Aftershocks of 26th January 2001 Bhuj earthquake and seismotectonics of the Kutch region

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The 26th January 2001 Bhuj earthquake was followed by intense aftershock activity. Aftershock data from United States Geological Survey (USGS) utilized in this study encompasses three months period from 26th January to 26th April 2001. Epicenters of the aftershock are plotted on a map depicting active faults. All the aftershocks of magnitude > 5 and 70% of those ranging between magnitude 3 and 5 are confined to an area resembling a horseshoe pattern with a pointed end towards NE. The other 20% of magnitude 3 to 5 are enclosed within an almost parallel boundary. Only 10% are found to be beyond this limiting boundary. 50% of the recorded aftershocks took place within the first week of the main event and this study reveals that the basic characteristic pattern of aftershock activity can be determined on the basis of the data of only one week.

Four major NW-SE trending active faults are mapped in the Kutch region. They define the western limit of Cambay structure and also mark the western limit of Dharangadhra and Wadhwan basins along the SE continuation in Saurashtra. These faults separate the Kutch region into two geologically different blocks. On the SW side the mapped horseshoe pattern gets characteristically truncated along the western most fault, which is characterized by a strike-slip movement in the south and vertical movement in the north. The present study has revealed that the epicenter of the 26th January earthquake is located in the vicinity of the Bhachau township, close to the intersection with the Kutch mainland fault. Furthermore, it has been noticed that most of the epicenters of the aftershock are confined in the intersectional area of the Kutch mainland fault and the NW-SE faults.

1. Introduction

The Kutch region of Gujarat is very active seismically and is grouped in zone V of the seismic zonation map of India. In recorded history this region has been hit by five major devastating ($> 6M$) earthquakes in 1819, 1845, 1885, 1956 and 2001. Apart from these major events, innumerable earthquakes of lesser magnitude have also been recorded from this region. The aftershocks of the 26th January 2001 earthquake have been studied and their relationship with the major active faults of the region worked out. The major active faults have been mapped from satellite imagery. Although, the 26th January earthquake was followed by intense aftershock activity, no precursor activity was recorded in the Kutch region. The only pre-shock activity (magnitude up to 4.4) in entire Gujarat, was witnessed in August 2000 in the vicinity of Bhavnagar (Gupta *et al* 2001). The Bhavnagar area is located within a different seismically active region, in the vicinity of the intersection of faults related with two main geological structures, (the Cambay and Narmada-Tapi tectonic zone) and is more than 300 km away from Bhuj and with a five month time gap between the two events, this seismic activity *sensu stricto* can not be called a pre-shock activity.

Keywords. Bhuj earthquake; aftershock activity; seismotectonics; Kutch region.

