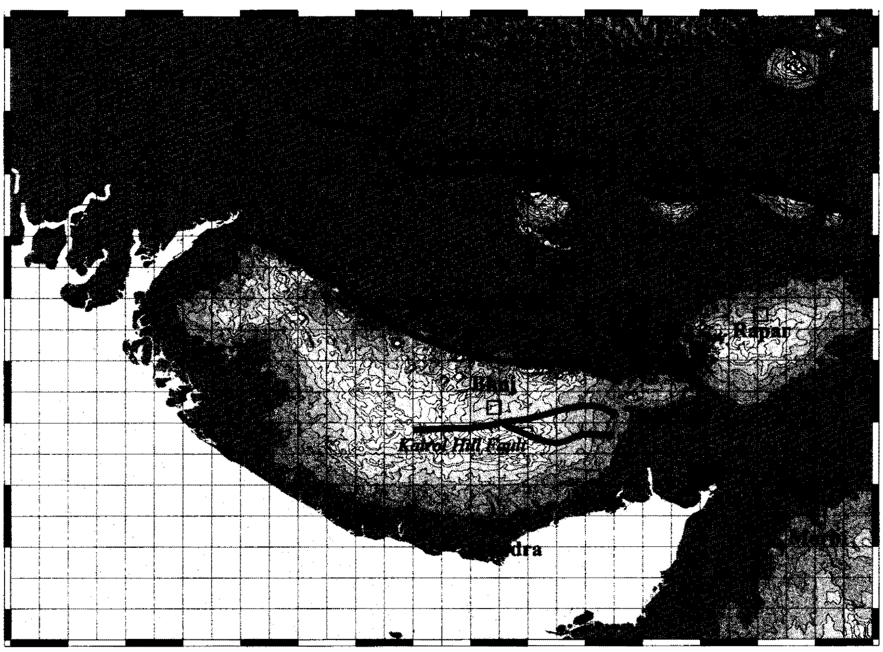
December 2001

Research Report on Natural Disasters

A Comprehensive Survey of the 26 January 2001 Earthquake (Mw 7.7) in the State of Gujarat, India



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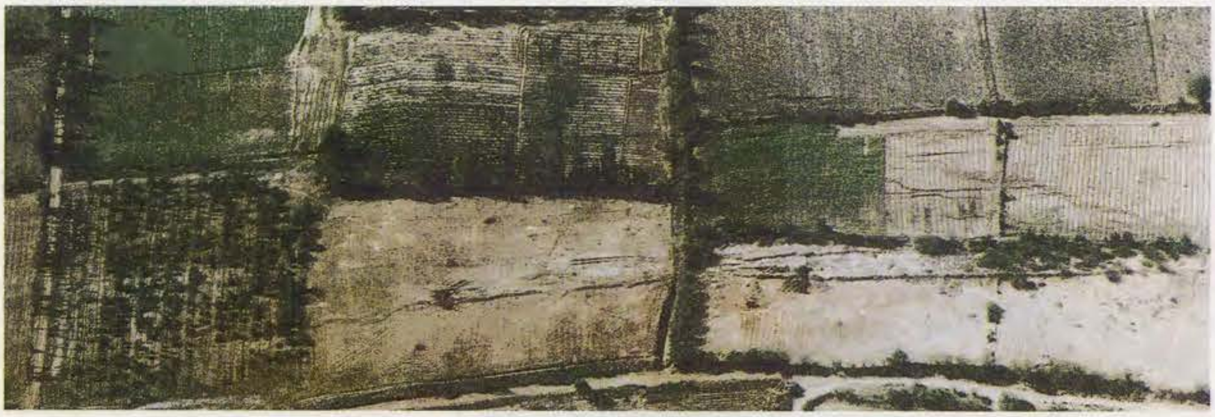

