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Geology and Hydrocarbon Potential of Central Indus Basin, Pakistan

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ABSTRACT

Central Indus basin extends approximately between 27.5° to 32.5°N latitude and 67°E longitude to the eastern boundary of Pakistan. Its tectonics, stratigraphy and hydrocarbon potential are described based on data obtained from the study of outcrops and wells drilled in the area. Of about 35 exploratory wells drilled, three commercial gas discoveries in Jurassic Samana - Suk sandstone on its eastern plain, two gas and one condensate-gas discoveries in Paleocene Ranikot and Cretaceous Pab Sandstones on its central portion and five gas discoveries in Eocene Sui/Laki-Kirthar limestones on its south-western part prove that hydrocarbons are present. However no commercial oil field is discovered so far. Considering the large area of about 280,000 sq km having sediments approximately 10^6 cubic km and the presence of natural reservoirs, seals, source rocks, oil shows, condensate and large gas fields indicate favourable conditions for the discovery of oil fields in central Indus basin with stepped up exploration and drilling. The main hydrocarbon fairways are Paleozoic-Mesozoic titled fault blocks, Tertiary reefal banks and drape compressional anticlines.

INTRODUCTION

Central Indus basin consists of Sargodha prominence-Bahawalpur high-South Punjab plain in the east, Safed Koh range-Marri Bugti transverse uplift-Sibi trough in the middle and Sulaiman-Kirthar meganticlinorium in the west (Figure 1). This basin covers an area of about 280,000 sq km and comprises southern Punjab province, northern Sindh province and north-eastern part of Balochistan province having latitude between 27.5° to 32.5°N and longitude 67°E to the eastern boundary of Pakistan. Outcrops are mostly confined to Sulaiman-Kirthar mountain ranges in the west and sediments as old as Permian age are exposed (Figure 1). No outcrop older than Permian is exposed in the area under study though few wells namely, Marot, Bahawapur East, Karampur and Warnali penetrated into basement rocks of Archean age.

Geological and geophysical investigations were carried out by OGDC and foreign oil companies in central Indus basin to locate the structural traps for oil and gas resulting in delineating numerous structural traps, thirty-five exploratory wells were drilled on selected structures and eleven discoveries were made. Three are commercial gas discoveries in Jurassic Samana Suk sandstone on the eastern plain, two gas and one condensate-gas discoveries in Cretaceous Pab and Paleocene Ranikot sandstones on the central portion and five gas discoveries in Eocene Sui/Laki-Kirthar limestones on its south-western part. However, no commercial oil field has been discovered to-date in the area under discussion. Considering the large areal extent of the basin (about 280,000 sq km) with a thick pile of sediments approximately 10^6 cubic km (Raza and Ahmed, 1990) and the presence of natural reservoirs, seals, source rocks, oil shows, condensate and large gas fields suggests possible conditions for the discovery of oil fields in the central Indus basin with stepped up exploration and drilling efforts.

Although a good deal of exploration has taken place in the area, yet extensive geological and geophysical investigations, especially in the areas south of Loralai and south and east of Sandeman in Sulaiman meganticlinoriun, Marri Bugti transverse uplift, Sibi trough and Punjab alluvium plain should be carried out to locate favourable hydrocarbon bearing structural traps, their depths and thicknesses in order to determine the possibility of drilling exploratory wells on them. Isopachs and facies maps of discovered hydrocarbon bearing reservoir formations namely Jurassic sediments, Pab Formation of Late Cretaceous age, Ranikot Formation of Early Paleocene age, Laki/Sui Formation of Early Eocene age and Kirthar Formation of Middle to Late Eocene age are drawn to show their thicknesses variations as well as sandstone and limestone percentages based on data obtained from Oil and Gas Development Corporation and foreign oil companies geological reports and logs (Figures 2-6).

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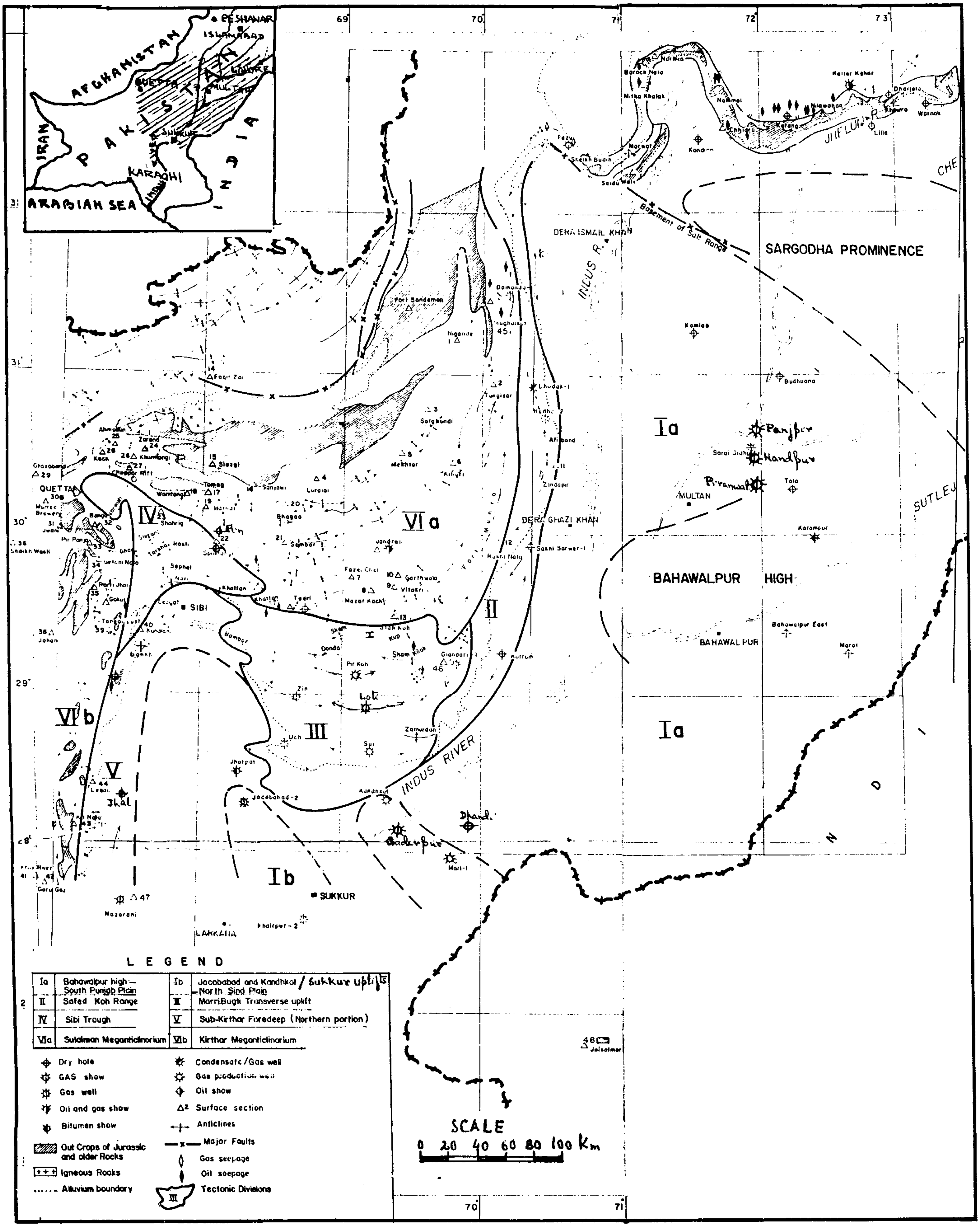


Figure 1– Index map of central Indus basin.

