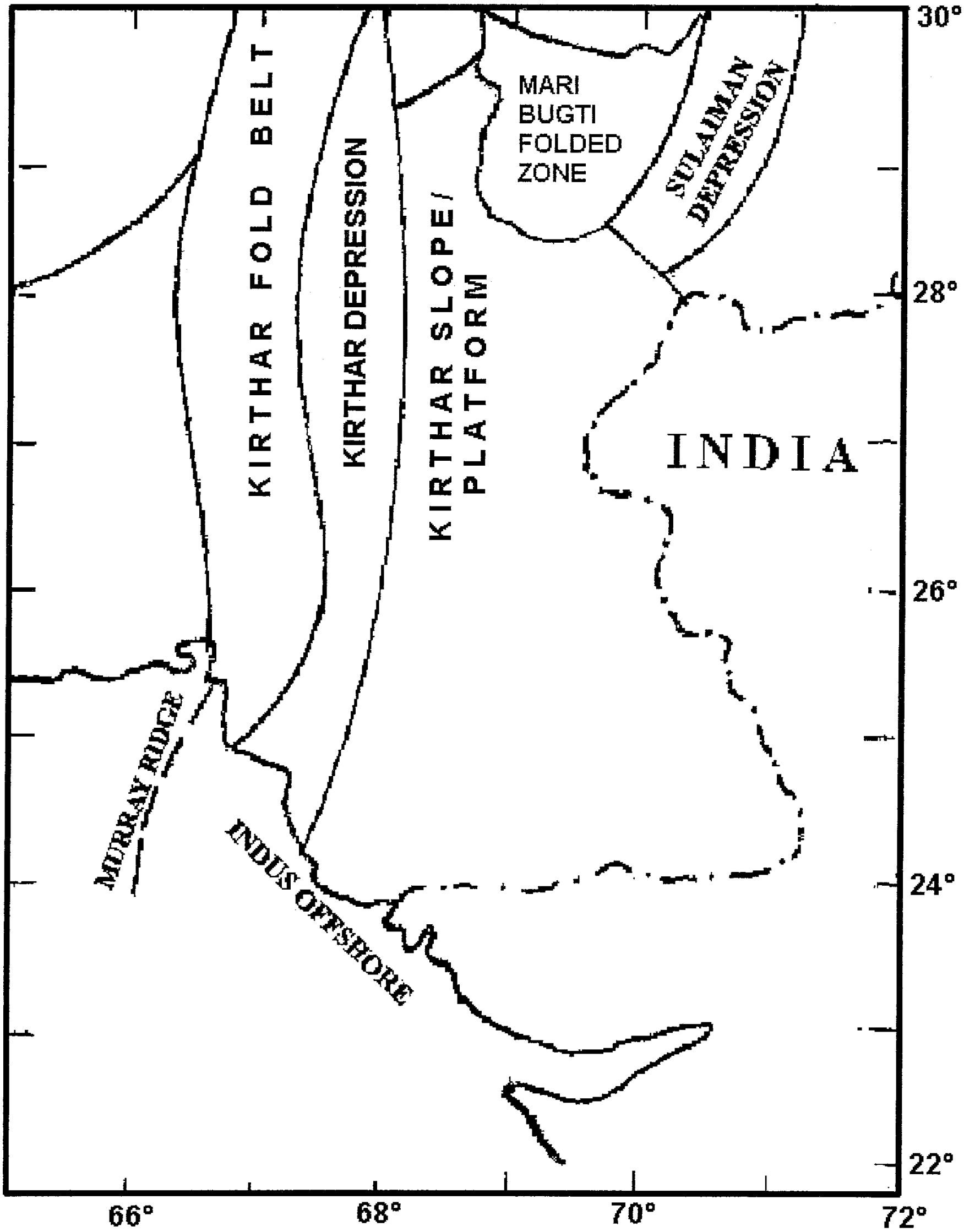

Figure 1- Location map of study area (Modified after Abid and Seddiqui, 1984).

