

A new seismic hazard map for the Indian plate region under the global seismic hazard assessment programme

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A new seismic hazard map for the Indian plate region, comprising the Himalaya, northeast India, the Indian shield, South China, Nepal, Burma and Andaman regions, was prepared under the Global Seismic Hazard Assessment Programme (GSHAP). A working catalogue of main shocks was obtained by merging the local catalogues from different countries, with the global catalogue of NOAA. Eighty-six potential seismic source zones were delineated based on the major tectonic features and seismicity trends. Using the probabilistic hazard assessment approach, the Peak Ground Accelerations (PGA) were computed for 10% probability of exceedence in 50 years, at locations defined by a grid of $0.5^\circ \times 0.5^\circ$. The PGA values over the grid points were contoured to obtain a seismic hazard map. The map reveals that the zones of highest risk are the Burmese arc, northeastern India and the Hindukush regions, with PGA values of the order of 0.35–0.4 g. Also, a majority of the north Indian plate boundary region and the Tibetan plateau region have a hazard level of the order of 0.25 g. In the Indian shield region, it is of the order of 0.05–0.1 g, whereas some locales like Koyna depict a hazard level of about 0.20 g.

SEISMIC hazard, in the context of engineering design, is generally defined as the predicted level of ground acceleration which would be exceeded with 10% probability at the site under consideration, in the next 50 years, due to the occurrence of an earthquake anywhere in the region. A lot of complex scientific perception and analytical modelling is involved in seismic hazard estimation. A computational scheme essentially involves delineation of seismic source zones and their characterization, selection of an appropriate ground motion attenuation relation and choosing a predictive model of seismic hazard.

Since earthquake catalogues constitute the first essential input for the delineation of seismic source zones and their characterization, preparation of a unified working catalogue for a region under consideration is an important task. Globally, the data from historic times to recent can be broadly divided into three temporal categories: (1) from 1964 till recent, for which modern instrumentation-based data are available; (2) from 1900–1963, the era of early instrumental data; and (3) pre-1900,

consisting of pre-instrumental data, based primarily on historical and macro-seismic information. The next key component of seismic hazard assessment is the creation of seismic source models, which demand translating seismo-tectonic information into a spatial approximation of earthquake localization and temporal recurrence. The seismotectonic maps need to be critically studied for defining areal seismic source zones and active faults. An earthquake recurrence model is then fitted to these source zones for defining the parameters that characterize the seismicity of the source region, which go as inputs to the algorithm for the computation of seismic hazard, viz. minimum and maximum magnitudes and the parameters a and b in the earthquake frequency magnitude relationship $\log N = a - bM$. The third main element required for seismic hazard assessment is the designation of the strong ground motion (ground acceleration) estimation equations, specifying the ground acceleration as a function of earthquake magnitude and hypocentral distance. These equations have been developed for only a few regions of the world. Obtaining realistic estimates of strong ground motions in all regions is a major challenge that must be met.

Although the steps involved in hazard assessment are specific to the region under consideration, certain standardization of the approaches is essential so that estimates can be compared worldwide and their consistency ensured across the regional boundaries. Global Seismic Hazard Assessment Programme (GSHAP) is a programme which has been coordinated internationally and implemented at the regional and local levels through a number of centers. It has adopted the probabilistic hazard assessment approach of McGuire to estimate the Peak Ground Accelerations (PGA) using the FRISK88M software. Each center has been responsible for a defined geographical territory for the preparation of a unified/homogeneous earthquake catalogue, compilation of seismo-tectonic information and earthquake source delineation, strong seismic ground motion studies and the computation of predictive seismic hazard. The National Geophysical Research Institute (NGRI), Hyderabad, India was identified as one such center, responsible for estimating the seismic hazard for the Indian region.

The issue of seismic hazard in India had been addressed by scientists as early as 1956 when a 3-zone (severe, moderate, minor hazard) seismic zoning map of India was brought out¹. This map was based on a broad concept of earthquake distribution and geotectonics. The severe hazard zones were roughly confined to plate boundary regions, i.e. the Himalayan Frontal Arc in the north, the Chaman fault region in the northwest and the Indo-Burma border region in the northeast. While the minor hazard zone was confined to the Indian shield region in the south, the moderate hazard zone covered the transitional zone between the two. Since then many versions of the seismic zoning map of India have been brought out. The Bureau

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of Indian Standards, which is the official agency for publishing seismic hazard maps and codes in India, prepared a six-zone map in 1962, a seven-zone map in 1966, and a five-zone map in 1970/1984 which is currently valid. The present five-zone map is under review. Khattri *et al.*² adopting a probabilistic hazard computational approach, published a map of, seismic hazard in units of 'g', for 10% probability of exceedence in 50 years.