TECTONIC FRAMEWORK

Central Indus basin may be divided into the following tectonic divisions as shown in (Figure 1).

Ia. Bahawalpur High-South Punjab alluvium plain.

Ib. Jacobabad and Kandhkot uplifts - North Sindh alluvium plain.

II. Safed Koh range.

III. Marri Bugti transverse uplift.

IV. Sibi trough.

V. Sub - Kirthar foredeep (northern portion).

VIa & VIb. Sulaiman - Kirthar meganticlinorium.

Ia. Bahawalpur High - South Punjab Alluvium Plain

The area is covered by alluvium and is situated east of Safed Koh range and Indus river (Figure 1). So informations are mainly obtained from geophysical investigations. Number of wells were drilled and gas was discovered at Panjpir, Nandpur and Piranwal. Marot, Bahawalpur East, Karampur and Warnali are the exploratory wells which drilled into basement crystalline rocks of Archean age (Figure 1).

Ib. Jacobabad and Kandhkot Uplifts - North Sindh Alluvium Plain

The area is mostly covered by alluvium and is situated south of Safed Koh range and Marri Bugti transverse uplift. Extensive geophysical investigations proved several uplifts and highs in the area namely Khairpur, Mari, Kandhkot, Qadirpur and Jacobabad. Wells were drilled on these structural uplifts/highs and gas fields were discovered in Early Eocene Laki/Sui Main Limestones in Khairpur, Kandhkot, Jacobabad and Qadirpur. Gas was also discovered in Mari structure in Habib Rahi Limestone of Late Eocene Kirthar Formation.

II. Safed Koh Range

Safed Koh range runs longitudinally and is situated between 29° to 31°N and 70° to 71°E approximately. Safed Koh range includes Kotrum, Sakhi Sarwar, Zindapir, Rodho, Afiband and Dhodak structures (Figure 1). On southern pitching end of Safed Koh range is a flat Sakhi Sarwar anticline made up of Upper Neogene molasse whereas in the northern direction it is dying out and becomes a narrow monocline dipping to the east and made up of Neogene deposits.

Geological and geophysical explorations were carried out by OGDC and foreign companies in this area. Gas was discovered at Rodho and condensate-gas at Dhodak in Late Cretaceous Pab and Early Paleocene Ranikot sandstones.

III. Marri Bugti Transverse Uplift

The uplift is the latitudinal link between southern extremity of Safed Koh range and northern extremity of sub-Kirthar foredeep. It separates Safed Koh range in the east from sub-Kirthar foredeep in the west, and lies between 28°20' to 29°30' N and 68°20' to 69°50' E approximately. Marri Bugti transverse uplift is covered by rocks of Paleogene along with Neogene molasse sediments. Neogene and Paleogene beds are crumpled into a system of sub-latitudinal anticlinal folds which appear to be more complicated from south to north. The change in relief from highly uplifted to mountainous up to 1.5 km high is also in the same direction.

The structural features of Marri Bugti area are divided into (a) southern platform zones of Uch-Sui anticlines and (b) northern folded zones consisting of Zin-Giandari anticlines and Bambor - Pirkoh anticlines. Anticlinal folds developed within these zones are linked in the western and eastern directions with the neighbouring foredeeps (Figure 1).

Difficulties were encountered in carrying out geological and geophysical investigations of the northern folded structures of Marri Bugti transverse uplift partly because the area is highly mountainous, partly because of lack of water supply, and mainly because of the hostile attitude of local tribal people. Nevertheless wells were drilled on Sui, Uch, Zin, Giandari, Loti and Pirkoh structures. Gas reservoirs were discovered in Sui, Uch, Zin and Loti structures in Early Eocene Sui Main Limestone. Gas was also discovered in Late Cretaceous Pab and Early Paleocene sandstones in Pirkoh structure. Thus the area is proved to be a hydrocarbon bearing province and to-date main gas producer in Pakistan.

IV. Sibi Trough

Sibi trough is of a super-imposed nature and has a transverse position with regard to the general trend of the folds of Sulaiman-Kirthar meganticlinorium. It is situated north of Sibi City forming roughly a triangle with the projection of one of its angles in the north-western direction up to Quetta anticlinorium and lies between 29°30' to 30°15' N and 67°10' to 68°15' E approx. (Figure 1).

Internal part of Sibi trough is made up mainly of Siwalik sediments folded into a system of arc-like anticlinal zones, the trend of which is perpendicular to the trough (Figure 1). The anticlinal zones are separated by flat and very wide synclines. Each anticline of the northern zone is tectonically more uplifted in comparison with the southern.

Main factors to be considered in evaluating the oil/gas prospects of the anticlines of Sibi trough are: (1) considerable thickness of post Paleogene sediments which make Paleogene sediments inaccessible for exploratory drilling in a number of folds at present, and (2) closure of folds. However, five anticlinal zones in Sibi trough are recognized which from north to South are: (1) Kanobi-Narwari, (2) Sivrani, (3) Tor Ghar-Tarkha Rasti-Godakin, (4) Sephal, and (5) Kot-Dezgat-Nari-Khattan (Figure 1).

V. Sub-Kirthar Foredeep

Sub-Kirthar foredeep represents comparatively narrow depression at the foothills of Kirthar mountains and situated south of Sibi trough and west of Marri Bugti transverse uplift and Jacobabad High between 26°30' to 29°30'N and 67°15' to 67°50'E approximately. Sub-Kirthar foredeep forms a narrow folded flank running almost longitudinally and transverse to the folds developed in Marri Bugti area. It consists of two main folded zones namely Sanni-Bannh zone in the north and Mazarani zone in the south (Figure 1).

VI (a&b). Sulaiman-Kirthar Meganticlinorium

Sulaiman-Kirthar meganticlinorium consists of a system of parallel ranges which form the watershed. It is 1200 km long and 100-160 km wide. It is divided into two distinct segments. The northern one is known as Sulaiman and the southern one is Kirthar with the dividing point in the town of Quetta where Sibi trough squeezed into it (Figure 1). Sulaiman meganticlinorium comes under central Indus basin. It appears to be an arch. Its north-eastern Sandeman area has longitudinal folds whereas its western Loralai area has latitudinal ones. Domanda-Mughalkot-Tangisar-Kingri- Fort Munro and other structures are situated in its eastern portion and have longitudinal folds whereas Spintangi-Sembar-Harnai–Sanjawi-Loralai and others are situated in the western part and have latitudinal folds (Figure 1). These are important structures from the point of view of prospecting oil and gas in pre-Paleogene sediments. Wells drilled in the area are shown in Figure 1. Gas was discovered in Late Cretaceous Mughalkot sandstone at Jandran.

