Credits: 3 + 0

Spring 2021 Semester

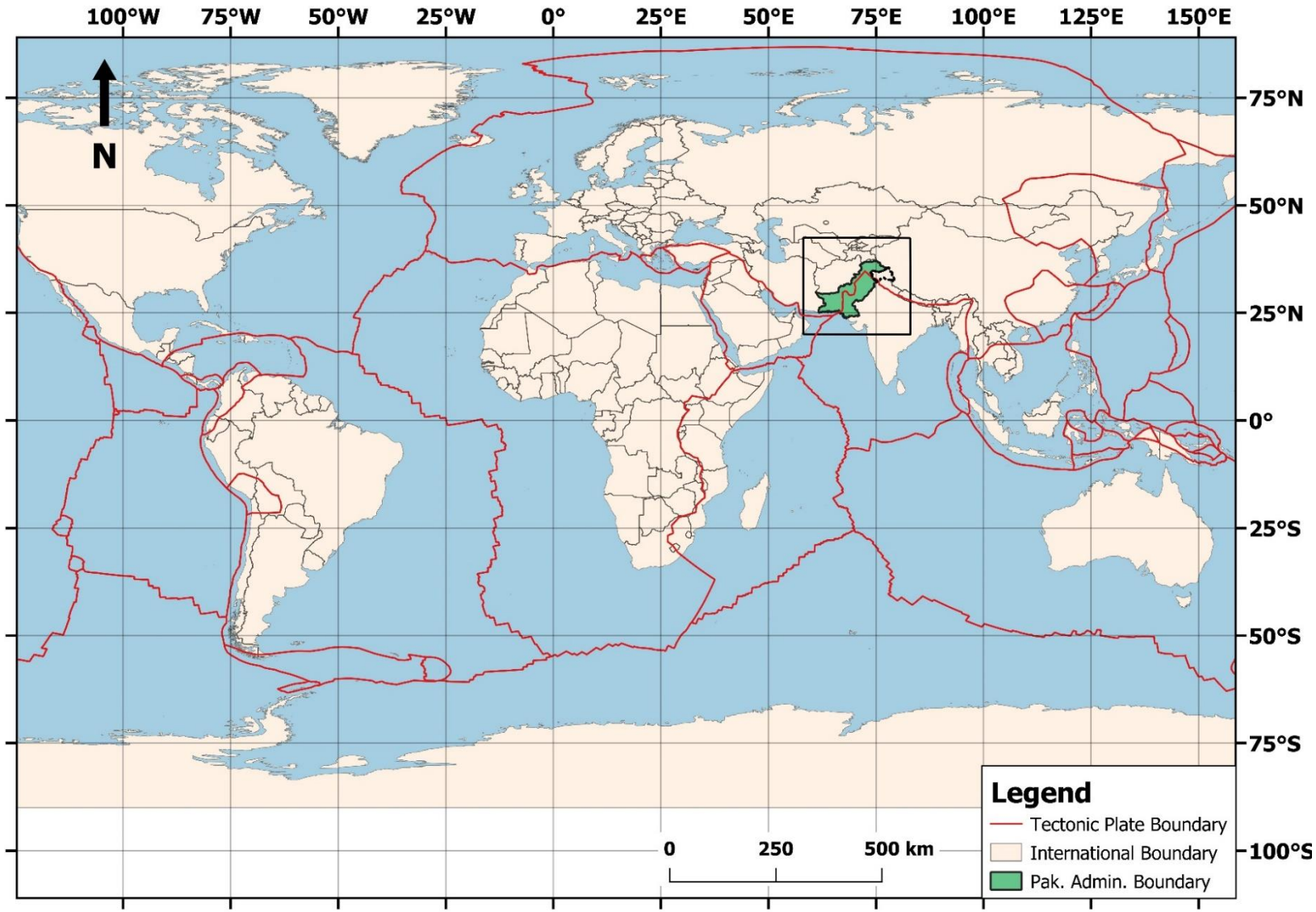
Performance-based Seismic Design of Structures

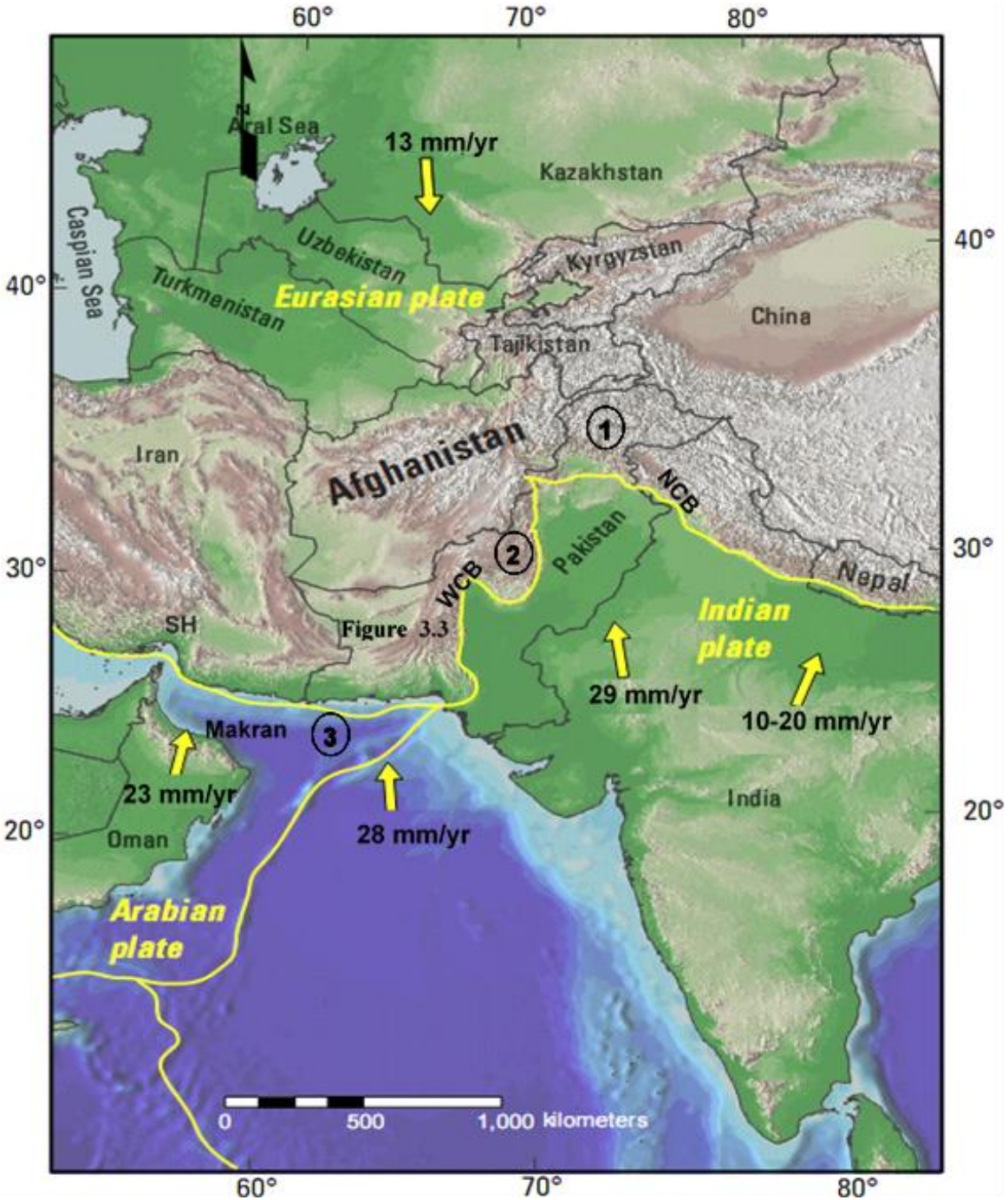
Fawad A. Najam, PE, PhD.
Assistant Professor (Structural Engineering)
Department of Structural Engineering
NUST Institute of Civil Engineering (NICE)
National University of Sciences and Technology (NUST)
H-12 Islamabad, Pakistan
Cell: 92-334-5192533, Email: fawad@nice.nust.edu.pk

