Tectonic Framework of the Kachchh Earthquake of 26 January 2001

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INTRODUCTION

The 26 January 2001 Kachchh earthquake (USGS M_W 7.6) is the most destructive event to hit peninsular India in historical times. This event, which occurred on India's Republic Day, was centered near Bhachau in the Kachchh (formerly known as Cutch and Kutch) peninsula in India's western Gujarat state. It was located ~150 km southeast of the estimated epicenter of the 1819 event, famous for the creation of the Allah Bund (mound of God) and having a similar, extensive felt area. Unlike the 1819 earthquake, the study of which was limited to descriptions of destruction (MacMurdo, 1824), a subsequent visit through the meizoseismal region (Burnes, 1835), and an analysis of collected data over a century later (Oldham, 1926), the January 2001 event is the subject of intense ongoing geological and seismological investigations. As the results of these investigations become available, they will improve our understanding of this and earlier seismicity in the region. In this paper we describe our current understanding of the tectonic framework within which the 26 January 2001 event occurred and suggest a possible model for its occurrence.

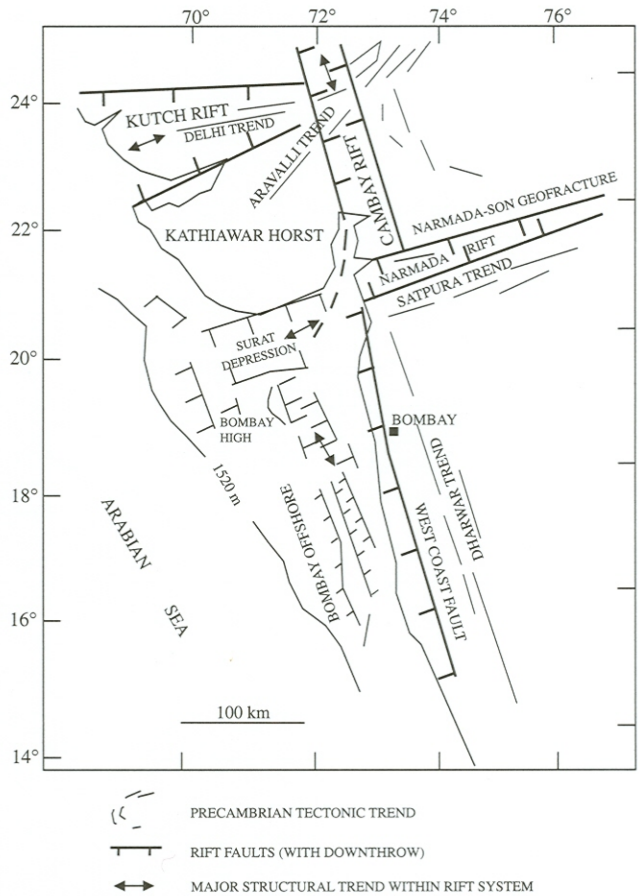
BACKGROUND

Development of the Kachchh Rift Basin

The development of the Kachchh and other rift basins on the western margin of India has been described by Biswas (1982, 1987) and Gombos *et al.* (1995). The following section has been extracted from those studies.

Biswas (1982) concluded that "the rifting events occurred in successive stages during the migration of the Indian plate after its break from Gondwana in Late Triassic or Early Jurassic." He concluded that these rift basins opened up successively along major Precambrian trends as a result of counterclockwise drift of the Indian craton. Figure 1, taken from Biswas (1982), is a tectonic map of the western margin of India showing the Kachchh, Cambay, and Narmada rift basins and major Precambrian tectonic trends. Following Biswas (1982) and Gombos *et al.* (1995) we divide the history of formation of these rifts into five stages:

Stage 1. According to Gombos *et al.* (1995) the break-up of Gondwana into two small continents, West and East



▲ **Figure 1.** Tectonic map of the western margin of India showing the Kachchh (Kutch), Cambay, and Narmada rifts, and major Precambrian tectonic trends (from Biswas, 1982).

Gondwana, occurred in the Middle Jurassic (150 Ma before present). West Gondwana consisted of Africa, while East Gondwana consisted of Antarctica, Australia, India, the Seychelles, and Madagascar. This initial rifting of Gondwana took place along the Precambrian Dharwar trend with moderate sinistral rotation. It also resulted in the initial opening of the Kachchh rift along the Precambrian Delhi trend (Biswas, 1982).

Stage 2. From Middle Jurassic time onward East Gondwana drifted away with a speed of 3 to 5 cm/yr, while rotating in a counterclockwise direction. In the Early Cretaceous (128–30 Ma) East Gondwana further split as Antarctica-Australia rifted away from the India, Seychelles, and Madagascar block (Gombos *et al.*, 1995). According to these authors, this separation occurred along the old Eastern Ghats trend of eastern India and defined the present coastline configuration of eastern India. On the western side, the Cambay rift opened up with the extension of the West Coast Fault along the Dharwar trend. The north-south-trending intracratonic Cambay Graben is fault bounded and varies in width from 55 to 100 km (Biswas, 1987). The east-west-trending Narmada rift and its offshore extension Surat Depression started to open across and to the south of the Cambay rift, and the Kathiawar block separated from the Indian craton. As a consequence of the counterclockwise rotation, the Kachchh rift widened and a basin formed (Biswas, 1982).

Stage 3. In the Middle Cretaceous (about 90 Ma) Madagascar began rifting from western India along the NNW-SSE-trending Dharwar basement grain, defining the western margin of India (Gombos *et al.*, 1995). In Late Cretaceous time the Seychelles India fragment continued to drift and the spreading speed reached its maximum (15 to 20 cm/yr), with a completion of 50° counterclockwise rotation of India (Biswas, 1982). Around 66 Ma the Deccan/Réunion hot spot erupted (Courtillot *et al.*, 1986) and the western margin of India crossed the equator and passed over the hot spot (Biswas, 1982). Extensive subaerial eruptions of flood basalts in the next million years covered an area of about two million square kilometers with several basalt flows, now known as the Deccan Traps. In response to the weakened lithosphere in the vicinity of the mantle plume the Seychelles separated from mainland India about 63 Ma. As India moved off the hot spot, lithospheric cooling was accompanied by subsidence and the formation of the Narmada Graben (along the Narmada geofracture) and its offshore extension, the Surat Depression (Biswas, 1982 and Gombos *et al.*, 1995).