The present study was initiated during an international workshop of the GSHAP, held at NGRI in February–March 1996. The study region comprised the Test Area #8 of GSHAP, covering parts of India, China, and Nepal, bounded by 20°N–40°N and 85°E–105°E. Towards the preparation of an earthquake catalogue for source zonation, the NOAA catalogue and several local catalogues were considered. A working catalogue of main shocks was prepared by removing duplicates, aftershocks and earthquakes without any magnitude. To start with, the test area was divided into 16 source zones on the basis of seismicity patterns emerging from a plot of epicenters in the region in conjunction with the tectonic information. Further exercises were subsequently carried out with 30 source zones and 56 source zones. After a critical examination of the seismicity and tectonic constraints along with the computed PGA values, it was felt that the 30-source zone model was best suited for the region³.

Subsequently, the study was extended to a larger region bounded by 0–40°N and 65–100°E, which included the entire Himalayan belt, northeast India, the Indian shield, South China, Nepal, Burma and Andaman regions.

To delineate the source zones based on seismicity and tectonic information, a compilation of the tectonic features of the Indian region was made (Figure 1), based on a generalized tectonic map of India², tectonic map of the Himalayan Arc⁴, tectonic map of India published by the Oil and Natural Gas Commission, sketch map of major tectonic features of southeast Asia⁵, map of the Tibetan region showing fault plane solutions of moderate earthquakes and active faults⁶ and some unpublished material. Figure 2a shows the seismicity map of the study region for earthquakes of magnitude 4 and above. Figure 2b shows the earthquakes of magnitude 6 and above, to highlight regions which have experienced major earthquakes in the past. As can be seen, the seismicity of the Indian region is intense along its plate margins and is rather diffused in other regions, except for some concentrations in regions like Koyna. The tectonic and seismicity patterns of the Indian plate boundary regions have been studied in detail using a large number of focal mechanism solutions of the Harvard CMT data^{7–9}. Based on the seismicity and tectonic trends, 86 potential source zones were delineated (Figure 2a, b), which are described here.

The boundaries of the Indian plate are characterized by a continental collision segment along the Himalaya in the north, a complex to an oblique subduction along the

Burma–Andaman arc in the east and transverse fault systems such as the Chaman fault in the northwest. It is now well known that the continued northward collision of the Indian plate with respect to the Eurasian landmass is the source of intense seismicity, and has produced the most gigantic topographic features of the world, viz. the Himalaya and the Tibetan plateau. The major tectonic features in this region include, from south to north, the Main Boundary Thrust (MBT), the Main Central Thrust (MCT) and the Indus Tsangpo Suture Zone (ITSZ). These linear tectonic features run all along the Himalayan belt from west to east having a NW–NS trend in the northwestern Himalaya, E–W trend in the western, central and eastern Himalaya and NE–SW trends in the northeastern Himalaya.

Most of the seismicity in the Himalayan region is concentrated along shallow north dipping planes, which indicate underthrusting of the Indian plate beneath the Eurasian plate. In addition to the four great earthquakes of magnitude exceeding 8 during 1897, 1905, 1934 and

