Thar Rift and its Significance for Hydrocarbons*

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Abstract

The southeastern part of Pakistan is dominantly a desert area and floodplains on the western margin of Indo-Pakistan subcontinent, known as the Thar Desert and the Lower Indus Plains, respectively. The whole region is covered by dunesands and Indus-Hakra River flood-related sediments of Quaternary age. With view to develop tectonic inter-relationship, an integrated study has been carried out, based on seismic profiles, seismicity events, and drilling data. The results of this study indicate the presence of a fossil rift beneath the Thar Desert, the Thar Rift. The southeastern uplifted limb of this rift is potentially rich in coal. About 176 billion metric tons of thick-bedded lignitic coal was discovered as a result of exploration activities under the collaborative program of Geological Survey of Pakistan, USAID, and US Geological Survey during the last decade. On the other hand, several oil and gas field were discovered in Badin area of Lower Indus Plain in the western part of the Thar Rift. This rift has been inferred as· a monoclinal basement structural feature. The eastern (or SE) limb is uplifted, but the western (or NW) limb/part is subsiding gravitationally forming the Thar Basin. This subsident limb forms a series of faulted and tilted tectonic blocks favorable for the accumulation of hydrocarbons. It is also inferred that this process would have provided favorable conditions for elevated temperatures imperative for thermal maturity of hydrocarbons within the basin, where shallow-water depositional environments of Mesozoic sediments included euxinic mud for source, shoreline sands and reef carbonates for reservoirs, and argillites/evaporites (?) for seals. Moreover, modern seismic data indicate Holocene re-activation of some of the faults associated with the rift.

Introduction

In the present plate-tectonic setting, Pakistan lies between northwestern corner of the Indian plate, the southern part of the Afghan craton, and the northern part of the Arabian oceanic plate (Figure 1). The eastern part of Pakistan was affected by Tertiary plate convergence with intense collision between the Indian and Eurasian continents in the Karakoram thrust-zone to the north and the translation between the Indo-

Pakistan subcontinent and the Afghan craton in the northwest (Chaman transcurrent fault-system). The western part of the country was also affected by the Tertiary convergence between the Arabian oceanic plate and the Afghan craton (the Chagai arc and the Makran flysch basin), and between a segment of the Arabian oceanic plate and the western-rifted margin of the Indo-Pakistan subcontinent. The suture zones are marked by ophiolites.

The study area consists of Thar Desert in the eastern part and floodplains of Indus-Hakra River systems in the western part (Figure 1). Surface rock exposures are almost absent. The only outcropping red-granite basement complex of the Precambrian age surrounded by dunes is found in Nagarparker; otherwise, the whole area is covered by dune sand to an average depth of 80 meters in the interdunal valley level in the eastern part. Due to lack of surface exposures of the subsurface geological sequences, the geology of the Thar Desert has been poorly understood. However, geophysical and drilling data have provided a fair subsurface geological understanding of the area under study.

Geology of the Area

The eastern part of the study area is covered dominantly by parabolic sand dunes, except for limited outcrops of granitic basement units in Nagarparkar. In addition to these granitic exposures, in the far eastern and southern areas across the Pakistan border, Mesozoic and Tertiary strata are exposed in the Jaisalmer and Rann of Kutch areas of India (Figure 2; Brown et al., 1928, Biswas, 1982). However, the results of the drilling, geophysical/geological logging, and geo-electric data, collected during the Thar Coal Exploration Program of GSP-USGS-USAID (Rehman et al., 1993; Fassett and Durrani, 1994; Zaigham and Mujeeb, 1996), indicate the presence of the following four major divisions of lithological sequences in ascending order.

Basement Complex

Granitic basement is encountered at depths ranging from 112 m to 279 m in holes drilled in the east and southeast of Chachro (Fassett and Durrani, 1994). On the other hand, rhyolitic/basaltic basement was also reported in a well near Pabban locality about 8 km south of Gadro (Hindel, 1980). Farther south along the border with India, dioritic basement was encountered at 253 m depth in a drill hole (Ploethner, 1992). Results of vertical electric soundings (VES) indicate two trends of apparent resistivity values associated with the shallow basement at different sites in the area south of Chachro (Zaigham and Mujeeb, 1996). One trend indicates massive granitic basement and the other trend reveals the presence of layered Archean metasediments.

Coal-Bearing Formations

The coal-bearing sequence of Thar consists of claystones, siltstones, sandstones, and lignite with intercalations of siderite bands and nodules, and granite wash at places. The thickness of this sequence ranges from zero to 185 m as the host of lignite beds with a cumulative thickness ranging from 0.5 m to about 34 m. The age of this sequence is debatable. Based on the physical tracing of geologic contacts on seismic sections, Ahmed and Zaigham (1993) concluded that the thickest coal in Thar is Jurassic in age, whereas the palynological studies of cuttings from water-well suggests late Paleocene to early Eocene age (Fassett and Durrani, 1994).

Oxidized Zone

Compact and loose clays, silts, and sands with ironstone concretions and siderite nodules compose this lithologic unit, which is distinguished from other subsurface units by its iron oxide and limonite staining. The thickness of this zone ranges from 11 m to 209 m. The age of this unit is considered Sub-Recent (Fassett and Durrani, 1994). This oxidized zone lies unconformably over the coal-bearing formation.

Dune Zone

This zone consists of well sorted fine- to medium-grained eolian sand. The soils of the desert contain about 8 % clay and silt near the surface and about 15 % clay and silt in the subsoil (Kazmi, 1995; Qadri, 1983). The thickness of this sand zone varies from north to south. It is thinner, about 5 m to 15 m thick, in Gadro-Khokhrapar area in northern part of the desert as compared to the central and southern Thar in Chachro-Islamkot-Mithi area, where its thickness ranges from about 40 m to 93 m. This range of Dune Zone thickness is with reference to the lowest possible elevation in the interdunal area where the boreholes were drilled. Since the relief of the sand dunes at the surface in the Thar Desert exceeds 100 m in places, the total average Dune Zone thickness overlying the Oxidized Zone averages more than 80 m throughout the area.

On the other hand, in the western part of the study area, the following sedimentary sequences have been encountered in the wells drilled for the oil and gas exploration (STANV AC, 1959 unpublished; Kemal et al., ·1992; Kadri, 1995):

- Quaternary sediments
- Eocene Kirthar and Laki formations
- Paleocene Ranikot Formation
- Cretaceous Goru and Sembar formations J
- Jurassic Chiltan and Shirinab formations
- Triassic Wulgai Formation

Mesozoic sequences were encountered down to a depth of about 4500 meters in boreholes drilled for oil exploration (Quadri and Shuaib, 1986). They continue to depths beyond current drilling depths, demonstrating that the basement is overlain by significantly thick Mesozoic (also possibly older) formations in the western and northwestern parts of the Thar basin (Kemal et al., 1992; Raza et al., 1990).

