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Earthquakes and the Neo-Tectonic Framework of the Kutch-Hyderabad-Karachi Triple Junction Area, Indo-Pakistan

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ABSTRACT

In order to better understand its components and the associated seismic risk, the tectonic framework of Kutch, Hyderabad, and Karachi triple junction area is considered. It is proposed that a major active graben, named the Hyderabad graben, underlies the Karachi arc, and extends eastward under the Indus alluvial cover. The boundary faults of the Hyderabad graben control the boundary faults of the Karachi arc on its northern and southern ends.

The Hyderabad graben contains the Luni-Sukhri River lineament and runs parallel to the Kutch graben on its north side, with the Nagar Parker uplift acting as the divide. Both grabens trend eastward, converge in the vicinity of Ajmer, and swing to the north as a prominent lineament. This lineament cuts across the Himalayan foot hills. Both grabens are actively subsiding under the tremendous Indus load, a process that may contribute to the eastward creep of the Karachi arc and also enhance the overall seismic risk.

The dynamics of the active Karachi triple junction (KTJ), ancient but active rift structures, river sediment loading, along with the ongoing plate collision in the north, are some of the complex factors that control the tectonics and seismicity of the entire region.

Due to the presence of major population centers within the subject area, that already has a disastrous seismic record, the importance of close monitoring, enforcing strict building codes, and further research, cannot be over emphasized. The study of known and hidden rift structures may also lead to the discovery of additional energy resources.

INTRODUCTION

The 7.7 magnitude Bhuj earthquake of January 26, 2001, killed over 20,000 people, injured hundreds of thousands, and did billions of dollars in property damage. Its epicenter was located 80-90 kilometers east of the city of Bhuj along the eastern end of the Kachchh fault, a vertical to high angle normal fault that changes upwards into a high angle reverse fault (Malik et al., 2000). According to a United States Geological Survey website report, the earthquake occurred due to thrust movement at a shallow depth of less than 25 kilometers. The Bhuj earthquake was just the latest calamity in a disaster prone area. Therefore, there is an urgent need for a better understanding of the neo-tectonic framework of the entire region that includes major population centers both in India and Pakistan. The present study is a small step in that direction.

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TECTONIC FRAMEWORK

The tectonic framework of the area of interest (Figure 1) is defined by a collage of horsts and grabens that were originally formed during the Mesozoic rifting of India from Africa, Madagascar and Seychelles, and evolved during its subsequent drift to the north. Many of these structures are well defined on the Indian side, such as the Narmada, Kutch, and Cambay rifts and the Kathiawar horst, and are clearly visible on the satellite photographs. However, the situation is different across the border in Pakistan, where the rifted structures are masked by the Indus alluvium and collisional mobile belts of the Sulaiman- Kirthar ranges and the Karachi Arc.

It has been suggested (Wadia 1957, Biswas, 1982), that the Precambrian orogenic trends of peninsular India, such as the Dharwar (N-S to NNW-SSE), Narmada-Son (ENE-WSW), and Delhi-Aravalli (NE-SW to E-W), were very influential in defining the Mesozoic rifting of India from the rest of Gondwanaland. The author believes that this influence is reflected in the various rift trends also in Pakistan (Figure 1). Major tectonic features of the area under discussion are briefly described as follows.

Karachi Arc

The Karachi arc (Figure 1, the southern part of the Khuzdar-Karachi tectonic block), is a thin-skinned fold and thrust belt that is currently moving eastward, on decollement surface afforded by the Cretaceous Sembar-Goru shales (Sarwar and DeJong, 1979, Schelling, 1991). While the Karachi arc appears to be bounded on its north and south ends by tear faults, it was not known as to what controlled these tectonic boundaries. It now appears that the tear faults at both ends of the Karachi arc are controlled by the underlying Hyderabad graben, whose ongoing subsidence, as discussed below, may be contributing to the eastward creep of the Karachi Arc.