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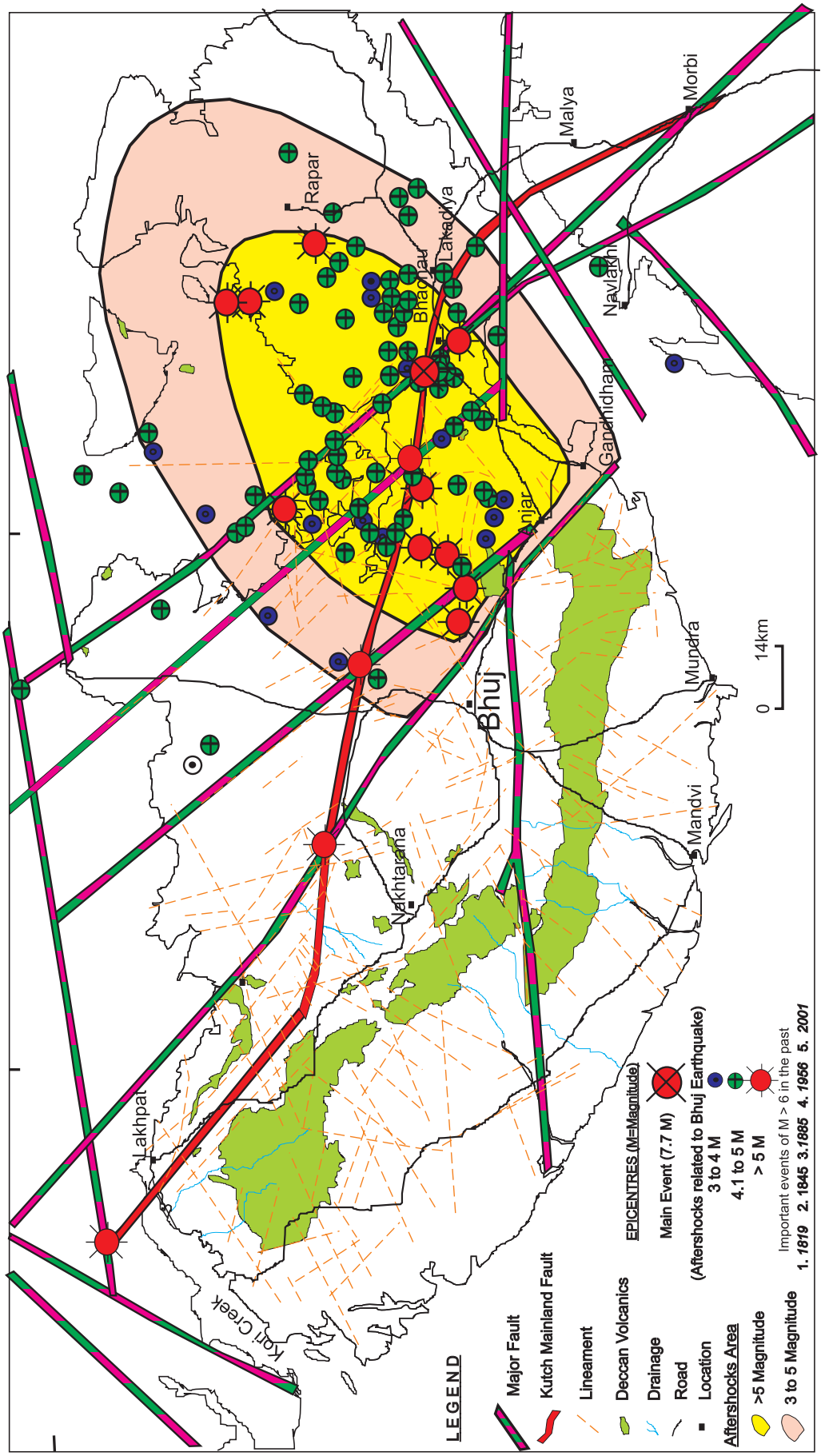

Figure 1. Map of Kutch region depicting the disposition of major faults and lineaments. Deccan volcanics and equivalents can be seen getting truncated along NW-SE trending fault which is traced from Nara to Gandhidham. Main event of 26th January, magnitude 7.7, is located at the intersection of Kutch mainland fault and eastern most fault of the zone defining the western margin of the Cambay structure. It can be seen that all the aftershocks of > 5 and 70% of those between 3 and 5 are confined within the darker shade while over 20% of aftershock of magnitude 3–5 are confined in the area paralleling this area as shown by lighter shade. The characteristic horseshoe pattern of the aftershock area is abruptly terminated along the western most fault having NW-SE trend. The volcanics of the Kutch region are largely confined to the western side of this region.

2. Geological setting

Geomorphologically the Kutch region can be divided into two main units. The Rann areas which get annually inundated by sea water and have been gradually subsiding along major fault zones. The other unit includes highland and occupies the southern part of Kutch. The study area mainly comprises the Mesozoics, the Deccan volcanics and the Tertiary rocks. The Deccan volcanic flows, are sandwiched between the Mesozoic rocks exposed in the north and the Tertiary rocks in the southern part. Many flows identified within the Deccan volcanics are generally dipping in the southerly direction. Structurally, the study area largely includes the E-W trending Kutch rift and the western part of NW-SE trending Cambay structure. The Kutch rift is defined by ENE-WSW trending faults while the Cambay structure is marked by NW-SE trending faults. These NW-SE trending faults divide the Kutch basin into two blocks, the Deccan volcanics being largely confined to the western block (figure 1). On the eastern side the Deccan volcanics are seen forming a southeasterly plunging anticlinal structure. The eastern limit of this structure is cut by NW-SE trending strike-slip fault (figure 2a). Remnants of this limb are located in the NW direction and it is concluded that sinistral strike-slip movement of about 17 km has taken place along this fault since the outpouring of the Deccan lavas (Misra 1999). Similarly on the western side, Deccan volcanics have also moved in dextral strike-slip pattern by approximately 15 to 17 km.