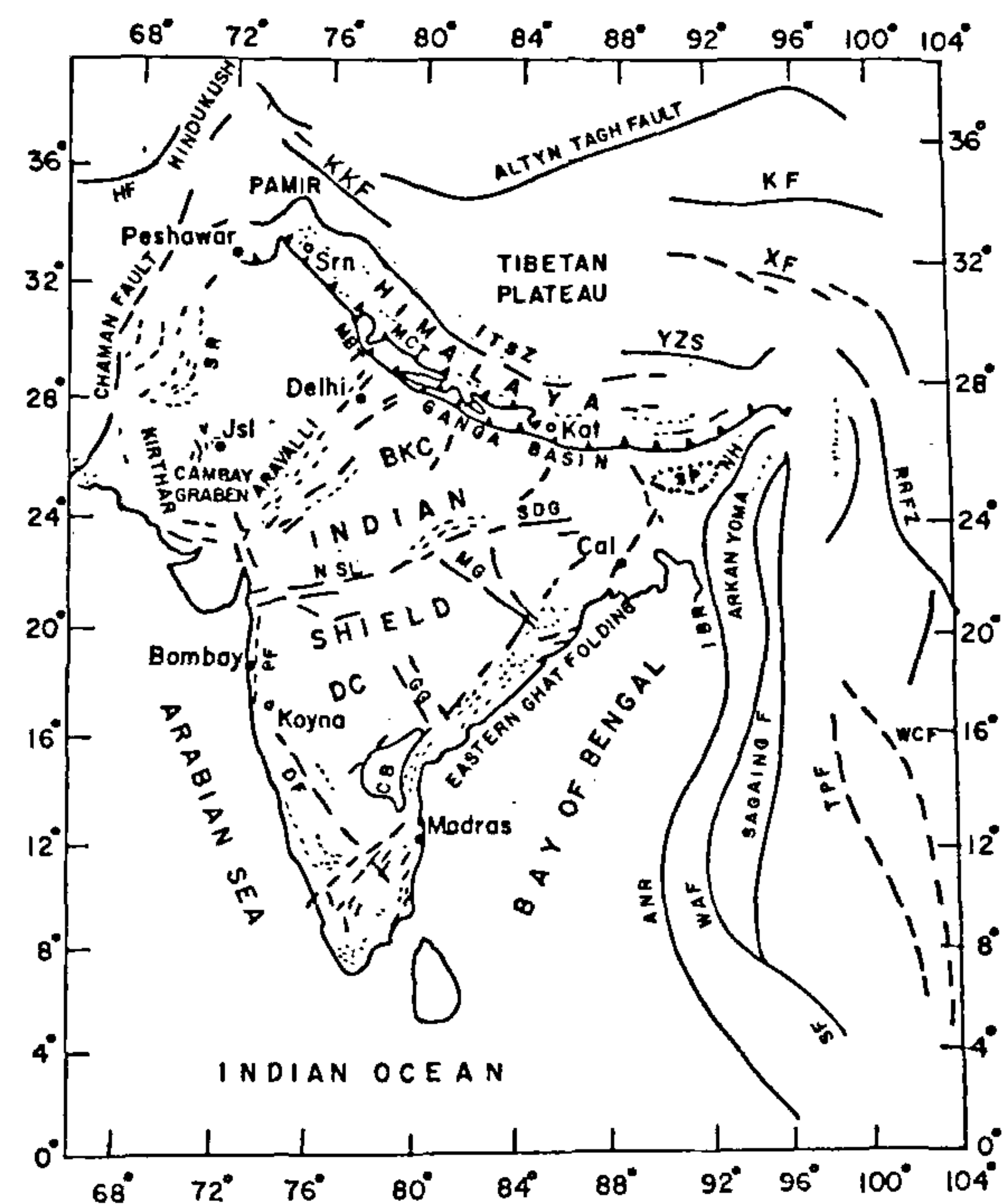


Figure 1. Generalized tectonic map of India and adjoining regions. Abbreviated Tectonic features are: ANR, Andaman Nicobar Ridge; CB, Cuddapah Basin; DF, Dharwar Fold; GG, Godavari Graben; HF, Herat Fault; IBR, Indo-Burma Ranges; ITSZ, Indus Tsangpo Suture Zone; KF, Kunlun Fault; KKF, Karakoram Fault; MBT, Main Boundary Fault; MCT, Main Central Thrust; MG, Mahanadi Graben; SDG, Satpura Damodar Graben; NH, Naga Hills; NSL, Narmada–Son Lineament; PF, Panvel Flexure; RRFZ, Red River Fault Zone; SF, Sagaing Fault; SR, Sulaiman Range; SP, Shillong Plateau; TPF, Three Pagodas Fault; WAF, West Andaman Fault; WCF, Wang Chao Fault; XF, Xian Shui He Fault; YZS, Yarlung Zangpo Suture. Cities shown are: Cal, Calcutta; Jsl, Jaisalmer; Kat, Kathmandu; Srm, Srinagar.