Hyderabad Graben

Modern satellite photographs clearly show that the east west running Kutch graben swings to northeast toward Ajmer, and narrows into a lineament that continues all the way to the Himalayas. It is probable that it actually links with the wrench faults that offset the Siwalik Hills west of Dehradun. Ramasamy et al.(1991) proposed that another feature, called the Luni-Sukhri River lineament, located

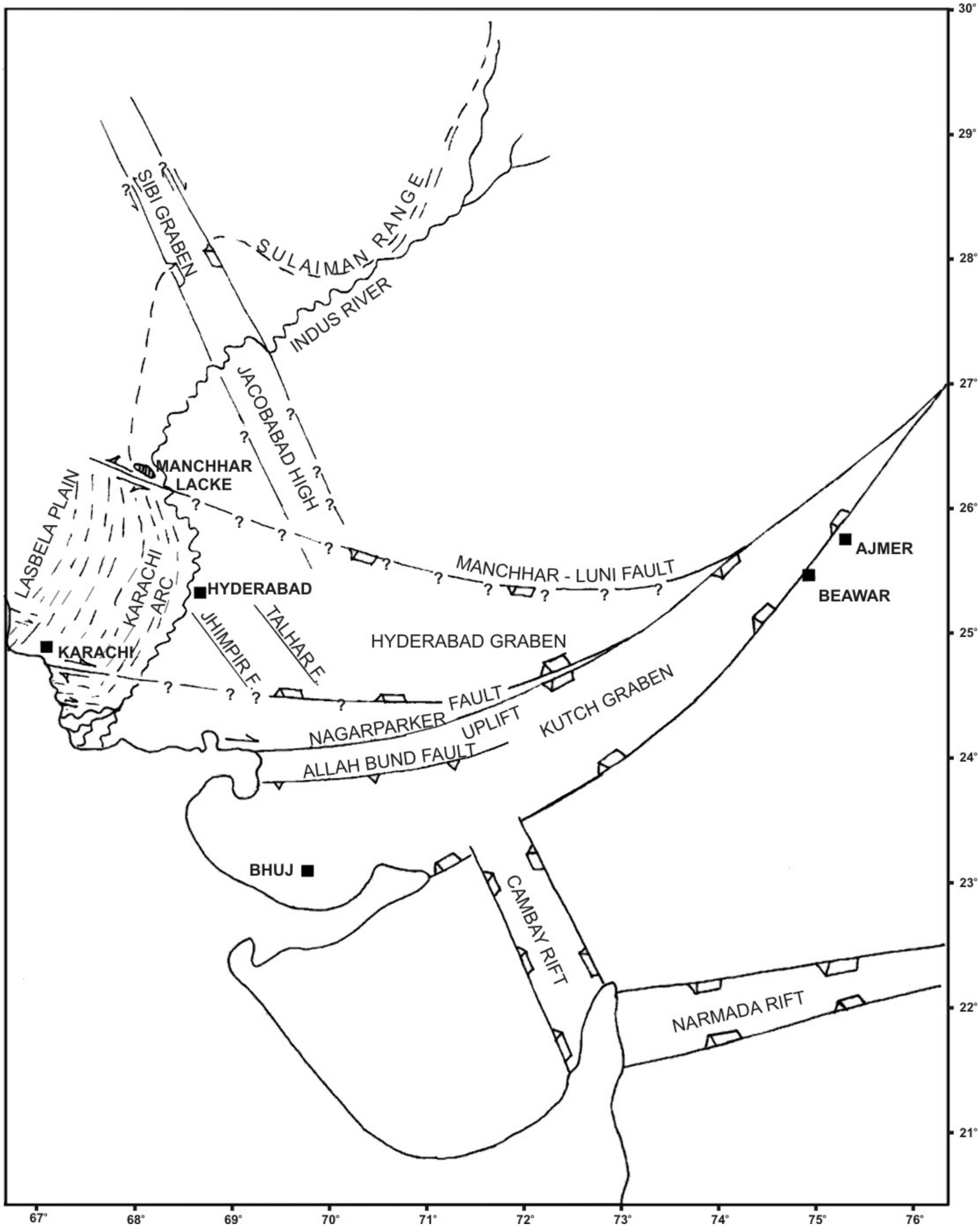

Figure 1- Schematic tectonic sketch map for the Kutch-Karachi area. The Manchhar-Luni fault runs along the northern edge of the Luni-Sukhri River lineament of Ramasamy et el., 1991. It forms the northern boundary of the Hyderabad graben proposed here.

southwest of Ajmer, also occupies an active graben. This graben runs parallel to the Kutch graben on its north side, and extends northward until it cuts across the Himalayan foothills as tear faults (Ramasamy et. al., 1991). It is clear from the satellite photographs that the Kutch and Luni-Sukhri grabens converge into a narrow structure in the vicinity of Ajmer (Figure 1) and continue as such northward.