STRATIGRAPHY AND HYDROCARBON POTENTIAL

Hydrocarbon potential in any region depends upon the presence of thick sedimentary sequence possessing potential source rocks with their lateral and vertical alteration of petroleum capacity and regional and local trap structures having reservoirs and seals. The central Indus basin possesses thick sedimentary sequence ranging in age from Precambrian to Pleistocene with number of regional and local traps having hydrocarbon potentialities.

The presence of numerous hydrocarbon surface and sub-surface shows; 13 gas fields namely Sui, Zin, Uch, Khairpur, Mari Jacobabad, Kandhkot, Rodho Qadirpur, Panjpir, Nandpur, Piranwal and Pirkoh; one gas-condensate field at Dhodak and the production of about 800,000 gallons of oil from thirteen shallow wells at Khattan (Table 3) are clear indications of both liquid and gaseous hydrocarbon potentialities of central Indus basin. Composition of oil and bitumen at Gokurt and Mughalkot seepages; composition of gas shows at Gokurt and Zindapir; stratigraphic positions of oil, gas and bitumen shows and discoveries; and gas reserves and their chemical analyses are shown in Tables 1, 2, 3 and 4 respectively.

Precambrian to Cambrian

Precambrian to Cambrian rocks are not exposed anywhere in central Indus basin. However, Karampur, Sarai Sidhu, Bahawalpur East and Marot wells situated in the eastern portion of central Indus basin, penetrated these rocks which consist of Salt Range Formation (Saline series), Khewra Sandstone (Purple sandstone), Kussak Formation (Neobolus shales), Jutana Dolomite (Magnesian sandstone) and Bhaganwala Formation (Salt pseudomorph shales). Traces of bitumen and heavy asphaltic oil were present in shale and dolomite of Salt Range Formation in Karampur well. The presence of these hydrocarbon indications suggest the possibility that dolomite and shale of Salt Range Formation may be considered as potential source rocks. Sandstones of Cambrian age have fairly good reservoir properties

Table 1. Composition (%) of oil and bitumen in Gokurt and Mughalkot seepages (after OGDC, 1964-65).

Contents	Gokurt (Dunghan Formation)	Mughalkot (Mughalkot Formation)
Oil	16.83	72.70
Alcohol Benzene Tar	12.63	4.50
Benzene Tar	62.38	18.30
Asphaltogenic Acid	-	4.50
Asphaltenes	12.31	-

Table 2. Composition (%) of gas at Gokurt and Zindapir (after OGDC, 1964-65).

Contents	Gokurt (Dunghan Formation)	Zindapir (Pab Formation)
Methane	89.08	74.08
Higher HCs	6.48	-
Nitrogen	0.94	4.35
Carbon-dioxide $\pm H_2S$	3.25	21.40

(Microlog porosities ranging from 22 to 43%) whereas Kussak Formation (Neobolus shales) and Bhaganwala formation (Salt pseudomorph shales) may serve as seals.

Permian

Sediments of Ordovician, Sulurian, Devonian and Carboniferous age are missing in central Indus basin. Talchir boulder bed (Tobra Formation) of fluvio-glacial origin forms base of Permian and rests unconformably on Cambrian rocks. Permian rocks consist of sandstones interbedded with shales and dolomite in the eastern portion of central Indus basin and have a total thickness of about 350 metres in Marot and Bahawalpur East and about 450 metres in Karampur and Sarai Sidhu wells (Figure 1). Many sandy beds show good reservoir properties having 37-41% microlog porosities with varying thicknesses ranging from 9 to 48 metres and a cumulated thickness of about 100 metres. However, facies changes take place from east to west and sandstones become more limy and shaly. Productus limestone interbedded with shale of Permian age are exposed in the axial belt in Ghazaband area of Quetta - Pishin district at the west but they are not favourable from the petroleum point of view because of their tightness, massiveness and argillaceous composition.

Triassic

Sediments of Triassic age seem to be formed under similar depositional conditions as those of Permian in central Indus basin. They mostly consist of sandstone interbedded with dolomite and shale in the eastern portion of central Indus basin and have a total thickness of about 130 metres in Tola and Sarai Sidhu wells (Figure 1). Triassic is missing in Karampur, Marot and Bahawalpur East wells. Many Triassic sandstone beds seem to have reasonably good reservoir properties like those of Permian. Triassic sediments of about 1282 metres thickness are encountered in Jhatpat-1 well in Jacobabad high area, and consist of sandstone - sandy siltstone and shale with stringers of limestone deposited in shallow marine to possibly deltaic environments. No well penetrated Triassic formations in the central and western parts of central Indus basin. However, facies changes take place both horizontally and vertically as well as thickness increases from the eastern portion of central Indus basin towards the west and become more limy and shaly. Shales interbedded with limestones are exposed in the axial belt of Ghazaband and Loralai areas.

Jurassic

Jurassic rocks are encountered in Karampur, Tola, Sarai Sidhu, Budhiana, Kamiab, Panjpir, Nandpur, Piranwal and Bahawalpur East wells in the eastern portion of central Indus basin and consist of sandstone, shale, limestone and dolomite having a maximum thickness of about 300 metres whereas in its central portion, they mostly consist of limestone interbedded with shale as encountered in Khairpur, Jacobabad, Jhatpat, Giandari, Tadri and Jandran wells having a maximum thickness of about 2100m in Jhatpat-1 well. Jurassic limestone interbedded with shale outcrop in several localities mostly along the axial belt of Sulaiman