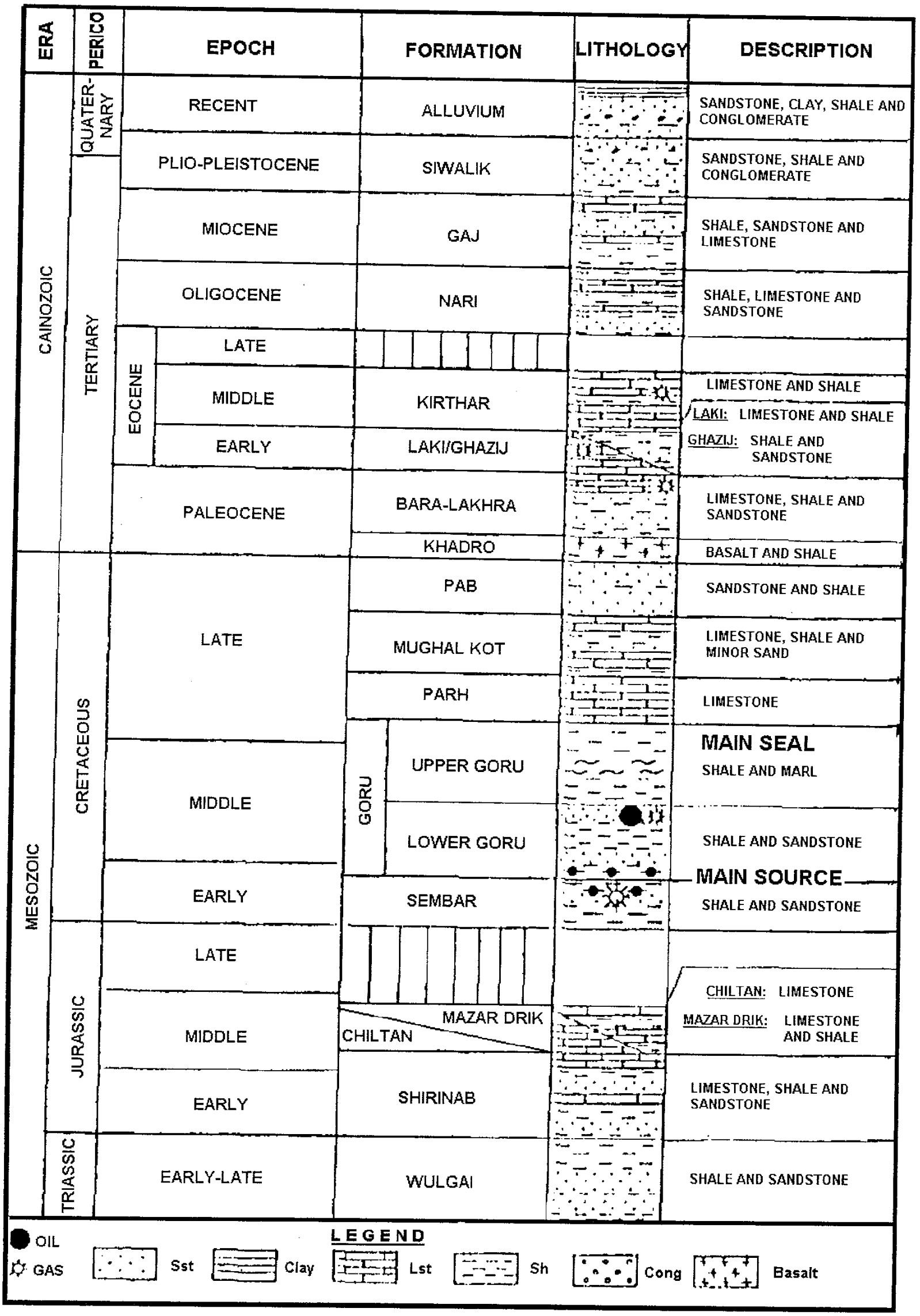

Figure 2- Generalized stratigraphy of Lower Indus Basin (After Raza et al. 1990).

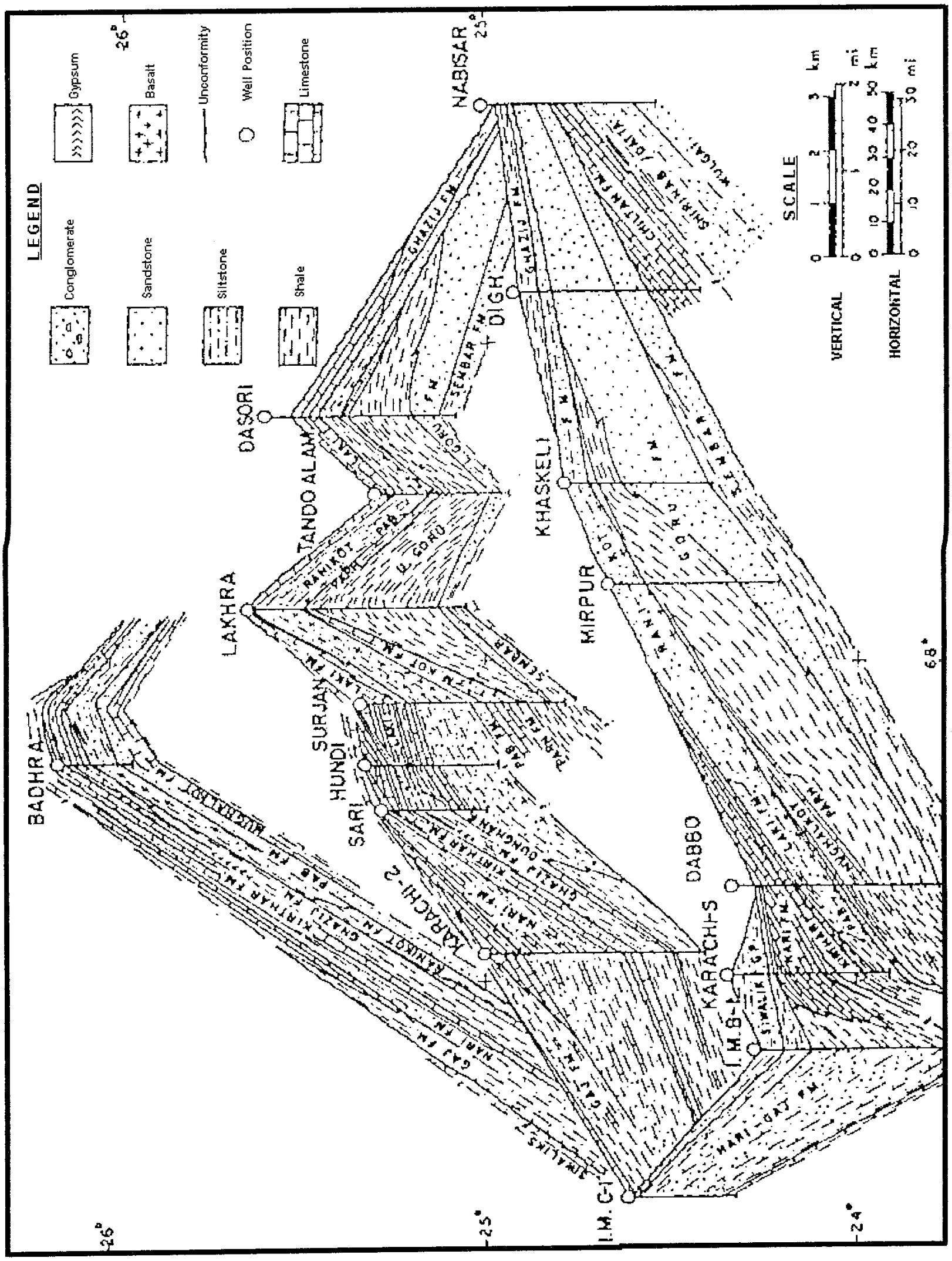

Figure 3- Fence diagram showing correlation of lithofacies and their distribution in Southern Indus Basin I.M. = Indus Marine (After Qaudri and Shuaib, 1986).

