Seismotectonic set up in East Central Sulaiman Range

M. A. SAMAD BAIG[1], FAIQ MAZHAR[1], MUJEEB-UR-RAHMAN[1] & HAMID MEHMOOD[2]
[1]Pakistan Atomic Energy Commission, NMC-1, D.G. Khan
[2]Atomic Energy Mineral Centre, P.O. Box 658, Lahore

ABSTRACT: *D.G.Khan city is located along the foothills of "Central Sulaiman Fold Belt", southeast of Zinda Pir Anticline which forms the nearest tectonic structure in the area. The Sulaiman and Kirthar Ranges were developed during Palaeocene times in the 4th episode of Himalayan Orogeny forming a huge shear zone (Sulaiman-Kirthar Shear Zone) as a result of the drag effect associated with northwest movement of the Indian plate. This zone is comprised of a number of transform and wrench faults associated with doubly plunging anticlines. The Sulaiman Shear Zone is seismically an active region due to activity along faults such as Kingri, Barkhan and Kohlu that are capable of causing seismicity of 5-7M. On the basis of present studies a "Peak Ground Acceleration" of <0.15g has been proposed for D.G.Khan city. The neotectonic survey along talus creep deposits, talus conglomerate and recent to sub-recent alluvial fans was conducted which do not indicate any recent ground movement. The D.G.Khan city can be considered a safe area for construction of large engineering structures.*

INTRODUCTION

Dera Ghazi Khan city is located along foothills of "Central Suleman Fold Belt" 30 km southeast of Zinda Pir anticline (Fig. 1) which forms the nearest tectonic structure in the area. The area has been investigated for regional studies (within a radius of 100km^2) and detailed studies (within a radius of 25 km^2). The nearest tectonic structure and recent alluvium were studied to observe structural disturbances and neotectonics to evaluate seismic potential of the area. A number of strike-slip and reverse-slip faults were observed in the area. The notable faults of the area are Bar-khan, Kingri, Khalifat, Harnai and Chaudhwan (Fig. 2). Kingri and Barkhan faults are located nearest of D.G.Khan at a distance of 70 -75 km. Maximum movement along some of these faults is measured to be more than 100m.

Although the area lies close to the folded thrust of Zinda Pir anticline yet no active faults are found to continue to the near vicinity of D.G. Khan city.

The regional studies were aimed at identifying the major tectonic structures that can impart seismic risk to the area. A number of active faults and lineaments lie in the west-south-west of the city and cluster of teleseismic events are found associated with these faults. The epicentres in most of the seismic events are shallow (< 50Km) while their magnitude vary between 5 -7.

REGIONAL STRATIGRAPHY

The Sulaiman Fold Belt is comprised of rock sequences ranging from Mesozoic to Recent in age. The rocks exposed in Sulaiman Range continue further east below the Punjab Plains but the different rock sequences thin out towards east. A schematic

Geological control on natural hazards: earthquakes and mass movement. Khan, M.A., Abbasi, I.A., & Khattak, G.A. (Eds.). Geological Bulletin, University of Peshawar, (Special Issue), Vol. 35, pp. 67-84, 2002

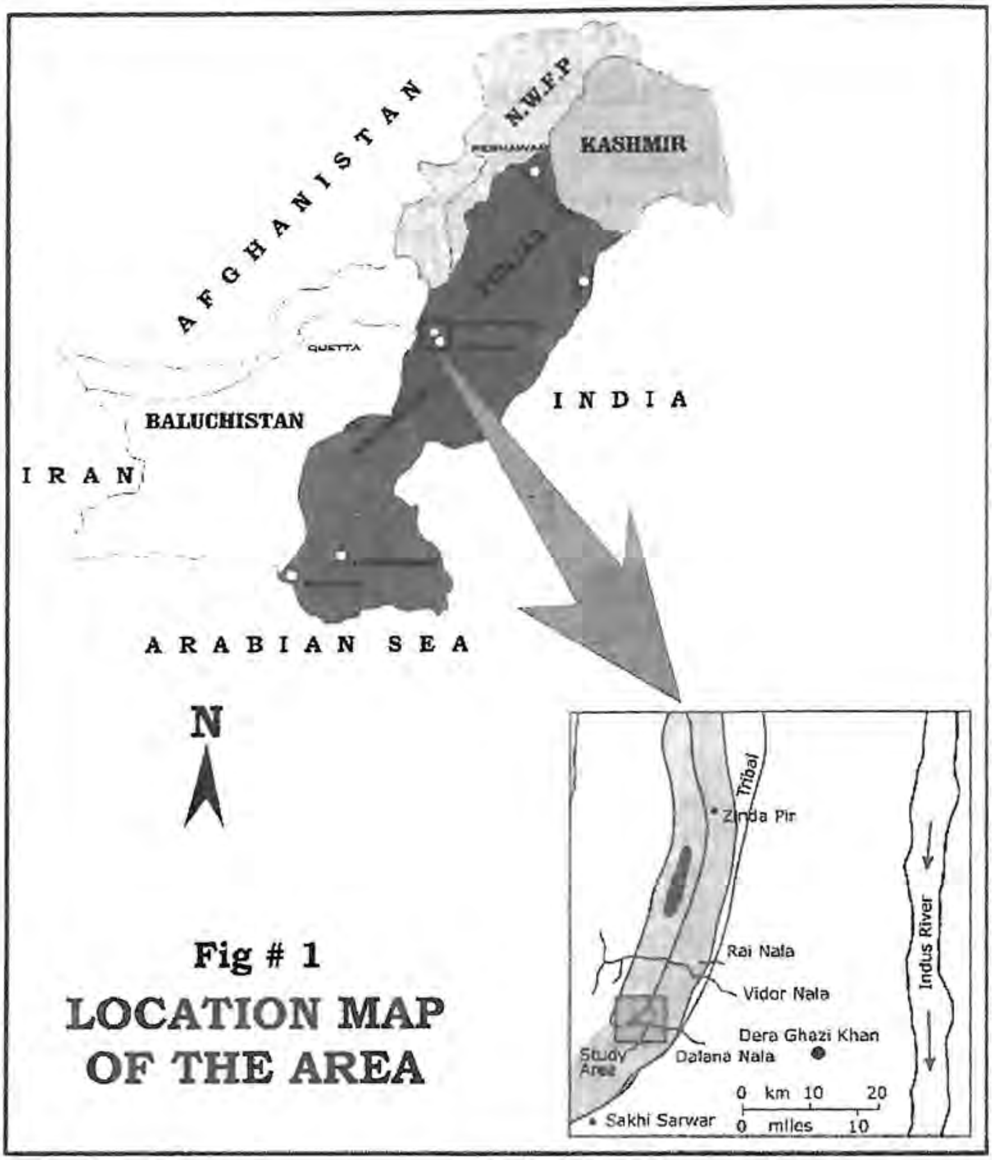

Fig # 1

LOCATION MAP OF THE AREA

diagram providing a generalised relation of the Sulaiman Range and Sulaiman Fore-land has been shown in a stratigraphic column (Table 1).

The general stratigraphic succession in the area is represented by sedimentary rocks of Palaeogene, Neogene and Quaternary ages. The Palaeogene rocks constitute Ghazij and Kirthar formations, which are largely marine and comprise limestone, marl and shale. There is a major unconformity between the Palaeogene and the overlying rocks. The Neogene and Quaternary rocks are mainly continental, represented by the Chitrawata, Vihowa, Litra, Chaudhwan formations, Dada conglomerate and the sub-recent to recent alluvial deposits. The rocks comprise sandstone, clay, conglomerate and unconsolidated surficial deposits.