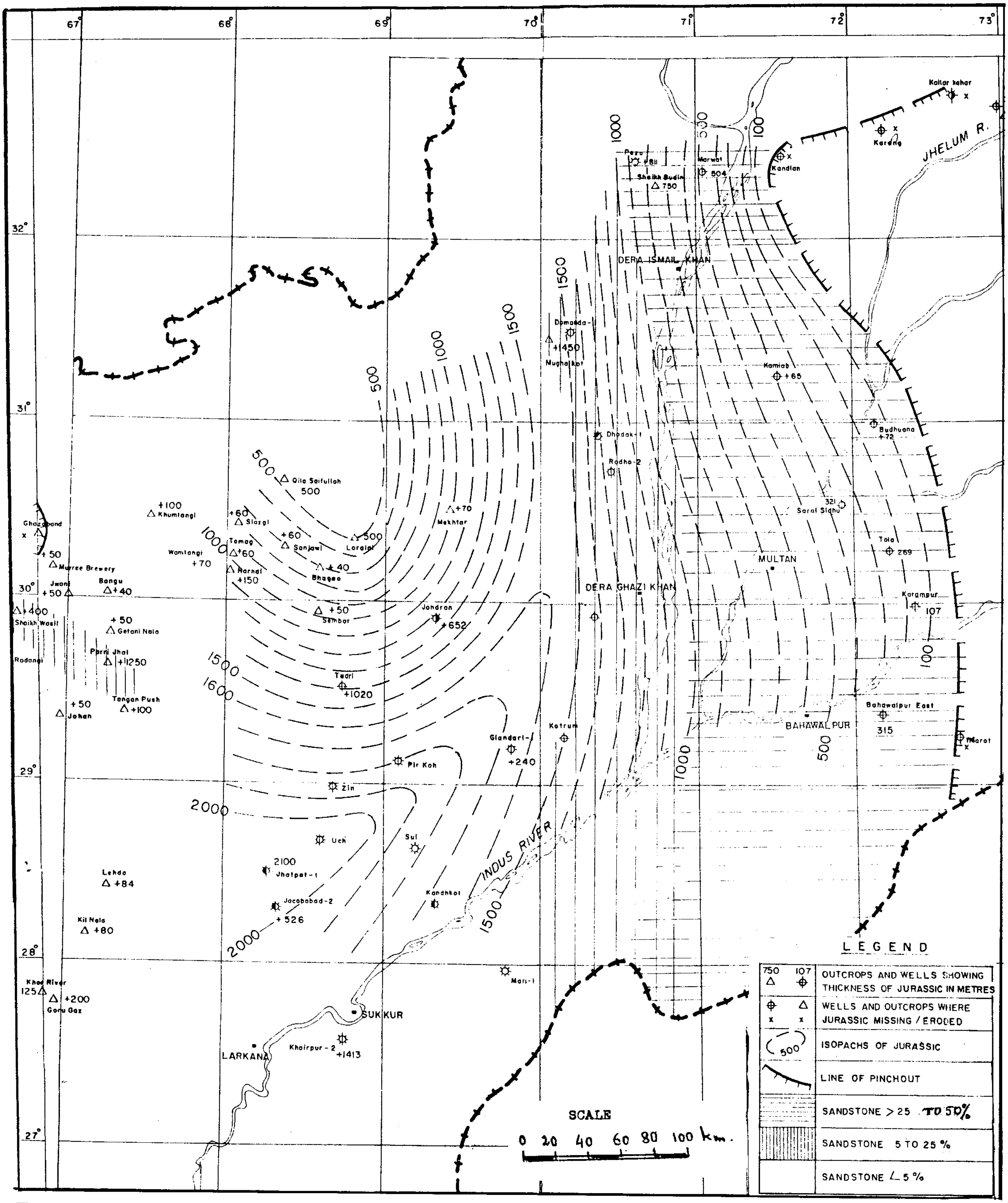


Figure 2– Possible isopachs and probable area of sandstone of Jurassic sediments (dominantly argillaceous limestone).

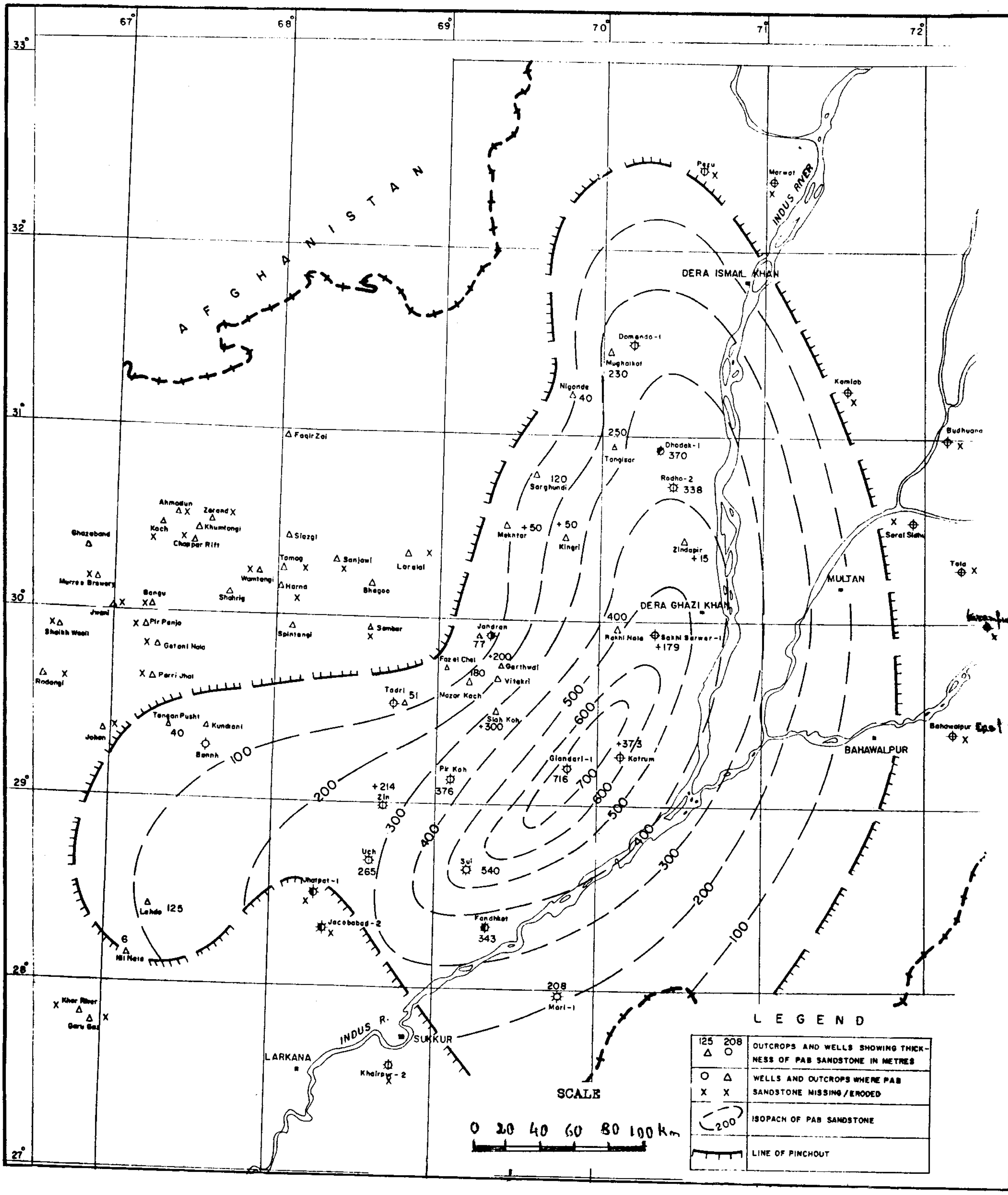


Figure 3– Isopachs of Pab Formation (dominantly sandstone) of Late Cretaceous age.