Wulgai Formation of Triassic Period has been encountered in wells drilled in the study area. This formation consists of indurated dark grey mudstone and shale with intercalations of thin limestone and calcareous mudstone and sandstone. In general, the thickness of Wulgai Formation is about 1200 meters.

Jurassic sedimentary sequence consists mainly of the Shirinab Formation, the Chiltan Limestone, and the Mazar Drik Formation. Shirinab Formation consists of interbedded limestones and shales which grade downward into a dominant shale lithology of Wulgai Formation. The limestone is thin- to medium-bedded, grey to dark grey and black. Argillaceous limestone is present at different levels and is generally associated with shale. The lower part locally includes sandstone intercalations. The associated shales are grey to dark grey, but occasionally orange, yellow, red varieties are also present. The thickness of Shirinab ranges between 1500 meters and 3000 meters. Chiltan Limstone is typically massive, thick bedded, dark limestone. It contains pisolitic limestone beds locally. The texture varies from fine-grained, sublithographic to oolitic, reefoid and shelly.

Cretaceous sedimentary rocks are exposed extensively in Pakistan. At many places, the Cretaceous sequence contains volcanic rocks, obducted masses of melanges, ophiolites and igneous intrusions. The heterogeneous lithological characteristics of the Cretaceous formations have resulted from variety of provenance and different processes of sediment transport. Lithology of Cretaceous sediments varies from shale to sandstone to conglomerate to limestone. Sembar Formation of Neocomian age is composed mainly of clastic rocks, primarily shales followed by sandstones and siltstones with minor limestones. The sandstones, probably derived from the Indian Shield, are more abundant towards the eastern limits of the Thar basin. On the other hand, shale and siltstone units are more abundant towards the west, decreasing proportionately to the east. The thickness ranges from +760 meters to + 1000 meters. Goru Formation of Albian-Aptian age is dominantly black to grey and locally maroon shale or mudstone. Sandstone is rare in upper part but increases significantly in the lower part. Environment appears to have been generally marine, with relatively deep water as indicated by the pelagic fauna. The thickness of the Goru Formation is about 2360 meters in Badin area.

Parh Limestone of Cenomanian-Turonian age occurs widely even throughout the adjacent southern Indus basin. It represents a light grey, white, cream to tan, thin bedded argillaceous limestone which exhibits lithographic to porcellaneous character. Maximum thickness of Parh Limestone, approximately 600 meters, is found west of the Kirthar range. Moghal Kot and Pab Sandstone formations are developed significantly in Thar basin. However, in the adjacent basin, Moghal Kot Formation of Maestrichtian age has also a more restricted distribution than underlying Parh Limestone in the southern Indus basin. It was deposited in a narrow but deep basin. The lithofacies pattern is quite varied. In general, the clastics account for the thick accumulations, and the carbonates, with fine clastics, were deposited in thinner sequences. The formation generally consists of a dark grey, calcareous mudstone with scattered intercalations of quartzose and argillaceous limestone. A dark limestone, often sandy, at the top of the formation is widely distributed. The limestone increases away from the main areas of clastic deposition. In southern Indus basin, most of the Moghal Kot deposition consisted of limestone and shale. Similarly, the Pab Sandstone of Maestrichtian age is areally the most restricted unit of the Cretaceous formations. The Pab is light grey to light tan to brown, quartzose, fine- to coarse-grained, hard to soft sandstone. The intercalations of dark grey shales are common, and at places it locally contains interbeds of argillaceous, micritic limestone. Tertiary sequences are also not completely developed in Thar basin.

Tectonic Analysis of Thar Basin

As the whole region is covered by dune-sands and Indus-Hakra rivers' flood sediments of Quaternary age, the subsurface geology of the study area has been analyzed based on the seismic profiles, seismicity events and drilling data in view to develop tectonic interrelationship model. Six seismic profiles, collected by Phillips Petroleum Company and acquired from Petroleum Cell and OGDCL, were analyzed (Figure 2). Moreover, in view to study tectonically active nature, the earthquake seismicity data of 180 years (from 1819 to 1998) have been taken from the catalog of USGS (Table 1) and plotted in relation to the basement. From the seismic data interpretation it is inferred that the Thar Desert rests upon a structural platform where granitic basement is at shallower depths. A geological cross-section, Figure 3, based on the seismic profile analysis in NW-SE direction, shows that the stratigraphic sequences are following the normal depositional environment of a gravitationally subsiding basin. They are dipping gently towards northwest without major tectonic deformation. This cross-section also illustrates thickening of the sedimentary sequences towards northwest and thinning and/or truncation towards southeast. The Tertiary and Cretaceous formations pinch-out near Chachro. On the uplifted horst block of the Thar fossil rift, the Jurassic or the older formation are expected to prevail and to be overlain by thick Quaternary eolian sediments.

On the basis of the present analysis, a fossil rift structure buried by a thick sequence of Cenozoic-Mesozoic has been inferred beneath the Thar Desert of Pakistan. This structure was likely developed during the initial stage of separation of Indo-Pakistan plate from Gondwanaland. The consistent depositional trends of the Mesozoic to Tertiary stratigraphic sequences indicate that the incipient rifting of the basement was pre-depositional, i.e. at least pre-Jurassic in age, which caused flexure and the ultimate development of the Thar basin under the normal subsidence phenomenon associated with the divergent tectonic process. The fossil-rift structures similar to Thar basin have also been reported from southern Indus basin (Zaigham and Mallick, 2000) and from other parts of the world, like, New Madrid, Kutch, Basel, and Hainan Island (Johnston and Kanter, 1990). Gravitational movements of individual blocks of the inferred incipient oceanic crust have developed horst and graben structures.

The overview of the basement depth contours shows three distinct anomalous zones (Figure 4). The first zone lies in the southeastern part of the map, i.e., the area between Chachro and Satidera. The contours indicate an area of gentle dip towards northwest. Farther southeastward, the basement appears at shallower depth, i.e., less than 200 meters. The pattern of shallow depth contours also indicates that the lateral extensions of geological formations in the northeast and in the southwest are bounded by relatively steeper dips. In the second zone, which lies to the northwest of Chahcro, there is a sharp gradient of depth contours trending northeast-southwest, indicating relatively steep slope of the basement in northwest direction. The third zone is to the west and northwest of the second zone.

From a study of earthquakes in the New Madrid and Kutch stable continental crust areas, it was inferred that faults were reactivated millions of years after their development and generated earthquakes (Johnston and Kanter, 1990). Faults created in the continental rifted margins by ancient extensional stresses may be dormant for millions of years, and thus gradually be covered by a blanket of sediments. Later on, compressive stresses may reactivate a fault which slips in reverse direction, either vertically or horizontally or both, generating an earthquake and causing tectonic deformation of the upper crustal cover of the sediments (Figure 5). Similarly, the presence of seismicity events in and around the study area indicates that the progressive Tertiary compression within the Indo-Pakistan subcontinent might have reactivated these older transverse faults associated with the inferred Thar fossil-rift, causing them to move obliquely and to generate earthquakes. Figure 4 shows the distribution of seismicity events indicating that the counterclockwise movement of the IndoPakistan subcontinent is still in progress, which is causing the progressive accumulation of compressional energy. The presence of epicenters in the southwest of Chachro area indicates the reactivation of the faults associated with the Thar rift. Similar reactivation of dormant faults associated with the Rann of Kutch can also be observed. The details of the earthquake events have been summarized in Table 1.