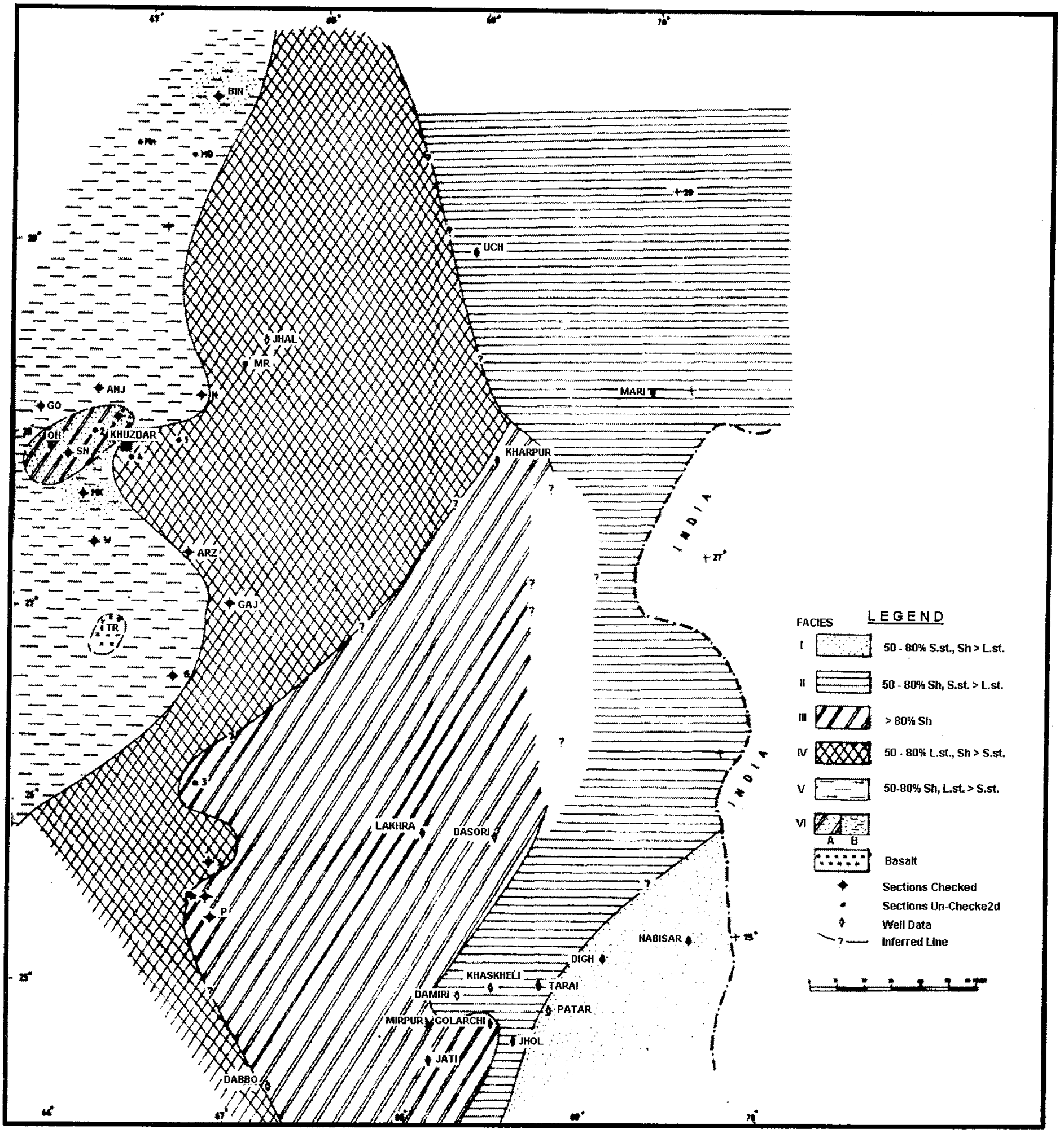

Figure 4- Lithofacies map of Goru Formation in Kirthar foredeep (After Iqbal, 1990).