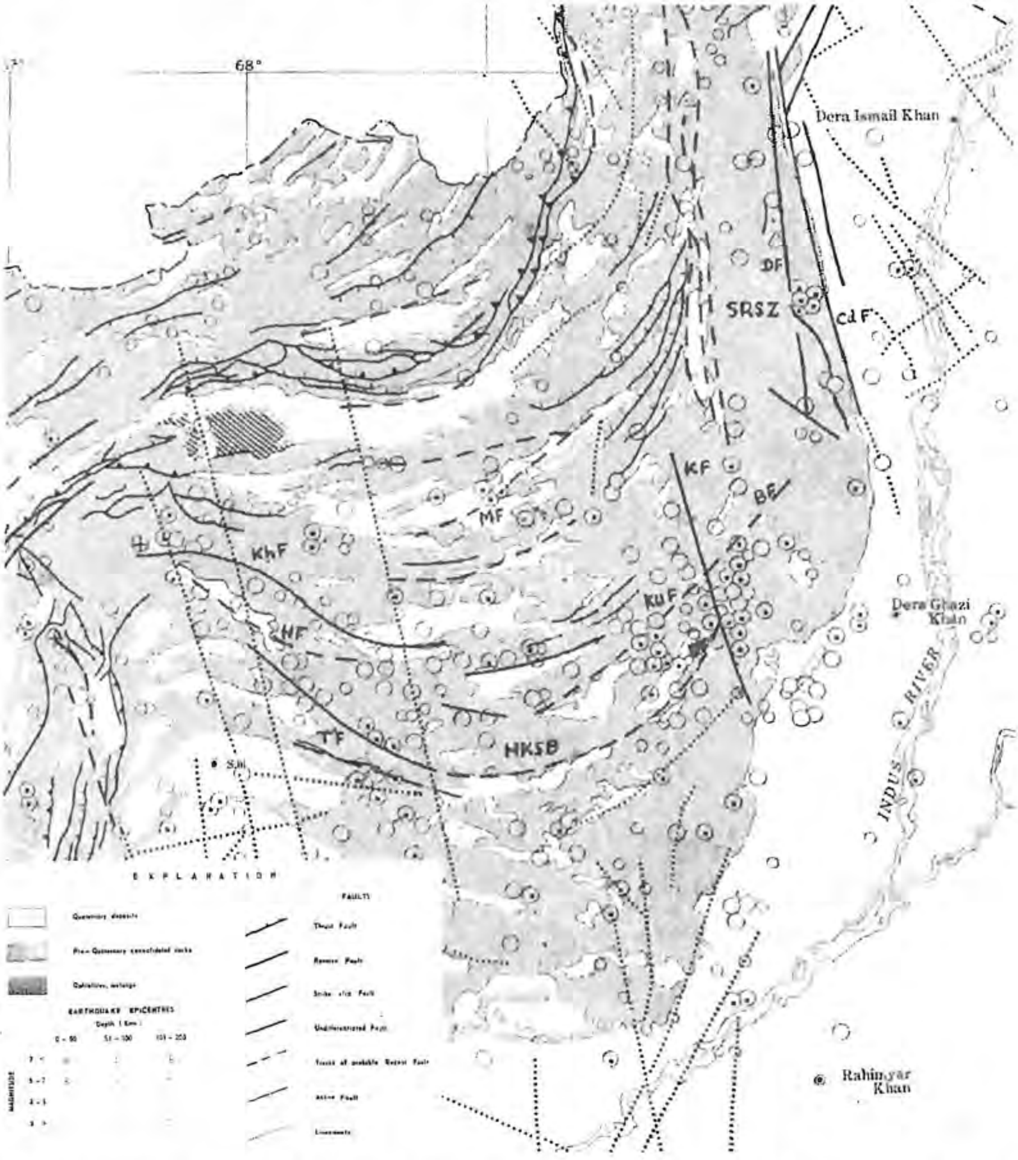

Fig. 2. Seismotectonic map of Sulaiman Seismic Zone. DF:Domanda Fault, Cd: Chaudhwan Fault, SRSZ: Sulaiman Range Seismic Zone, KF: Kingri Fault, BF: Barkhan Fault, MF: Mekhtar Fault, KuF: Kohlu Fault, KhF: Khalifat Fault, HF: Harnai Fault, TF: Tatra Fault, HKSB: Harnai Kohlu Seismic Belt (After Kazmi 1979)

REGIONAL TECTONIC FEATURES OF THE SULAIMAN-KIRTHAR FOLD BELT

On the basis of plate tectonic features, geological structure, orogenic history and lithofacies, Pakistan can be subdivided into different tectonic Zones (Kazmi and Jan, 1997). The deformation of the Sulaiman-Kirthar fold-belt took place during 5-major Orogenic Episodes (Wang et al., 1996).

Table 1

STRATIGRAPHIC SEQUENCE IN THE INDUS PLATEFORM AND FOREDEEP ZONE

ERA	PERIOD	PUNJAB PLATEFORM SLOPE AND SULAIMAN FOREDEEP	
		Plateform	Foredeep
CENOZOIC	Neogene	Siwalik Gr	Siwalik Gr. Gaj Fm.
	Oligocene		Nari Fm.
	Eocene	Sakesar Lst.	Kirthar Fm. Ghazij Fm.
	Paleocene	Nammal Fm. Patala Fm.	Pab sandstone
MESOZOIC	Cretaceous		Mughal Kot Fm. Parh Fm. Guru Fm. Sembar Fm.
	Jurassic	Samana Suk Fm. Shinwari Fm. Datta Fm	Chiltan Fm. Shirinab Fm.
	Triassic	Kingriali Fm. Tredian Fm.	Wulgai Fm.
Paleozoic	Permian	Zaluch Gr. Nilawahan Gr.	
	Cambrian	Jhelum Gr. Salt Range Fm.	
pC	Precambrian	Kirana Fm	

Orogenic Episode	I	Palaeocene-Eocene
Orogenic Episode	II	Upper Eocene
Orogenic Episode	III	Early Middle Miocene
Orogenic Episode	IV	Late Miocene-Pliocene
Orogenic Episode	V	Pleistocene till now

This vast fold belt (1250 km long and 75 to 180km wide) has a faulted contact with the central axial belt to the west, whereas towards south and east its folds gradually loose their amplitude and merge with the fore-deep zone under the Punjab Plain (Fig. 3)

The major collision in the area of the present Sulaiman and Kirthar province took place during Palaeocene times (D. Bannert et al, PR 1988) while the huge shear zone in the area comprising of various transform and wrench faults developed as a result of the third tectonic episode (Wang et al., 1996). During this tectonic event a fore-deep basin also started developing along the eastern margin of Sulaiman Range. In the northern and central part of the fold belt there are extensive high angle thrust faults such as the Ziarat, Khalifat, Mekhtar, Kohlu and Barkhan thrusts (Fig. 2). The fold belt contains several large NW and NNW trending strike slip faults along its eastern and western margins respectively. Most significant among these are the right lateral Harnai and Tatra faults along the western margin while the left lateral Kingri, Chaudhwan, Domanda, Sulaiman and Mughal Kot faults were developed along eastern margin (Fig. 2).

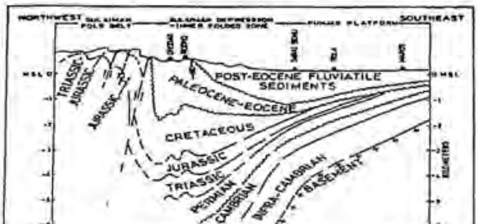

Fig. 3. Regional Cross-Section, Sulaiman Region after Raza et al., (1989).

The foreland basin, developed along the eastern flank of Sulaiman Fold Belt, controlled the initiation and development of the Paleo-Indus river system as well as the formation and lay out of the famous fluvial facies, the sub-molassic formation i.e. the Siwalik Series. The Episode–IV is characterised by a strong compressional movement, which led to the up-warping of the Girdu anticline. This anticline provided detritus for the development of Chaudhwan Formation. During this period the Barthi-Baghal Chur-Sakhi Sarwar synclines between Girdu and Zinda Pir anticline started to develop (Fig. 4). The episode-V of the Himalayan orogeny is characterised by multiphase integral uplifts that resulted in the formation of multilevel terrace geomorphological landscape (Photo 1 & 2).

NEOTECTONICS

The neo-tectonic activity in an area is assessed on the basis of structural disturbances in recent to sub-recent sediments. The detailed study of these deposits has been carried out considering the following features;

i. Traces of faults
ii. Truncation of strata
iii. Angularity of the bedding plane
iv. Joints/fractures
v. Faulted contacts of Recent deposits with older rocks

These studies indicate whether the area has undergone any fresh deformation or not. According to the modern perception such studies should engulf the events within a time period of 35000 years from the present day, because it is considered that recurrence of any deformation event within this period in an area represent active tectonism that ranks an area unstable (IAEA Guide 50-SG-S-1, 1991).