It is intriguing that the southern end of the Luni-Sukhri River graben (Ramasamy et al., 1991, Figure 9) is aligned with the Karachi arc, located on the west side of the Indus plain. This may be little more than just a matter of coincidence. It is strongly suggested here that the Luni-Sukhri River graben most probably extends to the west below the Indus alluvial cover, and underlies the Karachi arc-Las Bela plain area. If that is the case, the tear faults on the north and south ends of the Karachi arc may be the surface expression of the boundary faults of this graben, named here the Hyderabad graben. Thus, the northern edge of the proposed Hyderabad graben runs along the Manchhar fault and (along the north edge of) the Luni-Sukhri River lineament, and the southern edge would run along the Kutch graben, on the north side of the Nagar Parker uplift (Figure 1). The Hyderabad graben, as defined here, extends from the Karachi triple junction east north east toward Ajmer and contains the Luni-Sukhri River lineament of Ramasamy, et al. 1991.

The Nagar Parker uplift or horst seems to separate the Hyderabad graben from the Kutch graben (Figure 1). It appears that these grabens actually form a large horst-graben complex containing several up warped and down warped areas within. Examples are the northwest trending oil field structures along the Jhimpir-Talhar faults in the Badin area, the northeast trending Thar coal fault (Fasset and Durrani 1994, with no coal on the up-thrown side to the east), and the structures described by Malik et al., (2000) from the Kutch graben.

Sibi Graben

The Jhimpir- Talhar faults seem to follow the NW-SE Cambay rift trend, which also extends to the Sibi graben that is wrapped around by the Quetta syntaxis (Figures 1 & 2). The Sibi graben or Sibi trough is filled with 15 kilometers thick strata of Triassic to recent age, the upper 7 kilometers of which is Siwalik molasses of Oligocene-Pliocene? age (HSC, 1961; Movshovitch and Malik, 1965; Sarwar and DeJong, 1979; Kazmi and Jan, 1997).

Southeast of the Sibi trough, reduced sedimentation during the Cretaceous and Paleocene indicate the presence of a structural swell (Jacobabad-Khairpur High; Figure 1; Bakr and Jackson, 1964; Meissner and Rahman, 1973). Regional 2D seismic profiles also reveal stratigraphic thinning and onlap relationships on the flanks of this uplift that seems to have subsided in the Early Tertiary. On the other hand, the Sibi trough that accommodated a 7 kilometers thick sequence of clastics during the Oligocene to Pleistocene period, has since been uplifted. This involved a tremendous amount of tectonic inversion, since it produced the 3580 meters high Zarghun peak, the loftiest in Baluchistan. This peak, constituted by the Pleistocene Dada conglomerate, forms the northwestern end of the inverted Sibi graben wedge that is fundamental to the origin of Quetta syntaxis (Sarwar and DeJong, 1979).

From the above it can be concluded that the Sibi graben has had a complex evolution, with various parts having been uplifted or down-warped at various times during its history. Flower structures interpreted from limited seismic data (Ahmad et.al, 1992), indicate that strike slip movements probably also took place along the Sibi graben. Preliminary field work northeast of Quetta (Sarwar, unpublished), also suggested the possibility of wrench movement along the shear cliffs of the Dada clastics that constitute the western flank of the rift fill. It is believed that lack of field study and subsurface data availability are the main problems, otherwise we would see tremendous strike slip movement along this zone.

Between the Sibi and the Hyderabad grabens the basement architecture is not clear. It is probable that there are additional wrench and/or rift structures hidden under the Kirthar mobile belt between Chaman fault and the Indus River (Zaigham and Mallick, 2000).

DISCUSSION

In the past, the eastward movement of Karachi Arc has been explained by a counter-clockwise rotation of the entire Khuzdar Knot-Karachi Arc block induced by the drag along the Ornach-Nal transform fault during the northward drift of the Indian plate (Sarwar and DeJong, 1979). This rotation was pivoted at the Khuzdar knot that suffered intense deformation as it rotated and developed swirling folds. The Karachi Arc, on the other hand, moved eastward as a system of folds and thrust faults, with its movement facilitated by decollement in the Cretaceous Sembar-Goru shales at a shallow depth of 3-4 kilometers (Schelling, 1991).

Other factors contributing to the eastward movement of the Karachi Arc may be the subsidence of the western end of the Hyderabad graben due to (at least in part) tectonic loading by the Karachi Arc, and sedimentary loading by the Indus sediments. In fact, the Indus system has responded to this by migrating westward throughout the Holocene (Ramasamy, et.al 1991), and now wraps around the Karachi Arc. This area is part of the greater Indus foreland basin that has evolved east of the Kirthar-Sulaiman mobile belt since the Paleocene collision along the Ornach Nal-Chaman fault boundary.