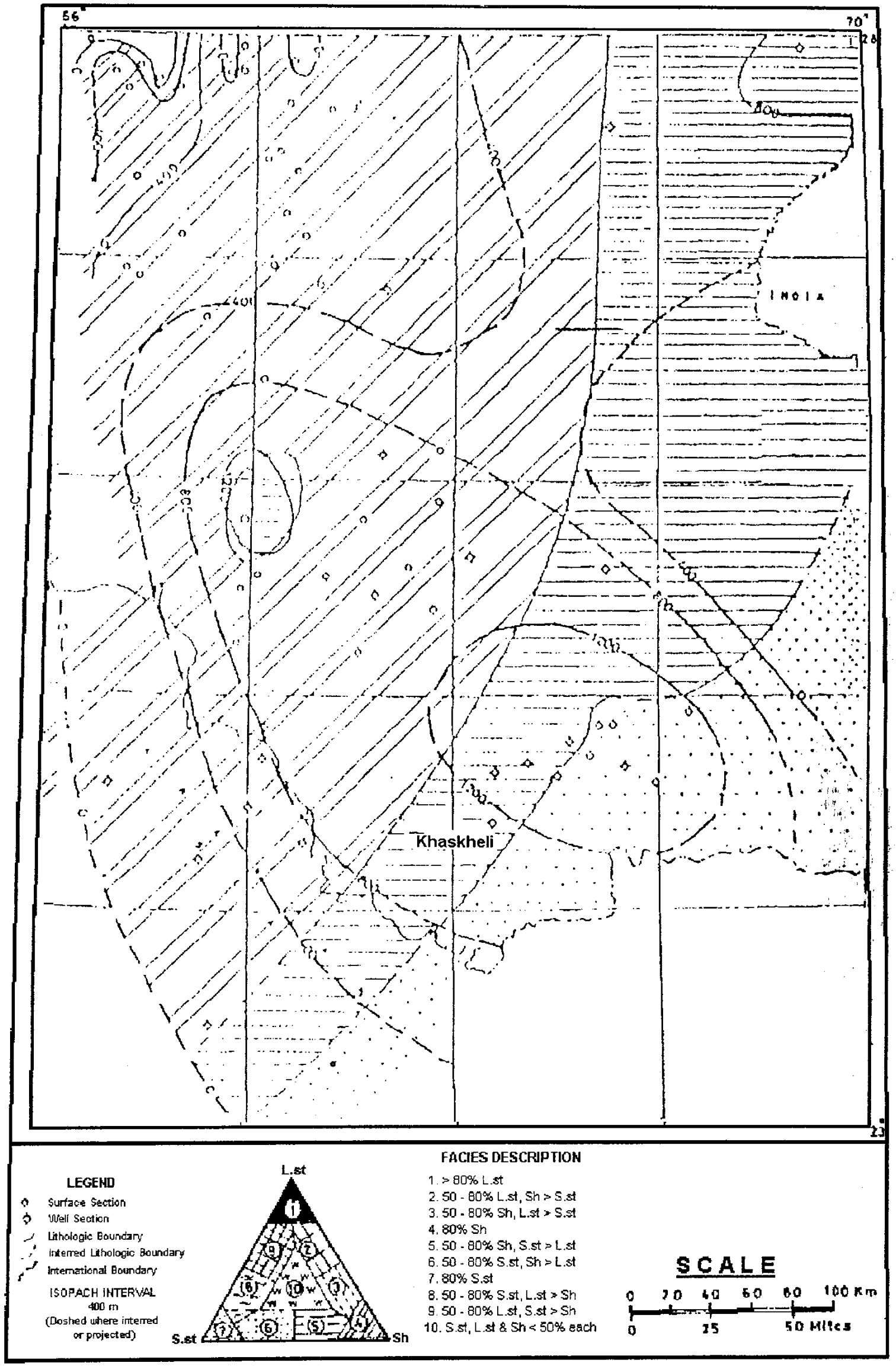

Figure 5- Thickness and lithofacies map of Lower Goru (After Raza et al., 1990).

Based on the lithological data about the Goru Formation from several outcrops in the Kirthar Foldbelt and integrating with the subsurface information from wells in the Kirthar depression and platform area, Iqbal (1990) has divided the Goru Formation into six sub-facies (Figure 4). The figure reveals that sandstone and siltstone are the dominant lithologies of the Goru Formation in the southeastern and eastern part of the area. The sedimentry units are thicker in the west than in the east.

Review of the available literature shows that depth to top of the Lower Goru Formation varies from place to place in wells. It is 1000 m in Khaskheli to more than 2400 in grabenal portion in the NW of Thatta (Hussain et al., 1991). This situation has been shown in figure 6.

This variation is probably due to topographic variation during the time of deposition which might have been caused due to tectonic events that started at least in Early Cretaceous and the rift tectonics that caused the formulation of horsts and grabens leading to differential sedimentation.

The alternating shale and sandstone sequences in the southeastern part also reflect a cyclic deltaic deposition, but towards the northwest sandstone diminishes. Thus the basin had experienced subsidence and thick clastic sediments were deposited parallel to the Kirthar Slope and Platform. It is generally believed that the dominant clastic sequence at the basal part of the Lower Goru Formation is the result of erosion from the Indian Craton (Hussain et al; 1991). The widespread distribution of Beleminites from Cretaceous sequence reported from the Kirthar Foldbelt (Iqbal, 1990), indicates the influence of full marine environment in the area.The carbonaceous limestones were deposited in deeper water environment but at relatively shallower level than its contemporaneous argillaceous sequence in the south.

Based on the above interpretation we assume that the area occupied by facies I, II and III of figure 4 should have more hydrocarbon prospectivity where as the facies of siltstone and shaly sequences in the adjoining areas should have less reservoir potential, however, the later may act as seal for hydrocarbons.

Available information shows that on the basis of interpretation of the electric logs and well cuttings, the Goru sandstone in the area under investigation has been divided into 5 discrete sand bodies, however the basal and upper most units are considered to be the primary pay horizons.

The general range of porosity in the Lower Goru is 5-22%, but in some cases within the Badin Block the porosity goes upto 40 %. (Hussain et al 1990, qoutes Qaudri and Shoaib 1986).

TREND OF POROSITY AND PERMEABILITY DEVELOPMENT IN LOWER GORU FORMATION

It has been attempted to contour the Lower Goru sands in Lower Indus Basin on the basis of porosities and permeabilities which are shown in figures 7 and 8, respectively. Those informations will lend support to the future exploration in the area. Porosity and permeability contours of individual fields (reservoirs) have also practical use as all the wells drilled in the same field are not cored because of high cost. But using the data of the cored wells of the field the contour maps of porosities and permeabilities can be constructed. Using these contour maps the porosity and permeability can be estimated at any place.

The total wells drilled so far in the Lower Indus Basin are approximately 380. Out of this, 149 wells (Table 1) were selected for data collection for the study. However, data for porosity and permeability was available for 114 wells and 25 wells, respectively. Since the wells selected are falling at very closed space and to avoid their intermingling, field locations were selected as central points for construction of contour maps. The data used in construction of contour maps is presented in tables 2 and 3.

Both porosities and permeabilities in the Lower Goru Formation show higher values on the eastern side of the study area reaching upto 25.6 % and 1280 md, respectively (Figures 7 & 8). Lithofacies map also show development of more sand in the south-eastern part and predominance of fine clastics in the west (Figure 4-6), indicating better reservoir potential shoreward (eastern part) than basinward (western part).