The study area comprises high dipping rocks of Siwaliks and earlier ages, rising abruptly from the Punjab plains. This abrupt uplift and the subse-

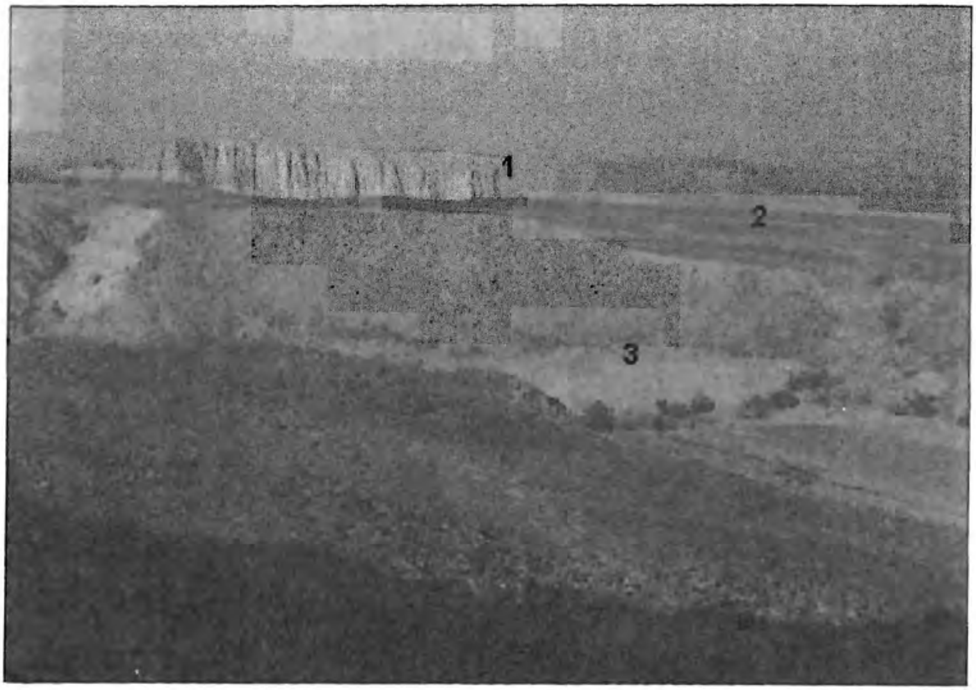

Photo 1. Terrace Levels at the Mouth of Vidor Nala

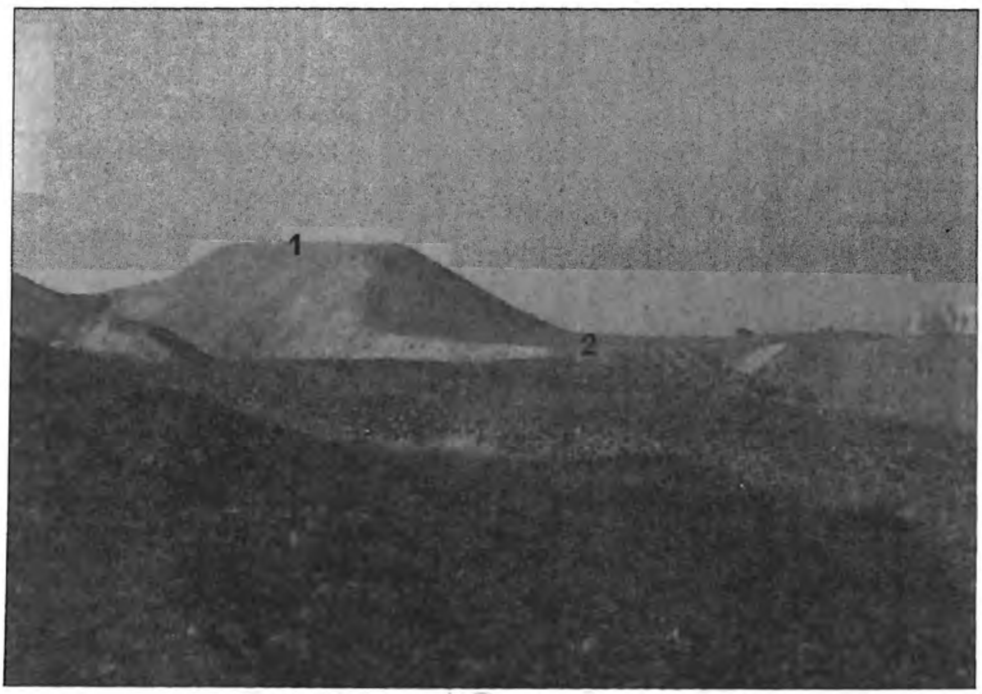

Photo 2. A View of Terrace Levels in the Background

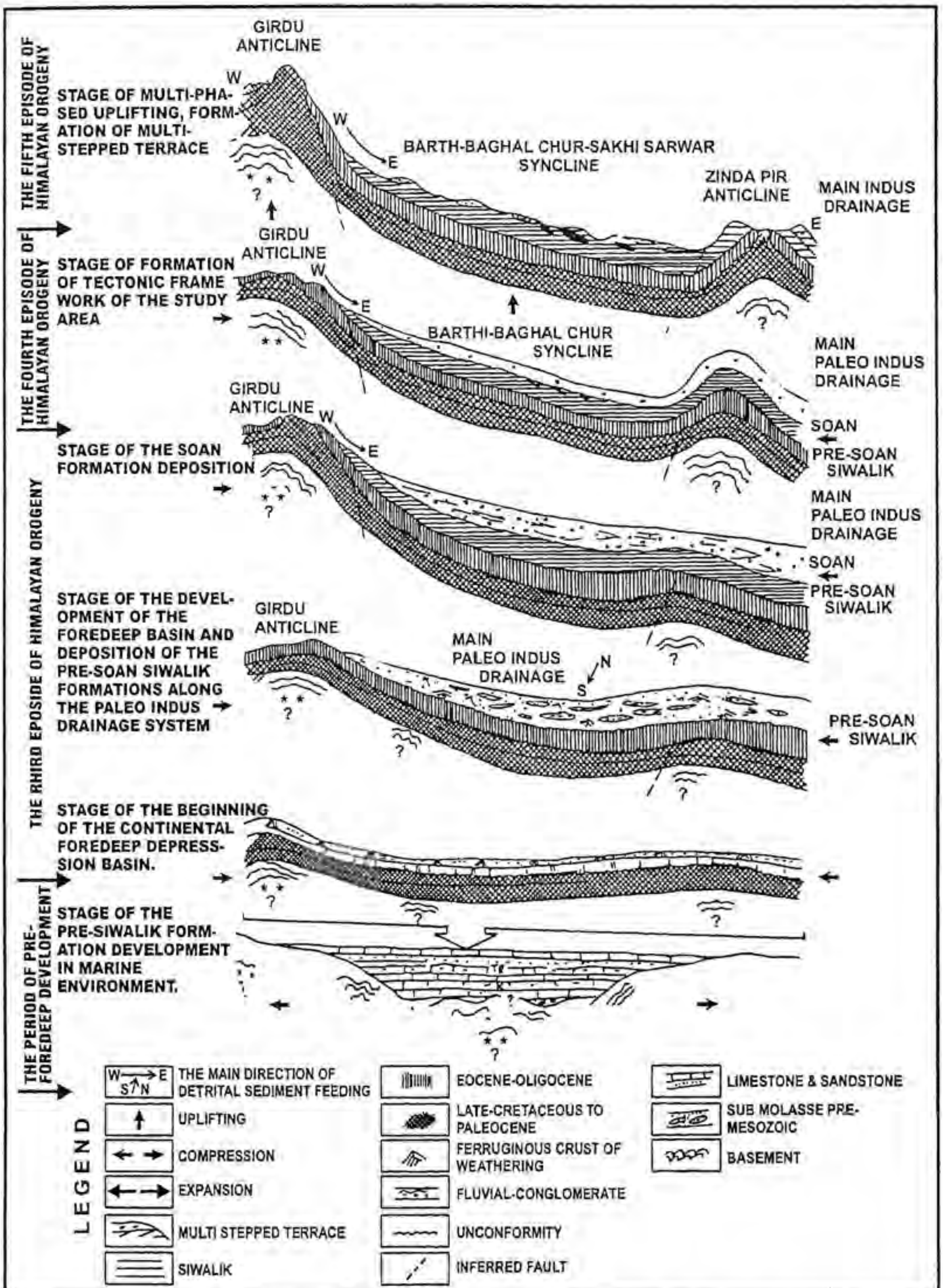

Fig. 4. Conceptual diagram illustrating tectonic evolution of the Sulaiman foreland and Zinda Pir anticline (after Wang et al. 1996). Not to scale.

