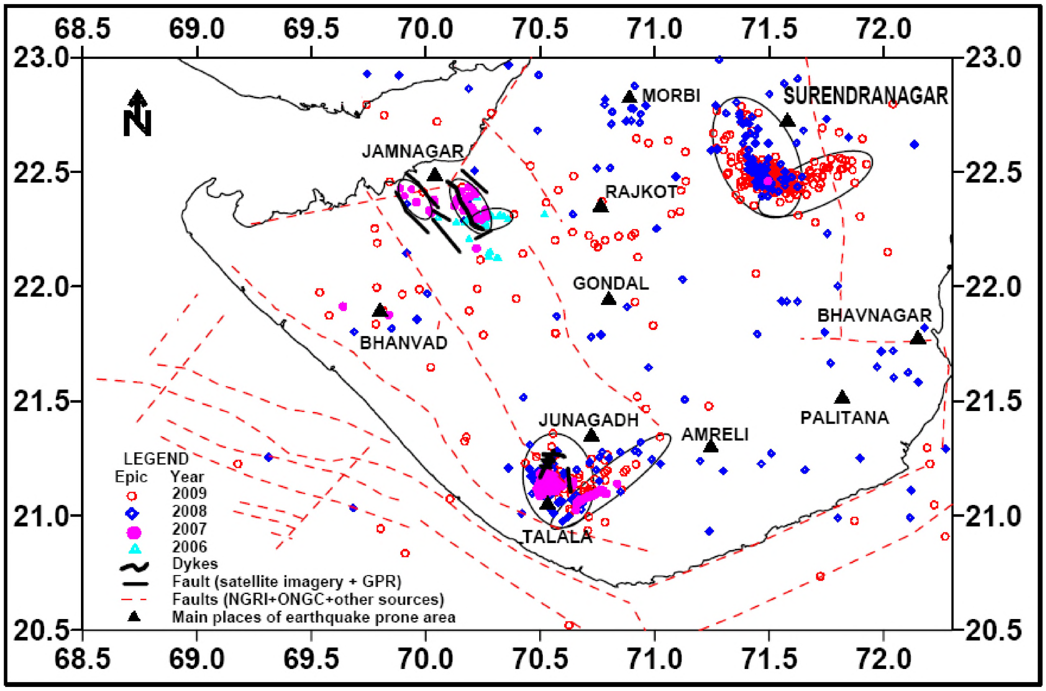
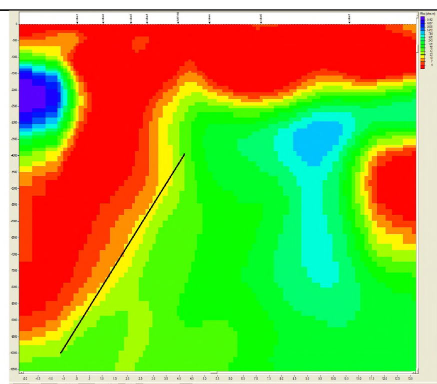
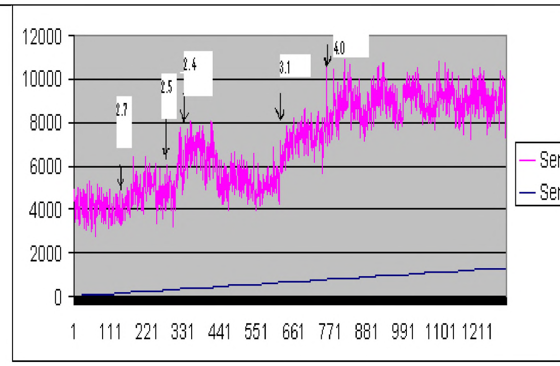
Institute of Seismological Research

ANNUAL REPORT: 2009-10







Department of Science & Technology,
Government of Gujarat
Raisan, Gandhinagar-382 009

Web: www.isr.gujarat.gov.in Email: dg-isr@gujarat.gov.in

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Prologue

In a short span of about four years, the Institute of Seismological Research at Gandhinagar, Gujarat has been developed into a Centre of Excellence in Earthquake Science. It has its own sprawling campus and has rich assemblage of laboratories and instruments. As has been expressed by several national and international experts, this Institute is bound to be developed as one of the best Centre in the world of Seismology due to all round facilities available and beautiful ambience of the campus and city. The Institute has now the strength of over 23 Scientists, 25 Research Scholars and 25 Technical Personnel working on various aspects of seismological research. The work of Institute can be categorized into five areas: (i) Earthquake Monitoring, (ii) Study of Physics of the Earthquake Processes, (iii) Earthquake Hazard Assessment using Geophysical Surveys, GPS studies and paleoseismology, (iv) Earthquake Prediction Research and (v) Seismic Microzonation. For initial few years, ISR is concentrating over the Gujarat region. However, from this year, it has started expanding its activities in other parts of the country. In this direction, ISR has started participating in a project on Active Fault Studies in the Himalayas. During 2009, the Optically Stimulated Luminescence (OSL) and the Geotechnical Laboratories became functional and Tsunami modeling was done over the Indian Ocean.

Gujarat seismic network of 50 Broadband Seismographs and 50 Strong Motion Accelerographs has been operated smoothly during 2009. Data of 19 broadband stations were processed in real-time through VSAT at ISR round the clock to determine the epicenter and magnitude of earthquakes within minutes of arrival of the seismic waves.

Seismicity in Gujarat has increased multifold in the first decade of the 21st Century. The seismicity in Kachchh was found to have been extended first eastward and north-eastward and then in the north along newly activated faults from 2006 to 2008. Further it extended to the Saurashtra region since 2006. The seismicity seems to be affected by the 2001 Great Bhuj Earthquake and the long-distance and long-delayed triggering have been explained to be caused by rheological and visco-elastic changes in the upper mantle. Coulomb stress has been estimated due to earthquakes in the NW Himalayas. Tremors in Kachchh have been found to be preceded by clustering of small earthquakes and quiescence.

Work continued towards preparation of probabilistic seismic zoning map of India; the task assigned to ISR by the Bureau of Indian Standards. A catalog of earthquakes in India and the surrounding regions has been prepared; seismic zones have been marked and the statistical parameters 'a' and 'b' have been estimated. Acceleration attenuation has been worked out for the Gujarat region and correlated with local ground conditions and Vs30.

Seismic, gravity, magnetotelluric, resistivity, GPR and other geophysical surveys were carried out for study of crustal structure and faults. Detection of active faults and pre-historic earthquakes in Kachchh continued through paleoseismological studies.

Crustal deformation study is being carried out through GPS measurements in seismically active belts of Gujarat. Twenty-two permanent GPS stations were setup in Gujarat and eleven campaign mode GPS stations were deployed in the Kachchh region. InSAR studies continued in Kachchh.

Microzonation was carried out at Dholera Special Investment Region (SIR), Gujarat International Finance Tech (GIFT) city and Gandhinagar. Microzonation at Bharuch was started in collaboration with Geological Survey of India. Seismic Vulnerability and Risk Assessment at Gandhidham was carried out in collaboration with IIT, Hyderabad and IITk. Assessment of seismic vulnerability of the installations in coastal regions of Gujarat was carried out.

For Gandhinagar area, a number of boreholes have been drilled for soil investigations; information on soil characteristics available at different agencies has been compiled. Vs30 measurements were carried out at a few more sites and amplification due to actual earthquakes has been estimated from broadband seismographs deployed at several locations. Study of site response, amplification factor, shear-wave velocity to 30 m depth, soil strength and liquefaction potential has been continued for microzonation of Kachchh.

Microzonation studies in 250mx250m grid including measurements of Vs30, resistivity, and geotechnical investigations through about 100 boreholes were carried out in Dholera SIR Region. Seismotectonic investigations including seismic reflection, seismic refraction and geotechnical investigations were carried out in Mundra area.

Earthquake Research Center at Bhachau and three multi-parametric geophysical observatories for earthquake prediction research in Kachchh were run smoothly. Precursory signals were observed in radon, gravity and magnetic fields.

Five research papers in SCI Journals and three research papers in non-SCI Journals, 11 Technical Reports and fifteen abstracts were published and few of them were presented by ISR Scientists in Seminars/Symposia. Several new studies were started during last year and I am confident that significant findings from these studies will help in understanding physical processes of earthquake phenomenon and seismic hazard assessment in Gujarat.

ISR is indebted to the Gujarat Chief Minister, Sc. & Tech. Dep't., GSDMA, GIDB, GSPC and various other Departments of GoG, like Finance and General Administration as well as MoES - GoI, ISRO, NPCIL, World Bank, Asian Development Bank, National Geophysical Research Institute for their contribution towards the development of ISR.

Dr. B. K. Rastogi
Director General

CONTENTS

1 SEISMICITY OF GUJARAT FROM HISTORICAL TIME TO 2009

The earthquake catalogue of Gujarat and the adjoining region bounded by 20^0–25.5^0 N and 68^0–75^0 E has been prepared from the earliest times to 2009 with the help of all available earthquake catalogues (historical and recent) pertaining to the region. Historical earthquakes of this region before 1900 were taken from the catalogue prepared by Oldham (1883). The catalogues prepared by Tandon and Srivastava (1974), Chandra (1977), Quittmeyer and Jacob (1979), and Malik et al. (1999) for this region and the Indian subcontinent have also been taken into consideration for some other historical and modern earthquakes. The Intensity values given for historical earthquakes have been converted to magnitude using relation between Magnitude and Intensity. The sources of modern seismicity database are India Meteorological Department (IMD); Geological Survey of India (GSI); NEIC-USGS; International Seismological Centre (ISC); Gujarat Engineering Research Institute (GERI), National Geophysical Research Institute (NGRI) and Institute of Seismological Research (ISR). The catalogue contains 217 earthquakes of magnitude greater or equal to 2.0. This catalogue contains total 37 earthquakes of magnitude ≥ Mw 5.0, 73 earthquakes between M 4.0 - 4.9, 89 earthquakes between 3.0-3.9 and 18 earthquakes of M < 3.0. Locations of these earthquakes are shown in Fig.1.1.

The catalogue has been homogenized for magnitude Mw taking the equivalent values. Aftershocks have been removed from the whole catalogue. As most of the regions have been populated for centuries, it is expected that for the last 200 years no earthquake of magnitude ≥ 4 is missed as, such earthquakes are found to be felt strongly in wide areas. However, the catalogue completeness has been also assessed with respect to time and it is observed that for the earthquake of magnitudes M 4.0-4.5, it is complete for the period 1918 -2009, for M 4.6-5.0, it is complete for 1908 - 2009, for M 5.1-5.5, it is complete for 1890 -2009 and M ≥ 5.5 for 1802 – 2009.

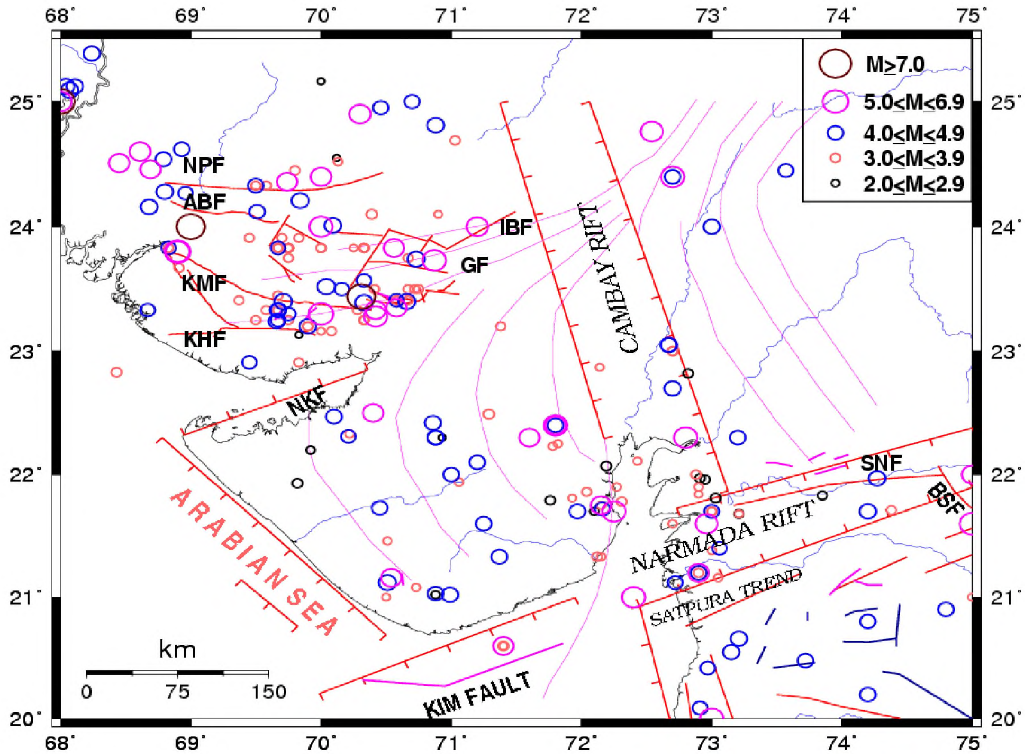


Fig. 1.1: Felt earthquakes from historical times to 2009

2 EARTHQUAKE MONITORING AND SEISMICITY PATTERNS IN GUJARAT (Sumer Chopra, Santosh Kumar, Sandeep Aggarwal, Babita Sharma, Srichand Prajapati, Mukesh Chauhan, Pallabee C., Kisansinh Zala, Vandana Patel)

2.1 SEISMIC NETWORK

Gujarat State Seismic Network being maintained by Institute of Seismological Research, Gandhinagar since July 2006 (Fig. 2.1) functioned well with 19 Broadband Seismological Stations (BBS) spread throughout the state and connected via VSAT to ISR, 25 offline broadband seismographs, 3 offline very broadband seismographs and 50 Strong Motion Accelerographs (SMA) . The network has detectibility of M 2.0 in the Kachchh active area and M 2.5 in the other areas of Gujarat.

2.2 STRONG MOTION ACCELEROGRAPH DATA

Strong Motion Accelerographs (SMA), which record near-source strong motion, recorded a total of 114 strong motion time histories for 58 earthquakes of magnitude between 2.1 and 4.4, during the year 2009. The M4.1 shock that occurred on 12-04-09 was recorded on 7 stations. M4.3 shock that occurred on 05-09-2009 was recorded on 11 stations. M4.1 earthquake that occurred on 09-10-2009 was recorded on 3 stations and M4.4 shock that occurred on 28-10-2009 was recorded on 8 stations.

Table 2.1.a: List of earthquakes recorded by Accelerographs

YEAR	MON	DD	HR	MIN	SEC	LAT	LONG	DEPTH	M	NST
2009	2	7	17	18	3.3	23.636	70.497	27.9	3	3
2009	2	13	18	45	17.1	23.385	70.363	25.1	2.6	1
2009	2	20	11	7	28	23.749	70.533	6.5	2.7	1
2009	2	26	8	11	57.6	23.553	70.347	31.1	3.7	2
2009	3	3	1	1	56.4	23.314	70.297	15	1.5	2
2009	3	3	1	57	32.5	21.310	70.559	6.1	1.9	1
2009	3	4	22	39	58.4	23.337	70.271	11.3	2.5	1
2009	3	10	2	34	49.5	23.450	70.434	15	2.1	1
2009	3	26	5	15	37.5	23.392	70.340	20.1	2.7	1
2009	3	28	15	25	45.6	23.535	70.340	13.3	3.3	1
2009	3	31	1	44	13.5	23.463	70.400	23.7	3.6	3
2009	4	1	17	29	3.9	23.450	70.417	24.6	2.6	1
2009	4	12	18	42	10.9	23.416	70.138	18.7	4	7
2009	4	15	21	15	14.3	23.573	70.507	20.3	3.3	1
2009	4	18	13	47	48.6	23.398	70.334	21.4	3.2	3
2009	5	8	4	55	6.4	23.585	70.149	30.5	2.6	1
2009	5	18	4	28	50	23.356	70.218	23.4	3.8	2
2009	6	24	9	44	58.5	23.400	70.117	17.7	3.3	2
2009	6	24	18	24	56	23.477	70.430	10.4	3.4	2
2009	6	27	1	56	37.6	23.495	70.407	15.1	3.4	2
2009	6	27	2	1	13.3	23.498	70.373	6.1	3.2	2
2009	6	28	8	32	11.9	23.378	70.351	25	3.5	4
2009	7	7	3	44	43.1	23.528	70.443	25.1	2.8	1
2009	7	23	17	21	51.5	23.577	70.093	8.7	3.2	1
2009	8	3	17	51	29.2	24.296	69.856	10.7	3.7	1
2009	8	21	3	13	12.5	23.848	69.876	6.8	1.7	1
2009	8	26	12	15	6.1	23.605	70.487	23.3	3.2	3
2009	8	29	10	4	17.8	23.606	70.420	17.5	3.3	1
2009	8	30	6	50	7.1	23.469	70.391	19.6	3.3	3
2009	9	3	17	54	39.2	23.504	70.405	23.9	3.7	1
2009	9	3	8	26	53.5	23.312	70.123	30	3.3	1
2009	9	5	6	40	7	23.405	70.228	26.4	4.3	11
2009	10	7	6	21	53.4	23.545	70.276	15	3.6	4
2009	10	8	5	56	54.1	23.506	70.416	24.4	3.2	1
2009	10	9	13	24	0.2	23.555	69.420	9.7	4.1	3
2009	10	14	10	23	13.2	23.439	70.478	23	3.4	2
2009	10	27	6	43	13.7	23.716	69.937	7.4	3.3	1
2009	10	28	13	40	10.2	23.710	69.909	8.5	4.4	8
2009	11	18	15	3	32.7	23.465	70.212	20	3.1	1
2009	11	29	10	23	28.3	23.396	70.072	20.6	3	1
2009	12	19	5	16	36.3	23.505	70.409	7.9	2.7	1
2009	12	30	4	4	18.8	23.352	70.201	19.7	3.3	1

Table 2.1.b: List of earthquakes recorded by accelerographs on single station.

Year	Mon	Date	Hr	Min	M	NST	Duration	Region/Station
2009	1	13	14	57	1.1	1	5	Near Hirenvel
2009	1	22	5	58	1.0	1	3	Near Hirenvel
2009	2	16	23	41	1.0	1	4	Near Hirenvel
2009	2	17	1	18	1.0	1	4	Near Hirenvel
2009	2	17	3	22	1.0	1	3	Near Hirenvel
2009	2	17	4	20	1.0	1	4	Near Hirenvel
2009	2	17	4	37	1.2	1	6	Near Hirenvel
2009	2	17	10	51	1.0	1	4	Near Hirenvel
2009	2	18	7	27	1.1	1	5	Near Hirenvel
2009	2	18	8	4	1.2	1	6	Near Hirenvel
2009	2	19	1	5	1.0	1	4	Near Hirenvel
2009	2	21	3	58	1.0	1	4	Near Hirenvel
2009	2	21	4	0	1.1	1	5	Near Hirenvel
2009	2	24	13	4	1.0	1	4	Near Hirenvel
2009	2	25	10	19	1.0	1	4	Near Hirenvel
2009	2	25	12	27	1.1	1	5	Near Hirenvel
2009	4	9	1	48	1.3	1	10	Near Khavda
2009	4	15	0	29	1.0	1	4	Near Hirenvel
2009	4	17	15	57	1.0	1	3	Near Hirenvel
2009	10	4	15	49	1.1	1	5	Near Hirenvel
2009	11	5	9	25	1.2	1	8	Near Nakhtarana
2009	11	11	11	33	1.0	1	5	Near Nakhtarana
2009	12	23	10	34	1.0	1	4	Near Nakhtarana

The Hirenvel (21.05°N 70.52°E) station is very near to epicenter of Talala earthquake of M5.0 that occurred on 6th Nov. 2007. The Khavda (23.99°N 69.75°E) station is about 80 km North of Bhuj city in district Kachchh. The Nakhtarana (23.34° N 69.27° E) station is situated at 55 km from Bhuj city in the western part of Kachchh.

2.3 DESCRIPTION OF EARTHQUAKES IN GUJARAT DURING 2009

Magnitude-wise distribution of earthquakes in the three regions of Gujarat during 2009 is shown in Fig. 3 and given in Table 2.2.

Table 2.2: Regional Distribution of Earthquakes Located in Gujarat during 2009

Region	M ≥4	3.0 to 3.9	2.0 to 2.9	< 2.0	Total	
Kachchh	4	72	422	1594	2092	
Saurashtra	-	6	22	420	448	
Mainland	-	-	36	65	41	
Total	4	78	480	2019	2581	

In the Kachchh region 2092 shocks were located (80% of total in Gujarat).
In the Saurashtra region 448 shocks were located (18% of total in Gujarat).
In the mainland 41 shocks were located (2% of total in Gujarat).

During 2009, the network recorded 2623 shocks of magnitude 0.5 to 4.4 in Gujarat out of which hypocentral parameters of 2581 shocks were located (Fig. 2.2). Additional 24 regional and 36 distant earthquakes of magnitude 6.5 or greater were recorded. This year there was no large or even moderate earthquake in Gujarat. All were small tremors or microearthquakes, the largest 4 tremors being in the magnitude range 4 to 4.9 in Kachchh (Table 2.3). Focal depths of Kachchh earthquakes are depicted in Fig. 2.3

Table 2.3: List of earthquakes of magnitude ≥ 4 which occurred during 2009 in Kachchh (*one in Pakistan)

S. No.	Date	Lat. Lon.	Depth	Magnitude
1	12 Apr. 2009	23.42 70.14	18.7	4.1
2	05 Sep. 2009	23.39 70.22	26.4	4.3
3	09 Oct. 2009	24.56 69.49*	10.0	4.1
4	28 Oct. 2009	23.71 69.91	8.5	4.4

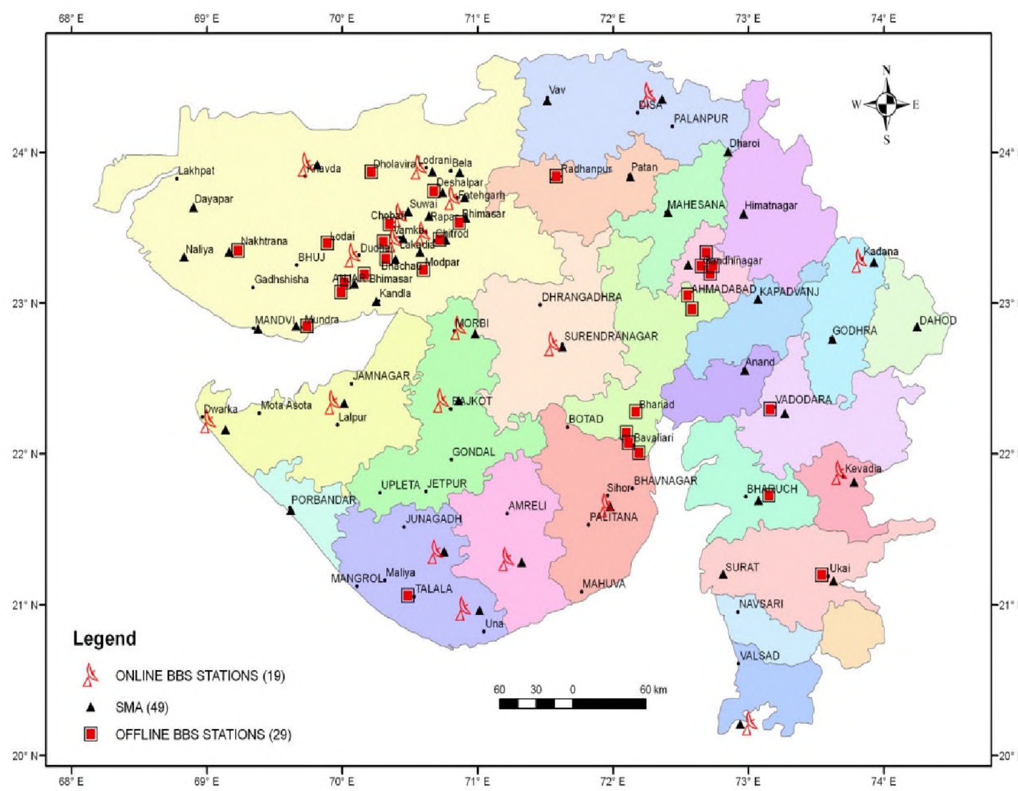


Fig. 2.1: Seismograph stations in Gujarat Net including 19 online Broad Band Seismographs, 3 online Very Broad Band Seismographs, 29 offline Broad Band Seismographs and 49 Accelerographs.

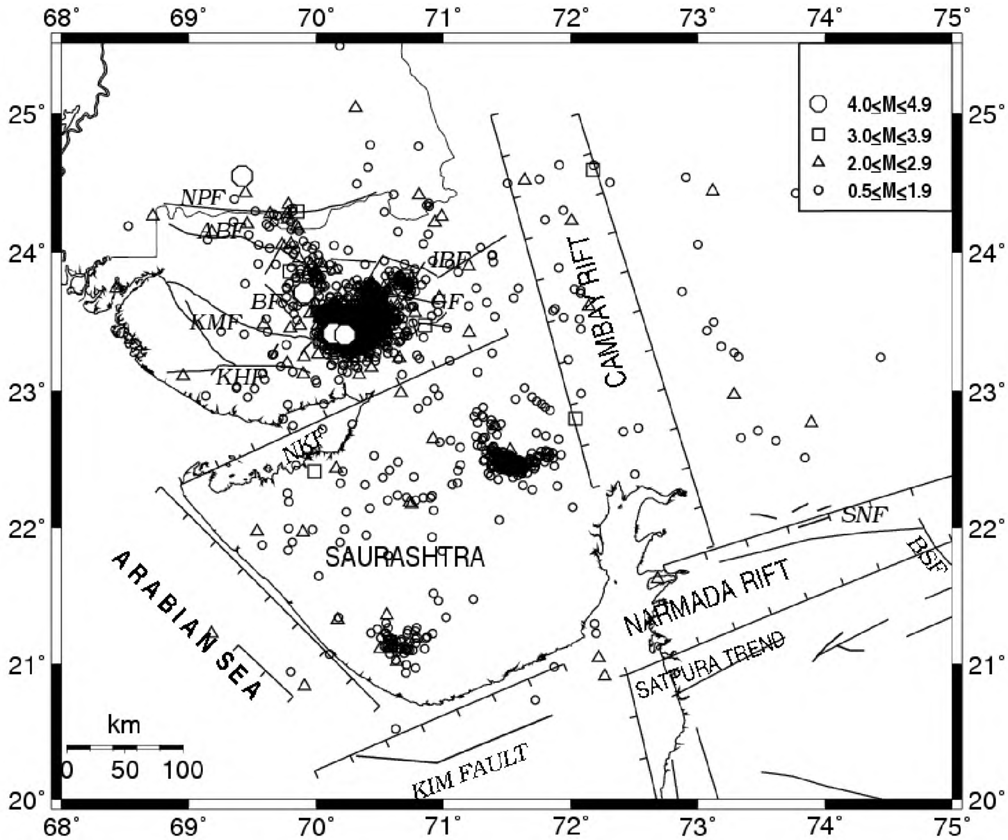


Fig.2.2: Epicenters of earthquakes in Gujarat during 2009

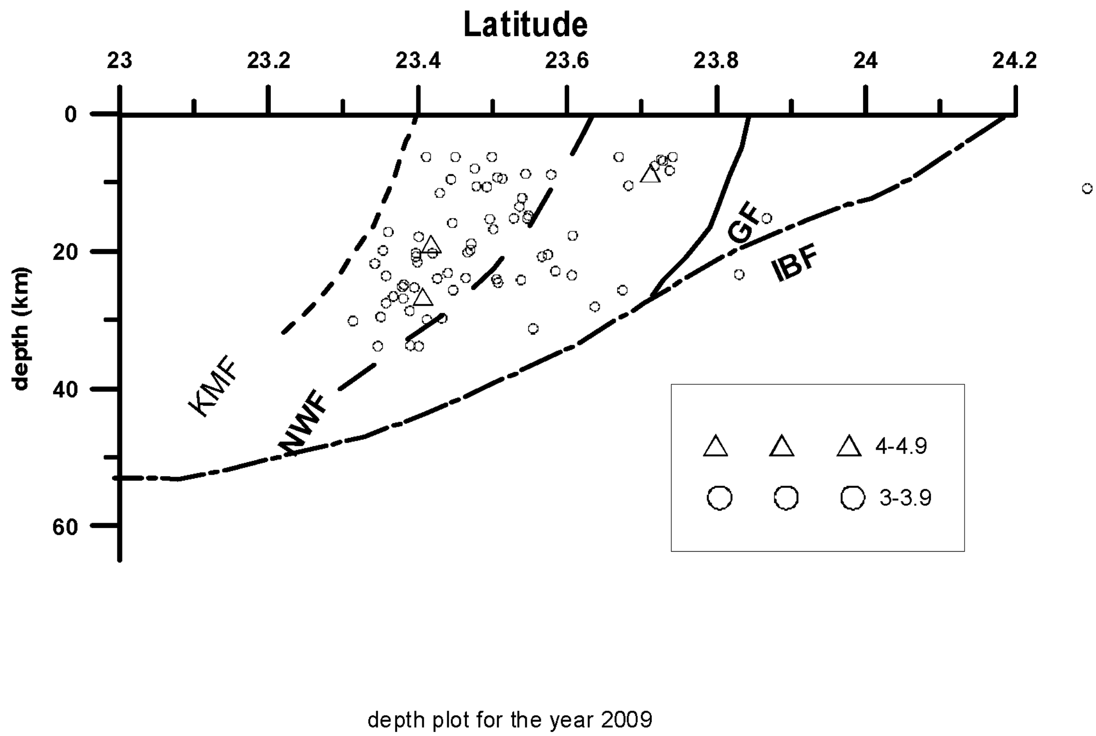


Fig 2.3: Focal depths of the earthquakes in Kachchh during 2009.

2.4 Description of earthquakes in different parts of Gujarat during 2001 - 2009

Seismicity in Kachchh:

The aftershocks activity is continuing north of Bhachau, close to the North Wagad Fault, since the 26th Jan. 2001 damaging earthquake of Mw 7.7 and activity has spread in adjoining areas. Though seismicity reduced from 2002, there was a spurt of increased activity for the two years period of 2005-2006. During this period the activity migrated to the Wagad area towards E and Gedi fault to the NE. Subsequently it further migrated to Allah Bund and Island Belt in the north and Saurashtra in the south. In Kachchh until 2009, 2154 earthquakes are of magnitude M3-3.9, 271 earthquakes are of magnitude M4-4.9 and 20 are of magnitude M5.0-7.7. Fig. 2.5 depicts number of earthquakes in Kachchh during 2001 to 2009 in three magnitude categories. Fig. 2.6 depicts the annual number of earthquakes in Kachchh during 2001 to 2009 in three magnitude categories. Fig. 2.7 shows the focal depths.

Table 2.4 gives the annual number of earthquakes in Kachchh in three magnitude categories of 3-3.9, 4-4.9 and ≥5 while Table 2.5 lists earthquakes of magnitude M≥5.0 in the Kachchh region during 2001 to 2009

During 2006 there were 4 damaging earthquakes of magnitude 5.0 to 5.7, 49 slightly damaging earthquakes of M4-4.9 and 312 strongly felt shocks of M3-3.9. During 2007 there were 6 slightly damaging earthquakes of M4-4.9 and 82 strongly felt shocks of M3-3.9. During 2008 there were 5 slightly damaging earthquakes of M4-4.9 and 66 strongly felt shocks of M3-3.9. During 2009, 4 strong tremors of M4-4.4 and 75 strongly felt shocks of M3-3.9 have been identified. List of the significant earthquakes of magnitude M≥ 4.0 that occurred in the Kachchh region during 2009 is given in Table 2.3.

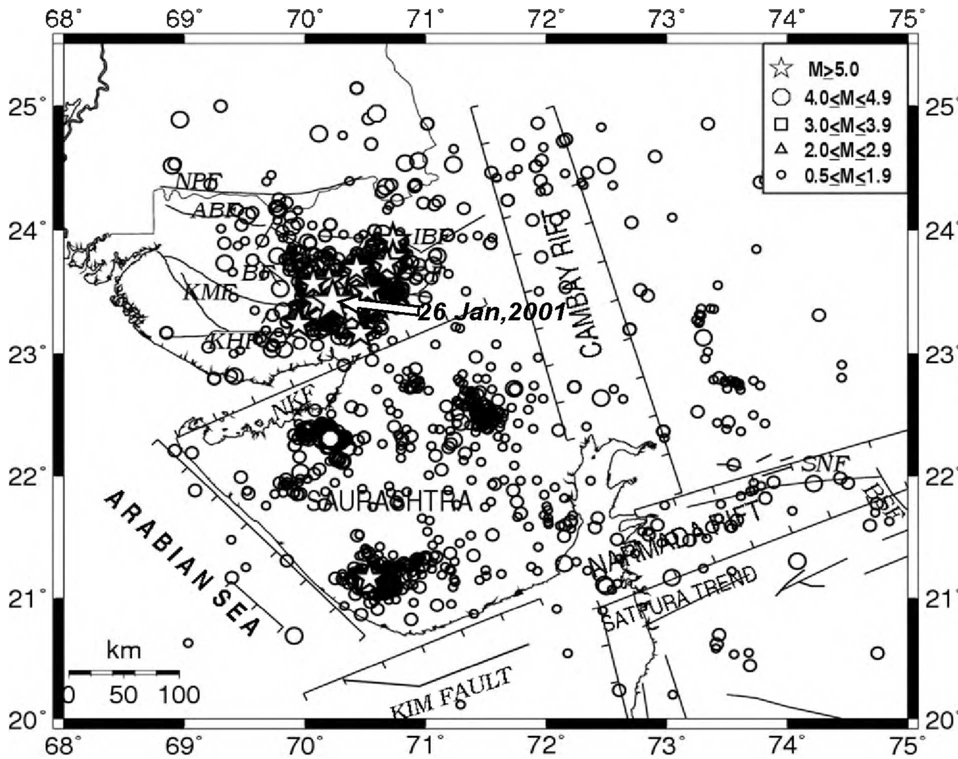


Fig. 2.4: Epicenters of earthquakes in Gujarat during 2001-2009

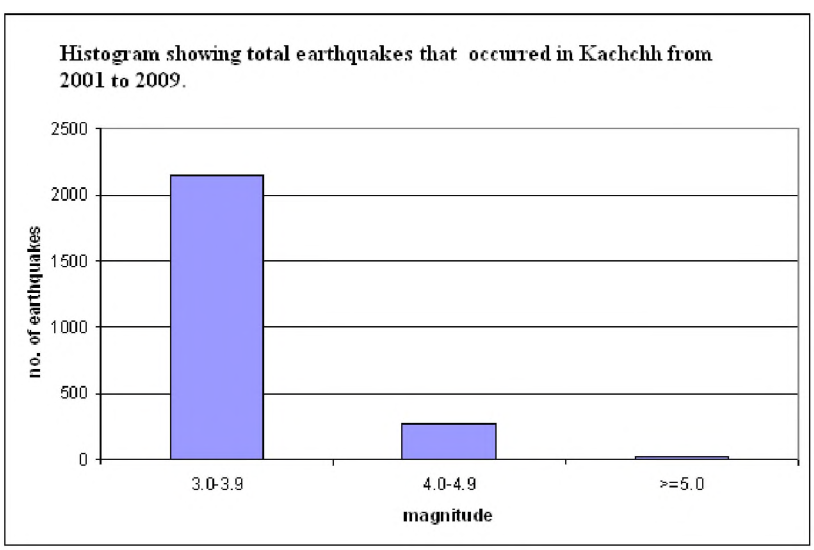


Fig. 2.5: Seismicity of Kachchh during 2001 to 2009 in three magnitude categories

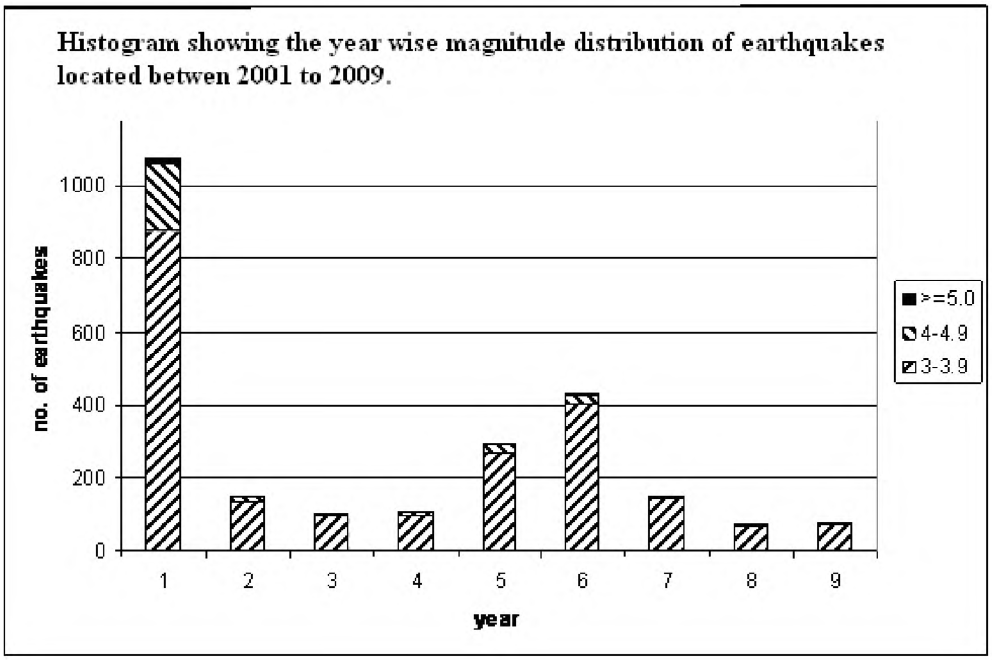


Fig. 2.6: Year-wise seismicity of Kachchh during 2001 to 2009 in three magnitude categories

Table 2.4: Year wise seismicity distribution in Kachchh region
(Source: NGRI+ISR+USGS+IMD)

Year **M**	2001	2002	2003	2004	2005	2006	2007	2008	2009	Total
3.0-3.9	877	135	98	99	267	405	143	66	73	2154
4.0-4.9	186	15	3	6	16	20	6	5	4	271
5.0-7.7	15	__	1	__	__	4	__	__	__	20
Total	1078									

Table 2.5: List of earthquakes of magnitude M≥5.0 in the Kachchh region during 2001 to 2009

S.No.	year	Mn	date	hr	mn	Sec	Lat	long	depth	Ml	Mb	Ms
1	2001	1	26	3	16	40.5	23.42	70.23	16	6.9	7.7 (Mw)	
2	2001	1	26	3	33	29.17	23.25	69.84	10	5.5	5.3	
3	2001	1	26	3	55		23.399	70.599	10	5.0	4.9	
4	2001	1	26	3	58	59.47	23.246	69.47	10	4.8	5.0	
5	2001	1	26	4	23	41.97	23.421	70.119	10	5.2	5.2	
6	2001	1	26	4	48	14.25	23.25	70.35	10	5.2	5.1	
7	2001	1	26	7	32	28.74	23.425	70.076	9.2	5.2	5.2	
8	2001	1	27	4	36	8.41	23.40	70.38	9.7	5.1		
9	2001	1	28	1	2	10.7	23.65	70.64	9.2	5.7	5.8	6.0

10	2001	1	28	11	10	43.61	23.25	70.39	9	4.7	5.4	4.6
11	2001	2	3	3	4	32.89	23.66	70.43	9.1	5.1	5.3	5.0
12	2001	2	8	16	54	41.02	23.73	70.44	9.2	5.2	5.1	4.9
13	2001	2	19	2	11	14.5	23.52	70.235	9.1	5.0	4.6	4.8
14	2001	2	19	8	24	20.16	23.57	70.07	10	5.2	5.4	5.5
15	2001	3	4	7	54	23.47	23.17	70.46	19	5.0	4.8	4.7
16	2003	8	5	11	8	1.91	23.69	70.43	10		5 .0	4.7
17	2006	2	3	0	54	25.4	23.2	70.73	3	4.4	4.5	5.0Mw
18	2006	3	7	18	20	43.4	23.78	70.73	10	5.2	5.5	5.7Mw
19	2006	4	6	12	2	54.59	23.73	70.68	10	4.7	5 .0	
20	2006	4	6	17	59	18.2	23.34	70.39	29.3	5.5	5.5	5.6Mw

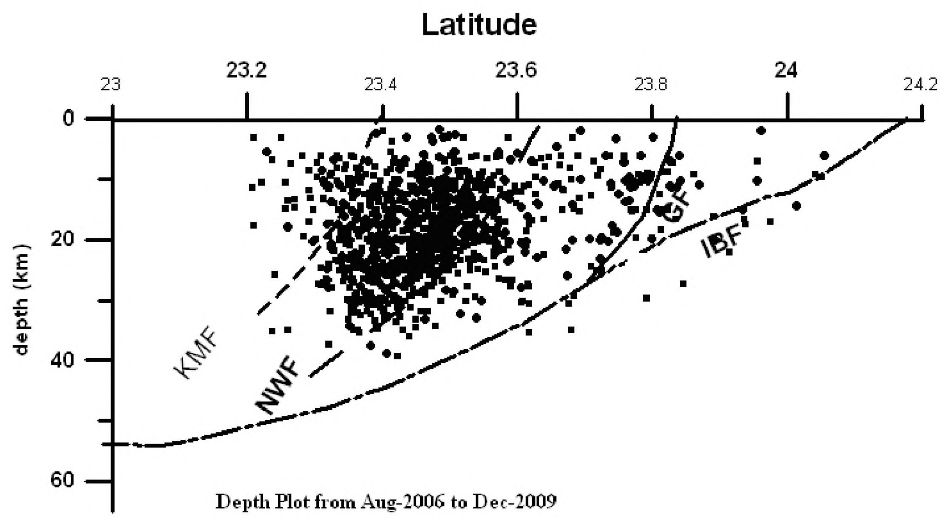


Fig 2.7: Focal depths of earthquakes in Kachchh recorded by ISR between the period Aug.2006 to Dec.2009

Earthquakes in Saurashtra:

Epicenters of earthquakes of magnitude 0.5 to 5.0 in Saurashtra are shown in Fig. 2.8. The zoomed portion of epicentral map in Jamnagar district is shown in Fig. 2.9 while that of Junagadh district in Fig. 2.10. During August 2006 to October 2009, 83 earthquakes have occurred of M3-3.9, **4** earthquakes of M4-4.9 and **1** earthquake of M5.0 in Saurashtra (Tables 2.6 to 2.8 and Figures 2.11 to 2.14). Currently tremors are concentrating at Talala (Mmax. 5.0 on 6th November 2007), South of Jamnagar (Mmax. 4.0 on 30th September 2006), Surendranagar (Mmax. 3.2 on 14th November 2008) and near Rajkot (Mmax. 3.0 on 28th march 2009). Around Talala the epicenters extended sparsely up to Dhari in ENE direction for 110 km. Bhanvad area SW of Jamnagar also experienced some shocks. Bhavnagar, Junagadh and Rajkot districts had experienced several earthquake sequences after 2000 (Rastogi, 2000; 2002; 2003). It appears that faults in the Saurashtra region have become activated by stress perturbation due to 2001 Bhuj earthquake of M7.7. There is an increased probability of occurrence of locally damaging earthquakes of magnitude 6.0 in any of these areas but especially in Talala, South of Jamnagar and southwest of Surendranagar.

Fig. 2.8: Epicenters in Saurashtra and offshore during 2006 to 2009 of M 0.5 to 5.

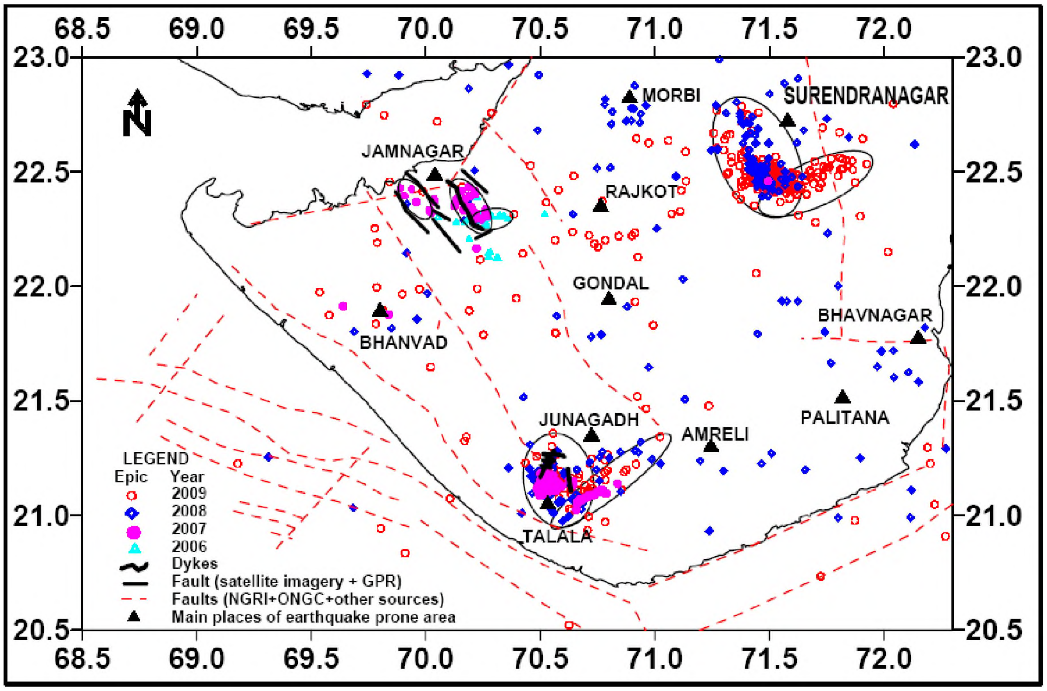


Fig. 2.9: Epicenters in Jamnagar District during 2006 to 2009 of M 0.5 to 4.0.

Table 2.6: Seismicity of M≥ 3.0 from Aug. 2006 to October, 2009 in the Saurashtra region

Magnitude Range	No. of earthquakes
3.0-3.9	84
4.0-4.9	4
5.0-5.9	1

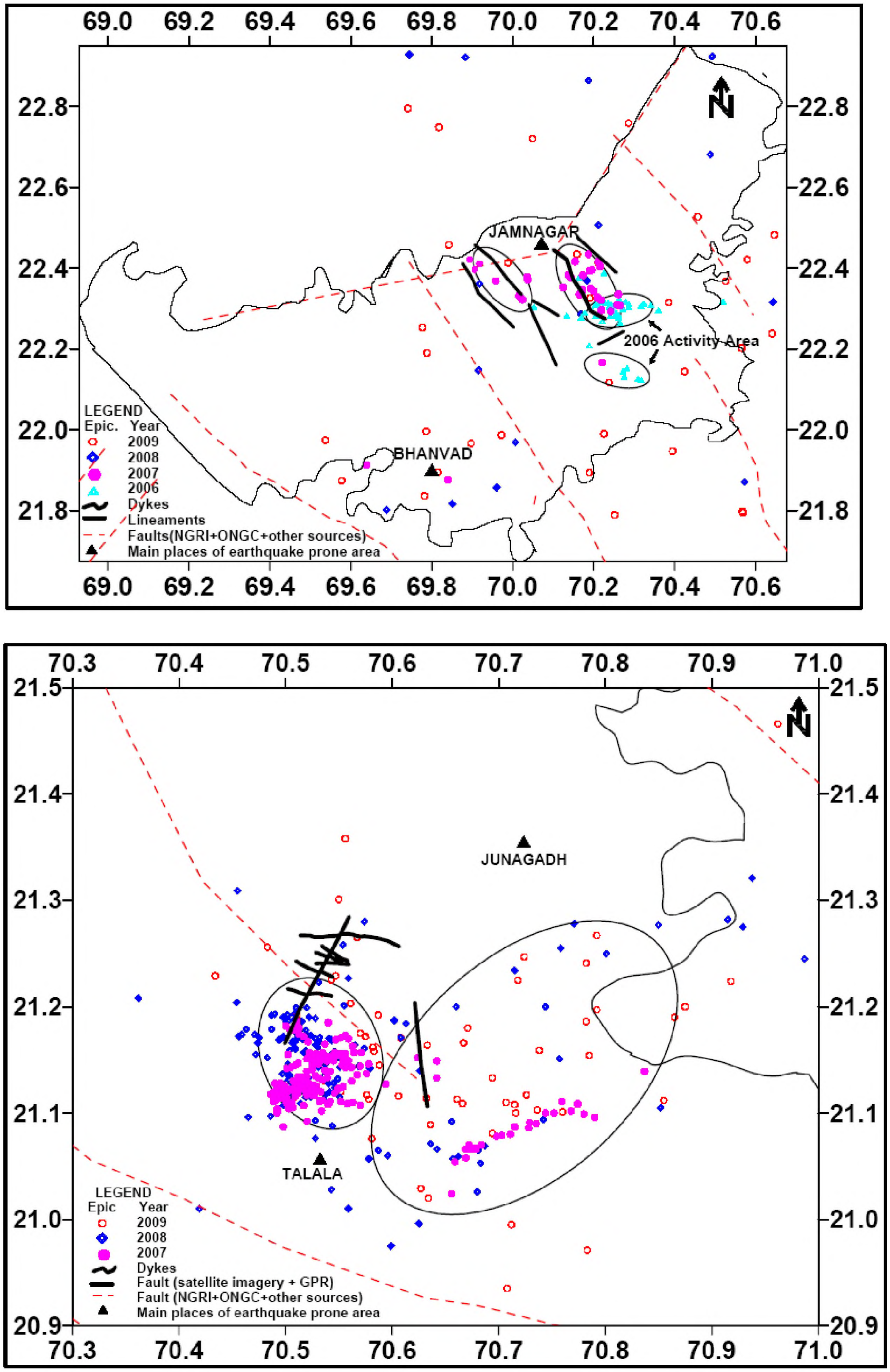


Fig. 2.10: Epicenters in Talala area, Junagarh District during 2007 to 2009 of M 0.5 to 5.0.

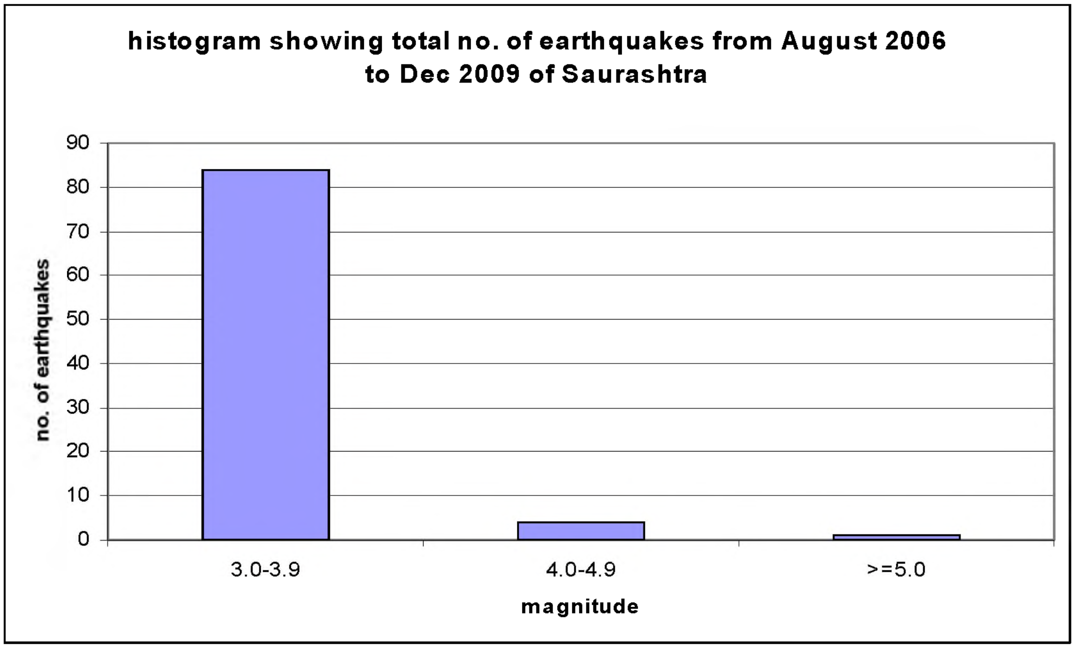


Fig. 2.11: Number of earthquakes in Saurashtra during Aug. 2006-Dec. 2009 in three magnitude categories

Table 2.7: List of earthquakes with magnitude M$\geq$ 4.0 in the Saurashtra region during August 2006 and December 2009.