ACKNOWLEDGEMENTS

The authors are highly indebted to Mr. Muhammad Iqbal (Sr. Geologist) and Mr. M. Mujtaba (Pr. Geologist) for guidance and assistance in writing the geological aspects of the area. Mr. Riaz Ahmed, Chief (Petroleum Geology Division), is acknowledged for critical review of the manuscript and technical advice for integrating the reservoir characteristics of the producing formation with the regional geology. For the computer based assistance we are also thankful to Mr.Mumtaz Alam, Mr. Shahid Aziz & Mr. Mushtaq Hussain.

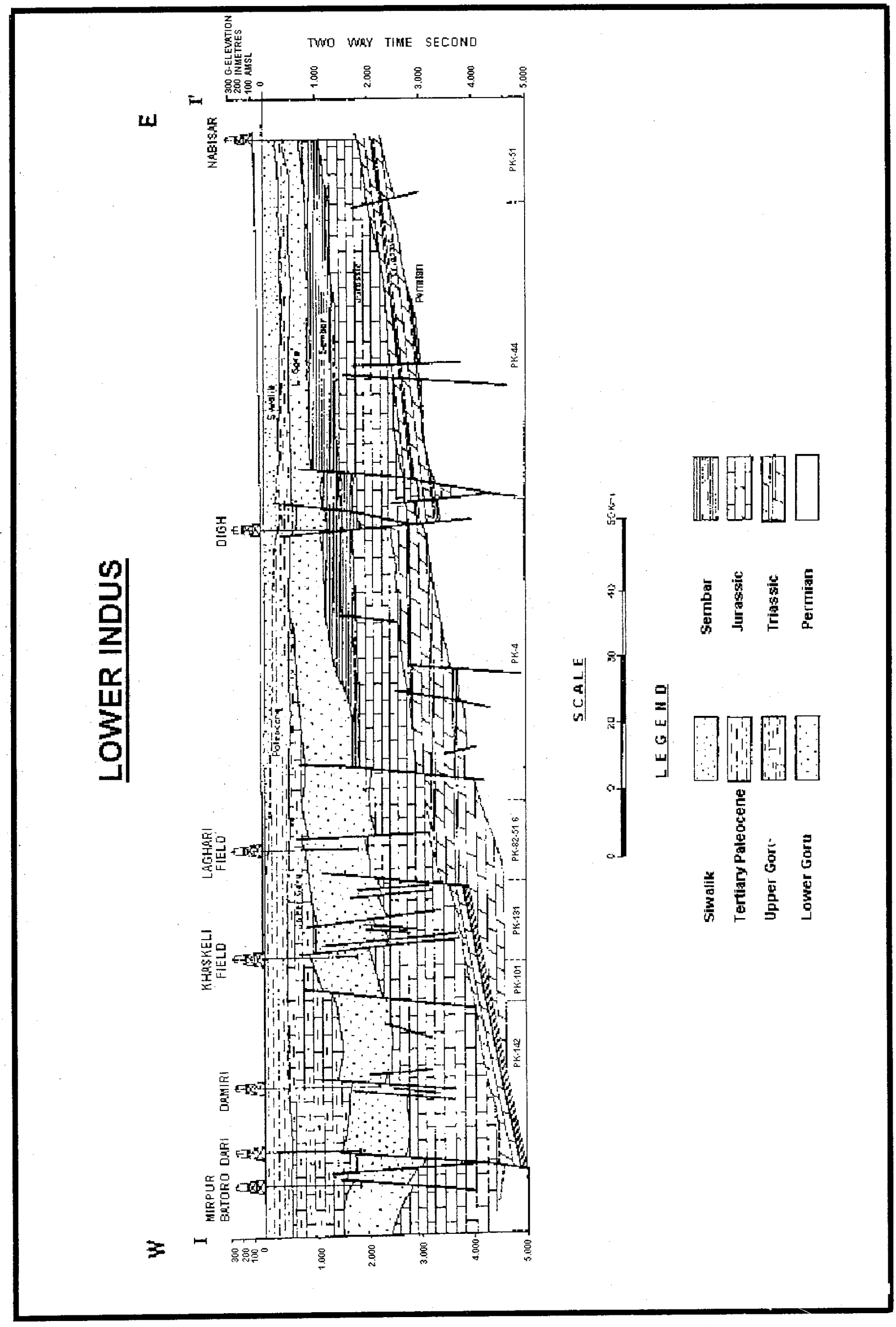

Figure 6- Structural cross section showing the extentional tectonic of Lower Indus Basin (Modified after Kemal, 1991).