Hydrocarbon Prospects in Thar Basin

The western margin of the Indo-Pakistan subcontinent plate is characterized by a number of rift systems from Bombay (India) in the south to southern Indus basin (Pakistan) in the north. These include the Narmada, Cambay, Rann Kutch, and Thar rifts. Cambay rift (India) has known oil and gas accumulations (Biswas, 1982). In the western part of the Thar rift, an oil and gas field (Badin Block) discovered by Union Texas at Khaskheli, about 150 kilometers east of Karachi, in 1981 (Shuaib, 1982; Quadri and Shuaib, 1986; Raza et al., 1989). The eastern limb of the Thar rift is potentially rich in coal (Fassett and Durrani, 1994; Zaigham and Ahmed, 1996). Table 2 shows the exploration activities in and around Thar rift.

Continental margins are controlled by the extent of post-rift downwarping and by the sedimentation after the initial separation of continental fragments. These processes differ on the various continental margins owing to differences in distance from detrital sediment source and to differences in depth of water and in bottom gradient (Thompson, 1976). Our inferred geological models of the Thar basin represent a characteristic extensional basin which includes incipient formation of basaltic magma in the upper asthenosphere, thinning of the overlying lithosphere, broad tectonic upwarp, and probable limited volcanism at the earth's surface during Paleozoic to Early Mesozoic (7) time. The divergent process would have provided favorable conditions for elevated temperatures, imperative for thermal maturity of hydrocarbons within the Thar basin. Concurrent tectonic subsidence provides shallow-water depositional environments for the Mesozoic sediments which include euxinic muds for source, shoreline sands and reef carbonates for reservoirs and argillites/evaporites (?) for seals, in general.

Source rocks, reservoir rocks, seals, traps, adequate maturation of organic matter and migration are prerequisites for economic accumulation of hydrocarbons. Within extensional basins, hydrocarbon potential is increased due to higher temperature gradients (from magmatic proximity) favorable for generation and expulsion of oil and gas. Within the rift, shallow-water sedimentation favored the formation of the sources and reservoirs (Thompson, 1976). Stratigraphically, the shale series of the Lower Cretaceous Sember Formation and the Lower Goru Formation is the main documented oil and gas source rock units in the Thar basin (Hussain et al., 1991). In general, upper Paleocene marine transgressive shales are the secondary source rock series, deeply buried in the western half of the southern Indus basin, but in Badin area they are not deeply buried. In the Thar basin (Badin Block), the main oil and gas productive reservoir rock units are the Cretaceous Lower Goru sandstones (Figure 6). The basal transgressive sandstones of the Lower Cretaceous Sember Formation may be important hydrocarbon targets. Moreover, hydrocarbon targets may also exist in the Jurassic Chiltan Limestone. The upper Goru shales are the main reservoir seal in the basin. In general, the transgressive shales of Cretaceous (Sember Formation) and Tertiary (Bara-Lakhra, Laki-Ghazij, and Kirthar formations) provide seals to Jurassic and Tertiary reservoirs.

Figure 7 illustrates the present areas having hydrocarbon discoveries associated with the western part of Thar basin and the lignite coal resources associated with the uplifted eastern part of the Thar rift. From a critical study of cross-section shown in Figure 3 and Figure 6, it is revealed that i) the Thar basin deepens in northwestern area of the rift between Umarkot and Murpur Khas, and ii) the thickness of stratigraphic sequences may be greater along the NW-SE cross-section (G-H) as compared to NE-SW cross-section (Figure 6), because the NE-SW cross-section is subparallel to the strike of the rift, whereas the other section (G-H) is taken perpendicular to the strike of the rift.

In the lower Indus plains, oil and gas discoveries are associated mostly with the Lower Cretaceous strata in the western part of Thar rift in Badin Block. The interpreted NW-SE geological cross-section shows hydrocarbons in the Thar basin associated with the horst and graben segments (or faulted and tilted blocks) of the fossil rift. In view of the present inferences, a more detailed study of the basement structures is imperative to decide the precise targets for the oil and gas traps in and around Umarkot area.

Many of the present preliminary observations are less encouraging since adequate subsurface data is not available from the Thar basin at this stage of exploration. The industry is needed to explore vast areas of the Thar basin. In time many *sweet spots* will be found buried within the thick sedimentary sequences in the basin.

Discussion

From the seismic study, a northeast-southwest trending fossil rift structure has been identified but covered by thick sequences of Mesozoic and Cenozoic sediments in the Thar basin. The structure developed as a manifestation of rifting of the Indo-Pakistan subcontinent from Gondwanaland. Sediments deposited after the development of the failed-rift structure were deposited under the normal subsidence. Progressively increasing compression was due to the northwestward movement of Indo-Pakistan continental plate along with its counterclockwise rotation. The dormant transform faults associated with the failed rift were reactivated as transcurrent faults and subsequently created the horst and graben structures. Seismicity associated with the inferred transcurrent faults indicates past and present relative movements of blocks of the failed-rift structure. These structures were developed as a consequence of divergence and convergence along the western margin of the Indo-Pakistan subcontinent.

A geological history of a basin can be compiled by considering the basin-forming tectonics and depositional sequences (Kingston et al., 1983). The western margin of the Indo-Pakistan continental plate is characterized by past extensional tectonics resulting in rifted protocontinent and new oceanic crust created during seafloor-spreading (Powell, 1979; Biswas, 1982; Zaigham, 1991).

From data analysis, it became evident that, during rifting, the lithosphere was stretched and consequently thinned. Simultaneously, the basaltic magma formed in the upper part of the asthenosphere causing broad tectonic upwarping. Full-fledged spreading centers did not develop in the beginning, but rather the continental crust stopped stretching and subsequently the edges cooled and subsided. Hence, the stretched crust subsided to become a broad sediment-filled basin or trough. Initiation of seafloor spreading from continental rifting may have special significance for petroleum exploration because of the high heat flow, favoring generation of oil and gas. Likewise, the deposition of shallow-water deposits yield favorable sources, reservoirs, and seals for hydrocarbons. The inferred fossil rift opens bright prospects in the Thar basin for the petroleum potential.