Although, due to dams and canals, the current load may be lower, the Indus has historically carried a sediment load of over 675 million tons per year (Milliman et al. 1984). This may well be an underestimate. However, it still is a tremendous load of sediment, part of which is bound to be trapped by the seismically active Hyderabad graben (Quittmeyer et al., 1979) that lies at the southern end of the Indus flood plain. The Indus has built a largely sub-aerial delta that is bigger than the Mississippi River delta, and has historically maintained a high degree of progradation (Wells and Coleman, 1984). Whatever load escapes from here, is delivered to the Kutch graben where it forms the proximal part of the Indus marine fan, that shows a maximum thickness of over 11 kilometers in that area. (Figure 1, Coumes and Kolla, 1984). Because of this loading, the western part of the Kutch graben has also subsided, whereas its eastern end has been raised. The resulting marine incursion has contributed to the wide spread salt flats in the Great Rann of Kutch.

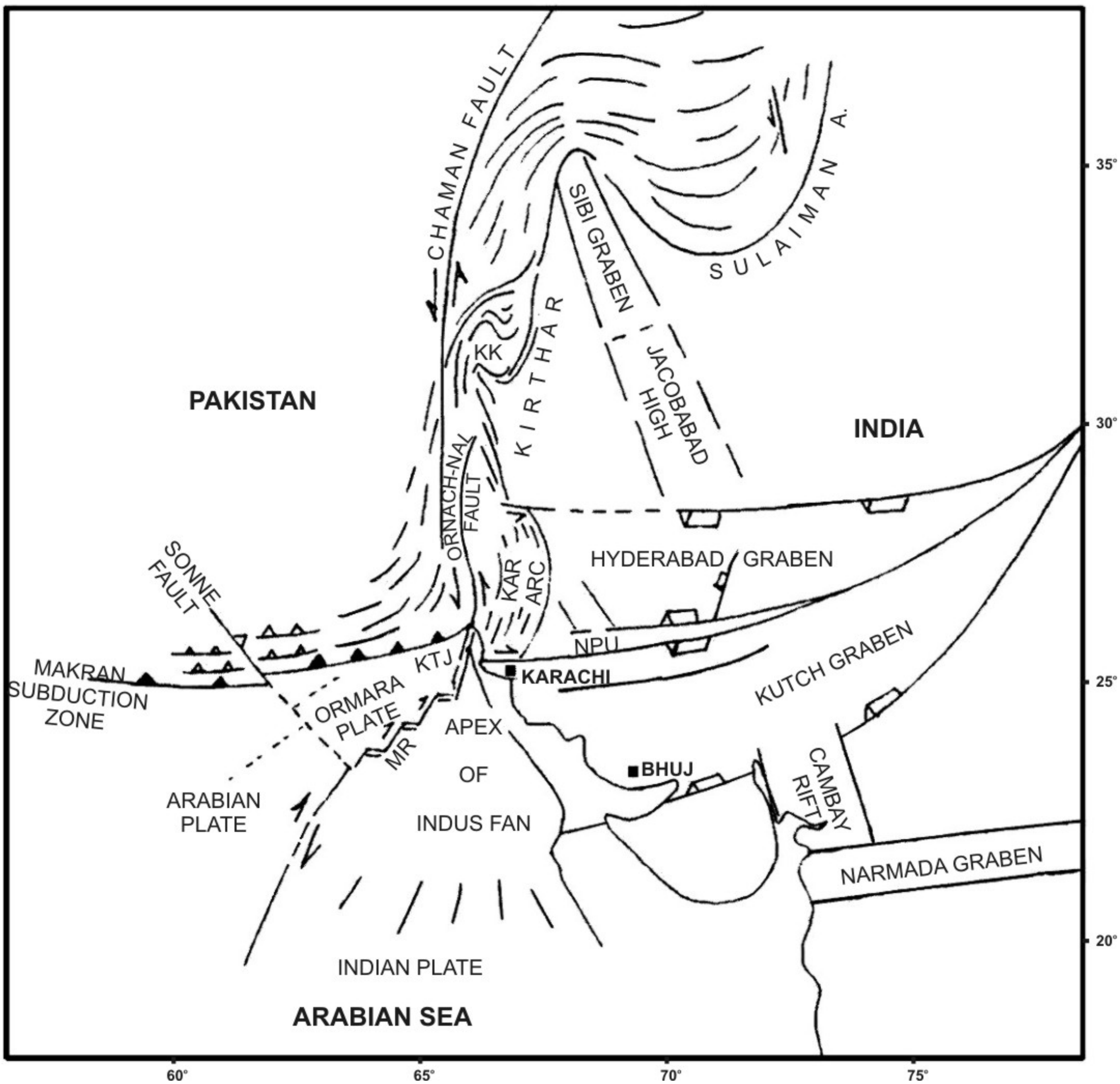

Figure 2- Schematic plate tectonic sketch map showing the Karachi triple junction (KTJ) and its tectonic environment. The Sonne transform fault is from Kukowski et al., 2000.
KAR. ARC: Karachi Arc, KK: Khuzdar Knot, DT: Dalrymple Trough, MR: Murray Ridge. NPU: Nagar Parker Uplift.

It is hard to quantify as to how much the Indus load has contributed to the subsidence and seismicity of the Kutch graben area which is supposed to be in a state of compression along a NE-SW direction due to plate collision (Bendick et al., 2001). Both the 1819 and 2001 Bhuj earthquakes have been linked to hidden reverse movements (blind thrusts) on shallow (less than 25 kilometers) faults that were initially normal.

In Pakistan, the seismicity of Karachi Arc and the Hyderabad graben seems to be subdued as compared to that of the Kirthar-Sulaiman belt to the north and the Kutch graben to the south (Quittmeyer et al., 1979). The Hyderabad graben has suffered only diffused and moderate (magnitude 4-6) seismicity whereas the other regions have suffered devastating earthquakes. It is suggested that the decoupling of the active Karachi Arc by the underlying decollement in the Cretaceous shales may be acting as a shock absorber. The NE-SW compressive stress field of the Bhuj graben (Bendick et al., 2001) is probably also relatively less effective in the thin-skinned Karachi Arc, which is moving eastward under its own east west compression.

Another factor that may be affecting the neo-tectonics of the area is the dynamics of the Karachi triple junction (KTJ, Figure 2). The western boundary of the Indian plate changes from a right lateral transform (OFZ, Figure 2) south of KTJ to a left lateral transform north of Karachi. This change would push the Ormara plate (Figure 2) into the west side of the Karachi Arc at the KJT, facilitating tectonic pileup and eastward creep of the Karachi Arc.