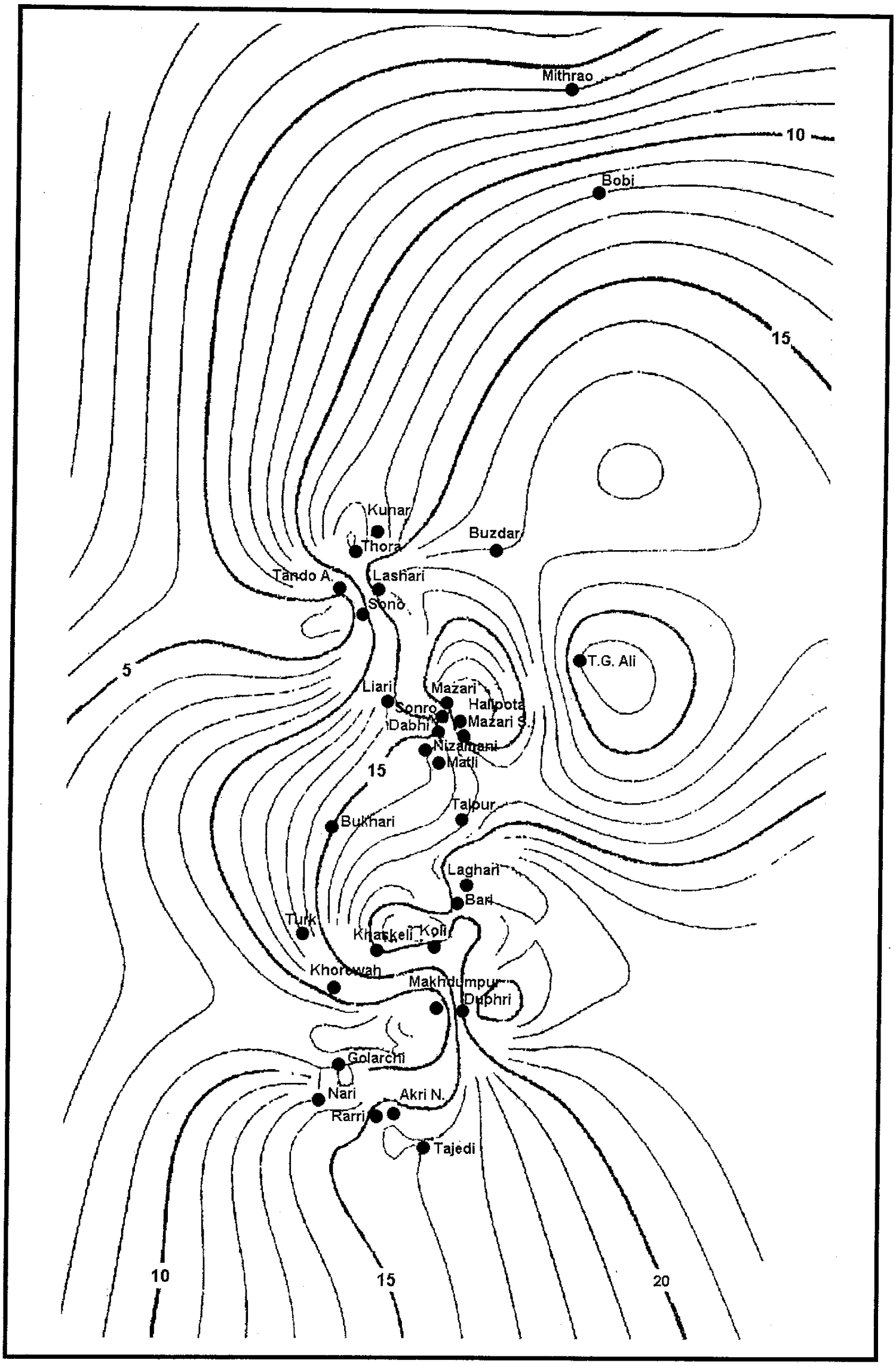

Figure 7- Porosity contour map of Lower Indus Basin (interval 1%).

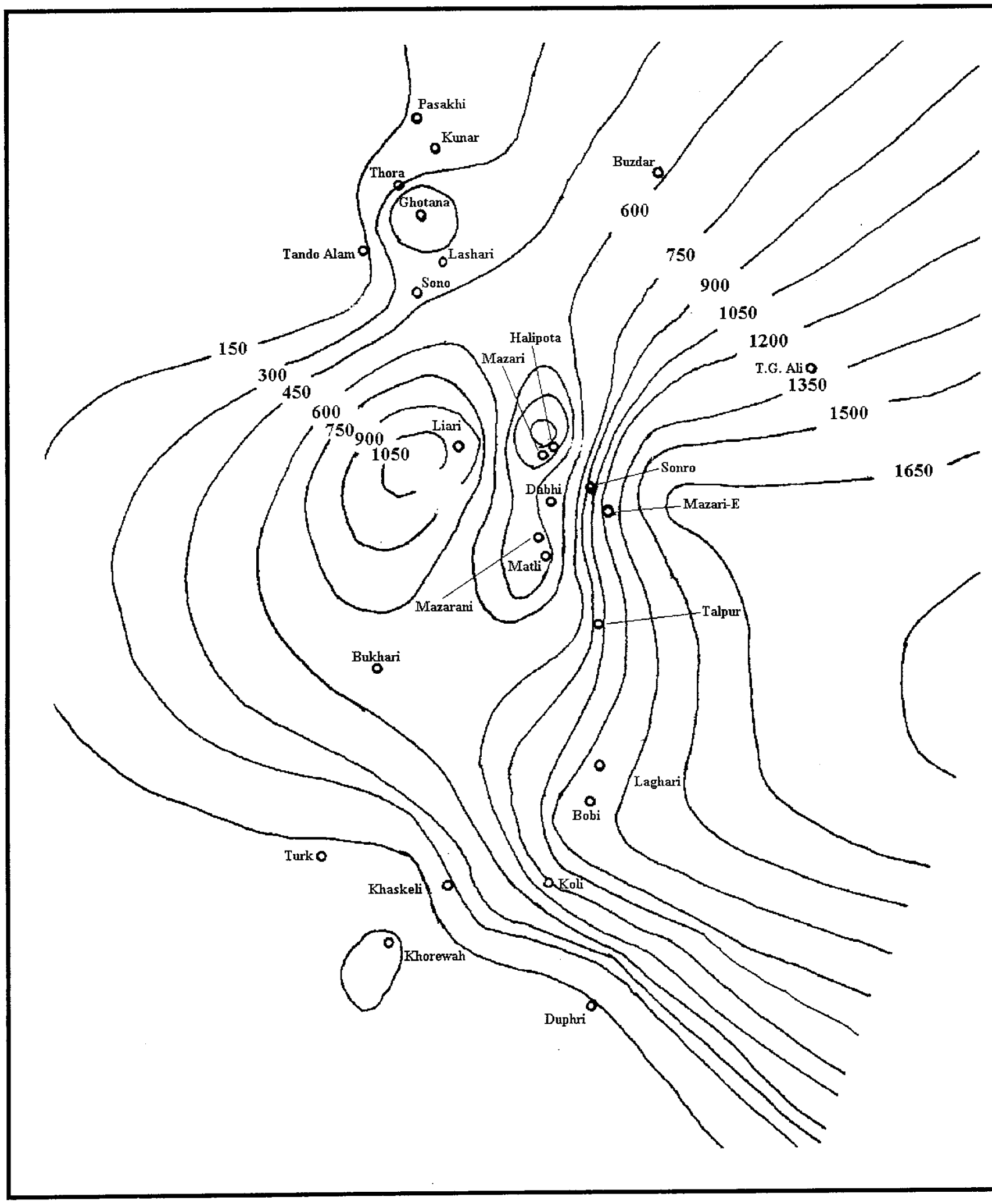

Figure 8- Permeability contour map of Lower Indus Basin (interval 150 md).