Stage 4. The onset of the collision of India with the southern margin of Eurasia occurred in late Paleocene-Eocene time. Estimates of the dates of collision range from ~50 Ma (Patriat and Achache, 1984; Besse *et al.*, 1984) to ~66 Ma (Jaeger *et al.*, 1989; Beck *et al.*, 1995). Following collision the spreading motion slowed down to 4 to 6 cm/yr (Biswas, 1982).

Stage 5. Beck *et al.* (1995) argue, based on stratigraphic data, that suturing was complete by 49 Ma. Other estimates, *e.g.*, Biswas (1982), suggest that "the final welding of India and Eurasia occurred in Eocene-Oligocene time, when motion nearly halted, anti-clockwise rotation was 9°, and slow northward movement continued into Miocene-Pliocene time." An increase in the rate of subsidence in the Surat Depression in Early Miocene (20 Ma) was interpreted by Gombos *et al.* (1995) "to represent structural response to stress reorientation associated with the Himalayan orogeny."

Thus by Late Miocene the east-west-trending Kachchh rift basin (KRB) had formed and was being subjected to a ~north-south compressive stress field. (The maximum horizontal stress that is responsible for current tectonic activity is oriented ~N-S to NNE-SSW; Gowd *et al.* [1992]).

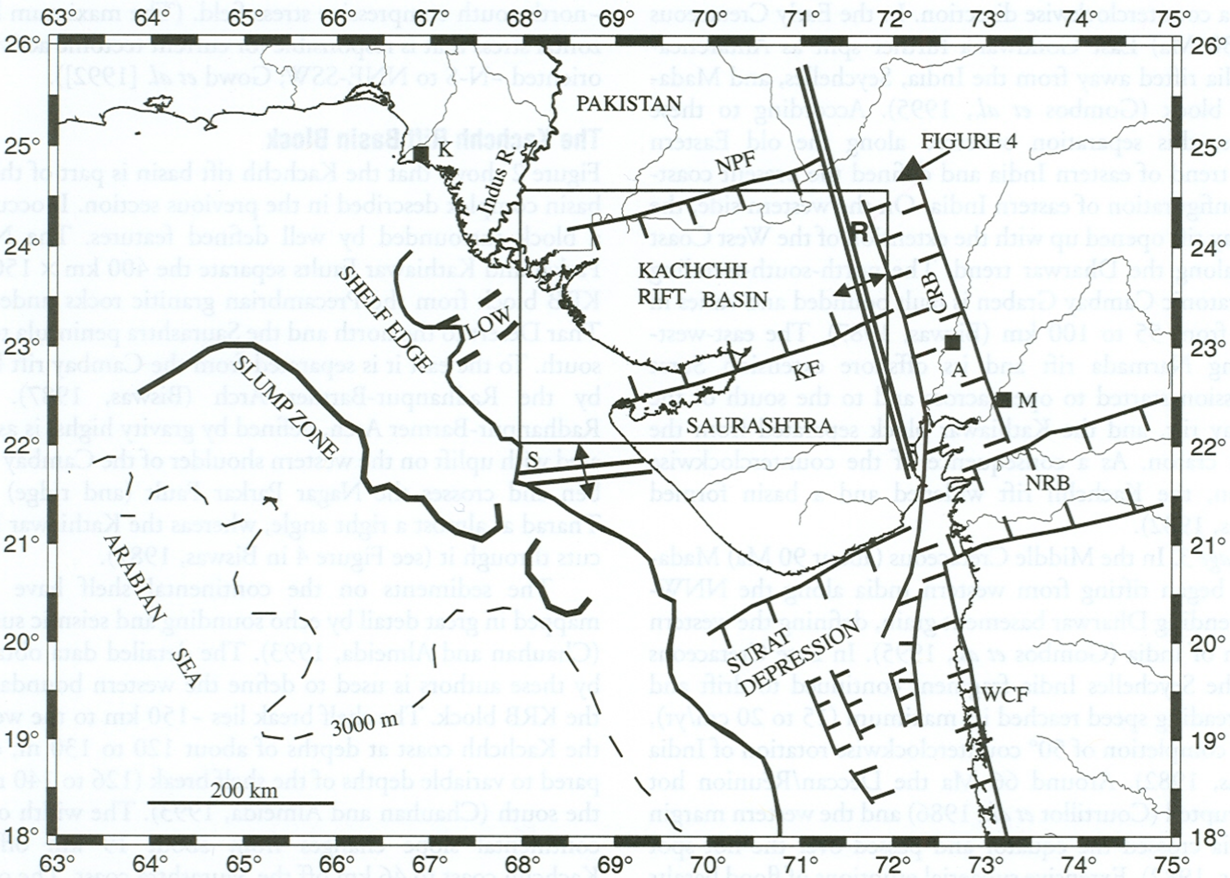
The Kachchh Rift Basin Block

Figure 2 shows that the Kachchh rift basin is part of the rift basin complex described in the previous section. It occurs as a block surrounded by well defined features. The Nagar Parkar and Kathiawar Faults separate the 400 km × 150 km KRB block from the Precambrian granitic rocks under the Thar Desert to the north and the Saurashtra peninsula to the south. To the east it is separated from the Cambay rift basin by the Radhanpur-Barmer Arch (Biswas, 1987). The Radhanpur-Barmer Arch, defined by gravity highs, is associated with uplift on the western shoulder of the Cambay Graben and crosses the Nagar Parkar Fault (and ridge) near Tharad at almost a right angle, whereas the Kathiawar Fault cuts through it (see Figure 4 in Biswas, 1987).