S.No	Year	MON	DD	HR	MN	Sec	Lat	Long	Dep.	M
1	2006	9	30	0	16	0.5	22.306	70.20	5	4.0
2	2007	11	6	0	27	28.8	21.116	70.51	8.5	4.8
3	2007	11	6	9	38	4.5	21.165	70.54	6	5.0
4	2008	10	5	11	33	38.1	21.168	70.54	12	4.3
5	2008	3	31	21	23	54.3	21.135	70.59	9.2	4.0

No earthquake of M $\geq$4.0 was recorded in the Saurashtra region during 2009. Table 2.8 shows annual number of earthquakes of M0.5 to 5.0 in different areas of Saurashtra region during 2007 to 2009.

Table 2.8: Annual number of earthquakes of M 0.5 to 5.0 in different areas of the Saurashtra region during 2007 to 2009

Year	**2007**	**2008**	**2009**
Rajkot	7	12	20
Surendranagar	39	174	325
Talala	361	375	67
Jamnagar	87	25	29
Total	494	586	441

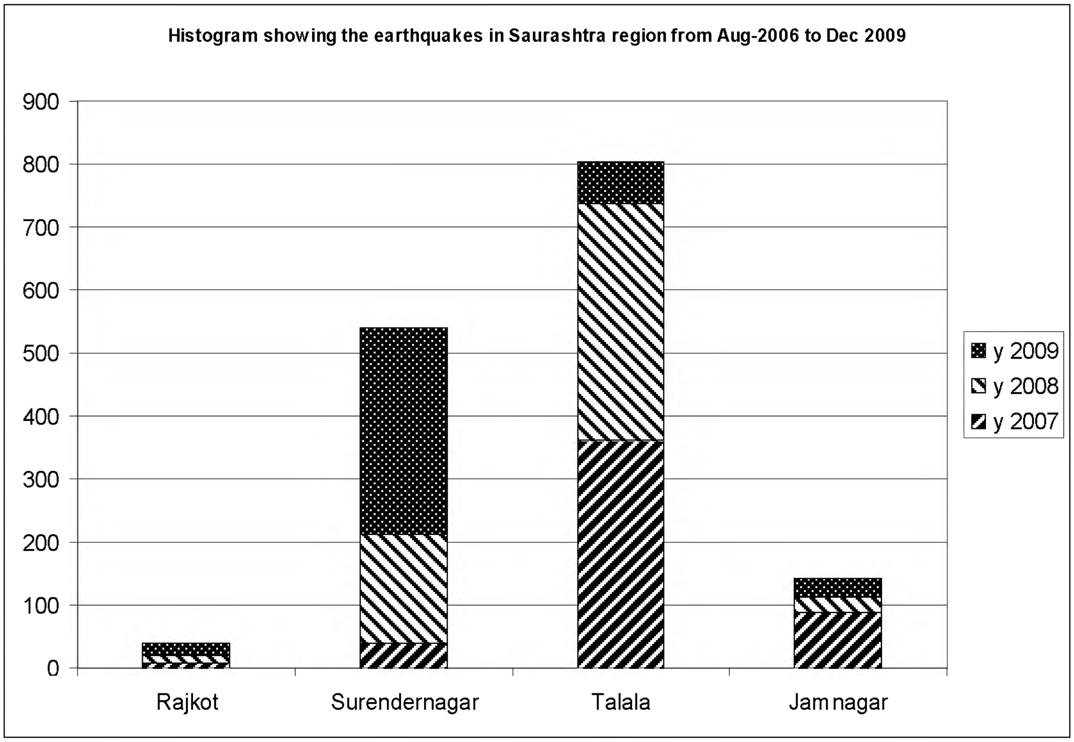


Fig. 2.12: Annual no. of shocks of magnitude 0.5 to 5 in different areas of Saurashtra

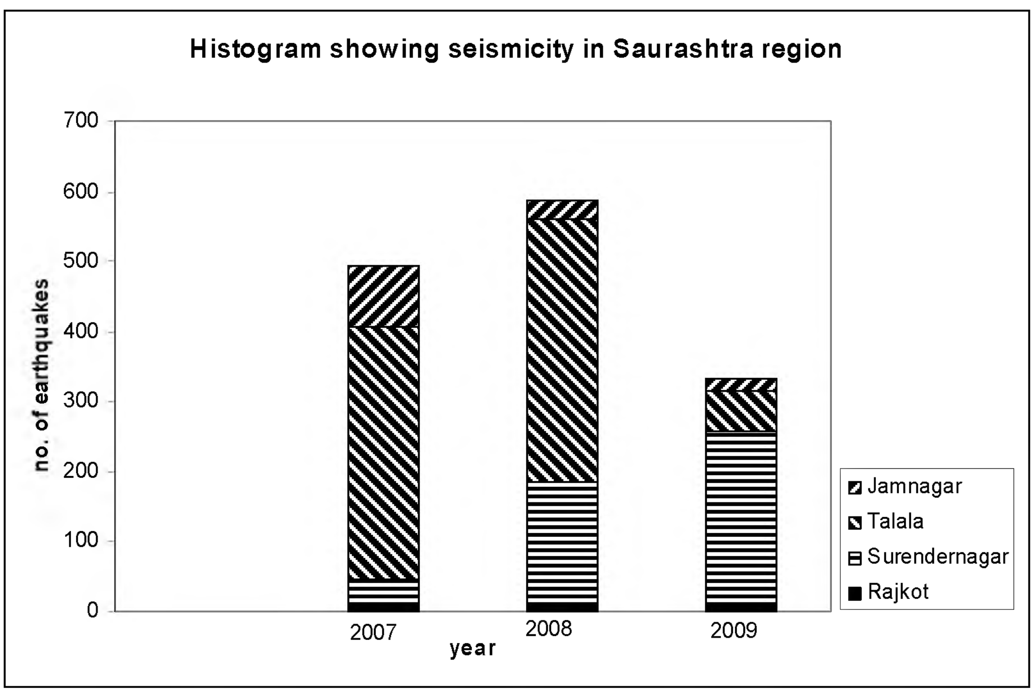


Fig. 2.13: Relative number of shocks of M>0.5 in four areas of Saurashtra

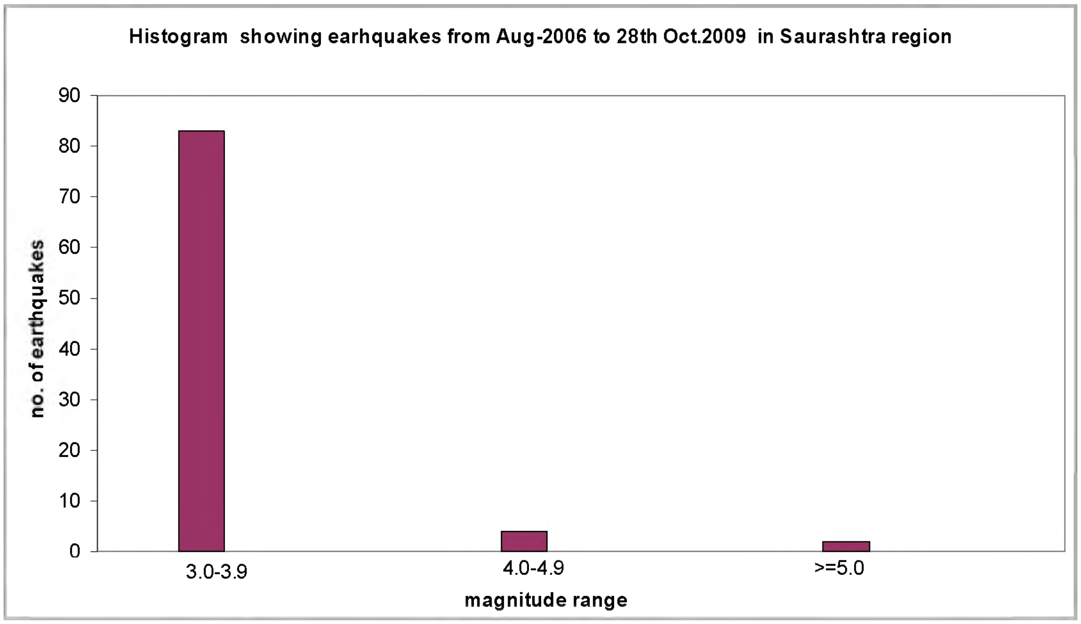


Fig. 2.14: Magnitude distribution of shocks in the Saurashtra region during Aug. 2006 to Dec. 2009

a. Earthquakes in Jamnagar district

In the historical past there has been no significant earthquake near Jamnagar barring a magnitude 4.4 (USGS) earthquake in 1886 and magnitude 5.0 (Chandra, 1977) earthquake in 1940 with uncertain locations. However, a swarm activity (felt shocks of possibly M3.0) was noticed about 30 km SSW of Jamnagar in 2003 near Lalpur. Some 30km south of Jamnagar about 200 shocks were felt around Khankotda village in 2006 and the same numbers of earthquakes were felt again in 2007 between Vijrakhi and Khankotda villages situated 15-30km south of Jamnagar. The maximum magnitude was 4.0 on September 30, 2006 (22.31°N 70.21°E) and 3.5 during 2007. The shocks were felt with blast like subterranean sounds. These shocks were of shallow depth (mostly within 6 km) and two of these caused cracks in some houses. A network of temporary seismic stations was deployed with the help of which about 40 shocks of magnitude ~2 or more were located in 2006 and over 50 in 2007. Most of the epicenters are located along a NW trending dyke and some along a parallel trend west of it. The tremors are probably triggered after heavy rainfall as seen in many instances in India in last several decades. In the year 2008 in Jamnagar area there were 25 events recorded with Mmax. 2.7, on 9th Aug 2008. In the year 2009, Jamnagar area experienced 29 earthquakes with Mmax. 3.0 on 31st Aug 2009. The epicenters during 2006 to 2009 are shown in Fig. 2.9.

b. Talala earthquake of November 6, 2007 in Junagadh District and its foreshock-aftershock sequence

Talala area of Junagadh district of Gujarat experienced an earthquake of magnitude 5.0 on 6 Nov 2007 at 15:08 hr IST. The earthquake was preceded by some foreshocks and a sequence of aftershocks for more than two weeks. The main earthquake resulted into partial collapse of 200 adobe (Kachchh) houses in seven villages covering an area of 13 km x 8 km. Significant cracks in several houses were observed up to 50 km distance and minor cracks up to 100 km distances while the earthquake was felt up to 250 km distances. A foreshock of magnitude 4.8 that occurred about 9 hours prior to the main shock also caused some damage. The whole sequence had about 1300 micro earthquakes (M>0.5) out of which about 250 shocks of magnitude about 1.5 and or greater were located. There were 20 shocks of $M \geq 3$. The aftershocks reduced to a low level in 15 days but have continued till date. Epicenters are following a NE-SW trend over a length of 15 km**.** There is no major fault system near the epicenter zone. A small NE trending fault has been identified in the area from the satellite imagery and field investigation over a length of 15 km which displaces E-W trending dykes by 130 m. However, epicenters were sparsely located along ENE trend for about 100 km. This trend corresponds to a gravity low between two gravity highs. The area had earlier experienced swarm type of earthquake activity in 2001 and 2004-05. During Oct. 4-10 and Dec. 10-20, 2007, Ankolvadi area, about 20 km SE of Talala, experienced a swarm of activity along an ENE trend for a length of 30 km. In the year 2008, in and around Talala total 375 earthquakes were recorded. There were two strongly felt earthquakes of M4.1 and M4.4 which occurred on 31st March 2009 and 5th October 2009, respectively. In the year 2009, in and around Talala total 67 earthquakes have been recorded. There were two earthquakes of magnitude M3.3 and M3.5 recorded on 25th February 2009 and 28th June 2009, respectively. The epicenters near Talala during 2007 to 2009 are shown in Fig. 2.10.

c. Activity around Rajkot: In and around Rajkot, during the year 2008, there were 12 earthquakes with Mmax 2.1 on 28th July 2008. In 2009, 13 earthquakes have been recorded around Rajkot with Mmax 3.0 on 28th March 2009.

d. Activity around Surendranagar: In the year 2008, the area, 35 km SW of Surendernagar, experienced 174 tremors, with Mmax 3.2 on 14th Feb 2008. In the year 2009, 244 tremors were recorded from this area having Mmax 2.7 on 25th March 2009. The activity in this area was distributed in between Latitude 22.4N and 22.8N and Longitude 71.20N and 71.6N in an area of 36 km x 40 km.

It appears that faults in the Saurashtra region have become activated by stress perturbation due to 2001 Bhuj earthquake of M7.7.

Earthquakes in Mainland Gujarat

In mainland Gujarat, A few shocks of M<4.0 occurred along Tapi fault near Surat and offshore. The Surat earthquake of M 3.5 on May 20, 2008 caused cracks in houses in a wide area. Some shocks occurred west of Godhra and 50 km east of Gandhinagar.

3. SEISMOGENESIS OF EARTHQUAKES

3.1 Possibility of viscoelastic process or change in rheology in delayed and long-distance triggering of shocks in Gujarat after the 2001 Mw 7.7 Bhuj earthquake

The Gujarat region is seismically one of the most active intraplate regions. It was known to have low seismicity but high hazard region in view of the occurrence of several large earthquakes but fewer moderate or smaller shocks. The scenario is changed during the first decade of the 21st Century when 30 felt shocks (of M4 or so) occurred at 20 different locations. In contrast the twenty decades earlier to this decade experienced hardly one or two felt shocks with the exception of the decade of 1930's when 5 earthquakes of M4-5 were felt at Paliyad in Saurashtra (Table 3.1). The Gujarat region has EW trending major faults of the failed Mesozoic rifts of Kachchh and Narmada which are getting reactivated by thrusting. There are some smaller transverse strike-slip faults. In the Deccan Volcanics of Saurashtra, south of Kachchh, the NW and NE trending smaller strike-slip faults are activated in the form of moderate earthquakes in response to the plate-tectonics stress.

Table 3.1: Decennial number of earthquakes in Saurashtra

Decade	No. of earthquakes	Magnitudes
1870 -1879	1	5.0
1889 -1889	4	4.4x4
1890 -1899	1	4.4
1900 -1909	-	
1910 -1919	1	5.7
1920 -1929	1	4.3
1930 - 1939	8	4.3, 4.1, 5.5, 5.7
1940 -1949	1	5.0
1950 -1959	-	
1960 -1969	2	4.3, 4.3
1970 -1979	5	4.3, 3.3, 3.1, 3.6, 3.3
1980 -1989	7	3.2, 2.9, 3.2, 3.1, 3.5, 4.3, 3.8
1990 -1999	5	3.1, 4.4, 3.0, 3.2, 2.5
2000 -2009	16	3.6, 4.6, 4.2, 2.5, 2.0,3.1, 2.5,3.0, 4.0, 3.3, 3.1, 5.0, 2.9,2.8, 3.2, 3.0

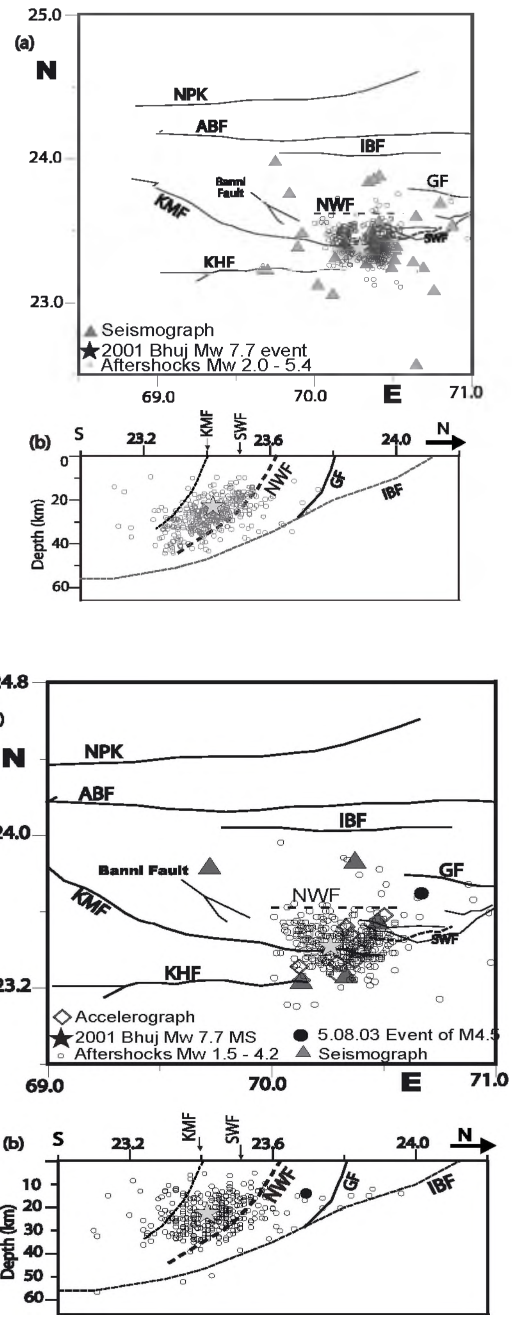


Fig. 3.1: Epicenters and focal depths of Kachchh earthquakes during 2001 shows that they were confined to NWF and 40 km x 40 km area (top two diagrams) while during next two years of 2002 to 2003 the other faults became slightly active (bottom two diagrams) (NGRI data)

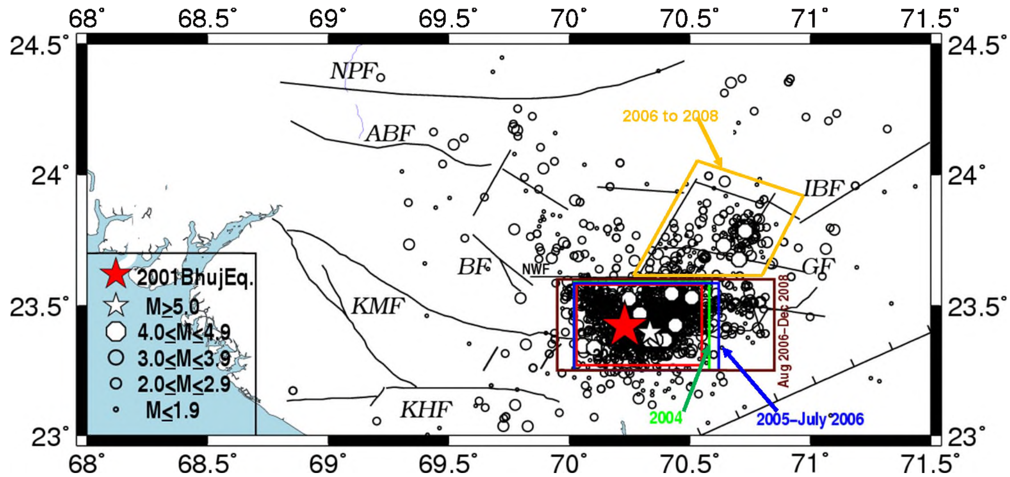


Fig. 3.2: Epicenter of the M7.7 Bhuj earthquake, epicenters of M>1 during 2006-2008 and temporal change in the epicentral areas. By 2006 the South Wagad and Gedi faults were activated while by 2008 the Allah Bund Fault also became active.

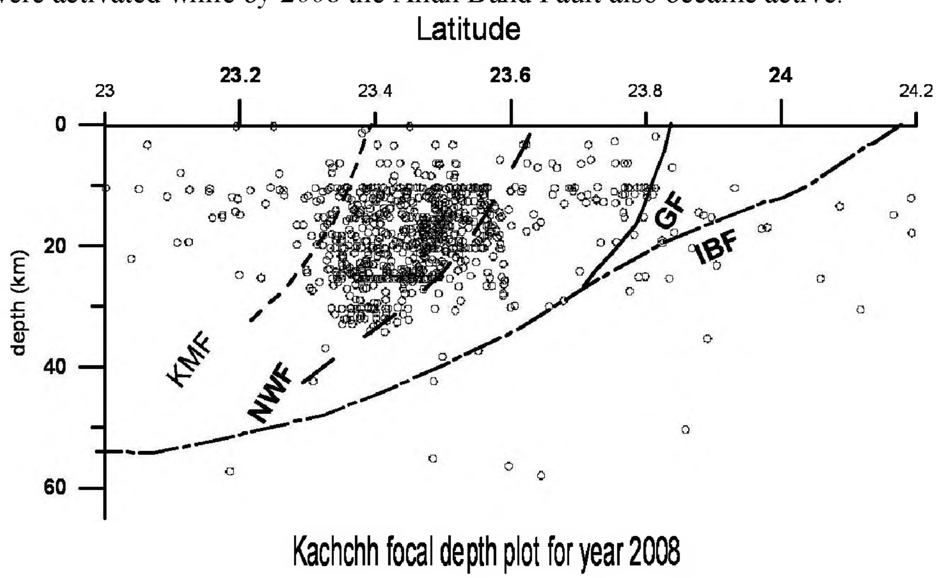


Fig. 3.3: During 2006 the Gedi fault area in the northeast, shown by yellow rectangle, became active. By 2008, the South Wagad Fault towards east became active and also several other faults showed considerable activity.

Long-distance, long-time migration

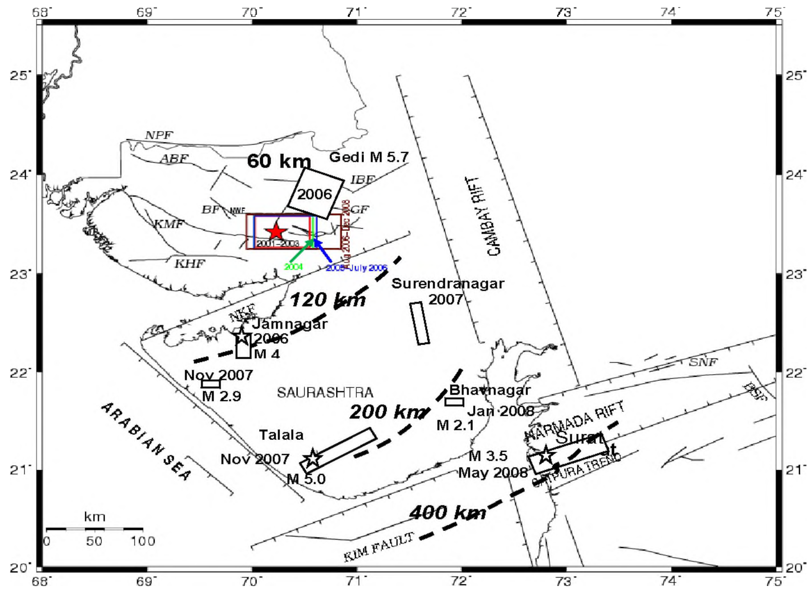


Fig. 3.4: Migration of seismicity in Gujarat from 2006 to 2008.

Aftershocks in the 2001 Mw 7.7 rupture zone in Kachchh are continued at M5.7 level until 2006 and M≤5 level subsequently. For two years the activity concentrated along the 2001 rupture zone in 80 km x 50 km area (Fig. 3.1). The epicentral area expanded to nearby areas along different faults in EW direction (more towards East). By 2004 the epicentral area expanded to 100 km x 75 km and then by July 2006 to 125 km x 75 km. In addition, the epicentral area expanded by 60 km towards NE to Gedi fault by March 2006 (Fig. 3.2). By 2008, the most active area further expanded to 200 km x 80 km and sparsely active area expanded to 250 km x 150 km covering South Wagad, Allah Bund and Island Belt faults also of the northern Kachchh with mostly M<4 shocks. Depth section of hypocenters (Fig. 3.3) shows that the Allah Bund Fault is active during 2008. The expansion of seismicity in E-W direction was as predicted from Coulomb stress change caused by 2001 earthquake but the expansion of seismicity in other directions cannot be explained by Coulomb stress change.

The activity had also spread towards south to Saurashtra and mainland Gujarat: 120 km by 2006 and 200 km by 2007 along several faults (Fig. 3.4). At three sites the activity is in the form of sequences along faults with largest shocks of M≤5 and several hundreds of M≥0.5 shocks recorded on local networks. At some sites the sequences had fewer shocks. Only one such sequence was reported earlier during 1986 in south Gujarat.

The shear deformation for adjustment process in the Bhuj earthquake zone is now negligible as deduced from only 2-3 mm/yr movements of the GPS stations. The viscoelastic process / rheology change appears to be the plausible mechanism for long distance and delayed triggering of earthquakes with diffusion rates of 5-50 km/yr.

3.2 CMT Solutions with local stations data (B. Sairam)

Centroid Moment Tensor (CMT) Solutions of 17 earthquakes of Mw 1.7 to 3.2 that occurred during 2006 to 2008 in Jamnagar area were obtained (Fig. 3.5).

Majority of the earthquakes indicate strike slip along NE-SW trending fault, while a few others along NW-SE trending fault, indicating activity along two conjugate faults.

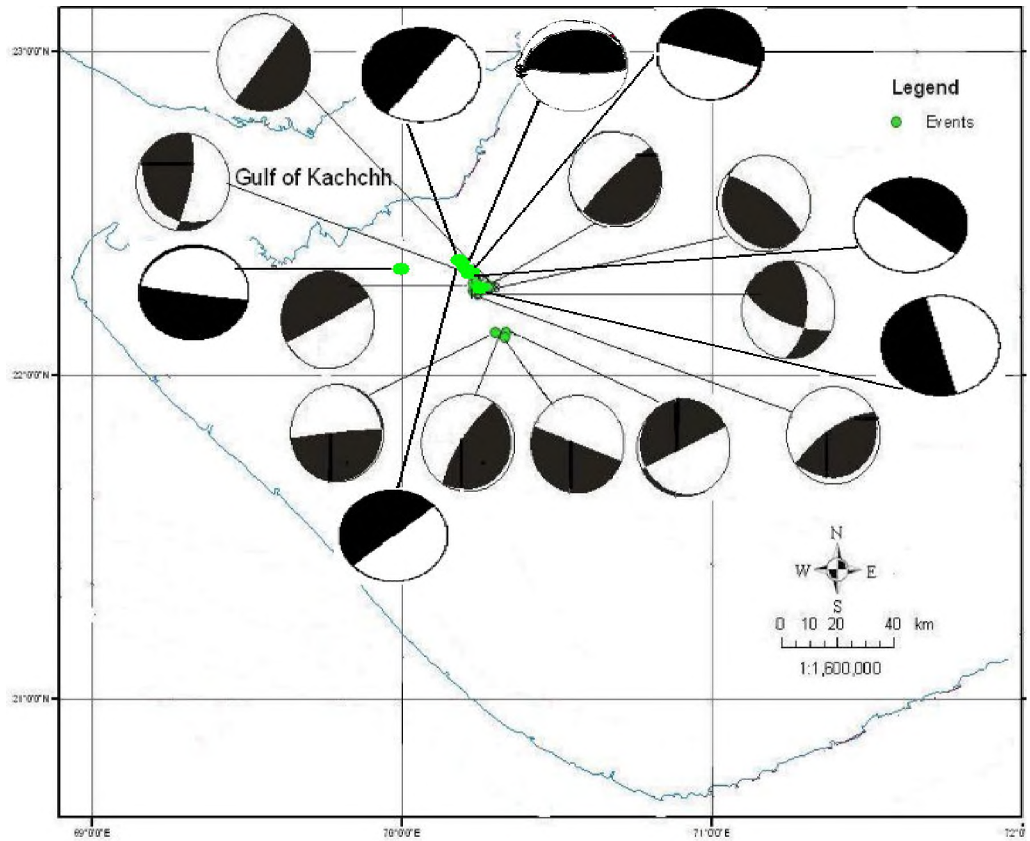


Fig. 3.5: CMT solutions of shocks south of Jamnagar with local data

Details of these solutions are as given below:

1. 2006 10 4 0523 59.9 L 22.252 70.247 5.0 0.5 GAP=171 ml 1.7
   STRIKE= 58.41 +- 12.76 DIP= 14.64 +- 1.73 RAKE= 90.83 +- 32.04
   STRIKE= 237.55 +- 12.76 DIP= 75.37 +- 1.73 RAKE= 89.78 +- 32.04

2. 2006 10 6 1424 1.6 L 22.125 70.331 3.1 0.3 GAP=149 ml 2.1
   STRIKE= 16.30 +- 165.68 DIP= 5.13 +- 42.89 RAKE= 22.47 +- 231.76
   STRIKE= 263.91 +- 165.68 DIP= 88.04 +- 42.89 RAKE= 94.74 +- 231.76

3. 2006 10 6 1438 47.6 L 22.136 70.303 7.9 0.2 GAP=151 ml 1.7
   STRIKE= 11.60 +- 6.88 DIP= 8.48 +- 3.39 RAKE= 248.87 +- 24.74
   STRIKE= 212.95 +- 6.88 DIP= 82.09 +- 3.39 RAKE= 273.08 +- 24.74

4. 2006 10 6 1441 16.5 L 22.133 70.335 3.1 0.3 GAP=148 ml 2.2
   STRIKE= 77.44 +- 0.04 DIP= 0.15 +- 0.02 RAKE= 235.73 +- 2.09
   STRIKE= 291.85 +- 0.04 DIP= 89.88 +- 0.02 RAKE= 270.08 +- 2.09

5. 2006 10 6 1608 4.1 L 22.119 70.332 5.0 0.4 GAP=150 ml 2.7
STRIKE= 142.47 +- 1.37 DIP= 9.46 +- 0.07 RAKE= 349.15 +- 3.18
STRIKE= 243.18 +- 1.37 DIP= 88.23 +- 0.07 RAKE= 260.71 +- 3.18

6. 2006 10 8 0821 1.2 L 22.265 70.232 3.1 0.4 GAP=135 ml 2
STRIKE= 127.74 +- 2.60 DIP= 22.06 +- 0.02 RAKE= 210.15 +- 4.61
STRIKE= 9.44 +- 2.60 DIP= 79.13 +- 0.02 RAKE= 289.31 +- 4.61

7. 2006 10 8 1034 11.6 L 22.275 70.290 4.9 0.2 GAP=146 ml 2.7
STRIKE= 4.02 +- 0.83 DIP= 2.17 +- 0.58 RAKE= 55.63 +- 6.08
STRIKE= 218.41 +- 0.83 DIP= 88.21 +- 0.58 RAKE= 91.22 +- 6.08

8. 2006 10 8 2321 10.2 L 22.277 70.280 3.2 0.2 GAP=128 ml 2.3
STRIKE= 146.42 +- 0.20 DIP= 15.74 +- 0.75 RAKE= 109.06 +- 0.52
STRIKE= 306.67 +- 0.20 DIP= 75.14 +- 0.75 RAKE= 84.74 +- 0.52

9. 2006 10 9 0012 17.9 L 22.274 70.280 3.1 0.2 GAP=129 ml 2
STRIKE= 77.95 +- 16.04 DIP= 8.48 +- 4.26 RAKE= 119.64 +- 81.95
STRIKE= 228.04 +- 16.04 DIP= 82.63 +- 4.26 RAKE= 85.78 +- 81.95

10. 2006 1010 0140 2.3 L 22.285 70.230 5.0 0.3 GAP=137 ml 1.8
STRIKE= 5.50 +- 3.01 DIP= 55.96 +- 2.94 RAKE= 151.99 +- 9.43
STRIKE= 112.08 +- 3.01 DIP= 67.10 +- 2.94 RAKE= 37.42 +- 9.43

11. 2006 1012 1322 35.7 L 22.295 70.240 3.1 0.3 GAP=149 ml=1.8
STRIKE= 232.73 +- 7.28 DIP= 1.27 +- 1.29 RAKE= 260.20 +- 69.57
STRIKE= 62.53 +- 7.28 DIP= 88.75 +- 1.29 RAKE= 270.22 +- 69.57

12 2006 10 8 1002 49.7 L 22.264 70.261 3.1 0.4 GAP=133 ml=1.7
STRIKE= 154.92 +- 0.06 DIP= 0.02 +- 0.07 RAKE= 79.55 +- 0.09
STRIKE= 343.72 +- 0.06 DIP= 89.98 +- 0.07 RAKE= 90.00 +- 0.09

13 2007 811 1918 29.5 L 22.310 70.220 11.8 0.4 GAP=155 ml=3.2
STRIKE= 251.43 +- 7.61 DIP= 18.83 +- 2.11 RAKE= 250.05 +- 17.79
STRIKE= 92.42 +- 7.61 DIP= 72.34 +- 2.11 RAKE= 276.64 +- 17.79

14 2007 813 1311 15.8 L 22.322 70.213 15.0 0.3 GAP=155 ml=2.3
STRIKE= 32.86 +- 17.82 DIP= 2.98 +- 1.62 RAKE= 196.75 +- 8.87
STRIKE= 286.13 +- 17.82 DIP= 89.14 +- 1.62 RAKE= 272.85 +- 8.87

15 2007 828 1510 56.6 L 22.351 70.190 15.1 0.3 GAP=155 ml=2.2
STRIKE= 133.33 +- 5.05 DIP= 0.24 +- 0.01 RAKE= 7.76 +- 9.75
STRIKE= 35.59 +- 5.05 DIP= 89.97 +- 0.01 RAKE= 90.24 +- 9.75

16 2007 9 4 0738 10.6 L 22.331 70.210 15.0 0.3 GAP=154 ml=2.3
STRIKE= 138.55 +- 0.67 DIP= 0.61 +- 0.02 RAKE= 359.44 +- 4.11
STRIKE= 229.10 +- 0.67 DIP= 89.99 +- 0.02 RAKE= 269.39 +- 4.11

17 2007 9 8 2022 42.8 L 22.313 70.232 15.0 0.3 GAP=123 ml=3.2
STRIKE= 124.08 +- 0.07 DIP= 0.21 +- 0.04 RAKE= 266.11 +- 0.14
STRIKE= 307.97 +- 0.07 DIP= 89.79 +- 0.04 RAKE= 270.01 +- 0.14

18 2007 9 9 2322 6.7 L 22.324 70.005 7.4 0.5 GAP=154 ml=2
STRIKE= 254.40 +- 0.44 DIP= 4.33 +- 0.76 RAKE= 245.85 +- 1.58
STRIKE= 98.62 +- 0.44 DIP= 86.05 +- 0.76 RAKE= 271.77 +- 1.58

3.3 CMT Solutions using regional stations data (Nagabhushana Rao, B.K. Rastogi and Purnachandra Rao)

The earthquake activity in the Kutch region recorded by ISR during 2006 to 2009 is shown in Fig. 3.6. Centroid Moment Tensor (CMT) Solutions have been determined for nine earthquakes in Kachchh and four in Saurashtra of magnitudes 4.1-4.9 which occurred during 2007 to 2009 using local and regional data of up to 8 Stations at distances between 50 and 250 km. Results of a few of these earthquakes were reported earlier. The moment tensor inversion solutions can explain the seismotectonics of different faults. The regional CMT method is found to be excellent in determining focal depth and faulting mechanism of the earthquakes. The synthetic seismograms are computed using the approach of Takeo (1987) which uses wave number summation method (Bouchon, 1981). Inversion program of Kikuchi and Kanamori (1991) and modified by Kosuga (1996) is used. Most of the earthquakes in Kachchh indicate thrust faulting along south dipping and nearly E-W trending planes.

An earthquake of M 4.6 occurred on 28 October 2009 along the Banni fault, near Khavda, Kutch. This fault was not associated with any shock of M>3 since 2001, though several microearthquakes were recorded near it. The Banni Fault is geologically oriented in NW direction (Fig. 3.6). CMT shows right-lateral strike-Slip movement along a NW trending plane that is dipping SW (Fig. 3.7). The pressure axis is oriented in NNE direction. The source time function indicates half source duration of 4.5 sec and maximum slip of 10 cm. The normalized errors for different focal depths in the range 3 to 25 km indicate least error for 8.5 km.

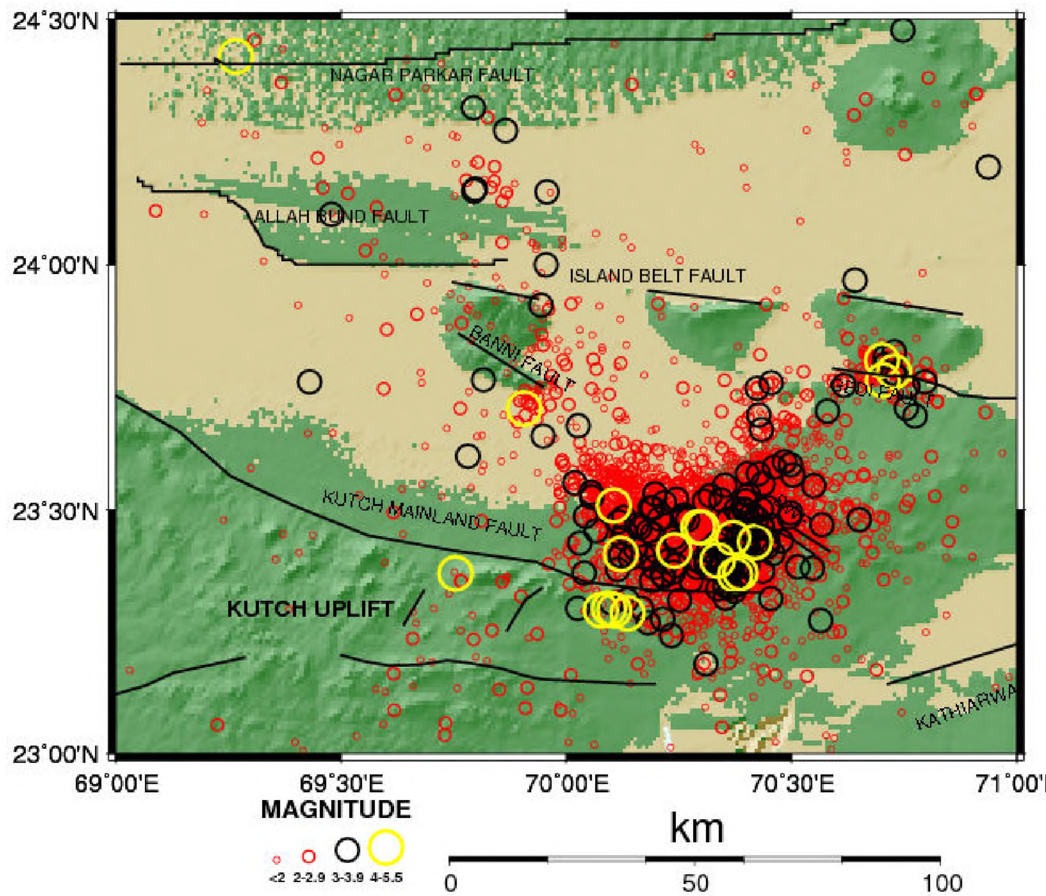


Fig. 3.6: Map showing the tectonic faults and the earthquake activity in the Kutch region during 2006-2009.

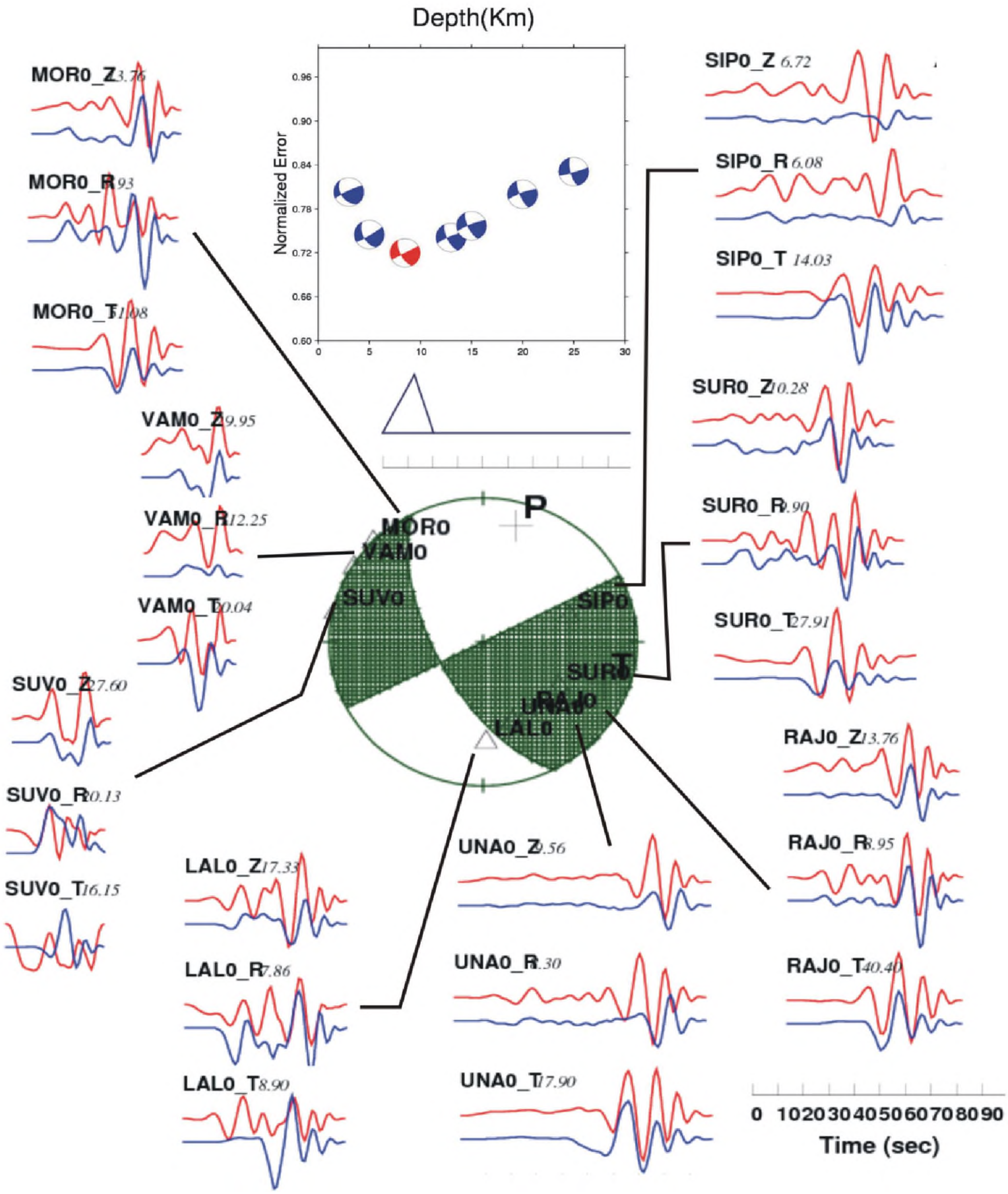


Fig. 3.7: The wave form match of observed and generated synthetic seismograms of different stations and the moment tensor solution for Mw 4.6 Banni earthquake of 28 Oct. 2009. The source time function and normalized errors for different focal depths.

3.4 Velocity Modeling of Different Parts of Gujarat Using Travel Times (Sandeep Aggarwal)

The velocity model of Mandal *et al.* (2007) over Kachchh has been modified in a way to give best-fit hypocentral locations of earthquakes in that region. Similarly the velocity model of Kaila et al. (1981) for Saurashtra & Mainland Gujarat has been modified (Fig. 3.8) to give best-fit results of Talala earthquakes which occurred during November 2007. In the revised model for Saurashtra and Mainland, the P-wave velocity is higher in the depth range between surface and 15 km, lesser in depth range of 15-30 km and again higher in depth range 30-42 km, compared to the starting model.

Kachchh Saurashtra

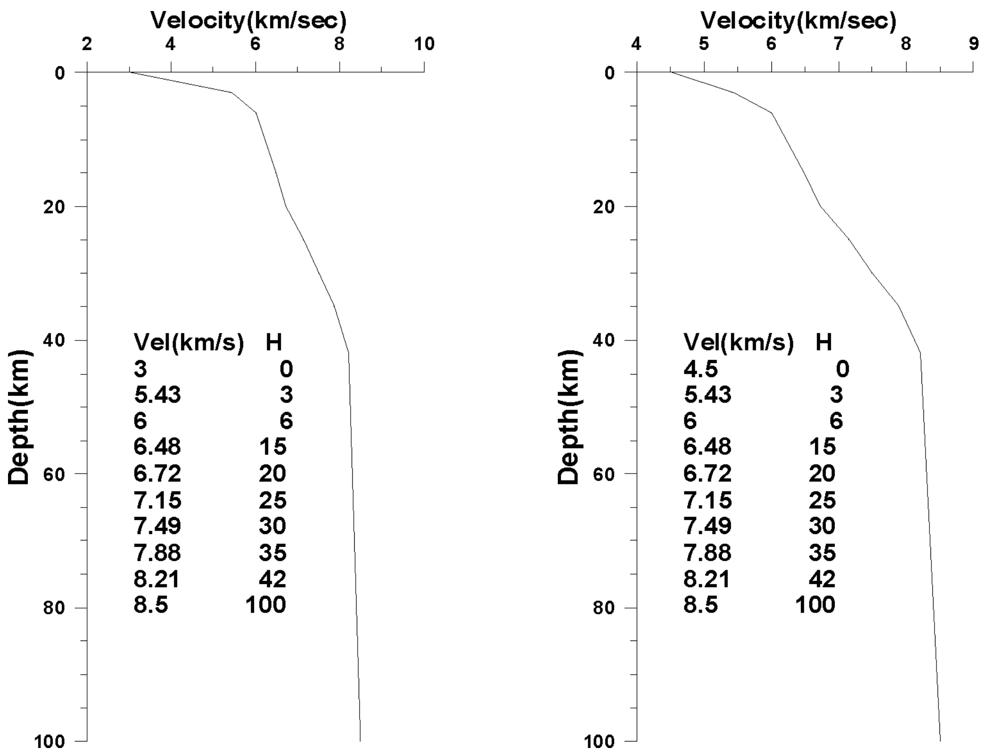


Fig. 3.8: Left side: Velocity model for Kachchh as given by Mandal *et al.* (2007). Right side: Velocity model derived for Saurashtra and Mainland Gujarat prepared from best fit to Talala epicenter locations that occurred in Nov. 2007 using the model by Kaila *et al.* (1981).

3.5 Velocity Model for Gujarat Region from Joint Inversion of Structure and Mechanism (Nagabhushana Rao)

A joint inversion for structure and mechanism has been done from waveform data of four Kachchh earthquakes of magnitude between 4.0 and 4.5. The stations used are 50-250 km covering the whole of Gujarat. The selection of models are taken by using Monte-Carlo method with 2000 velocity models simulated within specified search limits. Using the waveform match minimum average error criteria we have given the preference or rank for the good model. The model that fits best for all the waveforms is accepted as the best model. Next, a fine grid search is performed around the best model to get the final model (Fig. 3.9).

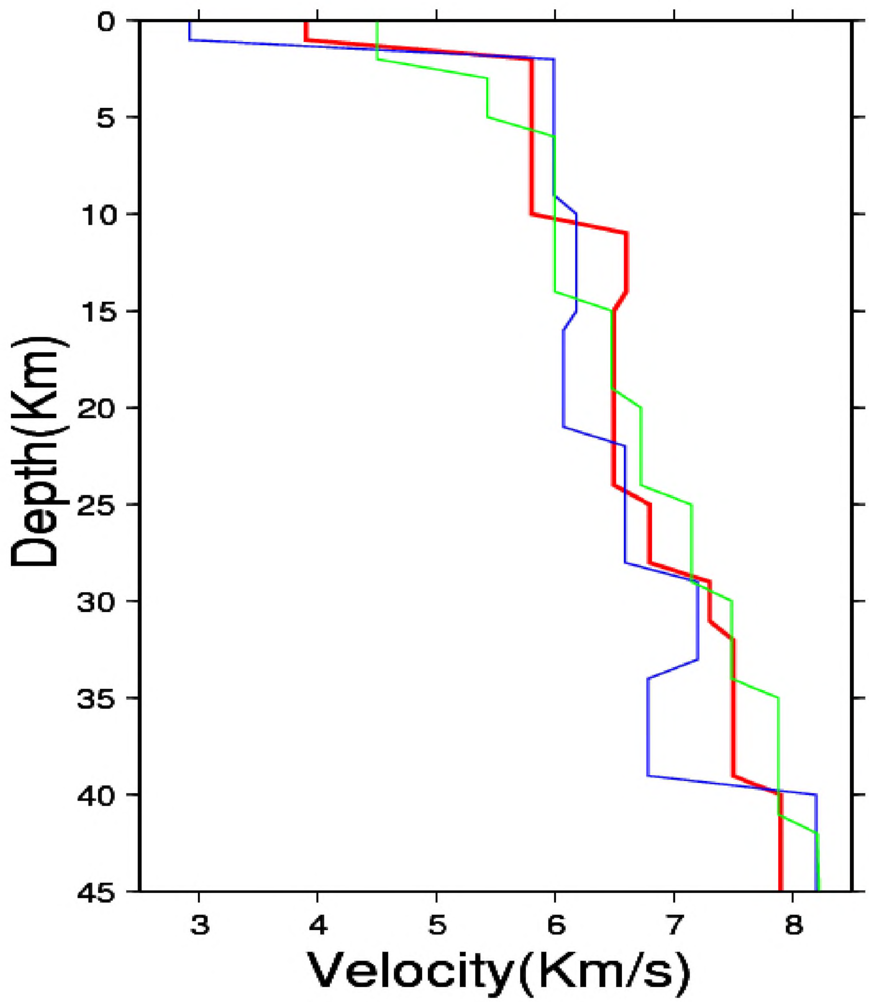


Fig. 3.9: A comparison of Mandal model (2007) (blue) with the final Gujarat model (red) and Saurastra model (Kaila et.al, 1981) as generated by waveform matching using the Monte-Carlo method.

4. EARTHQUAKE HAZARD ASSESSMENT

4.1 PROBABILISTIC SEISMIC HAZARD MAP OF INDIA

(RBS Yadav, Vikas Kumar, B.K. Rastogi)

The Bureau of Indian Standards under maps Sub-Committee 39.4 has assigned the job of preparing the Probabilistic Seismic Hazard Map for India to ISR along with some other organizations.