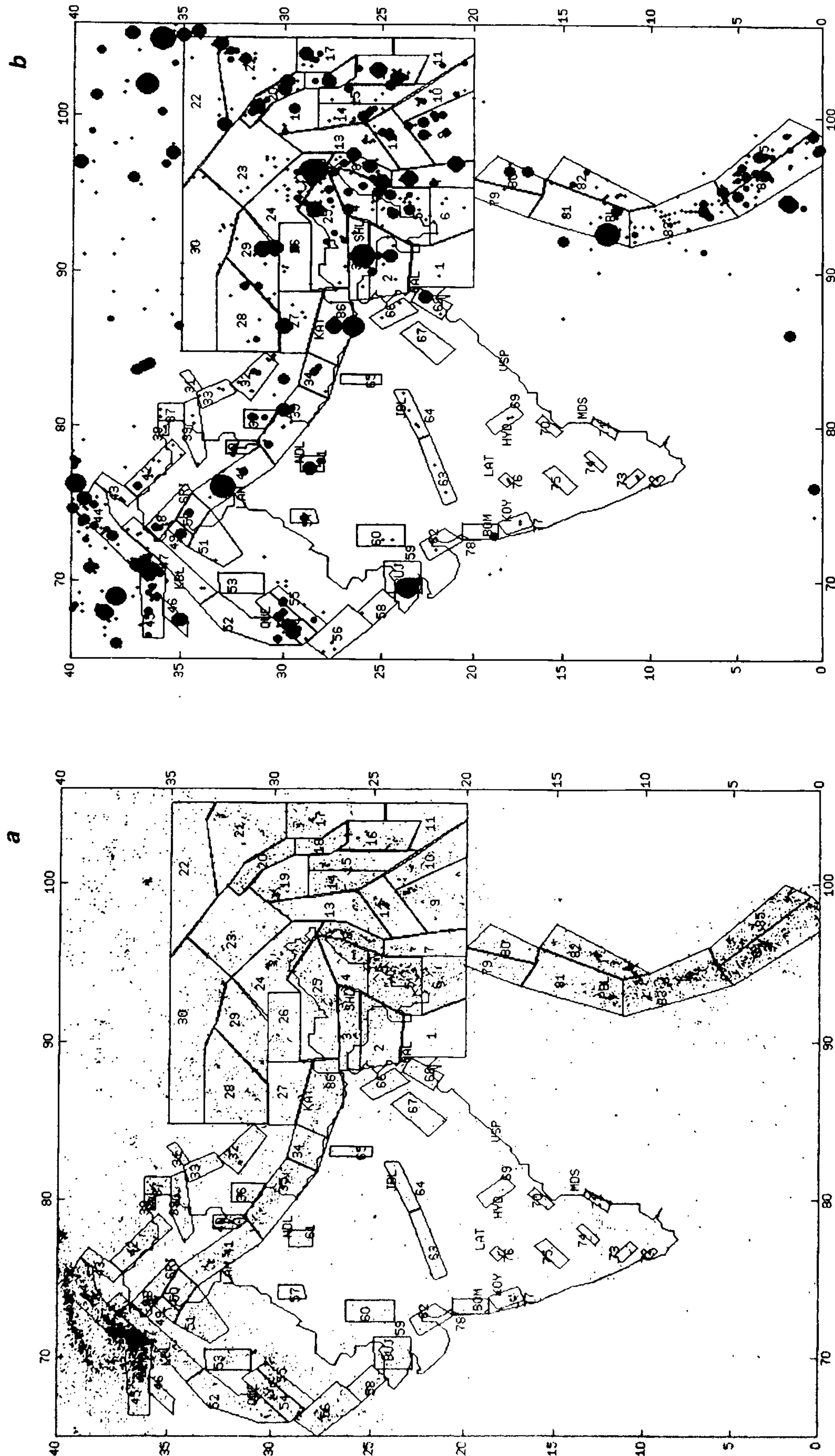


Figure 2. *a*, Seismicity and source zone map of India and adjoining regions. Dots are the epicenters of earthquakes of magnitude 4 and above. Blocks numbered 1 through 86 are the source zones. Some cities are shown for orientation purpose: BMB (Bombay), BUJ (Bhuj), CAL (Calcutta), HYD (Hyderabad), JBL (Jabalpur), KAT (Kathmandu), KBL (Kabul), KOY (Koyana), LAH (Lahore), LAT (Latur), MDS (Madras), NDL (New Delhi), PBL (Port Blair), QUE (Quetta), SHL (Shillong), SRI (Srinagar), VSP (Vishakhapatnam). *b*, Map showing locations of earthquakes of magnitude 6 and above in India and adjoining regions. Three letter locations refer to cities as listed in the caption of Figure 2 *a*.

1950, another 10 earthquakes exceeding magnitude 7.5 have occurred in the Himalayan belt during the past 100 years. From a very simple consideration, the whole Himalayan belt, from west to east, can be considered as one seismic-source zone. However, dividing the zone into smaller segments would be more appropriate. We have therefore segmented this region by source numbers 25 and 86 in the eastern sector, sources 34 through 36 in the central sector, 40 and 41 in the western sector and 37 through 39, 42, 48 through 50 in the northwestern sector.

In contrast to thrusting in the Himalaya, the extraordinarily thick crust of the Tibetan plateau in the north is characterized by crustal extension and eastward extrusion, manifested by earthquakes indicating normal faulting and strike-slip motion. The Altyn Tagh, the Kunlun and the Xianshuihe are the three major fault systems supporting the left-lateral strike-slip motion⁶. Sources 22 through 24, and 26 through 33 have been delineated in this zone based primarily on seismicity trends (Figure 2 *a*).

The Burma–Andaman arc marks the eastern margin of the Indian plate, along which an oblique convergence between the Indian and the Burmese plate has been suggested^{10,11}. The major tectonic features along the arc are the N-S trending Indo-Burman Ranges (IBR) in the north and the Andaman Nicobar Ridge (ANR) in the south. The Sumatran fault system in the southeast, the Western Andaman Fault (WAF) and the Sagaing fault further east, are the features supporting major right lateral movements in this region. The distribution of earthquakes in the Burmese arc region suggests the presence of a subducted Indian lithospheric slab beneath the Burmese plate^{12–15}. Occurrence of shallow and intermediate focus earthquakes has been reported in the Naga Hills (NH), and Arakan Yoma fold belt⁸. While the seismic source zones 4 through 8 cover the Burmese arc and adjoining region on the eastern side, the source zone 3 on the west encompasses the Shillong Plateau (SP) which experienced a strong earthquake of magnitude 8.7 in 1897. The tectonics of the Shillong plateau is distinctly different from that of the regions to its north, south and west¹⁶, and hence a separate zone for the region. The area further east, namely the south China region is characterized by many faults and lineaments such as Red River Fault Zone (RRFZ). The seismic sources 9 through 23 have been identified in this seismic province.

