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Seismic hazard assessment in the Alpide belt from Iran to Burma

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Abstract
The paper deals with the present status of knowledge necessary for mitigating earthquake hazard in Iran, Afghanistan, Pakistan, India, Nepal, Bangladesh and Burma. An effort is made to give relevant information about the existing earthquake catalogues, seismotectonics, strong motion data and seismic zoning maps prepared for these regions. It is noted that loss of human lives and property is much larger in these countries compared to other developed countries in the world, basically because of poor quality of construction of buildings and high density of human population.

1. Introduction

The portion of the Alpide belt from Iran in the west to Burma in the east is, seismically, one of the most active intracontinental regions in the world. The loss of human lives and damage to structures in this region is very high due to age old traditions of construction still being followed and high density of human population. For example, the 20th October, 1991 Uttarkashi earthquake in the western part of Indian Himalaya, although of only mb 6.6, claimed an estimated 2000 human lives and caused widespread damage (GSI, 1991; Episodes, 1992). As a matter of fact, this earthquake is found to be the most significant earthquake that occurred in 1991 (Episodes, 1992). In the present article, an effort is made to examine the region from Iran in the west to Burma in the east with respect to earthquake data base, seismotectonics, seismic hazard maps, building codes and strong motion data. This article should be considered as an input to the Global Seismic Hazard Assessment Programme (GSHAP) providing some important conclusions and references, particularly to the available earthquake catalogues. Considering the very large area being addressed an often scientific papers being published in local journals, no completeness of data presented can be claimed. Here we are broadly presenting the available information for Iran, Afghanistan, Pakistan, India, Nepal, Bangladesh and Burma. These are broad political divisions and there are several overlapping seismotectonic provinces. No effort is being made to constrain the seismotectonic provinces to political boundaries.

In an interesting study Tsapones and Burton (1991) have evaluated seismic hazard for the 50 seismically most active countries of the world using Gumbel's Third asymptotic distribution of extreme values. They have used a catalogue of 970 earthquakes of M $\geq$ 5.5 during the period 1898 to 1985. Figure 1 taken from this paper shows contour map of the seismic hazard based on the probable maximum magnitude of earthquakes for a period of 85 years for the region addressed in this paper.

2. Iran

In the recent years, a number of very interesting and informative papers on earthquake catalogues, seismotectonics and earthquake

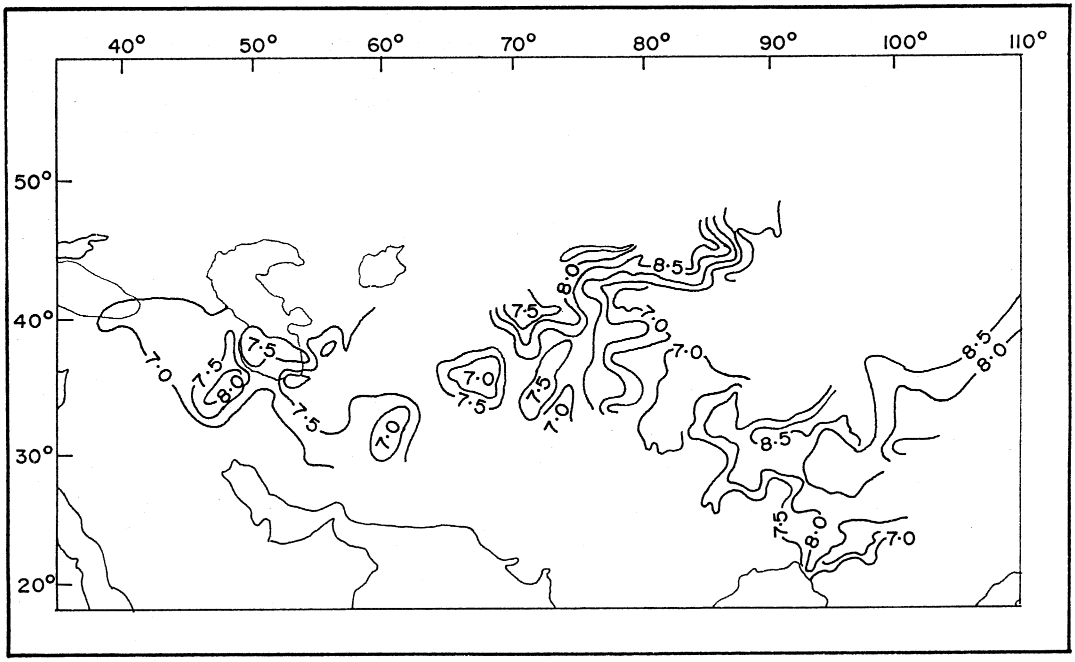

Fig. 1. Contour map of seismic hazard based on the probable maximum magnitude of earthquakes for a period of 85 years (after Tsapones and Burton, 1991).

risk for the Iranian region have appeared (for example, Berberian, (1981), Bozorgnia and Mohajer-Ashjai (1982), Nowroozi and Ahmadi (1986), Ni and Barazangi (1986) and others). The Iranian plateau is found to have a very high density of active and recent faults and reverse faulting dominates the tectonics of the region. Berberian (1981) has given a very good description of tectonics of Iran, has summarized the data of important active Iranian faults and major earthquakes associated with them, and has also presented a seismic risk map. He has compiled a map which shows faults observed on the surface and which are known to have been associated with earthquakes, as well as lineaments in seismicity that are not associated with surface features (fig. 2). Attention is drawn to several buried high angle reverse faults and the associated earthquakes. These deep seated faults play an important role in the present day tectonics of the region. One interesting part of the Berberian's work is that all the faults in fig. 2 have been provided with summary of major earthquakes associated with them.

In conclusion Berberian (1981) observes that the seismic activity in Iran, which is intimately connected with the reactivation of the existing faults, could broadly be classified into the following three categories:

a) in the active fold thrust belt of Zagros, the shortening along longitudinal high angle reverse basement fault is found to be absorbed by ductile layers of the deep sedimentary cover and therefore no earthquake rupture is usually observed on the surface;

b) the earthquakes in the Central Iran plateau are accompanied with surface fault along mountain bordering reverse faults;

c) Makran accretionary flysch wedge where the oceanic crust of the Gulf of Mann is subducted under Southeastern Central Iran.

It is observed that the seismic activity is not continuous and very often the time gaps could range from a few years to a few centuries. Berberian (1981) also presents a revised seismic risk map of Iran (fig. 3) where the region is divided broadly into three seismic zones. In this map, the earthquake intensities shown are not the maximum possible intensities but only probable intensities. The earlier efforts in this direction were made by Berberian and Mohajer Ashjai (1977).

In an interesting study Bozorgnia and Mohajer-Ashjai (1982) have estimated the level of seismic risk for major Iran cities in terms of peak horizontal ground accelerations versus annual risk and return period. A total of 324 seismic sources were modelled for Iran out of which 304 were fault segments and 20 were

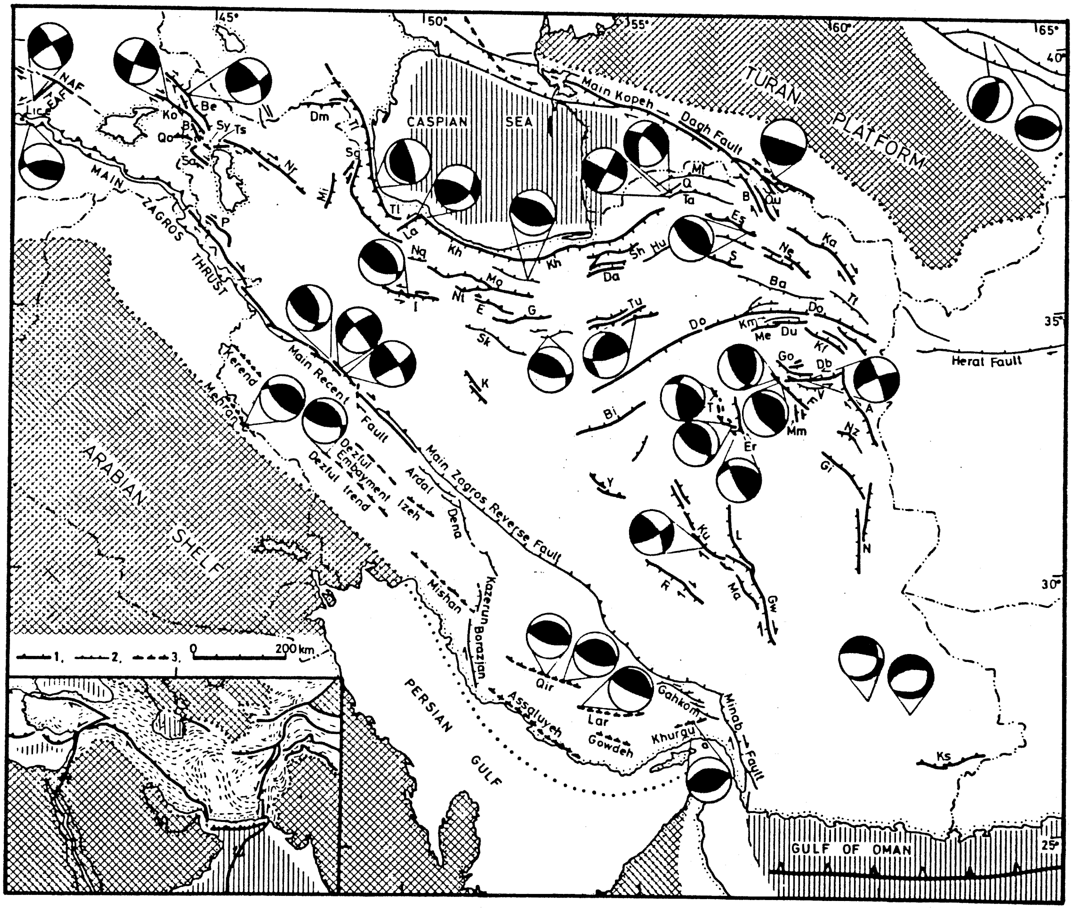

Fig. 2. A map of the documented seismically active faults of Iran (after Berberian, 1981). The map shows faults which are either observed on the surface and/or known to have associated with the earthquakes as well as those which are lineaments of seismicity. The mechanism of large magnitude earthquakes and geometry on active faults clearly shows that the active tectonics of the region is dominated by frontal reverse faulting at the foot of the fault thrust mountain belts.