The sediments on the continental shelf have been mapped in great detail by echo sounding and seismic surveys (Chauhan and Almeida, 1993). The detailed data obtained by these authors is used to define the western boundary of the KRB block. The shelf break lies ~150 km to the west of the Kachchh coast at depths of about 120 to 130 m, compared to variable depths of the shelf break (126 to 140 m) to the south (Chauhan and Almeida, 1993). The width of the continental slope changes from about 19 km off the Kachchh coast to 46 km off the Saurashtra coast. The orientation of the shelf break changes from northwest-southeast to east-west. Chauhan and Almeida (1993) attribute these changes both to tectonic causes and to the high rates of Holocene sedimentation on the shelf to the northwest of the Gulf of Kachchh. The heavy influx of sediments from the Indus (400 million tons annually before the construction of dams in 1962) could possibly also explain the long zone of slumping (Figure 2). Alternatively the slumping could be related to tectonic activity in the KRB block.

Two features suggest influence of tectonics in defining the morphology of the shelf. First, the change in orientation of the shelf break from northwest-southeast parallel to the Kachchh coast to east-west occurs along the westward extension of the Kathiawar Fault. Second, the bathymetry data define a ~35–40 km wide ENE-WSW zone of deepening centered about a line extending from about 23°N 66.9°E to 23.3°N 67.7°E (Figure 2 in Chauhan and Almeida, 1993). This depression (marked "LOW" in Figure 2) is roughly parallel to and south of the Nagar Parkar Fault. It is possibly the seaward extension of the Banni Graben in the KRB, described in a later section. Plate reconstructions suggest that the Banni Graben lies along a trend with the Diego, Majung, and Morondava Basins of northern Madagascar before the break-up of Africa from India (Sedgley *et al.*, 1997). An alternative explanation is that this feature (offshore low) is associated with channeling by the Indus River.

Chauhan and Almeida (1993) have interpreted the change in the direction of the shelf slope, and other sedimen-



▲ **Figure 2.** Tectonic framework of the Kachchh rift basin and surrounding region. Some structural elements are identified: Cambay rift basin (CRB), Narmada rift basin (NRB), West Coast Fault (WCF), Nagar Parkar Fault (NPF), and Kathiawar Fault (KF). Locations are shown by letters: Ahmedabad (A), Karachi (K), and Mahi River site (M). Boxed outline is shown in detail in Figure 4.

tological and geomorphic features, to suggest the presence of the NNE-SSW-trending Saurashtra Arch extending from the coast to the continental slope (Figure 2). They suggest that "the shelf edge orientation reflects tectonic movements associated with the formation of this anticline."

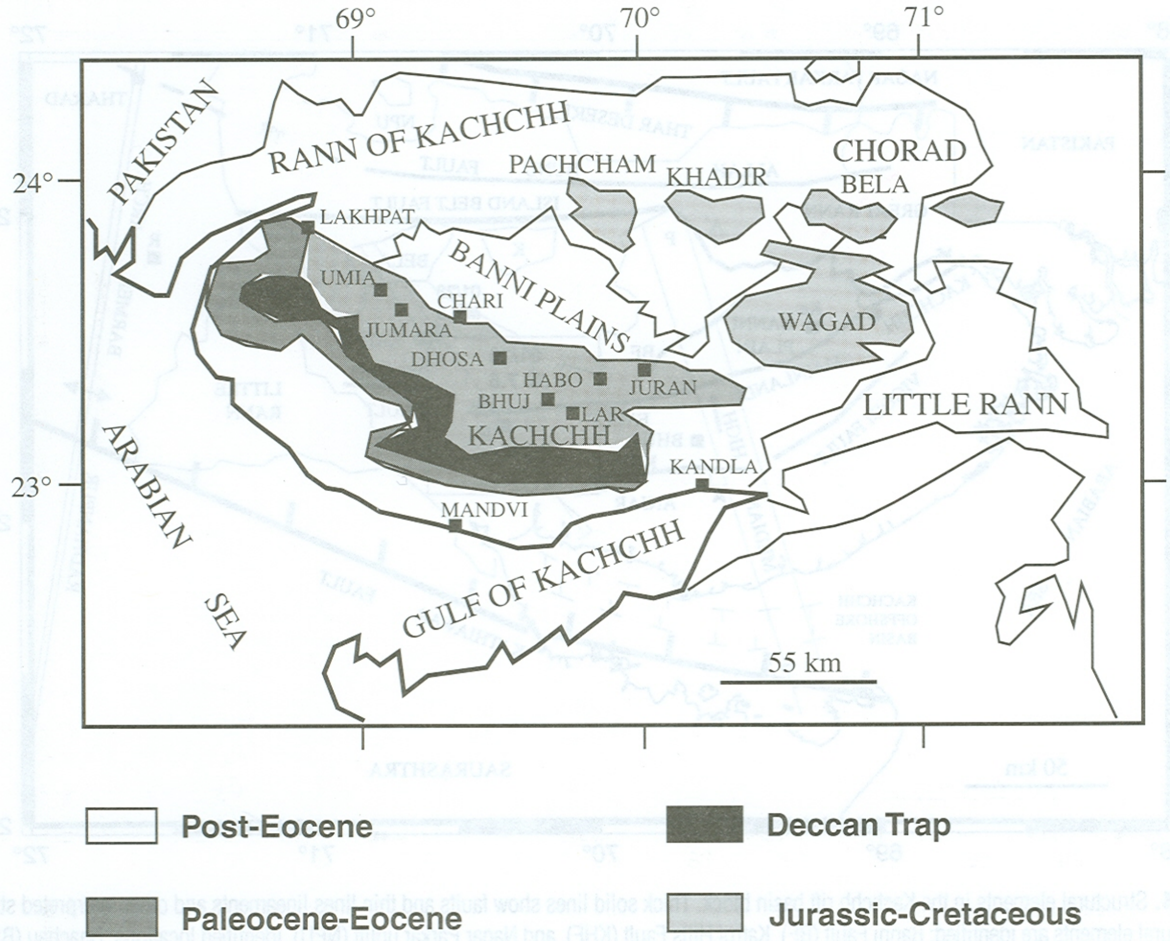
Based on the changes in the shallow offshore morphology we infer that the western boundary of the KRB block lies along the shelf break between the offshore extensions of the Nagar Parbat and Kathiawar Faults. Thus the KRB block is enclosed between the Precambrian granitic rocks to its north and south, an uplifted subsurface arch associated with gravity highs to its east, and the continental shelf to the west.