Table 1. Oil and gas exploratory and development wells reaching Lower Goru.

S. No.	Well / Well No.	Company	Foramtion	Status
1	Bachal / 2	UTP	-	Abandoned
2	Bari / 3	"	-	Oil
3	Bari / 4	"	-	Abandoned
4	Bobi / 3	OGDC	Lower Goru	Condensate
5	Bobi / 2	"	-	"
6	Bobi / 4	"	-	Gas
7	Bobi / 5	"	-	Abandoned
8	Bobi / 6	"	-	Condensate
9	Bukhari / 3	UTP	-	Gas
10	Bukhari / 2	"	-	"
11	Bukhari / 4	"	-	"
12	Dhabi / 3	UTP	-	Oil
13	Dhabi / 4	"	Lower Goru	"
14	Dhabi / 2	"	-	Gas
15	Paru / 3	OGDC	Lower Goru	Condensate
16	Paru / 2	"	" "	"
17	Duphri / 2	UTP	" "	Gas
18	Ghotana / 2	OGDC	" "	Oil
19	Ghungro / 2	UTP	" "	"
20	Gularchi / 2	"	-	Gas
21	Gularchi / 3	"	Lower Goru	Abandoned
22	Halipota / 2	"	" "	Oil
23	Khaskeli / 6	UTP	" "	"
24	Khaskeli / 7	"	" "	"
25	Khaskeli / 2	"	" "	"
26	Khaskeli / 5	"	" "	"
27	Khaskeli / 10	"	Lower Goru	"
28	Khaskeli / 4	"	" "	"
29	Khaskeli / 3	"	" "	"
30	Khaskeli / 9	"	" "	Injection
31	Khaskeli / 11	"	" "	Oil
32	Khaskeli / 14	"	" "	Abandoned
33	Khaskeli / 8	"	" "	"
34	Khaskeli / 13	"	" "	Oil
35	Khaskeli / 12	"	" "	"
36	Khorewah / 2	"	" "	Gas
37	Khorewah / 3	"	-	"
38	Khorewah / 4	"	-	"
39	Koli / 2	"	Lower Goru	Oil
40	Kothar / 2	OGDC	-	Abandoned
41	Kunar / 3	"	Lower Goru	Oil
42	Kunar / 5	"	-	"
43	Kunar / A	"	-	"
44	Kunar / 4	"	-	Abandoned
45	Laghari / 5	UTP	Lower Goru	Oil
46	Laghari / 2	"	" "	"
47	Laghari / 4	"	" "	"
48	Laghari / 3	"	" "	"

S. No.	Well / Well No.	Company	Foramtion	Status
49	Laghari / 6	"	" "	"
50	Laghari / 7	"	" "	"
51	Lashari Centre / 2	OGDC	-	Abandoned
52	Lashari Centre / 3	"	-	Oil
53	Lashari South / 2	"	Lower Goru	"
54	Liari / 2	UTP	-	"
55	Makhdumpur / 2	"	Lower Goru	Gas
56	Matli / 2	"	Lower Goru	"
57	Matli / 3	"	" "	Oil
58	Matli / 4	"	-	Gas
59	Mazari / 6	UTP	Lower Goru	Oil
60	Mazari / 3	"	" "	"
61	Mazari / 4	"	" "	"
62	Mazari / 5	"	" "	"
63	Mazari / 7	"	" "	"
64	Nari / 2	UTP	Lower Goru	"
65	Nari / 3	"	-	Gas
66	North Akri / 3	"	-	Abandoned
67	North Akri / 2	"	Lower Goru	Oil
68	Sono / 2	OGDC	" "	"
69	Sono / 3	"	" "	"
70	Sono / 4	"	" "	"
71	Sono / 5	"	" "	"
72	Sonro / 2	UTP	" "	"
73	South Mazari / 3	"	" "	"
74	South Mazari / 2	"	" "	"
75	South Mazari / 5	"	-	"
76	South Mazari / 4	"	-	"
77	South Mazari / 6	"	-	"
78	Tajedi / 2	"	Lower Goru	"
79	Tando Alam / 5	OGDC	" "	"
80	Tando Alam / 2	"	-	"
81	Tando Alam / 4	"	Lower Goru	"
82	Tando Alam / 7	"	" "	"
83	Tando Alam / 6	"	" "	"
84	Tando Alam / 3	"	" "	"
85	Tando Alam / 11	"	-	Abandoned
86	Tando Alam / 13	"	-	"
87	Tando Alam / 10	"	-	"
88	Tando Alam / 14	"	Lower Goru	"
89	Tando Alam / 8	"	" "	Oil
90	Tando Alam / 12	"	" "	"
91	Tando Alam / 15	"	" "	Abandoned
92	Tando Alam / 9	"	" "	Oil
93	Tando G.Ali / 2	UTP	-	Gas
94	Tangri / 3	"	-	Oil
95	Thora / 4	OGDC	-	"
96	Thora / 2	"	-	"
97	Thora / 3	"	-	"
98	Turk / 4	UTP	Lower Goru	Gas
99	Turk / 5	"	-	Oil/Gas