Seismicity of Pakistan and Surrounding Regions

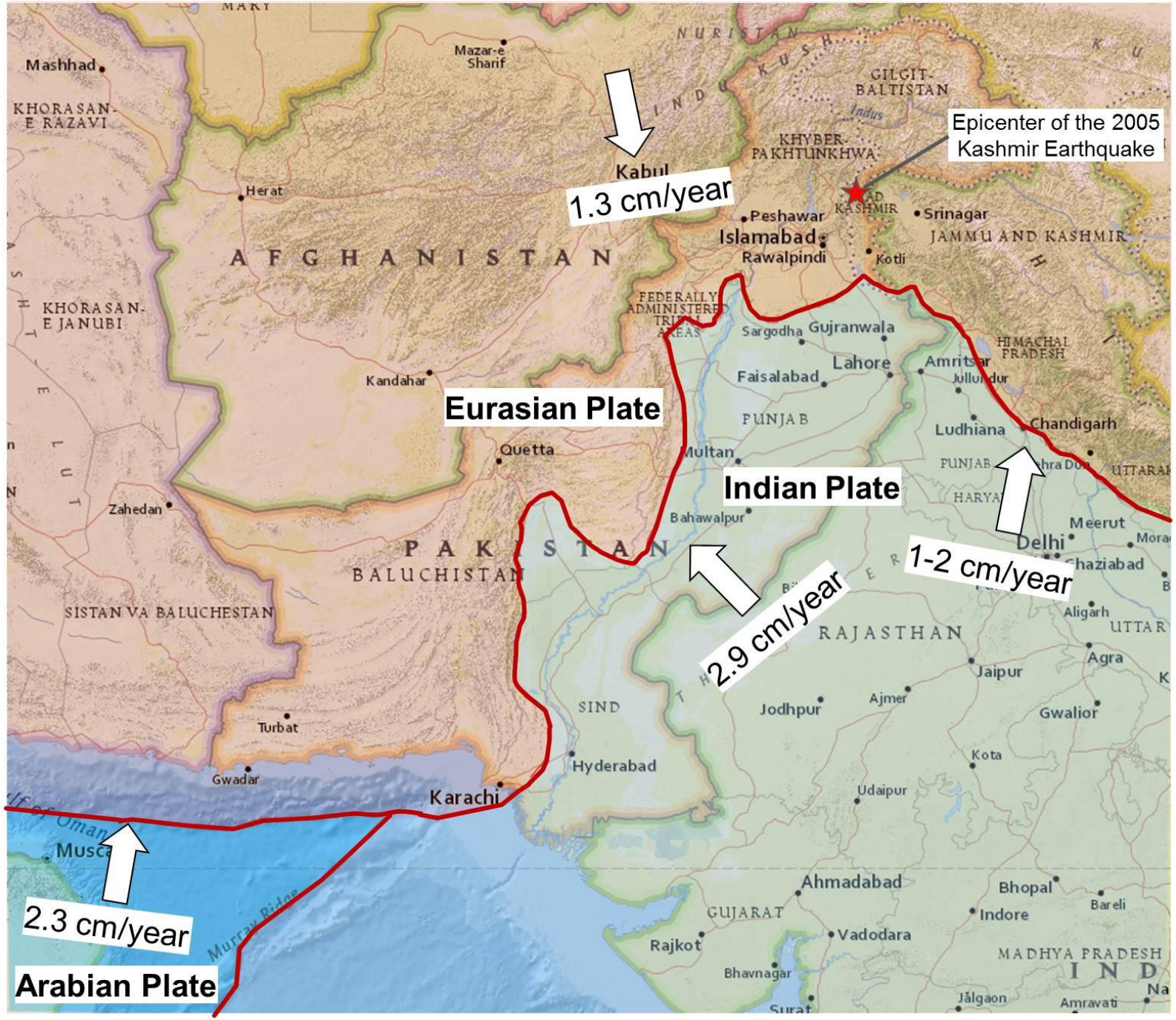
- Seismo-tectonic Environment of the Region
- Historical and Instrumental Earthquake Data
- Main Tectonic Features and Faults

Location of Pakistan and the Regional Tectonic Setting





Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan


Epicenter of the 2005 Kashmir Earthquake
1.3 cm/year
Eurasian Plate
Indian Plate
1-2 cm/year
2.9 cm/year
2.3 cm/year
Arabian Plate
AFGHANISTAN
PAKISTAN
BALUCHISTAN
PUNJAB
RAJASTHAN
GUJARAT
SIND
KHYBER-PAKHTUNKHWA
GILGIT-BALTISTAN
JAMMU AND KASHMIR
HIMACHAL PRADESH
KHORASAN-E RAZAVI
KHORASAN-E JANUBI
SISTAN VA BALUCHESTAN
MADHYA PRADESH
Mashhad
Herat
Mazar-e Sharif
Kabul
Kandahar
Zahedan
Quetta
Peshawar
Islamabad
Rawalpindi
Kotli
Srinagar
Sargodha
Gujranwala
Lahore
Faisalabad
Amritsar
Ludhiana
Chandigarh
Multan
Bahawalpur
Delhi
Meerut
Aligarh
Agra
Jaipur
Jodhpur
Ajmer
Gwalior
Kota
Udaipur
Turbat
Gwadar
Karachi
Hyderabad
Ahmadabad
Bhopal
Indore
Vadodara
Rajkot
Bhavnagar
Surat
Jalgaon
Amravati

Indian-Eurasian Plate Boundary

- Following remarkable mountain structures have resulted from this collision:
  - The Himalayan ranges in central region.
  - The Arakan-Yoma Mountain ranges of Burma in the east.
  - The Naga Hills of Assam towards the east.
  - The rising Tien-Shan Mountain ranges in the central Asia.
  - The Karakoram Mountain ranges in Pakistan.
  - The Hindu Kush Mountains and the Pamir ranges.
  - The Baluchistan arc marked by the Kirthar as well as Sulaiman ranges delineating the continent-continent collision zone in the west.