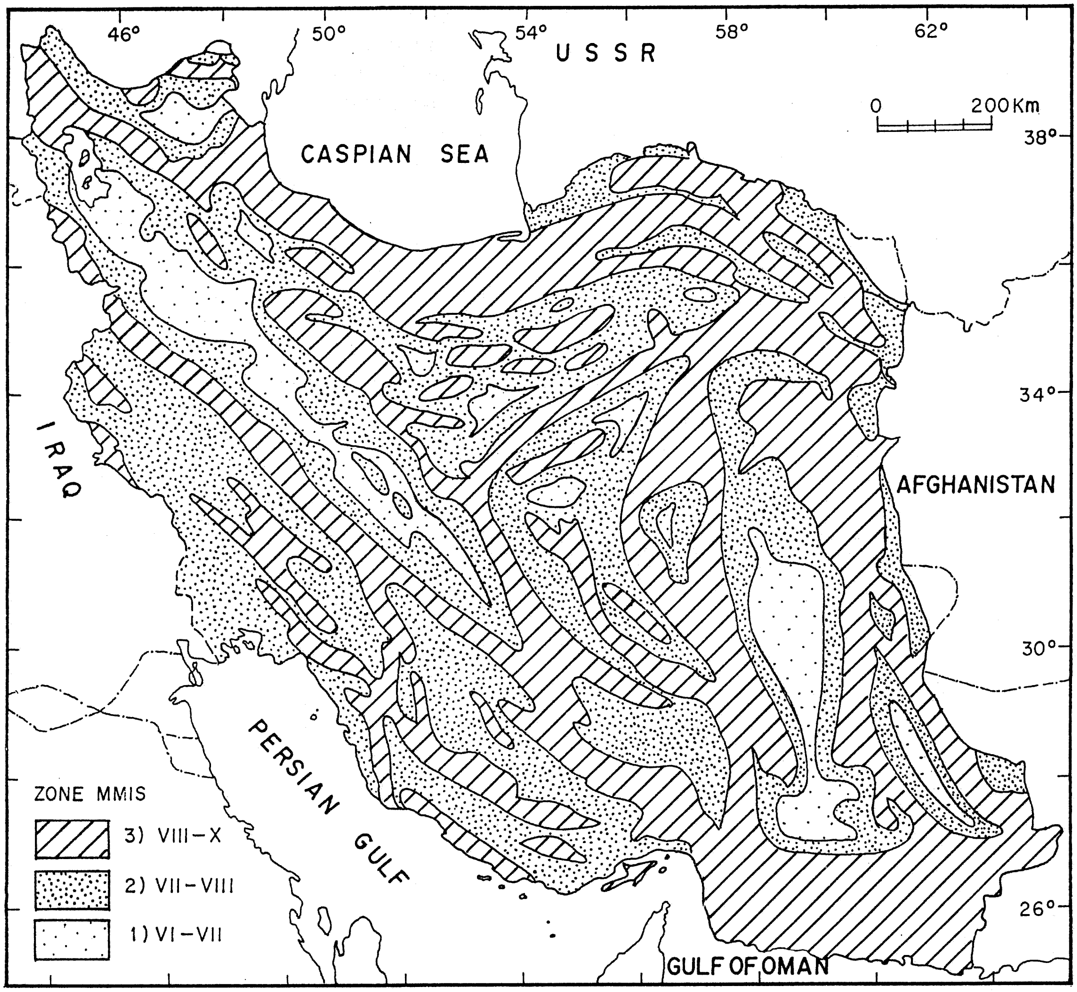

Fig. 3. A seismic map of Iran (after Berberian, 1981). The region is divided into three broad seismic zones. Zone 3 of maximum intensity covers the region of Quaternary faults and the area associated with past destructive earthquakes. The intensities shown are not the maximum possible intensities but the most probable intensities. This map is based on the first preliminary seismic risk map of Iran by Berberian and Mohajer-Ashjai, 1977.

area sources. They have estimated peak ground accelerations (g) for various annual risks for 26 Iranian cities (table I).

A seismotectonic province model has been used by Nowroozi and Ahmadi (1986) for the analysis of earthquake risk in Iran. For this purpose, the earthquake data for various seismotectonic provinces are compiled and analysed statistically. In this analysis, the coefficients of log-linear and log-quadratic earthquake magnitude frequency relationship are calculated and return periods for several earthquake magnitudes are estimated. From these coefficient, seismic risk, intensities and

Table I. Peak ground acceleration (g) for various annual risks (Bozorgnia and Mohajer-Ashjai, 1982).

Site	Annual risk							
	.05	.02	.01	.0067	.005	.002	.001	.0001
Abadan	.11	.13	.15	.16	.17	.20	.23	.23
Ahwaz	.23	.28	.32	.34	.36	.43	.49	.75
Bandar-Abbas	.29	.35	.41	.44	.47	.57	.65	-
Bushehr	.26	.31	.36	.38	.40	.48	.54	-
Gorgan	.18	.25	.31	.35	.38	.48	.58	-
Hamadan	.11	.14	.16	.17	.18	.22	.26	.41
Isfahan	.09	.10	.12	.13	.14	.16	.18	.28
Kerman	.18	.22	.26	.28	.30	.36	.42	.67
Kermanshah	.29	.35	.39	.42	.45	.53	.59	-
Khoram-Abad	.29	.34	.39	.42	.44	.52	.59	-
Mashad	.13	.17	.20	.22	.24	.30	.35	.58
Nain	.16	.20	.23	.25	.26	.32	.36	.57
Orumieh	.10	.13	.15	.17	.18	.23	.27	.44
Qazvin	.12	.16	.19	.21	.23	.29	.33	.54
Rasht	.12	.17	.22	.25	.27	.35	.43	.73
Sanandaj	.18	.22	.25	.27	.29	.35	.40	.61
Sari	.17	.23	.28	.32	.35	.45	.54	-
Shahre-Kurd	.16	.19	.22	.23	.25	.29	.33	.48
Shiraz	.27	.32	.36	.39	.41	.49	.55	-
Tabas	.28	.35	.41	.45	.49	.60	.71	-
Tabriz	.19	.26	.33	.38	.42	.55	.67	-
Tehran 1*	.18	.24	.31	.35	.39	.51	.61	-
Tehran 2**	.16	.21	.25	.28	.31	.39	.47	.79
Yazd	.24	.28	.32	.35	.37	.44	.50	.74
Zahedan	.12	.15	.19	.21	.23	.30	.36	.63
Zanjan	.16	.20	.24	.27	.29	.36	.43	.71

* Tehran 1 = 51.42E, 35.82N; ** Tehran 2 = 51.43E, 35.61N.

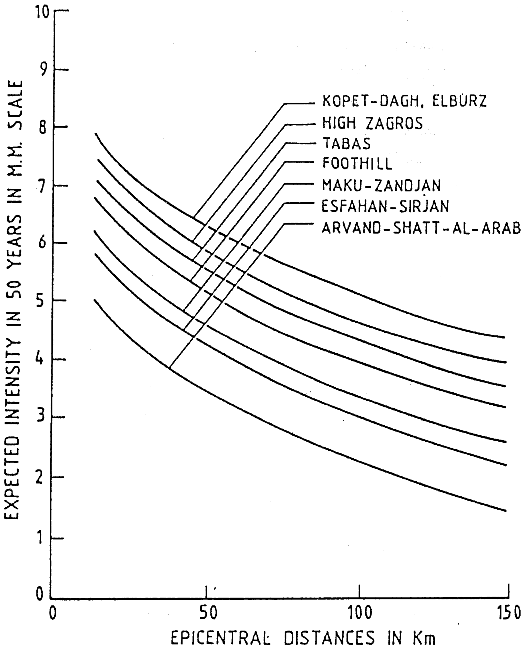

Fig. 4. Expected maximum intensity for range of epicentral distances in various provinces of Iran (after Nowroozi and Ahmadi, 1986).