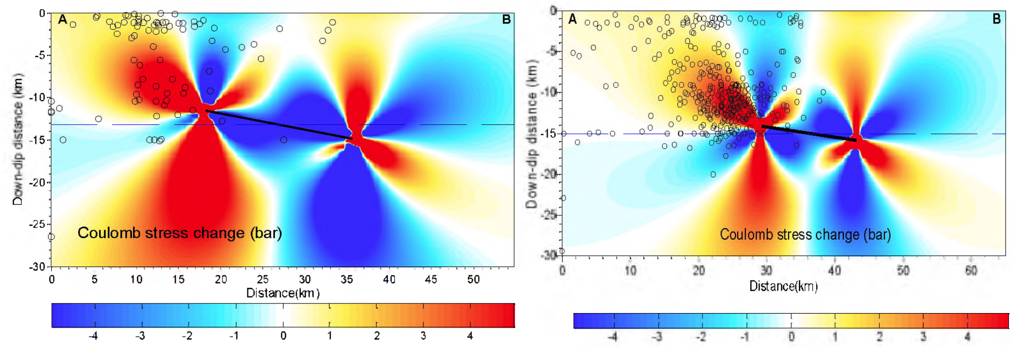
A catalogue of earthquakes for Indian sub-continent (0-40^0 N and 65-100^0 E) has been prepared for all magnitude ranges from earliest time to present using the sources of ISC (from 1900 to present), NEIC of USGS (from Dec. 2005 to present), Harvard CMT catalogue for Mw, IMD, catalogue of Bob Engdahl and several literatures. The catalogue is being processed for its homogeneity, completeness and declustering. The source zones have been assigned and seismicity parameters like recurrence rates and the ‘a’ and ‘b’ values are being estimated for different regions.

4.2 RELATION BETWEEN MAGNITUDE AND INTENSITY FOR SOIL COVERED AND HARD ROCK AREAS OF INDIA (RBS Yadav)

A catalogue consisting magnitude and intensity has been prepared for hard rock and soft ground conditions for Indian region and relationships have been developed between magnitude (M) and epicentral intensity (I_0) for these two types of ground conditions. The estimated relationship for hard rock is observed as $M = 0.598\ I_0 + 1.474$ and for soft soil as $M = 0.431\ I_0 + 3.001$. After comparing these relationships with US relationship for hard rock and soft soil, it is observed that a slightly higher magnitude is observed for the same intensity value for Indian region as compared to US. Further, these relationships have also been developed for the Himalayan seismic belt and stable continental region of the Peninsular India.

4.3 COULOMB STRESS MODELING FOR UTTARKASHI AND CHAMOLI EARTHQUAKES IN NW HIMALAYA: EVIDENCE OF SEISMICITY TRIGGERING (RBS Yadav)

The Coulomb stress changes for Uttarkashi (October 19, 199; Mw 6.8) and Chamoli (March 28, 1999; Mw 6.6) earthquakes have been modeled on optimally-oriented planes of reverse/thrust fault assuming compressive regional stress acting horizontally with its major principal stress axis in the direction of NNE (Fig. 4.1). The up dip and down dip edges of rupture area for Uttarkashi earthquake lie at the depths of 11.52 and 14.88 km, respectively which are constrained with the depth of detachment of the Himalayan seismic belt. The reverse slip and right-lateral slip are estimated as 0.86 m and 0.38 m. The up dip and down dip edges of rupture area of the Chamoli earthquake lie at the depths of 14.15 km and 15.85 km, respectively. The reverse slip and left-lateral strike slip are calculated as 0.78 m and 0.21 m. The cross-sectional views of the changes in Coulomb stress for these two Himalayan earthquakes are shown in Fig. 4.1 (*a*, *b*). It is observed that maximum number of aftershocks (about 90%) is concentrated near the up dip edge of rupture plane for both earthquakes where increase in Coulomb stress is observed. A good correlation is observed between the location of aftershocks activity and positive Coulomb stress region which support the hypothesis of earthquake triggering mechanism. This study reveals that the occurrence of majority of aftershocks for the Himalayan frontal arc earthquakes (Uttarkashi, Chamoli) is due to the high Coulomb stress at the up dip edge of fault rupture. Thus, it may be possible to predict the regions of future earthquake occurrences and aftershocks area for the Himalayan earthquakes.



(a) (b)

Fig 4.1: Coulomb stress changes (in bars) for Uttarkashi (a) and Chamoli (b) earthquakes showing maximum concentration of aftershocks in positive coulomb stress region at the up dip edge of rupture plane, which evidence the triggering of aftershocks due to building up of high stress at up dip edge of rupture plane.

4.4 TECTONIC IMPLICATIONS AND SEISMICITY TRIGGERING DURING MW 6.4 BALUCHISTAN, PAKISTAN EARTHQUAKE SEQUENCE OF OCTOBER 28-29, 2008 (RBS Yadav)

A damaging and widely felt earthquake (Mw 6.4) hit the rural, mountainous region of southwestern Pakistan on October 28, 2008 at 23:09 UTC. The main shock was followed by another earthquake of similar magnitude (Mw 6.4) on the next day. The spatial distribution of aftershocks revealed a NW-SE striking rupture in accordance with the centroid moment tensor focal mechanism solution implying right-lateral strike slip motion. The occurrence of these earthquakes suggests that strike-slip faults are present beneath the fold-and-thrust belt of Sulaiman-Kirthar ranges which may accommodate some of the relative motion of the Indian and the Eurasian plates.

To assess the properties of this sequence, the statistical parameters like aftershocks temporal decay (p-value), b-value of G-R relationship and spatial fractal dimension (D-value) have been examined. The b-value of 1.04 ± 0.42 suggests the tectonic origin of the sequence and crustal heterogeneity within crust. The low p-value being 0.89 ± 0.07 implies slow decay of aftershocks activity which evidences low surface heat-flow. A value of spatial fractal dimension of 2.08 ± 0.02 indicates random spatial distribution and the source is at a two-dimensional plane that is being filled-up by fractures.

The static coseismic Coulomb stress changes due to the foreshock (Mw 5.3) were found to increase stress by 0.004 bars at the hypocenter of the main shock (Fig. 4.2a). This indicates that the foreshock has minimal effect on triggering of the main shock. The coseismic Coulomb stress changes due to main shock suggest that most of the aftershocks were triggered by the main shock as most of the aftershocks lie in the region of positive coulomb stress, SE to the main shock rupture (Fig. 4.2b).

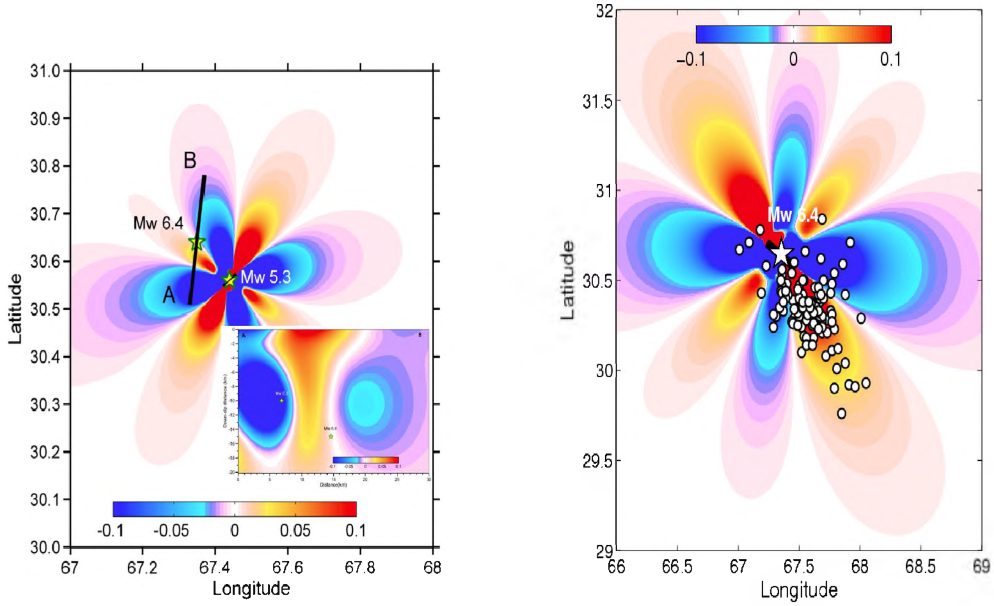


Fig. 4.2 (a): Coseismic Coulomb stress changes due to foreshock (Mw 5.3) occurred about 45 minutes before the mainshock (Mw 6.4). Picture in inset shows the cross-sectional view along line AB which shows the occurrence of the mainshock in positive stress region. (b) Static coulomb stress changes due to mainshock reveal a positive coulomb stress lobe SE to the mainshock rupture which is locale of the triggering of majority of aftershocks.

4.5 ATTENUATION OF ACCELERATION RELATION FOR GUJARAT (Kapil Mohan)

An attenuation relation has been prepared for Gujarat for hard rock sites from 93 recorded accelerations for magnitude 3 to 5.7 earthquakes at distance range 15 to 120 km during the period 2007-2009 (Fig. 4.3). This attenuation relationship has been further used to simulate earthquakes of magnitude 6 to 7.6 by way of creating one thousand and ninety two simulated samples of peak ground acceleration using the strong motion simulation technique of Midorikawa (1993). The attenuation relationship for magnitude 6 to 7.6 has been produced by regression analysis followed by inversion. The strong motion data has been tested with the linear and exponential fit. The fitting has been checked using various error-testing methods e.g. standard sum of errors and correlation coefficients etc. Finally the relationship has been established with the data inversion technique using the best-fit input data of magnitude and hypocentral distance.

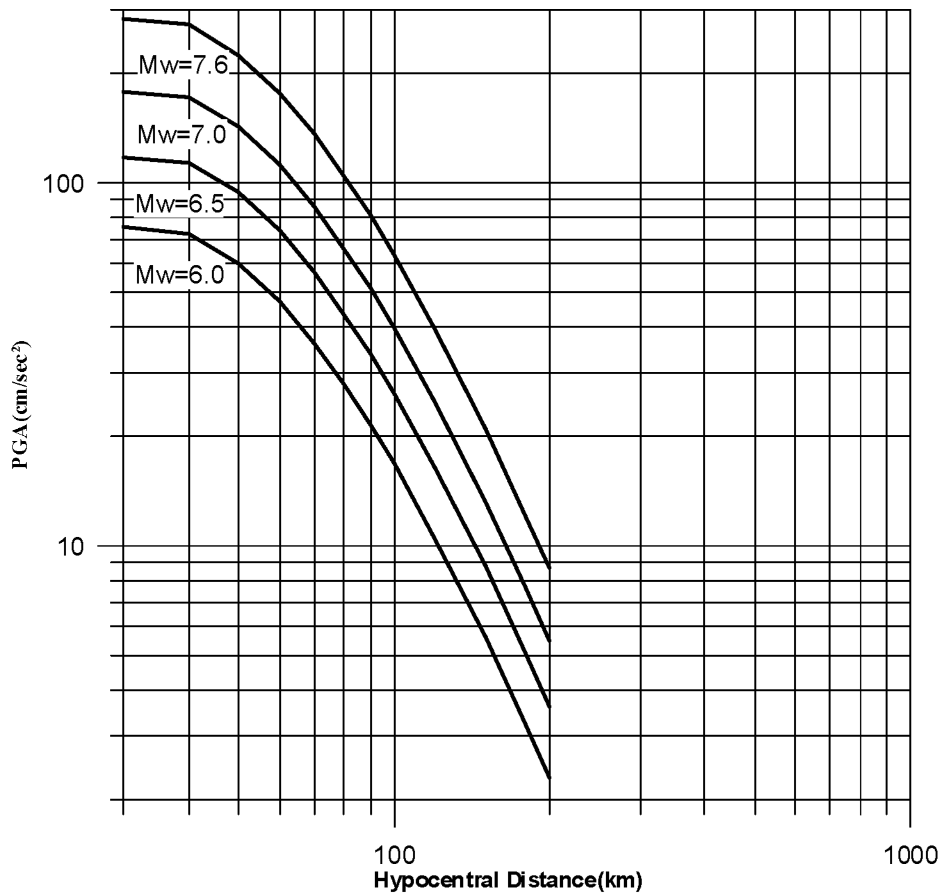


Fig. 4.3: Attenuation relationship estimated for Gujarat region from using hundreds of recorded acceleration for M 3 - 5.7 earthquakes.

4.6 A STUDY OF RESPONSE SPECTRA FOR DIFFERENT GEOLOGICAL CONDITIONS IN GUJARAT, INDIA (Sumer Chopra and Pallabee Choudhury)

In this study, the effect of ground geology on the response spectra is studied at 32 sites in Gujarat, India. The sites are grouped into areas of Proterozoic, Mesozoic, Tertiary and Quaternary formations. The normalized response spectra are determined for 407 horizontal component strong ground motions recorded at these sites which are for earthquakes of magnitude 3.0 to 5.7 (Fig. 4.4). In these calculations, 5% damping has been considered. The study shows that the shape of the response spectra is influenced by the underlying geological formations. The peak of maximum spectral amplification is between 0.03 sec to 0.06 sec in Proterozoic formations, 0.06 sec to 0.08 sec in Mesozoic formations, 0.12 sec in Tertiary and between 0.13 sec and 0.25 sec in Quaternary formations. The study shows that the response spectrum in the current Indian code (BIS, 2000) applicable for the entire country underestimates the seismic forces at hard-rock sites and overestimates at soft-soil sites.

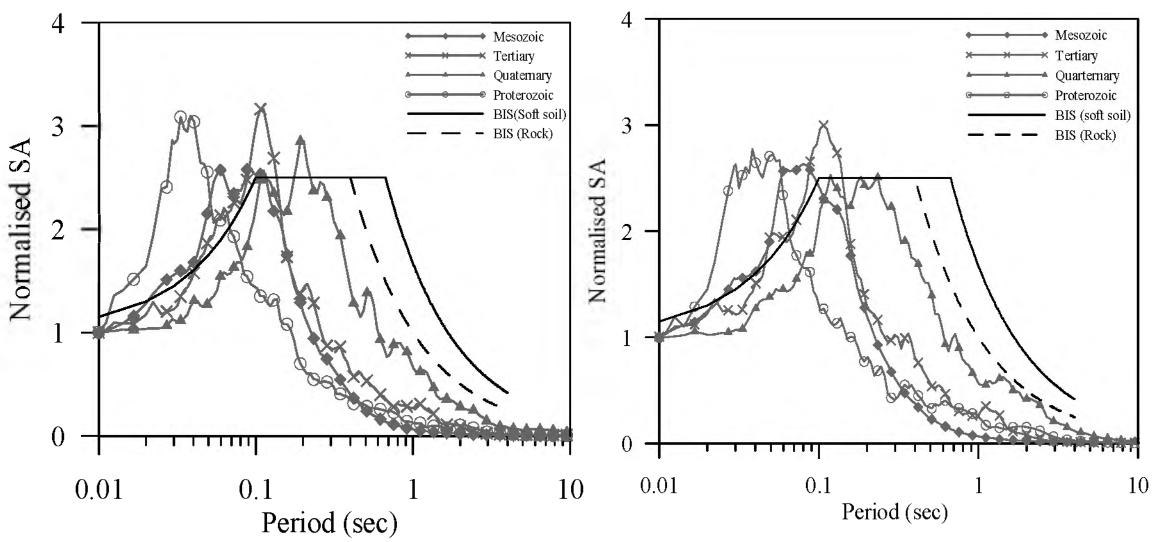


Fig. 4.4: Normalized response spectra for different geological conditions and its comparison with Indian code (left figure is NS component and right one is EW component, BIS: Bureau of Indian Standards).

4.7 ESTIMATION OF ATTENUATION RELATION WITH SHEAR VELOCITY MEASUREMENTS IN GUJARAT STATE (sponsored by NPCIL) (B. Sairam and Ketan Singha Roy)

Board of Research in Nuclear Sciences (BRNS) sponsored the work of generation of attenuation correlation for ground motion based on shear wave velocity to a depth of 30m in the Gujarat region to ISR. During the year 2009, ISR carried out Vs30 shear wave velocity measurements by MASW test at total of 58 sites including 17 Structural Response Recorder (SRR) locations, 14 Strong Motion Accelerograph (SMA) locations and 27 industrial locations. The recorded strong motions at these sites will be correlated with the velocity structure. The 1D velocity model derived from this study along with the geotechnical information will be inferred in terms of amplification of seismic waves.

Further, we have carried out ambient vibration survey at 16 sites using portable Broad Band Seismograph (BBS) purchased for the purpose and computed the amplification of the sites by H/V spectral ratio method. The frequencies at which amplifications have been noticed are converted into the depths to the corresponding layers. Portable BBS will be deployed at several more sites to estimate amplification and stratification using ambient vibrations and earthquake records.

We made a thumper or weight dropper for using as energy source in MASW testing. A weight of 30 kg is lifted to height of 1.5 m and is allowed to free fall on one square metallic plate. The energy generated by free fall of 30 kg weight is used as energy source for MASW testing. The weight dropper is operable manually. The weight dropper generates more energy than the 10 kg sledge hammer conventionally which is used as source for MASW testing and has given information down to 50 m at eighteen sites or even 70 m at several sites. Generation of the attenuation correlation between the recorded ground motion and Vs30 on different types of ground conditions is under progress. The correlation will be used to estimate the acceleration spectra at 0.8 Hz, 1.33 Hz and 2.5 Hz at the 27 locations where the industries are located.

Table 4.1: Amplification measured at 16 sites in Kachchh region by portable broadband seismograph

				f_{Range}: 0.01-1 Hz		f_{Range}: 1-3 Hz		f_{Range}: 3-10 Hz	
Sl no	**Site name**	**Lat N**	**Lon E**	**Amax**	**f (Hz)**	**Amax**	**f (Hz)**	**Amax**	**f (Hz)**
1	Meghpar (SMA)	23.39	70.31	1.27	0.53	0.88	3	1	5.3
2	Amarsar (SMA)	23.41	70.29	1.5	0.01	0.27	1.3	0.23	10
3	Baniari (SMA)	23.39	70.17	2	0.11	1.17	1	0.95	3.05
4	Vamka (SMA)	23.42	70.40	1.14	0.5	1.08	3	1.08	3
5	Niruna (SRR)	23.46	69.52	7	0.2	2.74	1.3	1.4	6
6	Bhuj (SRR)	23.23	69.66	1.5	1	1.33	1.14	0.69	8.6
7	Ahmedabad (SRR)	23.33	72.54	2.03	0.02	1.08	1	0.96	7.5
8	Nakhatrana	23.34	69.29	1.46	0.43	1.24	2.84	1.6	6
9	KPT-1, Kandla	23.02	70.20	4.89	0.86	6.8	1.5	1.23	3.05
10	IFFCO-P, Kandla	23.03	70.21	1.48	0.03	1.04	2.15	1.5	7.5
11	IFFCO-R, Kandla	23.03	70.21	0.86	0.43	1.13	2.47	2.7	6.2
12	KLTPS-1, Panandro	23.65	68.77	8	0.17	4.06	1.4	2.92	6.5
13	KLTPS-2, Panandro	23.65	68.79	1.08	0.01	1.68	2.4	1.7	4
14	Akrimotto-1	23.76	68.65	2.2	0.01	1.6	2.3	1.26	5
15	Akrimotto-2	23.77	68.65	2.3	0.01	1.09	1.3	1.14	6
16	Lakhpat	23.82	68.80	0.81	0.61	1.3	2.1	1.05	10

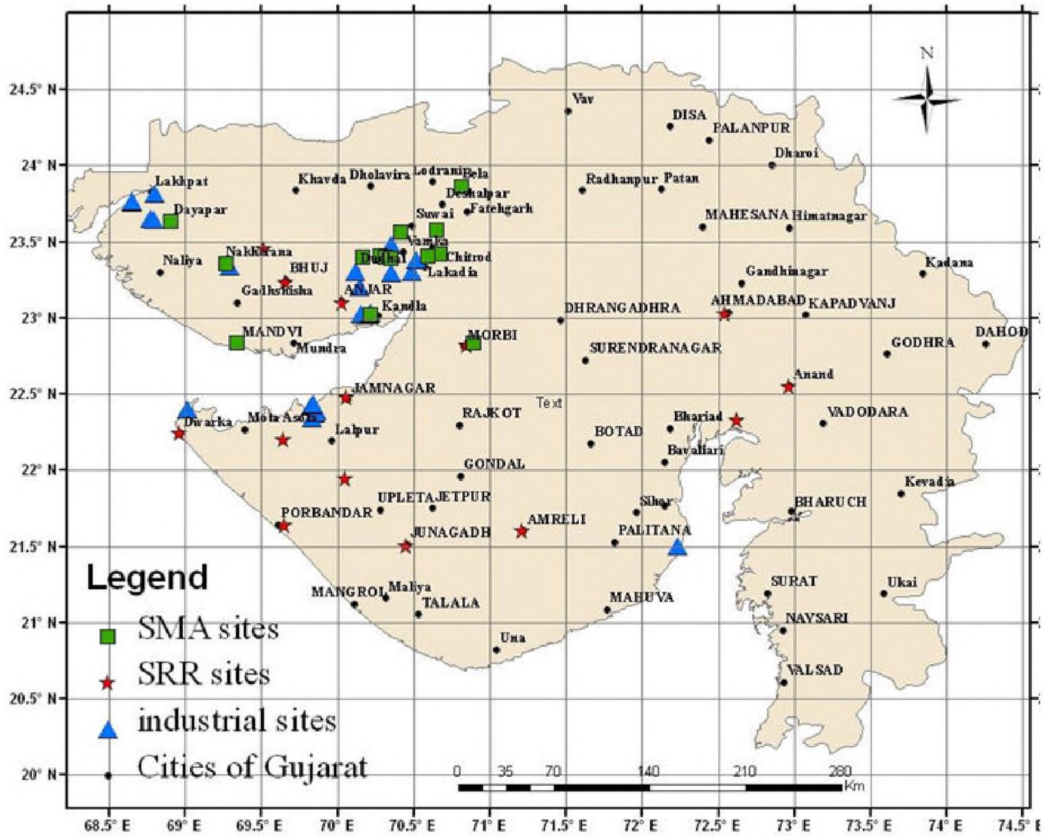


Fig. 4.5: Locations of shear wave velocity measurements at 58 sites in Gujarat state

4.8 Attenuation of Seismic waves/Site Amplification using reference site method/Inversion of coda wave envelope. (Babita Sharma)

Estimation of coda Q (Q_c) by Single Backscattering Model of Aki & Chouet (1975):

In this method, decay of coda amplitude with time is plotted at different frequencies. The decay rate of amplitude with respect to time gives Q_c. This model was applied for Koyna, Kachchh and Saurashtra. The outcome is given below:

Koyna: For this study the vertical components of thirty seven events recorded by National Geophysical Research Institute, Hyderabad during 1996 were used. The earthquakes were recorded at least at five stations and had focal depth up to 9 km and epicentral distances raging from 11 to 55 km. Frequency dependent relation obtained for Koyna is $Q_c=(117\pm2)f^{(0.97\pm.07)}$.

Kachchh: Data consisting of vertical component of 49 events recorded at three stations by Institute of Seismological Research, Gandhinagar having focal depth up to 38 km and magnitude ranging from 1.6 to 4.2 was used for estimation of Q_c for Kachchh in 2006. The frequency-dependent relation for Kachchh is obtained as $Q_c=(148\pm3)f^{(1.01\pm.02)}$.

Saurashtra: Digital seismograms related to vertical component for Junagarh (62 events) and Jamnagar (33 events) recorded by the broadband network of Institute of

Seismological Research with magnitude range 1.5<Mw<4.9 and up to 25 kms focal depths have been used for the attenuation studies:

(a) Junagarh: $Q_c=191f^{1.01}$.

(b) Jamnagar: $Q_c=224f^{0.98}$.

The results related to Coda Q indicate that among the three regions the Saurashtra has relatively less heterogeneity as compared to Koyna and Kachchh (Table-1).

- Estimation of Q_α (Quality factor using P-waves) and Q_β (Quality factor using S-waves) by Coda Normalization Method of Aki and Chouet (1980) extended by Yoshimoto *et al.* (1993)

In this method, spectral amplitude of P and S waves are divided by spectral amplitudes of coda waves whose decay rate with distance are used to determine Q_α and Q_β. This method was applied for Koyna, Chamoli and Kachchh areas. Data used for Koyna and Kachchh for this study is same as used in Q_c estimates. For Chamoli region the data comprised of the waveforms of 25 aftershocks of 1999 Chamoli earthquake recorded at five stations. The results obtained in terms of frequency dependent relations for Koyna, Chamoli and Kachchh are given in Table 4.2. The results show the average ratio of Q_s/Q_p is more than unity for three regions. This average ratio and strong frequency dependence of estimated Q suggests that the scattering is a significant factor contributing to the attenuation of body waves in these regions.

- Separation of Q_c into Q_s (Scattering attenuation parameter) and Q_i (Intrinsic attenuation parameter) using Wennerberg formulation:

Separation of Q_c into Q_s and Q_i was carried out for Kachchh area using the following equation of Wennerberg (1993):

$$1/Q_c=1/Q_i+\{1-2\delta(\tau)\}/Q_s$$

where, $\delta(\tau)$ is -1/(4.44+0.738), $\tau = \omega t/Q_s$, ω is the angular frequency and t is the lapse time. The results are given in Table 4.3. It is found that the Q_c estimates lie between the estimates of Q_i and Q_s but closer to Q_i at lower frequencies. This is in agreement with the theoretical as well as laboratory measurements. A comparison between Q_i and Q_s shows that intrinsic absorption is predominant over scattering.

- Inversion of Coda Wave Envelope:

The three-dimensional spatial distribution of relative scattering coefficients is estimated in the Kachchh region, western India, by means of an inversion technique applied to coda wave envelopes. Data used consist of selected vertical-component, broadband recordings from 438 earthquakes with moment magnitudes M_w ranging from 1.6 to 4.2 and epicentral distances up to 235 km recorded by the Institute of Seismological Research. The results of the inversion analysis yield relative scattering coefficient estimates between ~1.3 and ~0.8. Most of the analyzed region reveals small spatial perturbations of the scattering coefficient of the order of ±16%, thus suggesting a uniform distribution of scattering coefficients in the lithosphere beneath the Kachchh region for the analyzed frequencies between 1 and 2 Hz. This uniformity is broken by the presence of some strong scattering areas distributed in several clusters through the region. A clear picture of the Moho in this region is imaged at average depths between 32 and 42 km.

- Site Amplification Study using Reference Site Method

Amplifications at a few sites in Garhwal and Koyna were estimated by reference site method. For Garhwal, vertical components of twenty four stations for shocks of 1989 were considered. The coda amplitudes at different frequencies at three stations in Garhwal viz. Dhargaon (DHR), Chakrata (CHK) and Surkanda (SUR) were divided by the coda amplitude of Pauri (POR) reference site in the frequency domain. It shows up to 2 times amplification at DHR and SUR while up to about 4 at CHK (Table 4.4). Similarly in Koyna area, site amplification was estimated at Chikhli (CKL) and Katwali (KTL) stations considering Warna (WRN) as reference site. Data of thirty seven earthquakes that occurred in Koyna-Warna region in 1996 were used for this study. Site amplification is observed up to 3 at different frequencies (Table 4.4).

Table 4.2: Average frequency dependent relationships for four Indian regions. Quality factors using P-waves (Q_α), using S-waves (Q_β) and using coda-waves (Q_c)

S.No.	Region	Frequency range(Hz)	Average Frequency dependent relationships
1.	Koyna Region	1.5 to 18 Hz	Q_α= (59±0.5)$f^{(1.04\pm.04)}$, Q_β= 71±1.1)$f^{(1.32\pm.08)}$ and Q_c=(117±2)$f^{(0.97\pm.07)}$.
2.	Chamoli Region	1.5 to 24 Hz	Q_α= (44±1)$f^{(0.82\pm.04)}$ and Q_β=(87±3)$f^{(0.71\pm.03)}$.
3.	Kachchh Region	1.5 to 24 Hz	Q_α= (77±2)$f^{(0.87\pm.03)}$, Q_β=(100±4)$f^{(0.86\pm.04)}$ and Q_c=(148±3)$f^{(1.01\pm.02)}$.
4.	Saurashtra Region	1.5 to 18 Hz	Q_c=191$f^{1.01}$ and Q_c=224$f^{0.98}$ for Junagarh and Jamnagar respectively.

Table 4.3: Separation of Qc in terms of Qs (Scattering attenuation parameter) and Qi (Intrinsic Attenuation Parameter) using Q_β by Wennerberg formulations for Kachchh region.

Central Frequency(Hz)	Qc	Q_β	Qs	Qi
1.5	204	136	529	183
3	459	237	628	380
6	1093	615	1819	928
12	1680	881	2370	1402
24	3454	1424	3053	2668

Table 4.4: Values of relative site amplification factors for Garhwal (three sites i.e. DHR, CHK and SUR) and Koyna (two sites i.e. CKL and KTL) using reference site method

Central Frequency(Hz)	Site Amplification Factor				
	Garhwal Himalayan Region (Pauri reference site)			Koyna Region (Warna reference site)	
	Dhargaon (DHR)	Chakarta (CHK)	Surkanda (SUR)	Chikali (CKL)	Katwali (KTL)
1.5	-	-	-	1.4	2.1
3	1.42	3.72	1.63	1.2	1.9
6	2.25	1.48	1.51	2.5	1.6
12	1.53	2.99	1.37	3.3	2.7
18	1.11	2.56	2.07	1.8	3.1
24	1.23	2.73	1.68	-	-

4.9 Shear Wave Splitting Beneath the Northwestern Deccan Volcanic Province: Evidences for Lithospheric and Absolute Plate Motion Related Strain

(K.M. Rao and B.K. Rastogi with M. Ravikumar and Arun Singh of NGRI, Hyderabad)

The northwestern Deccan Volcanic Province in India has witnessed several tectonic episodes resulting in the formation of rift zones, wide spread magmatism and deep seated faults that are host to some deadly intraplate earthquakes. In this study, we attempt to decipher the mantle deformation beneath the region using the SKS splitting technique applied to high quality data from a regional network comprising 36 broadband stations sited on diverse tectonic environments. The first measurements of 280 (207 SKS and 73 SKKS) splitting parameters from 73 earthquake sources reveal two major anisotropy trends (Fig. 4.6), one coinciding with the absolute plate motion (APM) and the other with the strike of the local geologic fabric. The Kutch rift, southern part of Saurashtra, southern part of South Gujarat and northern and eastern side of Cambay rift reveal characteristics of ENE-WSW oriented anisotropy which is sub-parallel to the Delhi Aravalli fold belt. This characteristic feature suggests that the mantle in these regions retains the history of Precambrian deformational structures and subsequent deformation episodes.

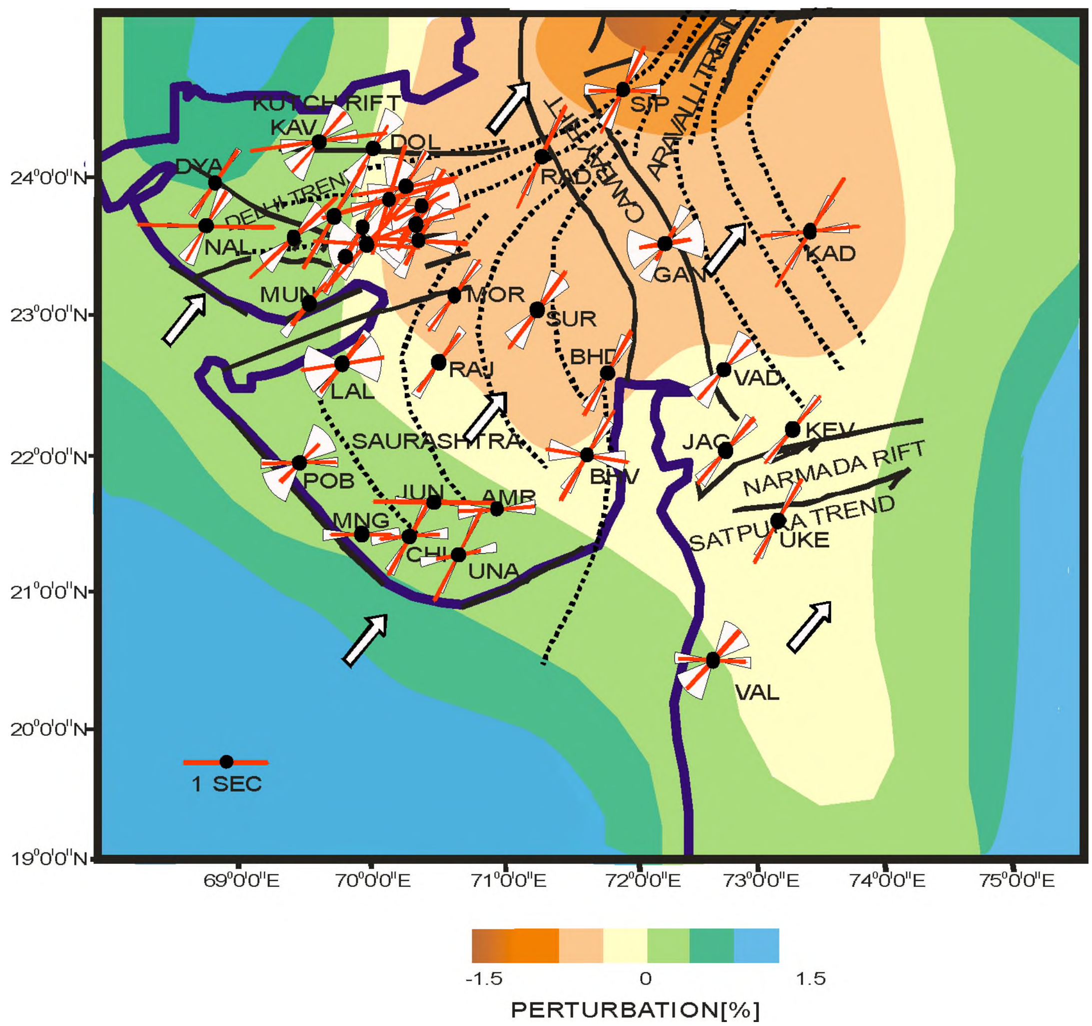


Fig. 4.6: Azimuths of fast polarization directions plotted on the P wave velocity contours obtained by teleseismic tomography (Kennett and Widiyantoro, 1999). Orientation and length of white bars indicate fast polarization direction and delay time respectively. Fans with a fixed length corresponding to a delay time of 1s, show 2 sigma errors in fast polarization directions. The APM directions are shown as arrows in a no net rotation frame (DeMets *et al.*, 1994). The closely spaced stations in the Kutch region are SUE, DUD, LKD, BAD, CHO, BHI, KOD, RAY and NAG.

Imprints of the Reunion plume (that is widely regarded as the source of volcanism) are absent in terms of signatures of an asthenospheric radial flow. Also, our observations are not consistent with anisotropy created by rifting process at the Narmada and the Cambay rifts. With the exception of large delay times (δt=1.8s) at five stations within the Kutch rift, which may be due to aligned melt pockets within mantle-lid, the delay times at all the other stations are close to 1s, similar to the previous estimates from other parts of the Indian shield. Previous measurements of shear wave anisotropy in the northwestern DVP have been very sparse to comprehend the mantle deformation in this region of tectonic complexity. SKS splitting measurements restricted to data from only two broadband stations (BHUJ, DHR) as a part of the continental scale study of the Indian shield anisotropy (Ravi Kumar and Singh, 2008) reveal small delay times of 0.6±0.3s and 0.9±0.5s with fast polarization azimuths of 62±26.5° and 30±22.5° for stations BHUJ and DHR respectively. **(Communicated to JGR)**

4.10 STRUCTURE OF THE CRUST BENEATH THE NORTHWESTERN DECCAN VOLCANIC PROVINCE FROM TELESEISMIC RECEIVER TRANSFER FUNCTIONS (K.M. Rao and B.K. Rastogi with M. Ravikumar of NGRI, Hyderabad)

The northwestern Deccan Volcanic Province in India and associated pericratonic rift basins were reactivated during several stages of India's northward drift after the break-up of the Gondwanaland during the late Triassic-early Jurassic and post collision with Asian plate. In this study, we attempt to decipher crustal thickness and average crustal Vp/Vs ratios beneath the region using the slant stacking of 2687 teleseismic receiver functions from a regional network comprising 40 broadband seismic stations sited on diverse tectonic environments. Most of the receiver functions reveal clear negative phases between 0 and 5 seconds after the first S arrival (Fig. 4.7). Results from slant stacking analysis reveals the Moho depths are varying between 33 and 43 km in the Kutch region, 31 and 38 km in the Saurashtra region, 27 and 34 km in the Cambay basin, (28 - 36 Km) in the Narmada region and between 40 and 42 km in the north and eastern part of the Cambay basin. Higher Moho depths are found under the SE part of KMU (~43 km) and Wagad uplift (~42 km) in the Kutch region, Jasdan plateau (~37 km) in the Saurashtra region due to mass deficiencies from thickening of crust caused by isostatic overcompensation and also in the eastern part of the Cambay basin (~42 km). Lower Moho depths are found beneath the Cambay and the Narmada rift basins and the coastal areas. Shallower crust (30-33 km) is also observed in the region surrounded by the extension of western limb of the Proterozoic Aravalli trend in Saurashtra, its eastern limb and the Narmada fault in the south as compared to the surrounding regions (36-40 km) (Fig. 4.8). High Vp/Vs ratios are detected beneath Kutch (1.8-2.03), coastal areas of Saurashtra (1.79 – 1.99) and NE part of the Cambay basin (1.82-1.97) indicating the existence of mafic/ultra mafic crust providing evidence for the extensive magma underplating beneath these regions. At all other stations, the Vp/Vs ratios are in the range of (1.70 – 1.76) which indicate the rocks in the area to be felsic with dominance of Quartzite rocks, similar to the global average for Precambrian shields (Fig. 4.9).

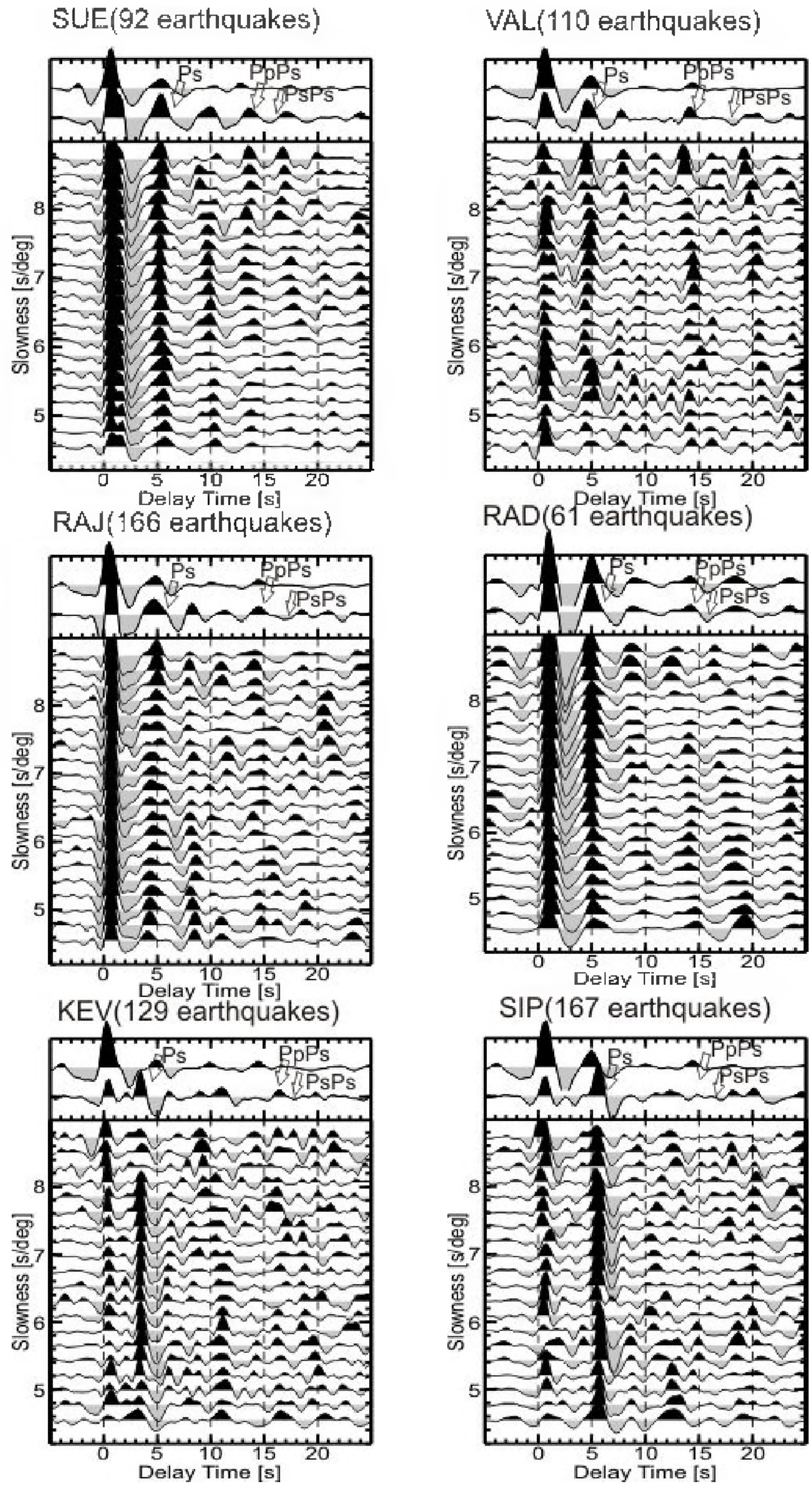


Fig. 4.7: Examples of Receiver functions of six stations

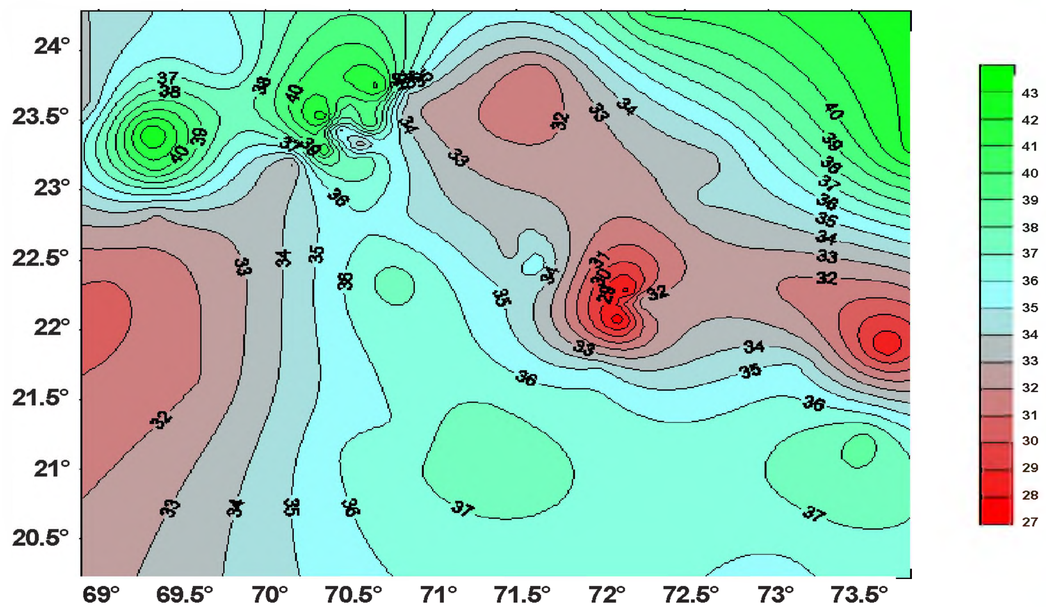


Fig. 4.8: Contour plot of Moho depth as revealed by slant stacking analysis of receiver functions

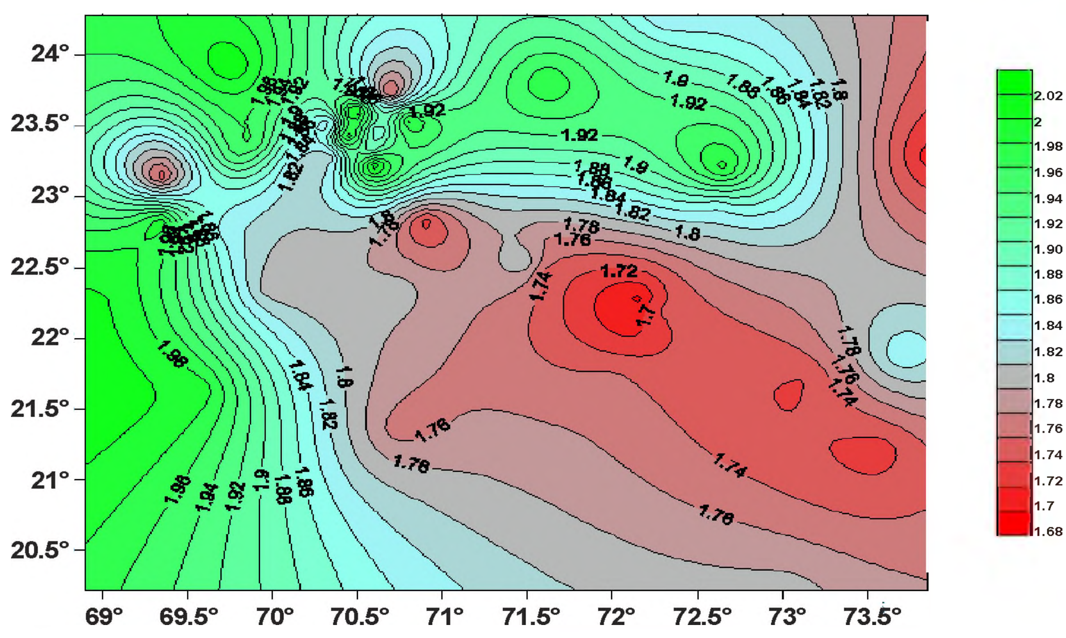


Fig. 4.9: Contour plot of Vp/Vs ratios as revealed by slant stacking analysis of receiver functions

The Moho depths derived in our study are consistent with previous gravity and deep seismic studies (DSS) (Kaila *et al.*, 1981).. The correlation coefficient between Moho depths obtained by the present study and the DSS estimates is 0.92. Combined with high regional heat flow and mid-crustal layers of high electric conductivity, the large intra crustal S-wave velocity reduction and the high average crustal Poisson's ratios are consistent with partial melt which may be related to the process of magmatic underplating in the lower crust beneath Kutch, coastal areas of Saurashtra and NE part of the Cambay basin. **(To be communicated to Gondwana Research)**

4.11 PALEOSEISMOLOGICAL AND ACTIVE FAULT INVESTIGATIONS IN KACHCHH (B.K. Rastogi, M. S. Gadhavi, Girish Ch. Kothyari, Falguni Bhattacharya in collaboration with IITk and PRL)

Paleoseismology, geomorphology and dating of recent tectonic features has been done in Kachchh to determine ages of pre-historic earthquakes and rates of movements along geological faults. The study helps in establishing recurrence interval of earthquakes for past several thousand years and helps in forecasting of earthquakes. The first step of the study was thorough checking of satellite stereo images for tell-tale signs of earthquake deformations like pressure ridges and then ground combing for confirmation of the desired features. After asserting good chances of getting Quaternary deformation trenches were dug and the sediment samples were collected. Analysis of these samples is done in OSL Lab for determining the ages of the sediments and how they were formed. Paleoseismology studies are complemented by geophysical investigations such as GPR and MASW survey, leveling measurements using RTK and Total Station. The study revealed clear evidences of neotectonic activity and pre-historic earthquakes. The active fault map of Kachchh prepared for the first time by ISR is shown in Fig. 4.10.

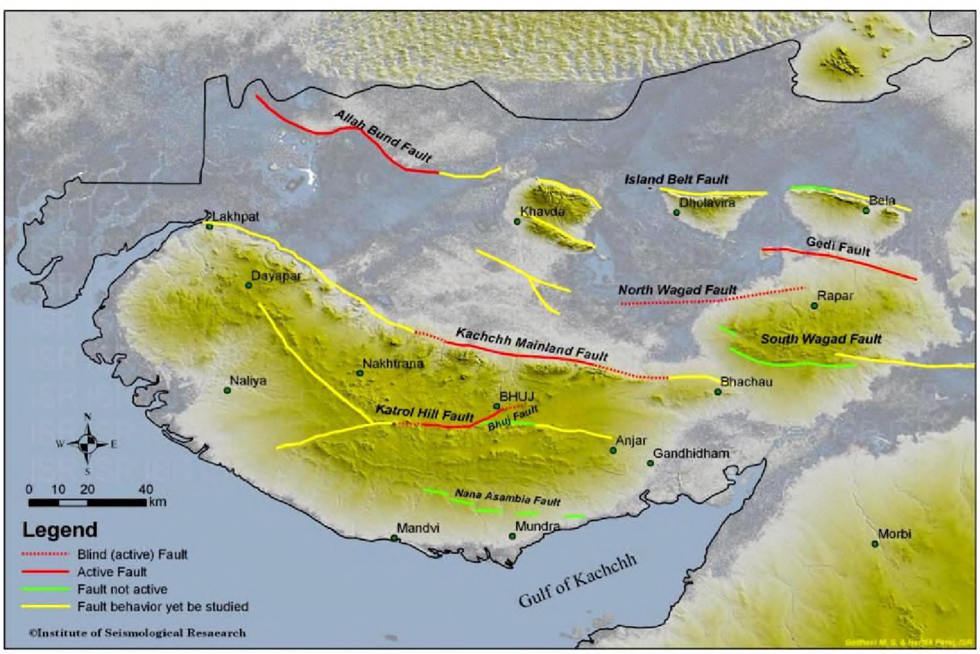


Fig. 4.10: First time ever produced active fault map of Kachchh by ISR

Paleoseismic and Morpho-Tectonic Studies at Allah Bund in Great Rann of Kachchh

The region of Kachchh was devastated by a severe earthquake on 16 June 1819. A noticeable morphological change related to this earthquake was the upliftment of a broad area trending nearly E-W, 80 km in length and 6-7 km in width. This resulted into damming of Nara/Puran River, then eastern most distributary of the Indus River. The structure was locally named as Allah Bund (God's Dam).

Field investigations, levelling & trenching surveys and OSL dating of paleochannels was carried out to quantify geomorphic changes in the area. Total 7 levelling profiles were collected across Allah Bund. Longest levelling profile of 5.3 km across the bund on western bank of Nara River revealed that the present elevation of the bund above the lake level is ~4.4 m, 30% lower than the 6.2 m measured by Baker in 1844 (Fig.4.11). In contrast, the bed of the Nara is ≈50 cm above lake level compared to ≈50 cm below lake level as measured by Baker. These comparisons suggest that the level of Lake Sindri is the same as in 1844 and 2007. The north-south width of the Bund (≈5 km) measured in 2007 is approximately the same as in 1844. In eastern segment elevation difference of dry bed of Lake Sindri and bund is 5.82 m. In central part of bund few trenches were excavated at the southern edge of bund. The exposed section in trenches shows inclined laminated succession with about 3° -5° dipping due south. Though main fault is not encountered in any of the trenches, micro-faulting was common. In central part of bund normal faults and, to the south, near the edge of bund reverse faults are observed. Two N-S oriented trenches were excavated at Vigokot (an archaeological site 10 km north of bund). Trenches at Vigokot are characterised by liquefaction craters of different dimensions. On the basis of cross cutting relationship of three large craters and disrupted occupation levels of human settlement three large and/or near source events are recognised. Other than these three events three to four small or distance source events are also envisaged on the basis of small sand blows. Dating of charcoal and OSL samples is in progress.

Numerous paleochannels were recognised from satellite data as well as during field investigations in the area. A N-S oriented paleochannel, comparable in dimensions with that of Nara River, yielded OSL date of 3 ka at height of 140 cm. Levelling profile along its course is convex in shape signifying that it is uplifted at least by 2 m (Fig.4.12). Another small paleochannel uplifted to the elevation of 4 m west of Nara River exhibit OSL age of 2 ka at depth of 40 cm. Sediments of paleochannels are comprised of well sorted, medium to fine micaceous sand interspersed with clayey sands suggesting deposition under a fluctuating tidal-continental environment. Uplifted Rann sediments, at a height of 130 cm from level of Lake Sindri were dated to 5 ka whereas the top sample at height of 290 cm gave an age of 4 ka. These ages suggest that around Sindri, sedimentation of the tidal flat facies (Rann) occurred during >5 ka and continued beyond 4ka. Minimum age of uplifted paleochannel indicate that maximum age of uplift of bund near Nara River could be 2 ka. But there is possibility that uplift could be much younger, because the channel may have been abandoned prior to uplift due of the influence of climatic or fluvial processes.