Source: Shah M. A., 2011

Seismo-tectonic Features of Pakistan

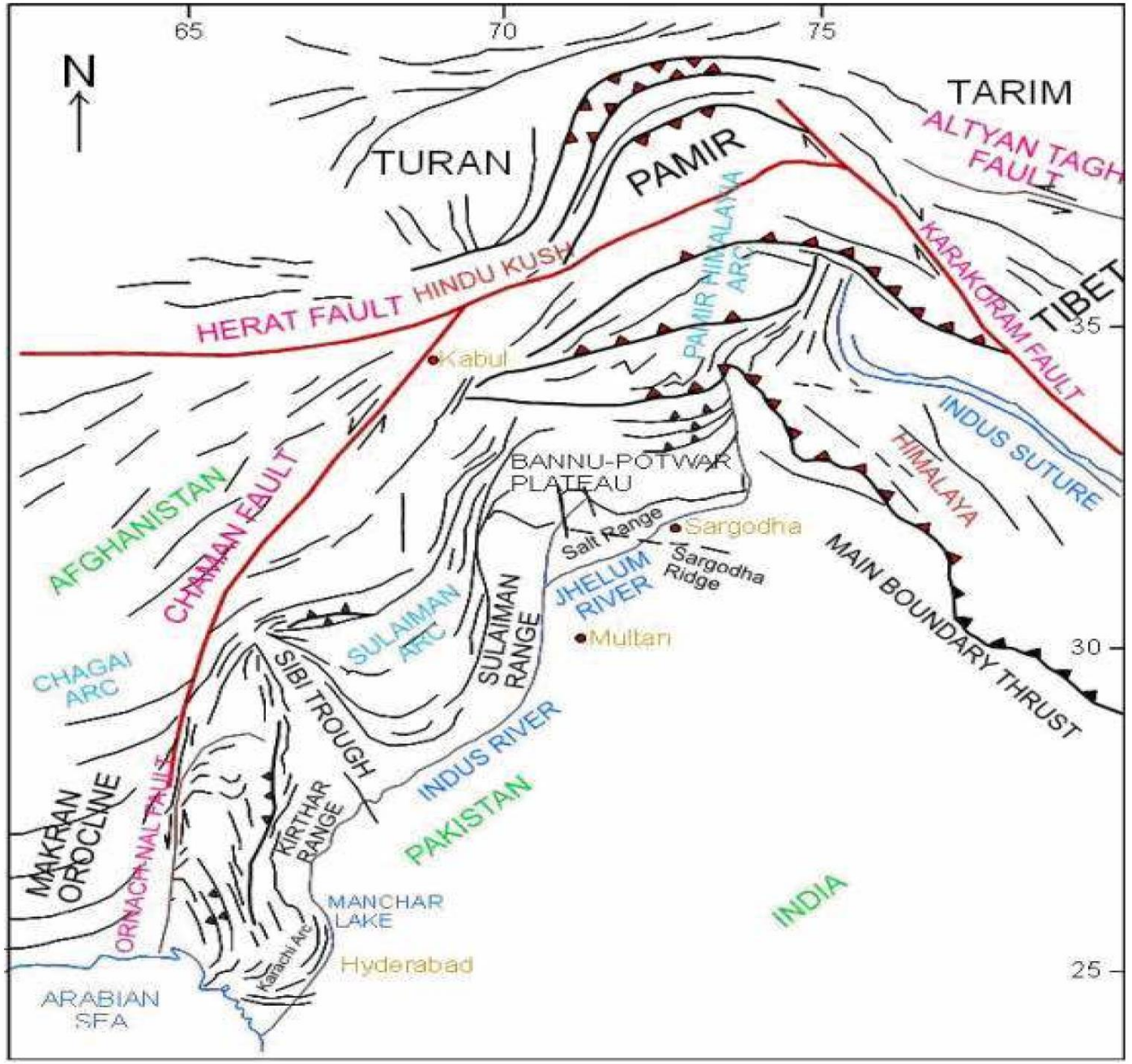
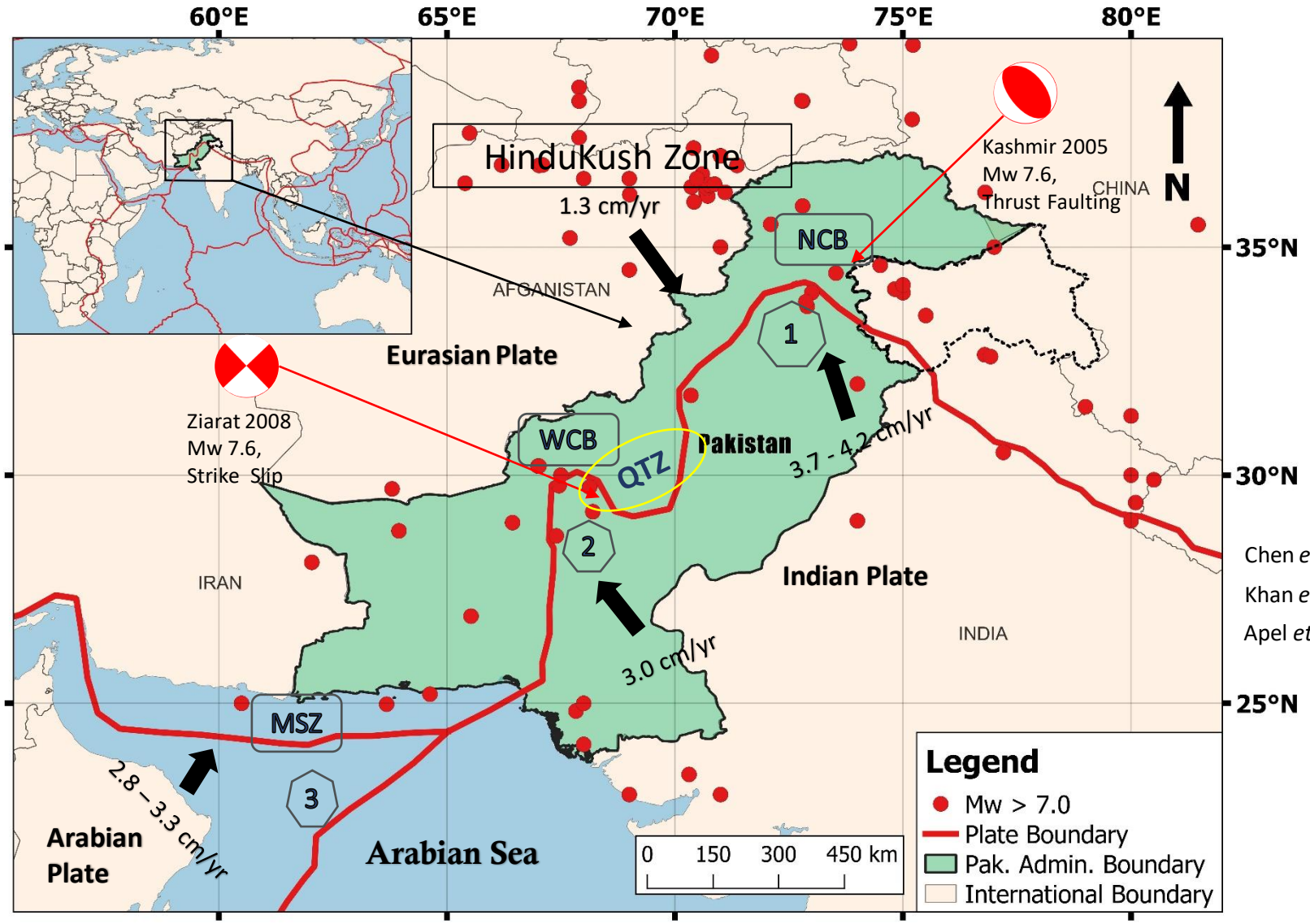
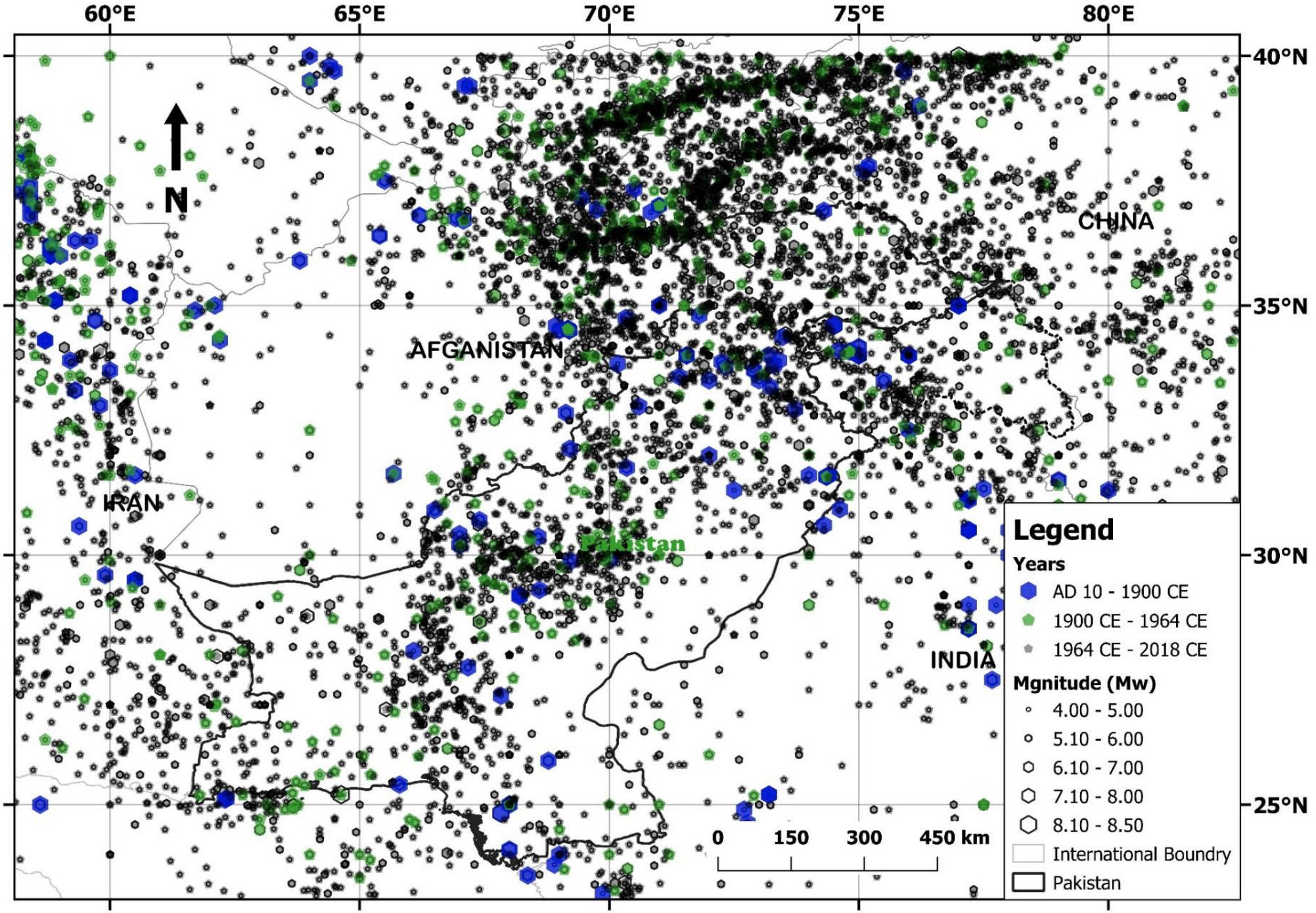