General Geology

The geological history of the Kachchh basin has been attributed to the reactivation of primordial faults along the Delhi-Aravalli trend in the Early Jurassic (Biswas, 1987). Sediments were laid down on a Precambrian granitic basement and the KRB is filled with sediments ranging in age from Middle Jurassic to the recent. The Mesozoic sediments "were uplifted, folded, intruded and covered by Deccan Trap basaltic flows in Late Cretaceous and Early Paleocene time" (Biswas, 1987). Based on a study of fossils and other markers Krishna *et al.* (1983) suggest a marine origin for the Jurassic-Cretaceous units of Kachchh. Figure 3 shows the distribution of Eocene and older sediments. The Early Jurassic-Cretaceous sediments occupy the highlands, including the Pachcham, Khadir, and Bela islands and Wagad highland. Early Eocene transgression and subsequent Tertiary activity filled the surrounding lows in the Banni Plains and the Ranns of Kachchh (Biswas, 1987). Glennie and Evans (1976) studied the recent sediments of the Ranns of Kachchh with respect to their provenance and tectonic setting. They found that immediately following the Pleistocene rise in sea level, the depressions occupied by the Ranns were once gulfs of the sea. Originally sediments were carried into these depressions by the Indus, Nara, and other rivers on the western part of the Indo-Gangetic plain and during the monsoon season by the local streams draining upland Kachchh and Kathiawar.

Structural Framework

The landscape of Kachchh can be divided into four major east-west-trending geomorphic zones. From south to north they are: (a) the coastal zone on the Gulf of Kachchh, (b) the rocky mainland, (c) the raised mud flats composing the Banni Plains, and (d) the vast saline wasteland comprising the Great Rann in the north and the Little Rann in the east



▲ **Figure 3.** Pre-Eocene geology of Kachchh after Krishna *et al.* (1983).

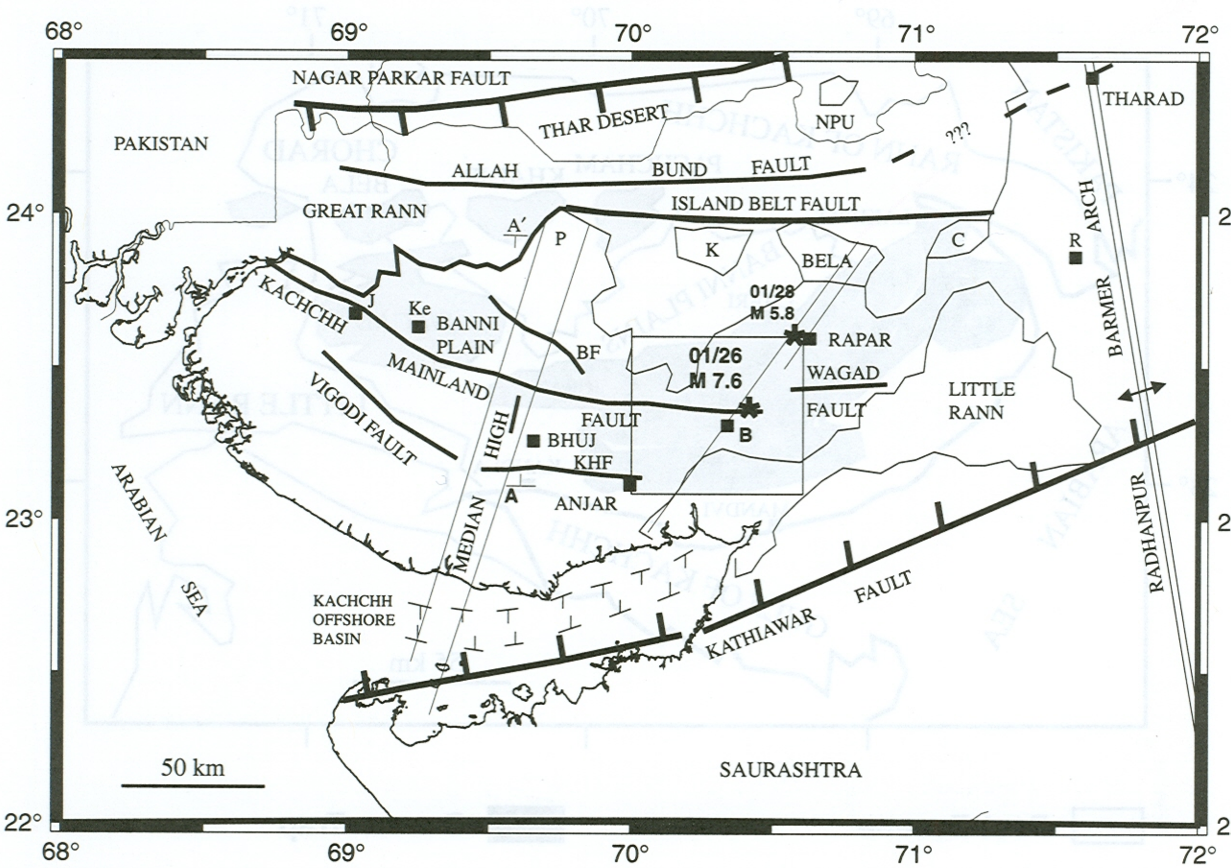
(Malik *et al.*, 2000). The Kachchh mainland lies on the rocky southern part consisting of the pre-Eocene rocks, which also occupy the uplifted Pachcham, Khadir, and Bela islands (Figures 3 and 4). The Banni Plains and the Rann occupy the lowlands (Figure 5).

The structural features in the KRB block have been described by Biswas (1987), Malik *et al.* (2000), and the Geological Survey of India (GSI) (2001). They appear as east-west-trending active fold and thrust belts. Biswas (1987) has described various features as "ridges" and noted that those are bounded on at least one side by faults, whereas Malik *et al.* (2000) describe them as faults and GSI (2000) as faults and lineaments. Figure 4 shows these faults and follows the nomenclature of Malik *et al.* (2000). The KRB is bounded to the north by the Nagar Parkar Fault. This fault was labeled "fault bounding the Nagar Parkar - Tharad Ridge" by Biswas (1987) and the Luni-Shukri Lineament by GSI (2001). To the south the KRB is bounded by the Kathiawar Fault, called North Kathiawar Fault by Biswas (1987) and GSI (2001).