ground accelerations for a set of return periods and epicentral distances are estimated for several provinces. Figure 4 shows the expected maximum intensity for a range of epicentral distances in various provinces, while fig. 5 and 6 show the expected maximum acceleration and probability of earthquake occurrence with a range of ground acceleration in these provinces for a 30 year period. Nowroozi and Ahmadi (1986) concluded that the provinces which are located southwest of Zagros thrust and northeast of Arabian landmass are most active in producing earthquakes with a magnitude of 6 once every 10 years, while the northern and northeastern provinces are capable of producing a 7.5 magnitude earthquake once every 100 years. The seismic risk is found to be the lowest for Esfahan-Sirgan, Arabian platform, Persian Gulf, Kavir in Central Iran, and Arvand-Shatt-al-Arab provinces; while the seismic risk is the highest for El-

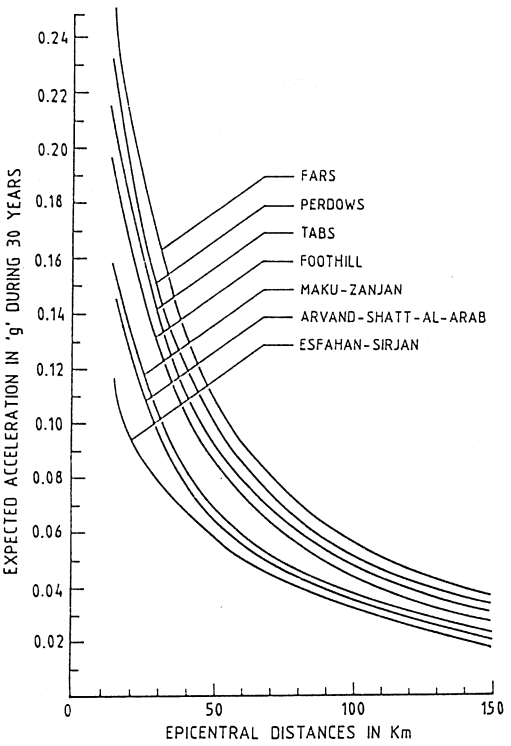

Fig. 5. Expected maximum acceleration for various provinces in Iran (after Nowroozi and Ahmadi, 1986).

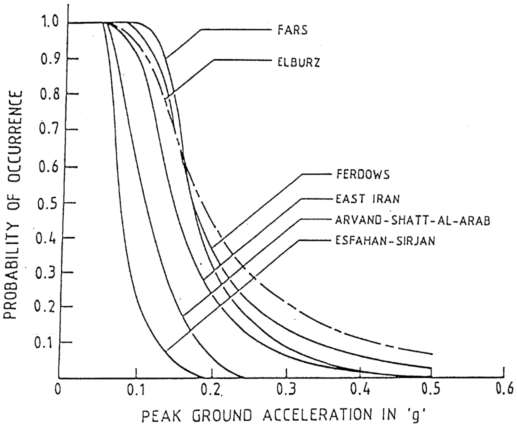

Fig. 6. Expected maximum probability of earthquake occurrence and peak accelerations for various provinces in Iran for a period of 30 years (after Nowroozi and Ahmadi, 1986).

burz, Kopet-Dagh, Ferdows and Fars provinces.

Ni and Barazangi (1986) have investigated the seismotectonics of the Zagros continent collision zone and compared it with Himalaya. They found that in the Zagros region, 16 medium to large earthquakes that they investigated had shallow depth of 6-12 km and had no tendency to deepen towards the Main Zagros Thrust, these earthquakes occurred in the uppermost Precambrian basement. In contrast to the Zagros Thrust, the Himalayan earthquakes of medium to large sizes define a shallow north dipping detachment that separates the under thrusting Indian plate from the Lesser Himalayan crustal block.

From the above it may be noted that for the Iranian region detailed earthquake catalogues have been prepared. Association of earthquakes with known surface faults as well as inferred hidden faults has been investigated. Seismic risk maps for cities as well as provinces have been prepared using standard statistical techniques.

3. Afghanistan and Pakistan

Unlike Iran for which several studies have been reported in the literature, not much work has been reported on seismotectonics of Afghanistan. There is one much cited paper by Abdullah (1981) were he has presented a map showing major faults in Afghanistan (fig. 7) and has also presented a seismic zoning map (fig. 8). Abdullah reports that epicentres are

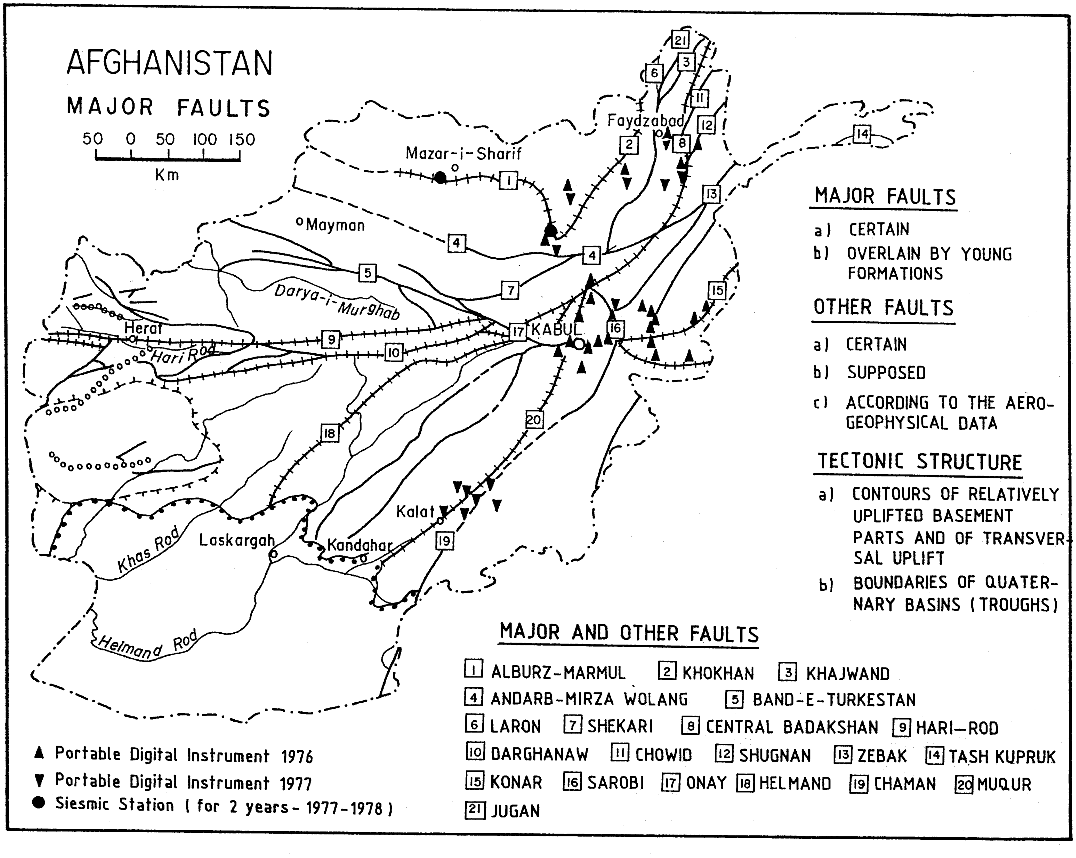

Fig. 7. Tectonic map of Afghanistan (after Abdullah, 1981).

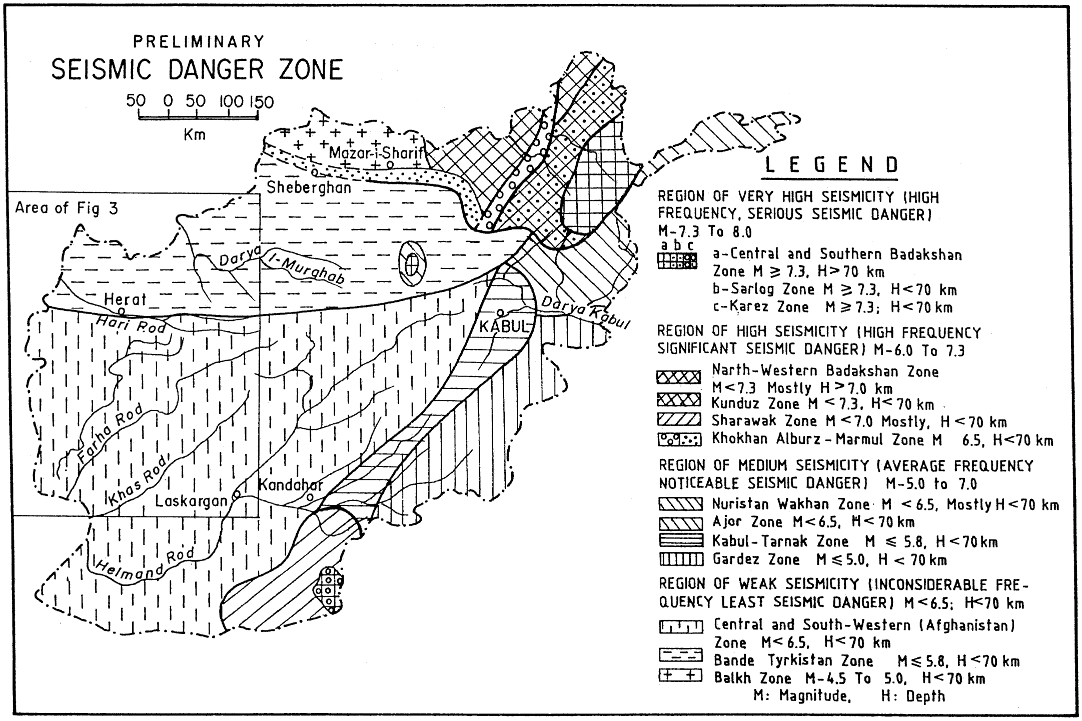

Fig. 8. Seismic zoning map of Afghanistan (after Abdullah, 1981).

widespread in the country with a variation in frequency, magnitude and focal depth. He reports that the depth of earthquake foci and magnitude increases from west to east and from southwest to northeast (Slavin *et al.*, 1970; Heuckroth *et al.*, 1970). In the northeastern part of the country which is a zone of high seismicity, Abdullah reports that during the period from 1930 to 1967, 160 earthquakes were registered. On the basis of the seismic data and tectonics of the region, the Afghanistan region has been divided into zones of high, medium and weak seismicity (fig. 8).