Figure 5-3. Major tectonic features in Pakistan (courtesy: Geological Survey of Pakistan)

NCB North Collision Boundary
WCB West Collision Boundary
MSZ Makran Subduction zone
QTZ Quetta Transverse Zone

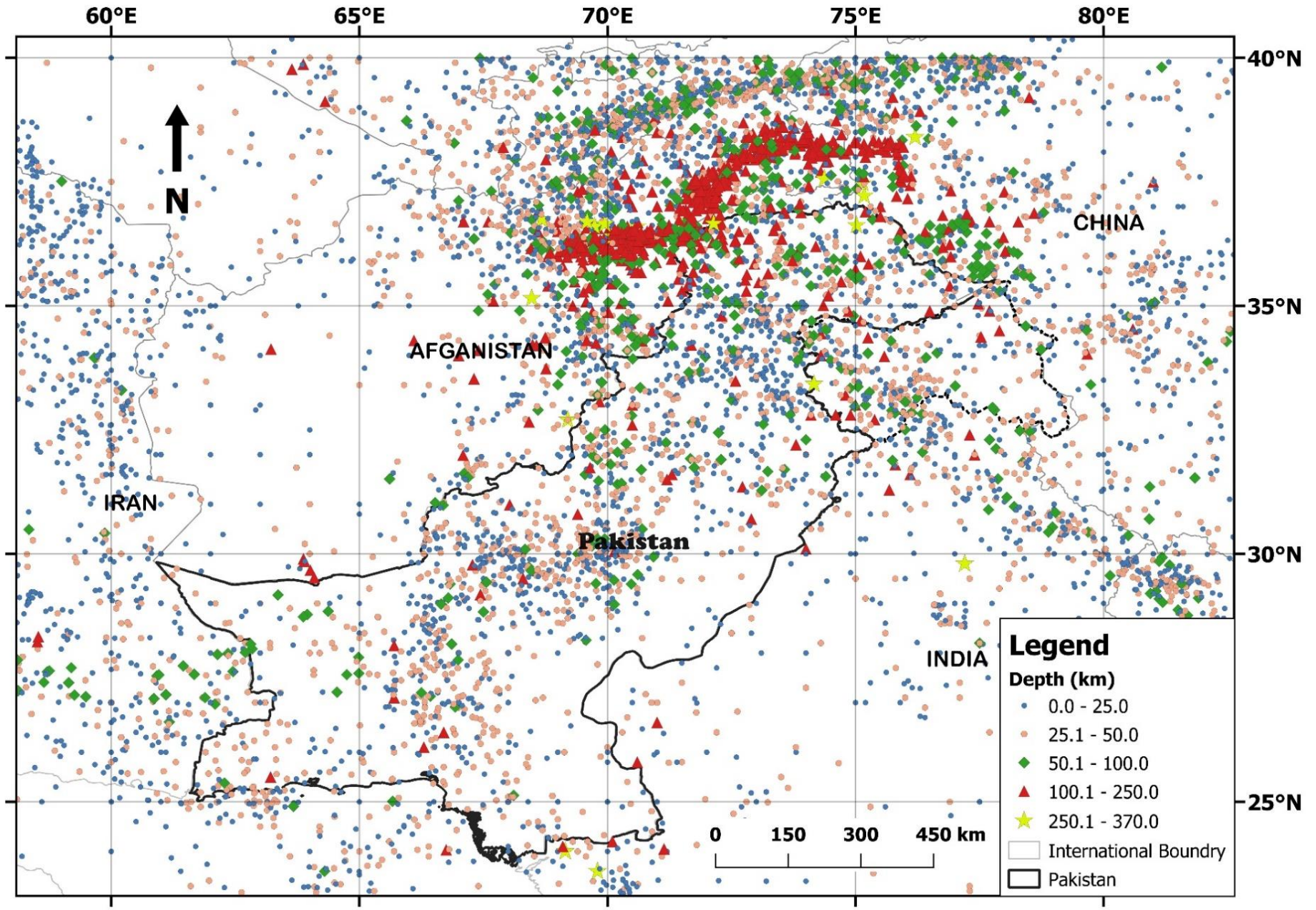


Chen *et al.*, 2000
Khan *et al.*, 2018
Apel *et al.*, 2006


60°E
65°E
70°E
75°E
80°E
40°N
35°N
30°N
25°N
N
AFGANISTAN
IRAN
Pakistan
CHINA
INDIA
0
150
300
450 km
Legend
Years
AD 10 - 1900 CE
1900 CE - 1964 CE
1964 CE - 2018 CE
Mgnitude (Mw)
4.00 - 5.00
5.10 - 6.00
6.10 - 7.00
7.10 - 8.00
8.10 - 8.50
International Boundry
Pakistan

Seismogenic Depths

Determination of focal depths of earthquakes is extremely important (Maggi, Priestley and Jackson, 2002)