Based on the stratigraphic studies of the exploratory data from oil and gas fields, it is found that the Upper Jurassic – Lower Cretaceous Sember Formation is the major hydrocarbon source for charging the oil/gas fields of the Thar basin and surrounding areas. Generation of hydrocarbons from kerogen is controlled by geothermal gradient, burial depth, and duration of source-rock burial (Tissot and Welte, 1978). Based on the available bottomhole temperature data, it is found that the thermal gradients increase from east to west in the Badin-Hyderabad block, i.e., from 2.36°C/100m in Nabisar in the east to 4.3°C/100m in the west (Quadri and Shuaib, 1986). In view of the westwardly increasing trends, high geothermal gradients over 4 °C/100m are expected to be found within the inferred Thar failed rift region in the basin around Umarkot. The thermal events, caused by the rifting tectonism, are thought to have brought about the generation and subsequent migration of the hydrocarbons during the Cretaceous time, when the main fault block traps were already in existence according to proposed models. The Lower Goru sandstones of the Cretaceous may be the major reservoir rocks also in the Umarkot area, similar to oil and gas fields associated with the western part of the Thar rift basin (Badin Block), while the Sember shales are the proven source rocks in the Thar basin. In addition, thick Triassic sandstones and carbonates with secondary porosity, Jurassic sandstones, and the Ranikot Formation of Paleocene age can also be considered to have good reservoir quality. Further systematic exploration studies are imperative to define the targets for specific tracts in the basin. The northwestern part of the fossil rift, the Umarkot area may be a good target, considering the oil and gas fields of the Badin Block associated with the western part of the Thar rift, because this part seems to have relatively thicker stratigraphic sequences than those associated with the Badin area.

Conclusions

- Seismic data indicate a deep-seated NE-SW trending fossil failed rift beneath the Thar Desert on western margin of the Indo-Pakistan continental plate.

- Horst and graben structures (faulted and tilted blocks) have been identified in the subsurface associated with the Thar fossil rift.
- The deep and extensive sedimentary basin, known as Thar basin, appears to have developed due to the formation of the failed rift and subsequent subsidence and sedimentation processes.
- The distribution of seismic epicenters in and around the Thar Desert exhibits a close association with the transcurrent faults related with the Thar fossil rift, which seems to be active even at present, causing deformation and readjustment of the overlying tilted and faulted blocks.
- The presence of the fossil failed rift has identified encouraging prospects for new oil and gas discoveries in the Thar basin, since favorable conditions related to sources, thermal history, reservoirs, and seals prevail in relatively thicker sediments, similar to those found in the Badin Block. The present basement interpretation, combined with the presence of known hydrocarbon source beds, reservoirs and structures found in the surrounding basins, should be further studied and interpreted to delineate new exploration targets as vast tracts await to be drilled in the basin, particularly in and around Umarkot area.

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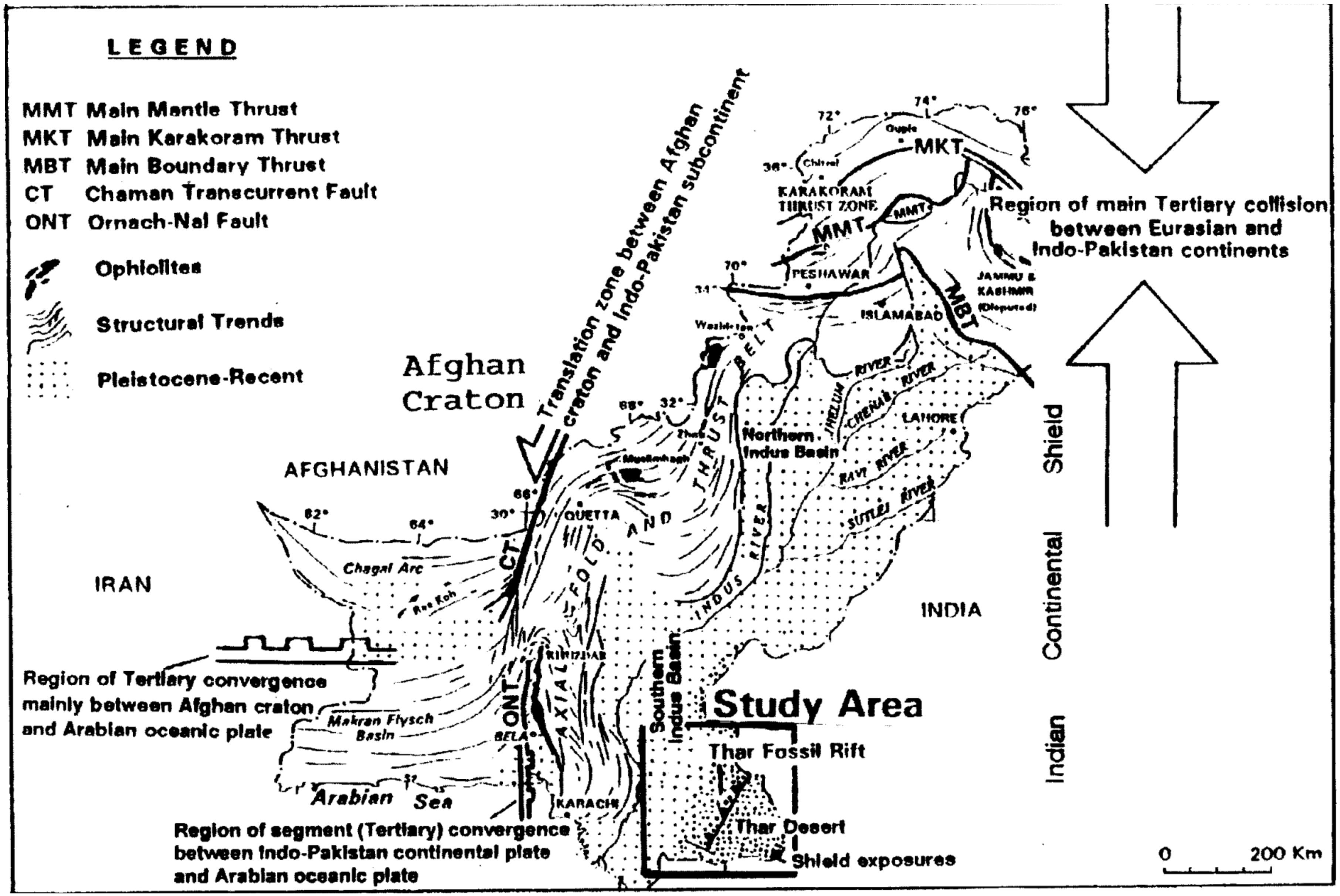

Figure 1. Index map of Pakistan showing location of the study area and salient tectonic features.