In a very comprehensive and interesting paper Quittmeyer and Jacob (1979) have examined the historical and modern seismicity of Afghanistan, Pakistan, Northwest India and Southeast Iran. First of all they have catalogued earthquakes in these regions and the earliest entry goes back to 25 A.D. Basically they have catalogued earthquakes under categories of intensity > 8 MM, historical noninstrumental seismicity and instrumental seismicity. Figure 9 taken from Quittmeyer *et al.*, 1979 depicts the maximum documented intensities at any given location for the period from 25 A.D. to 1972. Based on geological information, tectonics and earthquake data, the entire region of Pakistan has been divided into 14 seismotectonic provinces (Quittmeyer *et al.*, 1979). These provinces are depicted in fig. 10. The important conclusion by Quittmeyer and Jacob (1979) is that Chaman fault of Pakistan and Afghanistan is currently characterized by a low to moderate level of seismic activity. However, both these segments have experienced large earthquakes in the past. It is also observed that other morphologically prominent strike-slip features such as Herat and Karakorum faults appear to be inactive in the modern times. They observe that the limitation of historical earthquake data with com-

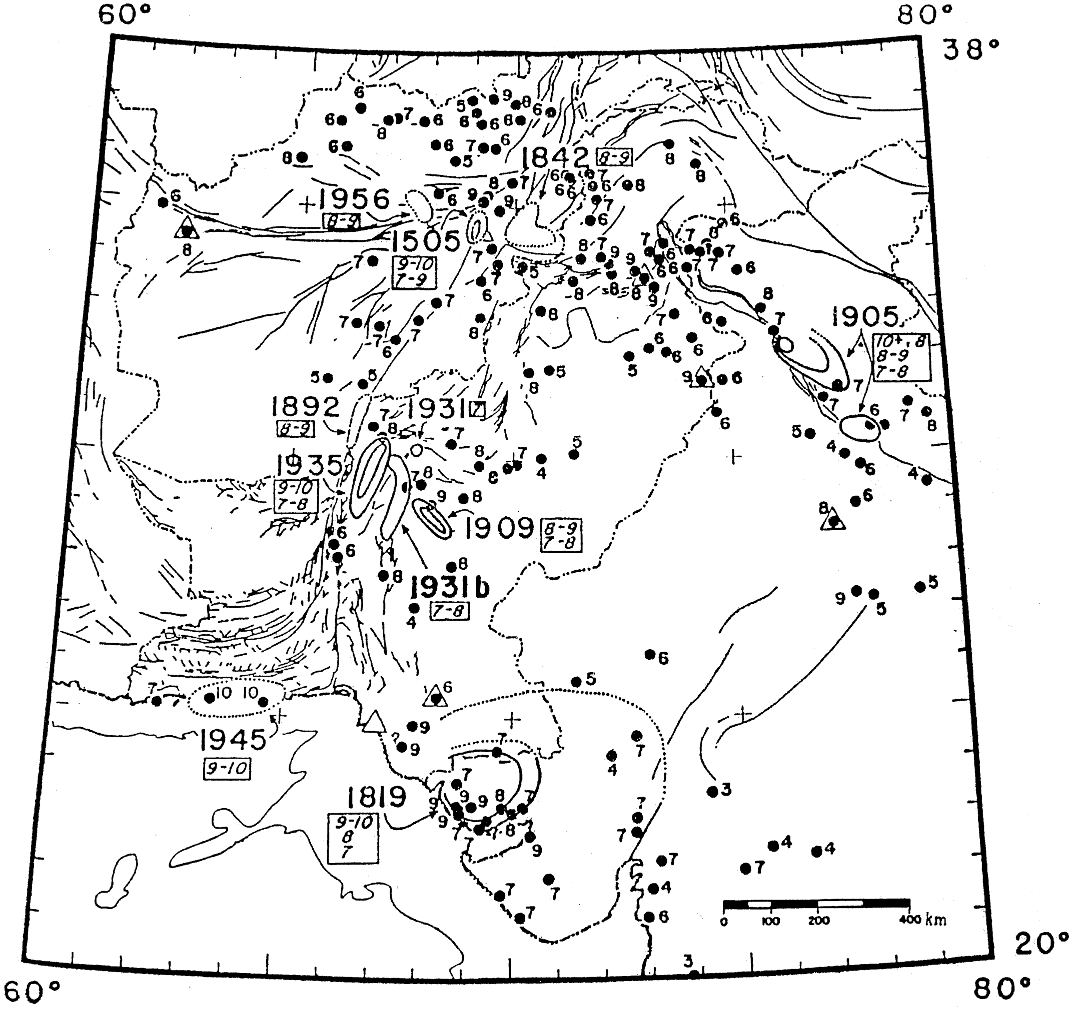

Fig. 9. Map of maximum documented intensity on MM scale at any given location (after Quittmeyer *et al.*, 1979). Isoseismals are plotted for some of the largest known earthquakes. The year of the occurrence of earthquake is indicated. The intensity value associated with the isoseismals is given in the small box below the year of earthquake. The authors point out that this figure must not be misinterpreted as representing maximum credible intensity at a given location. It is a record of the past earthquakes.

bination of long recurrence intervals for large earthquakes in this region makes it difficult to apply the concept of seismic gap hypothesis usefully in this region. Palaeoseismic investigations are necessary to have better control on recurrence intervals. They, however, observed that seismicity variations prior to the great earthquake in the Makran region along the south coast of Pakistan in 1945 was consistent with patterns identified before large earthquakes elsewhere in the word. They further observed that the present day seismicity pat-

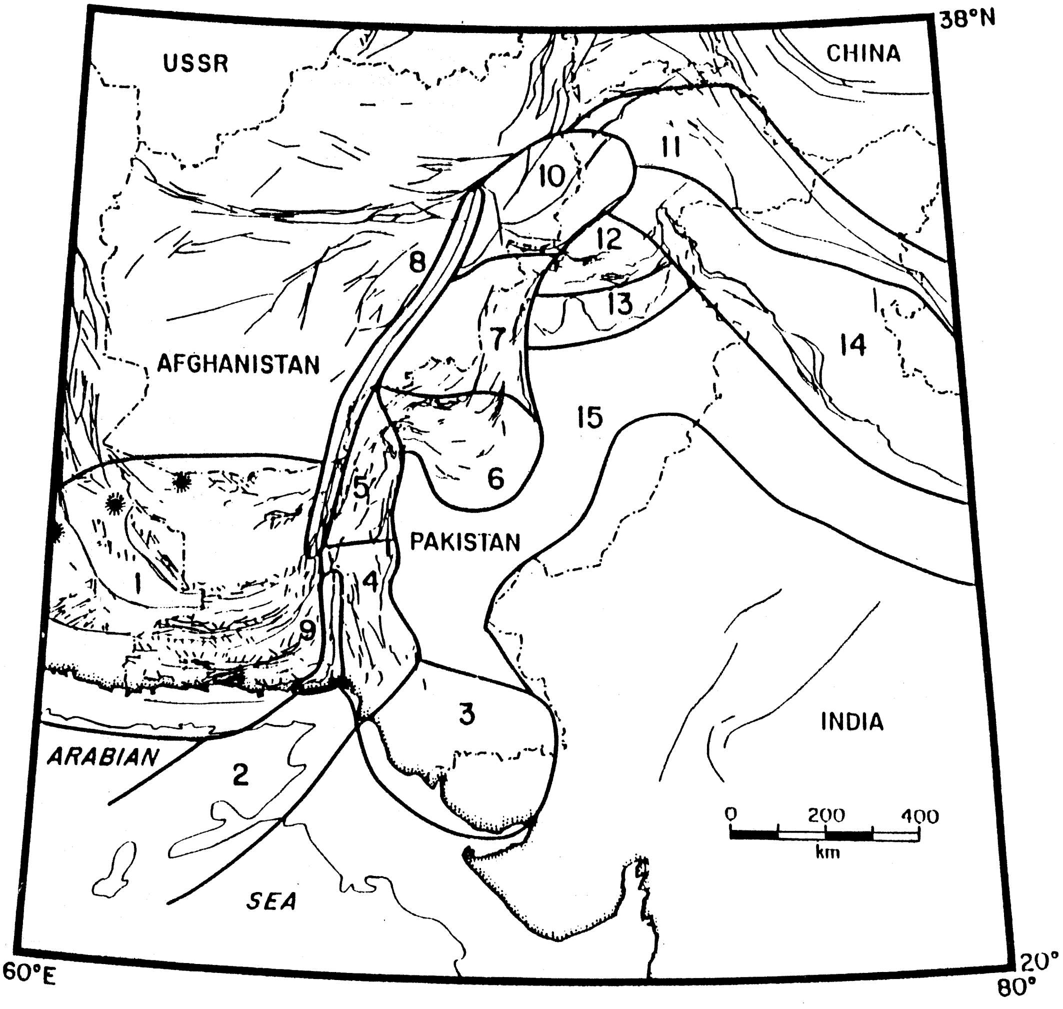

Fig. 10. Seismotectonic provinces of Pakistan (after Quittmeyer, 1979). The numerals correspond to the following seismotectonic provinces: 1) Makran Region; 2) Murray Ridge; 3) Coastal Region; 4) Southern Kirthar Ranges; 5) Northern Kirthar Ranges; 6) Quetta Transverse Zone; 7) Sulaiman Range; 8) Chaman Fault Zone; 9) Ornach-Nal Fault Zone; 10) Gardez, Kunar Fault Zones; 11) Pamir-Karakorum Region; 12) Hazara Region; 13) Salt Range; 14) Himalaya.

tern furthest west along the Makran coast appears to be indicative of occurrence of large earthquakes in the future.