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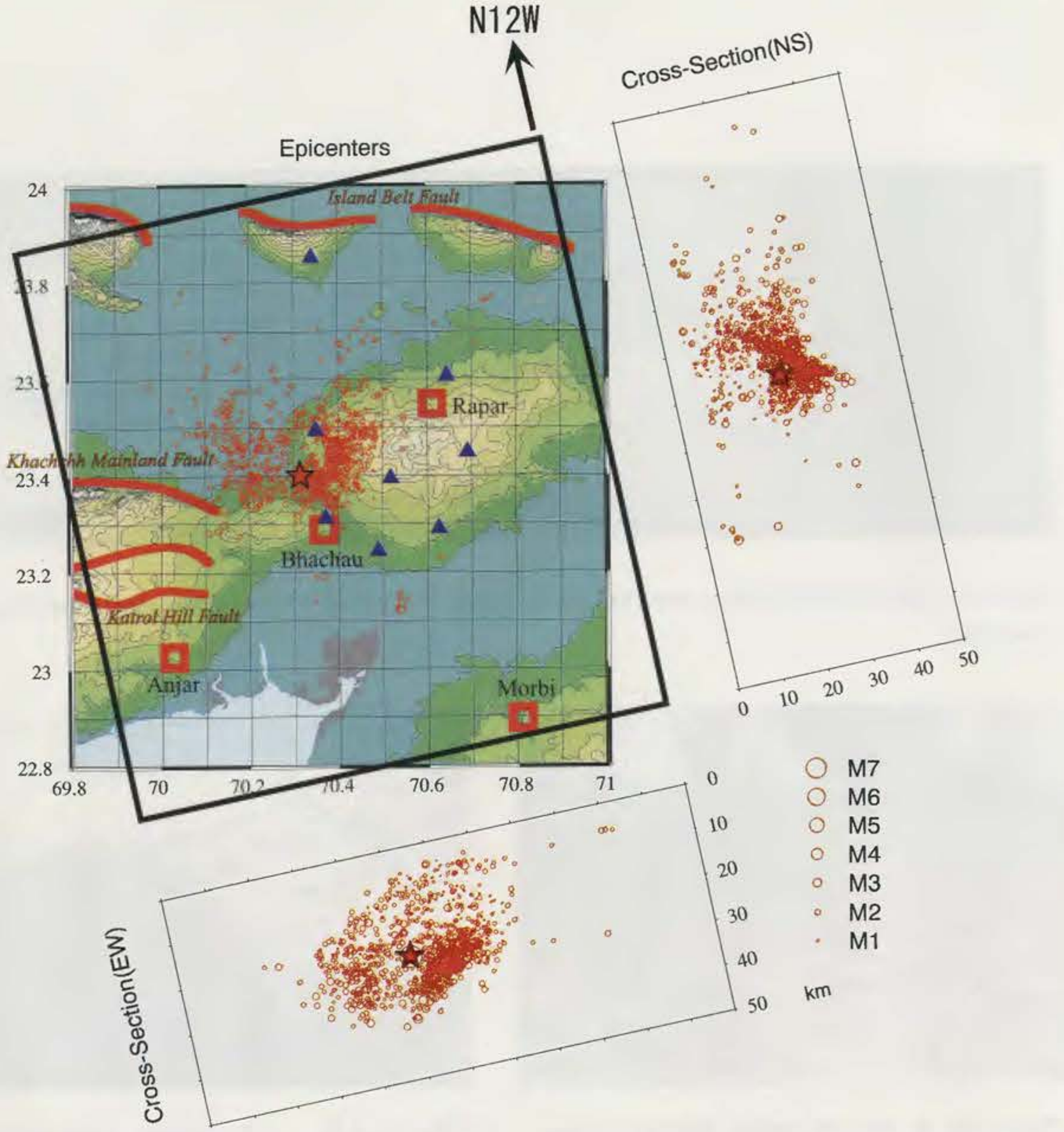