quent erosional processes caused development of alluvial fans, along the foothills. Furthermore, 3 to 4 levels of boulder terraces are also observable within the study area, which indicate episodes of upheaval, interrupted by periods of relative stability. Scores of faults, fractures and joints are associated with Siwalik exposures within this area but the continuity of such structural deformations in the terrace, talus creep deposit, conglomerate deposit or Recent/sub-Recent alluvial fans can possibly determine the neotectonics for the subject area.

A very thorough study of these Recent/ sub-Recent deposits have been undertaken in order to ascertain the presence of any neotectonic feature so as to assess the status of the area. These studies were conducted in the following deposits in the area.

i) Talus creep along high dipping cliff forming rocks of Dada Conglomerates and Drug Limestone
ii) Terrace conglomerate deposits
iii) Recent/sub-Recent Alluvial Fan Deposits
iv) Surface Ruptures
v) Flood-plain Deposits

Talus creep deposits

These deposits are confined to escarpment slopes and are found as heaps atop the resistant cliff forming rocks of limestone and indurated Dada Conglomerates. This debris like talus deposits developed as a result of physical weathering of the rocks due to seasonal and diurnal temperature ranges and/ or severe shearing due to structural disturbances produced by the seismic events. Due to their unindurated nature such deposits are incapable of recording any proof of the neotectonics, as such the same are not helpful in such studies in this area. In study area, talus deposits indicate a normal wear and tear process as a major cause of their development rather than shattering of rocks by some tectonic process.

Terrace conglomerate deposits

Along the foothills of Sulaiman Range, low lying, high dipping sequence of Middle Miocene age is often seen overlain by flat lying boulder conglomerate rocky terraces. These terrace deposits were presumably developed during the last phases of the Himalayan Orogeny dating back to various episodes of Pliestocene age. The post Pliestocene rocks of the Sulaiman Range experienced abrupt uplift under the influence of EW compressional forces triggered by the northward push of the Indian Plate. The rocks in the core areas of Sulaiman Range attained high altitude due to which speedy erosion and denudation caused transportation and deposition of detritus from source to the top of the then peneplained fluviatile Siwalik sequence in the form of a blanket spread. Due to repetition of similar episodes 3-4 terrace levels were developed and are now found in the subject area. The oldest terrace levels occupy highest altitudes and are often seen tilted due to the proceeding episodes of uplift while later terraces are sitting undisturbed. The youngest terraces, in Dalana and Vidor nala localities are occupying a position roughly 10-15m above the present day stream level. It means that the stream cutting uplift episode is currently in progress.

Alluvial fan deposits along Vidor, Dalana and Sakhi Sarwar nalas

The main nalas in the vicinity of the subject area are Vidor, Dalana and Sakhi Sarwar. These streams empty their load in the plains during flash floods and have deposited a vast spread of alluvial fans at their mouths. These recent sediments cover the low-lying rocks of the uppermost Siwaliks and the adjacent plains. The alluvial fan deposits comprise of a mix of boulders, cobbles, pebbles, grit and sand released from the catchment rocks in these streams, due to the episode of flash floods caused by rainfall. The stream laid deposits also contain a small fraction of wind blown alluvial sand, which at places move in dunes. These deposits are un-indurated, hence, are not considered appropriate for neotectonic studies. The deposits were however, thoroughly studied and investigated for any rupture, dislocation or any recent movement in the sediments. It has been observed that all the sediments are lying undisturbed and no movement or dislocation has been noticed in them. Moreover, the movements/dislocation has also been studied in relation to the adjacent upper Siwalik rocks. Although the Siwalik rocks are intensely fractured, faulted and jointed but such features are never found to continue in the recent fan sediments. This indicates that the area is relatively calm since the deposition of the recent sediments.

Surface Rupture Studies

On the basis of observations made in various terrace deposits of the area as well as recent alluvium, found in the foot hills it has been observed that none of the faults, fractures or lineaments, which were located and traced in the exposed upper most beds of Siwaliks, more than 50000 years old, are seen truncating within the Siwalik strata itself. None of these structures are found to continue either in the horizontally laid terrace conglomerate of Dalana and Vidor area or the foothill alluvial deposits, which are lying horizontally without being disturbed (Photo 3-5). On the basis of the above observations it can be envisaged that none of the seismic event, generating from the active seismic zone of the area, within 100 km radius has caused any structural deformation to the rocks of recent times (less than 50,000 years age). As such the area can be considered safe in terms of active seismicity.

Flood Plain Deposits

D.G.Khan City is located over flood plain deposits of the Indus River. This flood plain received major load from north, while some contributions were also made by perennial streams draining the uplifting Sulaiman Range. The flood plain comprises alternate layers and lenses of sand and clay deposits with intermittent intercalation of stream channel conglomerates. At no place any trace of recent activity is observed in the form of fault scarp or raised benches in this monotonous alluvial plain. In some areas however, the houses have registered oblique fractures in walls that have been investigated. As a result of the investigation, it was revealed that this fracturing is due to differential setting of the fast deposited perennial stream load which could not register proper settling due to lack of time factor. None of the fracturing or shearing activity has been reported from the area which could be attributed to any tectonic event dating back to35000 years (IAEA Guide 50-SG-S-1, 1991).

SEISMIC POTENTIAL OF THE AREA

Relative movement between the Indian and Eurasian Plates has been considered to be responsible directly or indirectly for most of the seismic activity observed in Sulaiman Seismic Zone by nearly all research workers. (Quittemeyer et al, 1984). This zone is also known as Kirthar-Sulaiman Shear Zone. This zone covers the entire Sulaiman fold and thrust belt and is characterized by shallow earthquakes of moderate to high magnitude (5-7). It can be seen from Fig. 6 that at present it is most seismically active region within Pakistan where shallow seismicity is being experienced. This region is comprised of a series of thrust faults. However, as is evident from the figure, it is the western sections of the thrust faults that are more active as compared to the eastern sections. The shear zone, which is also referred to as Quetta-Sibi syntaxis or Quetta Transverse Zone, is bounded in the west by the left lateral strike slip fault zone of Kirthar fold belt while it is bounded by the oblique faults of the Sulaiman Range towards NE. It is an inverted extensional basin with high angle (45° – 55°) reverse faults (Ahmad and Ali, 1991), existing in an arcuate manner almost parallel to each other. This is a logical explanation in the particular scenario where the Indian Plate is moving northward dragging along the adjacent structures due west. Most of the recent events of 5-7M are linked with this mega