3. Major active faults and lineaments

Mapped active faults largely show parallelism with the known geological structures notably the Kutch rift and the Cambay structure. Sharp geomorphological anomalies define the major active faults as lineament zones on the satellite imagery. It has been possible to map the active faults because of the neo-tectonic activity along these and accentuation by various geomorphological processes. Drill hole data suggest vertical movement of several (8–10) thousand meters along these faults during the Mesozoic and the Tertiary sedimentation. The NW-SE trending active faults coincide with the western limits of the Cambay structure. In Saurashtra they are seen to be limiting the sedimentaries belonging to the Dhangadhra and Wadhwan basins in the west.

3.1 *Kutch mainland fault*

The Kutch mainland fault is identified by the expression of intense neotectonic movements and abrupt termination of highland on the southern side as well as the creation of the Rann areas on the northern side. Intense brecciation is found along this and associated parallel sister faults. During the present study it has been mapped from Lakhpat in the north to Morbi in the south. It has also been found that the entire stretch of this fault is seismically active. Approximately a 50 km wide zone along the SE sector of the Kutch mainland fault shows development of irregular cracks and fissures which either trend in the ENE-WSW or the NW-SE direction. This indicates that these fissures have developed under extensional regime corresponding with the Kutch rift and Cambay structure. Epicenters of all the five major devastating earthquakes are located very close to the intersection of the Kutch mainland fault and the NW-SE trending faults parallel to Cambay structure. The epicenter of the 26th January 2001 earthquake is located in the vicinity of this intersection. Apart from this, a majority of epicenters of aftershock are also located around the intersectional area of the Kutch mainland fault and the NW-SE trending marginal faults of Cambay structure. From a detailed study of the compressional features such as flexures and folds generated in the epicentral area due to the 26th January earthquake (Rajendran *et al* 2001) have also concluded that this event originated on an imbricate blind thrust, located north of the Kutch mainland fault. The swarm type of activity in the vicinity of Lakadiya further suggests the seismogenic activity along this fault.

4. Aftershock activity

A total of 101 aftershocks of magnitude > 3 have been recorded from the vicinity of the main event (CGS/USGS 2001). Aftershocks of magnitude > 5 took place within the first month of the main event (figure 2b) Approximately half of these occurred during the first week of the main event (figure 2c). The activity died gradually during the following weeks. All these aftershocks are classified into three categories ranging between M 3–4, 4.1 to 5, and > 5 magnitude. Eight aftershocks had a magnitude > 5, a large majority (69) had a range between 4.1 and 5, and 24 between 3 and 4. The epicenters of all these are plotted on a map and delineated. The entire aftershock activity is found to be confined within two co-centric parallel regions forming a horseshoe figure which has a north easterly pointed end. This characteristic horseshoe pattern of the area is abruptly terminated by the NW-SE trending active fault, which seems to divide the Kutch basin into two geological entities.