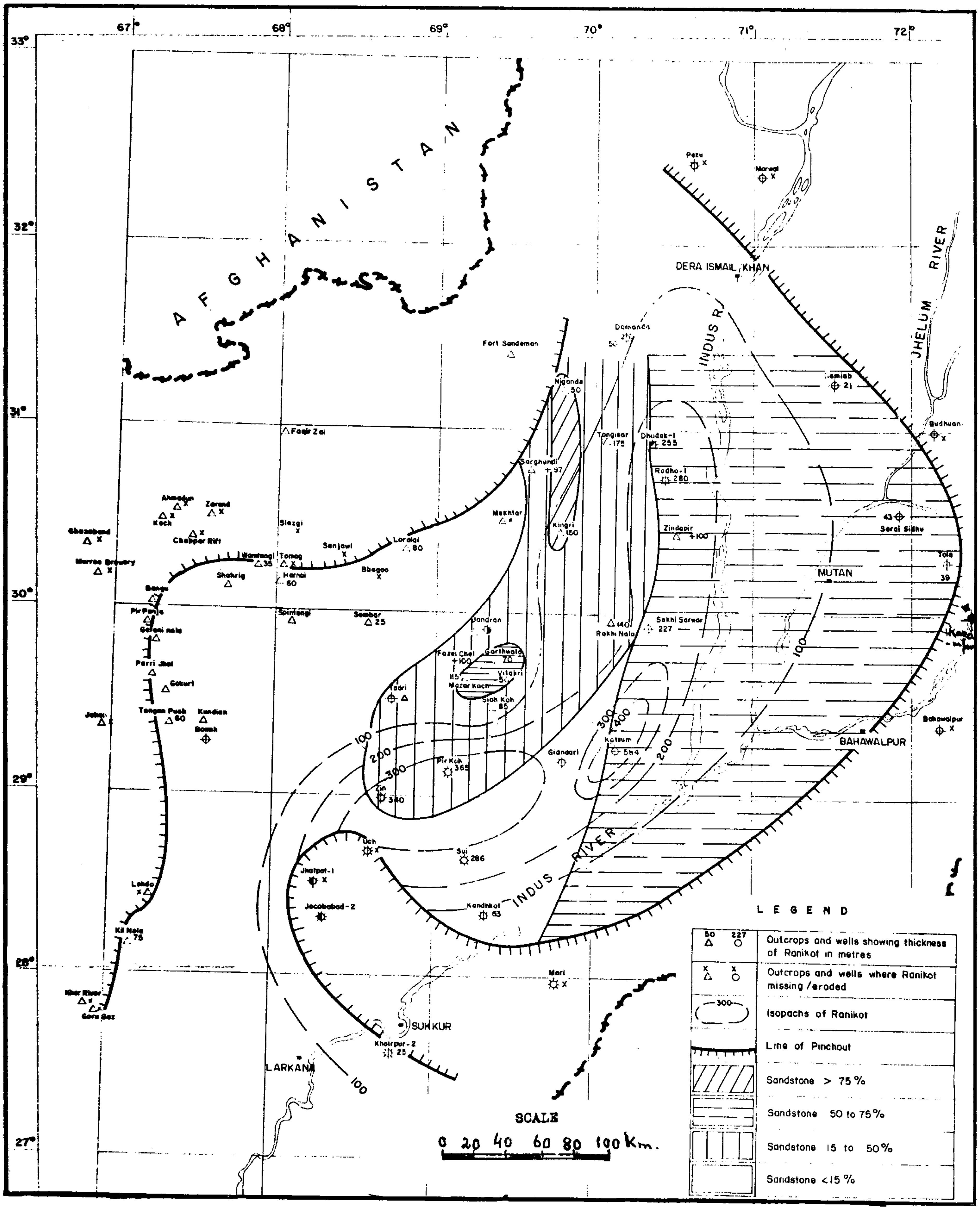


Figure 4– Isopachs and sandstone of Ranikot Formation (dominantly sandstone /shale) of Early Paleocene age.

meganticlinorium (Figure 2). Sandstone percentage increases towards the east and gas reservoirs were discovered in Jurassic Samana Suk sandstone at Panjpir, Nandpur and Piranwal (Table 3).

Cretaceous

Cretaceous sediments in central Indus basin include Sembar and Goru/Lumshiwal (Belemnite shales interbedded with sandstone and limestone) of Early Cretaceous age, Parh and Mughalkot (limestones interbedded with shales) and Pab Formation (sandstone with bands of shales and sandstone) of Late Cretaceous age.

Sembar-Goru Formations.– They consist of shales interbedded with limestone and sandstone (Quadri and Shuaib, 1986) and possess properties of both reservoir as well as source rocks. Generally sandstone percentage increases from negligible in the west to about 70% towards platform in the east . Sandstones of the formations seem to be good reservoirs and cumulated thickness ranges from 45 to 405 metres distributed within shaly series. Sandstone beds yielded upto 2800 bbl/day of salt water in Mari well and 2100 bbl/day of salt water with gas in Giandari well which are very well covered by the shales of the same formation. Sembar-Goru shales contain abundance of pyrite and carbonaceous matter which indicate reducing conditions of deposition and as such may prove to be good source rocks. Maximum thickness of 1284 metres of Sembar Formation is recorded in Giandari well and more than 1500 metres of Sembar-Goru formations along Giandari-Mari axis.

Parh Formation.– It consists of mainly compact, hard, aphanitic, argillaceous limestones and as such generally fail to have good reservoir properties. However, it seems to have the properties of source rocks having abundance of organic remains and has a maximum thickness of 720 metres at Giandari.

Mughalkot Formation.– It generally consists of limestones interbedded with shales having a maximum thickness of greater than 1000 metres along Mughalkot - Tangisar - Jandran - Tadri axis (Malik et al., 1988). Limestones are mostly compact, argillaceous and carboniferous and so fail to have reservoir properties. However, it is rich in organic matter and mostly gives off a strong fetid smell when broken and as such could be good source rocks for hydrocarbon generation. Oil seepages at Mughalkot gorge are probably generated from Mughalkot limestones/shales.

Sandstones are present in the eastern portion of central Indus basin and possess good reservoir properties. Percentage of sandstone increases from negligible in the western and central areas of central Indus basin to about 50% in the east near platform.

Pab Formation.– It crowns Cretaceous sediments and consists of mainly sandstone with bands of shale and siltstone. It is developed within two areas separated by Khairpur - Jacobabad highs and may be considered as Pab Formation of central Indus basin and southern Indus basin. Pab Formation of central Indus basin forms more or less a crescent shape having a maximum thickness of greater than 700 metres at Giandari area and from where it thins out in all directions as shown in isopach map (Figure 3). Pab Sandstone in Giandari well shows 5-30% porosity and 3-250 md. permeability but has a protective cover of about 15 metres of Dunghan Limestone/shale and as such fails to have a proper cap rock whereas thick seal rocks of Early Eocene Ghazij shales of about 1000 metres thickness are present in Dhodak, Rodho and Pirkoh areas. Pab Formation is mainly composed of quartzose sandstone which possesses excellent reservoir properties and has proved to be gas reservoir in Dhodak, Rodho and Pirkoh wells as well as gas - condensate at Dhodak.