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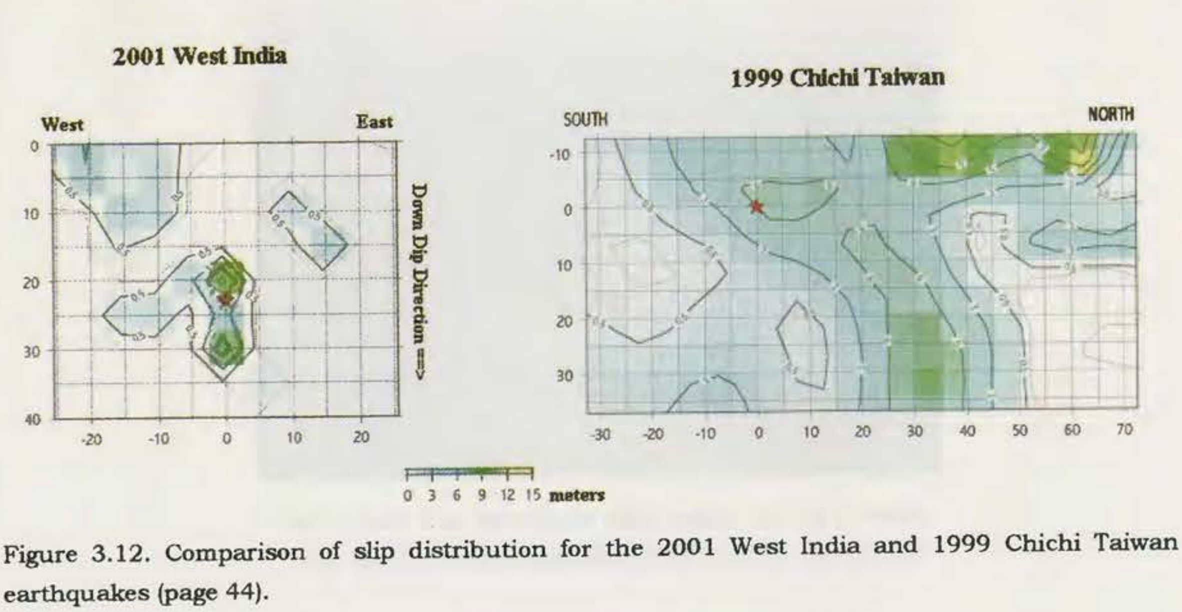

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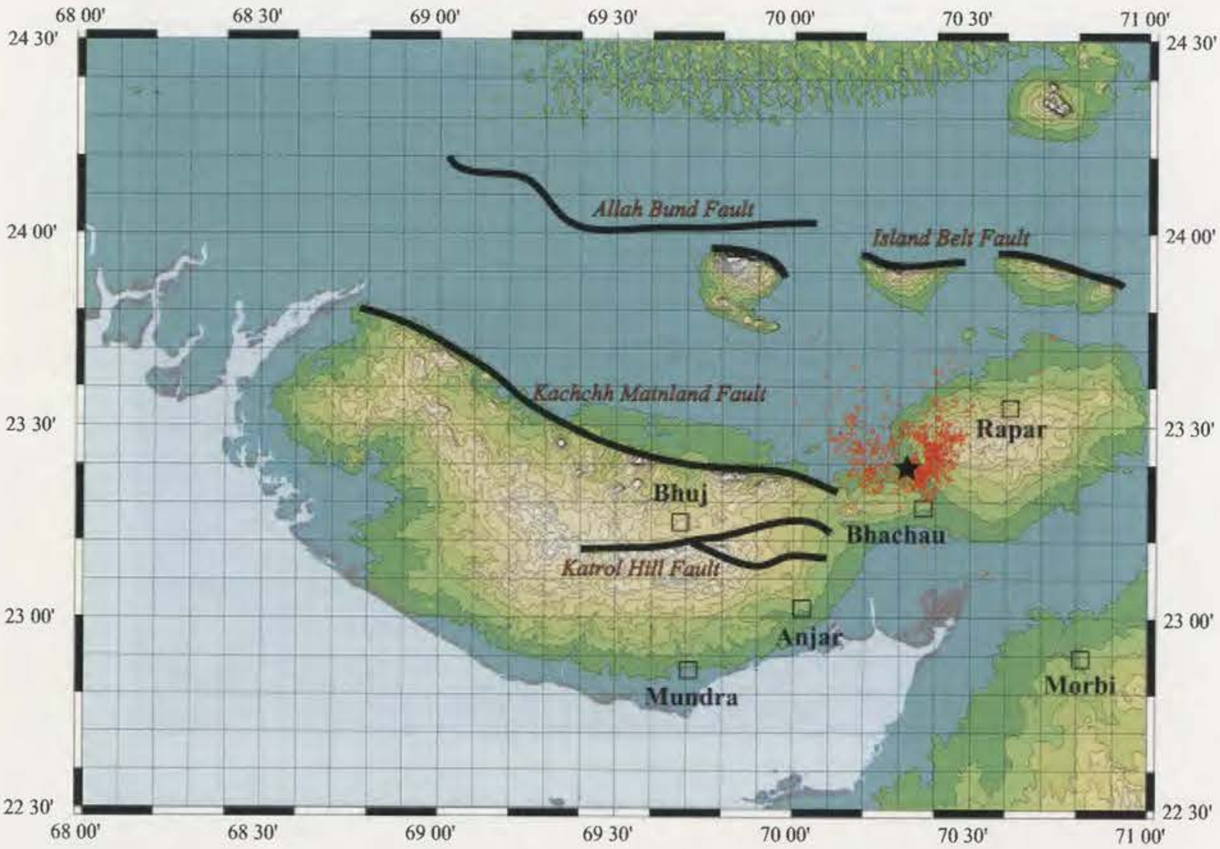