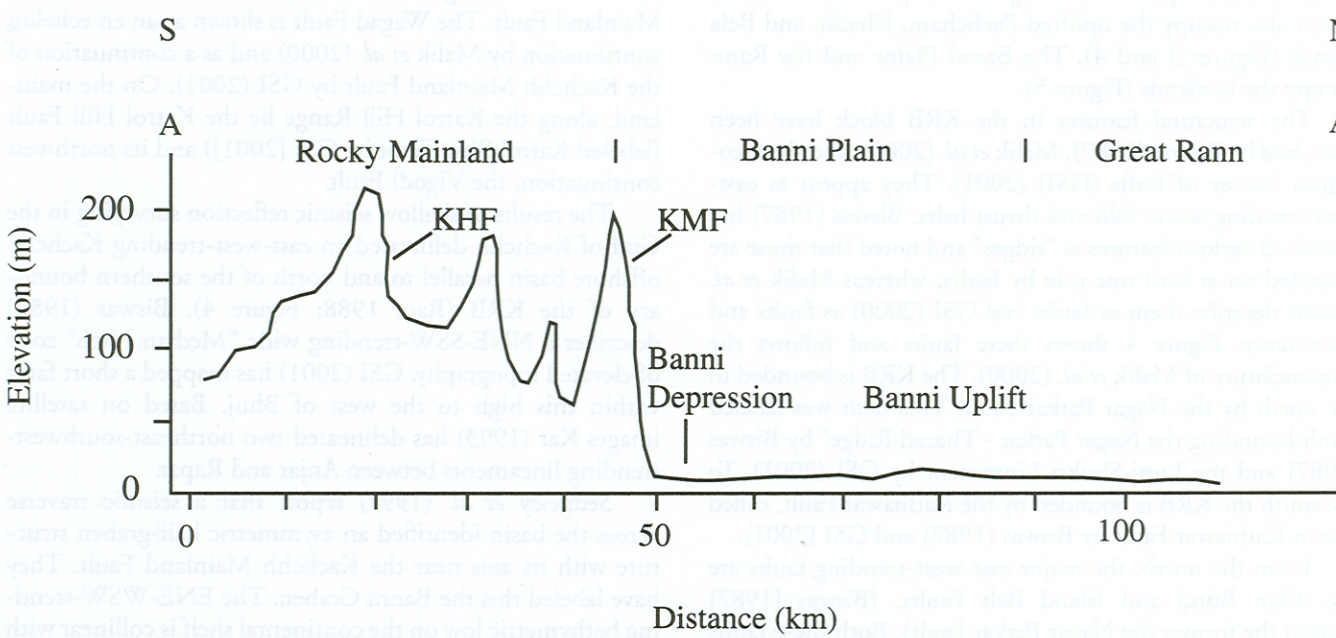
From the north, the major east-west-trending faults are the Allah Bund and Island Belt Faults. (Biswas [1987] labeled the former the Nagar Parkar Fault). Both these faults lie in the Great Rann. Malik *et al.* (2000) have also identified the Banni Fault in the Banni Plains. It is associated with the Banni uplift (Figure 5). Separating the Banni Plain from the Northern Hill Range of the Kutch mainland is the Kachchh Mainland Fault. The Wagad Fault is shown as an en echelon continuation by Malik *et al.* (2000) and as a continuation of the Kachchh Mainland Fault by GSI (2001). On the mainland, along the Katrol Hill Range lie the Katrol Hill Fault (labeled Katrol Bhuj Fault by GSI [2001]) and its northwest continuation, the Vigodi Fault.

The results of shallow seismic reflection surveying in the Gulf of Kachchh delineated an east-west-trending Kachchh offshore basin parallel to and north of the southern boundary of the KRB (Rao, 1988; Figure 4). Biswas (1982) describes a NNE-SSW-trending wide "Median High" zone of elevated topography. GSI (2001) has mapped a short fault within this high to the west of Bhuj. Based on satellite images Kar (1993) has delineated two northeast-southwest-trending lineaments between Anjar and Rapar.

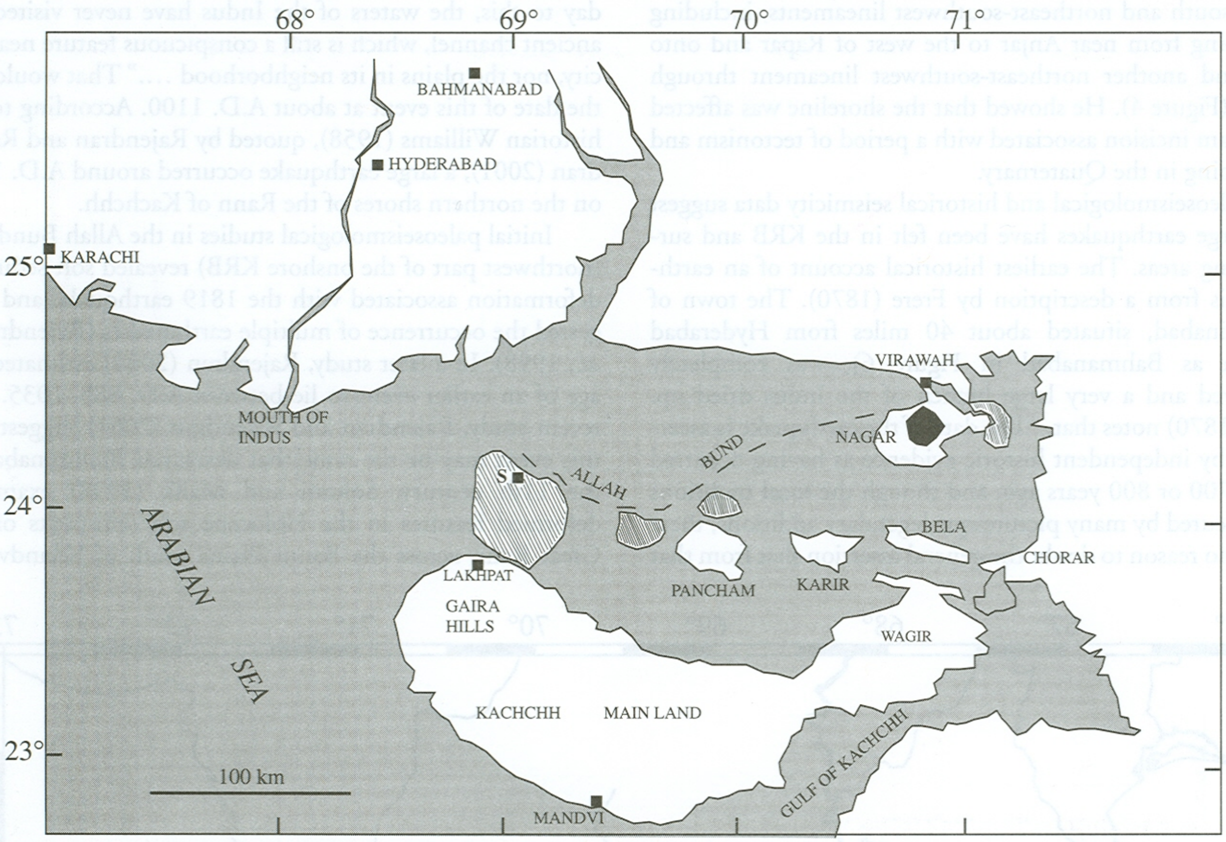
Sedgeley *et al.* (1997) report that a seismic traverse across the basin identified an asymmetric half-graben structure with its axis near the Kachchh Mainland Fault. They have labeled this the Banni Graben. The ENE-WSW-trending bathymetric low on the continental shelf is collinear with the proposed Banni Graben and may be related to it, providing a channel for the influx of sediments from the Indus.