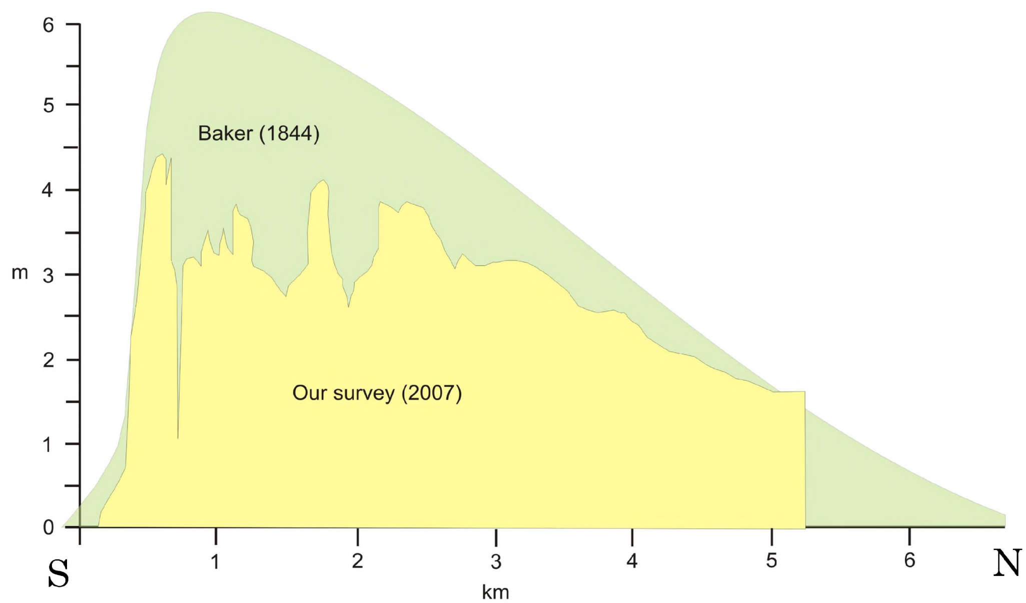


Fig.4.11: Average of several elevation profiles taken with auto leveler in western part of Allah Bund

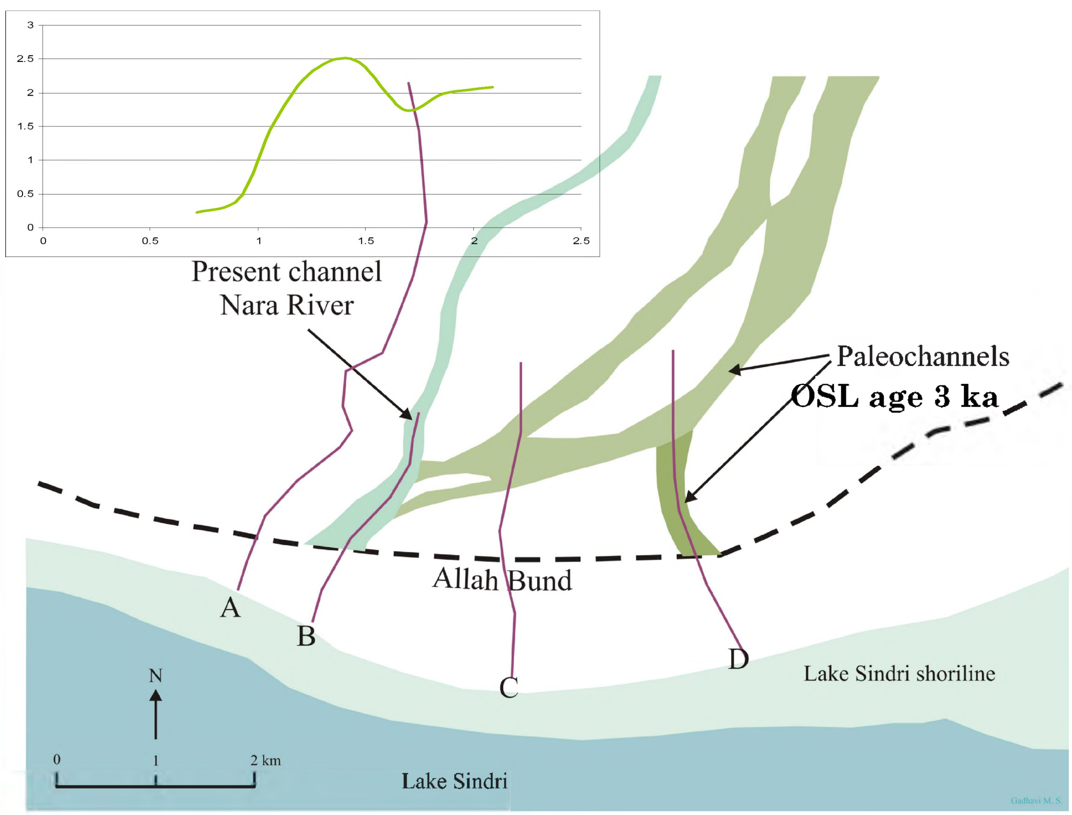


Fig. 4.12: Locations of paleochannels in western segment of Allah Bund and levelling profiles. Levelling profile D along a paleochannel is convex upward indicating uplift in the region. A small paleochannel with OSL age of 2K west of profile A shows 4m uplift

Examination of Corona stereo images revealed a few linear trends over the eastern part of Allah Bund Fault near Dharamshala. On ground check they were found to be sand dykes formed by liquefaction. Some small faults were observed. A few shallow trenches were dug and the rock/soil samples were collected for dating

Fig. 4.13: Sand dykes observed over eastern part of Allah Bund near Dharamshala

4.11.1 A 2D GPR INVESTIGATION ALONG ISLAND BELT FAULT IN KACHCHH (Girish Ch. Kothyari and Mahendrasinh Gadhavi)

This study involved an integrated high-resolution geophysical and sedimentological approach. The internal stratification of the Rann was investigated using a Ground Penetrating Radar (GPR) system with a 200 MHz transceiver. The northern limit of Kachchh region is defined by Great Rann. A total 1km GPR records were collected in this region. The study area (Fig. 4.14) is characterized by presence of thick Quaternary cover over the Mesozoic rocks belonging to Patchham Formation (Rajnath, 1932). Therefore the study of GPR 2D profiling is needed to understand subsurface structure and thickness of sediment over it. Two 15 m deep N-S profiles north of Bela Island (BI) are collected for the study of structural pattern (Fig. 4.15 a & b).

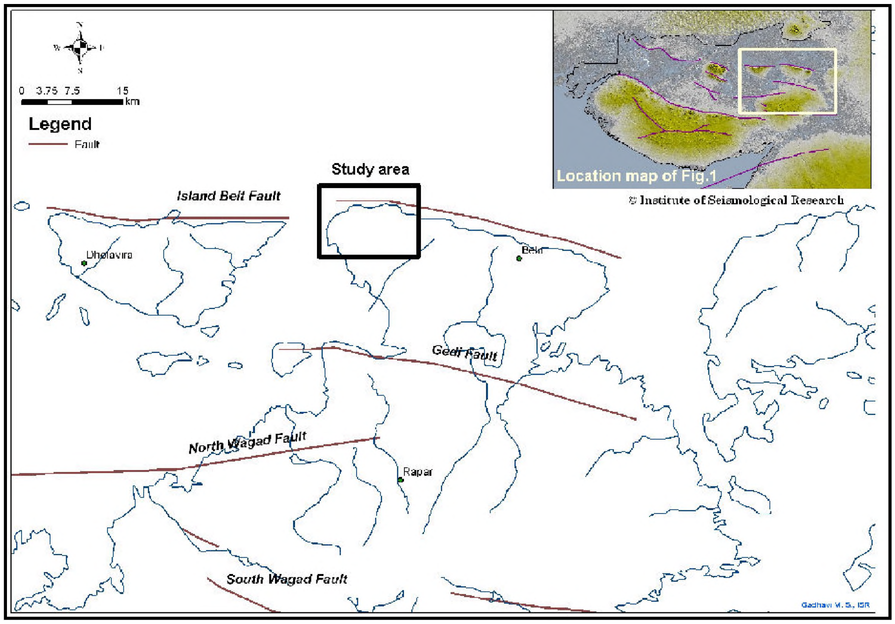
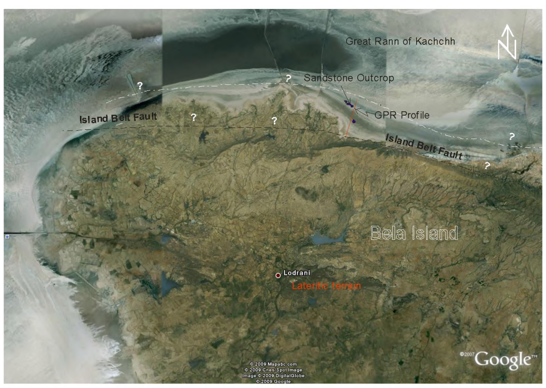


Fig.4.14: Location map of the GPR study area near Gedi and Island Belt Faults



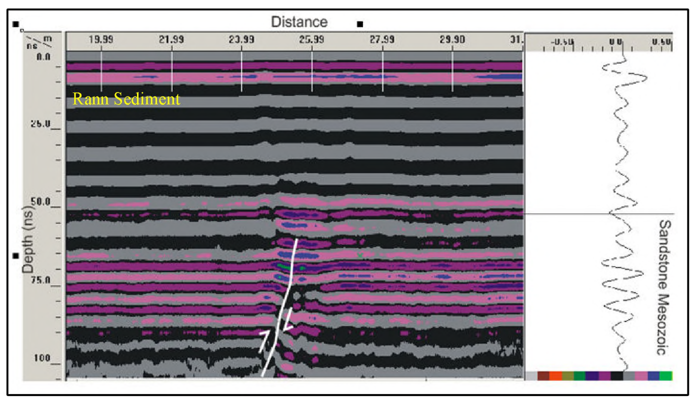


Fig. 4.15a Bird eye view of study area

Fig. 4.15b: GPR profile showing development of fracture on Mesozoic sedimentary unit and thickness of Quaternary sediment

2D GPR Image clearly indicates development of major fracture at a depth of 6m and below. The reflection of hyperbola in the fracture zone indicates influence of compressional tectonic environment (Fig. 4.15 b). At a depth of ~12 m strong hyperbola deflection is observed. The strong reflection at 112 ns represents a material of comparatively larger dielectric value of sandstone. Probably the same sandstone has outcrop just 1.25 km north of Bela Island surrounded by Rann sediments (Fig. 4.15 a). The litho-units in this region are gently dipping towards south.

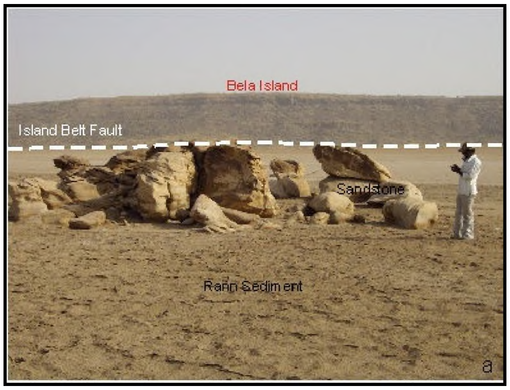


Fig. 4.16: Field photograph showing (a) sandstone outcrop within the Rann sediment, 1.25k north of Bela Island. (b) Cross bedding have been observed within the sandstone

The pink colored sandstone is gritty in nature. Planner cross beds have been observed within the sand stone unit. Trough-shaped sets of cross-beds can be produced by different kinds of bed-forms that have closed topographic depressions. The structure shown here is also recognizable by vertical profiles of cross-bed (Fig. 4.16 b). The direction of dip is constant through each bed.

Brittle Tectonics and GPR investigation

The faults/Lineament in the foothill Zone of Bela island of Great Rann were studied by using satellite data and followed by ground check and further verified using GPR studies. The

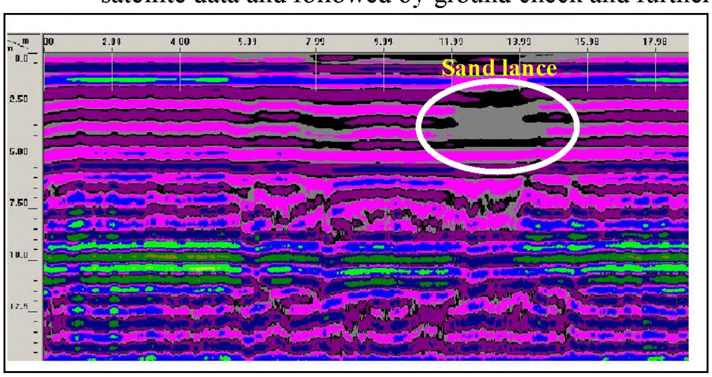


Fig. 4.17: (a) 2D GPR profile showing presence of sand lance within the Runn sediment indicates channel fill. (b) Conjugate joints observed near the foothill zone of Bela Island

Great Rann, north of Bela Island is characterized by presence of an E-W trending Island Belt Fault (IBF) and NW-SE to NE-SW trending transverse fracture pattern (Fig. 4.14 & 4.17). The IBF is steeply south dipping reverse fault along which the Bela Island got uplifted and developed the island morphology (Biswas; 1974 & 1980).

Weak reflections up to the depth of 6 m indicate presence of clay, silt and sand in the region. At a depth greater than 6 m the strong reflections reveal presence of sandstone formation (Fig. 4.15 b). Deflection and offsetting within the two hyperbolas suggest that the conjugate joints are the dominant structures with strike-slip and dip-slip component (Fig. 4.18) followed by simple shear which indicate orientation of faults in different manner. Compressional tectonics in the strike-slip environment produced transpressional faults.

Results and Discussion

GPR survey has for the first time produced high-resolution 2D images of stratigraphy for both Quaternary and Mesozoic formations in Island Belt fault area. The geophysical and geological investigation reflects regressive facies environment all along the Bela Island. The variation in depositional environment of top sedimentary cover and basement units represents variation in evolution of Rann and sea level changes with the time span. The GPR data suggests that the Quaternary sediment thickness in the foothill zone north of Bela Island (for 1km distance) is 6m.

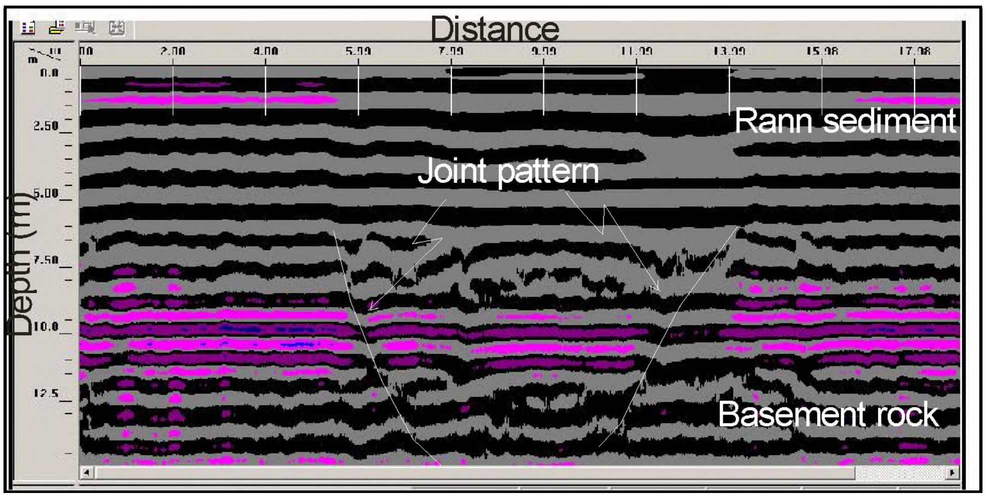


Fig. 4.18: 2D GPR profiles of frontal zone of Bela Island showing development of conjugate joints.

Studies of GPR, geological and satellite data suggest that the studied portion of IBF does not contain signature of active faulting. Markers of tectonic activity such as pressure ridges/popup structures, sag ponds, linear valley/ridges, juvenile drainage pattern, stream offsetting and triangular facets and cones, fault scarp are not observed in the study area. Occurrence of gently south dipping Jurassic sandstone in Great Rann at a distance of 1.25 km north of Bela Island indicates persisting bedrock erosion during recent time.

References:

Biswas, S. K. (1974) Landscape of Kutch – A morphotectonic analysis. Indian Jour. Of Earth Sci., V.1 (2), PP, 177-190.

Biswas, S. K. (1980) Structure of Kutch-Kathiawar Region, Western India; Proc. 3rd Ind. Geol. Congr. Pune, PP. 255-319.

Rajnath, (1932) A contribution to the stratigraphy of Kuchchh. Quart. Jour. Geol. Min. Met. Soc. India. V.4 (4), PP. 161-174.

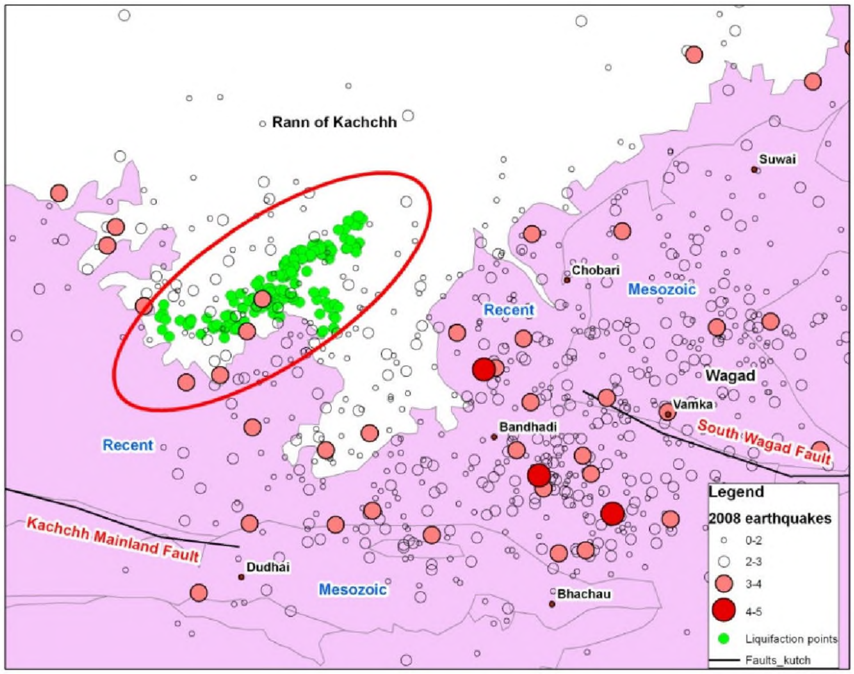


Fig. 4.19: Liquefaction sites as mapped from Google images near Dudhai and the epicenters of earthquakes in Kutch during 2008

Fig. 4.20: Sand-blow liquefaction crater formed due to liquefaction of one of the sites near Dudhai during May 2009

Fig. 4.21: Water collected due to liquefaction at one of the sites near Dudhai during May 2009

4.11.2 INVESTIGATION OF GAS & WATER COMING OUT UNDER PRESSURE IN BANNI/RANN AREA NORTH OF DUDHAI IN KACHCHH (B.K. Rastogi with AM Dayal and Patil of NGRI)

It was noticed during 2007 that methane gas emanating at some places in Banni/Rann area south of Khavda is burning in small amounts. The gas and water oozing out in Banni/Rann area north of Dudhai in Kachchh was noticed in 2008 and 2009. The water and gas in big bubbles is emanating under pressure in craters which are small or as big as several meters in diameter (Fig. 4.21). Such craters can be seen in Google maps and an area of about 15kmx5km was noticed to have such craters (Fig. 4.20). Ground check was done for about a kilometer.

In total 5 samples were collected from the area and were taken to NGRI, Hyderabad for analysis. Dissolved CO_2 and methane gases in three water samples were analyzed. Detection of hydrogen, oxygen and radon is being done in the remaining two samples. ISR interest for carrying out investigation was that weather these gases are related to any stress and strain accumulating at depth related to any impending large earthquake. As the gases are emanating in big bubbles it can be said that the source is at some depth and is under stress and strain. If the source was trapped vegetation (called Biogenic) it will be only at a depth of about a meter or so. If the source is lignite beds (still Biogenic source) it will be at some tens of meters. If the gases are from some oil beds they will be deeper in depth (few kilometers).

The samples were analyzed for C isotope ratios using Thermo Finnegan's Delta Plus XP Mars spectrometer with GC-CIII combustion interface. Data reduction was done using ISODATNT software. The data is reported in 'δ' delta notation as

$$\delta^{13}c = \left\{ \frac{(13c/12c)\ \text{sample}}{(13c/12c)\ \text{Ref}} - 1 \right\} X\ 1000$$

The results are reported with respect to an international standard called PDB (Per Dec Belamnite) in per mil (%o)

The following results of measurements in three samples indicate concentration of dissolved CO_2 and methane gases:

	δ^{13}c PDB (Methane)	δ^{13}c PDB (CO_2)
S. No 4 120	-58.4	-14.54
S. No 2 118	-45.1	-30.3
S. No 1 391	-49.2	-14.6

The results of measurements of sample no 4 are shown in the spread sheet.

Range of δ^{13}c methane for Biogenic and Thermogenic (Petroleum) are as follows:

Biogenic	-90 %o to -60 %o
Thermogenic	-60 %o to -30%o.

Gas looks to be thermogenic on the basis of δ^{13}c values of methane (less than -60). It is possible that the values may be much less than -60 if the samples are collected as required. Even though the samples were collected only 2-3 days before the measurements, it is possible that some biodegradation must have set in because no insecticide was added to the water after collection of samples. Biodegradation will make the value still negative i.e. even though the gas is thermogenic because of biodegradation it will fall in biogenic range. It is suggested that the gas may be collected without water in it to set the proper/ meaningful value for concentration of methane. However, if the investigations have to be carried out this year, the samples have to be collected before mid June 2009 or else it will be possible only in summer season of next year.

RECOMMENDATION

The Banni and Rann area of Kachchh appears to have petroleum prospects as revealed by emanation of thermogenic methane gas under pressure and needs to be investigated.

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NGRI Stable Isotope Lab
GC II-III Interface Results

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Line	Peak Center	GC Method	Identifier 1	Analysis	Method
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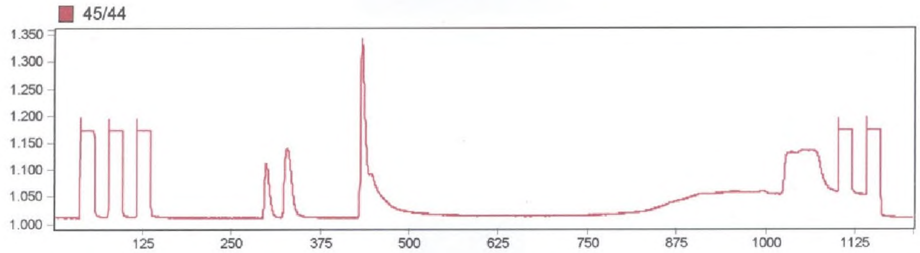

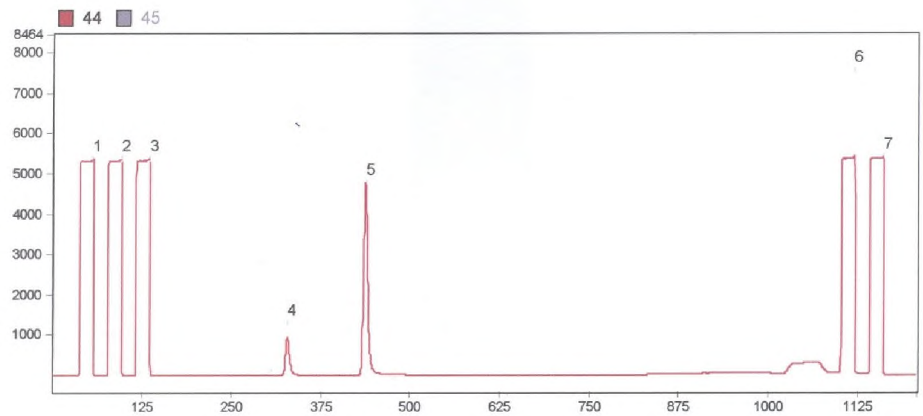

Peak Nr.	Component	Ref. Name	Rt [s]	End [s]	Width [s]	Ampl. 44 [mV]	Ampl. 45 [mV]	Ampl. 46 [mV]	BGD 44 [mV]	BGD 45 [mV]	BGD 46 [mV]	Area All [Vs]	d 13C/12C [per mil] vs. VPDB
1	CO2_REF1	CO2 Lab.Tank	55.6	58.5	23.0	5371	6316	7471	5.6	6.8	11.2	105.688	-34.097
2*	CO2_REF2	CO2 Lab.Tank	95.5	98.2	23.0	5371	6317	7468	5.7	7.1	12.9	105.871	-34.120
3	CO2_REF3	CO2 Lab.Tank	135.4	138.1	23.0	5373	6319	7473	5.7	7.1	13.3	106.459	-34.044
4	METHANE	CO2 Lab.Tank	329.2	343.2	21.9	939	1082	1283	5.9	7.2	24.2	6.060	-58.426
5	CO2	CO2 Lab.Tank	437.9	460.0	30.9	4784	5774	6536	5.5	6.7	16.3	33.098	-14.544
7	CO2_REF6	CO2 Lab.Tank	1120.7	1123.4	23.0	5380	6327	7482	48.3	57.0	71.7	105.998	-33.897
8*	CO2_REF7	CO2 Lab.Tank	1160.4	1163.9	23.8	5379	6324	7479	41.9	49.5	63.3	106.375	-34.120

(1)

Fig. 4.22: NGRI Stable Isotope Lab GC II-III Interface Results of samples collected near Dudhai – May 15, 2009

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NGRI Stable Isotope Lab
GC II-III Interface Results

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Line	Peak Center	GC Method	Identifier 1	Analysis	Method
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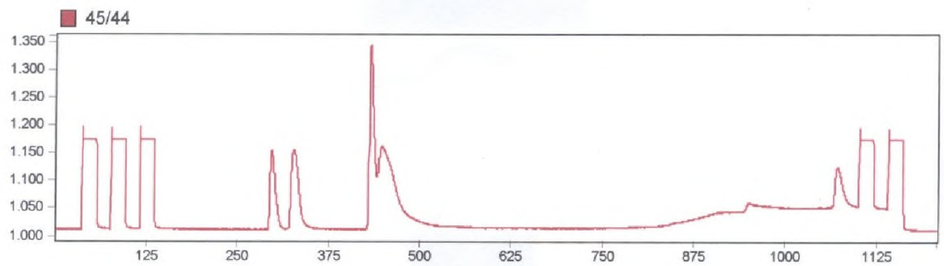
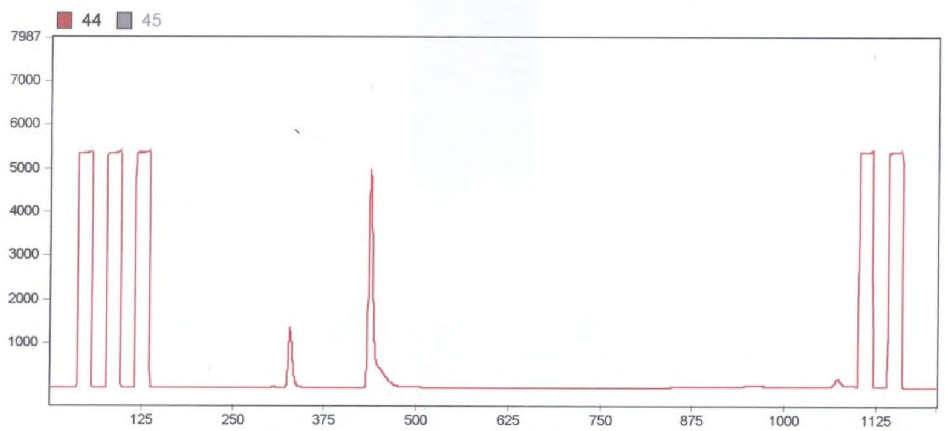




Peak Nr.	Component	Ref. Name	Rt [s]	End [s]	Width [s]	Ampl. 44 [mV]	Ampl. 45 [mV]	Ampl. 46 [mV]	BGD 44 [mV]	BGD 45 [mV]	BGD 46 [mV]	Area All [Vs]	d 13C/12C [per mil]
1	CO2_REF1	CO2 Lab.Tank	55.8	58.5	23.0	5411	6365	7526	5.4	6.6	11.8	106.625	-34.044
2*	CO2_REF2	CO2 Lab.Tank	95.5	98.4	23.2	5400	6351	7512	5.7	7.0	13.8	106.487	-34.120
3	CO2_REF3	CO2 Lab.Tank	135.4	138.1	23.0	5404	6358	7517	5.7	7.1	14.3	107.004	-34.056
4	METHANE	CO2 Lab.Tank	328.5	343.0	22.4	1354	1579	1856	6.2	7.5	27.2	8.712	-49.190
5	CO2	CO2 Lab.Tank	437.2	478.8	50.2	4994	6020	6833	5.6	6.9	18.0	41.441	-14.588
8	CO2_REF6	CO2 Lab.Tank	1120.4	1123.4	23.0	5388	6337	7493	41.7	49.2	63.9	105.983	-33.925
9*	CO2_REF7	CO2 Lab.Tank	1160.4	1163.9	23.8	5378	6325	7480	37.8	44.6	58.9	106.131	-34.120

(1)

Fig. 4.23: NGRI Stable Isotope Lab GC II-III Interface Results of samples collected near Dudhai – May 15, 2009

4.12 CRUSTAL DEFORMATION STUDIES BY GPS MEASUREMENTS

(Pallabee Choudhury, Sumer Chopra and Rakesh Dumka)

Post seismic deformations are going on in Kachchh region due to relaxation process of the 2001 Bhuj earthquake. Moreover, some newly active faults in Saurashtra, Gujarat; faults along Narmada, Gujarat and Madhya Pradesh also show substantial seismic activity. Hence, for monitoring the crustal deformation in and around Gujarat Institute of Seismological Research (ISR) had deployed at total of 20 permanent GPS stations by 2008. During 2009, additional 5 were installed making a total of 25 permanent GPS stations (Table 4.5). Several permanent GPS stations have now been operated for 2-3 years. Locations of proposed five more permanent stations are listed in Table 4.6. In addition eleven campaign stations are being operated since 2006 in Kachchh (Table 4.7). The antenna at permanent stations and 4 campaign sites were mounted on concrete pillars grouted to the bedrock as shown in Fig 4.24. Antenna at rest 7 campaign stations were mounted on bipods above the bedrock. The campaign mode GPS sites were occupied twice a year for 3-4 days with a sampling interval of 30 sec and an elevation mask of 15°. All the permanent and campaign stations deployed by ISR are exhibited in Fig. 4.25.

Co-ordinates and velocities of 3 permanent and 8 campaign stations were estimated in the ITRF 2005 reference frame by stabilizing IGS reference stations using GAMIT/GLOBK, GLORG. The obvious outliers were removed and a combined solution to obtain a consistent set of coordinates and their velocities for all the stations were estimated. The results reflect Indian plate velocity of about 46-50±1mm/yr towards NNE direction as shown in Fig. 4.26. Concurrence of the velocities and time series of IGS stations obtained by us and those provided by SOPAC validates our results. The observed velocity at the Gandhinagar permanent site, a far off site from the earthquake source region, is 48±1 mm/yr in N47°E, which is consistent with the predicted motion of Indian plate at Gandhinagar. The velocities estimated in ITRF05 and in India-fixed reference frame are shown in Table 4.8.

To estimate local deformation in this region, the Indian plate motion was subtracted from these measurements. All sites show very small movement of the order of 2- 5 mm/year in India-fixed frame (Fig.4.27). Site LLPR, situated in Wagad area and much east of the 2001 epicenter, indicates larger velocity, and movement towards SE. It appears that the Wagad area may be moving towards east. Station Dudhai, situated on hanging wall side of the 2001 rupture plane, shows northward movement conforming to the main earthquake rupture. Stations on hanging wall side indicate movement towards WSW conforming to the main-earthquake rupture.

Fig. 4.28 presents total displacement of two ISR stations, namely DUDH and GIBF with respect to ISRG. The recent work by Chandrasekhar et. al. (2009) also presents displacement of a few GPS stations with respect to Ahmedabad (AHMD). Since two of their stations, namely DHAM and RATN, are found very close to two of ISR stations, namely DUDH and GIBF, in terms of location and geology, their time series are combined together. The composite map shows north and east displacement as a function of time with respect to ISRG site for ISR stations and with respect to AHMD site for IIG stations. A logarithmic relation of the form $D=F*\ln(1+\Delta t/\tau)$, where D is the displacement (mm), F is a magnification factor (mm), Δt is the time elapsed since the earthquake (years), and τ is the decay time (years) was fitted to the composite time series (Freed, 2007). The post-seismic time series at these two stations show decay time of 0.08 yr and 0.24 yr for NS and EW component for the station DUDH and 0.16 yr and 0.57 yr for NS and EW component respectively for the station GIBF. The post-seismic relaxation is faster in the station DUDH which is closer to epicenter of Bhuj earthquake than the station GIBF which 50 km north of the same. Also, the relaxation process in the NS component is taking place at a faster rate, almost 3 times than the EW component for both the stations.


Fig. 4.24: GPS site of Vandh, south of KHF

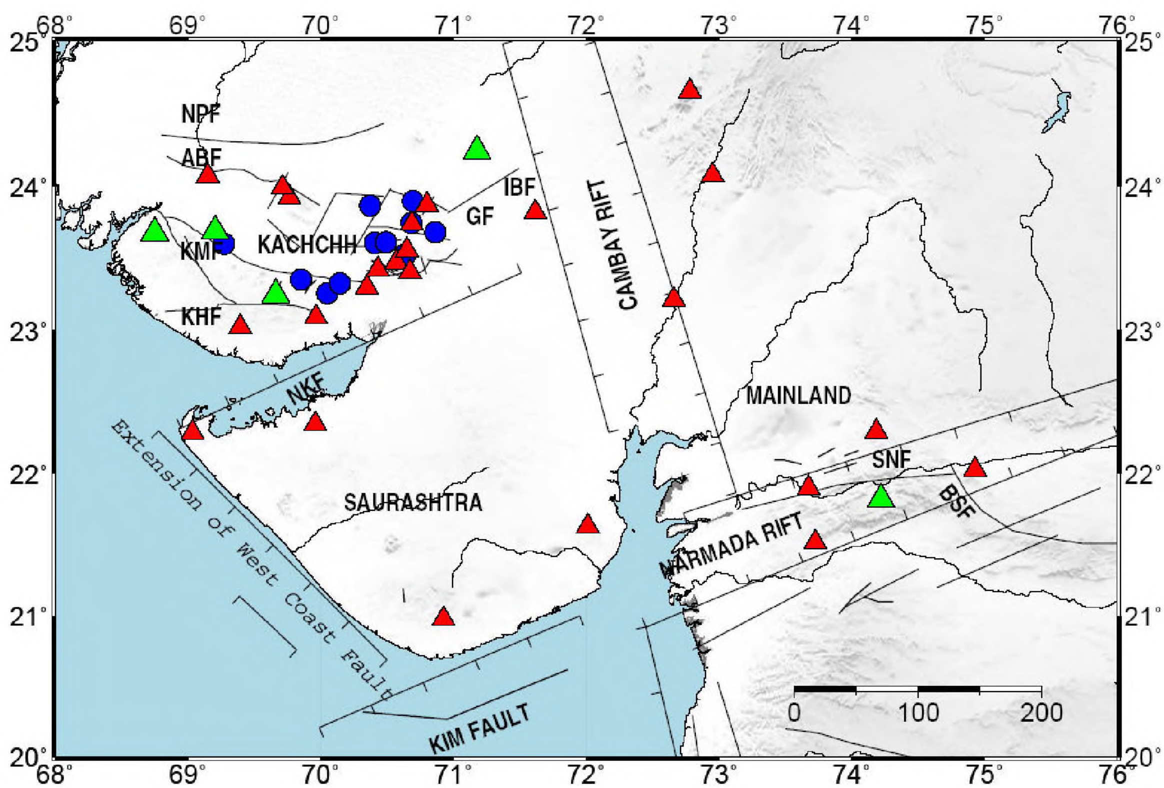


Fig. 4.25: GPS permanent (red triangles), campaign (blue dots) and proposed permanent (green triangles) stations installed by ISR.

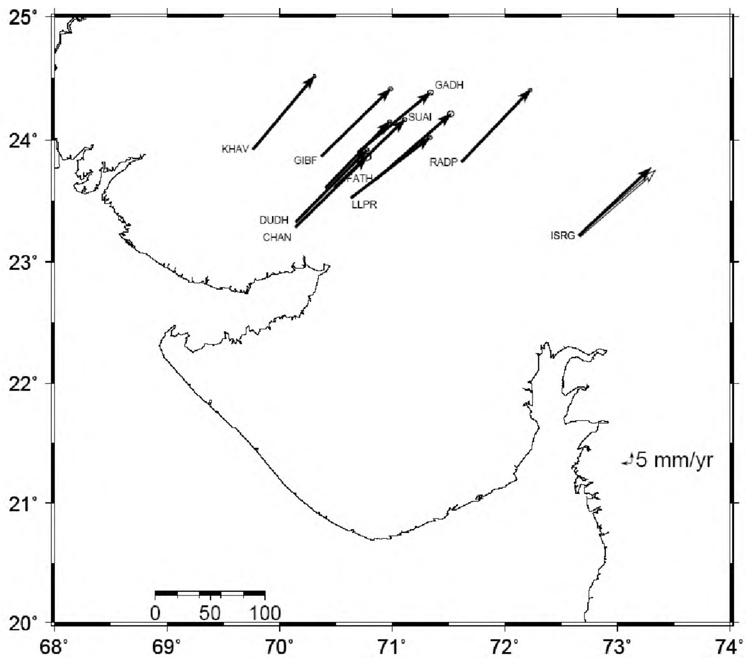


Fig.4.26: Velocity vectors of 3 permanent and 8 campaign stations in Kachchh region in ITRF05. The error ellipses (at the tip of the velocity vector) are drawn such that they give 95 percent confidence level. At ISRG site, the black arrow represents the observed velocity and the white arrow represents the expected velocity. Near perfect match indicates reliability of the station and our data processing.

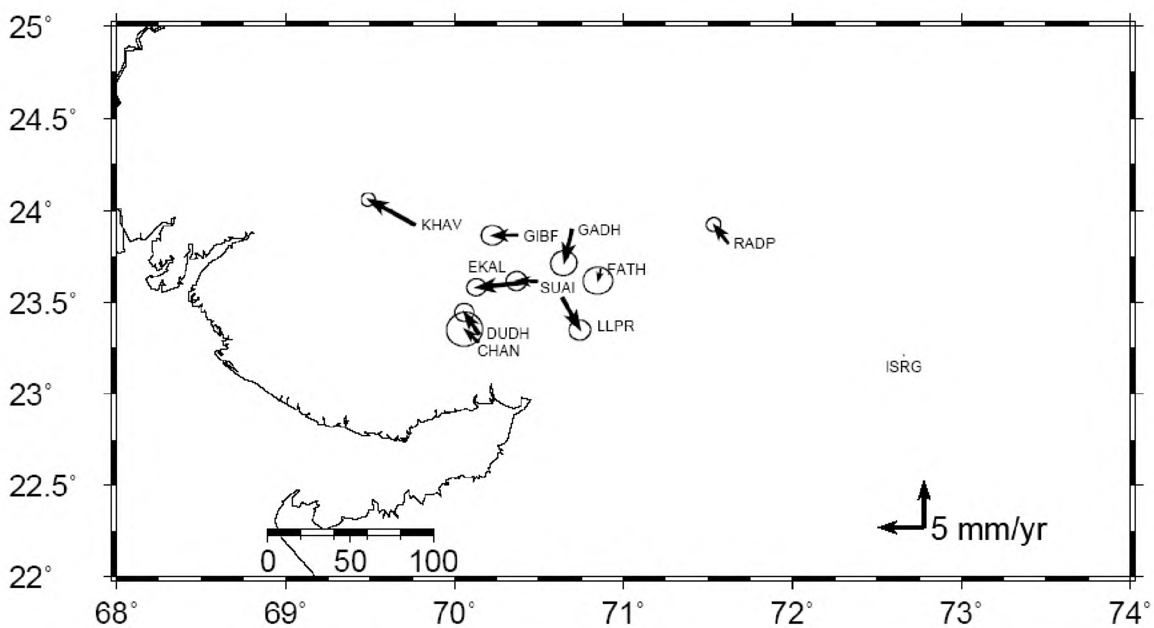


Fig.4.27: The velocity vectors with 95 percent confidence error ellipses of all stations in Gujarat with respect to ISRG permanent station. Post seismic deformation at Lilpar in Wagad show movement towards east. The seismicity has migrated in this area since 2006. Stations north of 23.5°N, lying on footwall of NWF, show movements towards west while DUDH and CHAN on hanging wall side show movement towards north in conformity to the main rupture of 2001.

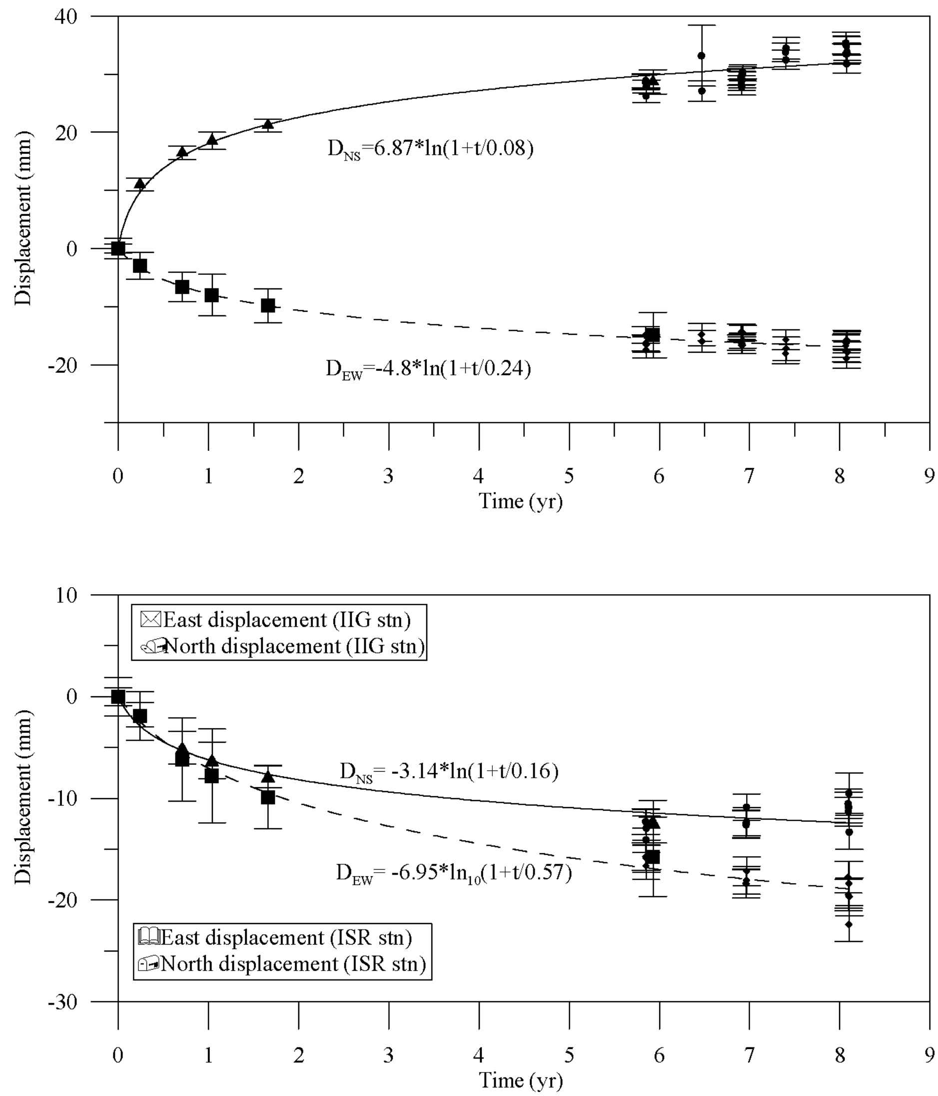


Fig.4.28: Composite map of North and East displacement of 2 GPS sites (DHAM-DUDH and RATN-GIBF) plotted with respect to ISRG from 14 days to 8 years after the 2001 Bhuj earthquake. The solid and dotted line show logarithmic fit to the data based on a decay times and magnitude factors as shown in the equations.

Table 4.5: Existing Permanent Stations in Gujarat deployed by ISR

	Name of GPS site	Latitude	Longitude	Date of Installation	Installed by	Funded by
1.	Gandhinagar	23^{0} 12’ 52.47	72^{0} 39’34.66	28 June 2006	S. Chopra	MOES
2.	Khavda	23^{0} 55’ 19.20	69^{0} 45’57.91	5 Jan 2007	S. Chopra	MOES
3.	Radanpur	23^{0} 49’ 11.89	71^{0} 37’ 01.97	23 Jan 2007	S. Chopra	MOES
4.	Una	20^{0}58’38.59	70^{0} 55’35.06	26 June 08	R K Dumka	GOG/WB
5.	Lalpur	22^{0} 20’48.83	69^{0} 57’47.36	27 June 08	R K Dumka	GOG/WB
6.	Bhachau	23^{0} 18’01.79	70^{0} 20’56.07	28 June 08	R K Dumka	GOG/WB
7.	Rapar	23^{0} 33’33.88	70^{0} 39’30.62	28 June 08	R K Dumka	GOG/WB
8.	Bela	23^{0}51’ 59.41	70^{0} 22’ 23.23	1 August 2008	R K Dumka	MOES
9.	Dharoi	24^{0} 04’ 37.16	72^{0} 57’ 06.68	4 August08	R K Dumka	MOES
10	M.Abu	23^{0}39’ 11.46	72^{0} 46’ 47.34	6 August 08	R K Dumka	MOES
11	Dwarka	22^{0} 17’19.41	69^{0} 02’ 11.80	1 September 08	R K Dumka	GOG/WB
12	Kevadia	21^{0} 53’ 56.69	73^{0} 40’ 26.60	16 October 2008	R K Dumka	GOG/WB
13	Devgana	21^{0} 37’ 49.65	72^{0} 00’ 44.50	17 October 2008	R K Dumka	GOG/WB
14	Desalpar	23^{0} 44’ 31.34	70^{0} 41’ 11.72	18 October 2008	R K Dumka	GOG/WB
15	Vamka	23° 25'30.27	70° 25' 50.18	18 October 2008	R K Dumka	GOG/WB
16	Raisan	23° 12'52.470	72° 39' 34.66	23 October 08	R K Dumka	MOES
17	Badargadh	23^{0} 28’ 29.24	70^{0} 34’ 15.11	26 November 08	R K Dumka	GOG/WB
18	Sinugra	23^{0} 05' 38.86	69^{0} 57' 55.82	5 April 2009	R K Dumka	GOG/WB
19	Vandh	23^{0} 01' 29.775	69^{0} 23' 41.98	7 April 2009	R K Dumka	GOG/WB
20	Chitrod	23^{0} 24' 25.54	70^{0} 40' 26.14	6 April 2009	R K Dumka	GOG/WB
21	Kuar Bet	23^{0} 59' 27.36	69^{0} 42' 47.52	31 March 2009	R K Dumka	GOG/WB
22	Vigu Kot	23^{0} 09' 47.26	69^{0} 06' 01.71	16 July 2009	R K Dumka	GOG/WB
23	Sagbara	23^{0} 32' 50.06	73^{0} 47' 25.36	25 August 2009	R K Dumka	GOG/WB
24	Barwani	22^{0} 02' 39.93	74^{0} 54' 06.08	26 August 2009	R K Dumka	GOG/WB
25	Alirajpur	22^{0} 17' 13.77	74^{0} 21' 08.08	26 August 2009	R K Dumka	GOG/WB

Table 4.6: Proposed Permanent Stations

Sl No.	Station Name	Lat (^{o}N)	Long (^{o}E)	Remarks
1.	Panandhro	23.68	68.752	Kachchh
2.	Luna	23.69	69.207	Kachchh
3.	Bhuj	23.25	69.663	Kachchh
4.	Nada Bet	24.245	71.179	Kachchh
5.	Dhadgaon	21.82	74.22	Narmada

Table 4.7: Campaign mode stations in Kachchh deployed by ISR

Sl No.	Station Name	Four letter code	Lat (^{o}N)	Long (^{o}E)	No. of epochs of measurement
1.	Bela	GADH	23.898	70.694	3
2.	Chandrani	CHAN	23.26	70.05	3
3.	Desalpar	DESP	23.746	70.684	2
4.	Dudhai	DUDH	23.328	70.145	4
5.	Ekal	EKAL	23.609	70.408	4
6.	Fatehgarh	FATH	23.683	70.864	4
7.	Gadhada	GIBF	23.867	70.373	3
8.	Hubai	HUBA	23.354	69.852	2
9.	Lilpar	LLPR	23.526	70.636	4
10.	Palanpur	PALN	23.603	69.273	2
11.	Suvai	SUAI	23.614	70.492	4

Table 4.8: GPS stations velocities (Vel) and 1σ uncertainities. Longitude (Long) and Latitude (Lat) are given in degree. North and east velocities and uncertainities with reference to ITRF05 and ISR permanent station are given in mm/yr.

Stations	Long	Lat	ITRF 2005				With respect to ISRG			
			E Vel	N Vel	Eσ	Nσ	E Vel	N Vel	Eσ	Nσ
ISRG	72.66	23.215	35.06	33.03	0.07	0.07	0	0	0	0
RADP	71.617	23.82	33.51	35.13	0.33	0.31	-1.55	2.09	0.33	0.31
KHAV	69.766	23.922	29.96	35.81	0.3	0.28	-5.1	2.77	0.3	0.29
FATH	70.864	23.683	36.14	31.66	0.62	0.56	-0.31	-1.26	0.66	0.6
GADH	70.694	23.898	35.57	29.28	0.54	0.49	-0.88	-3.64	0.59	0.54
LLPR	70.636	23.526	38.4	29.44	0.42	0.38	1.94	-3.48	0.48	0.44
SUAI	70.492	23.614	34.16	33	0.39	0.37	-2.29	0.09	0.45	0.42
EKAL	70.408	23.609	31.31	32.4	0.36	0.33	-5.14	-0.52	0.42	0.38
GIBF	70.373	23.867	33.71	32.89	0.43	0.39	-2.74	-0.03	0.49	0.44
DUDH	70.145	23.328	34.84	35.3	0.37	0.34	-1.62	2.38	0.43	0.39
CHAN	70.142	23.285	34.93	34.29	0.77	0.72	-1.52	1.37	0.8	0.75

4.13 InSAR STUDY IN KACHCHH (Falguni Bhattacharya, B. K. Rastogi P. Choudhury and R.K. Dumka in collaboration with K. M. Sreejith and T. J. Majumdar of SAC, ISRO)

Kachchh rift basin in Gujarat has been seismically active since historical period. The devastating Bhuj earthquake of 26th January 2001 is considered as one of largest intraplate events. After a period of quiescence, since 2006 the area became active with several earthquakes of magnitude >5 and numerous low magnitude events. These are attributed to post-seismic relaxation of the region. An attempt has been made to study the seismic deformation using differential interferometry (DInSAR) aided with corner reflectors and DGPS observations. The generated ENVISAT ASAR interferogram and DGPS results of 3 permanent and 11 campaign stations from June-2008 to October-2009 were analysed. No signals related to the deformation could be identified on the interferogram. Analysis of DGPS data for a period of 2007-2009 shows very low deformation rates of about 1mm/yr in vertical and 2mm/yr in horizontal directions. The inferred deformation rate may be resolved with the analysis of more SAR data at regular time intervals. However, the currently operating SAR sensors like ENVISAT, ALOS have very limited data availability over India. The indigenous Radar Imaging Satellite (RISAT) of Indian Space Research Organisation proposed to be launched by the end of 2010 will be able to provide continuous SAR data to monitor the area on an operational basis.