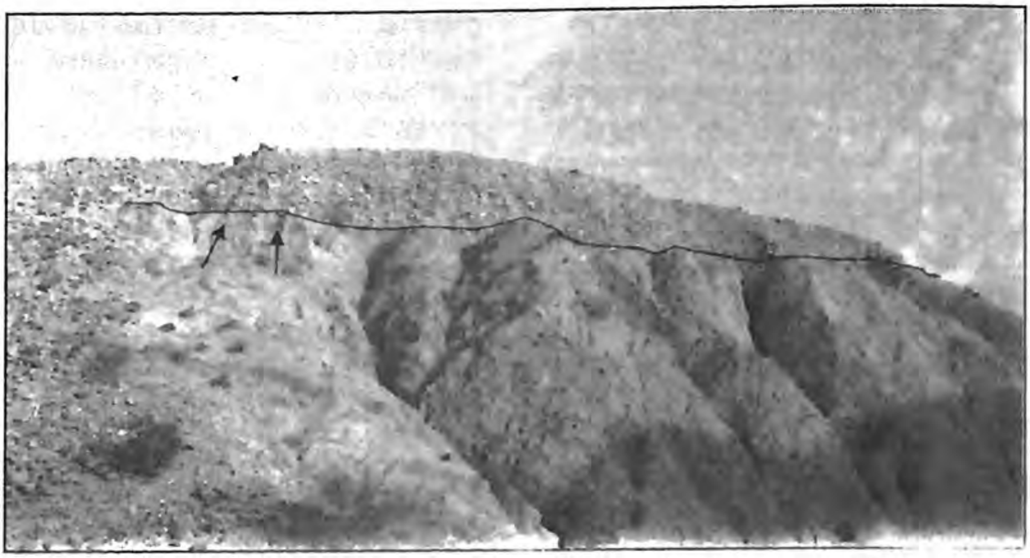

Photo 3. Fractures in the Underlying Siwaliks do not Continue in the Overlying Boulder Terrace

Photo 4. Fractures in the Underlying Rocks do not Penetrate the Terrace Cover

Photo 5. The Cracks/Joints of the Litra Formation do not Penetrate the Boulder Cover

structure. It has been broadly divided into the following seismic belts (Fig. 2).

1. Harnai Kohlu High Seismic Belt
2. Harnai-Sharigh Seismic Belt
3. Loralai Mekhtar Seismic Belt

Harnai-Kohlu High Seismic Belt

It is an arcuate, 25 to 50 km wide belt located about 70 km southwest of the study area. It follows the general EW orographic and structural trend and lies between the Gumbaz valley to the north and the Kaha valley to the south (Fig. 2).

From Khost, in the west, this belt extends 250 Km eastward upto Rakhni and is bounded by the Khalifat fault towards north, the Tatra fault in the south and the Kingri fault due east. This high seismicity belt contains a number of large NE, EW and NW trending thrust faults. Major thrusts of this belt include Karahi thrust, Karmari thrust and Pir Koh thrust (Fig. 6, 7).

The seismicity in this belt may be attributed to the movement of a single continuous fault or a number of smaller faults (Quittmeyer et al 1984). The interpretation of 'P' waves indicate that earthquakes of Jan-24, 1966 and Feb-7, 1966 (Fig. 8) were associated with the strike slip motion in a left lateral sense along a north-northeasterly trending nodal plane (Nowroozi, 1972).

Nowroozi inferred that the earthquakes were related to left lateral shear within the Sulaiman Range. A close examination of the distribution of after shocks of the earthquake on Feb- 7, 1966 (event 10, Fig. 9) suggests that Kingri fault is seismically active. Epicentres for activity (after shocks), over the next 3 months of this probable seismic event, fall very close to the surface trace of the Kingri fault (event 16-21, Fig. 9).

On Jun-26, 1999 a moderate level earthquake (M=5.5) occurred in this region i.e. the eastern part of the seismotectonic province, near the town of

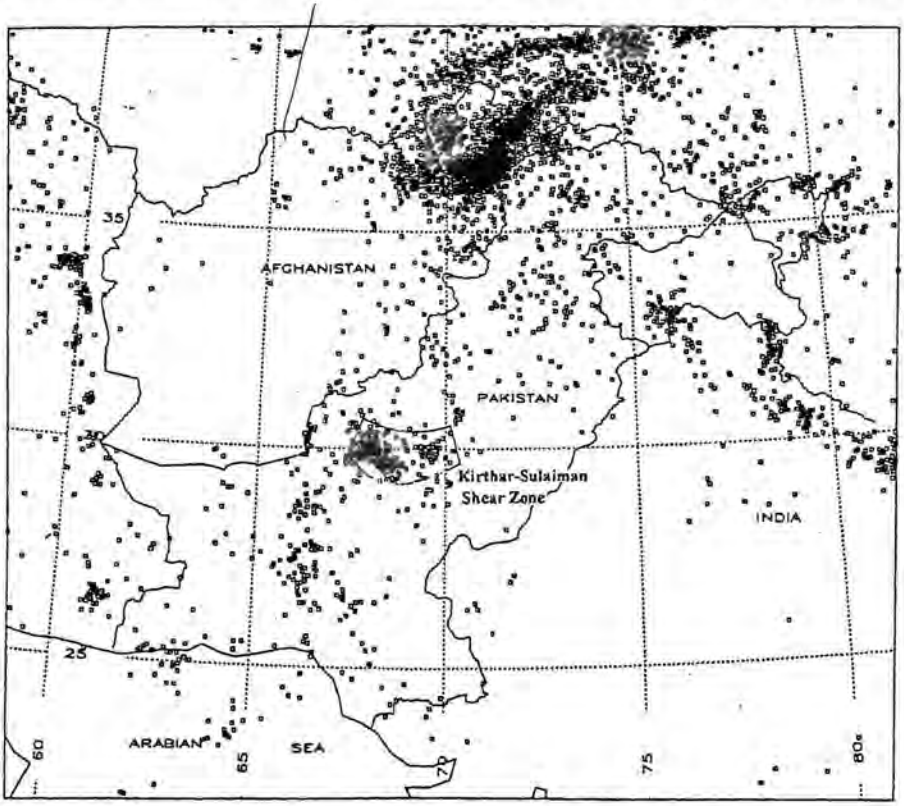

Fig. 5. Seismicity of the Kirthar-Sulaiman Shear Zone (Outlined) 1900-Apr, 1999 (After Khan et al 1999)

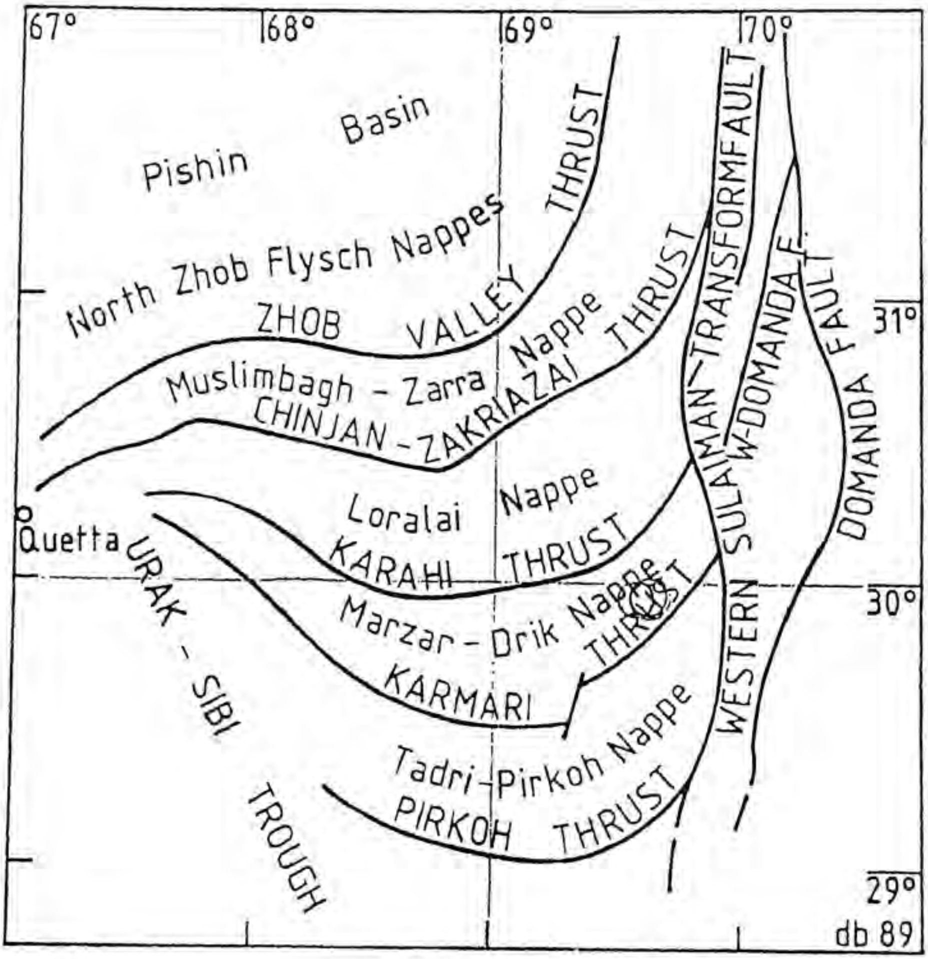

Fig. 6. Tectonic units of the Marri Bugti Hills and Sulaiman Anticlinorium (after Bannert et al, 1989)

Barkhan. It was followed by 41 after shocks of magnitude about 2.0 upto Jun-30, 1999. On Jul-12, 1999 the region was again shocked by another earthquake of magnitude 5.5 with epicentres located at almost the same location. This earthquake was followed by 46 after shocks of magnitude > 2.0 upto Jul-31, 1999. Depths of both the earthquakes are less than 10 km (Khan et al; 1999). The two main shocks and after shocks are plotted in relation to local tectonics in Fig. 10. The earthquakes and after shocks seem to lie on the eastern part of the Karmari thrust (Fig. 10).