▲ **Figure 4.** Structural elements in the Kachchh rift basin block. Thick solid lines show faults and thin lines lineaments and other interpreted structures. Some structural elements are identified: Banni Fault (BF), Katrol Hills Fault (KHF), and Nagar Parkar uplift (NPU). Identified locations: Bhachau (B), Chorar (C), Jumara (J), Khadir Island (K), Keera (Ke), Pachcham Island (P), and Radhanpur (R). Asterisks show the USGS location of the 26 January 2001 event and its aftershock. The rectangle surrounding them shows the location of the epicentral area of aftershocks through about 15 February 2001. A–A′ are the endpoints of a south-north elevation profile shown in Figure 5.



▲ **Figure 5.** South-north elevation profile through the Kachchh Mainland (from Malik *et al.*, 2000).



▲ **Figure 6.** Sivewright's (1907) map of "Kachchh and Adjacent islands with the mainland at the time of the Arab conquest of the Sind 712 A.D." showing north of the mainland under water ("Pancham" = Panchcham; "Karir" = Khadir). Superimposed is the outline of the Allah Bund and four inundated depressions (stippled pattern) that resulted from the 1819 earthquake (from Oldham, 1926). Fort Sindri (S) was submerged after the earthquake. With the deposition of sediments, naval access to the port of Virawah was denied and the seafaring families established a new port at Mandvi.

Suggestions that the Great Rann may have been under water as recently as A.D. 712 come from historical accounts. Sivewright (1907) recounts that in accounts of Alexander's military raid to India (325 B.C.) Periplus (Alexander's historian) describes the Rann as being navigable. Alexander sailed south on the Nara (an eastern branch of the Indus, now dry) past a group of islands between 22°45′ and 24° N latitude and 68°30′ and 71° E longitude and on to the Arabian Sea. Figure 6 is a map reproduced from Sivewright (1907) showing a map of Kachchh at the time of the Arab invasion of the Sind province in western India (A.D. 712). This map shows that the Arabian Sea extended as a gulf to Virawah, a thriving seaport near the Nagar Parkar highland.

The presence of the uplifted ~east-west-trending Saurashtra Arch (Figure 2), the folded highlands in the south (Figure 5), and in historical times an open sea in the north of the KRB suggest that the KRB block was tilted to the north about the Saurashtra Arch axis. We discuss evidence of ongoing tectonic activity in the next section.