Some very detailed seismicity studies have been carried out in the vicinity of the Tarbela dam site (Jacob *et al.*, 1979). On the basis of statistical analyses, interesting variance of the maximum probable earthquake in this fault zone at Tarbela site during the 50 year period has been estimated (table II).

In another interesting study on the seismicity of the Pakistan and its relation to surface faults, Quittmeyer *et al.*, (1979) have examined the earthquakes in Pakistan and its vicin-

Table II. Earthquake occurrence probability on the Indus fault zone in the vicinity of Tarbela site.

	Maximum probable earthquake on the Indus fault zone at the Tarbela site during a 50 year lifetime of the dam	Recurrence time of maximum credible earthquake (M=6.5) on the Indus fault zone at the Tarbela site	Probability of the maximum credible earthquake (M=6.5) occurring during a 50 year life-time	Factor by which the seismic activity in the Indus zone is higher than the average activity over the Hazara arc and surrounding region
Most favourable likely value (80%)	5.0	13 000 years	1/260	10
Most likely value	5.5	1 200 years	1/24	50
Least favourable likely value (80%)	6.2	116 years	1/2.4	300

ity in relation to the mapped surface faults. Earthquakes could be classified into three broad categories:

a) earthquakes with large source dimensions which are found to be associated with a fault on the basis of surface rupture, after shock areas, or focal mechanism that define a trend;
b) narrow and elongated zones of earthquakes that may be related to movement along a single continuous fault or a group of similarly oriented faults;
c) continuous seismic activity which is not related to any individual fault.

They also pointed out that the seismic activity defines portions of Indus basin as seismically active, although no surface fault is mapped in that region.

In the recent years a number of papers have been written dealing with tectonics of the region, hidden faults, nucleation and predictability of earthquakes and structural data (Pennock *et al.*, 1989; Yeats and Hussain, 1989; Brune *et al.*, 1990; Lillie *et al.*, 1987 and others).

4. India, Nepal and Bangladesh

The seismic activity associated with the Himalayan Frontal Arc which effects India, Nepal and Bangladesh is very intense. The approximately 2000 km long Himalayan Frontal Arc from the western syntaxis in Kashmir to the eastern syntaxis in Assam has been seismically very active. More than a dozen earthquakes of magnitude $\geq$ 7.5 have occurred in this region since 1897 (table III). The northward movement of the Indian plate caused continental collision with an estimated rate varying from 44 mm to 61 mm per year (for example Minister and Jordan, 1978; Armejo *et al.*, 1989 and others) and as a result of this collision the Himalayan mountain range got created. The seismic activity is the result of continued collision between the Indian and Eurasian plates. The seismotectonics of the region has been discussed in a number of papers (Wadia, 1931; Gansser, 1981; Crawford, 1974; Valdiya, 1981, 1992 and others).

The earliest catalogue of earthquakes for this region was prepared by Oldham (1883) more than 100 years ago in 1883 which is an excellent reference of historical earthquakes in the region. In the recent years, useful catalogues have been prepared by Bapat *et al.* (1983); Tandon and Srivastava (1974); Chandra (1978, 1992); Gupta *et al.* (1986) and others. It may be noted that reliable estimates of magnitude of earthquakes for the region are available only for the past 90 to 100 years. Figure 11 adapted from Chandra (1992) depicts

Table III. Earthquake of M ≥ 7 1/2 in the Himalayan region since 1897.

Date			Lat (° N)	Long (° E)	Location	Magnitude
June	12,	1897	25.9	91.8	Assam	8.7
April	4,	1905	33.0	76.0	Kangra Valley	8.6
Dec.	12,	1908	26.5	97.0	N. Burma	7.5
May	23,	1912	21.0	97.0	-	8.0
July	8,	1918	24.5	91.0	Assam	7.6
Jan.	27,	1931	25.6	96.0	-	7.6
Jan.	12,	1934	26.5	86.5	Bihar-Nepal	8.4
May	30,	1935	29.5	66.7	Quetta	7.6
Sept.	12,	1946	23.5	96.0	-	7.7
July	29,	1947	28.5	94.0	N.E. Assam	7.9
Aug.	15,	1950	28.5	96.7	Assam	8.7
Nov.	18,	1951	31.1	91.4	-	8.0
Aug.	17,	1952	30.5	91.5	-	7.5

all the known epicentres in the region for earthquakes of magnitude 7 or larger as well as earthquakes that have claimed human lives.

For a long time assessment of earthquake hazard in a given region it is necessary to develop suitable model and identify zones of possible future earthquakes. From among the models available for the Himalayan Frontal Arc, the one developed by Seeber and Ambruster (1981) is a preferred one. It is argued that the continental subduction along the Himalayan Frontal Arc is similar to oceanic lithosphere subduction along the arcs. Therefore, the concept of earthquake gaps should hold good for the Himalayan region as well. In both the cases detachment is ruptured by great earthquakes. The Himalayan Frontal Arc has had four great earthquakes exceeding magnitude 8 in a short span of 53 years. These include Shillong earthquake of 1897; Kangra earthquake of 1905; Bihar-Nepal earthquake of 1934 and Assam earthquake of 1950.

It is estimated that over a total lenght of about 2000 km of the Himalayan Frontal Arc, some 1400 km has been broken by these four great earthquakes and some 600 km is left to be broken in the future great earthquakes. Reliable data are not available for the period earlier than 1897. However, possibly there were three other great earthquakes that occurred in 1885 in Kashmir, in 1833 in Western Bihar and in 1803 in Uttar Pradesh. These ruptures are depicted in fig. 12. There is an opinion that considering the ruptures associated with the above mentioned past 7 great earthquakes, the known unruptured portions between the 1803 and 1933 earthquakes in Uttar Pradesh and between the 1885 and 1905 earthquakes in Kashmir could be the sites of future great earthquakes. Seeber and Ambruster (1981) have estimated that repeat time for a 8 magnitude earthquake could be 200 to 270 years. The period required for the entire Himalayan Frontal Arc detachment to be ruptured is estimated to be between 180 and 240 years. It may be mentioned that opinions differ. For example, Singh and Gupta (1980) estimated the rupture associated with the Bihar-Nepal earthquake of 1934 to be 130 km as against an estimate of 300 km by Seeber and Ambruster. However, this (Seeber and Ambruster, 1981) is a good model for future work.

In fig. 13 we reproduce probabilistic seismic hazard map of Himalaya and adjoining areas prepared by Khattri (1992) where contours of peak acceleration in % g with 10% probability of exceedence in exposure period from 1981 to 2031 are depicted.

A special reference may be made here of an interesting work carried out by Gupta and Singh (1986) in the Northeastern Indian region where they found that the Kachar earthquake of December 30, 1984 was preceded by a well defined precursory swarm and quiescence periods. Encouraged by these results, they carried out an in depth study of all earthquakes of magnitude 7.5 and larger since 1897 and several smaller magnitude earthquakes that occurred after 1962 for possible precursors. In their study they discovered that the main shock magnitude (Mm) has correspondence with the largest events (Mp) in the swarm and the time interval (Tp) between the onset of the swarm and the occurrence of main shock in days. They found the following relation between these three parameters:

$$Mm = 137\ Mp - 1.41 \text{ and}$$
$$Mm = 3 \log Tp - 3.27$$

Gupta and Singh (1986) observed that it is important to recognize swarm and quiescence before the occurrence of main shock. They discovered one such region in the vicinity of Indo-Burma border and concluded that:

1) moderate magnitude to great earthquakes in the Northeast India region are found to be preceded, generally, by well defined earthquake swarms and quiescence periods;

2) on the basis of an earthquake swarm and quiescence period, an area bound by 21° N and 25 1/2°N latitude and 93°E and 96°E longitude is identified to be the site of a possible future earthquake of M 8 ± 1/2 with a