The spread of aftershocks indicate NE-SW trending rupture plane, which coincides with the eastern section of the Karmari thrust (Fig. 10).

Harnai-Sharigh Seismic Belt

This belt is located about 200km WSW of the site area, in the vicinity of Harnai fault. It is characterized by a cluster of recent seismic events along two narrow, N S trending, 180 km long bands along the eastern and western margins of the main Sulaiman range (Fig. 2). These high seismicity bands coincide with left lateral active faults and lineaments

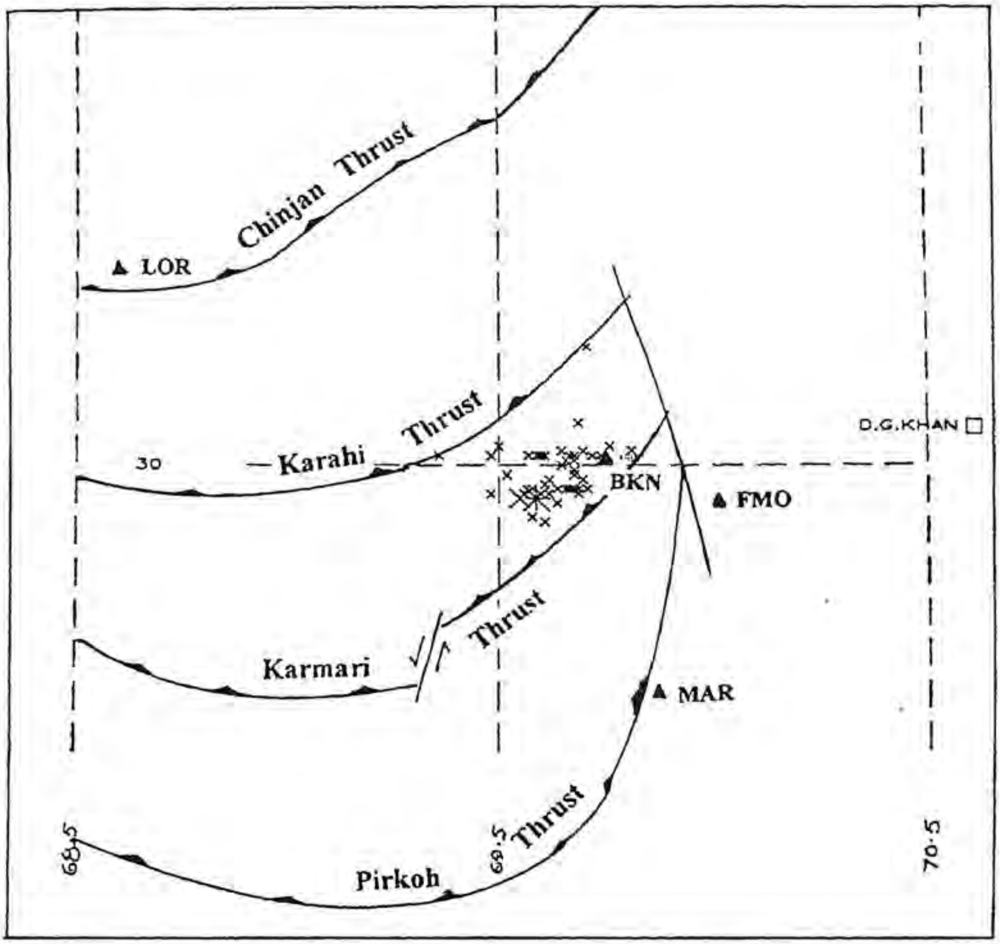

Fig. 7. Barkhan Earthquake of June 26, 1999 and afterschoks (After Khan et al., 1999). Bkn-Barkhan.

(Gawad, 1971, Kazmi 1979). This region is affected by Aug, 1966 earthquakes (events 24, 25, 27, 28, 30, 31, 32 & 34 of Fig. 9). Here, both the strikes of the nodal planes for one of the foreshocks, in the distribution of the aftershocks, suggest that the rupture zone has the same orientation as the structures observed at the surface i.e. approximately EW. Another severe earthquake shook the region on Feb-27, 1997 near the town Harnai. The main shock of magnitude 6.2 was followed by 50 aftershocks with magnitude more than 3.5 within five hours. The epicentre was located at 29.84° N, 67.38° E, at a depth of less than 10 km (Khan et al; 1997). The main shock was followed by a train of aftershocks. In three weeks time, 240 aftershocks of magnitude less than 3.5 were recorded. The main shock and aftershocks are plotted in figure 11 a & b. The aftershocks of magnitude as low as 3.0 are plotted in Fig. 11b where as in Fig. 11a, earthquakes of magnitude 4.0 and above are shown. Fig. 11a shows the main rupture area of roughly 110x22 Km spreading out in NW-SE orientation. Fig. 11b shows the movements on other smaller faults in the vicinity, which occurred as a result of the process of stabilising the area. This creates a complex picture. The distribution of the aftershocks sequence (Fig. 11 a & b) indicates NW-SE orientation of the rupture plane, which is in accordance with the existing tectonic setting.

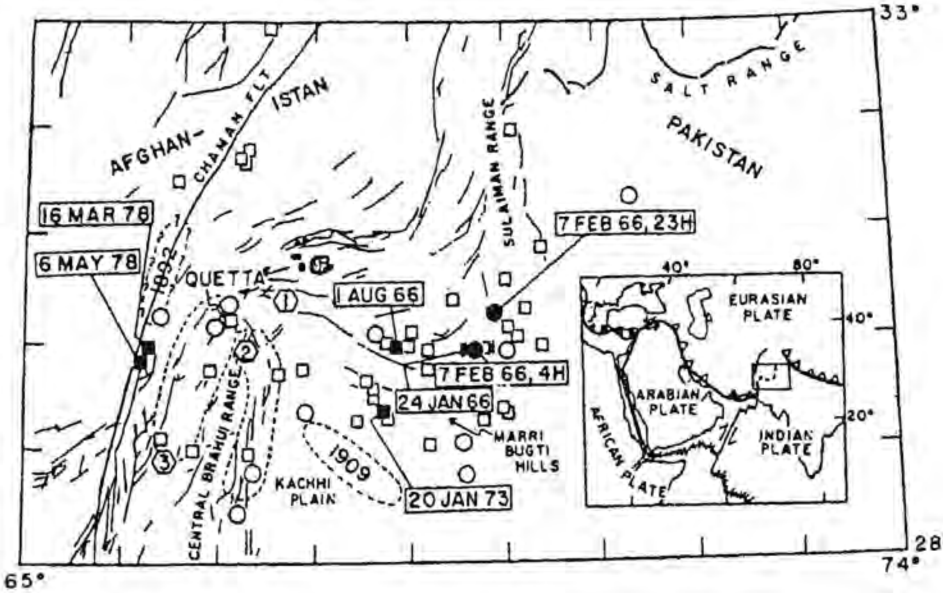

Fig. 8. Regional tectonic setting for central Pakistan. Earthquake with magnitude greater than 5 from Jan, 1914 through Apr, 1975 (Quittmeyer and Jacob, 1979) are represented by the following hexagon, 8>M<7; circle, 7>M<6; square, 6>M<5