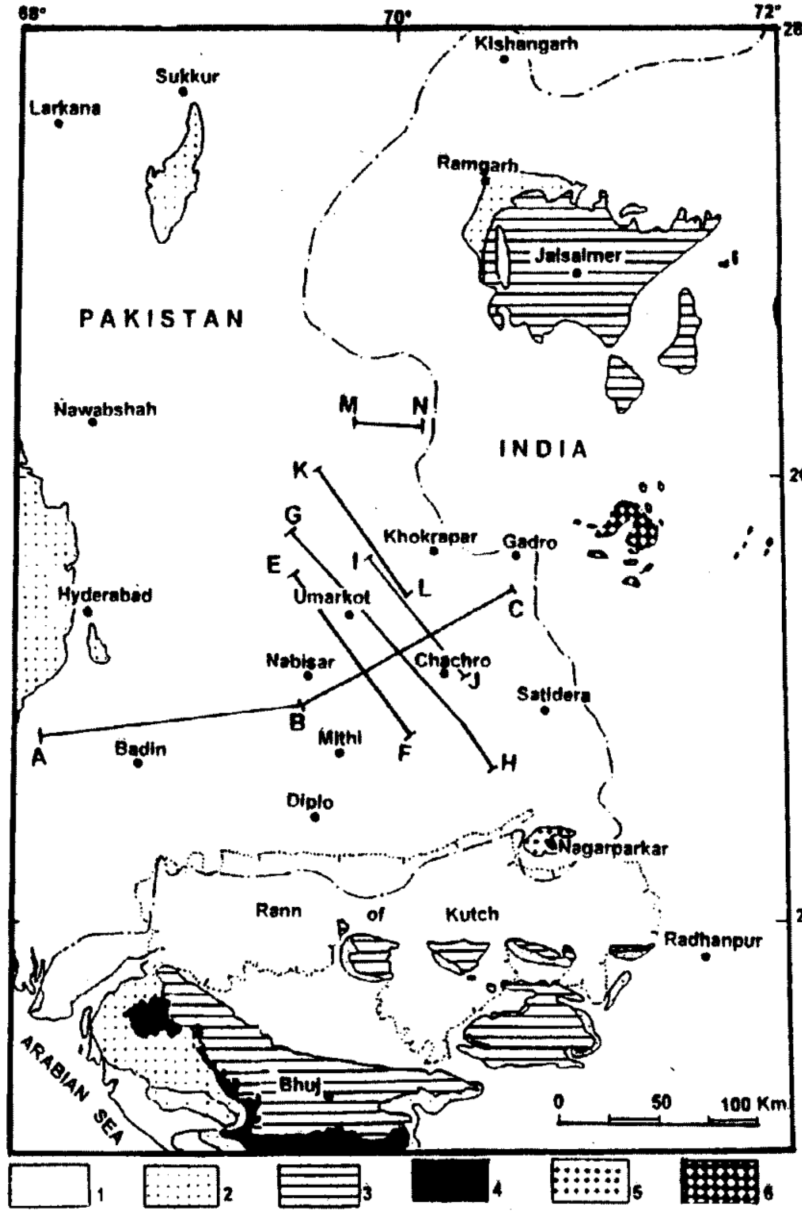

Figure 2. Map of general geology, locations of seismic profiles, and geological cross-sections. Geologic legend: 1) Quaternary sediments / Desert dune sand, 2) Tertiary sequences, 3) Mesozoic-Jurassic sequences, 4) Lava flows - Deccan traps, 5) Precambrian units, 6) Rhyolites-Malani beds.

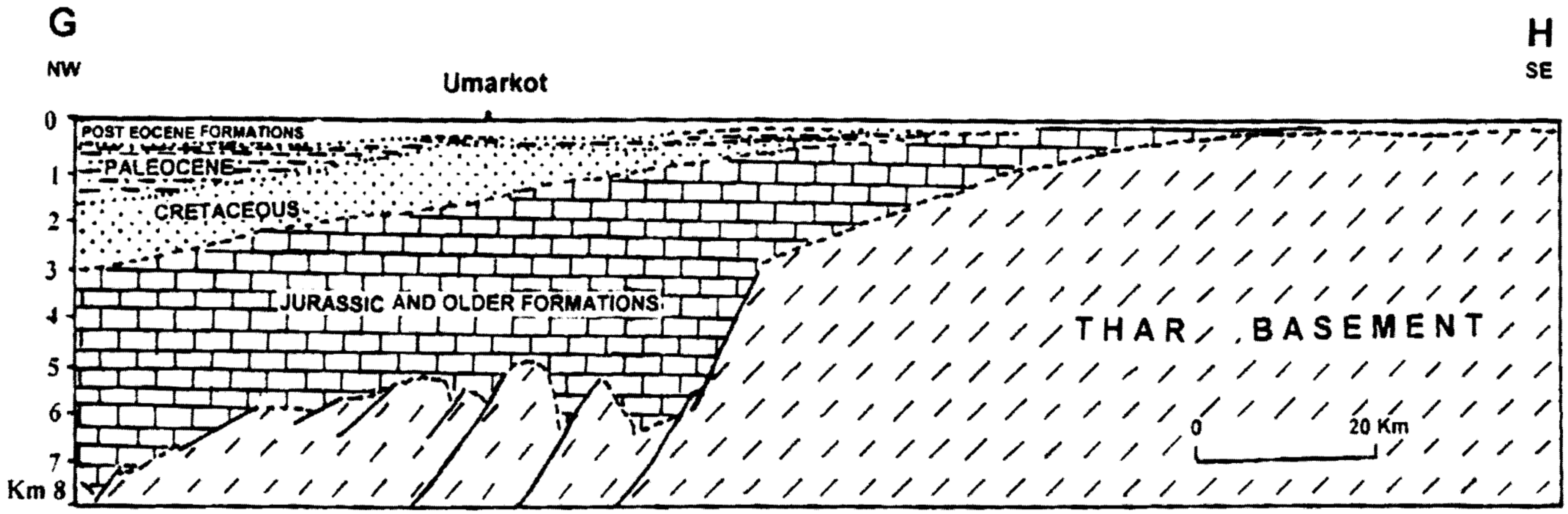

Figure 3. Geologic cross-section in NW-SE direction, interpreted from seismic profile GH (shown in Figure 2), showing the vertical configuration of the Precambrian basement and distribution of the sedimentary sequences.