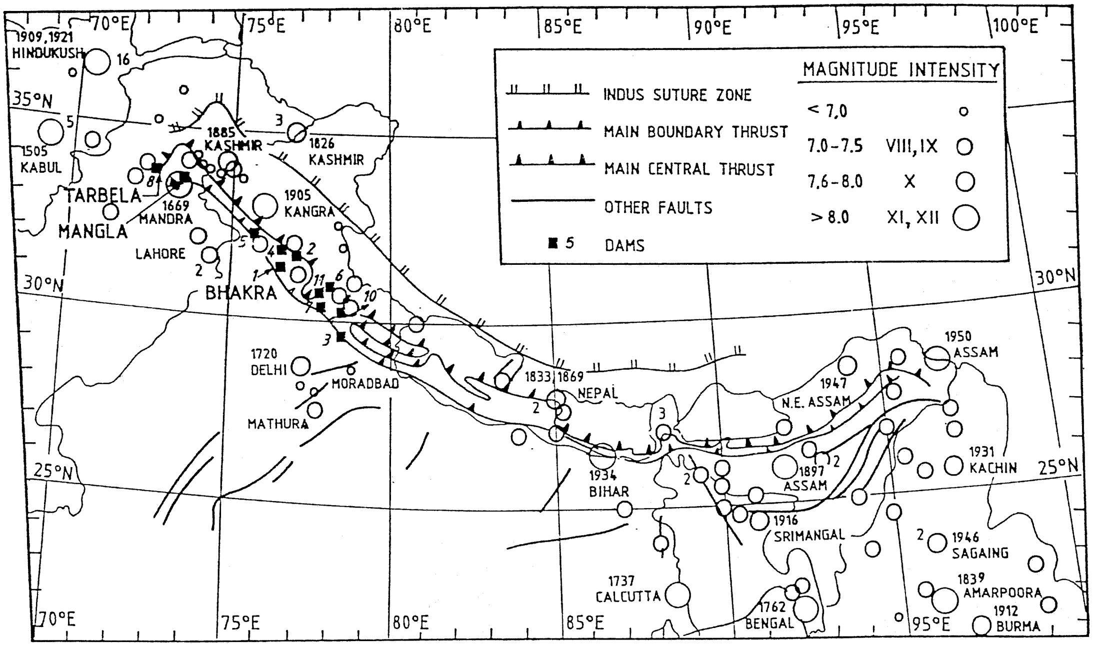

Fig. 11. Earthquakes of magnitude greater and equal to 7 as well as earthquakes that claimed human lives in the vicinity of the Himalayan Frontal Arc (updated from Chandra, 1992).

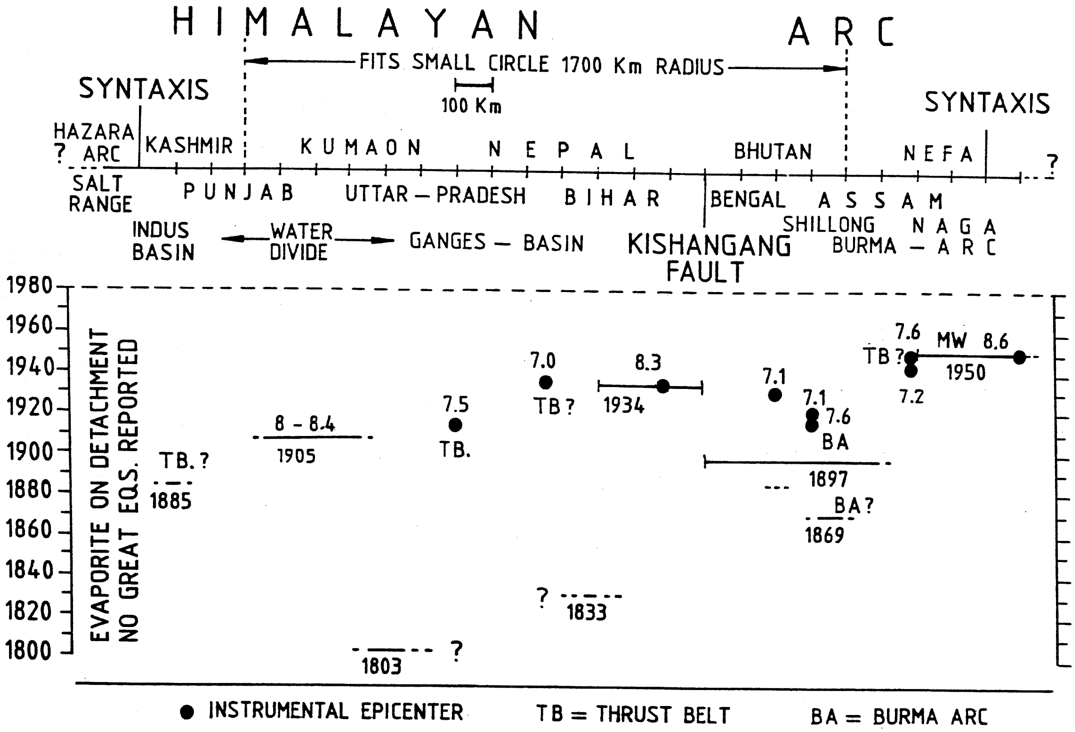

Fig. 12. A model with space time diagram of ruptures associated with major and great earthquakes in the Himalayan Frontal Arc since 1800 (adapted from Seeber and Ambruster, 1981). Please note that data are scanty and incomplete before 1897.

focal depth of 100 ± 40 km. This earthquake should occur any time from now onwards. Should it not occur till the end of 1990, this forecast could be considered as a false alarm.

The epochs of background/normal seismicity, swarm and quiescence for the above mentioned regions are included in fig. 14. It was pointed out by Gupta and Singh (1989) that the annual frequency during the swarm period is several fold higher than the background seismicity and quiescence epochs. The occurrence of August 6, 1988 earthquake with focal parameters mentioned in table IV show that this medium term forecast of Gupta and Singh (1986) has come true. This success encourages one to make similar investigations elsewhere in the Himalayan Frontal Arc for concentrating earthquake hazard related investigations in a few critical areas (Gupta, 1988).

The population density has increased considerably in the foothills of Himalaya during the last few decades. Therefore, the number of people likely to be affected by great earthquakes has increased considerably as the construction of houses continues to be of poor quality. Arya (1992), in an interesting study, has made an estimate of the damage scenario if the great Kangra earthquake of 1905, which had claimed an estimated 19 000 lives, was to repeat today. Arya hypothesizes that the distribution of earthquake intensity will be similar to the 1905 earthquake and areas of 500 km^2, 2000 km^2, 5000 km^2, 26 000 km^2 will come

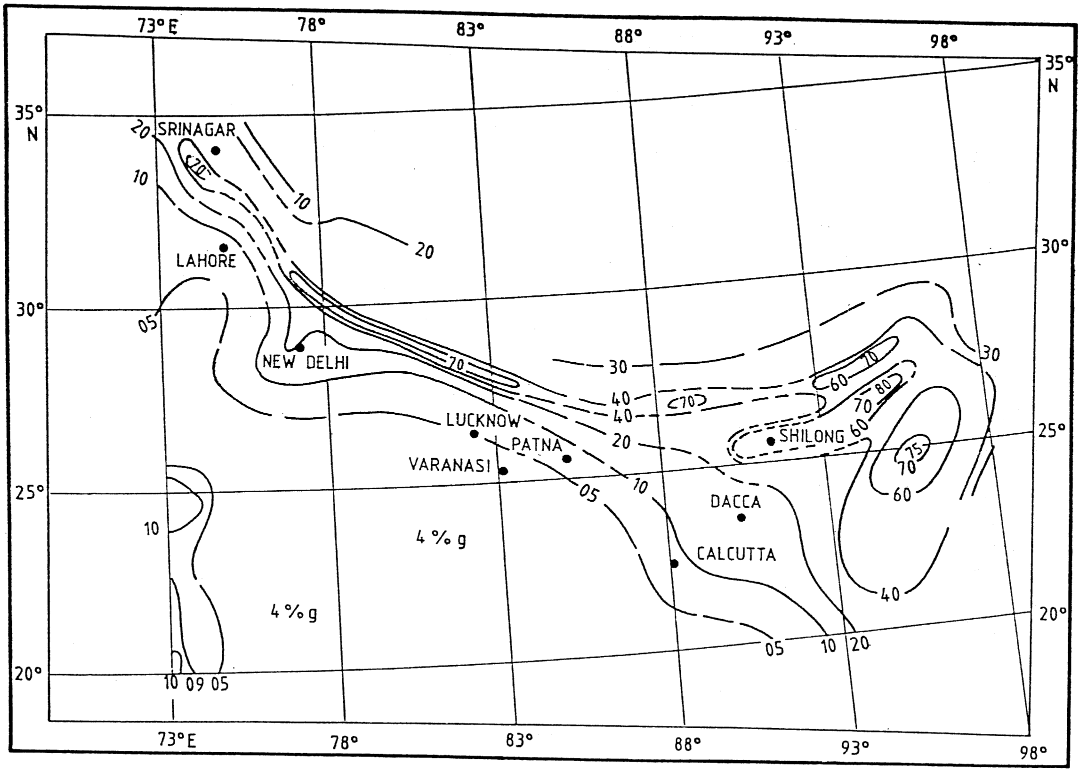

Fig. 13. Probabilistic seismic hazard map of Himalaya and adjoining areas for an exposure period from 1981 to 2031 after Khattri (1992). The diagram depicts the contours of peak acceleration in % g with 10% probability of exceedence in exposure period.