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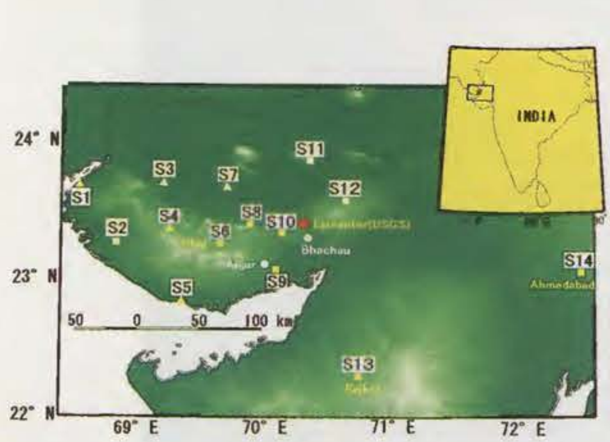

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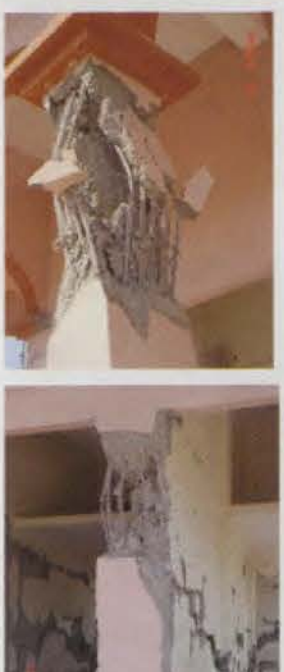

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FORWARD

Tamao Sato

A devastating earthquake of magnitude Mw 7.7 rocked the Kachchh District, Gujarat State, India, on January 26, 2001. This earthquake was the most deadly in India's recorded history. As of March 20, about two months after the earthquake, official figures from the Government of India placed the death toll at 20,005 with 166,000 injured and 247 missing. The number of destroyed houses is estimated at 370,000 and damaged houses at 920,000 with 600,000 people left homeless. Because of the compressional stress resulting from India's northward collision with Asia, the Kachchh Peninsula has a long history of strong earthquakes.

With a Grant-in-Aid for Scientific Research from the Monbu-Kagaku-sho (Japanese Ministry of Education, Culture, Sports, Science and Technology), a research team was formed and dispatched to Gujarat for investigating seismological aspects of this earthquake and evaluating the earthquake damage. The team consisted of eighteen members including four Indian researchers. A list of the members is shown below. The research team set four main targets for the investigations, i.e., (1) search for surface faults associated with the earthquake, (2) aftershock observation for determining the configuration of the main-shock fault, (3) GPS monitoring of post-seismic crustal deformation, and (4) evaluation of casualties

Members of the Research Team

(1) Search for surface faults associated with the earthquake

Takashi Nakata	Hiroshima University, Japan
Hiroshi Sato	Earthquake Research Institute, University of Tokyo, Japan
Toshikazu Yoshioka	National Institute of Advanced Industrial Sci. and Technology, Japan
Javed N. Malik	JSPS Fellow at Hiroshima University, Japan

(2) Aftershock observation

Tamao Sato	Hirosaki University, Japan (Leader)
James J. Mori	Disaster Prevention Research Institute, Kyoto University, Japan
Hiroaki Negishi	National Research Inst. for Earth Sci. and Disaster Prevention, Japan
Ramesh P. Singh	Indian Institute of Technology Kanpur, India

(3) GPS monitoring of post-seismic deformation

Kaoru Miyashita	Ibaraki University, Japan
Teruyuki Kato	Earthquake Research Institute, University of Tokyo, Japan
Gurubax S. Lakhina	India Institute of Geomagnetism, India