Paleocene

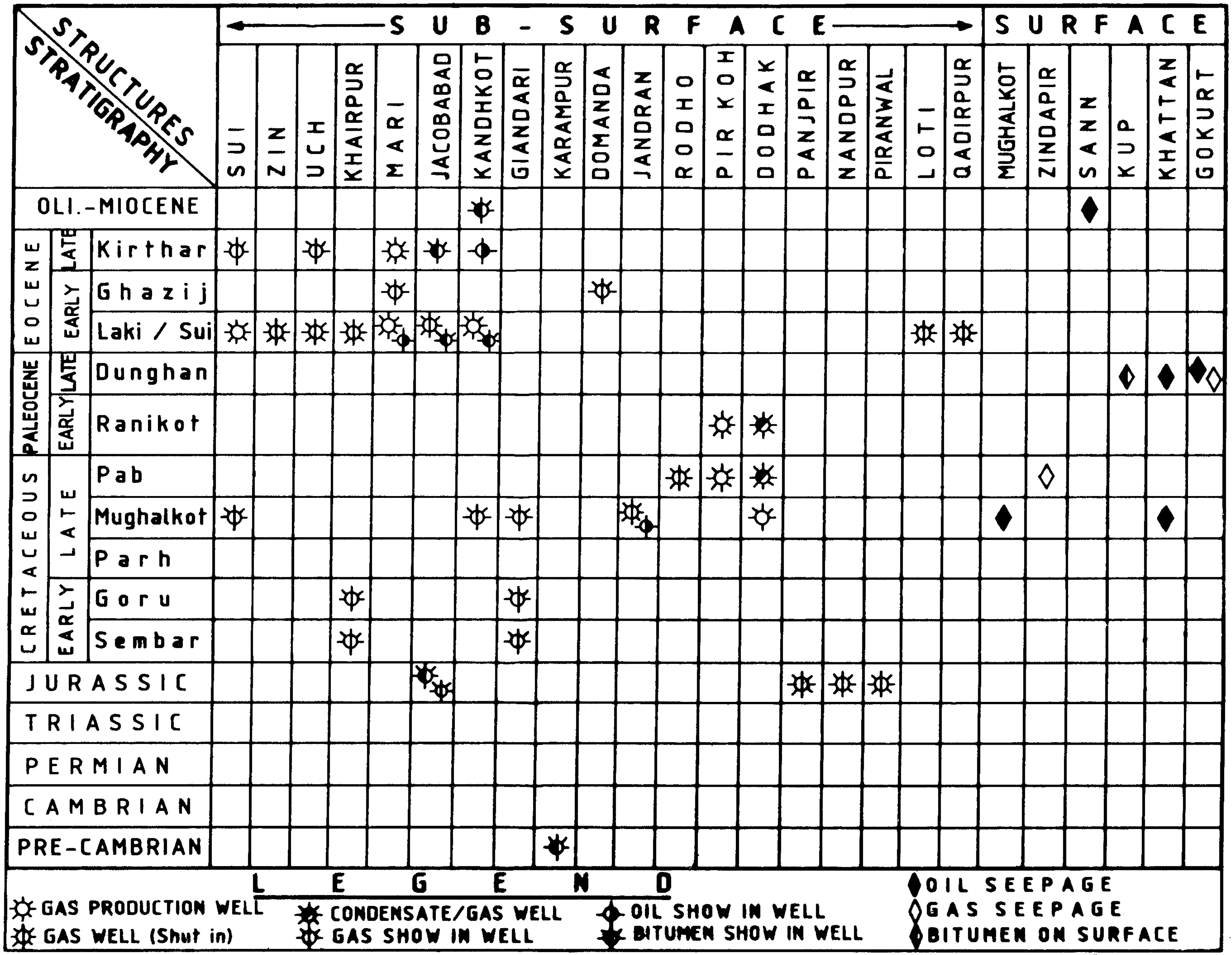
Paleocene sediments in central Indus basin may be divided into Ranikot Formation of Lower Paleocene and Dunghan Formation of Upper Paleocene age.

Ranikot Formation.– It is dominantly sandy in the eastern portion but becomes dominantly shaly in the western portion of central Indus basin as shown in isopach and facies map of Ranikot (Figure 4). Thus Ranikot contains both reservoir and source potentialities for hydrocarbon. Fluvio-lacustrine sandstones of Ranikot Formation have high reservoir potential whereas shelf shales and shore face cycle shales and siltstones are the potential source beds. Gas is encountered in Ranikot sandstone at Pirkoh and Dhodak.

Dunghan Formation.– It is dominantly limestone in the eastern and western portions of central Indus basin but in the central narrow areas, it becomes dominantly shaly (Malik et al., 1988).

Sui and Sui Main Limestones are described as Early Eocene Laki Limestones in composite logs of wells drilled in Marri Bugti and adjoining southern areas, as such they are dealt with under Laki Limestone.

Table 3. Stratigraphic position of oil, gas and bitumen shows and discoveries.



Eocene

Eocene sediments of central Indus basin may be divided into Ghazij/ Laki Formation or its equivalents of Early Eocene age and Kirthar Formation or its equivalents of Middle to Late Eocene age.

Early Eocene sediments are represented by Ghazij shales in the central and north-western portions of central Indus basin and they are proved to be excellent seals about 1000 metres thick at Domanda, Dhodak, Rodho and Pirkoh areas. Ghazij shales in the area are of deep marine origin and contain abundant marine type kerogen, as such may be considered also as potential source rocks for hydrocarbon generation. In the eastern portion of central Indus basin, Early Eocene sediments are represented by interbedded shale-marl-limestone-sandstone as encountered in Marot, Bahawalpur East, Karampur, Tola, Sarai Sidhu, Budhiana and Kamiab wells having a maximum thickness of about 250 metres at Sarai Sidhu and Bahawalpur East. Both limestone and sandstone beds seem to have reservoir properties but have ineffective cover rocks namely Siwaliks. However, sandstone disappears towards west and in Marri Bugti and adjoining southern areas, it is represented by Laki/Sui Limestone with bands of shales as encountered in Jacobabad, Khairpur, Mari, Kandhkot, Jhatpat, Uch, Sui and Zin wells having varying thicknesses from 150 to about 500 metres (Figure 5). Laki/Sui limestones are gas reservoirs in Khairpur, Mari, Kandhkot, Uch, Sui and Zin structures.

Middle to Late Eocene Kirthar Formation consists of mainly limestone interbedded with shale but is missing in the easternmost portion of central Indus basin in Marot, Bahawalpur East, Karampur, Tola, Sarai Sidhu, Budhiana, Kamiab and Pezu wells (Figure 5). However, limestone predominates in the western portion whereas shale predominates in the eastern portion. Limestone percentage gradually decreases from the west to the east of the central Indus basin (Figure 6).

Kirthar Formation is divided by the Stratigraphic Committee into Habib Rahi Limestone, Domanda shales, Pirkoh Limestone and Drazinda shales. The only possible reservoirs are the two limestones namely, Habib Rahi Limestone and Pirkoh Limestone. Habib Rahi Limestone in Kandhkot well shows 18% porosity and gave a small inflow of water (400 bbl/day) with traces of gas and asphalt. Gas was discovered in Mari-1 well and a small inflow of salt water (160 bbl/day) in Mari-2 well in Habib Rahi Limestone which is well covered by the over-lying shales of the same formation. Pirkoh Limestone has the same porosity as Habib Rahi Limestone. It gave some gas in Mari-1 well and small inflow of salt water (160 bbl/day) in Mari-2. Carbonaceous shale and bituminous limestone of lower portion of the formation seem to have potential source capabilities.