The nature of convergence varies from a continental type in the Burmese arc to an oceanic type in the Andaman arc, with a relatively quiet seismic zone marking the transition^{8,17}. Shallow and occasional intermediate depth earthquakes delineate the subducted slab under the Andaman Nicobar islands joining the seismicity trend of the Indo-Burman ranges. A distinct, separate lineation of shallow focus earthquakes passes under the Central basin of the Andaman sea and indistinctly follows the line of the Sagaing fault, towards the eastern Himalayan syntaxis¹¹. The transition seismic zone referred

above has been divided into sources 79 and 80. In the region south of this, along the Andaman Nicobar region sources 81 through 83 have been assigned. Further south the sources 84 and 85 cover the northern Sumatra region.

The northwestern Himalayan region also has the characteristic Himalayan tectonic features, namely MBT, MCT and is bordered by the Hindukush syntaxis and the Pamir knot region in the extreme northwest. The Hindukush and Pamir knot region are characterized by the junction of several tectonic features. This plate boundary region experiences high level of seismicity varying from shallow to intermediate depth earthquakes. Sources 43 through 46 cover this region. The other prominent tectonic features in the northwestern Indian region are the transverse fault systems known as the Chaman fault, the Kirthar and Sulaiman Ranges (SR). The tectonics of the Kirthar Ranges and Sulaiman Ranges is influenced by transcurrent faulting. This region also belongs to the plate boundary and experiences a high level of seismicity. These areas are covered by sources 47, and 51 through 55.

The Indian shield region is marked by several rift zones and shear/thrust zones. Although considered to be a stable continental region (SCR), it has experienced many earthquakes of magnitude $M \geq 6.0$ since the 18th century¹⁸, some of which were disastrous. Among them are the Mahabaleshwar (1764), Kutch (1819), Damooh hill (near Jabalpur, 1846), Mount Abu (1848), Coimbatore (1900), Son-Valley (1927), Satpura (1938), and Jabalpur (1997) earthquakes. The spatial distribution of these moderate earthquakes is shown in Figure 2 *b*. The seismicity in the shield region is quite diffused except for a few localized alignments, which is detailed in this figure. Generally speaking, the Indian shield region can be considered as one single seismic source zone for hazard computations. However, smaller seismic zones can be delineated in this region, primarily based on the locales of the major earthquakes and seismic lineaments, some of which are not so well defined. Next, we describe the nature of seismicity, tectonic trends and the distribution of seismic sources.

The Narmada–Son Lineament (NSL) is a prominent tectonic feature of the Indian shield, trending ENE–WSW from 21°N, 72°E on the western coast of India to 24°N, 88°E on the eastern side. This apparently divides the shield into 2 sectors, which we name as the northern and the southern sectors, to facilitate further description and discussion. The Narmada–Son region has been experiencing earthquakes of different magnitudes in the past, the recent one being the 21 May 1997 Jabalpur earthquake of magnitude 6.0. This is an SCR earthquake with an unusual focal depth of about 30 km. At least 4 earthquakes of magnitude > 5.4 have earlier occurred along this zone, two of them in the proximity of the 1997 Jabalpur earthquake¹⁹. We have assigned 2 probable seismic zones in the central part of the Narmada–Son lineament numbered 63 and 64. Further, while the northeast portion of the Indian shield is covered by sources 66 through 68,

the region west of the Burmese arc and south of the Shillong plateau is described by sources 1 and 2.

The major tectonic constituents in the southern sector of the Indian shield include the massive Deccan Volcanic Province (DVP), the South Indian Granulite Terrain (SIGT), the Dharwar Craton (DC), the Cuddapah Basin (CB), the Godavari Graben (GG), the Mahanadi Graben (MG), and the Eastern and the Western Ghats on the east and west coast of India, respectively.

The Eastern ghat region in general is a quiet zone, characterized by diffused low magnitude shallow focus earthquakes and an occasional earthquake of magnitude 5–6. The preferred fault plane solutions generally indicate NE–SW orientation with left lateral strike-slip motion. An alternate set of solutions indicate thrust faulting along northwest orientation. Not very many historical earthquakes are reported to have occurred in this region. Based on localized concentration of seismicity, we have delineated sources 70, 71 and 74 along the Eastern Ghat region.