Five 1-m width trihedral passive corner reflectors were deployed over the seismologically active Kachchh region during June 2008 and October 2009. The ascending and descending scenes for InSAR observations are shown in Fig. 4.29. The coherences image generated from ENVISAT ASAR images is shown in Fig. 4.30. Bright patches are showing regions with high coherences. Loss of coherences could be observed in most of the study area during the period of observation (July 2008 and October 2009). The study will also be useful for calibration of ENVISAT ASAR images. Fig. 4.31 shows movement of GPS stations around InSAR study area with respect to ITRF05 indicating plate movement of about 46-50 ± 1 mm/yr towards NNE direction. Fig. 4.32 shows the residual movement of the GPS locations during this time frame which is very meager (~ 1-2 mm/yr).

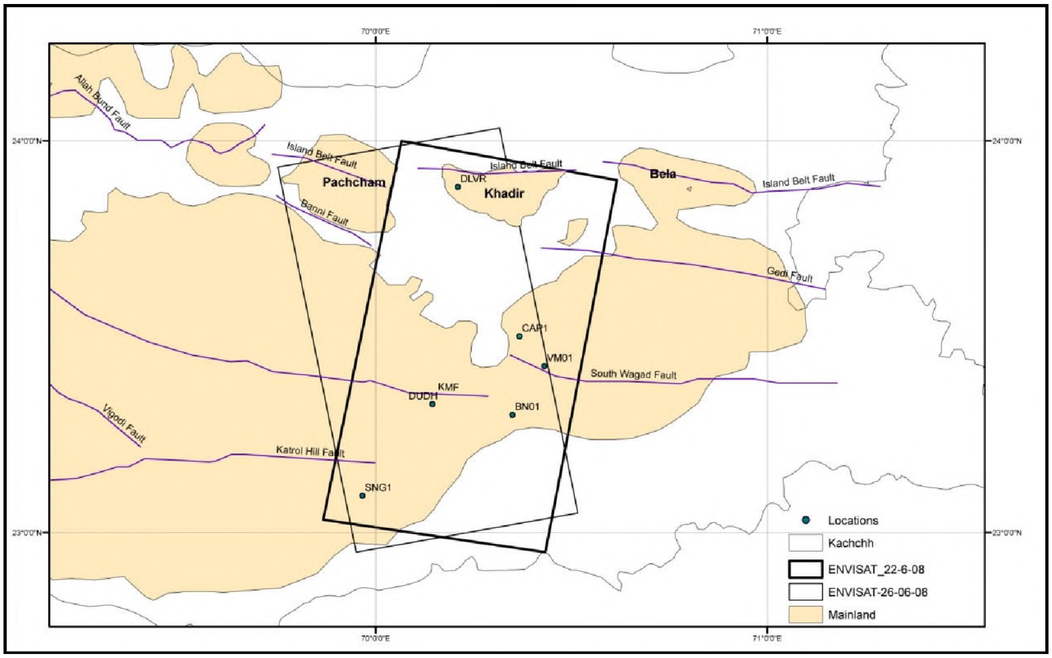


Fig. 4.29: ENVISAT Scenes over the study area

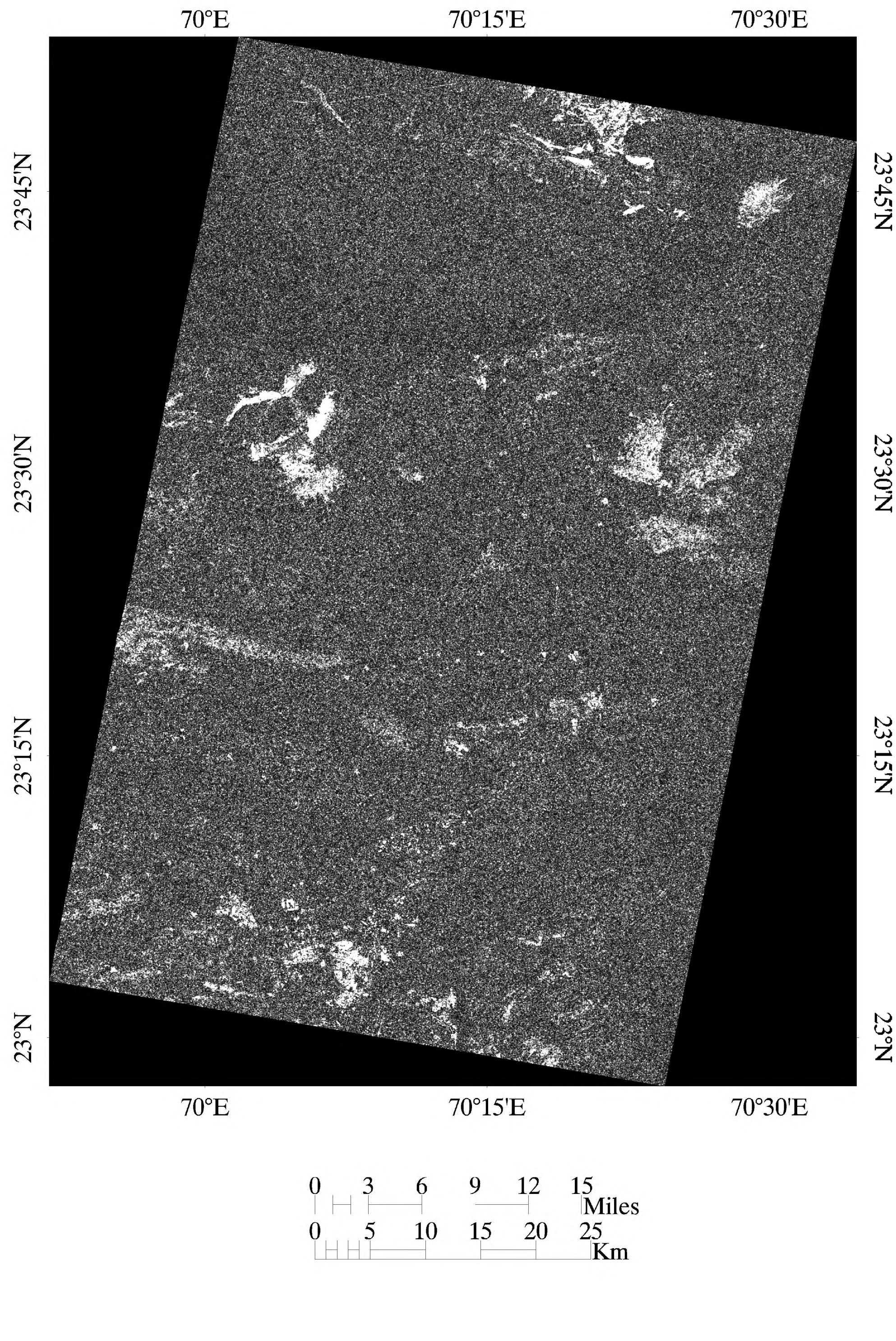


Fig. 4.30: Coherence image generated from multitemporal ENVISAT Scenes over the study area

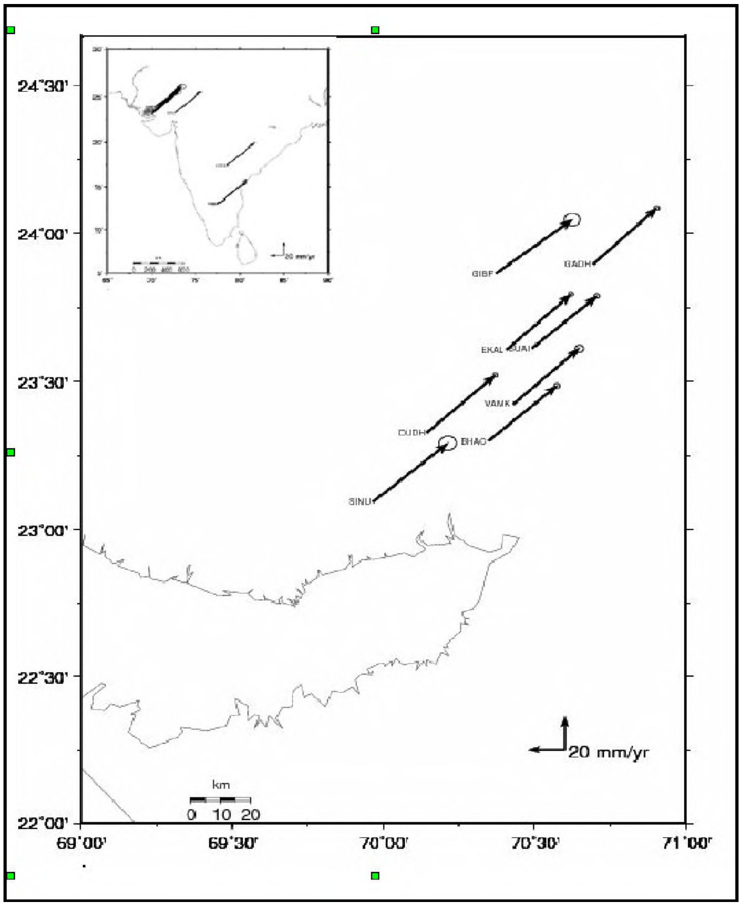


Fig. 4.31: Absolute ITRF05 velocities of GPS sites used for SAR study

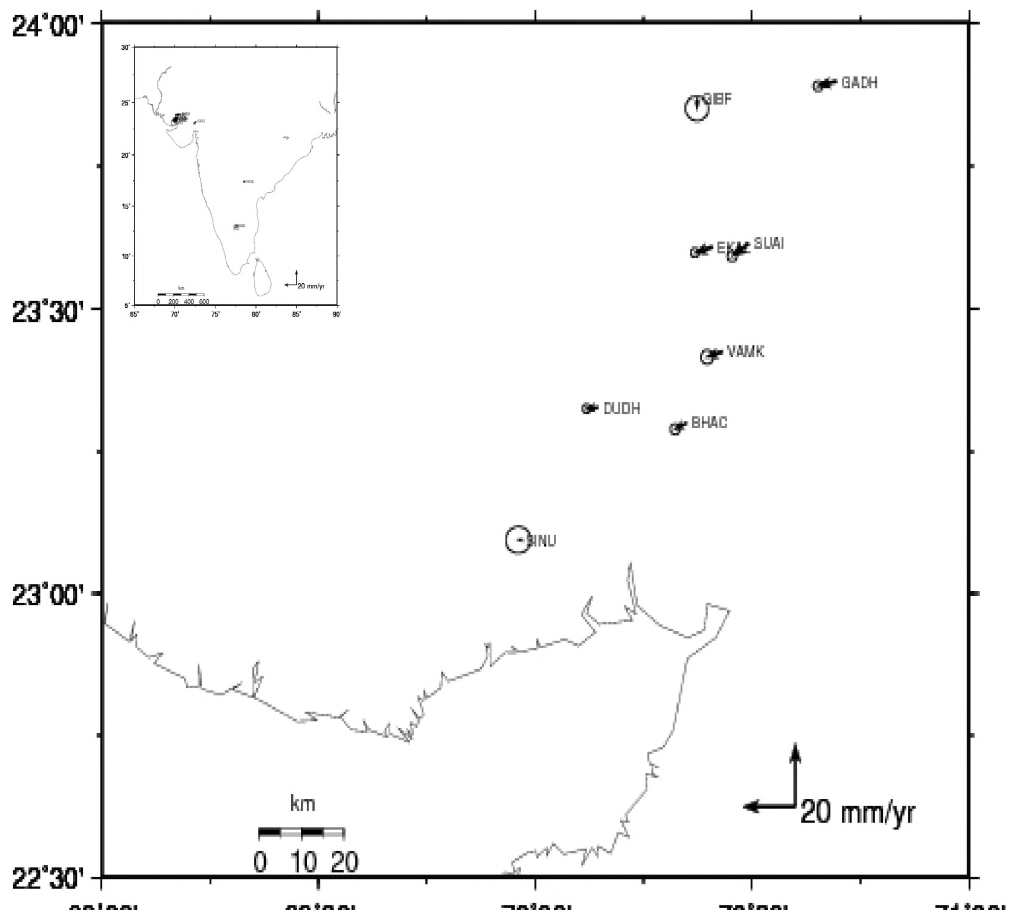


Fig. 4.32: India fixed velocities of GPS sites used for SAR study

4.14 GEOPHYSICAL SURVEYS

4.14.1 Detection of Subsurface Pipelines of ONGC in Ankleshwar by GPR and Resistivity Methods

(Hardik Patel, Janki Desai, Vasu Pancholi, Sameer Tiwari, Taru Shikha Singh, Girish Patel)

Institute of Seismological Research was awarded the task of detecting the subsurface ONGC pipelines by Gujarat Industrial Development Corporation. The geophysical survey methods used were Ground Penetrating Radar and Electrical Resistivity. The GPR survey was carried out for eight days. Some 23 profiles were taken at 16 different locations and total 3-4 km was covered by GPR survey which confirmed the locations of 8 pipelines. The ONGC pipelines are of 10 cm diameter and are mostly present between 0.60 m to 1 m depth below surface. The pipelines were exposed at many places across the drainage cuttings and were found to be at depth of 1m or less beneath the surface. The result obtained from the resistivity survey has shown some indications of the presence of pipeline in the area but could not definitely pinpoint the location. Resistivity survey indicates that the water table depth in the area is about 5-10 m and the ground water quality is saline.

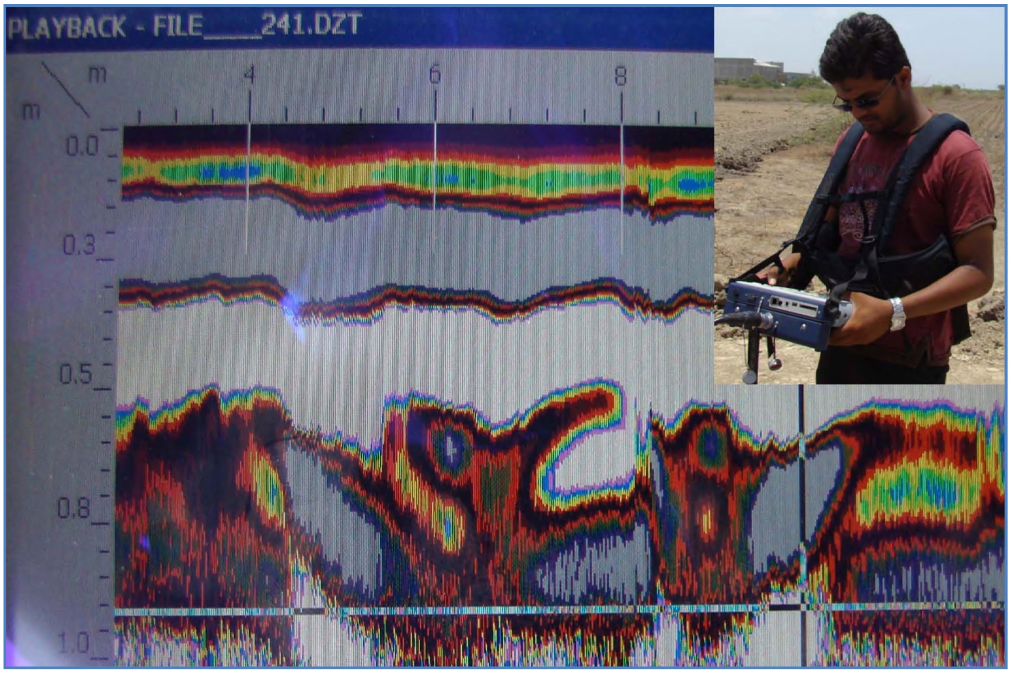


Fig. 4.33: An example of GPR real time data gathering in software SIR 3000

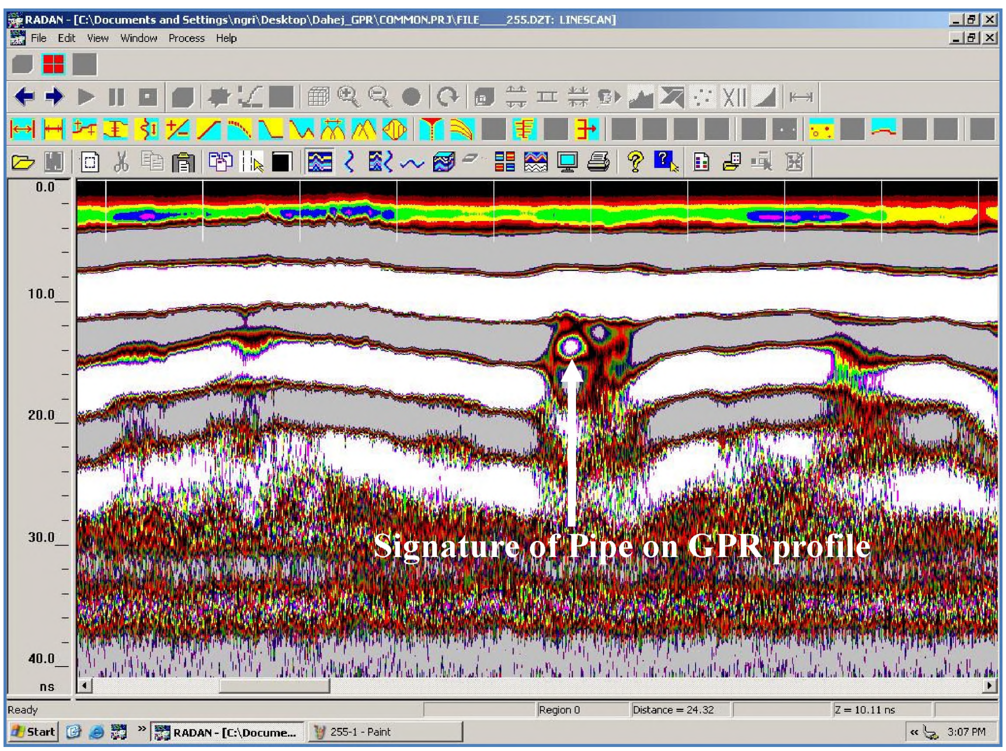


Fig. 4.34: GPR data processing using Software RADAN 6.5 at another site

4.14 GRAVITY SURVEYS FOR DETECTION OF FAULTS IN KACHCHH

(R.K. SINGH, RASHMI PRADHAN AND MEHUL JAGAD)

Gravity Profiles across the Conjectural Mundra Fault

Four 1-3 km long profiles were taken across the conjectural Mundra Fault at station spacing of 100m (Fig. 4.35). The profiles do not indicate presence of any fault (Figs. 4.36 and 4.37).

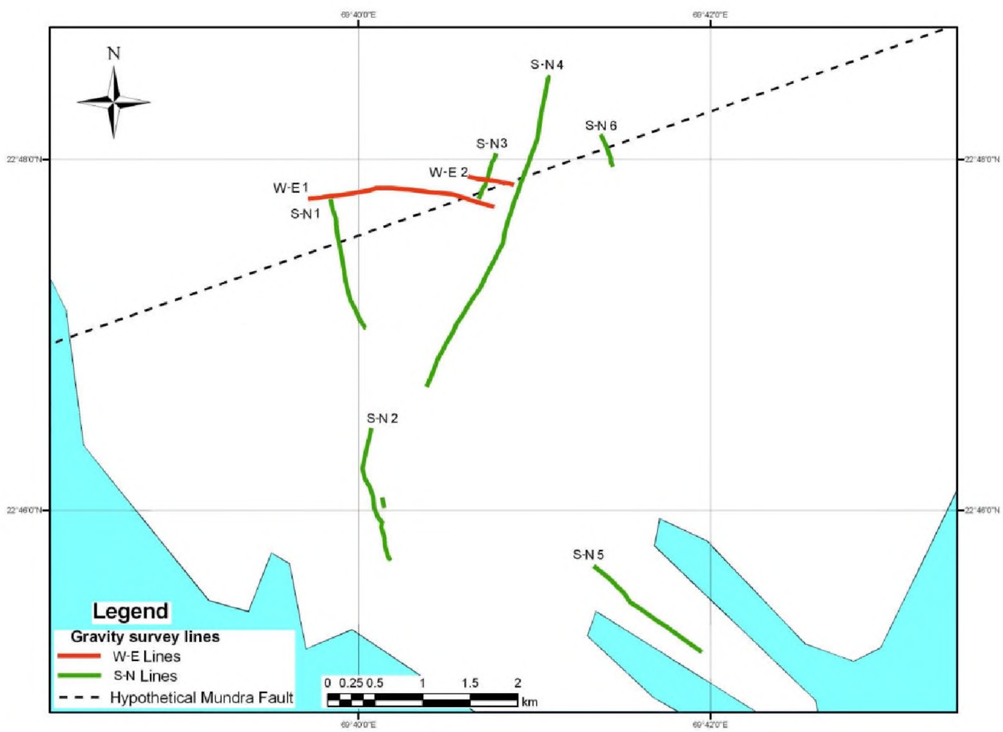


Fig. 4.35: Locations of gravity profiles. Total eight numbers of profiles have been taken (six S-N and two W-E). The S-N1, S-N2, S-N4 and S-N5 have been combined into a single profile.

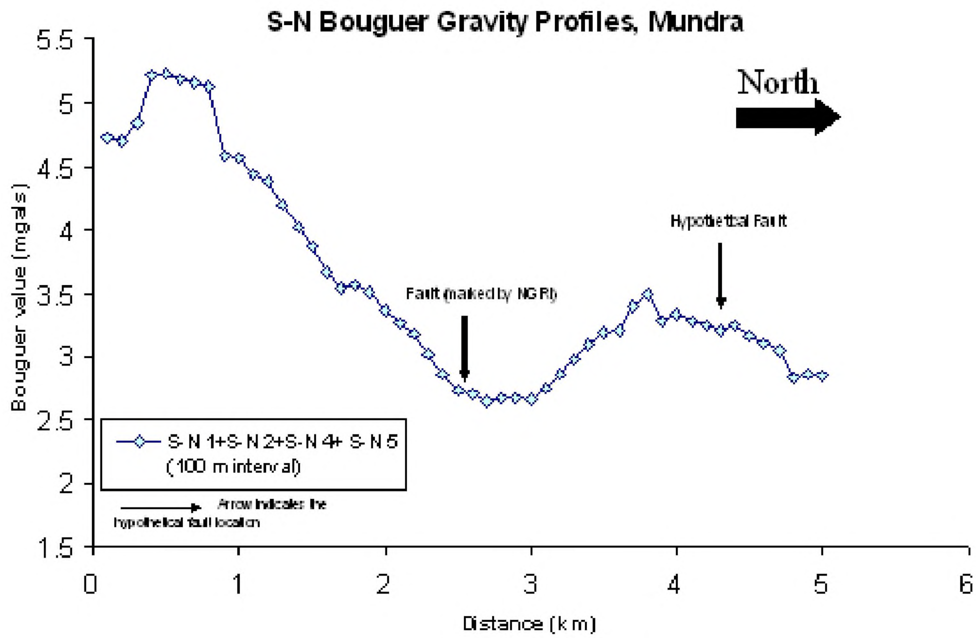


Fig 4.36 (a): The five km long S-N Bouguer Gravity anomaly profile has station interval of 100 m. This profile is combined one of S-N 1, 2, 4 and 5. The combined S-N profile indicates gradual rise of Moho (thinning of crust) or increase in the Deccan Trap thickens towards the coast. Vertical arrows indicate the positions of the hypothetical Mundra Fault and a small fault south of it detected by NGRI 2D seismic reflection. These faults are not depicted in gravity profile.

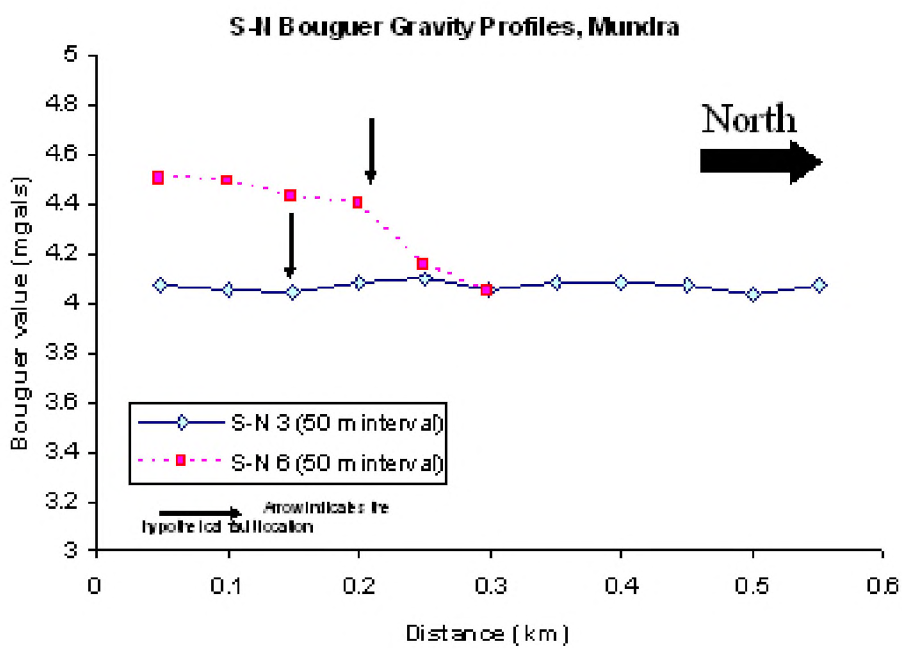


Fig. 4.36 (b): S-N 3 and S-N 6 Bouguer Gravity anomaly profiles. Both profiles have station interval of 50 m. The upper profile S-N 6 is 250 m long

and the lower profile S-N3 is 500 m long. Arrows mark the position of the hypothetical Mundra Fault.

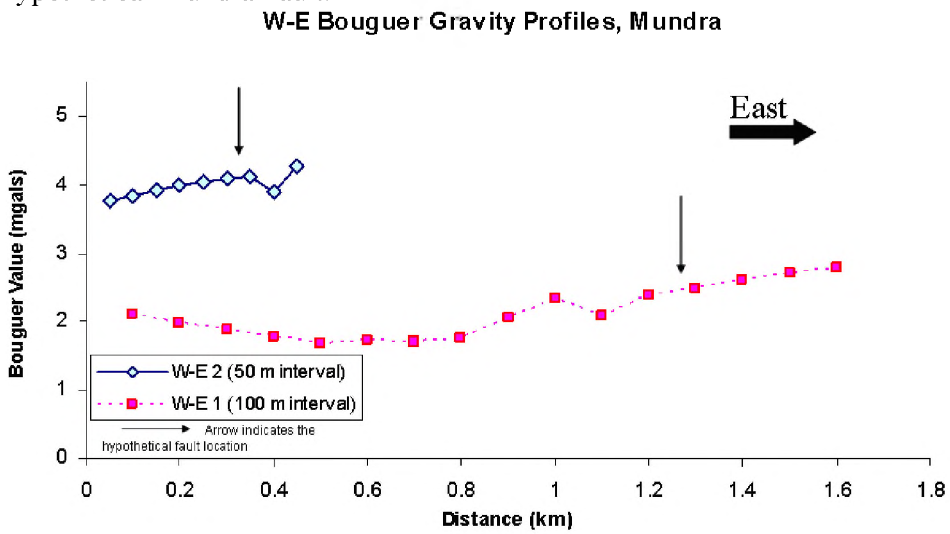


Fig. 4:.37: West to East Bouguer Gravity anomaly profiles. The upper profile W-E 2 has station interval of 50 m and is 450 m long and the lower profile W-E1 has station interval of 100 m and is 1600 m long. Arrows mark the position of the hypothetical Mundra Fault.

Crustal Configuration of Seismically active area of the Kachchh Basin from Gravity Studies (R.K.Singh and Rashmi Pradhan)

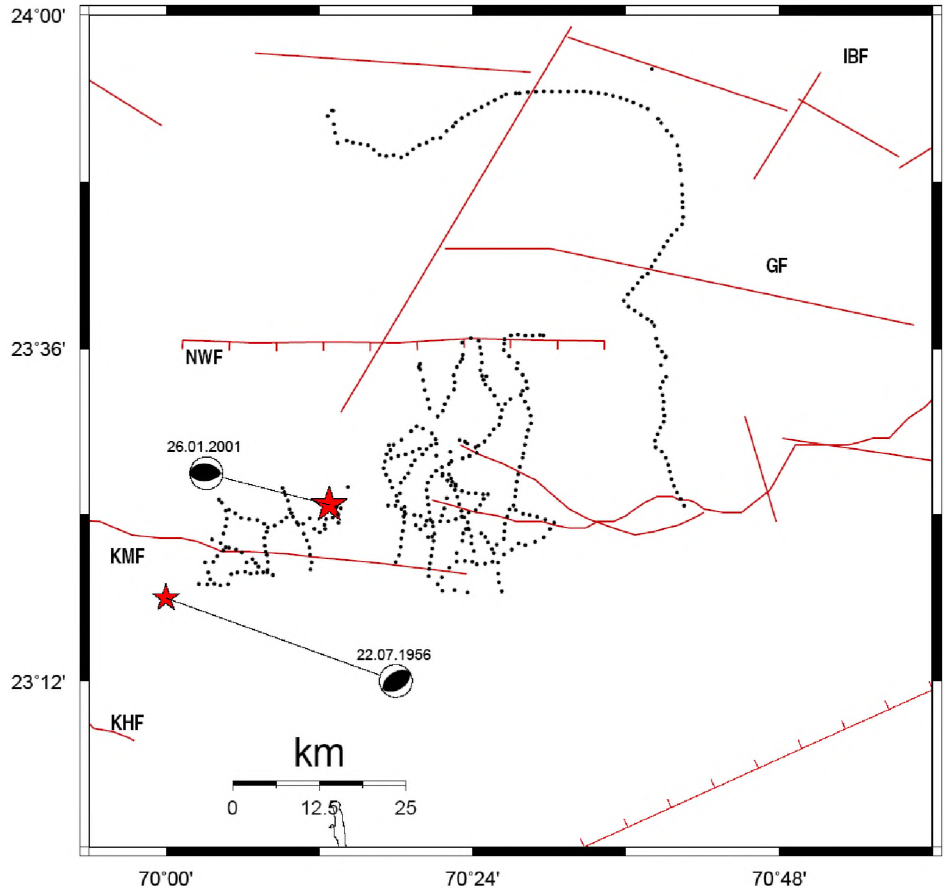


Fig. 4.38: Gravity stations over tectonic map of Kachchh region by ISR during 2008 and 2009

After the 2001 Bhuj earthquake, the Kachchh basin has attracted major attention with several scientific studies. Gravity surveys have been carried out by ISR using CG-5 Autograv gravimeter at an interval of 1 km (approx.) along nine 15-20 km long profiles in the epicentral area covered in Survey of India degree sheet 41 I, in and around Chobari, to decipher the known and blind faults (Fig. 4.38). Some faults have been detected near Kharoi, Kuda, Kadol and Baniari by semi-regional gravity surveys, which are likely to be active because earthquakes of magnitude ≤ 3.5 occur periodically in this area.

The Bouguer anomaly map prepared for the area is characterized by sharp gravity gradients at few places, which may be associated with hidden subsurface faults. A sharp gravity gradient is seen towards northern part of Wagad Uplift. The trend of Bouguer profile suggests that basement rises stepwise towards the north. This may be due to vertical tectonics of the rift, resulting from a vertical stress initially and then changing to horizontal stress due to the movement of Indian plate.

4.16 THE 2D RESISTIVITY PROFILES IN THE GIFT CITY AREA

(Kapil Mohan, Gagan Bhatia, Girish Patel)

2D resistivity profile was taken on 5.1the 0.2009 using Syscal-pro (SWITCH 72) instrument at 23° 09' 11''N 72°40' 59.6''E. The profile direction was N 109° E with length 497 m and initial electrode spacing of 7 m.

We have used dipole – dipole, Schlumberger and Wenner electrode configurations. Results of interpreted 2D resistivity sections are shown in Figs. 4.39-4.41. The dipole-dipole method gives better resolution of shallower layers to 22 m (Fig. 4.38), which shows resistivity contrast (layers) at 4 m and 9 m depths. The Schlumberger and Wenner electrode configurations depict resistivity contrast (layers) at 6.5 and 12, 15 and 35, 45m (Table 4.9). The profiles are E to W and show higher values towards west. The major layers are at 17 and 36 m depths.

Table 4.9: Resistivity Variation with depth

Layer	Depth (m)	Resistivity (Ohm-m)
1	4.5	20-90
2	6.5	5-100
3	9.5	20-80
4	12	20-25
5	15	20-30
6	35	40-80
7	45	5-25

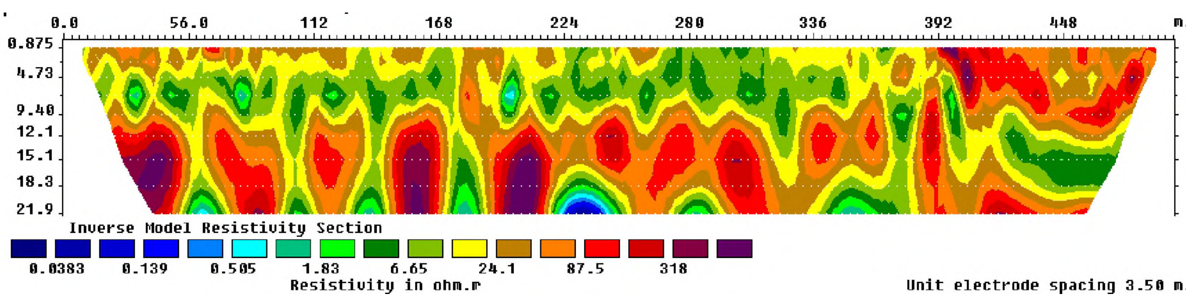


Fig 4.39: Resistivity survey carried out in GIFT city using dipole-dipole configuration. The profile is E to W and shows higher values towards west. East is left side and west is right side.

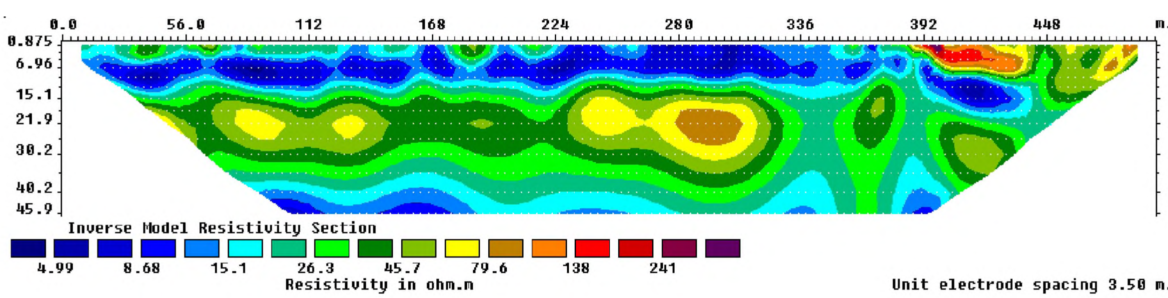


Fig 4.40: Resistivity survey carried out in GIFT city using Schlumberger configuration. The profile is E to W and shows higher values towards west. East is left side and west is right side.

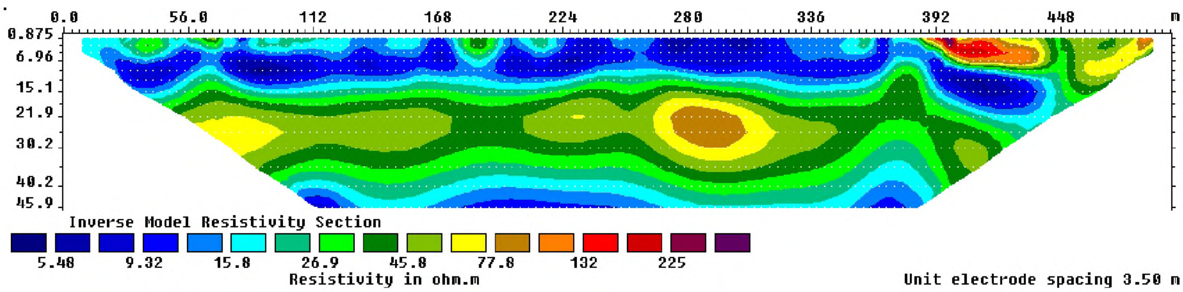


Fig 4.41: Resistivity survey carried out in GIFT city using Wenner configuration. The profile is E to W and shows higher values towards west. East is left side and west is right side.

4.17 Magnetotelluric studies in the epicenter zone of 2001, Kachchh earthquake

(Kapil Mohan, Gagan Bhatia, Girish Patel and B.K. Rastogi with R. S. Sastry, T. Harinarayana of NGRI)

Hundreds of aftershocks having magnitude M≥3 of 2001 Kachchh earthquake of Mw7.7 have been recorded by various agencies like National geophysical Research institute (NGRI) and Institute of Seismological Research (ISR). Until 2006, the seismicity was very high and the earthquakes of $M_w>5$ were recorded in the epicenter region. After 2006, aftershocks of Bhuj earthquake and seismic activity are concentrating in the eastern part of the epicentral zone along Samkhiali basin and Wagad area. To decipher the nature of the faults in this area, a detailed MT survey has been conducted from Sikara village in the west of Bhachau to Mae village in the north of Bhachau with an inter station spacing of 1 to 3 km (Fig. 4.42). The profile is about 25 km east of the epicenter of 2001 mainshock. It indicates a south dipping fault in Samkhiali Basin (Fig. 4.43).

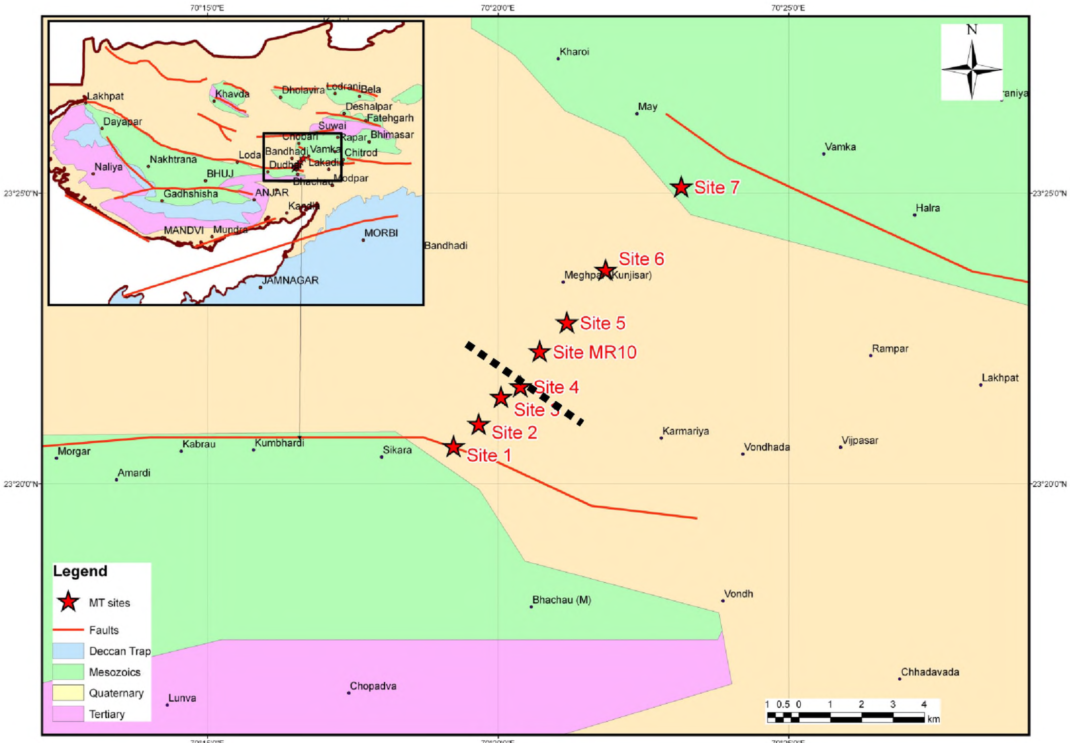


Fig 4.42: The MT Profile taken in the studied area (sites are marked with stars) overlapped on the geology and tectonic map of the region (after Biswas[2]). The dark dotted black line shows the probable location of a fault in Samkhiali basin. NW-SE trend of this fault is assumed on the basis of the trends of South Wagad Fault and Kachchh Mainland Fault in this area.

S **N**

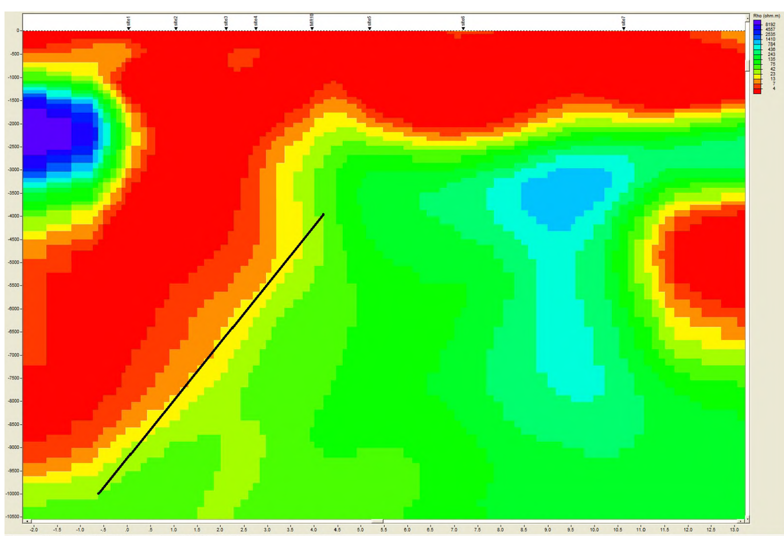


Fig 4.43: 2D Geoelectric depth section down to 10 km. The resistive block south of site1 (south end of the figure) is the Kachchh Mainland block and the resistive block north of site 4 is the Wagad block. The solid black line shows the position of the expected fault.

5. EARTHQUAKE PREDICTION RESEARCH

5.1 Operation of Multi-Parametric Geophysical Observatories for Earthquake Prediction Research (K.M.Rao, Dr.A.K.Gupta, M.S.B.S.Prasad, Rashmi Pradhan, Tarak Shah)

An earthquake research center at Bhachau and three Multiparametric Observatories are operational from March 2009 in Kachchh at Badargadh, Vamka and Desalpar (Fig. 5.1) for Earthquake Prediction Research. MPGO sites are east and northeast of the aftershock zone of 2001 Bhuj earthquake (Mw 7.7) where the activity has migrated from 2006 onwards. Magnitude 5 earthquakes are still occurring in Kachchh occasionally and 70 shocks of magnitude ≥1 are recorded on an average per month. An Earthquake Research Centre at Bhachau is also functional since March 2009. Very broad band seismometer, Accelerometer, GPS and radon recorders are installed at all the four sites. Fluxgate magnetometers are installed at Desalpar and Vamka while the Super Conducting Gravimeter has been installed at Badargadh. One water-level recorder has been installed at Desalpar while others are yet to be installed. Three Borehole Strain Meters have been procured and are yet to be installed. Overhauser Magnetometer, Declination/Inclination Magnetometers, ULF & VLF Magnetometers and Helium recorders are to be procured.

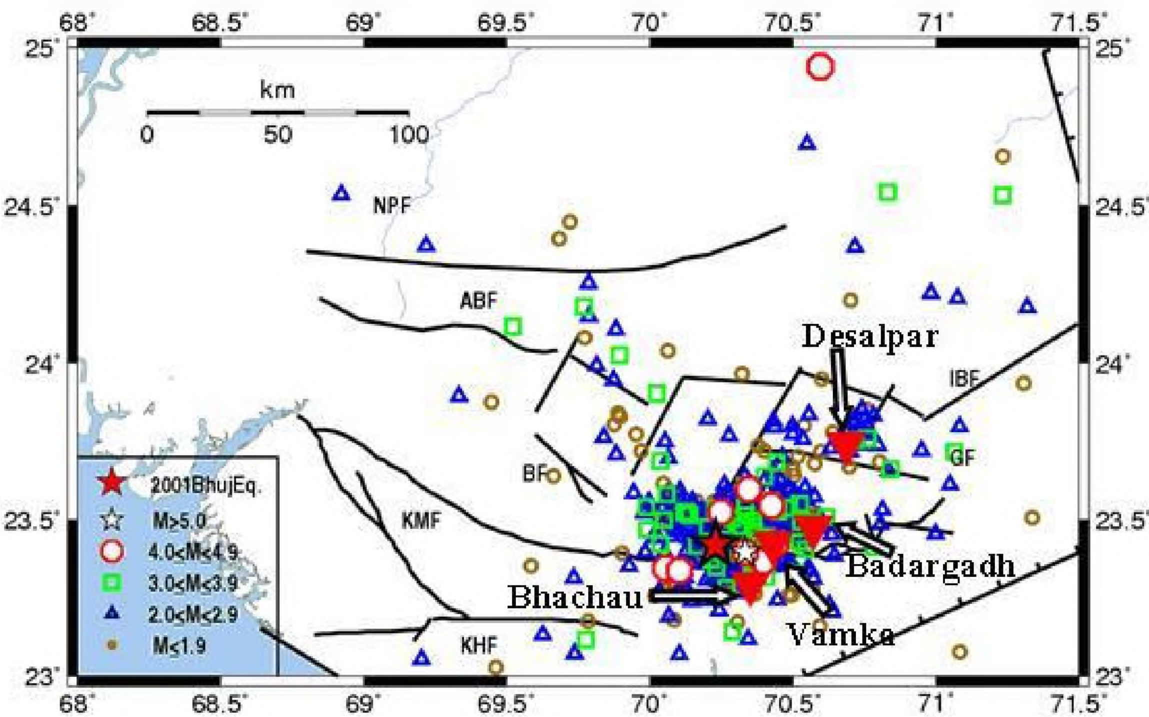


Fig. 5.1: Locations of three MPGO sites at Vamka, Badargadh and Desalpar as well as ERC centre at Bhachau in Kachchh

Analysis of SG data

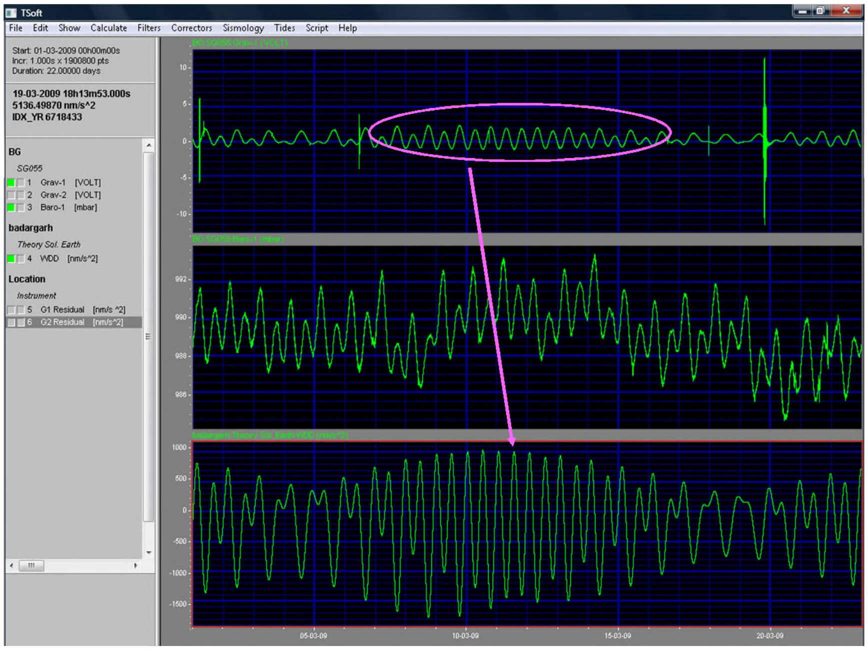


Fig. 5.2: Top trace shows Gravity signal as recorded by Superconductive Gravimeter from 1st March to 22nd March 2009. Middle trace indicates barometric signal. Bottom trace shows the Theoretical Earth Tides showing the effects of Atmospheric pressure and Earth Tides on Gravity Signal

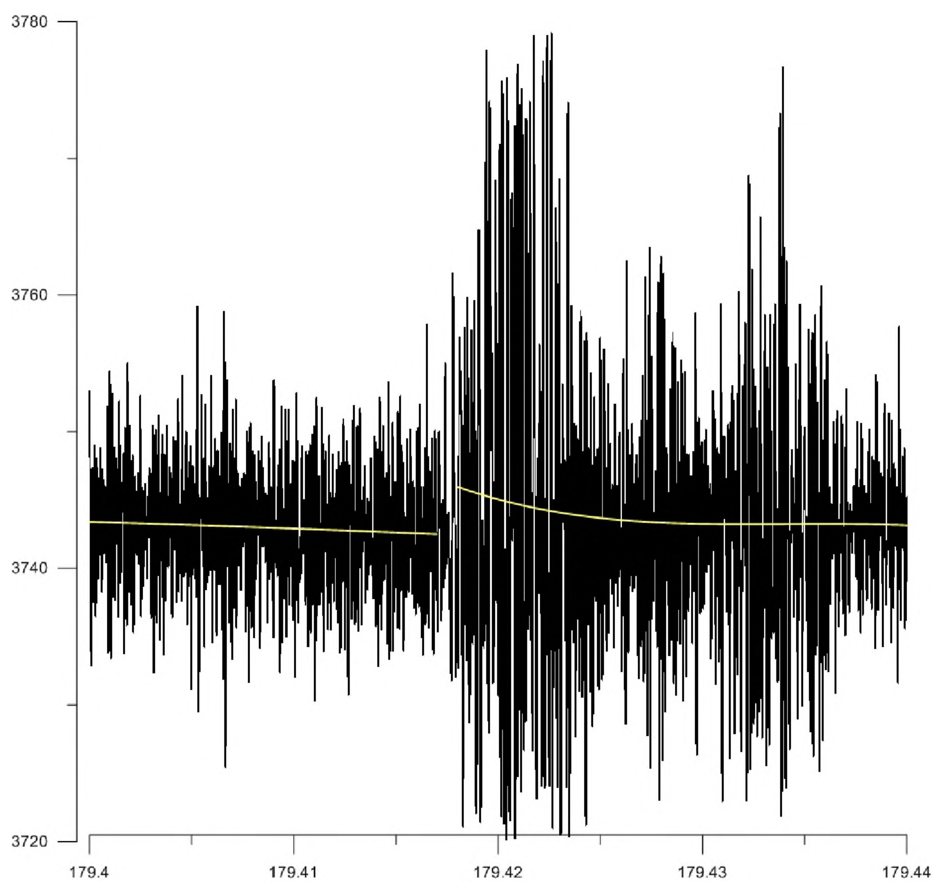


Fig. 5.3: Co-seismic Gravity change corresponding to Mw 3.5 earthquake, 10 km NNE of Bhachau, Kutch (28th June, 2009; 08:32:11.9; 23.378N, 70.351E)

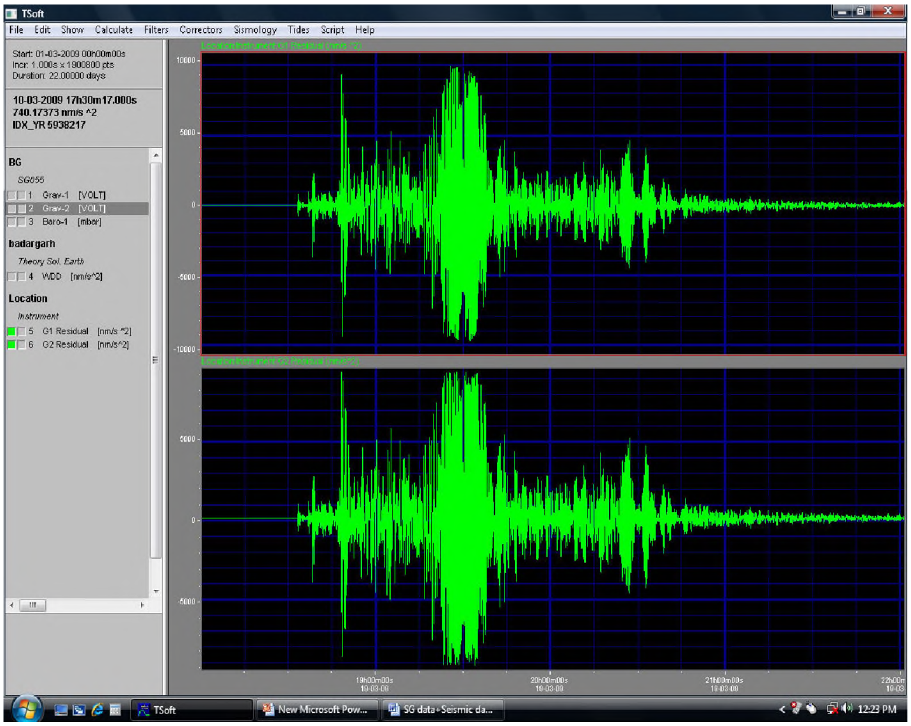


Fig. 5.4: Superconducting gravimeter signal for 3 hours duration for the M 7.9 earthquake on 19th March, 2009 in Tonga Region (18:17:38, 23.015S -174.182W, 10 km depth)

Observation of Earth's free oscillations in Gujarat with Superconducting Gravimeter at MPGO site at Badargadh in Kachchh (Arun Gupta, Rashmi Pradhan, Srichand Prajapati, Mukesh Chauhan and B.K. Rastogi)

The very sensitive dual sphere superconducting gravimeter (SG) is installed in March 2009 at Badargadh. Almost immediately after SG installation, the Tonga region earthquake (M 7.6) occurred on March 19, 2009 which had excited the earth's free oscillations. This earthquake is very well recorded on Badargadh SG. The frequency and amplitude of free oscillations have been estimated and compared with earlier global observations of seismometer and SG. Estimated free oscillations validate the quality of recorded data. Precise observations of low frequency earth's free oscillations are very useful for study of magnitude of very large earthquakes, source mechanism and density structure. Splitting and coupling of the free oscillations gives very useful information on the Q structure and the heterogeneity inside the earth, especially to constrain the long-wave length structure (thick layers).