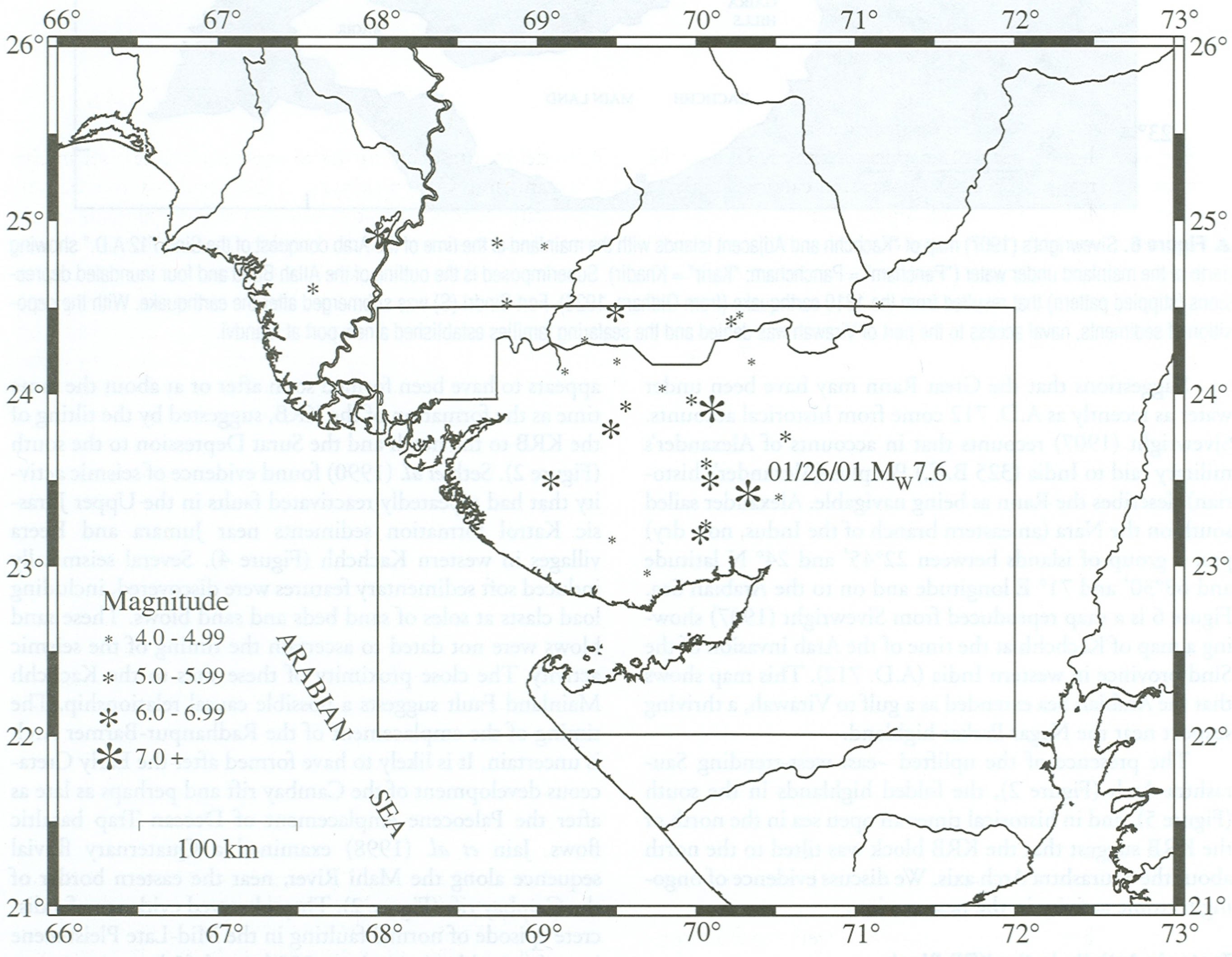
Tectonic Activity in the KRB Block

Various studies suggest that the KRB block and the surrounding regions were locations of tectonic activity since about the Late Jurassic. The Saurashtra Arch (Figure 4) appears to have been formed soon after or at about the same time as the formation of the KRB, suggested by the tilting of the KRB to the north and the Surat Depression to the south (Figure 2). Seth *et al.* (1990) found evidence of seismic activity that had repeatedly reactivated faults in the Upper Jurassic Katrol formation sediments near Jumara and Keera villages in western Kachchh (Figure 4). Several seismically induced soft sedimentary features were discovered, including load clasts at soles of sand beds and sand blows. These sand blows were not dated to ascertain the timing of the seismic activity. The close proximity of these sites to the Kachchh Mainland Fault suggests a possible causal relationship. The timing of the emplacement of the Radhanpur-Barmer Arch is uncertain. It is likely to have formed after the Early Cretaceous development of the Cambay rift and perhaps as late as after the Paleocene emplacement of Deccan Trap basaltic flows. Jain *et al.* (1998) examined a Quaternary fluvial sequence along the Mahi River, near the eastern border of the Cambay rift (Figure 2). They observed evidence of a discrete episode of normal faulting in the Mid-Late Pleistocene in an interval between about 300 ka and 60 ka.

A recent geomorphological study provides evidence of tectonic activity during the Quaternary in the region. Kar (1993) presents evidence of neotectonic activity along major north-south and northeast-southwest lineaments, including one going from near Anjar to the west of Rapar and onto Bela and another northeast-southwest lineament through Rapar (Figure 4). He showed that the shoreline was affected by stream incision associated with a period of tectonism and upwarping in the Quaternary.

Paleoseismological and historical seismicity data suggest that large earthquakes have been felt in the KRB and surrounding areas. The earliest historical account of an earthquake is from a description by Frere (1870). The town of Brahminabad, situated about 40 miles from Hyderabad (shown as Bahmanabad in Figure 6), was completely destroyed and a very large branch of the Indus dried up. Frere (1870) notes that, "The date of the earthquake is ascertained by independent historic evidence as having occurred about 700 or 800 years ago, and though the local traditions are obscured by many picturesque legendary additions, there seems no reason to doubt the general assertion that from that day to this, the waters of the Indus have never visited the ancient channel, which is still a conspicuous feature near the city, nor the plains in its neighborhood ...." That would put the date of this event at about A.D. 1100. According to the historian Williams (1958), quoted by Rajendran and Rajendran (2001), a large earthquake occurred around A.D. 1030 on the northern shores of the Rann of Kachchh.

Initial paleoseismological studies in the Allah Bund area (northwest part of the onshore KRB) revealed soft sediment deformation associated with the 1819 earthquake and suggested the occurrence of multiple earthquakes (Rajendran *et al.*, 1998). In a later study, Rajendran (2000) estimated the age of an earlier event to lie between A.D. 885–1035. In a recent study, Rajendran and Rajendran (2001) suggest that this event may be the same that destroyed Brahminabad in the 11th century. Sohoni and Malik (1998) examined deformed features in the Holocene soft sediments of the Great Rann across the Banni Plains south of Khandva on



▲ **Figure 7.** Seismicity map ($M \geq 4.0$) of the Kachchh rift basin and surrounding area from 1668 to present (from Malik *et al.*, 1999). The boxed outline shows the area in Figure 4. The labeled large asterisk shows the location of the Republic Day earthquake.

Pachcham Island. They inferred that these soft-sediment deformational features had been seismically induced by earthquakes with a magnitude $M_s \geq 5.5$.

While we await the results of studies of the 26 January 2001 event and its aftershocks, a brief comment about the current seismicity is in order. The most significant historical earthquake occurred in 1819. It has been described in great detail by visitors in the 19th century, and some of the historical and other data have been described in great detail in two recent studies (Bilham, 1998; Rajendran and Rajendran, 2001) and will not be repeated. We make only the observation that it was associated with the uplift of the Allah Bund to the north and formation of small lakes to the south (Figure 6). Figure 6 shows the Allah Bund as described by Oldham (1926). South of this uplifted mound there were signs of depression, which enclosed extensive flooded areas. Among these flooded depressions was a lake that formed near Fort Sindri and two that formed to the west and north of Pachcham Island. A fourth flooded area was formed to the east of the Nagar highlands. Based on these observations Oldham (1926) estimated the length of the Allah Bund to be ~150 km, as compared to a more recent estimate of 95 km by Rajendran and Rajendran (2001). This event appears to have been associated with the Allah Bund fault.