The western ghat region of the Indian shield also depicts diffused seismicity, except for some clusters, the prominent one being the Koyna–Warna region. The Koyna reservoir region has been experiencing induced earthquakes right from the date of its first filling in 1962. Over the past 34 years, the region around the reservoir has experienced 10 earthquakes of magnitude ≥ 5 , over 100 earthquakes of magnitude ≥ 4 , and about 100,000 earthquakes of smaller magnitudes. The world's largest reservoir-induced earthquake of magnitude 6.3 occurred in the Koyna region on 10 December 1967. Warna reservoir located 20 km south of Koyna began to be filled in 1986. The Koyna–Warna region has experienced a burst of seismicity since August 1993. More than thousand earthquakes of magnitude around 2–3 have occurred since then. Two earthquakes of magnitude 5 and 5.4 occurred on 8 December 1993 and 1 February 1994 respectively. Gupta *et al.*²⁰ and Rai *et al.*²¹ give a detailed picture of seismicity in the Koyna–Warna region. The seismicity in the region aligns itself beautifully along the local/regional fault systems. This Koyna–Warna region does assume a special relevance from the seismic hazard point of view. This region therefore has been considered as a separate seismic source zone numbered 77. The region along the western coast, north of Koyna has been considered as two sources, 78 and 62.

The source 78 around Mumbai is characterized by N–S tectonic lineaments such as the Panvel Flexure (PF) and similarly aligned seismicity patterns. This source region is also reported to have experienced a large earthquake in historic times. The source 62 encompasses the NW–SW trending features in the Cambay Basin and the western end of W–E trending Narmada–Son lineament also depicts reasonable level of seismicity to merit designation of an independent seismic source. Down south, near Trivandrum along the western margin we have delineated

source 72 primarily on account of some recent concentration of seismic activity.

In the central shield region south of the Narmada–Son lineament the seismic activity is considerable, although diffused. The Latur region in central India experienced an earthquake of M_w 6.1 in 1993. The inferred depth was about 5 km and the focal mechanism by several agencies indicated a thrust type faulting with the P axis trending NNE, consistent with the direction of the India–Eurasia plate motion. The inferred fault plane was strikes along the NW and dips 45 degrees SW. Seeber *et al.*²² suggested that the earthquake was caused by a new fault in the Deccan trap region. On the other hand, Rajendran *et al.*²³ inferred the trend of a pre-existing fault based on a study of Landsat images prior to the earthquake. On the basis of borehole studies across the fault, which indicate large displacement of 3 to 6 m, Gupta *et al.*²⁴ suggested that the displacement is far too much to be accounted by a single earthquake of M_w 6.1 and concluded that the fault is a pre-existing one. It appears that this region has also been active in historical times. In view of these considerations, the region around Latur has been taken as a seismic source zone numbered 76. The source 69 covers the Godavari Graben (GG) region which experienced a moderate-sized earthquake of magnitude 5.3, known as Bhadrachalam earthquake, in 1969. The regions around Bellary and Coimbatore have been demarcated as source zones 75 and 73, respectively on account of having experienced moderate-sized earthquakes in the past, as referred in the earlier section.

The northern sector of the Indian shield has relatively lower level of seismicity. The region has a prominent tectonic feature called the Bundelkhand Craton (BC) in the central area bounded by NNE–SSW to N–S trending lineaments on the west as well as on the east. Sources 57, 60, 61 and 65 are delineated in this region.

The northwestern corner of the Indian shield (in the vicinity of 24°N and 72°E) is characterized by N–S, NW–SE and E–W tectonic trends and shows a relatively higher level of seismicity. Sources 56, 58 and 59 have been identified in this region. The source zone 59 experienced the well-known 7.8 magnitude Kutch earthquake in 1819.

To facilitate the steps for source zone characterization, a software toolbox was developed, which performs the essential data handling and pre-processing tasks: (1) scanning of earthquake catalogues (of different formats) to segregate events for the specified rectangular block defined by latitude–longitude limits, or a polygonal block defined by latitudes and longitudes of the vertices; (2) merging different catalogues and sorting in chronological order; (3) removal of duplicates; (4) removal of after-shocks according to a defined criteria and preparation of a main-shock catalogue; (5) plotting of epicenters by superposing the source zones and tectonic features, geographical locations, etc.; (6) estimation of a and b values; and (7) extracting required information from the