Table IV. Forecast of August 6, 1988 earthquake.

Earthquake Parameters	Forecast (Gupta and Singh, 1986)	Occurrence NEIS (preliminary determination)
Location	21°N to 25 1/2°N 93°E to 96°E	25.149°N 95.127°E
Magnitude	8 ± 1/2	7.3
Depth	100 ± 40 km	90.5 km
Time	February 1986 to December, 1986	August 6, 1988 (00.36.26.9 G.C.T)

Table V. Estimated death potential if Kangra earthquake of 1905 was to repeat (after Arya, 1992).

Time of occurrence	Deaths in collapsed houses	Deaths in part collapsed houses	Total potential deaths
Midnight (sleeping)	40%	20%	344 000
Morning (awake and sleeping)	20%	10%	177 000
Noon time (out working)	10%	5%	88 000

under intensities of X, IX, VIII and VII respectively on the MM intensity scale. Keeping in view the building material and construction it is estimated that a total of about 145 000 houses will collapse completely and an estimated 267 800 houses will suffer severe damage. Arya (1992) estimates that depending upon the time of the day when the earthquake occurs the loss of human lives would vary between 88 000 and 344 000 (table V). It is essential to retrofit important buildings in Kangra region and elsewhere in the foothills of Himalaya.

On the basis of the 6th World Conference on earthquake engineering held at Delhi in 1977 and the International Workshop on strong motion measurements held at Hawaii in 1978, the Department of Science and Technology, Government of India, has supported installation of strong motion seismic arrays in Kangra region of Himachal Pradesh, Uttar Pradesh and Shillong in Northeast India region. The deployment of these three arrays is shown in fig. 15. Recently, Chandrashekar and Das (1992) have given a gist of results obtained by these arrays. The Northeast India region has been relatively more active and 4 events which occurred during 1986-1988 have resulted in 77 three-component accelerograms. Similarly, some very useful strong motion data have been obtained for Himachal Pradesh and Uttar Pradesh regions.

5. Burma

The earliest work on seismotectonics in the Burmese region was carried out by Evans and Crompton (1946), Gulati (1956) and others. With the development of concept of plate tectonics, the Burma region had renewed interest and the tectonics of the Burmese region is investigated by applying plate tectonics concepts (for example Brunnschweiler, 1966, Curray *et al.*, 1979; Mitchell and McKerrow, 1975; Le Dain *et al.*, 1984; Mukhopadhyay and Dasgup-

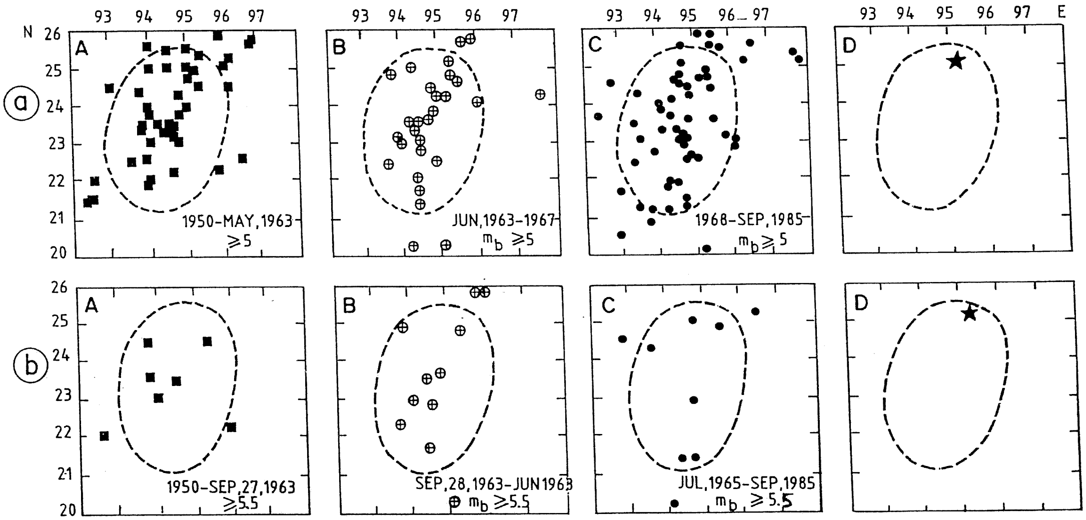

Fig. 14. Earthquakes in the vicinity of India-Burma border region. Earthquake data from 1950 through September 1985 are presented for a) earthquakes of M_b 5.0 and b) earthquakes of M_b 5.5. The epochs of background/normal seismicity (A, solid squares), swarm (B, circle with cross), and quiescence (C, solid circle) are well identified. The August 6, 1988, earthquake (star) occurred in the elliptical zone of preparation for a future earthquake delimited by Gupta and Singh (1986).

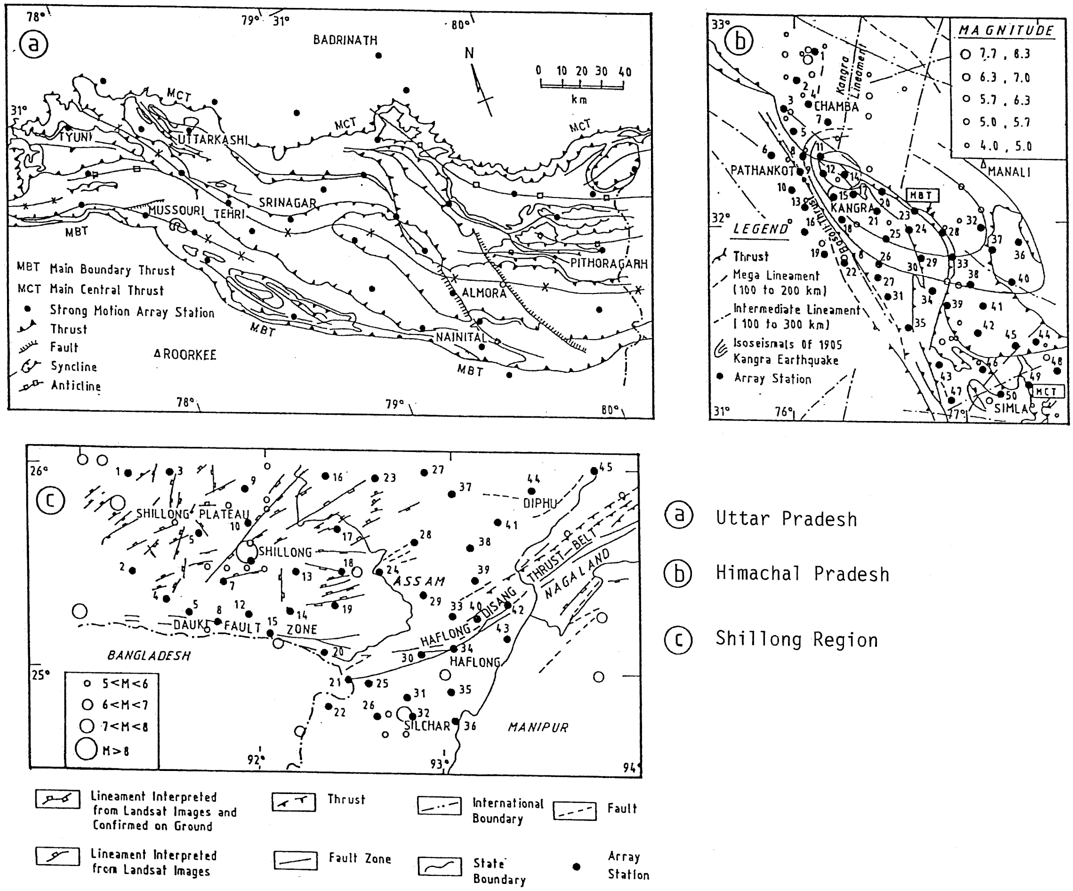

Fig. 15. Strong motion arrays in Indian region.

ta, 1988, and others). Le Dain *et al.* (1984) have investigated in detail the active faultings and tectonics in the Burma and the surrounding regions. They pointed out that the area represents a transition zone between the main Himalayan collision belt and the Indonesian Arc where, at present, the Indian plate is subducting under Asia (Fitch, 1970, 1972; Hamilton, 1977, 1979). They pointed out that northward or northeastward underthrusting of ocean floor was the most important part of the tectonics of Burma in the early Tertiary. As India has already penetrated into Eurasia past Burma, the Burmese region must accomodate the large strike slip movement of India with respect to Southeast Asia. This complicated tectonics makes it difficult to correlate the seismicity with known fault lineament and fault trends. Le Dian *et al.* (1984) have described the complicated surface tectonics of the area and have explained the transition from subduction to collision and strike slip motion in this very complex region. Figure 16 adapted from Le Dian *et al.* (1984) gives a seismotectonic map of Burma.