It appears that a number of complex factors are at work here and, in combination, have made Pakistan-western India region prone to devastating earthquakes on a recurrent basis. Some of the major factors may be the collision induced compression in the north, collision induced transpression in the north west, plate bending and rupture caused by loading from the Himalayan-Sulaiman-Kirthar belt, loading from the Indus delta and fan , pre-existing weakness within the rifted fabric, and the additional twist from the triple junction dynamics. This poses an enormous challenge to those who attempt to model, as to how to account for a combination of factors so diverse.

RECOMMENDATION

Due to high seismic risk to the population of the area, there is an urgent need to understand the neo-tectonic framework of the entire region. It seems that while the Indians have been putting a lot of effort in studying, mapping, modeling and trying to understand the seismic risk on their side, the Pakistanis need some help. There may be a relative “seismic calm” at present on this side of the border, but Nature knows no bounds. It so happens that Karachi and Hyderabad are not located in the Kutch graben (Figure 1) where the people have suffered the most, but the calm may be deceiving.

The guardian agencies of the Pakistani Government, the Geological Survey and the University Earth Science Departments must wake up to the challenge, study the problem and educate the public as much as they can. A strict building code must be devised and enforced. Not like Quetta, which is a disaster waiting to happen again. We seem to have forgotten the horrible earthquake of 1935 that had flattened Quetta and killed tens of thousands of people.

At this time, the entire area can be monitored at a reasonable cost using satellite based imagery, GPS systems, and ground tilt meters. Wells can be monitored to learn about any changes in the gas chemistry and fluctuations in the water table, in response to and ahead of any seismic activity. Unless we know the norm we cannot understand and deal with the abnormal.

CONCLUSION

This short paper provides a more complete picture of the tectonic framework of the Karachi triple junction and surrounding areas than available to date. The proposed Hyderabad graben is a new large structure and its link with the Karachi arc and the Luni River lineament is worth studying further. Field work, remote sensing, and seismic data can all be very helpful in understanding the neo-tectonics and the seismic risk of the whole area.

The proposed Hyderabad graben, and the potential for finding additional hidden structures in the region, should also be helpful in the exploration and development of additional energy resources in the region. Rift tectonics seem to have been very important in controlling the known coal and petroleum occurrences of this area of Indo-Pakistan.

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