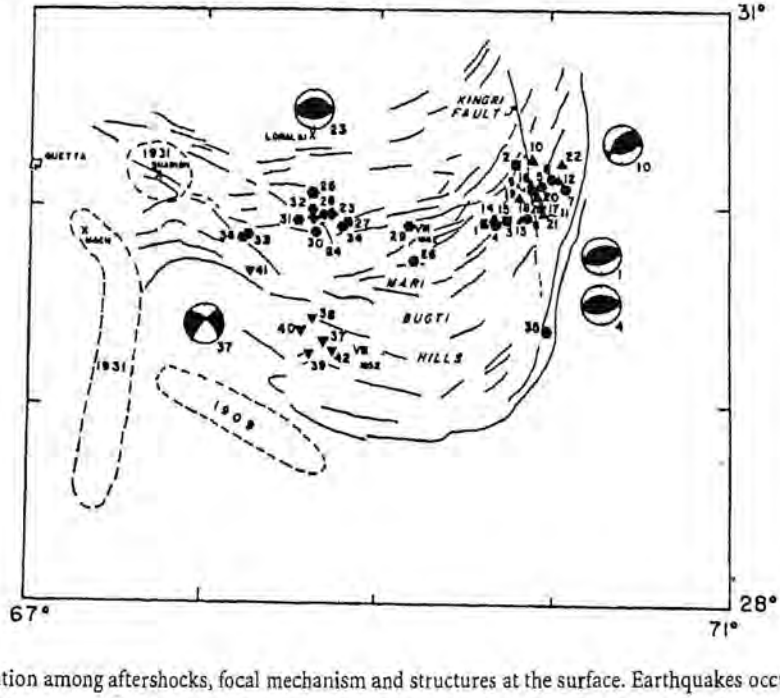

Fig. 9. Relation among aftershocks, focal mechanism and structures at the surface. Earthquakes occurring in 1966 and Jan-Apr, 1973 are shown. The earthquakes are numbered sequentially. (Quittmeyer et al 1984)

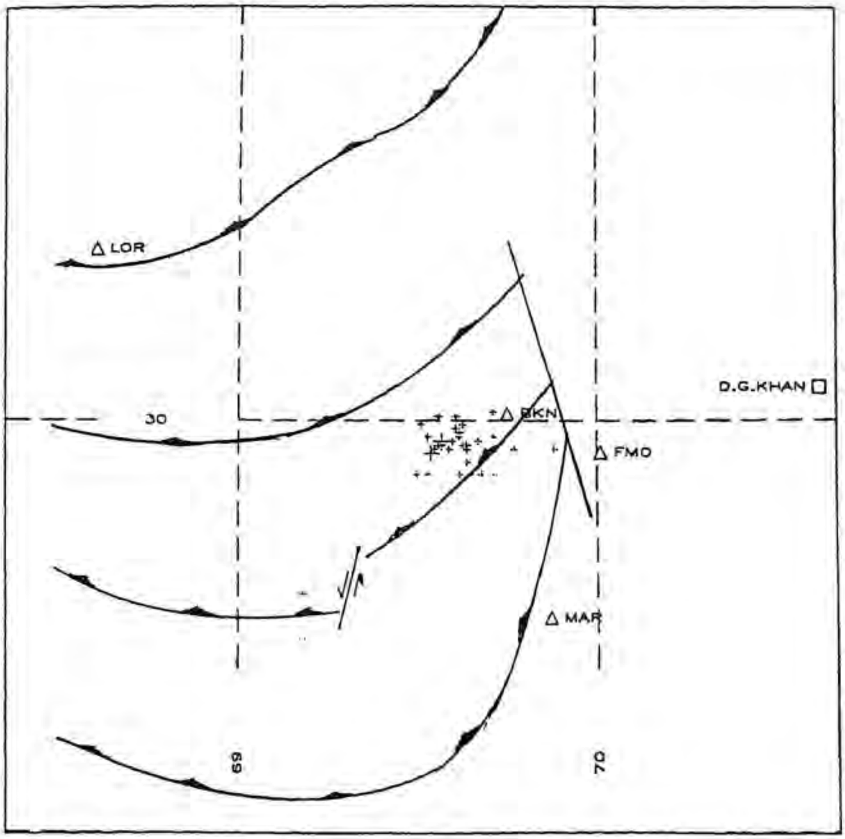

Fig. 10. Barkhan Earthquake of July 12, 1999 and aftershocks (After Khan et al 1999)

Loralai-Mekhtar Seismic Belt

North of the Harnai Sharigh seismic belt, exists another narrow, arcuate zone of high seismicity along the Loralai-Mekhtar valley located about 140km west of the area. It is characterized by shallow (<50 km), 3-6 magnitude events, which have been attributed to the active Mekhtar fault (Kazmi 1979). In other areas of the Sulaiman Seismic Zone, the seismicity is diffused as indicated by the wide spread epicentres (Fig. 2).

EVALUATION OF SEISMIC RISK

Maximum potential earthquake

The maximum earthquake generating capability of an earthquake source is determined on the basis of seismological and geological data. Factors like seismicity (historical & instrumental) and characteristics of geological structures (e.g. slip-rate-magnitude, rupture length-magnitude, displacement–magnitude, paleoseismic data) are considered. However, such data is not completely available in the developing countries and the maximum potential capability is determined on the basis of physical characterization of the structure/fault and limited seismological data.

For assessing the maximum potential capability of known faults in the vicinity of D.G.Khan, rupture length relations developed by Bonilla (1984) and Slemmons (1989) were used. These regression analyses permit the determination of surface wave magnitude (Ms) from rupture lengths of different

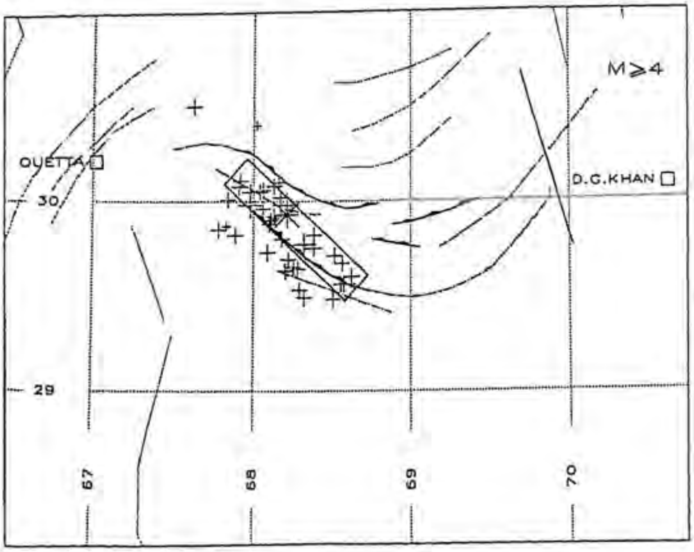

Fig. 11a. Earthquakes of M=4 and above (Barkhan) (After Khan et al 1997)

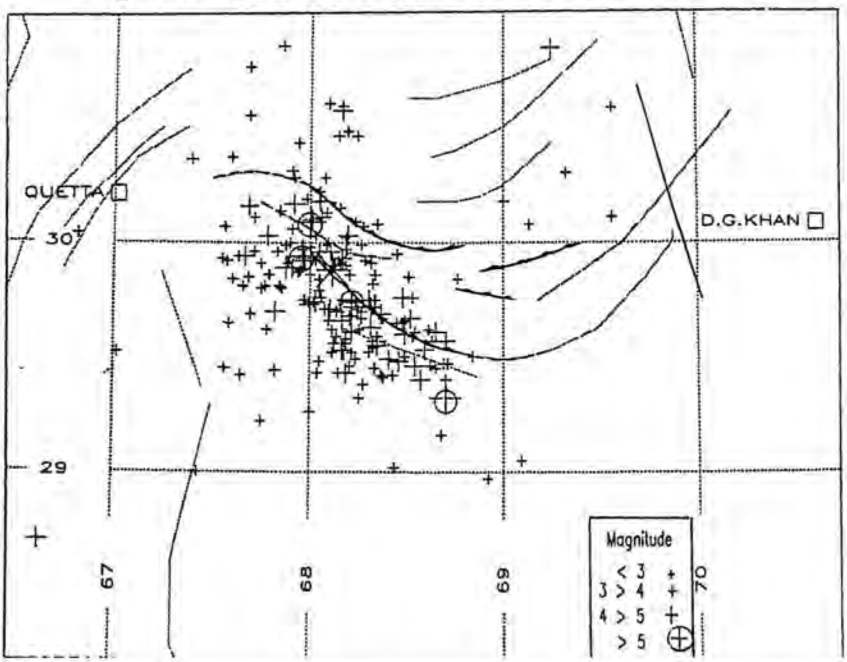

Fig. 11b: Barkhan Earthquake February 27, 1997 (After Khan et al 1997)

types of faults. The maximum potential earthquakes for the identified faults in the site region were estimated by considering 50% fault-rupture during an earthquake and the mean values determined through these relations were used.