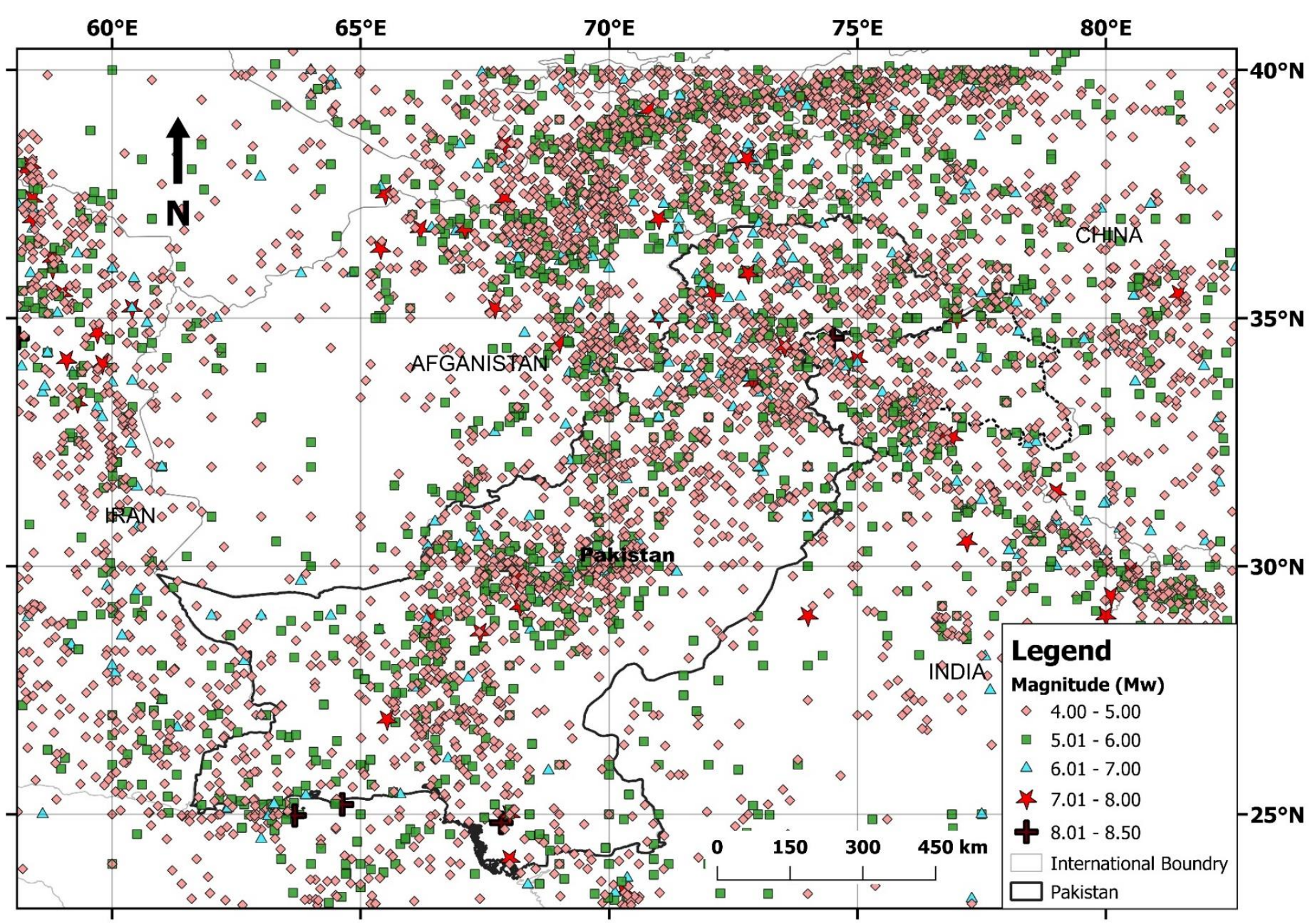


Historical Seismicity

Shallow Earthquakes

Depth < 50 km

Source: Rahman et al. (2021)