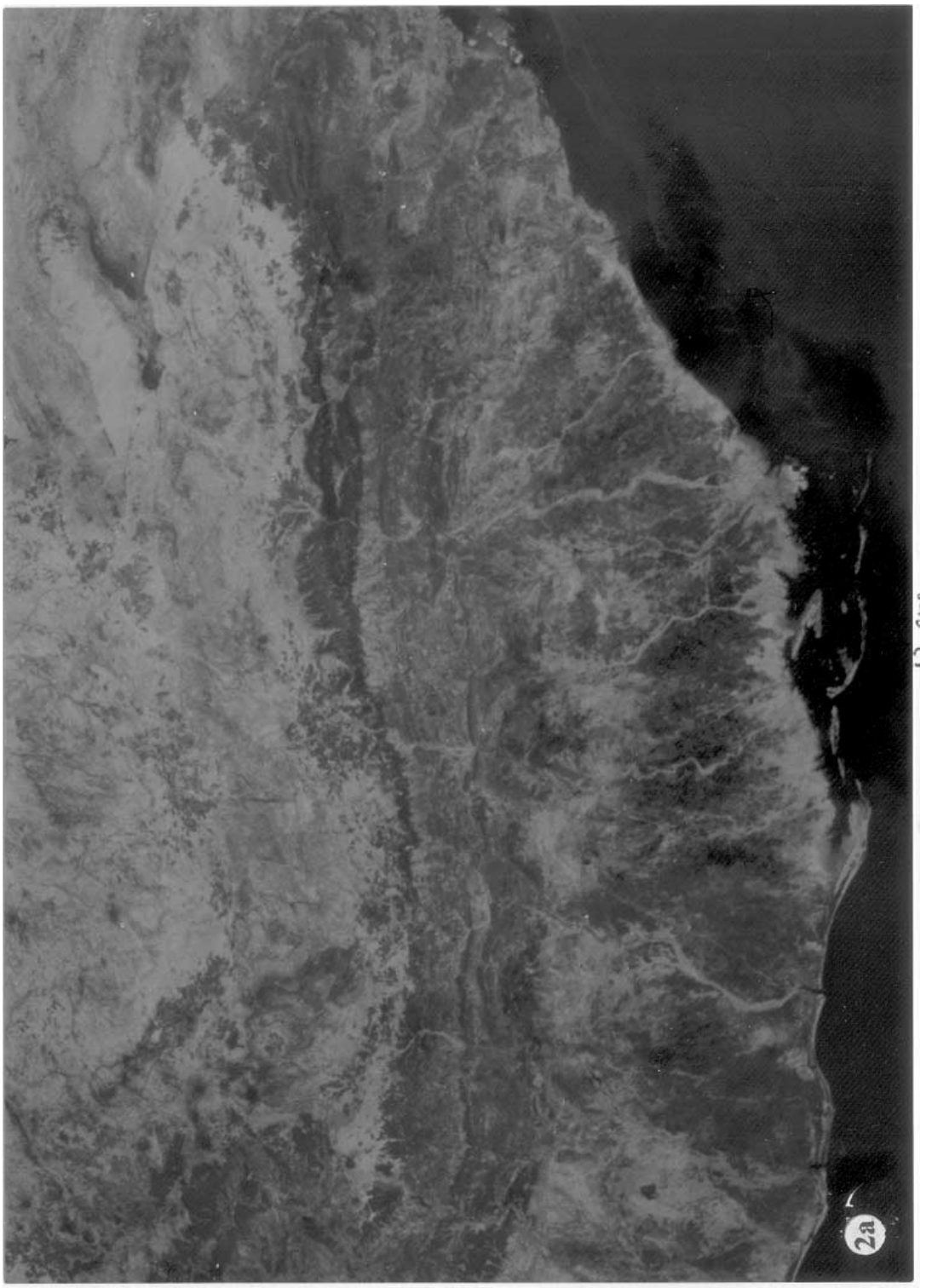

Figure 2(**a**). Thematic mapper image of the southern part of Kutch region. The greenish gray E-W trending banded formation in the central part of the image is the Deccan Volcanic flows, which are sandwiched between the Mesozoics exposed in the north and Tertiaries in the southern part. A number of flows comprising the Deccan volcanics are in general dipping in the southerly direction. On the eastern side Deccan volcanics can be seen forming a southeasterly plunging anticlinal structure, the eastern limit of which is cut by NW-SE trending strike-slip fault. Remnant of this limb is located in the NW direction and it is concluded that the sinistral strike-slip movement of about 17 km has taken place since the outpouring of Deccan lavas. Similarly on the western side, Deccan volcanics have also moved in dextral strike-slip fashion by approximately 15 to 17 km.