Assessment of peak acceleration

The peak ground acceleration and shape of spectrum at a site is dependent on the magnitude, epicentral/hypocentral distance, intervening medium and the local site conditions. Site acceleration values are usually calculated using the impirical attenuation relations developed from actual records for different regions of the world. As sufficient strong ground motion data is not available for the Pakistani sites, it was not possible to derive the site specific impirical relation. As such attenuation relations developed for different regions of the world were studied and most suitable ones, rich in database have been used.

Campbell (1997)

The equation developed by Campbell (1997) is applicable for:

i) The larger horizontal component of peak acceleration should be at least 0.02g.

ii) The moment magnitude should be equal or greater than 5.0.

iii) Valid for near field earthquakes (less than 60 Kms)

iv) Focal depth is less than 25 km.

v) Accounts for soil, soft rock and hard rock.

vi) Style of faulting – strike slip reverse & thrust.

$$\ln (A_H) = -3.512+0.904\ M$$

$$-1.328\ \ln\sqrt{R_{SEIS}^2 + [0.149\ \exp\ (0.697M)]^2}$$

$$+[1.125-0.112\ln\ (R_{SEIS}) -0.0957M]\ F$$

$$+ [0.440-0.171\ \ln\ (R_{SEIS})]S_{SR}$$

$$+ [0.405-0.222\ \ln\ (R_{SEIS})]S_{HR} + \hat{I}$$

Where A_H has units of g, Î is standard deviation, R_{SEIS} is shortest distance (km) to the zone of seismogenic rupture, M is magnitude, F=0 for strike Slip, = 1 for reverse/ thrust faults, $S_{SR}=1$ & $S_{HR}= 0$ for soft rock.

Sadigh et al., (1997)

The equation developed by Sadiqh is applicable to :

i) Shallow crustal earthquakes (20-25 km)

ii) Valid for soils and rock sites

iii) Relationships are for strike slip and reverse faulting earthquakes

iv) Earthquakes of moment magnitude M4 to 8+

v) Distances up to 100 Kms.

vi) Acceleration increased by 20% for reverse/ thrust

$$\ln(y) = C_1 + C_2M + C_3\ (8.5M)^{2.5} + C_4\ \ln\ (R\ rup + \exp$$

$$(C_5 + C_6M) + C_7\ \ln\ (R\ rup + 2)$$

Table: 2

Peak Ground Accelerations at D.G. Khan due to different Seismogenic Structures

Seismogenic Structure	Maximum Potential Magnitude	Closest Distance (Km)	PGA (Mean value) 'g'	
			Campbell 97	Sadigh 97
Chaudhwan	7.6	80	0.06	0.06
Domanda	7.5	78	0.06	0.06
Kingri	7.4	45	0.11	0.11
Barkhan	7.6	46	0.14	0.15
Mekhtar	7.4	140	0.02	0.02
Kohlu	6.8	86	0.03	0.02
Floating	6.0	20	0.11	0.11

Where Y is peak horizontal acceleration, M is moment magnitude, R rup is the closest distance to rupture surface and values of C1, C2, C3, C4, C5, C6, C7 and standard deviation are given in Ref: 7.

Design Basis Earthquake Ground Motion

The site accelerations from different seismogenic structures/ faults have been estimated using the attenuation relations of Campbell (1997) and Sadigh (1997).

The postulated magnitude for each seismogenic structure/fault alongwith maximum-recorded magnitudes are given in Table 2.

The estimated 'g' values (mean) at the subject area are shown in Table 2 for the seismogenic structures/faults and floating earthquake. The estimated accelerations vary from 0.02g to 0.15g. As such, 0.15g is proposed as the zero period acceleration value for the subject area.

REFERENCES

Ahmad. R. & Ali. S.M. 1991 Tectonic and Structural Development of the eastern part of Kirthar fold belt and its hydrocarbon potential. Pakistan Journal of Hydrocarbon Research, 3, 19-31.

Bannert, D., A. Cheema, and A. Ahmad, 1989. Interpretaion of Landsat-MSS Imagery of the Sulaiman and Kirthar Mountain Ranges in western Pakistan: A technical report of a co-operative project between Bundesanstalt fur Geowissenschaften und Rohstoffe, Hannover, West Germany and Hydrocarbon Development Institute of Pakistan, Project No.83.2068.1,49P.

Bonilla, Bull. of BSSA, Vol-74. No.6. PP-2379-2411, Dec-1984.

Campbell and Sadigh. Jan-Feb (1997) Research letter Vol-68 No.1 Seismological Society of America.

Kazmi, A.H., 1979. Active fault systems in Pakistan, in Geodynamics of Pakistan, edited by A. Farah and K. Dejong, PP. 285-294, Geological Survey of Pakistan, Quetta, Pakistan 1979.

Kazmi, A.H., & Jan, M.Q 1997. Geology and Tectonics of Pakistan, Graphic Publishers, Karachi, 513 p.

Khan. S.A, Mahmood. T, and Qaiser. M, 1992. Sibi, Baluchistan Earthquake of February 27, 1997. Micro Seismic Study Programme Report No.MSSP-50/97 May, 1997. Pakistan Institute of Nuclear Science and Technology Nilore, Islamabad.

Khan, S.A., Qaiser. M., & Khan, K. 1999. Sources Parameters of the Barkhan Earthquakes of June 26 and July 12, 1999. Micro Seismic Study Programme Report No.MSSP-54/99 August, 1999 Pakistan Institute of Nuclear Science and Technology Nilore, Islamabad.

Nowroozi. A. 1972. Focal Mechanisms of Earthquakes in Persia, Turkey, West Pakistan, and Afghanistan and Plate Tectonics of the Middle East, Bull. Seismol. Soc. Am.62(3)823-850.

Quittmeyer, R. C., Alan L. Kafka, and John G. Armbruster 1984. Focal Mechanisms and Depths of Earthquakes in Central Pakistan: A Tectonic Interpretation. Journal of Geophysical Research, Vol-89, No.B4, Pages 2459-2470, April 10.

Quittmeyer, R. C., and K.H. Jacob 1979. Historical and Modern Seismicity of Pakistan, Afghanistan, north-western India and southeastern Iran, Bull. Seismol. Soc. Am., 69, 773-823.

Raza H.A., Ahmed.R, Alan.S., & AN. S.M, 1989, Petroleum Prospects: Sulaiman Sub-Basin, Pakistan. Pakistan Journal of Hydrocarbon Research.

Sadigh, K., Chang, C.Y., Egan, J.A., Makdist, F. & Youngs, R.R. 1997. Attenuation relationships for shallow crustal earthquakes based on California strong motion data. Seismological Research Letters, vol. 68, 1.

Wang Z., Tang S., Chen. D., Lins. S., and Nie. F. 1996 Basic Geological Studies and Preliminary Evaluation of Uranium Potential of Siwaliks in the Middle Part of Sulaiman Mineral Belt Pakistan, an Internal Report of PAEC Dera Ghazi Khan.