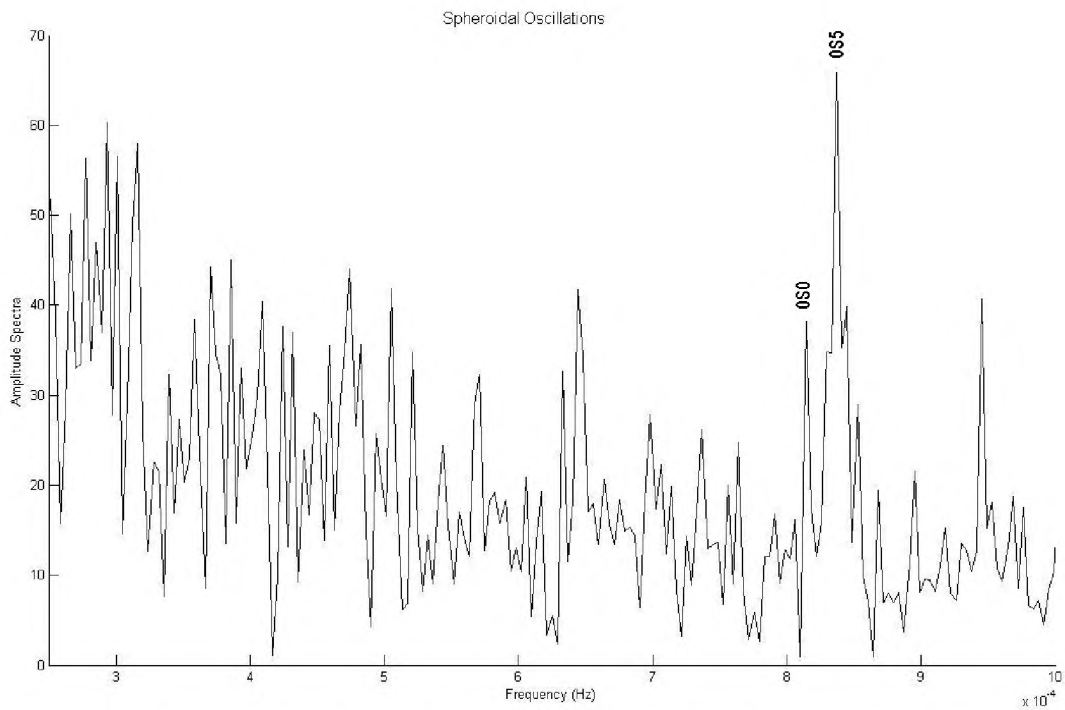


Fig. 5.5: Free Oscillations observed in Badargadh SG for M 7.9 earthquake on 19th March, 2009 in Tonga Region for 72 hours data

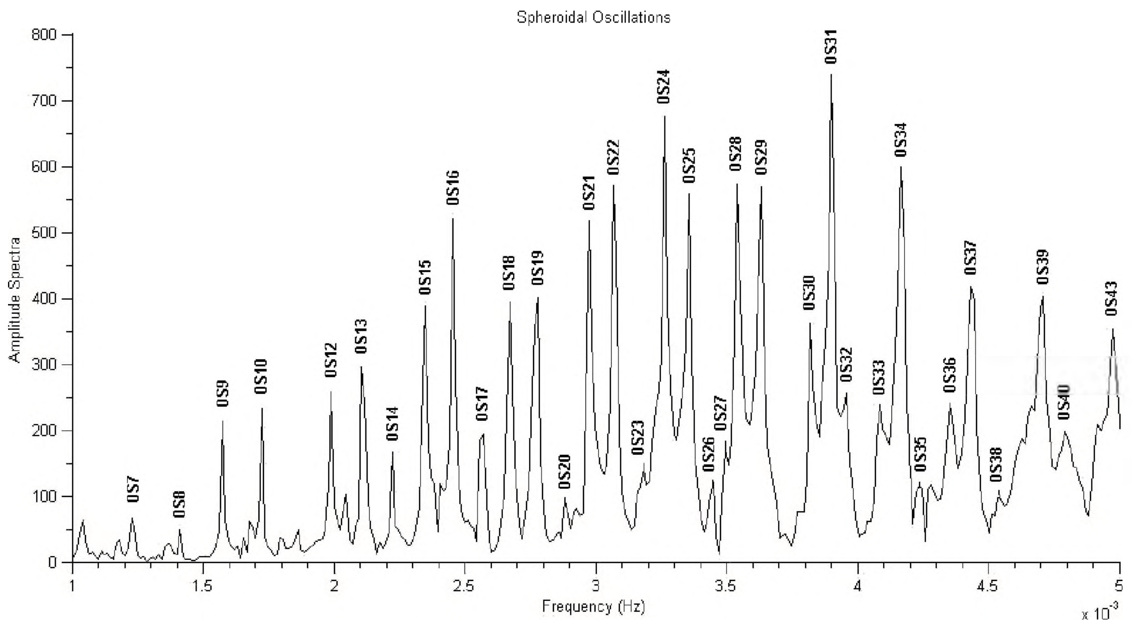


Fig. 5.6: Amplitude spectra of 24 h SG record starting from 3 hrs after the P-wave arrival at Badargadh showing clear fundamental free spheroidal oscillations, where $l = 0$ to 43

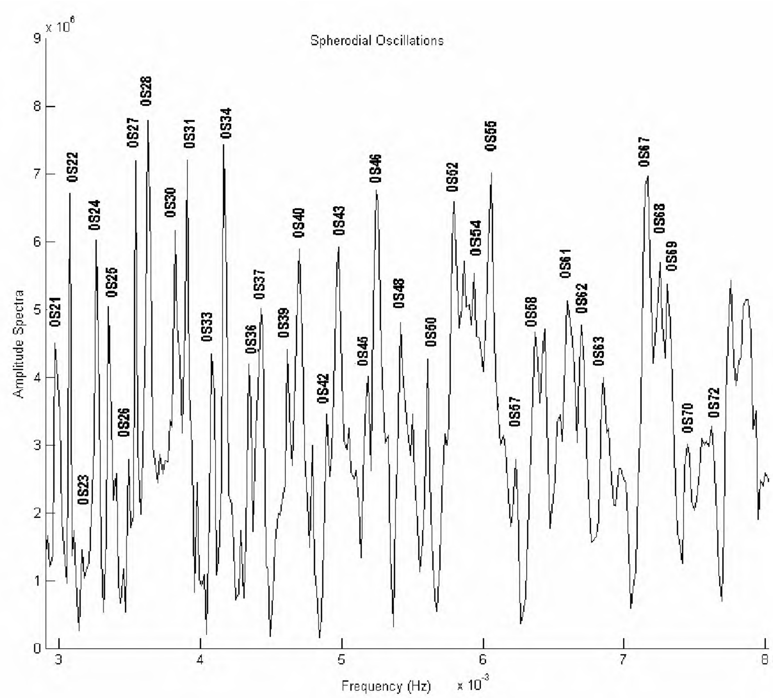


Fig. 5.7: Amplitude spectra of 24 h VBBS record of vertical component at Badargadh showing clear fundamental free spheroidal oscillations, where $l =$ 21 to72

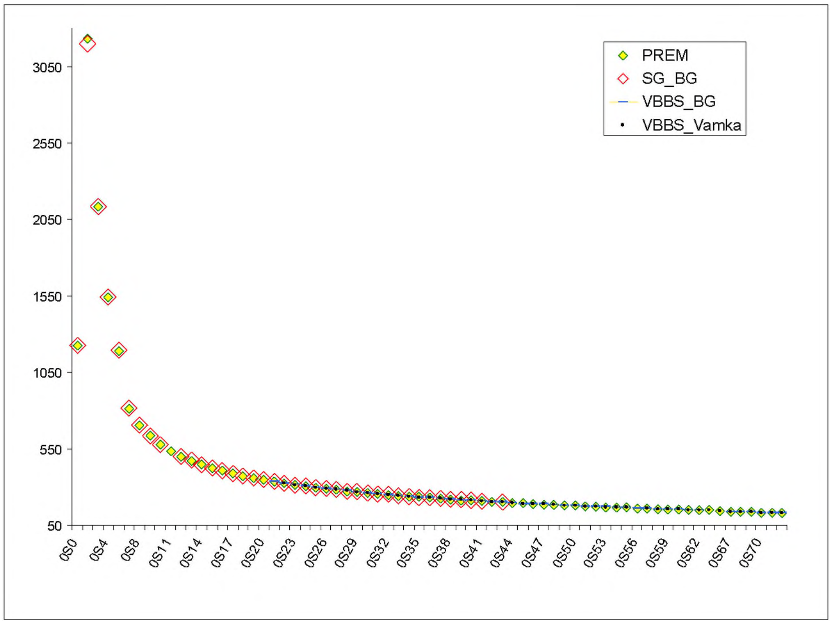


Fig. 5.8: Comparison of the periods of the spheroidal modes observed in Superconducting Gravimeter (Badargadh), VBBS (Badargadh) and VBBS (Vamka) with PREM model

Analysis of Radon in soil

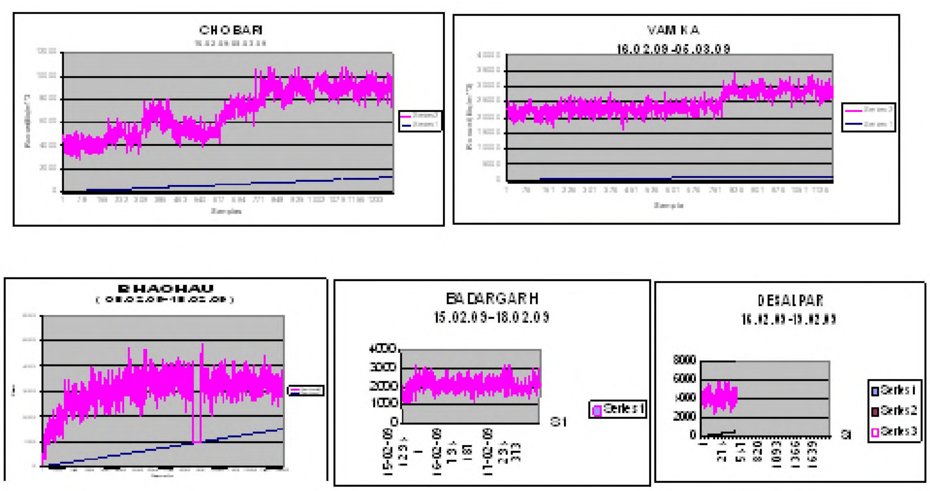


Fig. 5.9 : Radon Data at MPGO Sites

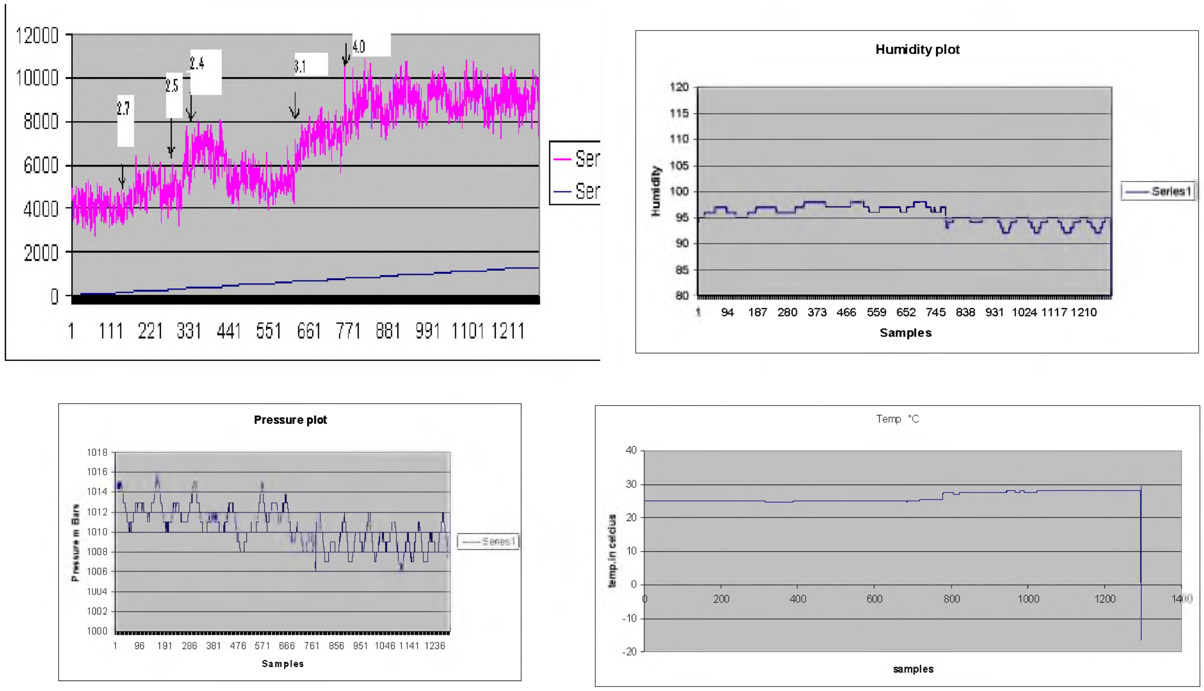


Fig. 5.10: Earthquakes affecting radon data of Chobari Station (Samples every 15 min, total 20 day). M 4 earthquake is 5km away and M 3 earthquake is 10 km away

Analysis of Fluxgate Magnetometer Data

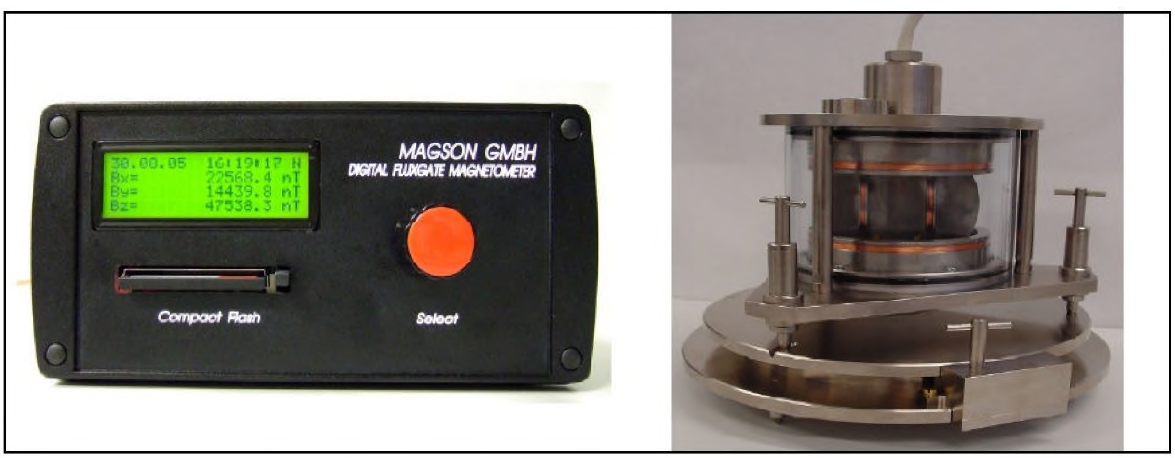


Fig. 5.11: Digital Fluxgate Magnetometer

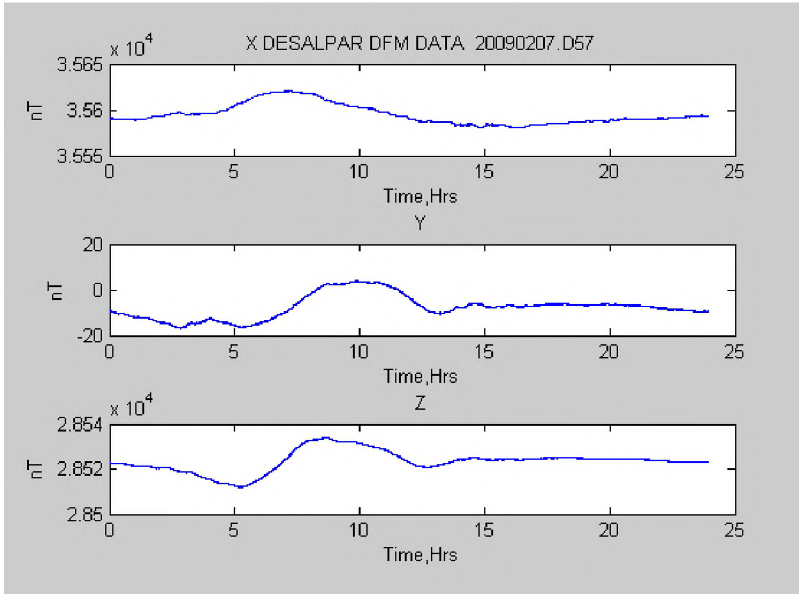


Fig. 5.12: Desalpar DFM data

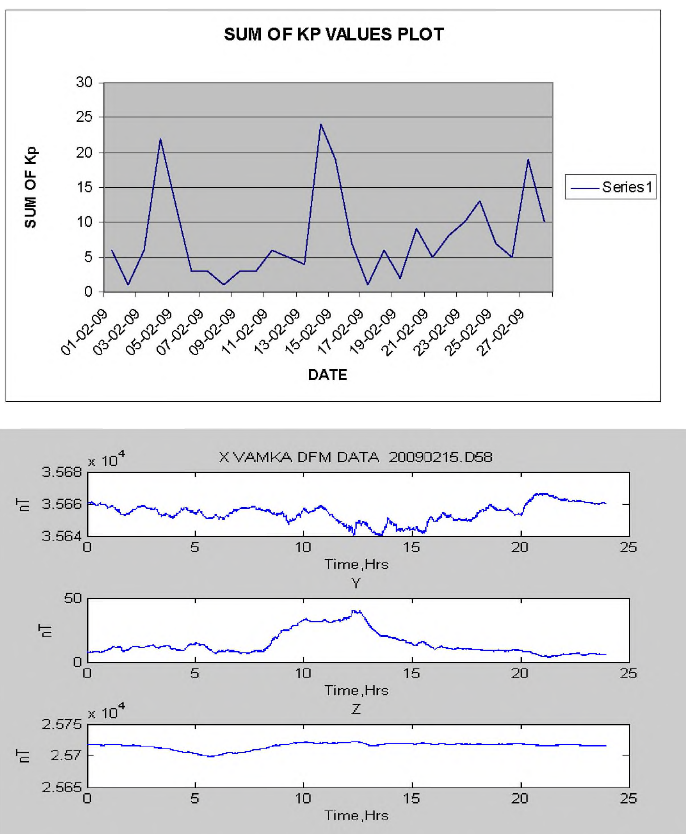


Fig. 5.13: Plot of sum of global Kp value showing high on 14 & 15th Feb. 2009 as shown by DFM data at Vamka

5.2 Foreshock Clustering and Nucleation as Precursory Pattern for the Kachchh Earthquakes (Sandeep Aggrawal, Kishan Jala, Vandana Patel, B.K. Rastogi)

The continued seismicity in Kachchh is being monitored by a dense network of 20 or more broadband seismographs. As the earthquake locations are precise, it is now possible to observe clustering of foreshocks prior to the seven earthquakes of M 3.8 – 4.4 during 2007 to 2009. Four to fourteen foreshocks in areas of 2.5 km to 20 km radius for duration of 7 days to 25 days have been observed. One to six days quiescence is observed in four cases. The foreshocks, in general, deepen from about 10 km focal depth to the focal depths of main shocks of 21 to 30 km in 6 cases. In one case of main shock along Gedi fault (M 4.1 on 15 Apr. 2008) the focal depth of the main shock and foreshocks are within 10 to 14 km.

This study gives hope of prediction of earthquakes as is being done for Koyna. In fact, 26 May 2009 earthquake of M 3.8 was internally predicted one day in advance after observing clustering of shocks for 24 days and 3 days quiescence. The detail study on mechanism and Coulomb stress transfer are in progress.

Sr. No.	Date	Time Hr:Mn UT	Magnitude	Cluster Radius (km)	Duration (Days) of foreshocks	No. of foreshocks within circle	Quiescence (Days)
1	08Apr2007	16:20	3.9	8	7	12	2 or 4
2	09Mar2008	11:10	4.4	2.5	7	5	Nil
3	15Apr2008	18:22	4.1	5	14	4	4
4	20Jun2008	21:19	4.1	4	14	12	3 or 6
5	10Jul2008	09:39	4.1	12	8	9	1
6	12Apr2009	18:42	4.1	5	11	11	Nil
7	26May2009	07:03	3.8	15	25	50	3

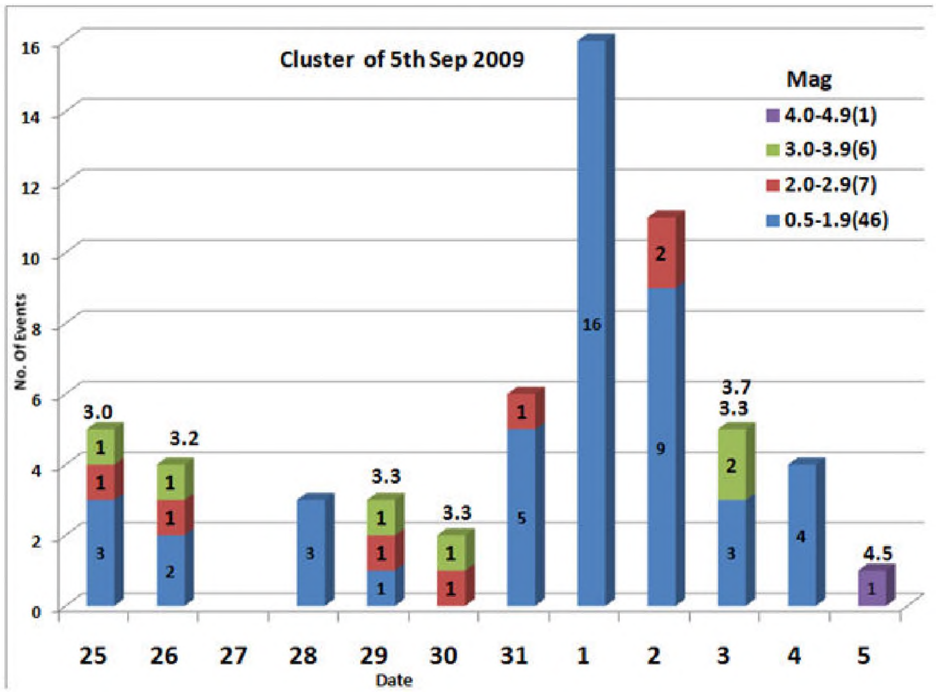


Fig. 5.14: Daily number of foreshocks of M 4.5 earthquake of 5 Sep.2009. Six shocks of M3 occurred in a span of 10 days. There was quiescence for one day prior the mainshock

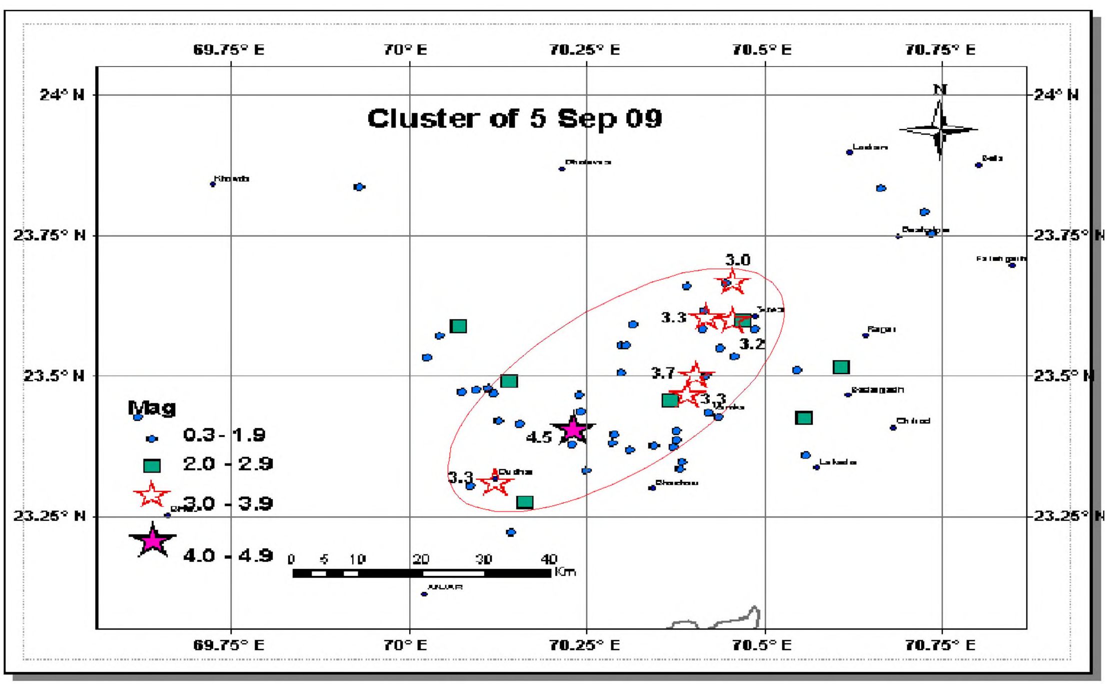


Fig. 5.15: Clustering of foreshocks in an area of 40 km x 15 km

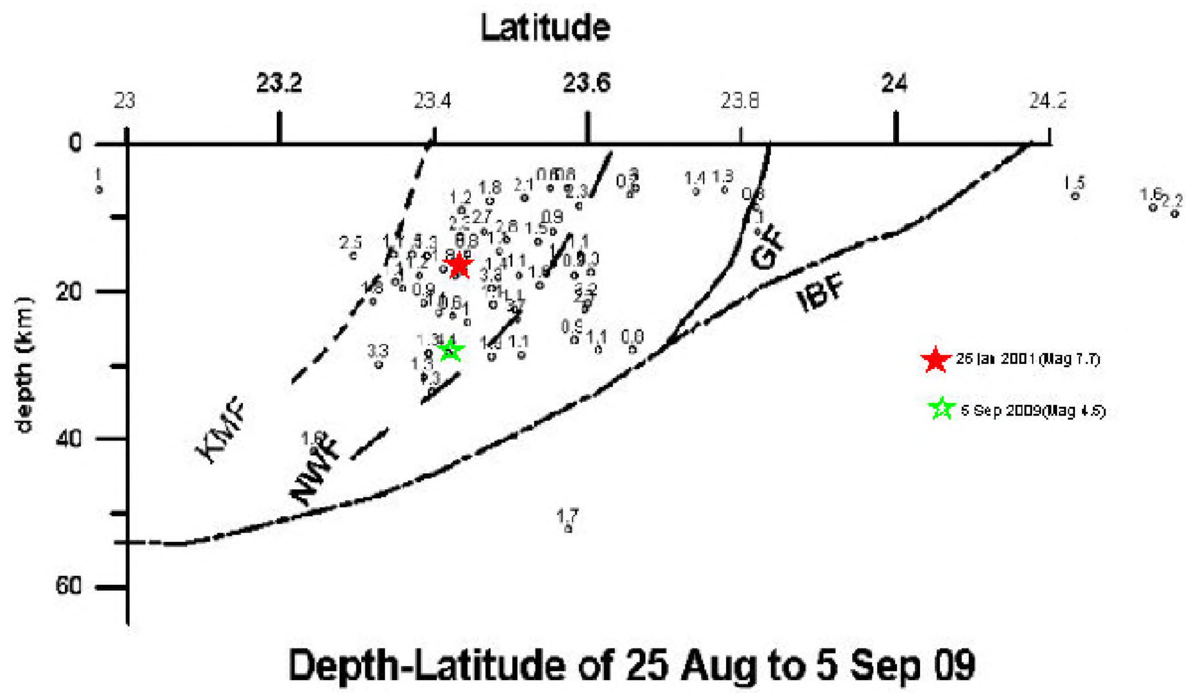


Fig. 5.16: Depth section of hypocenters from south to north along with the geological faults.

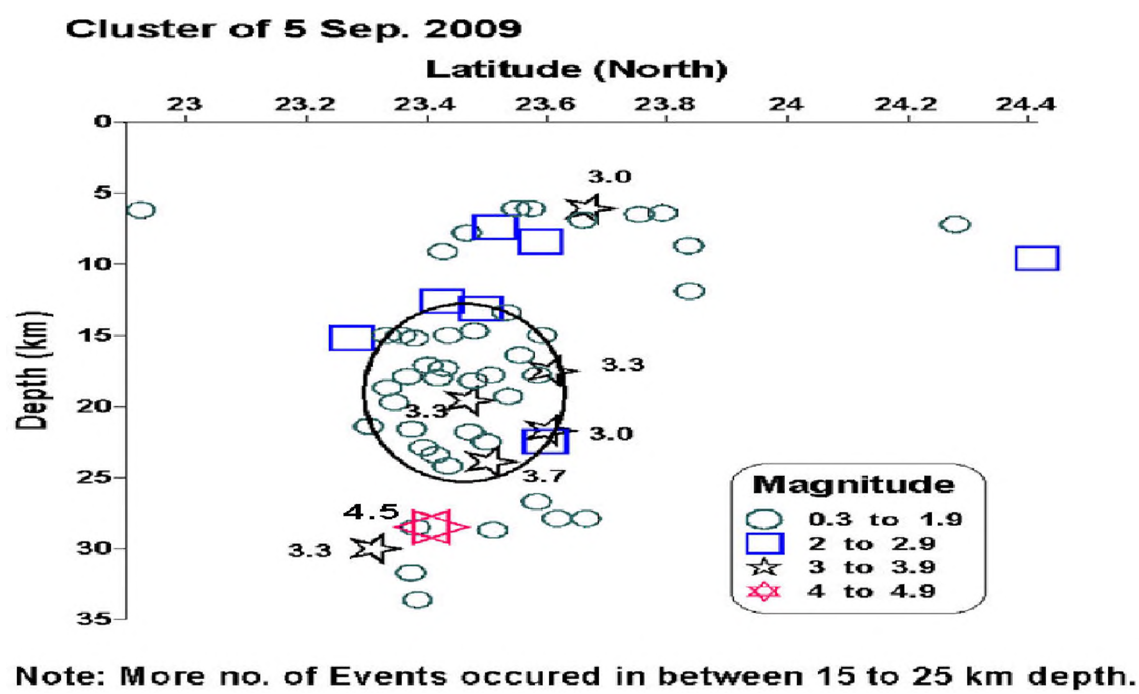


Fig. 5.17: Depth section of foreshocks in the cluster for M 4.5 earthquake of 5 Sep. 2009

6. SEISMIC MICROZONATION (Sumer Chopra, Janki Desai, Vasu Pancholi, Santosh Kumar, Babita Sharma, B. Sairam, A.P. Singh, Kapil Mohan, Sandeep Aggrawal, R.K. Singh, Vandana Patel and Kisansinh Zala)

ISR continued seismic microzonation studies in the coastal regions of Gujarat, Gandhinagar, and Dholera Special Investment Region located about 100 km south of Ahmedabad. Seismic microzonation of Bharuch area was started during 2009 in collaboration with the Geological Survey of India. The areas of microzonation study currently undertaken are shown in Fig. 6.1.

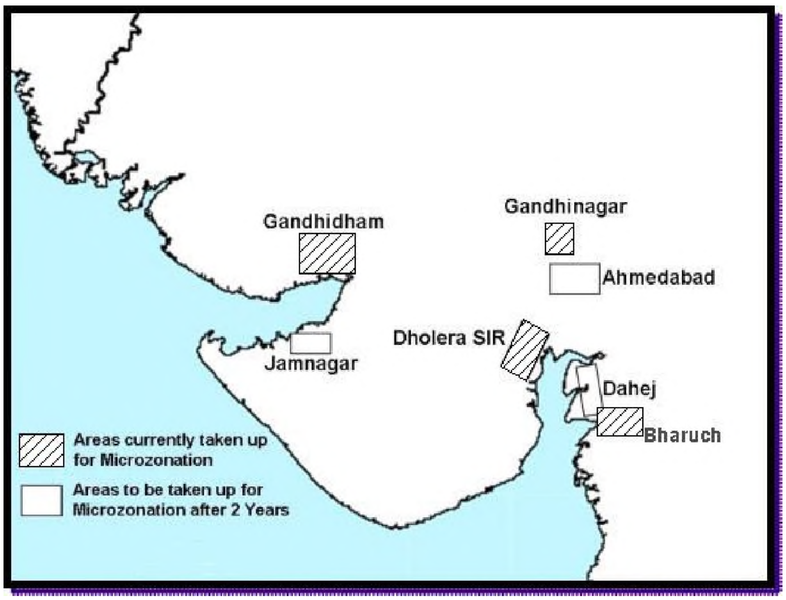


Fig 6.1: Locations of areas taken up and to be taken up for microzonation by ISR

Some significant studies are described in detail as follows:

6.1 MICROZONATION OF GANDHINAGAR (B.K. Rastogi, Sumer Chopra, B.Sairam, R.B.S. Yadav, Kapil Mohan, Mukesh Chauhan)

For microzonation study of Gandhinagar soil testing has been done with 15 boreholes. It is inferred that soil does not possess liquefaction potential as water table is 80 m even near the Sabarmati river basin. The N values range from 2-58 down to 10 m depth and higher at deeper depths. Bore logs and soil properties data made available to ISR by the Gujarat Engineering Research Institute has been compiled. It shows 1m thick silt top layer below which fine coarse grained sand layer exists and it is inferred that the Gandhinagar area has good soil with safe Bearing Capacity (SBC) ~ 13 t/m2 even at shallow depths of a few meters.

The preliminary results of microzonation at Gandhinagar indicate that the fundamental frequency is 0.6 Hz indicating about 300-350 m soil thickness over the Tertiary hard rock estimated by using the formula, $f = Vs/4H$. In Gandhinagar, the preliminary results indicate 3 – 4 times amplifications in frequency range 1 - 2 Hz and also for 0.4 – 0. 8 Hz as estimated from actual earthquake recordings on broadband seismographs. These frequency ranges correspond to 5 storey and taller buildings.

6.2 SEISMIC MICROZONATION OF DHOLERA SPECIAL INVESTMENT REGION (Most of scientific staff of ISR)

Government of Gujarat has planned to develop Dholera coastal region lying between Ahmedabad and Bhavnagar cities as a Special Investment Region (SIR) which will have several cities and industrial hubs along with an airport and railway station. The work of Seismic Microzonation of this area has been sponsored to ISR by the Gujarat Infrastructure Development Board. Total Area is around 800 sq km (**Fig. 6.2**). SIR falls in Zone III of Seismic Zoning Map of India. Microzonation in SIR involves detailed study on (i) Seismic Hazard Assessment, (ii) Site Amplification, (iii) Soil Strength and (iv) Liquefaction potential. Following investigations have been carried out:

1. Drilling of 81 boreholes of 15 to 80 m depth and geotechnical investigations
2. PS-Logging of 11 no. boreholes
3. Operation of seismic stations at 11 places to estimate depth to base rock and other sedimentary layers as well as seismic amplification due to these layers from the records of real earthquakes
4. Resistivity profiles for preparation of water table map
5. Vs30 measurements by MASW method at 15 locations
6. Array Microtremor measurements for base rock depth and shear wave velocity at 20 locations
7. Preliminary assessment of engineering bed rock
8. Study of activeness of Cambay basin faults
9. Preliminary assessment of Probabilistic and Deterministic Hazard as well as Response Spectra

SATELLITE IMAGERY INTERPRETATION OF DHOLERA REGION (Girish Ch. Kothyari)

The Dholera area is located in proximity of Gulf of Khambhat. Physiographically the area is predominated by coastal morphology and covered by Quaternary sediments. The area being flat, the satellite data interpretation using GIS software is a good tool to understand landscape pattern and evolution of drainage network. Most morphological features present in Dholera coastline area were probably formed due to interaction between shallow marine, aeolian and fluvial agents. We examined the following imageries to look for any neotectonic features present in the soil which are otherwise not explained by fluvial, aeolian and marine processes.

Digital LISS-III imagery with 25 m resolution was combined with SRTM-DEM on which drainage pattern was enhanced (Fig. 6.2). The stream pattern was studied in order to see any effect of tilting in drainage.

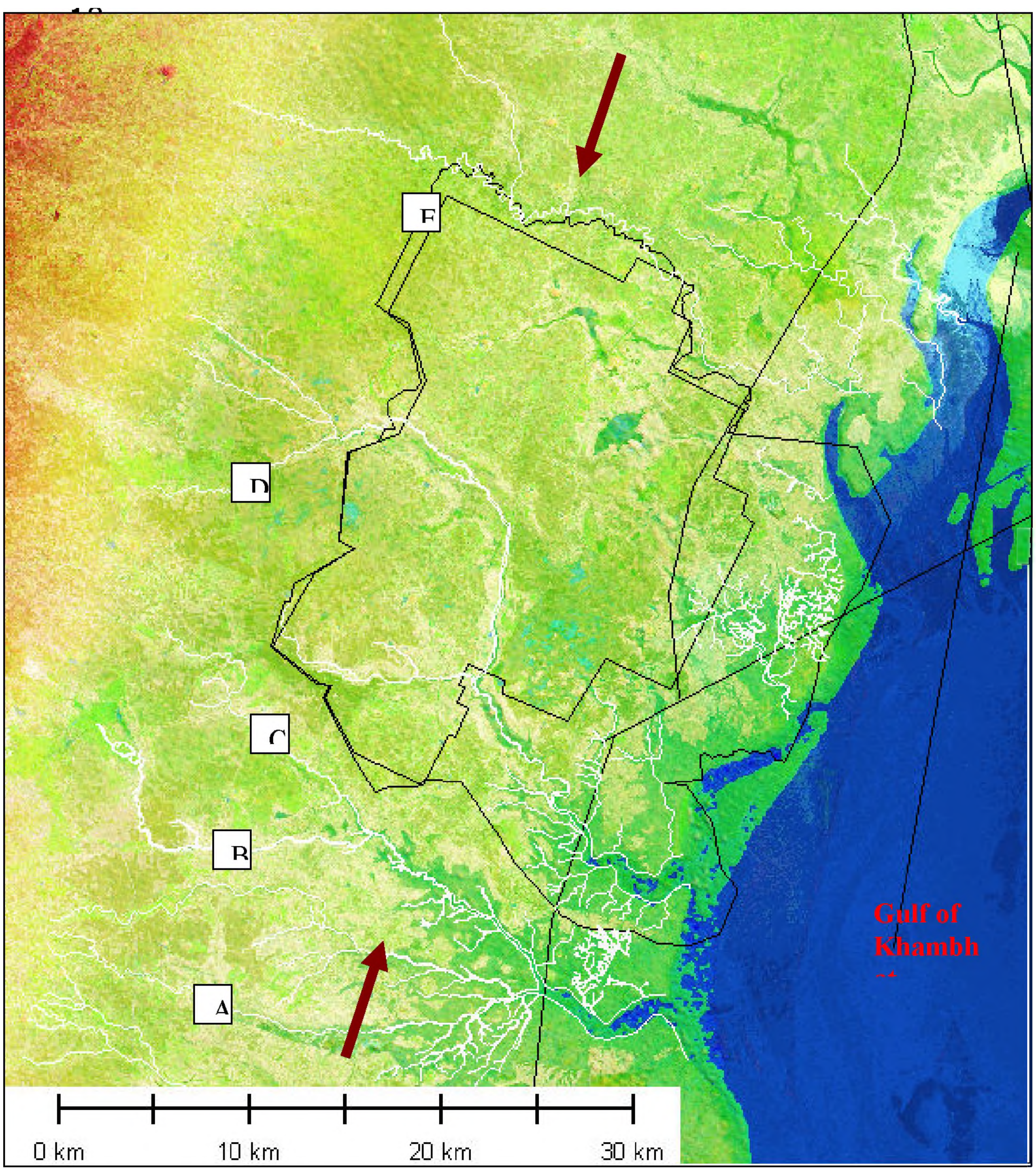


Fig. 6.2: LISS-III overlay SRTM DEM shows morphotectonic features in Dholera region (arrow indicates topographic break in the region

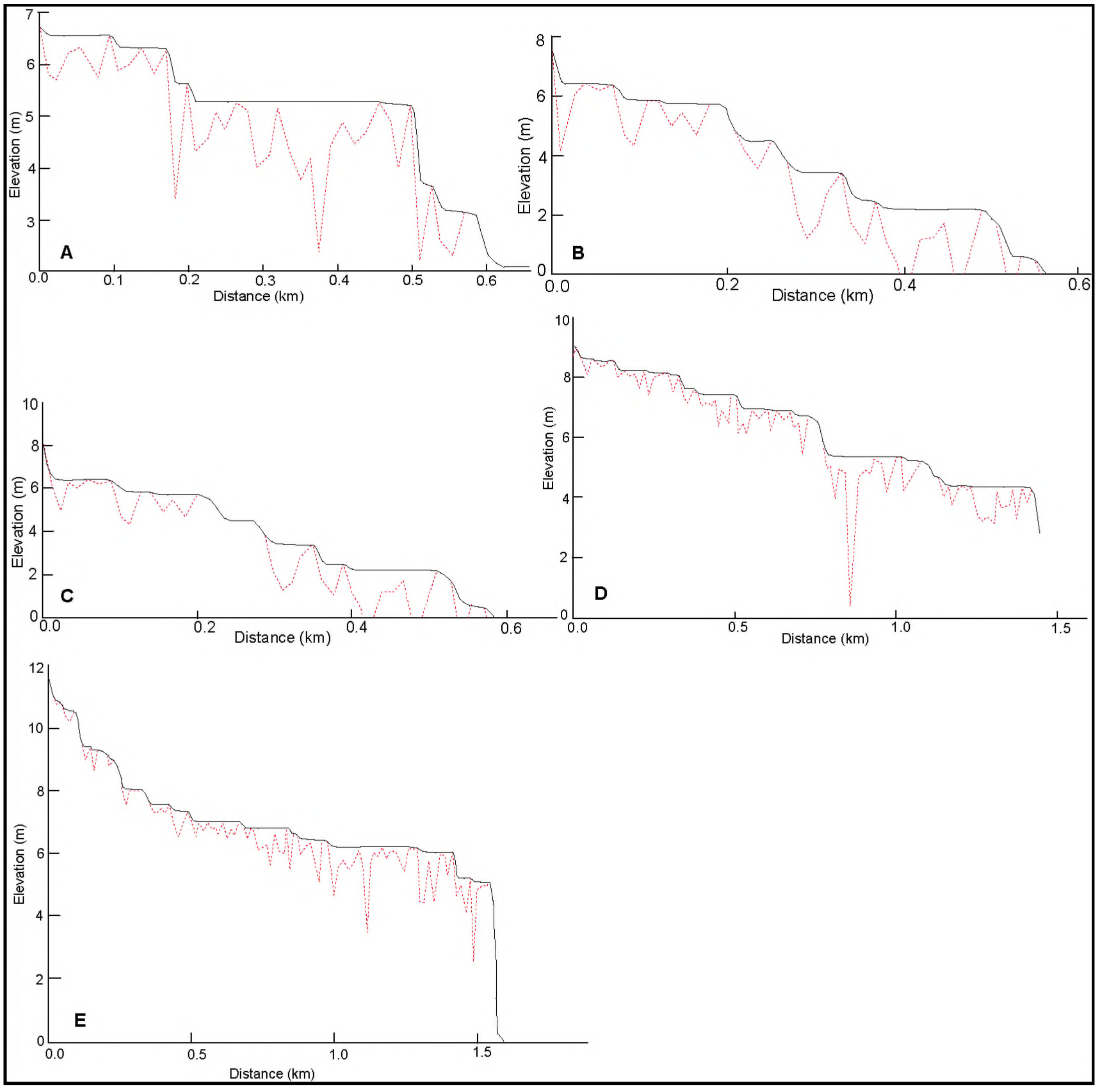


Fig. 6.3 Longitudinal valley profiles of some major stream passing from the area

Number of 2-dimensional longitudinal stream profiles (W-SE) were drawn to understand evolutionary history. Sudden topographic break within the profiles were marked by knick points (Fig. 6.3). Towards the SW of the area about ~1m slope break is seen in one profile, which can be formed either due to fluvial or marine process.

The above imagery if rotated by 90^0 (Fig. 6.4) shows some topographic break along the fault trace at the eastern end of the area. However, about 1 km E-W profiles do not show any elevation change. Another topographical break is seen in N-S direction in the middle of the area. The profiles across it show about ~1m elevation change (Fig. 6.5) which can be formed due to marine processes.

These two topographical breaks are seen in three dimensional density plot also (Fig.6.6) as sharp contrast of density. The density breaks may indicate presence of paleocoastlinese formed due to sea level fluctuations and tidal hit towards the coast during regression phases of the sea.

Hence, even thorough examination of satellite imageries does not indicate any neotectonic activity in and around Dholera region. We have not observed any signature of neotectonics in the region such as Quaternary landform deformation in the form of major changes in drainage pattern and pressure ridges etc.

14.
15.
16.
17.
18.
19.

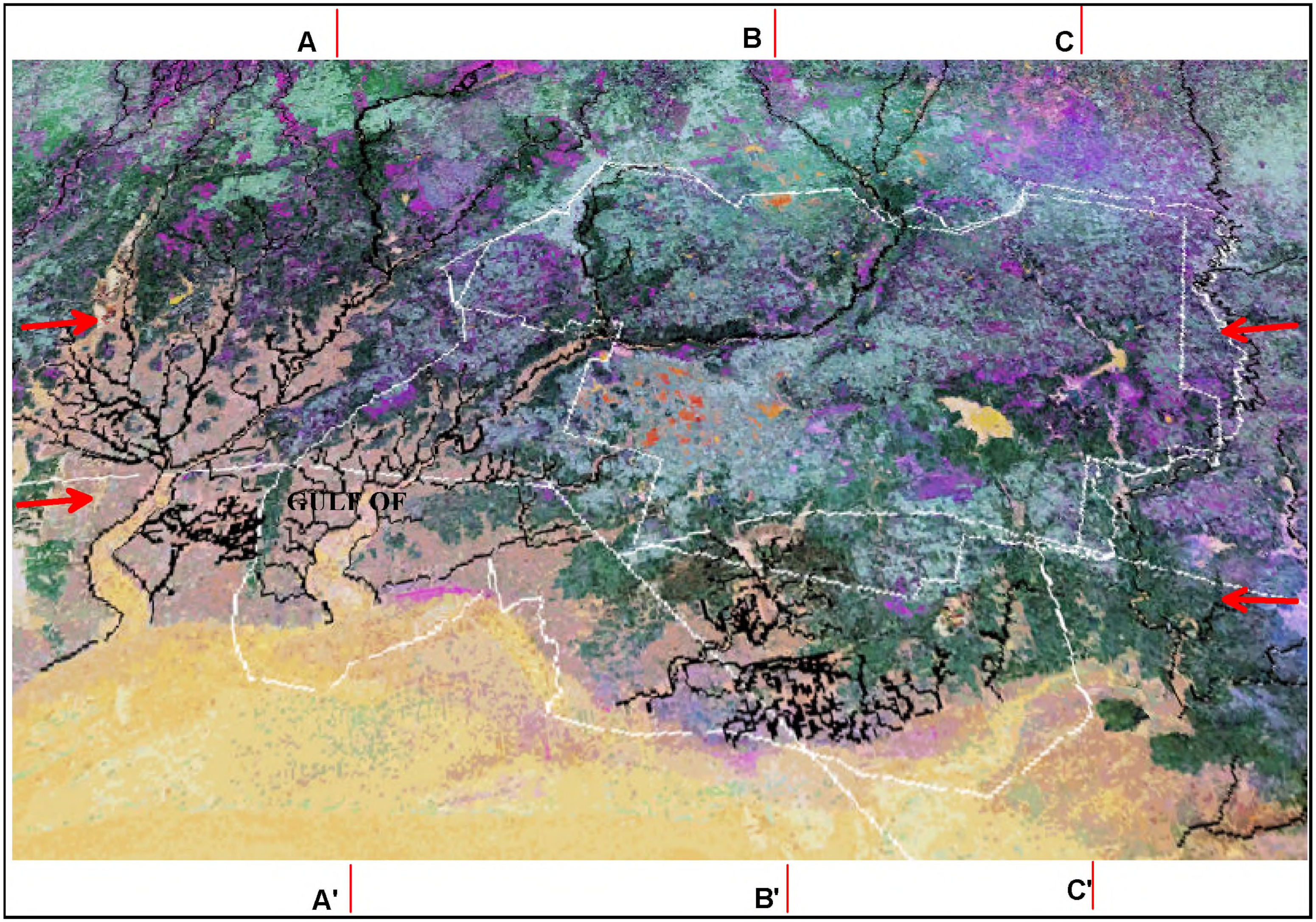


Fig.