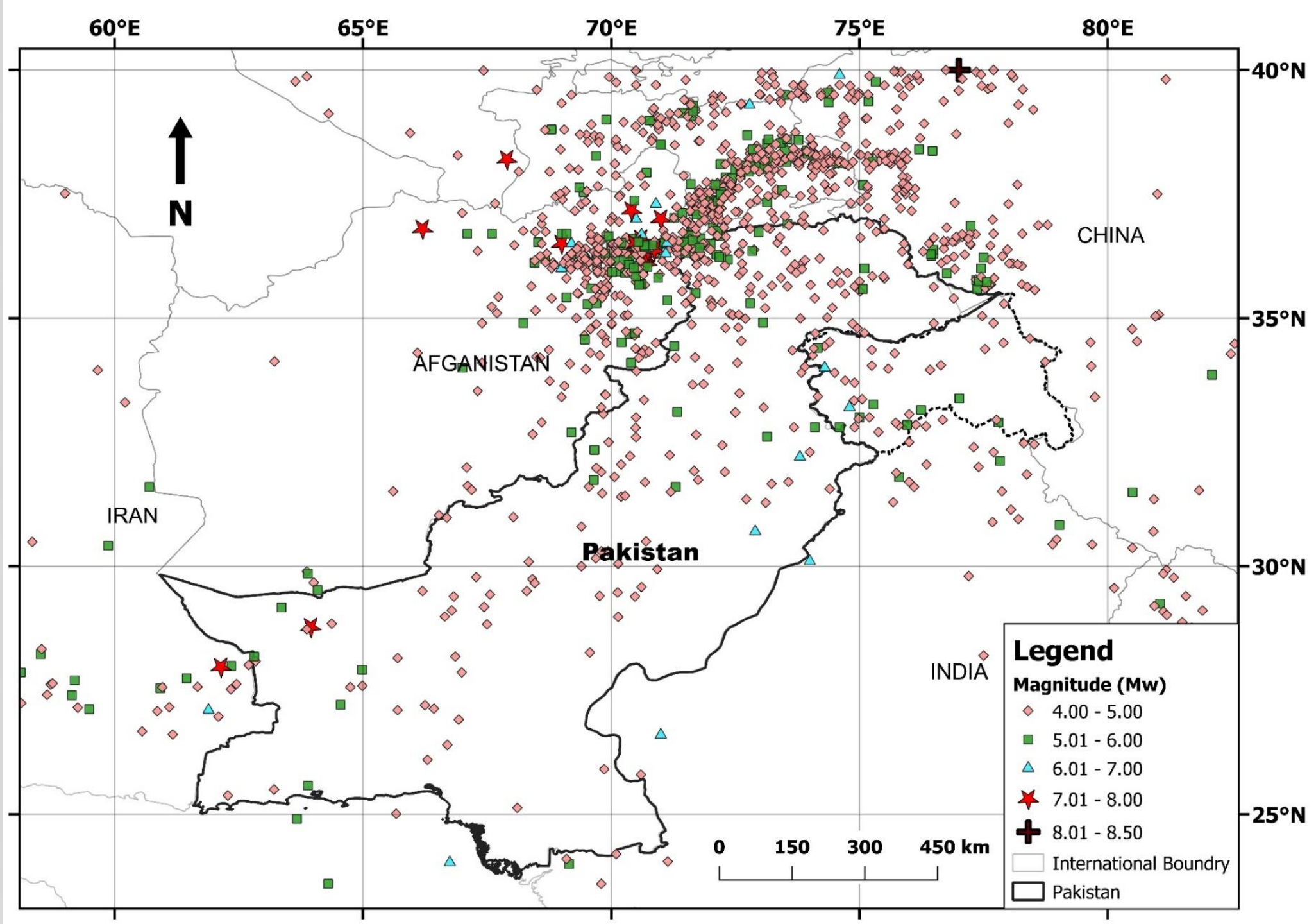


Historical Seismicity

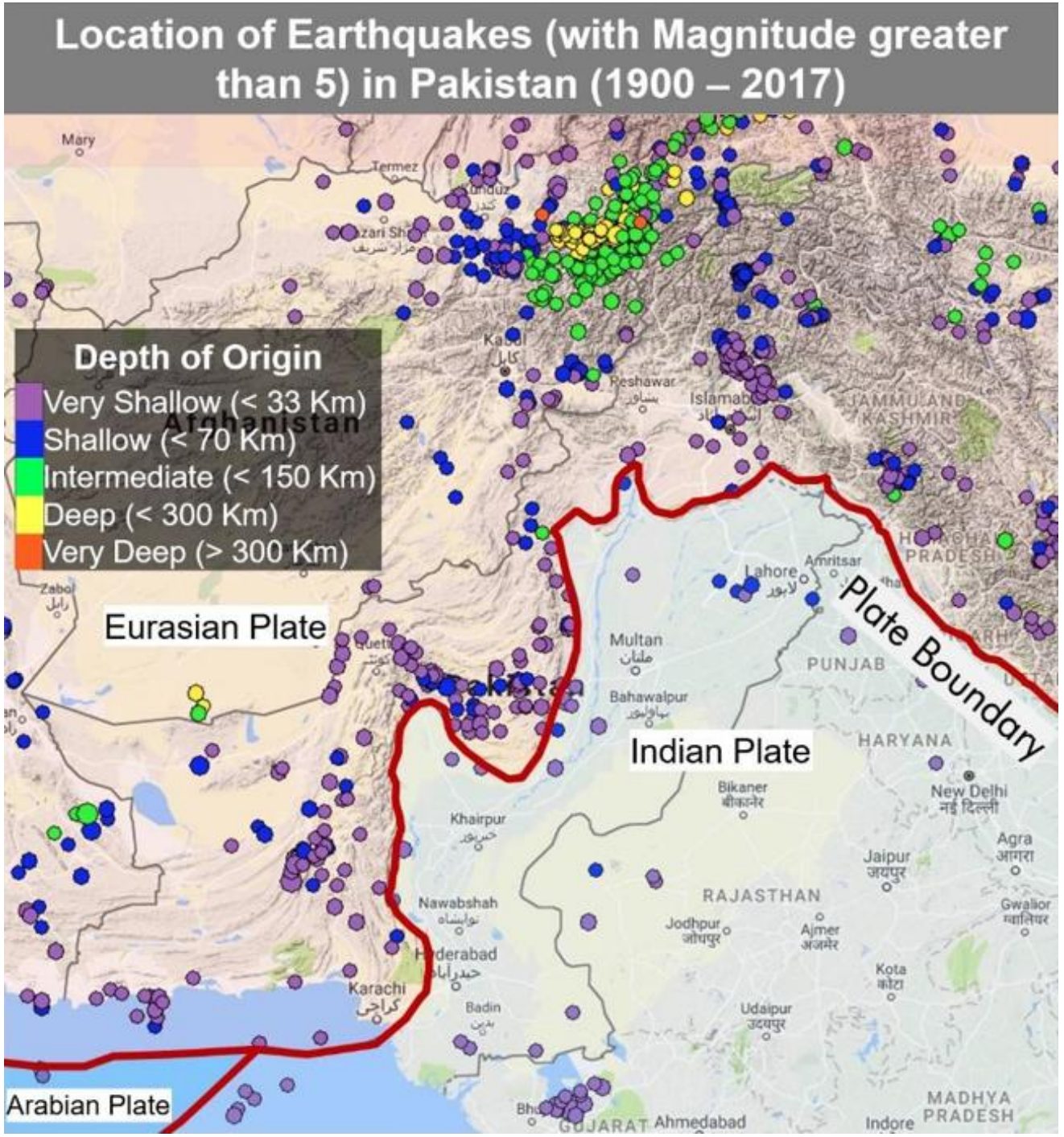
Deep Earthquakes

Depth > 50 km

Source: Rahman et al. (2021)