Figure 7 shows a map of seismicity of the KRB and the surrounding area with $M \geq 4.0$ based on a catalog (Table 1) compiled by Malik (1999). Although the accuracy of epicentral locations was not given by Malik *et al.* (1999), Figure 7 suggests that the KRB has been fairly active since the earliest recorded earthquake in the 17th century.

TECTONIC FRAMEWORK OF THE KACHCHH RIFT BASIN BLOCK

The foregoing sections suggest the following tectonic framework of the Kachchh rift basin block:

a. The formation of the Kachchh rift basin began in Middle Jurassic times and by Late Miocene it had moved to its present east-west configuration.
b. After an initial period of extension, the KRB has been subjected to ~north-south compression, at least since about 20 Ma.
c. The KRB forms a block consisting of post-Jurassic to recent formations enclosed within the Precambrian rocks forming the Indian craton.
d. The 400 km × 150 km KRB block is sandwiched between Precambrian granitic rocks to its north and south, an uplifted arch (associated with gravity highs) to the east, and the continental shelf to the west.
e. The KRB block was tilted to its north about the Saurashtra Arch early in its history.
f. The KRB block consists of east-west-trending fault-controlled folded belts forming the uplifted Kachchh Mainland to the south and a half-graben—the Banni Graben—to the north.
g. The Kachchh Mainland and other highlands consist of pre-Eocene-Jurassic rocks, including Deccan Trap basaltic flows. The (formerly submerged) Banni Graben has been filled with post-Eocene sediments and, notably within it, the Ranns have been filled with recent sediments.
h. The structural framework of the KRB block is characterized by a series of east-west-trending highlands and grabens associated with east-west-trending faults. These east-west-trending faults are cut by several north-south to northeast-southwest features that include the structural "Median High", various lineaments, and short faults.
i. A variety of data suggests that the KRB block has been tectonically active since the Jurassic. These include seismically induced deformation of the Jurassic Katrol formation, Mid-Late Pleistocene normal faulting in the adjacent Cambay rift, geomorphic evidence of Quaternary uplift along northeast-southwest and north-south lineaments, and Holocene, historical, and current seismicity.

A MODEL TO EXPLAIN THE CURRENT SEISMICITY

A model we presented earlier to explain intraplate seismicity (Talwani and Gangopadhyay, 2000) explains the current seismicity. According to this model, the KRB block is a local zone of weakness sandwiched within a strong Indian craton. It is probably also associated with a thin crust (the data to confirm this suggestion are lacking at present). In response to north-south compression associated with the northward migration of the Indian plate and the Himalayan orogeny, the 400 km × 150 km KRB block behaves like a compressed rectangular strip cut in a watermelon. The result is anomalously high strain rates in the volume composing the entrapped block. Within the highly strained volume composing the KRB block, anomalously high stresses build up at locations of stress concentrators. These stress concentrators (within the rifted block) consist of fault intersections, fault bends, plutons, and stress pillows. The current Bhachau event and its aftershock activity as described by Kayal (personal communication, 2001) appear to be spatially correlated with the Kachchh Mainland Fault and the northeast-southwest-trending tectonically active lineaments mapped by Kar (1993). Evaluation of aftershock and other data will provide a test of this model.

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TABLE 1
Seismicity in the Kachchh Rift Basin and Vicinity (from Malik *et al.*, 1999)

Date	Latitude (N)	Longitude (E)	Location	Magnitude
6 May 1668	25.00°	68.00°	Indus Delta	7.6
16 June 1819	24.00°	70.00°	Great Rann of Kachchh (Allah Bund)	7.8
13 August 1821	23.16°	70.16°	Anjar	5.0
20 July 1828	23.33°	70.50°	East of Bhuj around Bhachau	~4.3
1844	24.33°	69.50°	Great Rann East of Lakhpat	4.3
19 April 1845	24.33°	69.50°	Great Rann East of Lakhpat	5.0
19 June 1845	24.33°	69.50°	Great Rann East of Lakhpat	6.3
19 June 1845	24.30°	69.38°	Lakhpat	6.0
25 April 1845	24.00°	69.00°	Great Rann North of Lakhpat	6.0
29 April 1864	24.00°	70.00°	Great Rann-Banni Plain	5.0
14 January 1903	24.00°	70.00°	Great Rann	6.0
28 April 1904	23.16°	69.66°	Bhuj	4.0
26 October 1921	25.00°	68.00°	Indus Delta, Great Rann	5.5
31 October 1940	24.16°	70.50°	Northeast of Khadir in Great Rann of Kachchh	~5.8–6.0
21 July 1956	23.16°	70.00°	Anjar[a]	6.0
26 March 1965	24.30°	70.00°	North of Khavda in Great Rann of Kachchh	5.3
27 May 1966	24.76°	70.15°	Northeast of Khavda in Thar Desert (Pakistan)	5.0
4 June 1976	24.86°	68.45°	North of Allah Bund in Delta Complex Zone (Pakistan)	5.1
26 April 1981	24.21°	69.85°	North of Khavda in Great Rann of Kachchh	4.1
31 January 1982	24.36°	70.40°	North of Khadir in Great Rann of Kachchh	4.8
18 July 1982	24.66°	71.60°	Rapar	4.8
7 April 1985	24.61°	70.23°	North of Khavda in Great Rann of Kachchh	4.4
10 September 1991	24.48°	69.35°	Great Rann of Kachchh	4.7
10 September 1991	24.28°	69.13°	Great Rann of Kachchh	4.7
2 September 1993	25.00°	69.00°	North of Allah Bund (Pakistan)	4.3
17 February 1996	23.33°	69.66°	South of Bhuj	4.5
26 January 2001	23.39°	70.32°	Bhachau[a]	7.6

a. From USGS.

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