(4) Evaluation of caualties and damage to buildings and lifelines

Hitomi Murakami	Yamaguchi University, Japan
Yoshiaki Hisada	Kougakuin University, Japan
Yasuhiro Hayashi	Disaster Prevention Research Institute, Kyoto University, Japan
Sumio Sawada	Disaster Prevention Research Institute, Kyoto University, Japan
Venkataramana Katta	Kagoshima University, Japan
Masanori Hamada	Waseda University, Japan
Dilip K. Paul	University of Roorkee, India

and damage to buildings and lifelines. The field survey was carried out from 18 February to 13 March, about a month after the earthquake occurred.

Although the debris from collapsed houses and buildings along the crowded streets had already been removed in many places, we still saw numerous areas where there were piles of debris which had remained untouched along the narrow alleys in severely damaged areas. We witnessed many evacuees taking shelter in tents on the outskirts of towns and villages. Because of several damaging earthquakes in the past, the Kachchh District in Gujarat State had the highest rank in the seismic risk evaluations of India. Unfortunately, the awareness of the seismic risk did not facilitate implementation of earthquake-resistant design codes on the traditional buildings, which are quite vulnerable to strong ground shaking. It was fortunate that the earthquake took place in the dry season, otherwise the restoration following the devastating disaster would have been much harder.

This report mainly consists of contributions from the members of the research group supported by the Monbu-Kagaku-sho. But it also includes some papers written by researchers who closely collaborated with us from the start of this investigation. The addresses of all the authors who contributed to this report are listed in the appendix. We sincerely hope that the knowledge and insight gained during the present study will help in understanding the seismic hazard in this region and in reconstructing towns that are resilient in future large earthquakes.

In the literature, this earthquake of 26 January 2001 is called by different names, such as the Bhuj earthquake, Kachchh earthquake, Gujarat earthquake, and West India earthquake. In this report this event is for the most part referred to as the Gujarat earthquake, but the readers may find the event being called by other names throughout the text.

Soon after we returned to Japan from the field survey in India, we started to post the latest information on the progress of our investigations on a webpage. The webpage contains many photos showing damage to buildings, sites of surface deformation and liquefaction, etc., which are not included in this report because of lack of space. For this information, the readers are referred to the following web site:

http://kouzou.cc.kogakuin.ac.jp/mext/india

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This study was made possible by a Grant in Aid for Scientific Research provided by the Monbu-Kagaku-sho (Japanese Ministry of Education, Culture, Sports, Science and Technology). We are grateful to the personnel of the Ministry for funding our research project for this unexpected natural disaster. Professor Naoshi Hirata was instrumental in planning and organizing the research team at the onset. We thank him for his valuable assistance. Our thanks are also due to the Disaster Survey Committee of the Seismological Society of Japan, the Disaster Committee of the Architectural Institute of Japan, the Earthquake Engineering Committee of the Japan Society of Civil Engineers, and the Public Relations Committee of the Japan Association for Earthquake Engineering. They provided us with advice and support throughout the present study.

The research team was supported by many Japanese and Indian coworkers, especially, the following people: Yousuke Aoki, Kimiro Meguro, Fumiaki Uehan and Pradeep K. Ramancharla (Univ. of Tokyo); Toshifumi Imaizumi (Yamanashi Univ.); Hitoshi Tanaka and Susumu Kono (Kyoto Univ.); Chapidi D. Reddy (India Institute of Geomagnetism); Sushil Kumar, George Philip and Ambrish K. Mahajan (Wadia Institute of Himalayan Geology); Sanjay Pareek (Nihon Univ.); Ramanand N. Dubey, Ashwani Kumar (Univ. of Roorkee); Kathamana Vijaykumar (Ibaraki Univ.); Rama V. Karanth (Baroda Univ.). We thank these people for their cooperation that was very helpful in many aspects. Without the guidance of the Indian coworkers in the field, we could not have performed the necessary investigations so efficiently.

We express our gratitude to the Japanese Ministry of Foreign Affairs for issuing a diplomatic document to secure the welfare of the reconnaissance team in India. We thank Air India for providing extra freight service free of charge. The generosity of the airline company allowed us to transport the necessary equipment within our budget.