Table 1. Characteristics of the seismic source zones

Source no.	Max. magnitude	Nu (at mag. 5.0)	Beta	Source no.	Max. magnitude	Nu (at mag. 5.0)	Beta
1	6.5	0.016	1.379	44	8.0	3.385	1.610
2	8.5	0.378	1.194	45	8.5	1.434	1.549
3	8.7	0.422	1.449	46	7.5	0.042	1.549
4	8.5	0.566	1.134	47	7.5	0.689	1.617
5	8.5	1.712	1.134	48	7.0	0.150	1.649
6	8.0	0.482	1.570	49	7.5	0.089	1.671
7	8.0	0.201	1.130	50	7.0	0.104	1.671
8	8.0	0.591	1.340	51	7.0	0.151	1.919
9	7.0	0.416	1.008	52	8.0	0.205	1.771
10	7.0	0.602	1.068	53	7.0	0.079	1.634
11	7.0	0.172	1.263	54	7.5	0.349	1.668
12	7.5	0.243	1.062	55	7.5	0.154	1.634
13	6.5	0.352	1.139	56	7.0	0.074	1.795
14	7.5	0.410	1.445	57	7.0	0.001	1.379
15	7.5	0.287	1.268	58	7.5	0.011	1.266
16	8.5	0.353	1.071	59	8.5	0.126	1.266
17	7.0	0.383	1.278	60	6.5	0.034	1.379
18	7.5	0.192	1.387	61	7.5	0.026	1.379
19	7.5	0.221	1.219	62	6.5	0.049	1.379
20	8.0	0.285	1.219	63	6.5	0.034	1.379
21	7.5	0.487	1.292	64	6.5	0.022	1.379
22	8.0	0.199	1.421	65	6.0	0.008	1.379
23	7.0	0.422	1.432	66	6.5	0.001	1.379
24	8.5	0.704	1.253	67	6.0	0.039	1.379
25	8.5	0.864	1.073	68	6.5	0.028	1.379
26	8.0	0.270	0.979	69	6.5	0.033	1.379
27	8.5	0.133	1.495	70	6.0	0.050	1.379
28	8.0	0.494	1.362	71	6.0	0.006	1.379
29	8.0	0.426	0.997	72	6.0	0.008	1.379
30	7.0	0.739	1.308	73	6.0	0.016	1.379
31	6.5	0.247	1.394	74	6.0	0.001	1.379
32	7.0	0.164	1.394	75	6.0	0.006	1.379
33	7.0	0.077	1.394	76	6.5	0.003	1.379
34	8.0	0.171	1.230	77	6.5	0.128	1.379
35	8.0	0.631	1.406	78	6.5	0.128	1.379
36	7.5	0.086	1.406	79	6.5	0.148	1.378
37	7.0	0.143	1.634	80	7.5	0.139	1.378
38	7.0	0.030	1.634	81	8.5	0.694	1.434
39	7.0	0.174	1.764	82	7.0	0.677	1.367
40	7.5	0.155	1.193	83	7.5	1.809	1.361
41	8.5	0.405	1.388	84	7.5	1.676	1.440
42	7.5	0.298	1.323	85	7.5	1.259	1.409
43	7.5	0.069	2.131	86	8.5	0.395	1.495

output files of FRRISK88M, for preparation of hazard maps.

The minimum magnitude was assigned as 5.0 for all the source zones because it is the lower level of magnitude which would cause hazard of a significant level. The maximum magnitude was estimated from past seismicity for each of the zones separately. The seismic parameters a and b were estimated by applying the maximum likelihood method, and subsequently converted to Nu and Beta, which go as inputs to hazard computations.

The source zones corresponding to the seismically active regions in the plate boundary and adjacent regions contain enough statistics for independent computation of a and b values. However, the source zones in the Indian shield, do not contain sufficient information for this purpose. To overcome this problem, the b value was computed for the whole shield region as one unit and was assigned to each zone within it, while the a value was computed for each zone separately. A similar philosophy

was adopted for a few other source zones with sparse seismicity. The details of the characteristics of each source zone are listed in Table 1.

Using the probabilistic hazard assessment approach of McGuire adopted by GSHAP, the PGA were computed using the FRISK88M software for 10% probability of exceedence in 50 years, at locations defined by a grid of $0.5^\circ \times 0.5^\circ$ in the region 0°N – 40°N and 65°E – 100°E . Since no reliable estimates of attenuation values are available for the Indian region, the attenuation relation of Joyner and Boore²⁵ was used. The PGA values over the grid were contoured to obtain a seismic hazard map (Figure 3). A contour interval of 0.05 g was chosen, since we believe that problems and uncertainties associated with the source zone definition and paucity of the seismicity information would not permit a resolution better than 0.05 g. The hazard map depicts that a majority of the plate boundary region and the Tibetan plateau region have hazard levels of the order of 0.25 g with