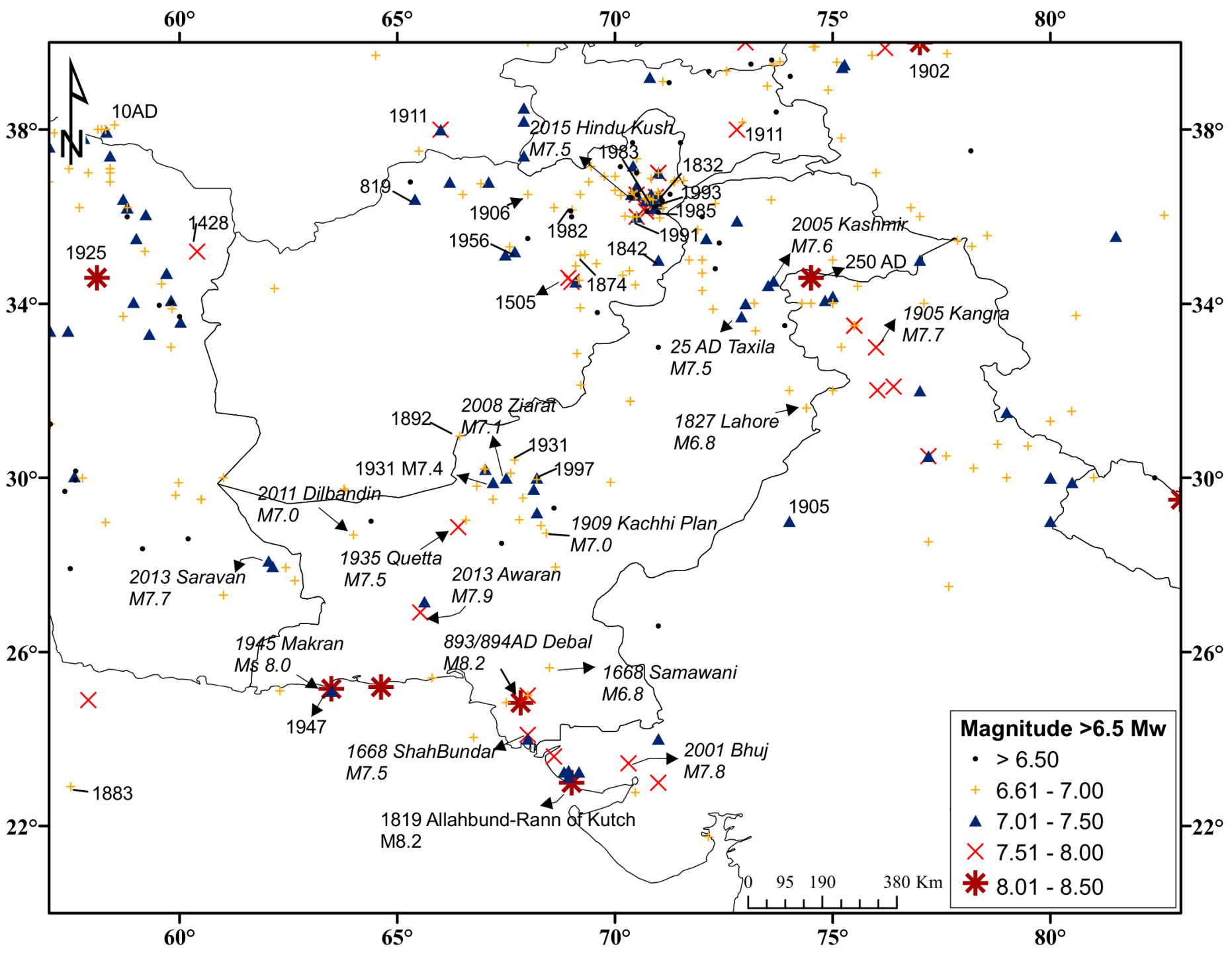
Seismicity of Pakistan



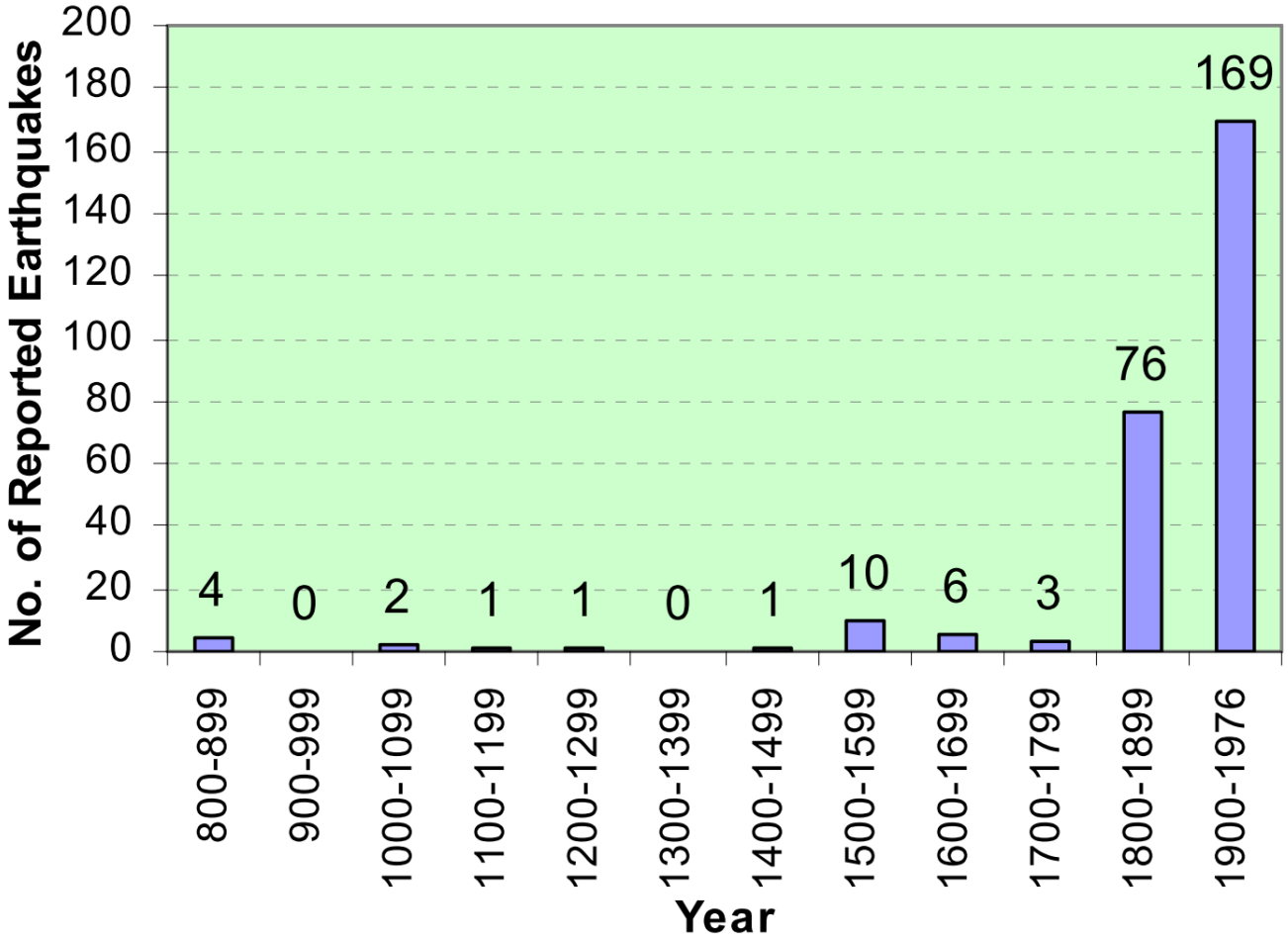
Earthquake (M 6.5+)

Spatial Distribution

Source: Khan S. et al., 2018



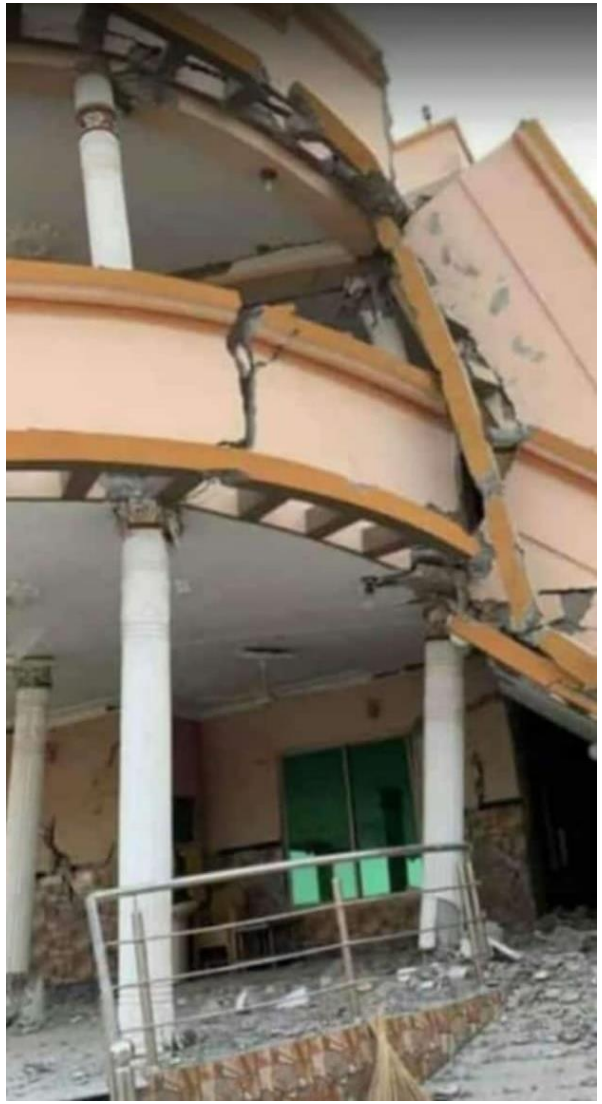
Development of Earthquake Catalogues for Pakistan



Source: Shah M. A., 2011

How safe is our infrastructure against earthquakes?