Contents

1. Tectonic Setting

Tamao Sato

The 2001 Gujarat earthquake occurred in western Gujarat state in an area about 300 km south of the Himalayan Frontal Fault System, where the Indian and Eurasian plates collide, and about 400 km east of the junction between the Owens Fracture Zone, Makran subduction zone, and Chaman Fault (Figure 1.1). This area is considered to be a stable continental region (Johnston, 1996) or a transition between stable continent and the active plate boundary. Even though the area is located away from the major plate boundaries, there are large east-west trending compressional features that cross the Kachchh Peninsula. The east-west structures include the Kachchh Mainland (uplifted and folded highlands of Mesozoic rocks) which is bordered on the north by the Kachchh Mainland fault and on the south by the Katrol Hill Fault (Malik et al., 2000). North of the Kachchh Mainland is the broad Banni Plain and farther north are the large salt flats that comprise the Rann of Kachchh (Photo 1.1). In the Rann of Kachchh are several more east-west trending faults, including the Island Belt, Allah Bund, and Nagar Parkar faults. These features are thought to be reactivated Mesozoic rifts (Rajendran and Rajendran, 2001). The Kachchh rift basin was created in successive stages during the migration of the Indian plate after its break from Gondwana in Late

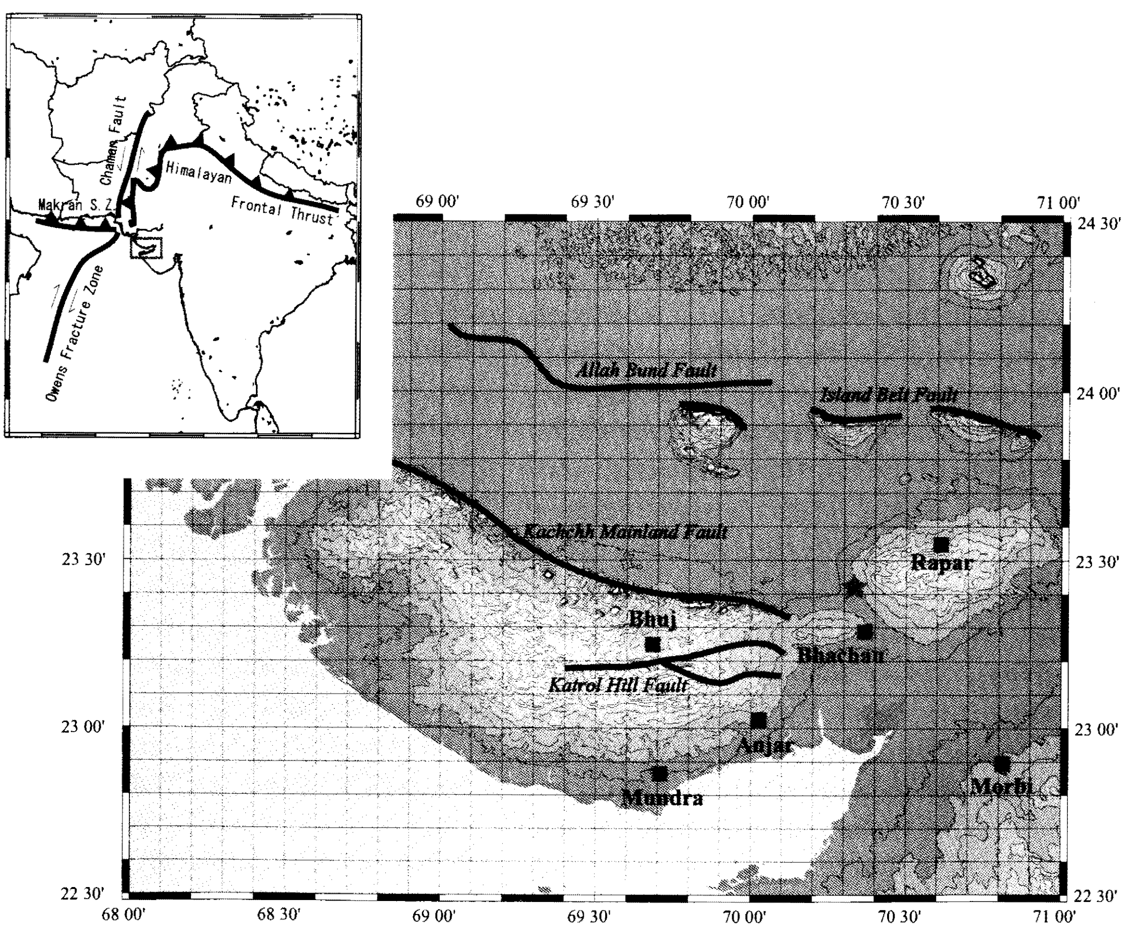

Figure 1.1. Tectonic and regional map of the area of the 2001 Gujarat Earthquake.Red star denotes the epicenter of the 2001 earthquake determined by IRIS. Faults are after Malik et al. (2000).