Fig. 6.4: IIRS LISS III False Color Composite (bands 2, 3 and 4) draped over SRTM image showing various topographic features in Dholera region (arrow indicates two major topographic break in the region

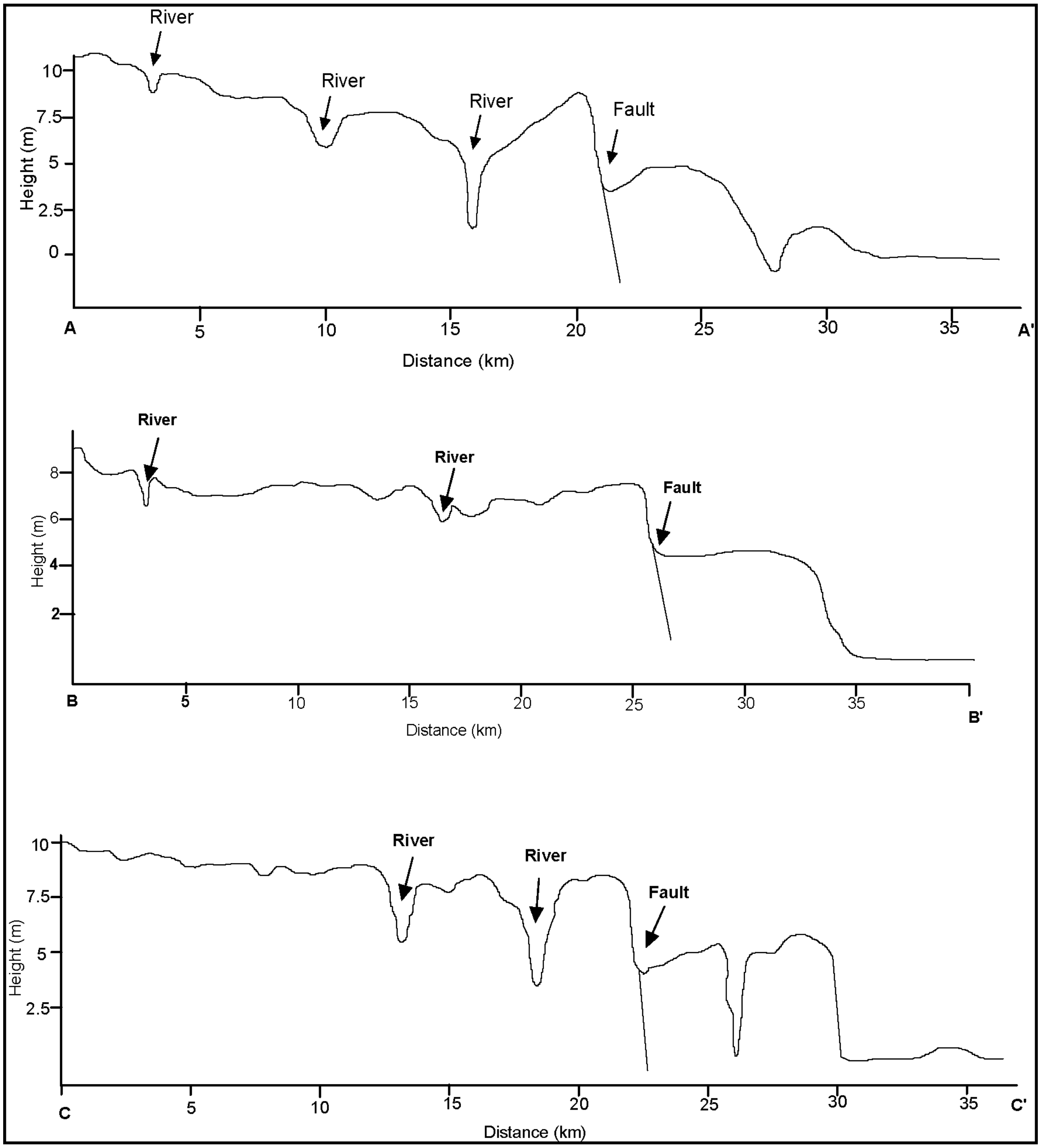


Fig. 6.5: Topographic profile has constructed along the E-W direction Cross profiles of the area showing sudden slope change along the knick point. Sudden topographic break shows position of fault (fault line marked after Biswas and Deshpande, 1971)

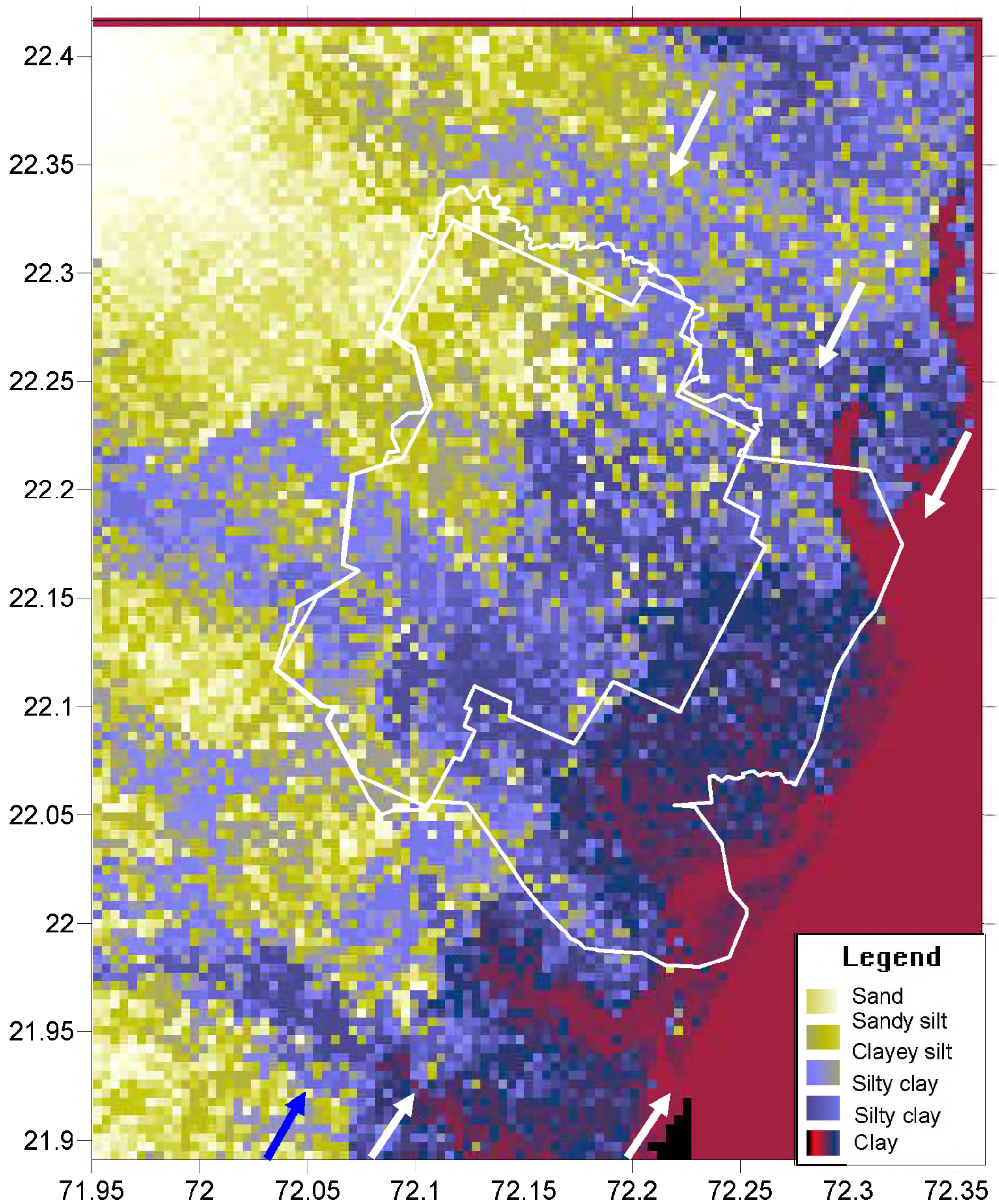


Fig. 6.6: Map of Dholera region extracted from overlapped LISS-III over SRTM using river tool IDL software. The map shows the color tone gradation that might reflect the desity of the surface formations or moisture content (arrows point to density variation zones)

GEOTECHNICAL INVESTIGATIONS IN DHOLERA

In order to assess the subsurface nature and geotechnical properties of soils of SIR area, 81 boreholes (BH) were drilled at 2.5 km interval. The drilling is not possible in the areas close to the coastline, creeks and rivers. The depth distributions of these boreholes are: 21 boreholes of 15 m depth, 19 boreholes of 30 m depth, 25 boreholes to 50 m depth and 16 boreholes of 80 m depth. Standard Penetration Test (SPT) was carried out at every change of strata or at each depth interval of 3 m. The categories of soil samples collected during drilling are: disturbed (DS), undisturbed (UDS), and SPT. Laboratory tests of these soil samles were carried out at Gujarat Engineering Research Institute (GERI), Vadodara, Nirma University, Ahmedabad and ISR, Gandhinagar. All the tests conform to **IS: 2131-1981**. During drilling two ISR persons were all the time observing the drilling and SPT work in progress. The sample testing at different labs was also checked by ISR persons from time to time. The physical tests on soil samples include water content, grain size, unit weight, Atterberg limit, while, the mechanical tests include unconfined and triaxial cyclic tests on limited no. of samples.

Water Table Contours in Dholera

Water levels in boreholes are recorded after drilling and a contour map is drawn. Based on these values and resistivity surveys water table maps are prepared.

Resistivity profiles numbering 15 have been carried out for assessing the ground water depth and to assess depth of soil layers to tens of meters. The measurements were first done during July 2008 and repeated during Jan. 2009. No significant change was noticed. The average thicknesses of the top three layers are found to be 1.38, 5.62 and 19.76 m, respectively.

By drilling data the ground water depth in the area is found to vary between 2 to 2.5 m whereas by resistivity survey it varies from 3 to 5 m. The difference in the results by two methods may be due to the highly conductive top clay layer below which water exists or the resistivity method gives the depth somewhere in the middle of the water bearing layer where resistivity is lowest.

The water table measurements along with the lithology and SPT values will be useful for estimating liquefaction potential of the region.

Vs30 MEASUREMENTS

Average seismic shear wave velocity to 30 m depth, Vs30, was measured at 30 locations by Multi-channel Analysis of Surface Waves (MASW) as recorded on 48 channel seismic recorder and generated due to active source with 100-200 m profile lengths. Vs30 contour map prepared from this data is shown in Fig.

FREQUENCY-DEPENDENT AMPLIFICATION AND THICKNESS/VELOCITY INFERENCES ABOUT SOIL AND SEDIMENTARY LAYERS BY OBSERVATION OF AMBIENT VIBRATIONS AND EARTHQUAKES IN NETWORK OF BROADBAND SEISMOGRAPHS

Broadband seismographs were deployed at 11 locations (4 at a time) to measure amplification of seismic waves by recordings of the actual earthquakes and ambient vibrations. Frequency-dependent amplification at these locations is found to be 4 to 7. For comparison of response on hard rock to soil, a telemetered station was established at Sihor on the Deccan Trap formation. The local microearthquakes recorded on these stations will provide information on the activeness of the faults in surrounding region of SIR.

The frequencies in the maxima of the H/V plot are observed at around 2.5 Hz, indicating Quaternary/Tertiary boundary at 100 m taking average Vs=1000m/sec. The Deccan trap is inferred at 600 m depth by H/V amplification at 0.5 Hz and taking an average velocity of 1200m/sec. The Deccan Trap depth matches with ONGC data.

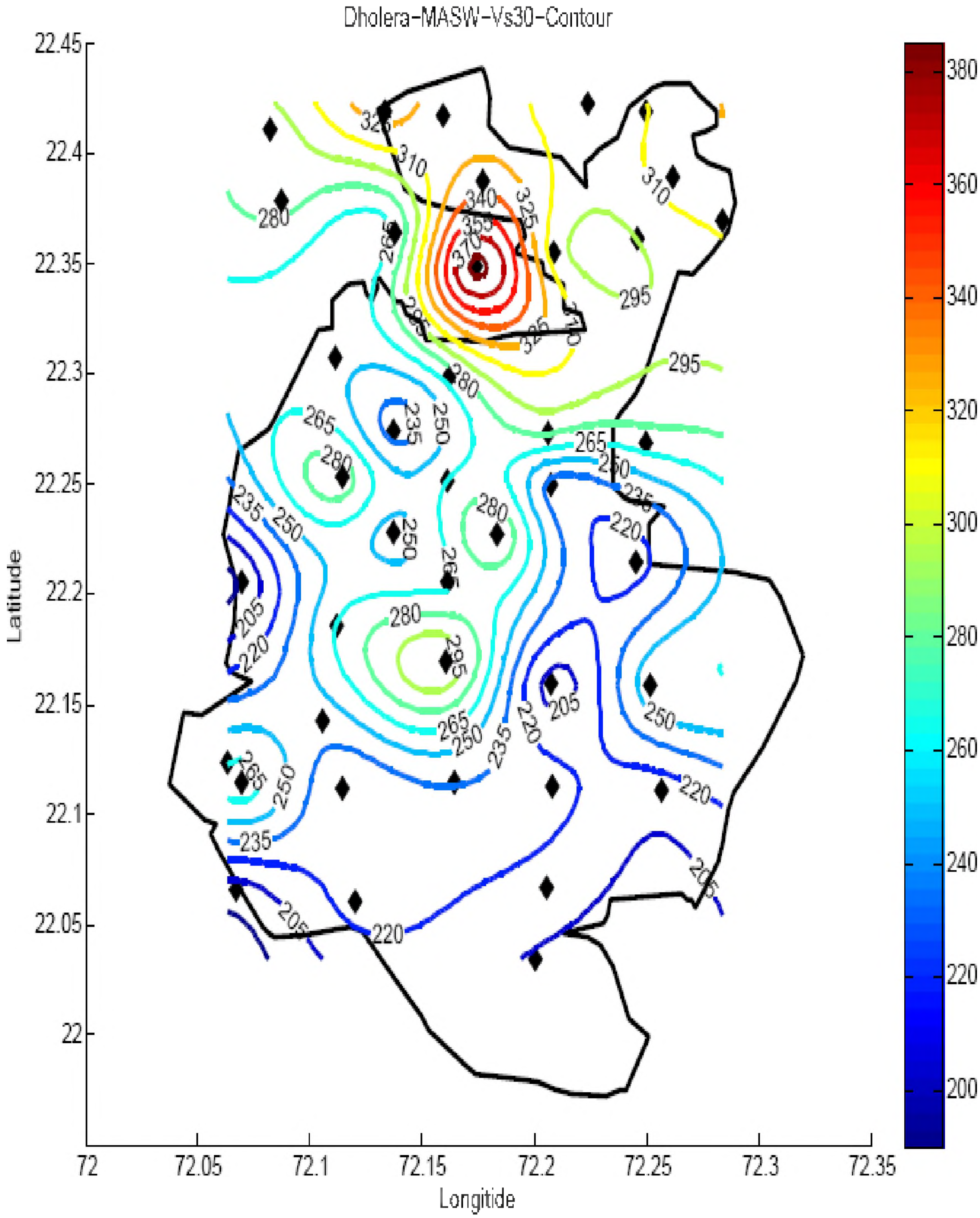


Fig. 6.7: Contour map showing average seismic shear wave velocity to 30 m depth, Vs30. Diamonds show the sites of measurements

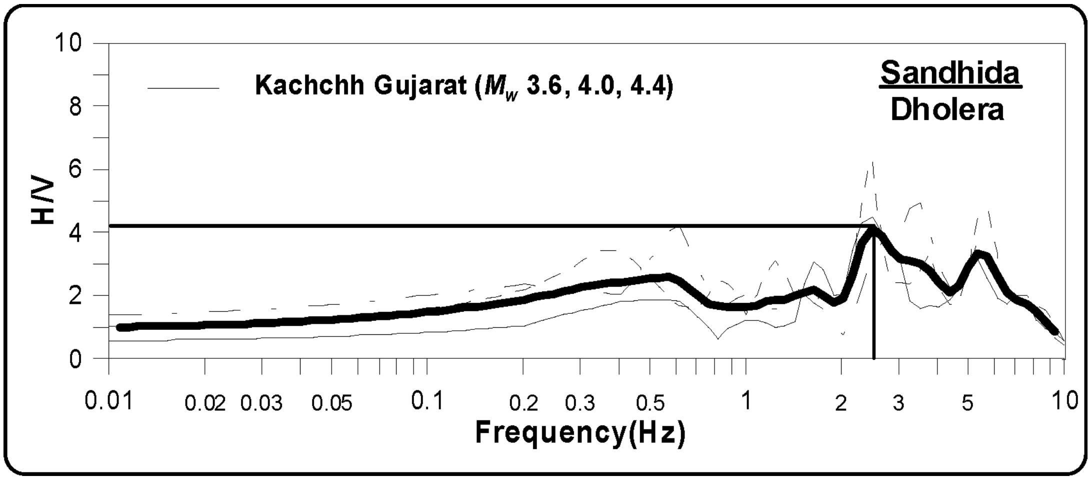


Fig. 6.8: H/V at one of the sites of broadband seismograph for three Kachchh earthquakes of M 3.6 - 4.4.

Array micro-tremor measurements were carried out at 15 places with 100m spacing of seven no. 5 sec period seismographs. From dispersion analysis of ambient noise deeper structure to 300 m depth was inferred. The data has been used for assessing the bedrock depth and amplification due to that layer.

Depth to engineering bedrock

Depth to engineering bedrock has been estimated from results of micro-tremor measurements, ambient noise recorded on broadband seismographs, Vs30 measurements, PS-logging, N-values from SPT tests and bore logs.

Probabilistic and Deterministic Earthquake Hazard Maps

Geological, geomorphic and seismotectonic features are assessed for the strong motion characteristics at engineering bedrock and the deterministic and probabilistic Peak Ground Acceleration (PGA) maps are prepared.

Deterministic seismic hazard maps for small areas have been estimated for expected magnitudes along the nearby faults. Maps of 2% and 10% probability of exeedence of PGA in 50 yr for Gujarat have been prepared incorporating seismicity data, recurrence rates, ‘a’ and ‘b’ values and using Hazard Assessment program of USGS.

GEOTECHNICAL LABORATORY AT ISR
(Janki Desai)

The Geotechnical Laboratory is equipped for: Grain size analysis, Atterberg’s limit, Direct shear test, Consolidation test and the Tri-axial Cyclic Test. These tests are being done on soil samples for seismic microzonation of different areas.

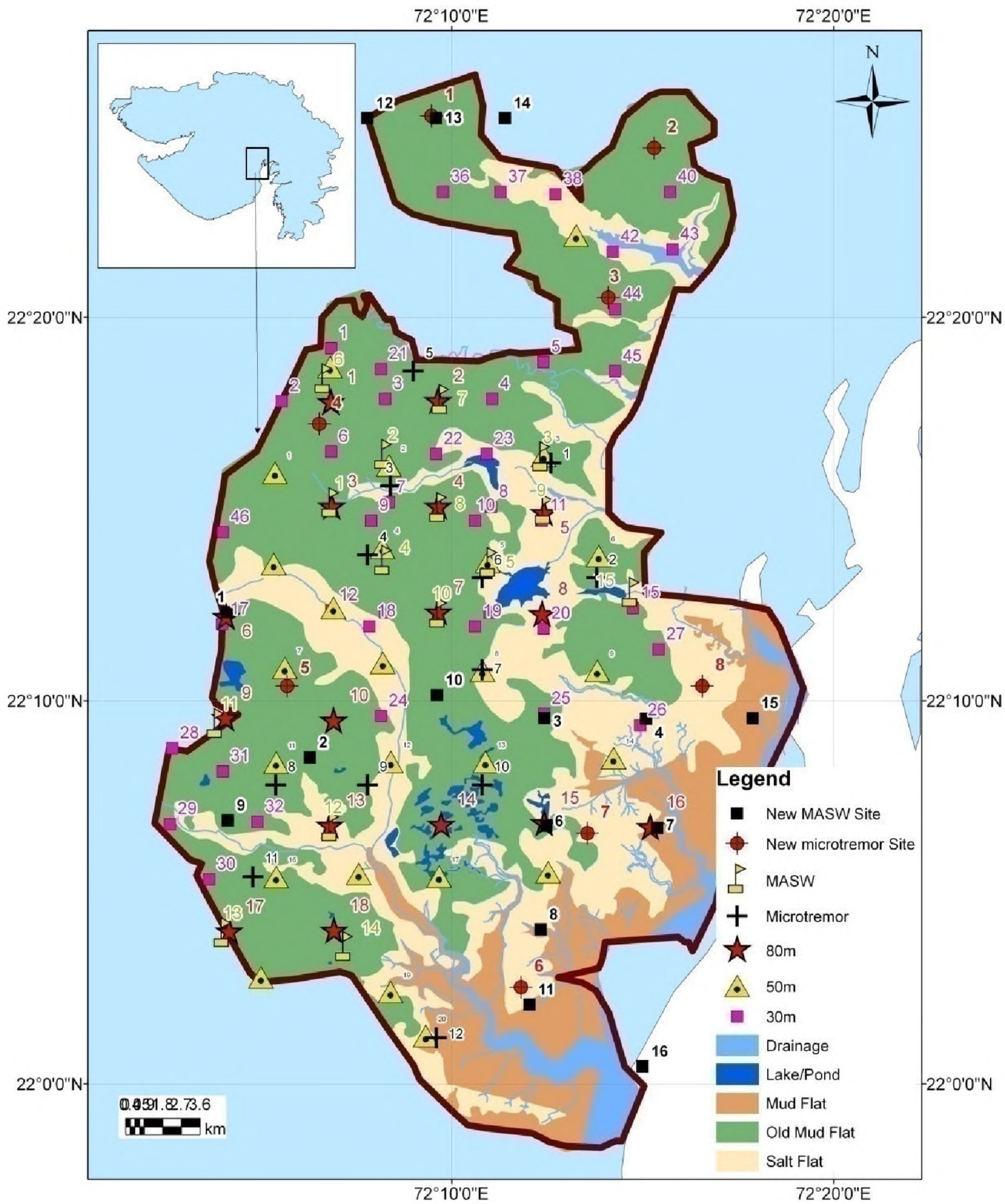


Fig.6.9: Locations of boreholes as well as MASW and Array-Microtremor measurements in the Dholera S.I.R. by October 2009 on geomorphology map

RAPID VISUAL SURVEY FOR VULNERABILITY AND LOSS ASSESSMENT OF BUILDINGS IN GANDHIDHAM AND ADIPUR CITIES (Santosh Kumar, Hardik Patel, A.P. Singh in collaboration with Dr. Sudhir Jain of IITg, Dr. Pradeep Kumar of IIIT, Hyderabad, Prof. Paresh Patel of Nirma Univ. and Tolani Polytechnic)

Bhuj earthquake of 26 January 2001 caused 14,000 casualties. Main reason for such huge casualties is low earthquake awareness and poor construction practices. Based on the technology advancement and knowledge gained after earthquake occurrences, the seismic code is usually revised. Last revision of IS 1893 (Criteria for earthquake resistant design of structures) was done in 2002 after a long gap of about 18 years. Some new clauses were included and some old provisions were updated. Assuming that concerned authorities will take enough steps for code compliance, the structures that are being constructed are now hoped to be earthquake resistant. In this context, what will happen to the safety of pre-code revision structures? These structures carry major percentage of vulnerable structure stock. Even if we have a very good disaster response system, it is impossible to reduce earthquake damage without considering the safety of pre-code revision structures. Moreover, it has to be checked that how the structure are constructed post-code. In this regard, a comprehensive study of seismic risk assessment of Gujarat is necessary. As a pilot study, Government of Gujarat has selected Gandhidham and Adipur cities in Kachchh district.

Rapid Visual Screening (RVS) was conducted on 16000 buildings in Gandhidham and Adipur cities. The RVS methodology is referred to as a “sidewalk survey” in which an experienced screener visually examines a building to identify features that affect the seismic performance of the building, such as the building type, seismic zone, soil conditions, and irregularities etc. This walk survey is carried out based on the checklists provided in a Performa for RCC and masonry. A Proforma was specially designed for RVS survey suitable for Indian conditions. A large number of buildings were photographed and geo-referenced by GPS. Other important data regarding the building is also gathered during the screening including the occupancy of the building and the presence of nonstructural falling hazards. Processing of the collected information has been completed. A performance score was calculated for the buildings based on numerical values on the RVS form corresponding to these features. The performance score is compared to a “cut-off” score to determine whether a building has potential vulnerabilities that should be evaluated further by an experienced Engineer. We have applied the Gaussian distribution methodology for cut off score in this study which is also commonly known as the "normal distribution".

Though, there are varied constructions practices, 26% constructions are RCC and 74% masonry structures. Results of the performance scores reveal that approximately 80% of both types of buildings are having good quality as these buildings have performance score > 80. The results of surveys also indicate that buildings practice have been changed from masonry to RCC after 2001. Due to design, RCC buildings will have more shear capacity to tolerate the seismic shaking in comparison to the masonry buildings. However performance score will have to be scaled locally for more appropriate results.

From RVS analysis some 300 houses have been selected for Preliminary Analysis in the classes of lower, medium and higher scores and out of which around 50 houses will be selected for detail analysis. This study is done for Vulnerability and Loss Assessment due to different magnitude earthquakes.

In a nutshell, the description of the flow of loss assessment work is as follows:

Seismic Evaluation of Existing Buildings in Gandhidham City project has following three phases:

- Rapid Visual Screening (RVS) of building stock in Gandhidham
- Preliminary seismic evaluation of selected buildings
- Detailed seismic evaluation of few buildings

The outcome of this project will be detailed maps of the damage or risk assessment for Gandhidham area. The detail of the phases given below as:

1. Phase I: Rapid Visual Screening

First phase of the project (May 2008-August 2009) is already completed and report has been submitted to GSDMA. A total of 16,000 buildings were surveyed.
During this phase an inventory has been developed by using RVS procedure for seismic evaluation of buildings in Gandhidham (Kachchh) proposed by Prof. Sudhir Jain et al. Collection of data was done by 50 teams and the data were uploaded using a portal prepared by IIIT Hyderabad. Based on the scores during this phase, some 300 structures were shortlisted for preliminary evaluation.

2. Phase II: Preliminary Evaluation

Around 300 buildings have been selected for doing preliminary survey.
This phase involves the following tasks:

- Collection of drawings and redraw (if possible) in autocad
- Identify the sizes of all columns and beams
- Load calculations
- Preliminary evaluation
    - ✓ Configuration related checks
    - ✓ Strength related checks

3. Phase III: Detailed Evaluation

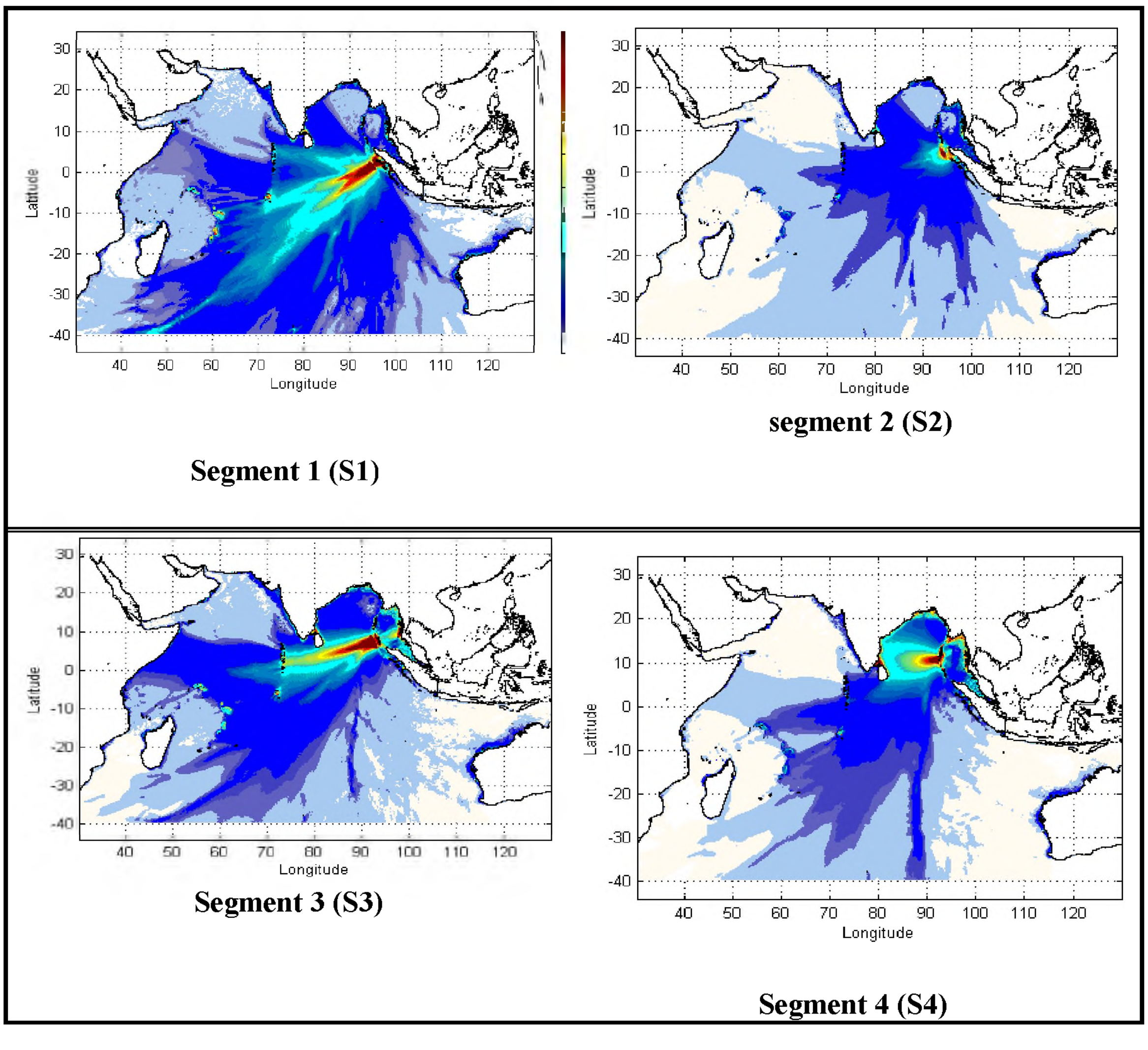
This phase involves the following tasks:

- Calculations
    - Vertical distribution of lateral forces by static method
    - Eccentricity calculation for additional torsional moment
    - Shear distribution to frames
    - Beam forces
    - Column forces
- Component level analysis
    - Calculation of moment of resistance in hogging & sagging
    - Check for shear capacity of beam
    - Column flexural capacity
    - Strong column weak beam considerations
    - Storey drift of the frame
- Evaluation summary

7. TSUNAMI STUDIES (A.P. Singh)

The great Sumatra-Andaman earthquake (M 9.3) which occurred on December 26, 2004 generated a Tsunami that propagated across the Indian Ocean and this event had highlighted the fact that the tsunami are the most underrated hazards over the Indian coast. In view of this, an attempt is made to simulate the devastating tsunamigenic earthquake that occurred on 26th December 2004 along the Sunda subduction zone for validation of our tsunami source and model potential and generate some possible directivity map which is important for hazard reduction. The total rupture length of about 1260 km for 2004 earthquake is divided into five rupture segments S1-S5 with different fault parameters. The directivity of tsunamis generated by individual segments and also for all the segments together has been modeled (Fig. 7.1).

As expected from the theory of directivity for thrust faulting, the tsunami energy is directed perpendicular to the strike of the fault. In the case of segments S1 and S2 (Fig.26), whose epicenters are located in the northern part of Sumatra, the energy is directed south of India. Due to this effect, most of the energy propagates towards the open Indian Ocean in the southwest direction and accordingly India would be safe from the Tsunami wave. The segment S3, whose epicenter is located in the north of Sumatra, affects Sri Lanka. By contrast, the S4 and S5 scenario along Andaman - Nicobar zone produce large amplitude and seriously affect almost the whole eastern coast of India.

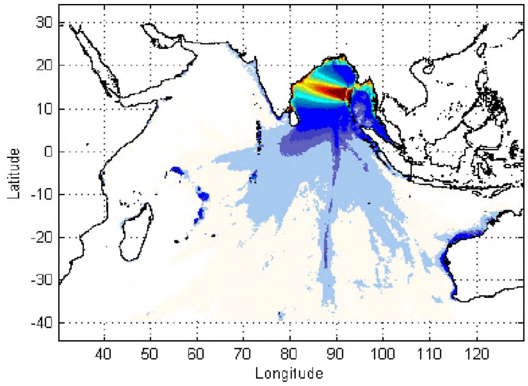


Segment 1 (S1)

segment 2 (S2)

Segment 3 (S3)

Segment 4 (S4)



Segment 5 (S5)

Fig. 7.1: Directivity of Tsunami from M 9.3 earthquake along Sumatra-Andaman subduction zone

Modeling of Tsunami travel time from the source of central Makran

On 27th November 1945, the western part of India experienced devastating tsunami (Rastogi 2007; Jaiswal, et al. 2009). This tsunami was triggered by an earthquake of magnitude 8.0 on the Richter scale of the coast of Makran. The most basic information of a tsunami warning center requires is expected times of arrival of the first tsunami wave at selected coastal locations from the area of tsunami generation in the ocean. Almost always the first wave in a tsunami event is not the wave with the greatest amplitude, nevertheless, tsunami travel time charts are generally constructed for the first wave, rather than the wave with the highest amplitude. Advanced knowledge of travel times for the first wave provides some additional valuable time to evacuate people, if and when evacuation is needed.

Modeling of tsunami amplitude and travel time has been made for the western Indian coasts from the central part of Makran sources using Tunami N2 model. The bathymetry data is taken from ETOPO-2 and near shore data from C-MAP. Makran, Fault strike 270°: The fault parameters of the earthquakes for the generation of tsunami are: fault area (200km length and 100km width), angle of strike, dip and slip (270°, 15° and 90°) and focal-depth (10 km).

Table 1 shows the arrival time of tsunami wave at various west coast of India. The simulation of model results show that the tsunami wave propagated initially very fast in Arabian Sea and it slowed down when it reached shallow region of Gujarat coast. The tsunami strikes Jakhau and Porbandar coast with more than 2.5 and 1.5 m amplitude and 2.0 m at the Dwarka region. The positive tsunami waves reach first at Dwarka in 2 hours and 10 minutes. The other places can be warned, minutes or hours before tsunami hits, if a tsunami warning system is placed at Dwarka

Table 1: The estimated possible arrival time with amplitude at various places

Place	Arrival Time (in hours)	Amplitude (meter)
Lakhpat	2.45	1.2
Koteshwar	2.55	1.5
Jakhau	3.02	2.5
Mandvi	3.10	0.7
Mundra	3.20	2.0
Kandla	3.30	2.0
Okha	2.35	2.0
Salya	3.05	1.2
Sikka	3.15	1.2

Bedi	4.02	1.5
Navlakhi	4.45	1.5
Dwarka	2.10	2.0
Veraval	2.52	1.0
Navabandar	3.02	1.2
Gulf of Khambhat	5.30	1.5
Suvali	5.10	0.4
Mumbai	4.45	2.0
Goa	3.08	1.0
Karwar (Karnataka)	3.12	1.0
Mangalore	3.36	1.0

STAFF OF ISR
SCIENTIFIC STAFF

Name	**Degree**	PG yr	**Activity**	**Joining**
1.Sumer Chopra, Sc. D	M.Tech. Geophys.IITr	1990	Strong motion, GPS	01.02.2006
2.K. Madhusudan Rao, Sc. B	M.Sc.Tech. Geophys, OU	1995	Earth's Structure	01.02.2006
3.Dr. A.K. Gupta, Sc. B	MSc Tech Geophys BHU PhD Geophys. 2004	1999	MPGO	15.02.2006
4.Dr. R.B.S. Yadav, Sc. B (resigned 16.3.2010)	MSc Tech Geophys BHU PhD Geophys. 2009	2004	Catalogs, Recurrence	02.08.2006
5.B.Sairam, Sc B	M.Sc.Tech. Geophys, OU	2003	Vs30 and PS logging	17.08.2006
6. Dr. (Mrs.) Babita Sharma, Sc. B	M.Tech Geophys. KU PhD Geophys. 2007	2000	Site amplification, and Attenuation	10.06.2006
7.M.S. B. S. Prasad, Sc. B	M.Sc Tech. Geophys, AU	1989	Radon, magnetism	11.06.2007
8.Santosh Kumar, Sc. B	M.Tech Geophys. KU	1996	Seismic network	01.04.2006
9. Ajay Pratap Singh, Sr. Geophysicist	M.Sc.Tech. Geophys, BHU	2002	Site response, Earthquake tomography, tsunami modeling	14.08.2006
10.Dr. Kapil Mohan, Sr.Geophysicist	M.Sc. Geophys. KU PhD Geophys. 2009	2001	Magnetotellurics, resistivity, TEM	11.07.2007
11.Sandeep Kumar Aggarwal, Sr. Geophysicist	M.Sc. Geophys. KU	2004	Broadband Seismology Site response	20.07.2007
12.Dr. (Miss) Pallabee Chaudhary, RA	MSc. Phys., Tezpur Univ. MSc. PhD Phys 2006	2001	GPS and strong motion	19.07.2007
13. R.K. Singh,Sr. Geophysicist	MSc Tech Geophys BHU	1979	Gravity & Resistivity	27.11.2007
14. Dr. Girish Chandra Kothyari, Geophysicist	M.Sc. Geol, Kumaon Univ PhD Geol. 2008	2001	Paleoseismology	13.04.2009
16. Srichand Prajapati, Geophysicist	MSc Tech Geophys BHU	2003	Seismology	25.07.2006
17.Mukesh Chauhan, Gophysicist	MSc Geol., BHU	2003	Surface-wave Dispersion	09.07.2007

18. Ms. Janki Desai, Sr. Geophysist	M.Sc. Geol., GU	2002	Geotechnical Investigations	13.04.2009
19. Rakesh Kumar Dumka, Geophycist	M.Sc. Geol, Kumaon Univ	2003	GPS studies	01.08.2007
20.Ketan Singha Roy, Geophysist	M. Tech. Comp. Seism	2009	Engg. Geophys.	30.07.2009
21.Partha Kalita, Geophysist	M. Tech. Comp. Seism.	2009	Phys. Earthq. Process	30.07.2009
22. Sidhartha Dimri, Geologist	M.Sc. Geol, Garhwal	2002	GIS, Remote sensing	15.01.2008
23.Ms. Rashmi Pradhan, Geologist	M.Sc. Geol	2005	Gravity, MPGO	04.03.2008
24. Vasu Pancholi, Geologist	M.Sc. Geol, GU, 2007	2005	Geotechnical Investigations	04.02.2009
25.Suresh Kumar Bharadwaj, Geeophycist	M.Sc. Geol		Geotechnical Investigations	
26.Shashi Bhushan Shukla	M.Sc. Geol		Paleoseismology	

List of JRFs

Name	Qualifications	Activity	Joined on
1. Vikas Kumar	M.Sc., Phys.	Earthquake Hazard	17.01.2008
2.Falguni Bhattacharjee	M.Sc. Geol.	OSL and InSAR	13.02.2008
3. Nagabhushan Rao	M.Sc., Phys.	Phys. Earthq. Process	15.01.2008
4. Ms. Vandana Patel	M.Sc., Phys.	Engg. Geophys.	06.09.2008
5. Kishansinh Zala	M.Sc., Phys.	Engg. Geophys.	06.09.2008
6. Gagan Bhatia	M.Sc. Electronics	MT	03.03.2009
7. Tarak Shah	M.Sc. Phys.	MPGO	02.03.2009
8. Dhruvkumar N.Rajyaguru	M.Sc. Phys.	PS logging	16.03.2009
9. Girish B. Patel	M.Sc. Electronics	MT	16.03.2009
10. Mehul K. Jagad	M.Sc. Phys.	Gravity	16.03.2009
11. Ms. Vishwa Joshi	M.Sc. Phys.	Microzonation	20.05.2009
12. Ms. Pooja Ramanuj	M.Sc.Env Sc & Tech	Geotechnical	28.05.2009
13. Ms. Jaina Patel	M.Sc.Env Sc & Tech	Geotechnical	01.06.2009
14. Kiran Kumar Mamidala	M.Sc.Geophys., OU 2009	Gravity	29.08.2009
15. Gumpidi Srinivas	M.Sc.Geophys, OU 2009	PS Logging	01.09.2009
16. Ms. Rita Singh	M.Sc. Geophys., KU 2009	MT	23.09.2009
17. Ms. Sarda Maibam	M.Sc. Earth Sciences, Manipur Univ. 2009	Geotech	05.11.2009
18. Limpou Luangmei	M.Sc. Earth Sciences, Manipur Univ. 2009	Geotech	16.11.2009
19. V.Gopala Rao	M.Sc.Geophys, OU 2009	Gravity	14.12.2009
20. K.Venkateswara Rao	M.Sc.Geophys, OU 2009	MT, TEM	15.12.2009
21.Ms. Ranjana Naorem	M.Sc. Earth Sciences, Manipur Univ. 2009	Geotech	30.01.2010

Scientific Assistant

1. Arvind Valand, JSA (superannuated 31.12.2009)

Technical Officer

	Qualification	Joined on
1. Ganpat Parmar	BE (EC)	17.11.2007
2. Jignesh B. Patel	BE (Computer Science)	12.04. 2006

Technical Assistant

1. Ankit Jadav	Dipl. Electrical	04.11.2006
2. Jay Pandit	B.Com.	16.06.2007
3. Nirav Patel	Dipl. Electrical	18.10.2007
4. Dilip Chaudhari	Dipl. Electrical	30.10.2007
5. Sandip Prajapati	Dipl. (EC)	24.12.2007
6. Gaurang K. Bhakhariya	B.Sc.	11.01.2008
7. Sandip Parmar	Dipl. Electrical	16.01.2008
8. Bharat D. Mevada	Dipl (EC)	18.01.2008
9. Gaurav Parmar	DCE	10.03.2008
10. Tejendra Vaghela	Dipl.Electrical	03.10.2008
11. Vijaysinh Vaghela	Dipl. Electrical	20.10.2008
13. Dharmendra Solanki	PG Dip.CA, B.Com, DTP, Hardware Networking	01.12.2008
12. Jignesh P.Patel	BE (EC)	06.02.2009
14. Paresh A. Paradiya	Dipl. Electrical	11.02.2009
15. Mahesh Valekar	Dipl Electrical	03.03.2009
16. Ankit Pandya	Dipl. Civil Engg.	01.04.2009
17. Pritesh Chauhan	Dipl. Comp. Engg	01.04.2009
18. Jayesh Parmar	DEC	01.04.2009
19. Bihari Darji	ITI Electronics	20.04.2009
20. Darshit Modi	DEC	04.05.2009
21. Ms. Hesha Pancholi, JLA (resigned 25.01.2010	M.Sc. Chem	06.07.2009

Administrative Staff:

1. Mrs. Bharti Vora, AO
2. B.G. Nayanwale, Ac.O
3. Ms. Daxa Parmar, Librarian
4. Manish Jadav, Jr. Clerk
5. Vashram Solanki, Office Supndt.
6. Nishant Patel, Project Acct.
7. Giriraj Chavda, Ac. Asst.

Visiting Professor: Dr. Roger Bilham, Uni. of Colorado, USA

Consultants: 1. Dr. S.K. Biswas, Ex-Director KDMIPE, ONGC,
2. Sri V.M Maru, Honorary Geophysicist, former Sc. NGRI, Hyderabad
3. Dr. Sivram Sastry, Geophysicist, former Sc. NGRI, Hyderabad

Staff Posted in Kachchh

Sr. No.	Name	Date of Birth	Educational Qualification	Date of Joining	Designation
1	Bhagirath M. Jadeja, Badargadh	17/08/1985	12th pass, Computer Knowledge	01/04/2009	Lab Assistant
2	Solanki Mitesh, Desalpar		B.E.		TA
3	Jayendra V.Jadeja, Vamka	14/01/1985	12th passed, Computer Knowledge	12/02/2009	Lab Assistant
4	Shaikh Mahammad Aarif, Vamka	02/01/1986	Diploma Electrical	01/10/2009	TA
5	Shambhu Ray, Badargadh	10/09/1982	B.A., Computer Knowledge	12/02/2009	Lab Assistant
6	Vimal A.Parmar, Bhachau	26/05/1984	Diploma in Electrical, 2005	12/02/2009	TA
7	Shivrajsinh Jadeja, Bhachau	10/06/1975	8th Pass	01/08/2007	Lab Assistant
8	Imran Ghanchi Desalpar	02/09/1986	B.Sc.(IT), 2008	12/02/2009	TA
9	Faizan Vohra, Desalpar	26/05/1984	ITI (RAAC)	04/12/2009	TA

List of Scientific staff that resigned from ISR during 2009

1. Sidharth Pandya, JRF (M.Sc., Phys) w.e.f. 21 .05.2009
2. Miss Neha Jhala JRF (M.Sc., Phys),(Joined 15.01.2008 resigned 03.06.2009
3. Dr.Mrs. Suneeta Harsh, Project Scientist (Chemistry), w.e.f. 08.06.2009
4. M.S. Gadhavi, Sc. B. (M. Sc Geol), w.e.f. 27.07.2009
5. Sameer Tiwari, JRF (M. Sc Geol), w.e.f. 29.08.2009
6. Dr. Uday Bhonde, Geophysicist (M. Sc Geol), w.e.f. 04.09.2009
7. Hardik Patel, Sr. Geologist (M. Sc. Geol), w.e.f. 16.09.2009
8. Ujjwal Nandi, JRF (M. Sc. Applied Geophysics) (joined 6.2009 resigned 13.07.2009)
9. Mandira Majumdar, JRF (M. Sc. Applied Geophysics) (Joined 6.2009 resigned 14.07.2009)
10. Kalyan Gorai, JRF (M. Sc. Applied Geophysics) (joined 6.2009 resigned 01.10.2009)
11. Debdeep Mukherjee, JRF (M. Sc. Applied Geophysics) (Joined 6.2009 resigned 13.07.2009)
12. Suman Vainala, JRF, M. Sc. Geophys, OU, 2009 (Joined 29.08.2009, Resigned 7.10.2009)
13. Miss Taru Shikha Singh, JRF, M.Sc. Geol, Ujjain (Joined 05.08.2008, resigned 15.02.2010)

14. Tanveer Saiyad, JRF, M.Sc. Geol GU (Joined 6.7.2009, Resigned 05.02.2010)
15. Ratnesh Pandey, Sr. Geophys. MSc Tech Geophys BHU (Joined 08.07.2009, resigned 21.01.2010)
16. Vasu pancholi, Geologist., M.Sc. Geol., Guj. Univ. (Joined 04.02.2009, Resigned 12. 2009)
17. Joyita Sengupta, Geophysicist, M.Sc. Tech Appl. Geop (joined 18.06.2009, Resigned 20.02.2010)
18. Mr. R.B.S.Yadav, Sc "B" M.Sc. Geophysics,(joined 02.08.2006, resigned 19.03.2010)
19. Partha Kalita Geophysicist M.Tech computational Seismology, M.Sc. in Mathematics (joined 30.07.2009, Resigned 25.03.2010)

List of Technical Staff that resigned

1. Miss Hesha Pancholi, JLA, MSc. Chemistry, Joined 06.07.2009 Resigned w.e.f. 25.01.2010

List of Administrative staff which resigned

1. Mrs. Seema Rau, Computer Operator (Resigned w.e.f. 20.08.2009)
2. Vimal Bidholiya, Computer Operator (Resigned w.e.f. 01.09.2009)
3. Miss Parulata Muchhadia, Computer Operator (Resigned w.e.f. 01.10.2009)

AWARDS /RECOGNITIONS

Consultant/Adviser

B.K. Rastogi appointed as Group-A consultant as per office order No. KLP-42008-57-(534)-2-Klapasar dated 26-9-2008 under the terms of GR No. KLP-112004-190-(1) Kalpasar dated 5.5.2006 as "national consultant for the work of tsunami studies for Kalpasar project.

B.K. Rastogi appointed as member of Performance & Monitoring Committee for physio-chemical, socio-economic & ecological environment data collection as a part of EIA study for Dholera Special Investment Region (DSIR), vide CEO-GIDB letter dated 5.10.2009

Sumer Chopra, Member Project Review Committee of GUJCOST
Sumer Chopra, Member, Board of Studies, Periyar Marriammai University, Thanjavore, TN

Ph.D. Thesis Awarded:

R.B.S. Yadav (2009). Seismotectonic modeling of NW Himalaya: A perspective on future seismic hazard. Department of Earthquake Engineering, Indian Institute of Technology, Roorkee, India

Kapil Mohan (2009). Seismic Hazard Assessment of Himalayan Regions (NE and Uttarakhand Himalayas) based on strong motion modeling of earthquake sources. Kurukshetra University.

Visits Abroad:

1. Sumer Chopra Sc. D, Deputation to Taiwan on Exchange Program, Aug 8-30, 2009.

2. RBS Yadav, Sc B, Training at Centram Geoforshung, Potsdam, Germany, Sep14-30, 2009.
3. Santosh Kumar, Sc. B, To participate in international workshop on "Managing Waveform Data and Metadata" organized by IRIS from 08-11-09 to 15-11-09 at Cairo, Egypt.

SEMINARS/WORKSHOPS

Seminars/Workshops Organized:

1. ISR organized MoES Workshop – cum – Meeting on GPS Networks in India on 3 Aug 2009.. It was chaired by Harsh Gupta and attended by 15 other participants from different parts of the country. ISR Participants: B.K. Rastogi, Sumer Chopra, Pallabee Choudhury, Rakesh Dumka and Srichand Prajapati
2. ISR visit of 80 participants of 2nd Asia Pacific Conference on Electron Spin Resonance and Luminiscence mainly held at PRL, 14 Nov. 2009

Seminars/Workshops Attended

1. International Conference on'Asia Pacific Luminescence and Electron Spin Resonance Dosimetry' organized by Physical Research Laboratory, Ahmedabad during 12-15, November, 2009. Name of participants: G.C. Kothyari, Geophycist and Falguni Bhattacharjee, J.R.F.