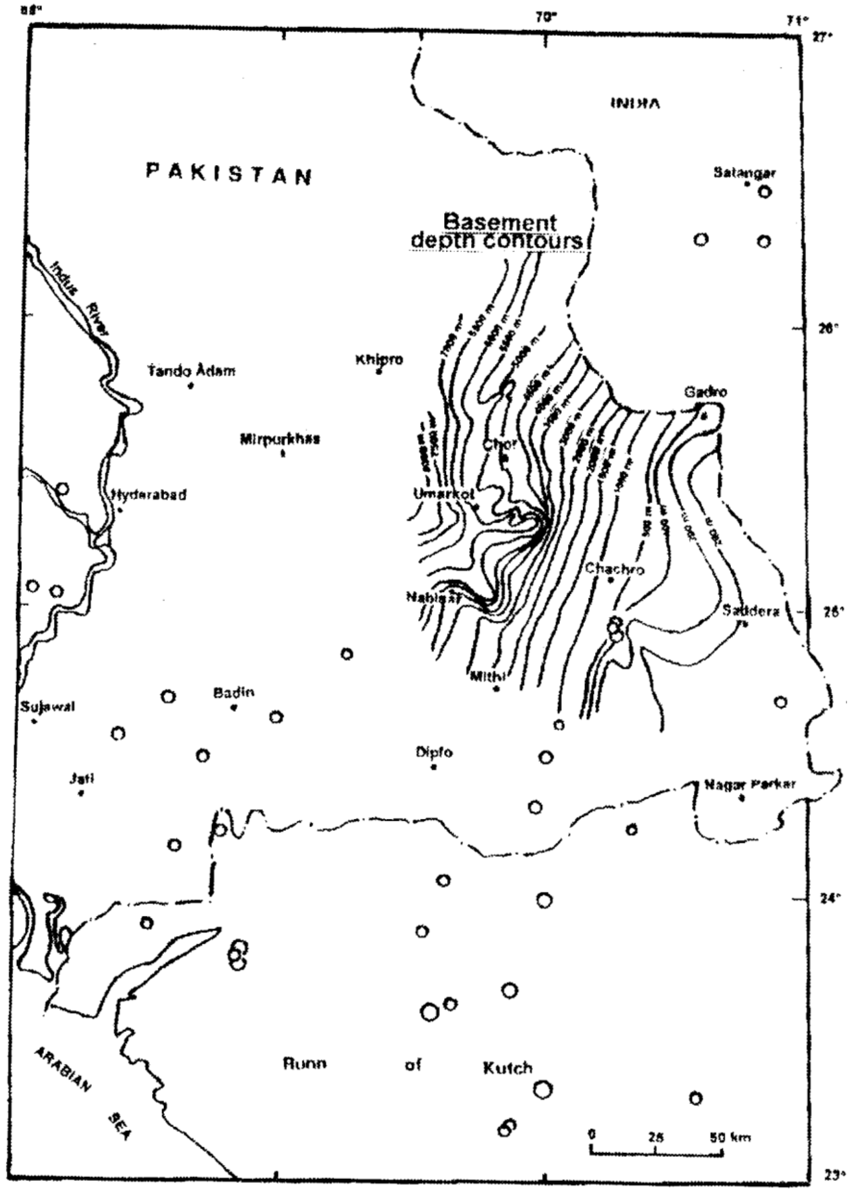

Figure 4. Contour map of the basement depth, along with the distribution of earthquake epicenters. The details of seismicity data are in Table 1.

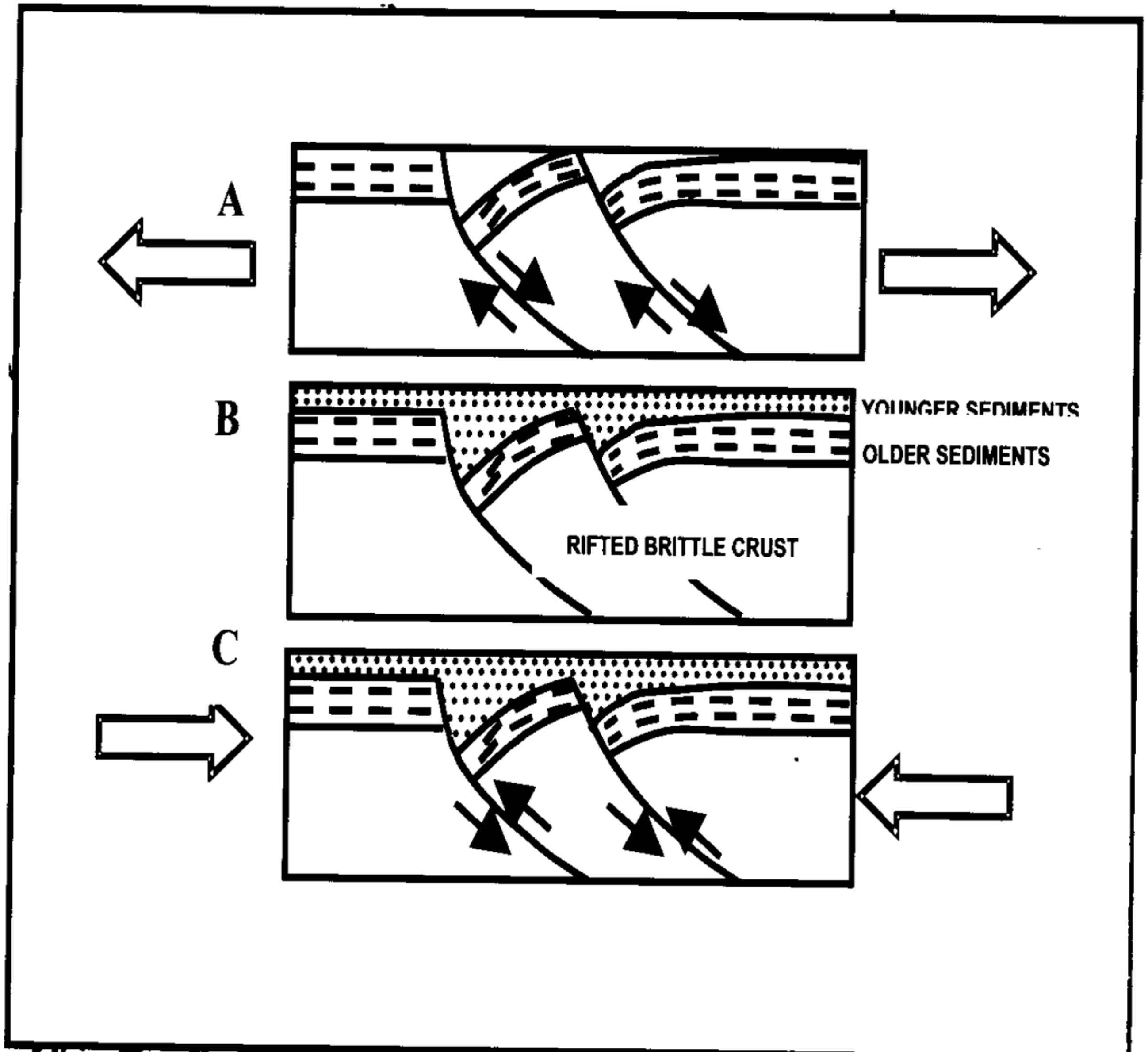

Figure 5. Models in cross-sectional views that show steps involved in generating earthquakes associated with the rifted stable continental crust. A. Normal faults created by ancient extensional stresses. B. Faults were dormant millions of years. C: Reactivation of dormant fault(s), with reverse direction of movement due to ongoing compressive stresses, generates an earthquake.