The region has been the site of several large earthquakes. Table VI gives major historical earthquakes near Burma. The great

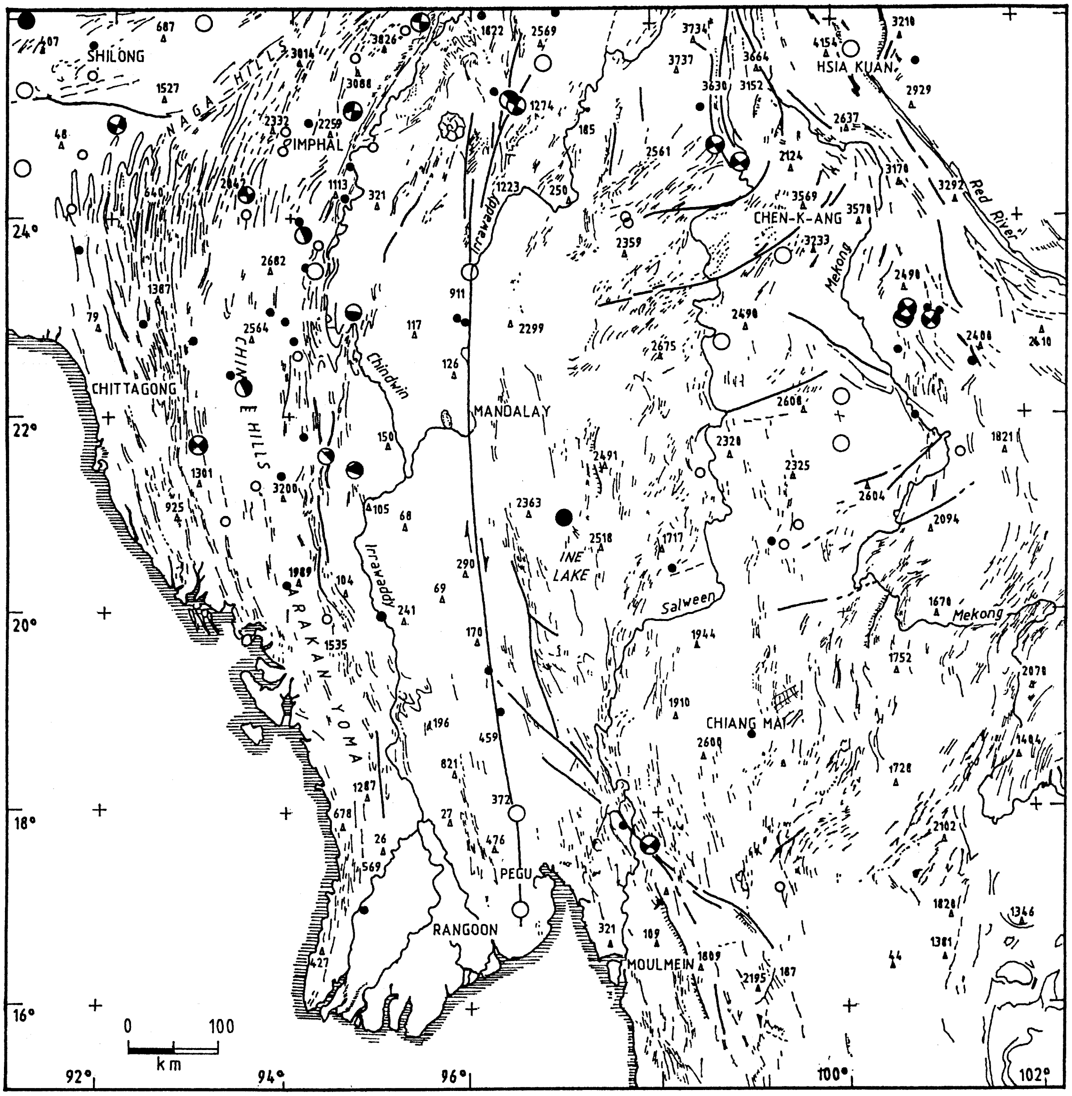

Fig. 16. Seismotectonic map of Burma and the neighbouring regions after Le Dain *et al.* (1984). Major faults: bold lines; less important faults: thin lines; bedding trends: dotted lines. Elevation are in meters. Large solid and open circles represent historic earthquakes with $M > 7.8$ and $7.8 \geq M \geq 7.0$ respectively.

Table VI. Major historical earthquakes in and near Burma (Le Dain *et al.*, 1984).

Date	Location	Magnitude or brief description
March 23, 1839	Near Mandalay	"Very destructive"
Feb. 6, 1843	Near 19 1/2°N, 95 1/2°E	Caused eruptions of mud volcanoes on Ramree Island
Oct. 30, 1843	Also near 19°N, 95°E	More violent than preceding event
Jan. 3, 1848	Also near 19 1/2°N, 95 1/2°E	Another damaging earthquake
Aug. 24, 1858	Near 19°N, 95 1/4°E	Strongest shaking at location given, but following earthquake False Island (at 18° 38′N 95°55 1/2′E) apparently disappeared «no trace of it being seen after the 24th August»
Dec. 31, 1881	West of Andaman Islands	Caused small tsunami, 1 m peak to through in height, felt in Burma, Bengal, and India and damaging on Andaman, Nicobar Islands
May 23, 1912	21°N, 97°E	$M = 8$, $I_{max} = IX$; numerous foreshocks and aftershocks; zone of intensity VII elongated in a north-south direction parallel to Kyaukkyuan fault; railroad tracks bent near fault but little deformed elsewhere
June 22, 1923	22 3/4°N, 98 3/4°E	$M = 7.3$
Sept. 9, 1923	25 1/4°N, 91°E	$M = 7.1$
March 16, 1925	25°N, 100°E	$M = 7.1$
Aug. 8, 1929	Near 19°N, 96 1/2°E	Bent railroad tracks, bridges and culverts collapsed, a loaded trucks overturned
May 5, 1930	17°N, 96 1/2°E	$M = 7.3$, $I_{max} = IX$, in a zone trending north-south for 70 km south of Pegu (therefore parallel to the Sagaing fault)
Dec. 3, 1930	18°N, 96 1/2°E	$M = 7.3$ railroad tracks twisted
Jan. 27, 1931	25.6°N, 96.8°E	$M = 7.6$, $I_{max} = IX$; numerous fissures and cracks
Dec. 26, 1941	21°N, 99°E	$M = 7.0$
Oct. 23, 1943	26°N, 93°E	$M = 7.2$
Sept. 12, 1946	23 1/2°N, 96°E	$M = 7$ 1/2
Sept. 12, 1946	23 1/2°N, 96°E	$M = 7$ 3/4
Feb. 2, 1950	22°N, 100°E	$M = 7.0$

Arakan earthquake of April 2, 1762 caused extensive changes in the level of Burmese coast (Richter, 1958).

Following this the 1878 earthquake caused an uplift of 6 m on the west coast of Ramree island, while another island farther north, False Island, seems to have disappeared (Richter, 1958). Later in 1881 a large event, west of the Andaman Islands, generated a small tsunami. Usually tsunamogenic earthquakes are associated with large component of underthrusting. Another event in 1843 was associated with eruption of mud volcanoes. The existance of mud volcanoes suggests high pore pressure in response to rapid burial due to overthrusting and tectonic stress (Westbrook and Smith, 1983). The region is also associated with intermediate focus earthquakes (Gupta and Bhatia, 1986). The negative free air and isostatic anomalies over the Indo-Burman ranges (Verma *et al.*, 1976; Warsi and Molnar, 1977) are also consistent with recent eastward subduction.

In conclusion we would like to mention that the Burmese region has been seismically active where several earthquakes exceeding magnitude 7 (as may be noted from table VI) have occurred. However, due to sparse population, in terms of loss of human lives and damage to man made structures, the Burmese earthquakes have not been as significant as earthquakes in Nepal, India, Pakistan and Iran. We are not aware of any specific work dealing with earthquake hazard assessment in the Burmese region. However, it is an important area and needs detailed studies.

6. Conclusions

We have briefly presented the earthquake catalogues, seismotectonics and strong motion information for a part of the Alpide belt from Iran to Burma. It may be noted that for Iran, very detailed seismotectonic maps exist and earthquakes have been identified to be associated with major faults in this region. Attention is also drawn to several earthquakes at some depth which do not show surface rupturing because of salt tectonics. Earthquake hazard maps as well as estimates of maximum acceleration in selected cities of Iran are also available. In the region of Afghanistan and Pakistan, earthquake catalogues going back to the beginning of the Christian era have been prepared. Micro-level seismotectonics studies are conducted for a few hydroelectric power projects, like Tarbela in Pakistan. For India, Nepal and Bangladesh catalogues of earthquakes are not as comprehensive as for the regions of Iran, and Pakistan. It may also be noted that this part of the Alpide belt was seismically very active during a short span of 53 years, from 1897 to 1950. Four great earthquakes namely, the Shillong earthquake of 1897, the Kangra earthquake of 1905, the Bihar-Nepal earthquake of 1934 and the Assam earthquake of 1950, all exceeding magnitude 8 occurred during this short duration. Strong motion arrays have been set up in Northeast India region, Himachal Himalaya and Uttar Pradesh Himalaya. These arrays have been providing extremely useful near source strong motion data which neet to be deployed in developing proper building codes. A mention must be made of a significant medium-term earthquake forecast made for the India-Burma border region which has come true. Relatively, much less is known for the Burma region.

This study draws attention to an urgent requirement of improving building construction practices in this region of the world were a lot more human lives are lost in medium to large size earthquakes than elsewhere in the world and the damage to structures is many fold more due to poor construction and high population density. It is hoped that through the efforts of GSHAP the situation will improve.

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