S. No.	Well / Well No.	Company	Foramtion	Status
100	Turk / 2	"	Lower Goru	Gas
101	Turk / 3	"	" "	"
102	Turk / 5	"	" "	"
103	Turk Deep / 1	"	-	"
104	Khaskeli / 1	UTP	Lower Goru	Oil
105	Golarchi / 1	"	" "	Gas/Condensate
106	Tajedi / 1	"	" "	Oil
107	Mazari / 1	"	-	Abandoned
108	Dabhi / 1	"	Lower Goru	Oil
109	Sonro / 1	"	" "	Gas/Condensate
110	Turk / 1	"	-	"
111	Mazari / 2	"	Lower Goru	Oil
112	South Mazari / 1	"	" "	"
113	Bukhari / 1	"	" "	Gas/Condensate
114	Dabhi South / 1	"	" "	"
115	Matli / 1	"	" "	"
116	Ghotana / 1	OGDC	" "	Oil
117	Makhdumpur / 1	UTP	" "	Gas/Condensate
118	Liari / 1	"	-	Oil
119	Halipota / 1	"	Lower Goru	Oil
120	Lashari / 1	OGDC	-	Abandoned
121	Lashari South / 1	"	Lower Goru	Gas/Condensate
122	Thora / 1	"	-	Oil
123	Kunar / 1	"	Lower Goru	Abandoned
124	Kunar East / 1	"	-	"
125	Sono / 1	"	Lower Goru	Oil
126	Kunar / 2	"	" "	"
127	Bobi / 1	"	" "	Gas/Condensate
128	Lashari-C / 1	"	-	Oil
129	Duphri / 1	UTP	Lower Goru	"
130	Lashari East / 1	OGDC	-	Abandoned
131	Khorewah / 1	UTP	Lower Goru	Gas/Condensate
132	North Akri / 1	"	" "	Oil
133	Daru / 1	OGDC	" "	Gas/Condensate
134	Thora East / 1	"	" "	Oil
135	Tando Ghulam Ali / 1	UTP	-	Gas/Condensate
136	Pasakhi / 1	OGDC	Lower Goru	Oil
137	Pasakhi North / 1	"	" "	"
138	Bobi-N / 1	"	-	Abandoned
139	Buzdar-N / 1	"	-	Oil
140	Thora-N / 1	"	-	Abandoned
141	Buzdar-South / 1	UTP	-	Gas/Condensate
142	Fort-Abbas / 1	OGDC	-	Abandoned
143	Bukhari-E / 1	UTP	-	"
144	Liari Deep / 1	"	-	Gas
145	Mithrao / 1	OGDC	-	Gas/Condensate
146	Mithrao / 1	"	-	"
147	Makhdumpur Deep / 1	UTP	-	Gas
148	Tarai Deep / 2	"	-	Abandoned
149	Khorewah Deep / 1	"	-	Gas

Table 2. Porosity of oil and gas fields in Lower Goru formation

Field	Av:Porosity (%)	Field	Av:Porosity (%)
Bari	19.0	Matli	16.3
Bobi	12.34	Mithrao	5.5
Bukhari	15.16	Mukhdumpur	4.2
Buzdar	17.0	South Mazari	20.0
Dhabhi	15.0	Mazari	17.0
Duphri	19.0	Nari	12.5
Forte Abbas	4.0	Nizamani	16.0
Golarchi	8.5	North Akri	16.0
Gotana	15.7	Pasakhi East	5.5
Halipota	20.7	Rarri	14.5
Koli	18.7	Sonro	22.0
Khaskeli	20.33	Sono	6.5
Kunnar	12.53	Tandoalam	6.53
Khorewah	11.0	Tando G. Ali	14.0
Lashari	15.7	Turk	9.5
Liari	14.33	Thora North	14.3
Laghari	25.6	Talpur / 1	18.0

Table 3. Permeability of oil and gas fields in Lower Goru Formation.

Field	Av:Permeability (md)
Bobi	56.00
Bukhari	667.00
Golarchi	42.00
Gotana	563.00
Halipota	182.00
Koli	900.00
Khaskeli	212.00
Kunnar	150.00
Khorewah	164.00
Lashari	430.00
Liari	1,000.00
Laghari	1,280.00
Matli	392.00
Mukhdumpur	24.40
South Mazari	59.00
Mazari	1,200.00
Nari	24.71
Sonro	1,100.00
Sono	78.30
Tandoalam	94.00
Turk	98.70
Thora North	293.50

REFERENCES

Abid, M.S., and N.K. Siddiqui, 1984, Satellite imagery and its use in petroleum exploration in Pakistan: PIP Seminar on "Petroleum Exploration in Pakistan," Karachi.

Hussain, M., S.L. Getz and R. Oliver, 1991, Hydrocarbon accumulation parameters in the central portion of the Lower Indus Basin of Pakistan. *In:* G. Ahmed, A. Kemal, A.S.H. Zaman, and M. Humayon, (eds.), Proc.: International petroleum seminar, New directions and strategies for accelerating petroleum exploration and production, Ministry of Petroleum and Natural Resources, Government of Pakistan, Islamabad, p.106-119.

Iqbal, M., 1990, The Goru Formation and its facies distribution in the Kirthar sub-basin: Pakistan Journal of Hydrocarbon Research, v.2, no.1, p.75-81.

Kemal, A., H.R. Balkwill, and F.A. Stoakes, 1991, Indus Basin hydrocarbon plays: *In:* G. Ahmed, A. Kemal, A.S.H. Zaman, and M. Humayon (eds.); Proc.: International petroleum seminar, New directions and strategies for accelerating petroleum exploration and production, Ministry of Petroleum and Natural Resources, Government of Pakistan, Islamabad, p.78-105.

Oldham, R.D. 1893, Report on the geology of Thal Chotiani and part of Mari Country: Geological Survey of India, Rec. 25, pt.1, p.18-29.

Qaudri, V.N., and S.M. Shoaib, 1980, Hydrocarbon prospects of southern Indus Basin, Pakistan: AAPG Bulletin, v.79, no.6, p.730-747.

Raza, H.A., S.M. Ali and R. Ahmed, 1990, Petroleum geology of Kirthar Sub-basin and part of Kutch Basin: Pakistan Journal of Hydrocarbon Research, v.2, no.1, p.29-73.

William, M.D., 1959, Stratigraphy of the Lower Indus Basin, West Pakistan: World Petroleum Cong. 5th, N. York, Proc., Sec.1, Paper 19.