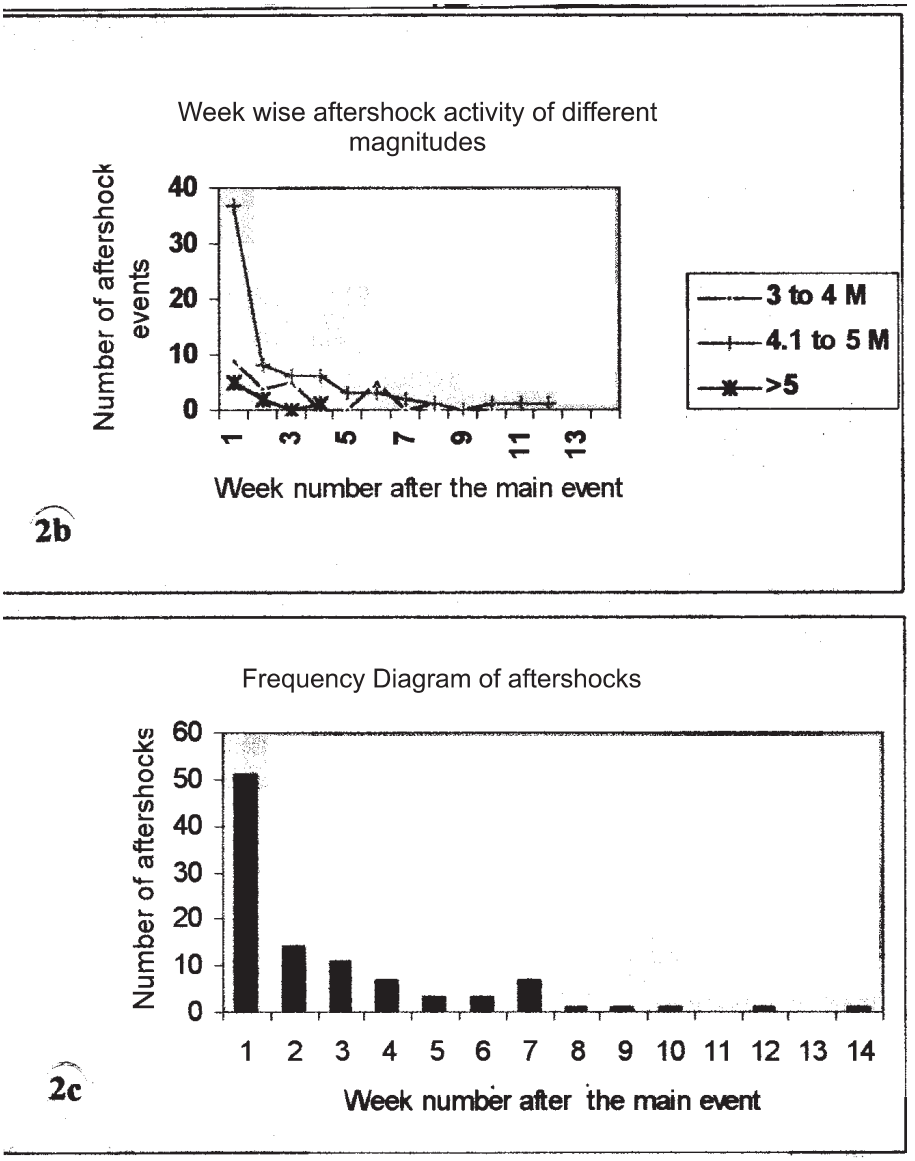

Figure 2. **(b)** Aftershocks of magnitude > 5 have taken place within the first month of the main event. The curves defining the magnitude of aftershocks indicate how the activity has died down; **(c)** Approximately 50% of aftershocks can be seen to have taken place within the first week following the main event. The bar diagram also indicates the pattern of aftershocks in successive weeks.

5. Conclusion

The most significant fact which has emerged from this study, is that the aftershock events are confined only on the north-eastern side of the NW-SE trending major fault and none of the aftershock events are recorded on the south-western side. Misra (2001) on the basis of various geomorphological, geological and seismic evidences observed attenuation of seismic waves while crossing similar boundary faults and also channelization along major basement blocks in the entire western India. The present study of aftershocks data also suggests localization of seismic events within major fragmented blocks. Higher concentration of epicenters of aftershocks in the vicinity of the intersection of active faults is recorded. These active faults are related to either the Kutch mainland fault or the Cambay structure. All five major devastating earthquakes of 1819, 1845, 1885, 1956 and 2001 have also been caused by the release of stresses at the intersection of these two fault systems. Characteristic patterns derived from the aftershock activity can also be obtained by using one week of aftershock data.

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