2. Workshop on "Global Positioning System and its Application" organized by Civil Engineering Department during 5-6 June 2009 at Institute of Technology Nirma University, Ahmedabad. Names of Participants from ISR: Mr. Srichand Prajapati, Mr. Rakesh Kr. Dumka, Dr. Pallabee Choudhury and Mr. Sumer Chopra

4.Visitors:

1. Prof. S. Rajaratnam, Center Disaster Management, Anna Univ. Chennai, 21.4.2009.
2. Dr. Pradeep Kumar, IIIT Hyderabad, 11.5.2009 and 27.11. 2009
3. Mr. Fumio Kaneko, Oyo Intl. Corp., 19-23.5.2001, 21-25.7.2009, 26-30.9.2009 and 10-14.11.2009.
4. Members of 13th Finance Commission (headed by Vijay L. Kelkar), 20 6.2009.
5. Sri S.M. Ingole, Dy. Chief Engg., NPCIL, Mumbai, 28.6.2009
6. Dr. D.P. Das, Director, Dr. S. Ghosh, Dy. Director, Airborne Mineral Survey and Exploration (AMSE), Bangalore and Shri Shekhavat, GSI, Gandhinagr, 1.7.2009.
7. Dr. S. K. Biswas, 14-16.07.2009 and 10-11.8.2009.
8. Prof. A.K. Mathur from IIT Roorkee, Uttarakhand, 30-07-09 to 01-08-09
9. Sri Rajesh Kishore, Principal Secretary-GoG, Prof. Sudhir Jain, Director IITg, Prof. R.D. Shah, MG Science College, Ahnedabad, Dr. T.J. Majumdar of SAC- ISRO and D. Natwar Sharma of GMRDS, 7.9.2009

10. M/S H.S. Rauth, Jigar Brahmabhatt and Dinesh Narang of Moser Baer Clean Energy, 17.9.2009.
11. Prof. B. R. Arora, Director Wadia Institute of Himalayan Geology, Dehradun, 17.9.2009.
12. Dr. Jerome Lave, CNRS, Paris, 3 Nov 2009

13. Dr. Michio Morino, Oyo Intl. Corp., 10-14.11.2009.

14. Dr. V.C. Thakur, former Director, Wadia Institute of Himalayan Geology, Dehradun,12.11. 2009
15. Dr. V.P. Dimri, Director NGRI, 13.11.2009
16. Prof. C.K. Rao, Dr. PBV Subbarao, and Sri Sandeep S. Khandagale of IIG, Mumbai, 15.11.2009.
17. Dr. Bernhard of Metronix along with Mr. Sanjay Gupta of Toshniwal, 27-29.11.2009.
18. Prof. Nilesh Bhatt, MS University, Vadodara, 9.12.2009.
19. Dr. Dipankar Sarkar accompanied by S/Sri Prakash Khare, Panigrahi, Srinivas Rao, CEO, Sesha Sai, and Smt. Vijay Kumari, of NGRI, Hyderabad, 9.12.2009.
20. Sri Amit Jha, Jt. Secretary and Dr. C.V. Dhrmarao, Jt. Advisor, of NDMA, New Delhi, 9.12.2009
21. Andre Razin, CEO, ARIS Geophsics, Moscow, 9.12.2009
22. Prof. Nilesh Bhatt, MS University, Vadodra, 9.12.2009

23. Dr. P.C. Pandey, Director, CORAL, IITkh,16.12.2009
24. Dr. Zafar Iqbal, Director and Dr. Dinesh Gupta, Sr. Geol., GSI Western Region, Jaipur., along with Dr. Gandhi of GSI, Gandhinagar, 21,12.2009.

List of groups of students/trainees along with the faculty members who visited ISR

1. 180 students from S.V. Vidyalaya, Kadi, Gandhinagar visited ISR on 12-06-09.

SEMINARS

Distinguished Scientists Lecture Series

1. Dr. B.R. Arora, Director, Wadia Institute of Himalayan Geology
"Multi-Parametric Geophysical Approach to Earthquake Precursory Research", 17.9.2009.

2.Dr. Jerome Lave, CNRS, Paris, "Seismotectonic Behaviour of the Main Himalayan Thrust fault", 4.11.2009.

3.Dr. V.P. Dimri, Director NGRI, "Inversion techniques in Geophysics", 13.11.2009

4.Prof. Prem Chand Pandey, Director, Center for Oceans, Rivers, Atmosphere and Land Sciences (CORAL), IITkh, "Antartica and Climate Change", 16.12.2009.

Seminar Talks

1. Dr. T. Harinarayana, Sc. 'G', NGRI, Hyderabad, "Use of magnet-telluric method for oil prospecting" and "Contributions MT technique for solving geological problems of India".
2. Dr. Ramancharla Pradeep Kumar, Assistant Professor, IIIThyd "*Seismic evaluation of existing structures in Gandhidham and Adipur cities*", 11.5.2009.
3. Dr. S.N. Bhattacharya, Formerly Addl. DG-IMD & Formerly Visiting Professor IITkgp '*Surface wave dispersion: measurement and inversion for evaluating velocity structure of crust and upper mantle*'. And the second lecture '*Evaluation of earthquake source mechanism through waveform inversion*'. 19.5.2009.
4. Dr. S. K. Biswas, "Structural, Tectonics and Active Fault of Kachchh Rift Basin, 16.07.2009.

5. Dr. R. Pradeep Kumar, Assistant Professor, IIIThyd, "Rapid Visual Survey (RVS) for Assessment of Seismic Vulnearability of Structures" July 2010
6. Prof. Ashok Kumar Mathur of IITr "Artificial Neural Network approach for site specific ground motion, 1.8.2009.
7. Prof. Nilesh Bhatt, MS University, Vadodara "Coastal Gemorphology and Quaternary Tectonics", 9.12.2009

Special / Invited Lectures`

1. Rastogi, B. K. (2009). Earthquake measurement and monitoring, ISTE Short term Training Programme, "Emerging Trends in Earthquake Resistant Design and Construction of Structures", Nirma University, May 26, 2009..

2. Rastogi, B. K. (2009). Seismic Microzonation, ISTE Short term Training Programme, "Emerging Trends in Earthquake Resistant Design and Construction of Structures", Nirma University, May 26, 2009

3. Rastogi, B.K., Chief Guest Address at the "Declamation contest of ICSE schools of five western states" at The New Tulip International School, Bopal, Ahmedabad.

4. Rastogi, B.K., Resource Person, 17th Children Sc. Congress, Ahmedabad, Video Conference on Planet Earth & Hazards, 28.12.2009.

5. Santosh Kumar, "Seismology, Monitoring Earthquakes", GIDM, Ahmedabad, "Comprehensive Course on Natural Disaster-Earthquake 8th to 13th March, 2010".

6. Sumer Chopra, "Use of GPS in monitoring crustal deformation", Nirma University, 25.5.2009

ISR Seminars

R.K. Singh, The Earth and its interior on the basis of seismological evidences, 28th August, 2009.
R.K. Singh, Geodynamic aspects of Crust and Mantle, 29th August, 2009
R.K. Singh, Identification of liquefaction zone deploying gravity and electrical techniques, 2 Sep 2009.
R.K. Singh, Gravity variations on Earth surface.
R.K. Singh, Isostacy in the Earth crust and its equilibrium and compensation.
R.K. Singh, Dansity, Gravityand Pressure in the Interior of the Earth.
R.K. Singh, Exploration techniques based on Electrical and Electromagnetic methods.
R.K. Singh: Isostatic compensation and vertical crustal movements, 16.12.2009
R.K. Singh: Electromagnetic method for locating conductive horizon in subsurface, 17.12.2009
R.K. Singh: Ground penetrating radar (GPR) technique for detection of shallow causative source, 18.12.2009.

TRAINING

Training of ISR scientists and Technicians at ISR

i. Rakesh Dumka, Samir Tiwari, RTK Suryeying, Training given by Mr. Soni of Elcome Technologies, Supplier of Leica GPS and RTK Rovers.
ii. Mr. R. K. Singh, Mr. Sameer Tiwari, Mr. Sidhartha Dimri, Mrs. Rasmi Pradhan, RTK Survey, 16.5. 2009. 1.
iii. A group of 10 JRFs and TAs trained on RTK survey by Sameer Tiwari on 27 and 28 Aug. 2009.
iv. Sandeep K. Aggarwal, Santosh Kumar, R.B.S. Yadav, K.M. Rao, Babita Sharma, B.SaiRam, A.K. Gupta, Mukesh Chauhan and Srichand, Training on (1)"Surface-wave Dispersion measurement and inversion for evaluating Velocity structure of Crust and upper mantle''.(2) Earthquake waveform modeling for source mechanism study'', By Dr. S.N. Bhattacharya, Formerly Addl. Director General IMD and formerly Visiting Professor IIT Kgp, May 19-22, 2009.
v. Dr. Kapil Mohan, …Training on magneto-telluric method of survey, Bernhard

Training of ISR Staff outside ISR

- Mr. R.K. Singh, Mr. Sameer Tiwari and Mrs. Rashmi Pradhan, Processing of gravity data, NGRI, Hyderabad, 26th April-7th May 2009.
- Mr. Kapil Mohan, Processing of magneto-telluric data, NGRI, Hyderabad, May 15-23, 2009.
- Sumer Chopra, RBS Yadav, Dr. Babita Sharma, A.P. Singh, Hardik Patel, Ms. Janaki Desai, Vasu Pancholi, Miss Taru Shikha, Kapil Mohan, "Emerging Trends in Earthquake Resistant Design and Construction of Structures", Nirma University, May 25-29, 2009.
- Miss Pallabee Choudhury, Training on GPS interpretation, at NGRI Hyderabad, during October 2008, March 2009 and GAMIT/GLOBK advanced user's workshop at C-MMACS, Bangalore during March 7-10, 2009.
- Nagbhushan Rao, Training on moment-tensor analysis with regional data, NGRI for extended periods
- Girish Ch. Kothyari Attended DST (SERC) sponsored training program on **"**Crustal Deformation and Tectonic Geomorphology: Climate and Tectonics". Conducted by Sikkim Institute of Techonology, Majitar, East Sikkim from 10th April-26th April 2009.
- Girish Ch. Kothyari Attended training on CORONA satellite data interpretation at IITK conducted by OYO International Japan and IIT Kanpur from 17th oct-29th Nov 2009

TRAINING TO STUDENTS

M. Tech. students in Computational Seismology

The three M.Tech students who carried out their studies during July 15, 2008 – May 31, 2009 submitted their thesis as given below:

1. Jwngsar Brahma (2009). Multi-channel Analysis of Surface Wave (MASW) Technique and Its Application.
2. Ketan Singha Roy (2009). Seismic Refraction Travel-time Tomography and Its Application.
3. Chintha Naresh (2009). Shallow Seismics in Earthquake Engineering

M. Sc. Students

Student Name	Institute Name	Training Period	Topic
Pratik Joshi			Development of ISR website
Darshana Patel	M.G.Science Institute	1/6/09 to 21/06/09	PS Logging study
Shabbir K. Dalal	M.G.Science Institute	1/6/09 to 21/06/09	Geo-technical Lab testing
Jaykumar H. Gohil	M.G.Science Institute	1/6/09 to 21/06/09	Litho-log study

7.PUBLICATIONS

Year	No of Papers Published		Reports	Abstracts
	SCI	Others		
2006	3	6	5	14
2007	3	5	10	15
2008	8	8	8	5
2009	4	3	11	7

Research Papers Published in SCI Journals

1. Jaiswal, R.K., A. P. Singh and B. K. Rastogi (2009) Simulation of the Arabian Sea Tsunami propagation generated due to 1945 Makran Earthquake and its effect on Western parts of Gujarat (India), *J. Natural Hazards*, 48(2), 245-258

2. Joshi, A. and Mohan, K. (2009) Expected peak ground acceleration in Uttarakhand Himalaya, India region from a deterministic hazard model, *Natural Hazards*, **52**, 299-317.

3.Yadav, R.B.S., P. Bormann, B.K. Rastogi, M.C. Das and S. Chopra (2009) A homogeneous and complete earthquake catalogue for northeast India and the adjoining region, Seismological Research Letters, 80(4), 609-627.

4.Sharma, Babita, S. S. Teotia, Dinesh Kumar and P.S.Raju (2009). Attenuation of P and S waves in the Chamoli region, Himalaya, India., *PAGEOPH*, 166, pp1949-1966.

5. Chopra,Sumer, Kumar, Dinesh and Rastogi, B.K. (2009). Estimation of sedimentary thickness in Kachchh region by converted phases, PAGEOPH, DOI 10.1007/S00024-009-0022-3

Research Papers accepted in SCI Journals

1. Yadav R.B.S., J. N. Tripathi, B. K. Rastogi, M. C. Das and S. Chopra, (2009) Probabilistic assessment of earthquake recurrence in Northeast India and adjoining region, *Pure and Applied Geophysics*,

2.Yadav R.B.S., D. Shanker, S. Chopra, and A. P. Singh, (2009) An application of regional time and magnitude predictable model for long-term earthquake prediction in the vicinity of October 8, 2005 Kashmir Himalaya earthquake, *Natural Hazard (accepted).*

3.P. Bormann and R. B. S. Yadav (2010). Reply to Comments of R. Das and H. R. Wason on "A Homogeneous and Complete Earthquake Catalog for Northeast India and the Adjoining Region" by R.B.S. Yadav, P. Bormann, B. K. Rastogi, M.C. Das and S. Chopra; *Seismological Research Letters* (accepted and will appear in March/April 2010 edition)

4. P. Bormann and R. B. S. Yadav (2010), Supplement to the paper "A Homogeneous and Complete Earthquake Catalog for Northeast India and the Adjoining Region" by R.B.S. Yadav, P. Bormann, B. K. Rastogi, M.C. Das and S. Chopra; *Seismological Research Letters* (accepted and will appear in March/April 2010 edition)

5.Yadav R.B.S., D. Shanker, B. K. Rastogi, M. C. Das and Vikas Kumar (2010), Probabilities for the occurrences of medium to large earthquakes in Northeast India and adjoining region, *Natural Hazard*, (accepted)

6. A. P. Singh, T. S. Murty, B. K. Rastogi and R. B. S. Yadav (2009) Earthquake generated tsunami in the Indian Ocean and possible vulnerability assessment for the east coast of India *J. Natural Hazards*, (Under print)

7. Maulishree Joshi and Girish Ch. Kothyari (2010) Assessment of tectonic activity in a seismically locked segment of Himachal Himalaya International Journal of Remote Sensing 30 (2), 651-659.

8. Girish Ch. Kothyari and P. D. Pant (2009) Neotectonics of north-western part of Almora District around Dwarahat-Chaukhutia area in Central Kumaun Himalaya: A Geomorphic perspective. Journal of Economic geologist and Resources management (Accepted 10/12/2009)

9.T. Srikanth, R. Pradeep Kumar, A. P. Singh, B. K. Rastogi and Santosh Kumar (2010) Earthquake vulnerability assessment of existing buildings in Gandhidham and Adipur cities, Kachchh, Gujarat (India). European Journal of Scientific Research (Accepted)
10.Sumer Chopra, Dinesh Kumar and B.K. Rastogi (2010). Estimation of strong ground motions for 2001 Bhuj (Mw 7.6), India earthquake (Accepted for publication in PAGEOPH)

11.Sumer Chopra, Dinesh Kumar and B.K. Rastogi (2010). Attenuation of high frequency P and S waves in the Gujarat Region, India (accepted with revision in PAGEOPH)

Research Papers communicated to SCI Journals

1.B. Sharma, E. Carcolé, A. Ugalde and B. K. Rastogi (2009) Spatial distribution of scatterers in the crust of Kachchh region (western India) by inversion analysis of coda envelopes, Journal of Seismology (under reveiw).

2. B.K. Rastogi , A.P. Singh, B.Sairam, Sudhir K. Jain, F Kaneko and J Mastsuo .The Possibility of Site Effects: the Anjar Case, following the past Earthquakes in Gujarat, India, Communicated to SRL. (Under Review)

3.R.B.S. Yadav, E.E. Papadimitriou, V.G. Karalostas, D. Shanker, B.K. Rastogi, S. Chopra, A.P. Singh and Santosh Kumar. The 2007 Talala, Saurashtra, western earthquake sequence: Tectonic implications and seismicity triggering. Journal of Asian Earth Sciences (Communicated).

4.K. Mohan and A. Joshi, Role of attenuation relationship in shaping the seismic hazard, Natural hazards (communicated).

5. Babita Sharma, Dinesh Kumar, Arun K.Gupta, Srichand Prajapati, S.S.Teotia and B.K.Rastogi(2009), Attenuation of Coda Q for Saurashtra, Gujarat (India), PAGEOPH (Communicated).
6. Girish Ch. Kothyari, P. D. Pant, Moulishree Joshi, Khayingshing Luirei and Jawed N Malik (2010). Active Faulting and Deformation of Quaternary Landforms, Sub-Himalaya, India (communicated after revision to Geochrnometrica)

7.Binita Phartiyal and Girish Ch. Kothayari (2009). Morphotectonic control on drainage network of Spiti river catchment: A case study from NW Himalaya (communicated to CATENA).

8. Girish C. Kothyari, P. D. Pant and Khayingshing Luirei (2009)Wedge failure analysis of landslides occurring in the Main Boundary Thrust (MBT) zone: Southeastern Kumaun, Uttarakhand, India (Communicated to Natural Hazards)

9. Karanpal S. Rawat, Girish Ch. Kothyari and Suman Joshi (2009). Sediment deformational structures in Garbyang area: Implications for palaeoseismicity in the Higher Central Himalaya, India (Communicated to Sedimentary Geology).

10. Maulishree Joshi, Girish Ch. Kothyari, Lalit Joshi and Nidhi Arya (2009). Evidences of Tectonic activity along Trans Himadri Fault in Goriganga valley, Higher Central Kumaun Himalaya, International Geology Review (Accepted 12/05/10).

Research Papers Published in non-SCI journals

1. Rastogi, B. K. (2009). Earthquake measurement and monitoring, Proc. "Emerging Trends in Earthquake Resistant Design and Construction of Structures", Nirma University, 7 pp.

2. .Rastogi, B. K. (2009). Seismic Microzonation, Proc. "Emerging Trends in Earthquake Resistant Design and Construction of Structures", Nirma University, 7 pp.

3. Rastogi, B. K. (2009). Geophysical Exploration for Oil: an Introduction, Petroleum University Distinguished Lecture Series, 12 pp.

Research Papers Communicated (Non-SCI)

Technical Reports

1. Arun Gupta, M. S. Gadhavi, Hardik Patel, Rashmi Pradhan and Taru Shikha (2009). 1st Report on Installation of Infrastructure at MPGOs in Kachchh. ISR Technical Report No. 24.

2. Uday Bhonde (2009) Report for the investigation of sudden gushing out of water in the streets from underground in Halvad town, Surendranagar dist. during November 2008. ISR Technical Report No. 25

3. B. K. Rastogi, Sumer Chopra, K. Madhusudn Rao, Arun Gupta, B. Sairam, Ram Bichar Singh Yadav, M. S. B. S. Prasad, Babita Sharma, Santosh Kumar, and M. S. Gadhavi (2009). 5th Progress Report for the period February 2008-March-2009 for the Project on Seismological Research and Application in Gujarat. ISR Technical Report No. 26

4. B. K. Rastogi, Sumer Chopra, V. K. Gahalaut, Pallabee Choudhury, Vikas Kumar (2009). Crustal Deformation and GPS studies in Kachchh. ISR Technical Report No. 27.

5. Hardik Patel, Janki Desai, Sameer Tiwari, Vasu Pancholi, Tarushikha Singh, Girish. A Report on GPR and Resistivity survey in GIDC area near Bharuch. ISR Technical Report no. 28.

6. B. Sairam, Hardik Patel, Kishan Jhala and Mukesh Chauhan. (2009). Seismic refraction survey at Mundra for investigation of shallow layers. ISR Technical Report no. 29. July PP 14.

7 Rastogi, B.K. , S. Chopra and S.K. Biswas "1st Interim Report on seismotectonic study around LNG terminal site at Mundra" ISR Tech. Report, No. 30, August 2009

8. R.K.Singh, Rashmi Pradhan, Ujjwal Nandi, Mandira Majumder, Sameer Tiwari (Sep 2009). Technical Report on Gravity Survey in Mundra Area. ISR Technical Report no.31. pp.06.

9. B. K. Rastogi, Sumer Chopra, Janki Desai, Vasu Pancholi, Tarushikha Singh (Oct 2009).A report on Drilling of boreholes, geotechnical and geophysical investigations in Dholera Special Investment Region, ISR Technical Report no.32, 126pp

10. R.K.Singh and Sameer Tiwari (2009). A Technical Report on Electrical Resistivity Survey in & around Dholera, Dist. Ahmedabad, Gujarat, October 2009, ISR Technical Report no.33, 12pp.

11.Rastogi, B.K., Sumer Chopra, K. Madhusudn Rao, Arun Gupta, B. Sairam, Ram Bichar Singh Yadav, M. S. B. S. Prasad, Babita Sharma, Santosh Kumar, and M. S. Gadhavi (2009). Project completion report, Seismological Research and Applications in Gujarat, ISR Technical Report no.34, 56pp.

Abstracts/ papers presented in seminars

IGU Conference at WIHG, Dehradun, October 5-7, 2009.

1. Babita Sharma, Dinesh Kumar, S.S. Teotia, B.K. Rastogi (2009). Attenuation Characteristics of three Indian Regions: An Overview,

Seminar "Seismogenesis to Prediction of Earthquakes: Himalaya and Indian Shield Pespective (SPRED-2009, WIHG, Dehradun, October 22-24, 2009

2. Sandeep Kumar Aggarwal, B.Sairam, Santosh Kumar and B.K. Rastogi (2009)., Seismotectonics study to characterize the seismic sources in Jamnagar, Gujarat, India.

3.Arun Gupta, Rashmi Pradhan, Srichand Prajapati, Mukesh Chauhan and B.K.Rastogi, Observation of free oscillations from Gujarat Superconducting gravimeter at Badargadh MPGO sites in Kachchh,

4. Arun Gupta, M.S.B.S.Prasad, Rashmi Pradhan, and B.K.Rastogi, Gujarat MPGO network in Kachchh,

5. B. K. Rastogi and Sumer Chopra (2009).Earthquake Hazard and Prediction Research in Gujarat

6. R.K. Singh and Rashmi Pradhan(2009), Crustal configuration of seismically active area of Kachchh basin from gravity surveys.

7. Srichand Prajapati, Mukesh Chauhan Arun Gupta, Rashmi Pradhan, and B.K.Rastogi (2009), The seismic quiescence in Kachchh: A study after 2001 Bhuj Earthquake.

2nd India Disaster Management Congress, Vigyan Bhawan, New Delhi, organized by NIDM, 4-6 Nov. 2009.

6. Sandeep Kumar Aggarwal, B.sairam and B.K. Rastogi (2009)., Foreshock clustering and precursory changes in source parameters for the Kachchh earthquakes Gujarat, India.

7.Girish Ch. Kothyari, P. D. Pant and Maulishree Joshi, (2009). Active faulting and Deformation of Quaternary landform Sub-Himalaya India. **Second Asia Pacific Conference on Luminescence and Electron Spin Resonance Dating in Physical Research laboratory (PRL)** from Nov, 12-15, 2009.

8.General Events

1. ISR celebrated "World Book Day" on 23 April 2009. The Librarian, the Chairman Library Committee and most frequent readers were felicitated. Highlights of some of the recent popular books in science, management and on countries development.
2. 13th Finance Commission of GoI under chairmanship of Vijay L. Kelkar visited ISR on 20 June 2009.

9.Recurring Funds

i. Corpus Fund Interest (of Fixed Deposit of Rs. 16 crore) Rs. 150.00 Lakh

ii. GoG Rs. 135.00 Lakh

Projects:

SN	Project	Sponsoring Agency	Period	Value Rs. Lakh	Recd.2009 Rs. Lakh
1	Paleoseismology in Kutch	GoG	Apr.2007-Mar.2012	300.00	45.00
2	Microzonation in Gandhinagar and a few towns in Kutch like Bhachau and Rapar	GoG	Apr.2007-Mar.2012	300.00	45.00
3	Surface Deformation in Wagad area of Kutch using InSAR	SAC, ISRO	Apr. 2008-Mar.2011	19.00	06.04
4	Vs30 measurements at sites of SMA stations, Power Distribution hubs etc. and determination of attenuation relation for Gujarat	NPCIL	Apr 2009-Mar 2010	11.69	10.96
5	Seismic Study for Dholera Special Investment Region	GIDB	Dec. 2008-Nov 2009	200.00	39.00
6	Seismotectonic Study around Mundra	GSPC	Oct 2008-Sep 2009	143.40	22.78
7	Seismic Microzonation of Guj. Intl. Finance Tech City	GIFT	May 2009-Apr 2010	27.00	07.45
8	Seismicity Research & Applications in Gujarat	MoES	Feb.2006-Aug 2009	256.91	39.13
9	Crustal Deformation in Kutch and Narmada	MoES-2	Apr 2007-Mar 2010	65.00	11.90
10	Assessment of Vulnerability of Installations near Gujarat Coast vis-à-vis Seismic Disturbances	MoES-3	April 2009 – March 2012	153.84	82.869
11	Seismic Microzonation of Ahmedabad, Guj.	MoES-4		37.68	17.54
			Total	1783.87	337.669

Short Duration Projects

SN	Project	Sponsoring Agency	Period	Value
1.	Fault Locations crossing the pipelines			Rs. 0.20 lakhs
2	Fault Locations crossing the pipelines			
3.	Identification of underground pipelines in Ankaleswar Oil Field area	Gujarat Infrastructure Development Corp.	June 2009	Rs. 1.00 lakh

8. Books and Journals:

The amount spent in books and journals is as follows:

For the year 2006-07………….Rs. 8.41 lakhs
For the year 2007-08………….Rs. 15.45 lakhs
For the year 2008-09………….Rs. 15.00 lakhs

9. Details of instruments of ISR:

Sr No	Name	Model No	Manufacturer	QTY	Cost lacs (Rs)	Funding Agency
Instruments procured during 2006 and 2007						
1	Broad Band Seismometer	CMG-3T 120 sec	GURALP, U.K	48	93.7 196.6 27.85	19-ADB, 25-WB, 4-GOI
2	Broad Band Seismometer	CMG-3T 360 sec	GURALP, U.K	3	22.8	3-WB
3	Digital Acquisition System for BBS	REFTEK DAS-130	REFTEK, U.S.A	29	123.4 21.14	25-WB, 4-GOI
4	Digital Acquisition System for BBS	DM-24	GURALP, U.K	22	75.3 20.5	19-ADB, 3-WB
5	Strong Motion Accelerographs	GSR-18	GEOSIG, Switzerland	46	94.7 19.4	40-ADB, 6-WB
6	Strong Motion Accelerographs	ETNA	Kinemetrics, USA	4	15.82	4-GOI
7	Global Positioning Systems	GRX1200 GG-PRO	LEICA, Switzerland	36	354.2 18.76	32 from WB, 4 from GOI
8	Global Positioning Systems		Topcon,	6	36	GOI

			Singapore			
9	Global Positioning Systems RTK enabled	RTK	LEICA , Switzerland	2	9.36	GOI
10	Engineering Seismograph 48 channel		Geometrics, USA	1	65	GOI
11	Ground Penetrating Radar (GPR) 100 MH and 200 MH antenna		GSSI, USA	1	45	GOI
12	5 SEC SEISMOMETERS	LE-3D/5S	LENNARTZ , Germany	8	30.99	GOG
13	MICROTREMOR RECORDER	CITY SHARK-II	LEAS, FRANCE	8	28.22	GOG
14	Resistivitymeter		IGIS, Hyderabad	1	0.37	GOG
15	ARCGIS software			1	12	GOG
			TOTAL		**1176.58**	
Instruments procured during 2008						
1	MAGNETO TELLURIC UNIT	ADU07	METRONIX	1	39.84	WB
2	GRAVIMETER	CG-5	SCINTREX , CANADA	2	64.446	WB
3	Triaxial Fluxgate Magnetometer		Magson, Germany	2	29.232	WB
4	Time Domain E.M profiling system		ZONGE , USA	2	81	WB
5	RESISTIVITY IMAGING SYSTEM	SYSCAL PRO	IRIS, FRANCE	1	39.161	WB
6	DIGITAL WATER LEVEL RECORDERS		IRIS, FRANCE	7	7.1166	WB
7	ELECTRONIC AUTO RADON MONITOR		SHARAD Germany	5	15.9935	WB
8	TL/OSL DATING SYSTEM (unit 1)		Riso Nat Lab Denmark	2	103.68	WB,
9	Super Conducting Gravimeter		GWR, US	1	420.288	WB
10	Borehole Strainmeters		GTSM Tech, Australia	3	450	WB
11	Total Station			1	5	WB
12	PS logging unit			1	40	
			TOTAL		**1295.76**	
GOODS PROCURED DURING 2009						
1.	Broadband Seismometers and DAS		Nanometrics	1	12	GoG
2	TL/OSL DATING SYSTEM (unit 1) Sr-90 Beta source		Riso Nat Lab Denmark	2	60	GoG
3	Magnetic Separator		AKV Enterprises Dehradun	1	18, 80, 316	GoG
4	Shake 2000 software		USA	1	26,250	GoG
5	Digital data Acquisition System (DM-24)		Guralp, UK	6	15.54	GoG
6	Direct Shear & other misc. Geotechnical		HELCO, New Delhi	1	3.26	GoG
7	Consolidometer & other Geotechnical instruments		AIMIL Ltd., Vadodara	1	4.65	GoG
GOODS UNDER PROCUREMENT						
1	Integrated Radon and water level measuring system in borehole			3	31	MoES
2	Auto Helium Monitor			3	36	MoES
3	Proton Precision Magnetometer			3	11	MoES

4	Over Hauser Magnetometer			3	39	MoES
6	Triaxial Flux Gate Magnetometer			3	33	MoES
7	Declination / Inclination Magnetometers		Lviv Institute Of Space Research, Ukrain	3	21	MoES
8	Magnetotelluric Unit			1	50	MoES
9	Long Period Magneto- Telluric Unit		Lviv Institute of Space Research, Ukrain	2	30	MoES
10	Ulf Magnetometer		Lviv Institute of Space Research, Ukrain	3	22	MoES
11	Absolute Gravimeter	FG-5	SCINTREX, CANADA	1	300	MoES
12	Vehicle			1	8	MoES
13	UPS			1	8	MoES
14	Generator			1	12	MoES
15	VSAT hardware				2	MoES
			Total from MoES		**697**	
	From GoG Funds					
1	AUTO LOCATION SOFTWARE		KINEMETRICS, USA	1	100	GoG
2	Magnetic Separator		Frank-Hertz, USA	1	12	GoG
			TOTAL		**112**	

Purchase of Computers, Laptops, Servers, Plotters, Printers and Computer Peripherals - Itemwise Detail

Year – 2010

Sr.No	Items Details	Price (Rs.)
1	Cartridges, Hard-disks, Toner	39,996/-
2	Desktops (10 nos. set), Laptops (3 nos.), Printers (2 nos.), Scanner (1 no.)	5,40,645/-
3	Antivirus (10 Users)	8,750/-
	Total	**5,89,391/-**

Year – 2009

Sr.No	Items Details	Price (Rs.)
1	Cartridges, Hard –disks, Ram, Pen drives, DVD –R/W, Cable, Mouse, Laptop Battery, Repairing peripherals	72, 681/-
2	Antivirus (35 users)	33,125/-
3	Desktops (26 nos. set), Laptops (10 nos.), Printers (14 nos.), Servers (6 nos.), Plotters (1no.), UPS (3 online & 15 offline), Projector (1 no.), LCD scrolling panel and motion display.	35,18,648/-
4	Alcatel EPBAX System, Digital, Analog phones and Users Hardware	3,47,758/-
	Total	**39,72,212/-**

Year – 2008

Sr.No	Items Details	Price (Rs.)
1	Cartridges, Hard –disks, Ram, Key -Boards, DVD –	1,03,085/-

	R/W, Cable, Mouse, Laptop Battery, Repairing peripherals, Antivirus	
2	Panasonic Tough Book (3 nos.), Color Xerox Machine (1 no.), Samsung LCD (40''), Digital camera	10,95,899/-
	Total	**11,98,984/-**

Year – 2007

Sr.No	Items Details	Price (Rs.)
1	Cartridges, Hard –disks, Ram, Pen drives, DVD –R/W, Cable, Mouse, Laptop Battery, Repairing peripherals, Palmtop cables, 24 port Switch, Jack Panel , Rack, Patch cord.	1,65,431/-
2	Antivirus, windows Server 2003, Tally, Office 2003 Indic software, ArcGis software.	11,97,036/-
3	Desktops (24nos. set), Printers (19 nos.), Laptops (3 nos.), workstation (1no.), Server (1 no.), Samsung LCD (40'')	84,40,386/-
	Total	**98,02,853/-**

Year – 2006

Sr.No	Items Details	Price (Rs.)
1	Desktops (20 nos. set), printers (3 nos.), Plotter (1 no.), Scanner (1 no.), Laptop (3 nos.), projector and screen (1 no.), Jack panel, Patch cord, Cables, Fax Machine, Xerox Machine.	11,21,450/-
	Total	**11,21,450/-**

- ISR is having Computers, Laptops, Printers, Tough books, Plotters(itemwise detail) below:-

Total numbers of Desktops: -	84 nos. (CPU + Monitors)
Total numbers of Laptops: -	21 nos.
Total numbers of Servers: -	07 nos.
Total numbers of Printers: -	41 nos.
Total numbers of Tough books: -	03 nos.
Total numbers of Plotters: -	02 nos.

- **Total Expenditure incurred (2006 - 2010):- 1,66,84,890/- (Rs.)**

CATALOGUE OF EARTHQUAKES IN GUJARAT REGION FROM EARLIEST TIME TO 2009

Year	Month	Date	Origin time	Lat(N)	Long(E)	Depth	Magnitude	Intensity	Location	Ref.
1668	05	06		25.00	68.00		7.8	X	Samaji, Indus	IMD
1684				21.20	72.90		3.7		Surat	USGS
1819	06	16		24.00	69.00		M_w 7.8	X	Kachchh	IMD
1820	01	27		23.20	69.90		3.7		Kachchh	USGS
1820	11	13		23.20	69.90		3.7		Kachchh	USGS
1821	08	13		22.70	72.70		4.6		Kaira	USGS
1828	07	20		23.24	69.66		4.4		Kachchh	USGS
1840	11	10		23.05	72.67		4.6		Ahmedabad	USGS
1842	10	09		22.30	73.20		4.3	V	Baroda	OLD
1843	02	08		23.00	72.70		3.7	IV	Ahmedabad	OLD
1844				24.33	69.50		4.3		Lakhpat	USGS
1845	04	19		23.80	68.90		6.3	VIII	Lakhpat	OLD
1845	06	19		23.80	68.90		5.7	VII	Lakhpat	OLD
1848	04	26		24.40	72.70		5.7	VII	Mount Abu	OLD
1856	11	02		23.20	69.90		4.6		Anjar	USGS
1856	12	25		20.00	73.00		5.7	VII	Surat	CHAN
1858	12	31		21.00	75.00		4.3	V	Khandeish	OLD
1863	11	18		22.00	75.00		5.0	VI	Barwani	IMD
1864	04	29		22.30	72.80		5.7	VII	Ahmedabad	CHAN
1869	07	04		20.20	74.20		4.3	V	Nasik	OLD
1869	07	12		20.90	74.80		4.3	V	Dhulia	OLD
1871	01	03		21.20	72.90		4.3	V	Surat	OLD
1871	01	31		21.20	72.90		5.0		Surat	USGS
1872	04	14		21.75	72.15		5.0	VI	Bhavnagar	CHAN
1882	06	10		23.20	71.38		3.5		Bhachau	MALIK
1882	06	28		23.35	70.58		5.0		Lakadia	MALIK
1882	06	29		23.35	70.58		5.0		Bhachau	MALIK
1883	10	20		21.70	71.97		4.4		Bhavnagar	USGS
1886	04	14		22.47	70.10		4.4		Jamnagar	USGS
1887	11	11		22.30	70.88		4.4		Rajkot	USGS
1888	08	20		23.83	70.00		3.5		Khavda	MALIK
1890	06	01		23.83	68.83		4.0		Lakhpat	MALIK
1891	07	27		21.33	71.37		4.4		Amreli	USGS
1892	01	11		23.83	70.00		3.5		Lakhpat	MALIK
1892	07	09		23.50	70.72		3.5		Rapar	MALIK
1893	11	04		23.83	68.83		3.5		Lakhpat	MALIK
1896	02	26		23.83	69.67		3.5		Lakhpat	MALIK
1897	10	00		23.00	72.70		3.7		Ahmedabad	USGS
1898	01	30		23.16	70.08		3.5		Anjar	MALIK
1898	04	01		23.25	69.67		4.0		Bhuj	MALIK
1898	09	13		23.30	69.75		4.0		Bhuj	MALIK
1898	10			23.05	72.67		4.3		Kheda	USGS
1898	10	15		23.33	69.67		4.0		Bhuj	MALIK
1900	12	21		23.50	70.67		3.5		Rapar	MALIK
1903	01	14		24.00	70.00		5.6		Kachchh	IMD

1904	04	09		23.33	68.67		4.0		Bhuj	IMD
1904	04	28		23.50	70.16		4.0		Anjar	MALIK
1904	07	30		23.83	70.33		3.5		Khadir	MALIK
1904	11	30		24.33	69.58		3.5		Lakhpat	MALIK
1905	07	10		23.33	69.67		3.5		Bhuj	MALIK
1906	01	11		23.83	70.33		3.5		Khadir	MALIK
1906	06	30		23.83	69.75		3.5		Khavda	MALIK
1906	08	15		24.40	72.70		4.3	V	Near Mount Abu	USGS
1907	03	12		23.83	69.75		3.5		Khavda	MALIK
1907	07	12		22.91	69.83		3.5		Mundra	MALIK
1907	10	09		23.83	69.75		3.5		Khavda	MALIK
1907	10	21		23.25	70.33		3.5		Bhachau	MALIK
1908	09	29		23.83	69.75		3.5		Khavda	MALIK
1908	10	21		23.83	69.75		3.5		Khavda	MALIK
1909	02	07		23.83	69.75		3.5		Khavda	MALIK
1909	04	09		23.25	70.33		3.5		Bhachau	MALIK
1910	03	24		23.25	69.75		3.5		Bhuj	MALIK
1910	08	01		23.83	69.67		3.5		Khavda	MALIK
1910	12	13		23.41	70.58		4.0		Lakadia	MALIK
1910	12	16		23.25	70.33		3.5		Bhachau	MALIK
1911	01	23		23.41	70.58		3.5		Lakadia	MALIK
1911	10	11		24.33	69.50		3.5		Lakhpat	MALIK
1912	10	01		23.83	69.75		3.5		Khavda	MALIK
1912	11	07		23.83	70.33		3.5		Khadir	MALIK
1913	06	26		23.75	69.75		3.5		Khavda	MALIK
1918	06	10		23.50	70.41		3.5		Bhachau	MALIK
1919	04	21		21.70	72.25		5.7	VII	Ghogha (Bhavnagar)	CHAN
1920	10	18		23.50	70.75		3.5		Rapar	MALIK
1920	11	13		23.33	69.58		3.5		Bhuj	MALIK
1921	02	11		25.00	70.70		4.2		Thar, Pakistan	ISC
1921	10	26		25.00	68.00		5.5		Indus-Kachchh	IMD
1921	10	27		23.83	69.67		4.0		Narayan Sarovar	MALIK
1922	02	09		23.41	70.67		3.5		Chitrod	MALIK
1922	03	13		23.41	69.37		3.5		Mandvi	MALIK
1922	03	13		22.00	71.00		4.3	V	Jhalavad	CHAN
1923	08	07		22.91	69.45		4.0		Bhuj	MALIK
1924	03	05		23.91	69.83		3.5		Khavda	MALIK
1924	10	25		23.67	68.91		3.5		Khavda	MALIK
1925	10	01		23.83	69.67		3.5		Khavda	MALIK
1925	10	13		23.33	70.28		3.5		Shikra	MALIK
1926	12	26		23.91	69.70		3.5		Khavda	MALIK
1927	11	18		23.45	69.67		3.5		Bhuj	MALIK
1930				22.40	71.80		4.3	V	Paliyad	CHAN
1930	12	30		23.91	69.45		3.5		Khavda	MALIK
1932	03	06		23.83	70.33		3.5		Khadir	MALIK
1935	01	25		23.75	70.67		3.5		Rapar	MALIK
1935	07	20		21.00	72.40		5.7		Surat	IMD
1935	07	23		23.25	69.50		3.5		Bhuj	MALIK
1938	06			22.30	71.60		5.0		Botad	TAN
1938	07	19		22.40	71.80		5.0		Paliyad	CHAN
1938	07	23		22.40	71.80		5.7	VII	Paliyad	CHAN
1940	10	31	10 03 50.00	22.50	70.40		5.0	VI	Jamuanathali,Jamnagar	CHAN
1940	11	13		23.57	70.33		4.0		Anjar	MALIK

1941	01	30		23.83	70.25		3.0		Khadir	MALIK
1950	06	14	04 24 16.00	24.00	71.20		5.3		Kachchh	CHAN
1956	07	21	15 32 26.00	23.30	70.00	35.00	M_w 6.0	VIII	Kachchh	IMD
1956	07	22		23.16	70.00		3.0		Anjar	MALIK
1962	03	12		24.10	70.90		3.0		Kachchh	MALIK
1962	09	01	22 01 30.00	24.00	73.00		4.6		Palanpur	IMD
1963	07	13	19 08 40.00	24.90	70.30	35.00	5.3		Thar, Pakistan	IMD
1965	03	26	10 04 15.00	24.40	70.00	33.00	5.1		Kachchh	IMD
1966	05	27	22 14 14.40	24.46	68.69	5.00	5.0		Thar, Pakistan	ISC
1966	11	12	12 16 47.20	25.12	68.04	33.00	4.8		Kachchh	ISC
1967	01	06	11 41 34.00	21.97	74.27		4.5		Tankhala	IMD
1968				21.60	71.25		4.3	V	Amreli	GSI
1968				21.73	70.45		4.3	V	Dhoraji	GSI
1969	03	23	04 21 34.00	24.54	68.79	19.00	4.4		Kachchh	ISC
1969	10	24	11 45 55.50	24.76	72.54	31.00	5.5		Mount Abu	IMD
1970	02	13	15 05 51.40	24.60	68.61	33.00	5.2		Kachchh	USGS
1970	03	23	01 53 01.00	21.60	72.96	8.00	5.4		Bharuch	USGS
1970	08	09		21.70	73.00		3.5		Bharuch	USGS
1970	08	30		21.70	73.00		4.1		Bharuch	USGS
1970	09	10		21.60	72.70		3.4		Bharuch	USGS
1971	05	14	17 14 40.90	25.12	68.11	57.00	4.5		Thar, Pakistan	USGS
1971	06	18		21.70	73.00		3.4		Bharuch	IMD
1973	06	05	01 19 30.30	25.09	68.07	33.00	4.8		Thar, Pakistan	USGS
1974	10	20		21.70	74.20		4.6		Narmada	USGS
1975				22.10	71.20		4.3	V	Jasdan	GSI
1975	09	19	16 49 52.20	24.69	71.03	33.00	3.7		Kachchh	USGS
1975	09	25		20.80	74.20		4.2		Gujarat	USGS
1976	06	04	00 43 41.44	24.51	68.45	18.00	5.1		Allah Band, Pakistan	ISC
1977	09	26	19 48 48.30	25.38	68.24	33.00	4.5		Kachchh	ISC
1978	04	10	09 10 03.00	21.84	72.90		3.0		Amod	IMD
1978	11	25	10 09 40.00	21.97	72.91		2.8		Amod	IMD
1979	02	22	22 11 00.00	21.33	72.15		3.3		Bhavnagar	GERI
1979	06	09	22 43 19.00	21.83	73.85		2.6		Rajpipla	GERI
1979	08	24	01 13 54.00	22.11	72.43		3.1		Khambhat	GERI
1979	09	05	10 08 00.00	21.33	72.12		3.6		Bhavnagar	GERI
1979	09	22	22 48 53.00	21.75	72.15		3.3		Bhavnagar	GERI
1979	12	10	22 19 35.00	21.90	72.90		3.2		Amod	GERI
1980	01	06	00 42 37.00	22.23	71.78		3.2		Botad	GERI
1980	03	18	18 22 08.00	21.81	73.03		2.9		Nabipur	GERI
1980	06	04	11 16 00.00	21.68	73.21		2.6		Nartrang	GERI
1980	06	04	11 17 00.00	21.68	73.21		3.1		Nartrang	GERI
1980	07	21	04 08 00.00	22.87	72.14		3.1		Nartrang	GERI
1980	08	27	06 20 00.00	22.82	72.82		2.7		Chandraga	GERI
1980	10	20	11 40 00.00	21.96	72.95		2.6		Kevadia	GERI
1981	04	26	18 12 20.61	24.12	69.51	33.00	4.3		Bhuj	ISC
1982	01	31	16 48 25.31	24.21	69.84	33.00	4.8		Kachchh	ISC
1982	03	10	03 45 00.00	21.38	73.00		3.1		Bharuch	GERI
1982	04	09	09 00 00.00	22.07	72.19		2.9		Khadi	GERI
1982	05	10	01 00 00.00	21.90	72.27		3.2		Bhavnagar	GERI
1982	06	24	01 27 00.00	22.00	72.88		3.6		Amod	GERI
1982	06	26	18 48 00.00	22.25	71.82		3.1		Dhandhuka	GERI
1982	07	02	16 30 00.00	21.86	72.04		3.5		Bhavnagar	GERI
1982	07	18	15 46 17.65	23.40	70.66	33.00	4.8		Bhuj	ISC

1984	09	13	04 48 50.24	24.95	70.46	33.00	4.2		Allah Band, Pakistan	ISC
1985	04	07	21 10 11.12	24.36	69.74	33.00	5.0		Kachchh	ISC
1985	04	27	04 59 50.50	20.66	73.21		4.6		Dharampur	GERI
1985	09	03		21.03	70.88		4.3		Visavadar,Junagadh	GERI
1986	02	26	12 47 55.46	20.48	73.72	33.00	4.3		Gujarat	USGS
1986	09	16		20.60	71.40		3.8		Rajula	GERI
1986	11	15	00 25 07.69	24.45	73.57	22.10	4.1		Near Mount Abu	ISC
1987	02	10	22 02 57.86	24.10	70.39	10.00	3.9		Kachchh	ISC
1987	04	10		24.55	70.12	10.00	2.0		Kachchh	IMD
1987	12	31		21.71	74.38		3.5		Narmada	GERI
1988	07	17		25.16	70.00	33.00	2.0		Kachchh	IMD
1989	03	21	00 57 05.80	24.27	68.96	33.00	4.0		Bhuj	ISC
1989	06	21	15 35 38.50	20.09	72.91	33.00	4.1		Valsad	ISC
1989	12	10	11 58 13.14	24.81	70.88	33.00	4.7		Kachchh	ISC
1991	01	20		23.13	69.83	35.00	2.0		Kachchh	IMD
1991	01	20	19 44 58.89	23.40	69.71	33.00	4.9		Bhuj	USGS
1991	01	30	10 44 30.50	20.55	73.15		4.6		Anklach	GERI
1991	09	10	06 54 4.68	24.16	68.68	35.50	4.7		Kachchh	ISC
1991	09	10	07 20 05.06	24.28	68.80	25.70	4.7		Kachchh	ISC
1992	05	04	11 20 41.32	24.52	70.13	33.00	3.4		Allah Band, Pakistan	ISC
1993	02	09	20 51 47.11	24.62	68.93	36.30	4.3		Allah Band, Pakistan	ISC
1993	08	09		20.60	71.40		3.1		Rajula	GERI
1993	08	24	23 18 90.00	20.60	71.40	29.00	5.0		Rajula	IMD
1993	12	31	13 32 04.31	21.12	72.72	35.20	4.1		Rajula	ISC
1996	02	17		23.33	69.67	33.00	4.5		Bhuj	IMD
1996	08	05	22 15 35.90	22.83	68.43	22.90	3.8		Bhuj	ISC
1996	11	17	18 12 26.97	21.40	73.06	10.00	4.0		Gujarat	ISC
1998	07	19		22.42	70.86		4.4		Rajkot	IMD
1998	09	21	06 23 48.3	21.81	71.93		3.0		Bhavnagar	GERI
1998	10	08	15 01 15.84	24.45	69.80	33.00	3.7		Bhuj	ISC
1998	11	28	16 59 44.70	21.94	71.06		3.2		Gondal	GERI
1999	09	21	11 00 00.00	21.70	72.10		2.5		Bhavnagar	GERI
2000	08	10	13 30 14.70	21.78	72.31		3.6		Bhavnagar	GERI
2000	08	13	13 28 21.26	21.02	70.99	7.00	4.6		Tulsi Shyam,Junagadh	ISC
2000	09	12	00 53 25.07	21.72	72.16	10.00	4.2		Bhavnagar	IMD
2000	12	24	11 22 02.23	24.01	70.09	43.40	4.7		Bhuj	ISC
2001	01	26	03 16 40.26	23.44	70.31	16.00	M_w 7.7	X	Kachchh	ISC
2001				21.02	70.88		2.5		Tulsi Shyam, Junagadh	GERI
2003	01	13		22.30	70.93		2.0		Rajkot	GERI
2003	01	29		21.46	70.51		3.1		Haripur, Junagadh	IMD
2003	08			22.20	69.92		2.5		LalpurTq, Jamnagar	GERI
2004				21.00	70.50		3.0		Talala Tq, Junagadh	GERI
2006	02	03	00 54 23.46	23.92	70.44	28.7	M_w 5.0 (m_b 4.5 USGS)		Gedi, Rapar	NGRI
2006	03	07	18 20 46.28	23.79	70.73	3.0	M_w5.7(M_w 5.5 USGS)		Gedi, Rapar	NGRI
2006	04	06	12 02 55.25	23.78	70.74	3.1	M_w4.8 (m_b 4.9 USGS)		Gedi, Rapar	NGRI
2006	04	06	17 59 16.46	23.34	70.39	29.3	M_w5.6 (m_b 5.5 USGS)		Lakadia	NGRI
2006	04	10	22 05 46.00	23.51	70.06	4.9	M_w4.9 (m_b 4.9 USGS)		Kachchh	NGRI
2006	09	30	00 16 00.80	22.31	70.21	10.10	M_w 4.0	V	Khankotda, Jamnagar	ISR
2007	07	16	21 21 22.0	22.49	71.29	17.80	M_w 3.9		Paliyad	ISR
2007	09	02	16 38 47.80	22.33	70.22	10.10	M_w 3.2		Khankotda, Jamnagar	ISR
2007	10	09	03 49 31.0	21.08	70.73	10.80	M_w 3.1		Ankolwadi, Junagadh	ISR

2007	11	06	00 27 28.8	21.12	70.51	8.50	M_w 4.8 (m_b 4.9 USGS)		Hirenvel, Junagadh	ISR
2007	11	06	09 38 04.45	21.16	70.54	4.50	M_w 5.0 (m_b 5.0 USGS)		Haripur, Junagadh	ISR
2007	11	11	13 03 04.00	21.93	69.82	10.00	M_w 2.9		Verad, Bhanwad	ISR
2008	01	25	23 36 55.06	21.79	71.76	35.1	M_w 2.8		Bhavnagar	ISR
2008	03	09	11 03 44.7	23.39	70.33	29.90	M_w 4.9 (m_b 4.5 USGS)		Chobari, Kachchh	ISR
2008	05	20	08 57 27.3	21.16	73.05	7.40	M_w 3.2		Surat	ISR
2009	03	25	13 16 13.8	22.474	71.465	9.1	Mw2.7		Surendarnagar	ISR
2009	03	28	12 27 5.7	22.17	70.75	6.2	Mw 3.0		Rajkot	ISR
2009	08	31	02 49 56	22.44	70.15	6.1	Mw 2.8		Jamnagar	ISR

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USGS- United States Geological Survey (USGS), National Earthquake Information Center

ISC- International Seismological Center, U.K.

GERI- Gujarat Engineering Research Institute, Gujarat, India

NGRI- National Geophysical Research Institute, Hyderabad, India

ISR- Institute of Seismological Research (ISR), Gandhinagar, Gujarat

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