Post-Eocene

Post-Eocene sediments in central Indus basin are Nari and Gaj formations. Their source rock potentiality is not established. Some shows are reported from Siwaliks in Domanda area, but they are regarded as coming through important faults from lower sources. The filling up of oil of the post-Eocene sediments would need, like in Potwar area, very special conditions. However, many good reservoirs which are present in these formations can never be regarded as well covered, the interbedded shale layers being always rare, thin and probably non-continuous.

CONCLUSIONS

Source Rocks

Potential source beds in central Indus basin are the following:

1. Precambrian dolomite and shale of Salt Range formation.

2. Permian-Triassic-Jurassic slope and deep basin dark shales and fine limestones.

3. Sembar basinal, pelagic, calcareous mudstone/ shale of Early Cretaceous age.

4. Goru organic rich limestone and argillacous, calcareous siltstone of slope turbidites of Early Cretaceous age.

5. Parh outer shelf fine limestone of Late Cretaceous age.

6. Mughalkot shelf, slope and deep basin shales and fine limestones of Late Cretaceous age.

7. Pab lower shoreface cycle shale and siltstone of Late Cretaceous age.

8. Ranikot outer shelf and lower shoreface cycles shales and siltstones of Early Paleocene age.

9. Dunghan organic rich limestone and shale of Late Paleocene age.

Table 4. Gas reserves and their chemical analyses.

GAS FIELDS / COMPOSITION	SUI (PPL)	ZIN (PPL)	UCH (PPL)	KHAIRPUR (PPL)	MARI (SVOC)	JACOB-ABAD (PPL)	KANDH-KOT (PPL)	RODHO (OGDC)	JANDRAN (AMOCO)	PIRKOH (OGDC)	DHODAK (OGDC)		PANJPIR (OGDC)	NANDPUR (OGDC)
METHANE %	88.52	46.10	27.30	12.20	71.20	25.00	79.20	82.78	90.00	81.91	79.47	100 MILLION BARRELS OF CONDENSATE RESERVE	52.49	38.40
ETHANE %	0.89	0.40	0.7	0.20	0.20	0.50	1.10	6.20	2.00	0.46	7.84		0.20	0.21
PROPANE %	0.26	0.15	0.30	0.10	–	0.10	0.20	2.70		0.20	3.57		0.03	0.60
BUTANE AND HIGHER %	0.37	0.15	0.30	–	–	0.50	0.40	1.87		0.06	3.11			
NITROGEN %	2.46	8.50	25.20	16.90	19.5	38.00	16.60	4.05	5.00	11.05	4.31		41.74	59.65
CARBONDIOXIDE %	7.35	44.70	46.20	70.60	9.0	37.00	2.50	1.80	3.00	6.34	1.70		5.53	1.67
HYDROGEN SULPHIDE GRAINS/100 CUBIC FEET	92.20	13.30	33.50	2.0	0.1	–	30.80	NIL						
MERCAPTAN SULPHUR GRAINS/100 CUBIC FEET	3.80	2.30	10.20	–	–	–	1.20	–						
GROSS HEATING VALUE B.T.U. CUBIC FEET	933.00	484.00	308.00	130.00	723.00	–	84200	1080.00		840.00	1150.00		Not available	
RESERVES MILLIAN MILLIAN CUBIC FEET	8.62	0.10	2.50	1.00	4.04	Small Pool	0.41	0.03	0.20	1.00	0.70		" "	
YEAR OF DISCOVERY	1952	1954	1955	1956	1957	1958	1959	1974	1975	1977	1976		1985	1984
FORMATION	EARLY EOCENE SUI LIMESTONES	EARLY EOCENE SUI MAIN L.ST.	EARLY EOCENE SUI MAIN L.ST.	EARLY EOCENE SUI MAIN L.ST	EARLY EOCENE SUI MAIN L.ST. AND LATE EOCENE HABIB RAHI L.ST	EARLY EOCENE SUI MAIN L.ST.	EARLY EOCENE SUI LIMESTONES	LATE CRETACEOUS PAB S.ST.	LATE CRETACEOUS MUGHALKOT SANDSTONE	LATE CRETACEOUS PAB & EARLY PALEOCENE RANIKOT SANDSTONES	LATE CRETACEOUS PAB AND PALEOCENE RANI-KOT SANDSTONES		JURASSIC SANDSTONES	JURASSIC SANDSTONE