Photo 1.1. Looking northward over the Banni Plain from the Kachchh Mainland.

Triassic or early Jurassic (Biswas, 1982). The onset of collision of India with the southern margin of Eurasia occurred in late Paleocene-Eocene time (Patriat and Achache, 1984; Jaeger et al., 1989) and following collision the Kachchh rift basin sustained stress reorientation. By late Miocene the east-west trending Kachchh rift basin 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 Pennisula has a history of active seismicity (Table 1.1) with several large damaging earthquakes in the magnitude 6 to 7 range over the last several hundred years (Quittmeyer and Jacob, 1979, Rajendran and Rajendran, 2001). The largest known historical event in the region was the 1819 earthquake (M7.5) that caused considerable damage in Bhuj and Anjar and 1500 casualties. This earthquake is notable for producing the Allah Bund (Wall of God) which is a 90km long feature with vertical uplifts of up to 4.3 m. Rajendran and Rajendran (2001) claim that this feature is a composite scarp formed from a series of earthquakes. Prior to the 2001 Gujarat earthquake, the 1819 event was considered to be the 4th largest historical earthquake in a stable continental region (Johnston and Kantor, 1990).

More recently the 1956 Anjar earthquake (Ms 6.1) occurred south of Bhuj with a thrust mechanism and compression in a north-northwest direction (Chung and Gao, 1995), similar to the 2001 event. Slightly further away, the October 24, 1969 Mt. Abu earthquake (M5.3) to the northeast and the March 23, 1970 Broach earthquake (M5.4) to the southeast, also had thrust mechanisms with north and north-northwest compression directions, respectively (Chandra, 1977). There are also numerous other small events (M3 to 5) scattered throughout the region (Malik et al., 2000).

Table 1.1. List of events in the Kachchh Peninsula up to 1996 after Rajendran and Rajendran (2001).

Date	Lat.(°N)	Lon.(°E)	Magnitude
00-05-1668	24.00	68.00	Moderate?
16-06-1819	24.00	70.00	7.5
13-08-1821	23.00	70.00	5
19-06-1845	24.00	69.00	>6
25-12-1856	20.00	73.00	5
29-04-1864	24.00	70.00	6
14-01-1903	24.00	70.00	6
18-11-1927	21.05	68.00	>5
31-10-1940	23.70	69.90	>5
21-07-1956	23.34	70.20	6.0
23-03-1970	21.60	72.96	5.2
18-07-1982	23.40	70.66	4.8
30-04-1991	20.78	73.30	--
24-08-1993	20.60	71.30	5.0
31-12-1993	21.20	68.70	4.3
01-08-1995	22.10	40.00	4.2
17-02-1996	23.20	69.40	4.5
17-11-1996	21.50	73.00	4.2

The 2001 Gujarat earthquake occurred west and north of the mapped Kachchh Mainland fault under the Banni Plains. The hypocenter parameters posted by IRIS currently are

OT= 1/26/2001 03h16m41s (UT)
Epicenter= (23.40°N, 70.32°E)
Depth=23.6 km
Mw = 7.7

The parameters revised by USGS/NEIC most recently are

OT= 1/26/2001 03h16m40.50s (UT)
Epicenter= (23.42°N, 70.23°E)
Depth=16 km
Ms = 8.0

The fault plane solutions by different institutes all indicate a reverse fault striking in east-west direction with the axis of maximum compressional stress roughly in north direction, in agreement with the east-west trending structures in the Kachchh Peninsula. Its shallow focal depth and large magnitude suggested that the fault of this earthquake would have manifested itself at the surface. Despite of efforts made by many geologists, however, the causative fault had not yet been found at the surface when our reconnaissance team arrived at the epicentral area.

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