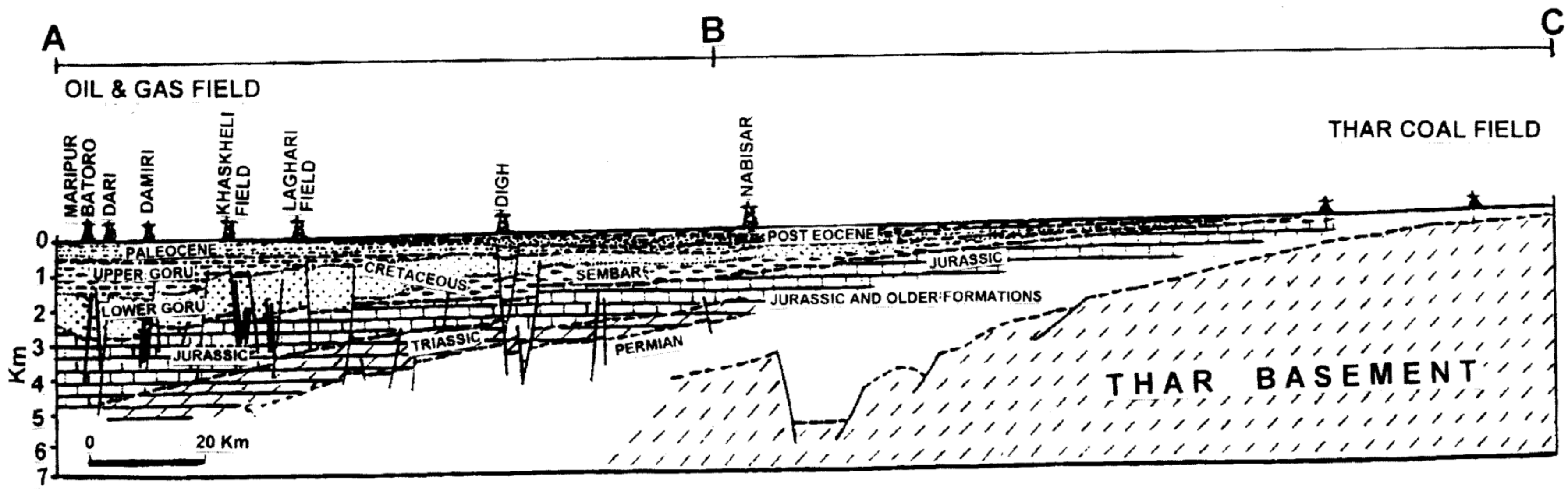

Figure 6. Geologic cross-section, essentially east-west in direction; location as ABC in Figure 2. Shown are oil and gas fields and Thar coal field. Configuration of Thar basin is almost parallel to the strike of the Thar rift.

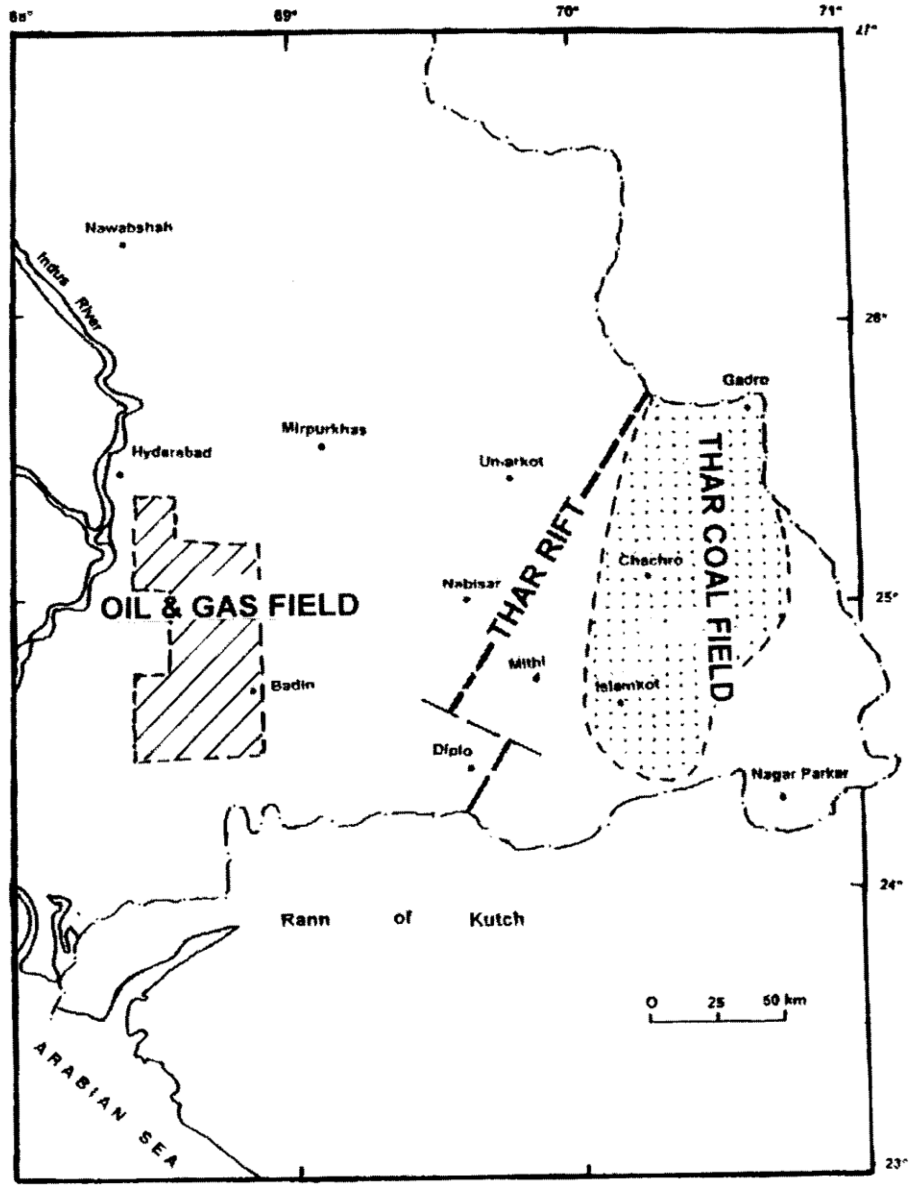

Figure 7. Location map of oil and gas fields investigated, together with Thar Coal Field and Thar rift.