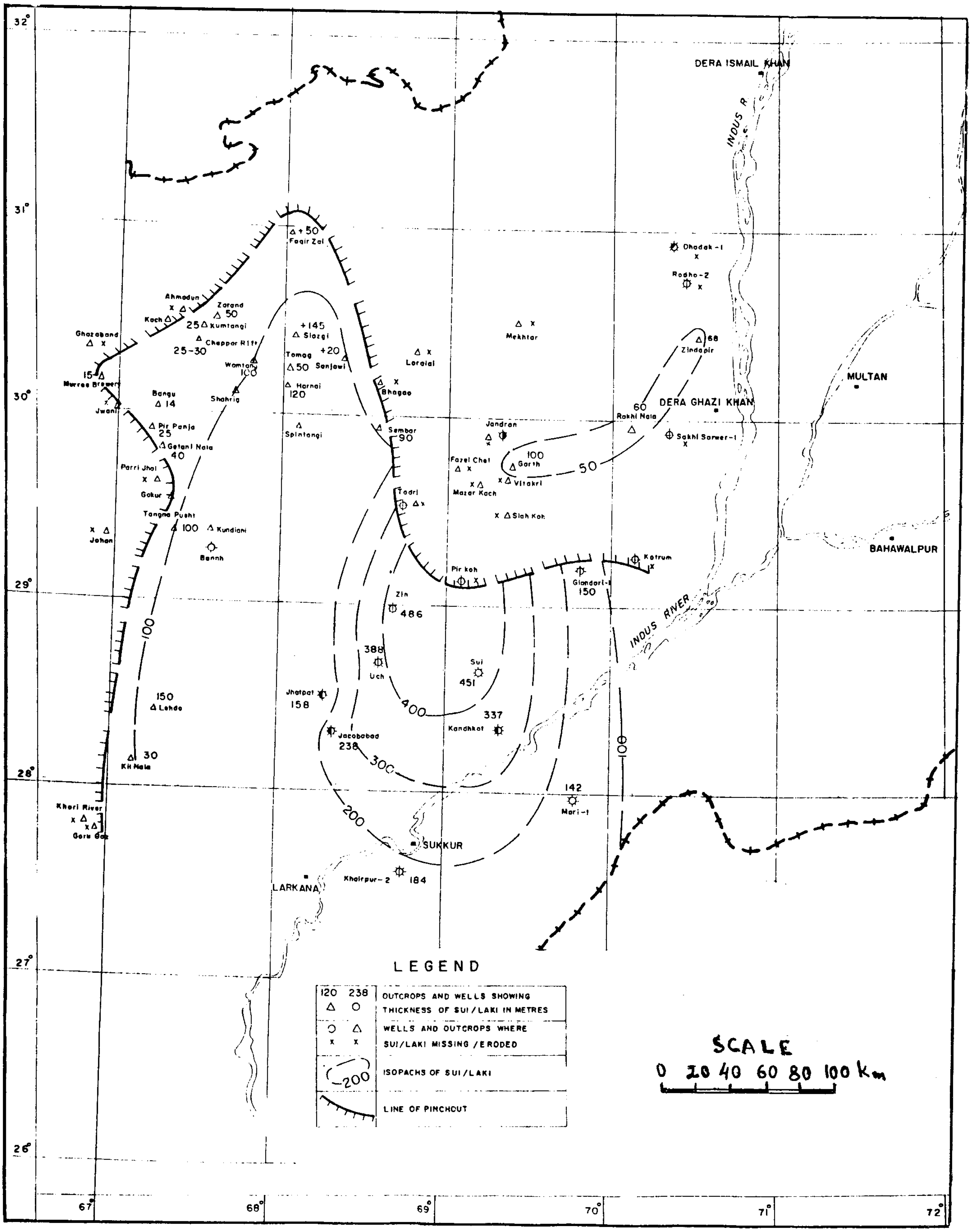


Figure 5– Isopachs of Sui Main Limestone/Laki Formation (limestone > 80%) of Early Eocene age.

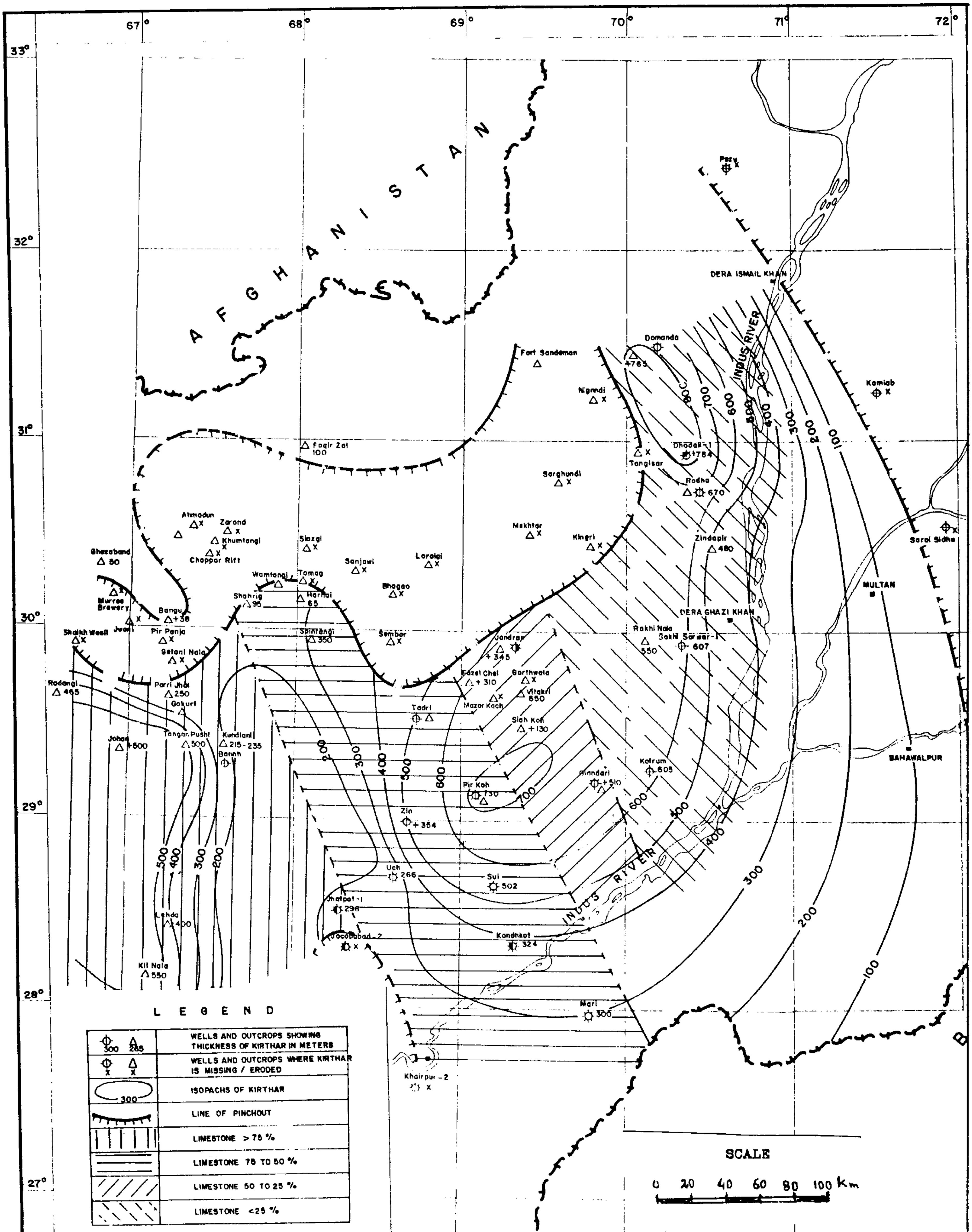


Figure 6– Isopachs and limestone of Kirthar Formation (dominantly limestone/shale) of Middle to Late Eocene age.

10. Laki bituminous fine limestone and shale of Early Eocene age.

11. Ghazij deep marine shale of Early Eocene age.

12. Kirthar organic rich fine limestone and shale of Middle to Late Eocene age.

Reservoir Objectives

Proven reservoir rocks of central Indus basin are the following:

1. Jurassic sandstone seems to be deposited in a shallow marine to continental environment. It has a high potential reservoir capacity in the eastern area in which Panjpir, Nandpur and Piranwal gas fields are discovered.

2. Pab Sandstone of Late Cretaceous age is mainly shoreface origin and as such has a wide spread distribution and uniform internal characteristics. It has proven important gas reservoirs at Pirkoh and Rodho as well as condensate-gas at Dhodak.

3. Ranikot sandstone of Early Paleocene age belongs to shoreface facies, as such has high potential reservoir units. Gas is discovered in Ranikot sandstone at Pirkoh and condensate-gas at Dhodak.

4. Sui/Laki limestones of Early Eocene age represent nearshore, subtidal, beach and algal reef facies. They are important gas reservoirs at Sui, Zin, Uch, Khairpur, Mari, Jacobabad, Kandhkot, Loti and Qadirpur.

5. Kirthar Limestone of Middle to Late Eocene age is the main producing zone at Mari gas field and seems to have been deposited in a restricted lagoonal environment. Gas indications have also been reported at Sui and Kandhkot.

Potential reservoir objectives are Cambrian, Permian, Triassic and Cretaceous sandstones of shoreface facies. Jurassic limestones belonging to marine, shoreface cycles are also potential reservoirs.

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