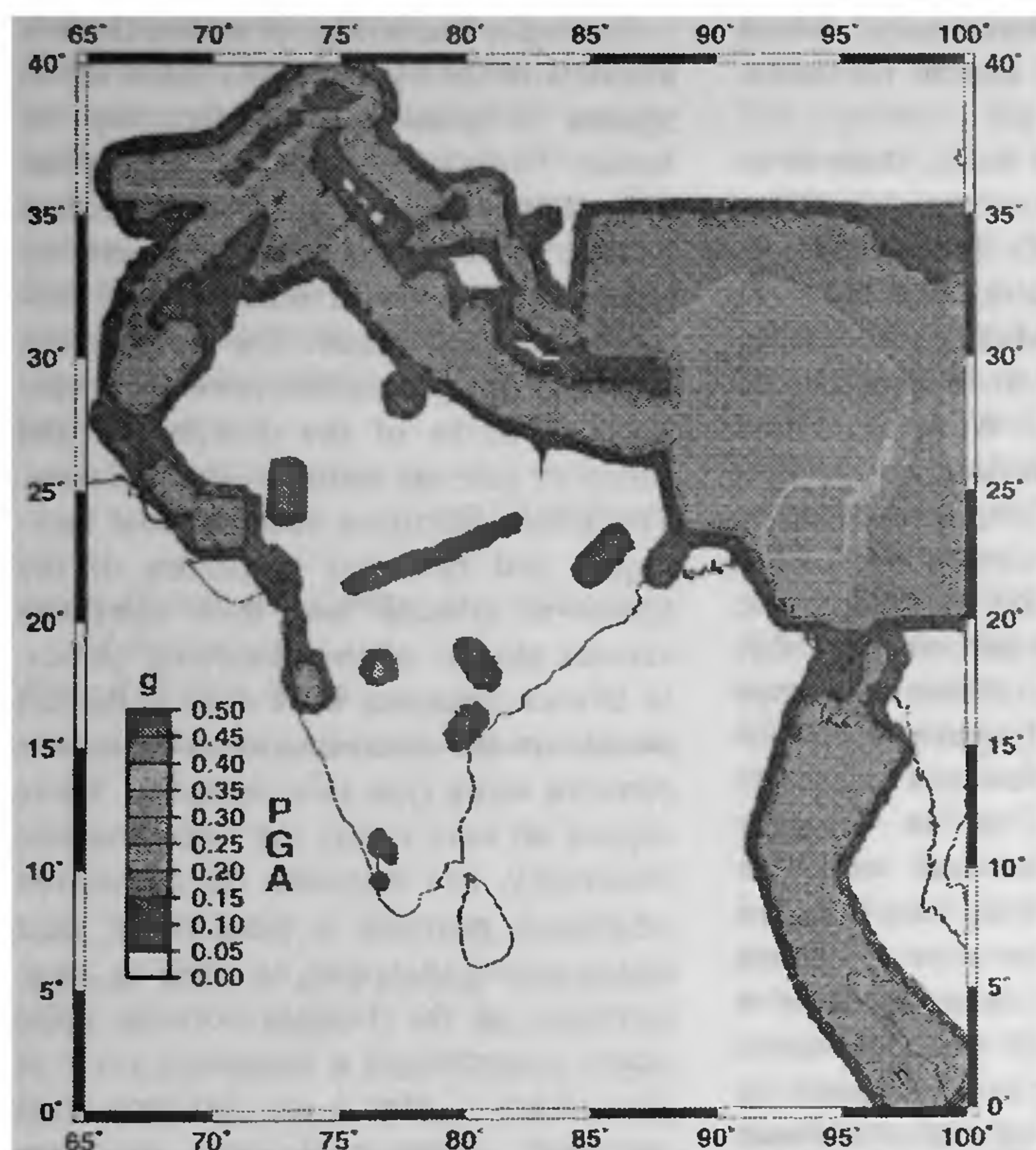


Figure 3. Seismic hazard map of India and adjoining regions for 10% probability of exceedence in 50 years. Contour interval 0.05 g.

prominent highs of the order of 0.35–0.4 g in the seismically active zones like the Burmese arc, northeastern India and northwest Himalaya/Hindukush region. In most of the Indian shield region, the regional seismic hazard is of the order of 0.1 g, whereas some locales like Koyna depict a hazard level of 0.20 g.

The computational experience gained in the GSHAP exercises has brought out certain concerns. The Indian region poses a lot of problems for data homogenization, and seismic hazard maps are strongly influenced by the size and shape of the seismic source zones. Another key issue which is a cause of concern is non-availability of representative strong motion attenuation formulae which compelled us to be satisfied with applying one of the internationally developed formulae. The seismic hazard map of India and adjoining regions presented here is one possible map with all constraints outlined. This map, we believe, gives a reasonably representative seismic hazard picture over the region covered.

We have carried out computations considering the probable source zone depth as 10 km. Any depth shallower than this would be unrealistic since large earthquakes do not take place at very shallow depths. Any depth deeper than 10 km would also not have much meaning because it would reduce the hazard considerably and one needs to take a conservative but realistic approach. The hazard values in the map presented here are lower than the ones given by Khattri *et al.*². We would

get the same level of hazard if the source depth was put at 0 km. Apparently Khattri *et al.*² took source depth of 0 km, which produced higher values of hazard estimates.

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