CAT.	YEAR	LAT.	LONG.	DEPTH	MAGNITUDE
HISTORICAL EARTHQUAKES					
INDIA	1819	23.60	69.60	8.30	UKOLD
INDIA	1820	23.20	69.90	3.70	UKOLD
INDIA	1820	23.20	69.90	3.70	UKOLD
INDIA	1845	23.80	68.90	6.30	UKOLD
INDIA	1828	23.20	69.90	4.30	UKOLD
INDIA	1844	23.80	68.90	4.30	UKUKN
INDIA	1845	23.80	68.90	6.00	UKTS
INDIA	1856	23.20	69.90		
INDIA	1870	25.80	68.80		
INDIA	1882	23.35	70.58		
INDIA	1882	23.35	70.58		
INDIA	1903	24.00	70.00	6.00	UKIMD
INDIA	1940	23.70	69.90	6.00	UKTS
INDIA	1950	24.00	71.20	5.60	UKTS
INDIA	1956	23.30	70.00	7.00	UKTS
INDIA	1962	24.10	70.90		
INDIA	1963	24.90	70.30	5.60	UKIMD
INDIA	1965	24.40	70.00	5.30	UKTS
INDIA	1966	24.50	68.70	5.10	UKPDE
INDIA	1969	24.40	68.70	4.40	UKPDE
INDIA	1970	24.60	68.60	5.20	UKPDE
INDIA	1971	25.10	68.10	4.50	UKPDE
INDIA	1973	25.10	68.10	4.80	UKPDE
MODERN EARTHQUAKES					***Km***
PDE	1973	25.10	68.07	33	4.80 mbGS
PDE	1975	24.69	71.03	33	3.70 mb GS
PDE	1976	25.02	70.32		14
PDE	1976	24.90	70.24	39	
PDE	1976	24.58	68.41	33	5.20 mb GS
PDE	1977	25.42	68.17	33	4.50 mb GS
PDE	1977	25.24	68.27	33	
PDE	1981	23.90	69.57	33	4.20 mb GS
PDE	1982	24.08	69.65	33	4.80 mb GS
PDE	1982	23.34	70.61	33	4.80 mb GS
PDE	1984	24.97	70.45	33	
PDE	1985	24.33	69.93	33	5.00 mb GS
PDE	1985	25.79	71.24	33	4.80 mb GS
PDE	1987	24.25	70.25	10	3.80 mb GS
PDE	1989	23.90	68.53	33	4.10 mb GS
PDE	1989	24.67	70.99	33	4.70 mb GS
PDE	1991	23.40	69.71	33	4.90 mb GS
PDE	1991	24.18	68.64	32	4.70 mb GS
PDE	1991	24.27	68.81	25	4.80 mb GS
PDE	1991	26.32	70.61	22	5.60 mb GS
PDE	1991	26.33	70.86	19	4.50 mb GS
PDE	1991	26.47	70.81	33	4.20 mb GS
PDE	1992	24.86	69.28	33	3.50 mb GS
PDE	1993	24.65	69.00	33	4.30 mb GS
PDE	1998	23.68	68.80	33	

Table 1. List of earthquake events. (Source: United States Geological Survey [National Earthquake Information Center]).

S. No.	Name of Wells	Status of Field	Year of Discovery	Location in S. Indus Basin	S. No.	Name of Wells	Status of Field	Year of Discovery	Location in S. Indus Basin
1	Sari Singh	Gas	1966	Southern part	39	Koli-1	Oil	1989	Southern part
2	Hundi	Gas	1971	Southern part	40	Pasahki-1	Oil	1989	Southern part
3	Kothar	Gas	1971	Southern part	41	Fimkassar-1	Oil	1989	Southern part
4	Khaskheli	Oil	1981	Southern part	42	Bhatti-1	Oil	1989	Southern part
5	Laghari	Oil	1983	Southern part	43	Rind-1	Oil & Gas	1989	Southern part
6	Golarchi	Gas	1984	Southern part	44	Dhamrakhi-1	Oil	1991	Southern part
7	Tando Alam	Oil	1984	Southern part	45	Noor-1	Gas	1991	Southern part
8	Tajedii	Oil	1984	Southern part	46	Buzdar-1	Gas	1991	Southern part
9	Mazari	Oil	1984	Southern part	47	Mian Ismail-1	Oil	1991	Southern part
10	Dabhi	Oil	1984	Southern part	48	Bobi North-1	Oil	1991	Southern part
11	Nari	Oil& Gas	1985	Southern part	49	Mahi-1	Gas	1992	Southern part
12	Turk	Oil& Gas	1985	Southern part	50	Bari-2	Oil	1992	Southern part
13	S. Mazari	Oil	1985	Southern part	51	Nakurji-1	Gas	1992	Southern part
14	Bukhari	Gas	1985	Southern part	52	Buzdar North-1	Oil & Gas	1993	Southern part
15	Dabhi South	Gas	19866	Southern part	53	Bachal-1	Oil & Gas	1993	Southern part
16	Matli	Gas	1986	Southern part	54	S.Mazari Deep1	Oil & Gas	1993	Southern part
17	Jabo	Gas	1986	Southern part	55	Jalal-1	Gas	1993	Southern part
18	Ghotana	Oil	1986	Southern part	56	Buzdar South-1	Oil	1993	Southern part
19	Makhdumpur	Gas	1986	Southern part	57	Buland-1	Gas	1993	Southern part
20	Liari	Oil	1986	Southern part	58	Zaur-1	Oil & Gas	1994	Southern part
21	Halipota	Oil	1986	Southern part	59	Liari Deep-1	Oil	1994	Southern Part
22	S. Lashari	Oil	1987	Southern part	60	Mithrao-1	Gas	1994	Southern part
23	Thora	Oil	1987	Southern part	61	Turk Deep-1	Oil	1994	Southern part
24	Ghunghro	Oil	1987	Southern part	62	Jhol North-1	Oil	1995	Southern part
25	Sona	Oil	1987	Southern part	63	Tangri-2	Oil	1995	Southern part
26	Kunar-2	Oil& Gas	1988	Southern part	64	Makhdumpu rD1	Gas	1995	Southern part
27	Pir-1	Gas	1988	Southern part	65	Charo-1	Gas	1995	Southern part
28	Paniro-2	Oil	1988	Southern part	66	Khrewah Deep1	Gas	1995	Southern part
29	Duphri-1	Oil	1988	Southern part	67	Zaur Deep-1	Gas	1995	Southern part
30	Bobi-1	Oil	1988	Southern part	68	BuzdarS.Dep1	Gas	1995	Southern part
31	Korewah-1	Gas	1988	Southern part	69	Chak-5 Dim S-1	Oil &Gas	1996	Southern part
32	Injra-1	Oil	1988	Southern part	70	Jagir-1	Oil	1996	Southern part
33	N. Akri-1	Oil	1988	Southern part	71	Pali	Oil	1996	Southern part
34	Daru-1	Oil& Gas	1988	Southern part	72	Sakhi-1	Oil	1996	Southern part
35	Bagla-1	Gas	1988	Southern part	73	Muban-1	Oil	1997	Southern part
36	Thora East-1	Oil	1988	Southern part	74	Sakhi Deep	Gas	1998	Southern part
37	Kunar-1A	Oil& Gas	1988	Southern part	75	M. Ismail Deep	Gas	1998	Southern part
38	T. G. Ali-1	Oil	1989	Southern part	76	Dabhi North	Oil	1998	Southern part

Table 2. Exploration activities and discoveries of oil and gas in and around study area (modified after Progress, 1994).