Date	Locality, district, or province	Mag.	Deaths	Injuries
2019-09-24	New Mirpur, Azad Kashmir	5.6 Mw	40	852
2015-10-26	Badakhshan	7.5 Mw	399	2,536
2013-09-24	Awaran District, Balochistan	7.7 Mw	825	700
2013-04-16	Balochistan	7.7 Mw	34	105
2008-10-29	Ziarat District, Balochistan	6.4 Mw	215	200
2005-10-08	Azad Kashmir, Balakot	7.6 Mw	86,000	69,000–75,266



M 7.6 Kashmir 2005 Earthquake Event

Source: Shah M. A., 2011

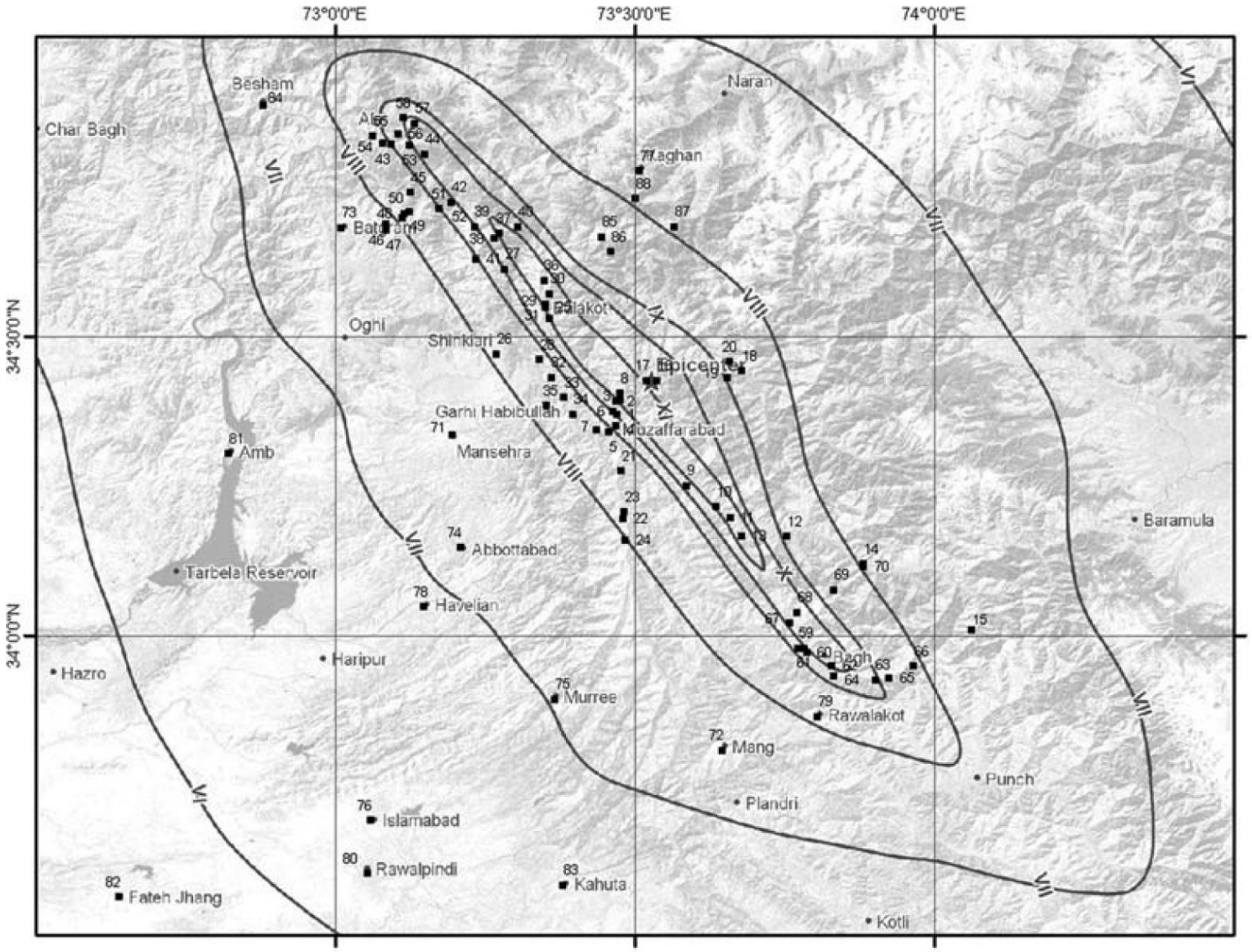


Figure 4-2. Map showing the distribution of MMI intensity observations of Muzaffarabad earthquake, along with the intensity isoseismals of the mainshock.

M 7.6 Kashmir 2005 Earthquake Event

Source: Shah M. A., 2011

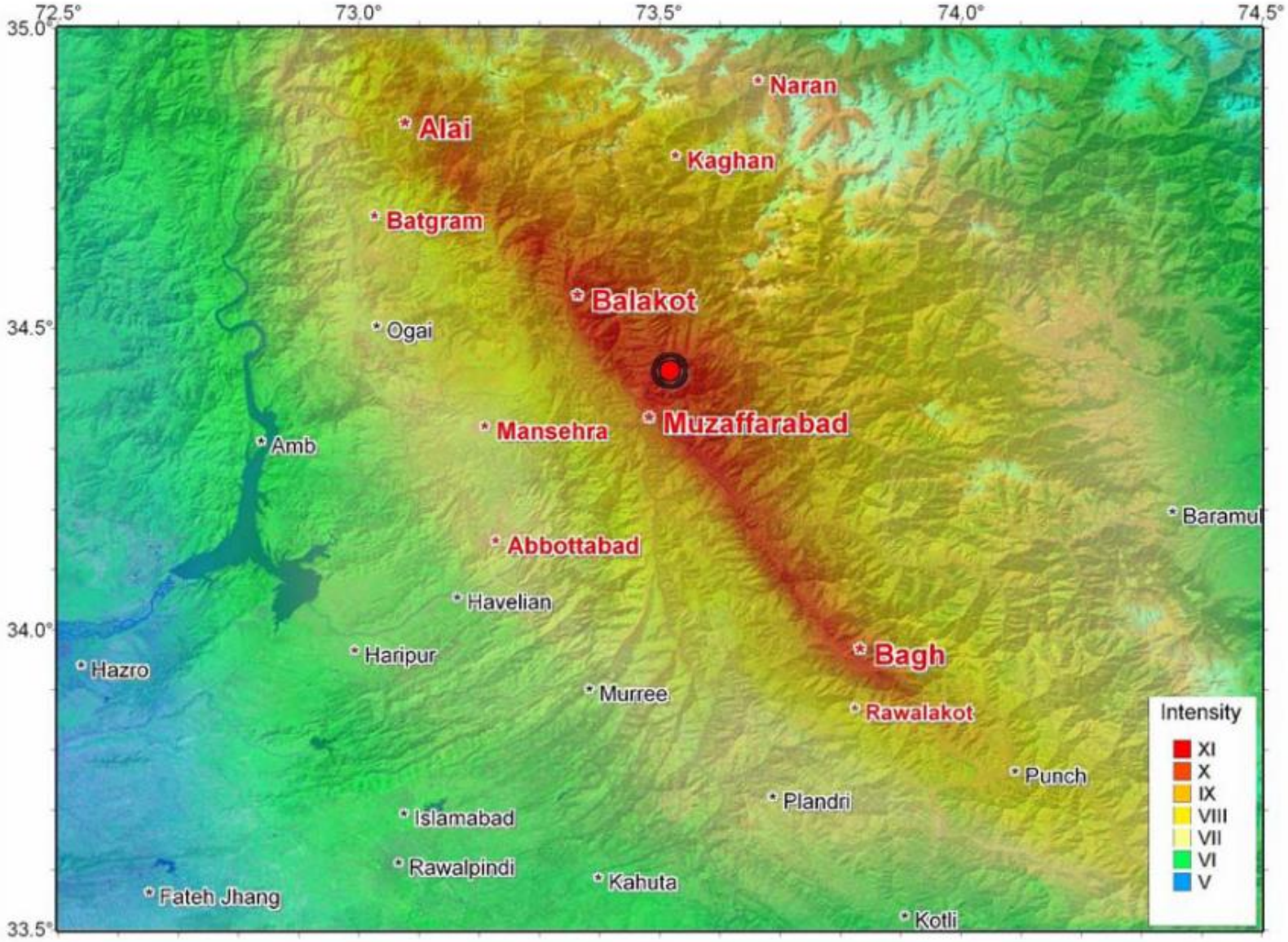
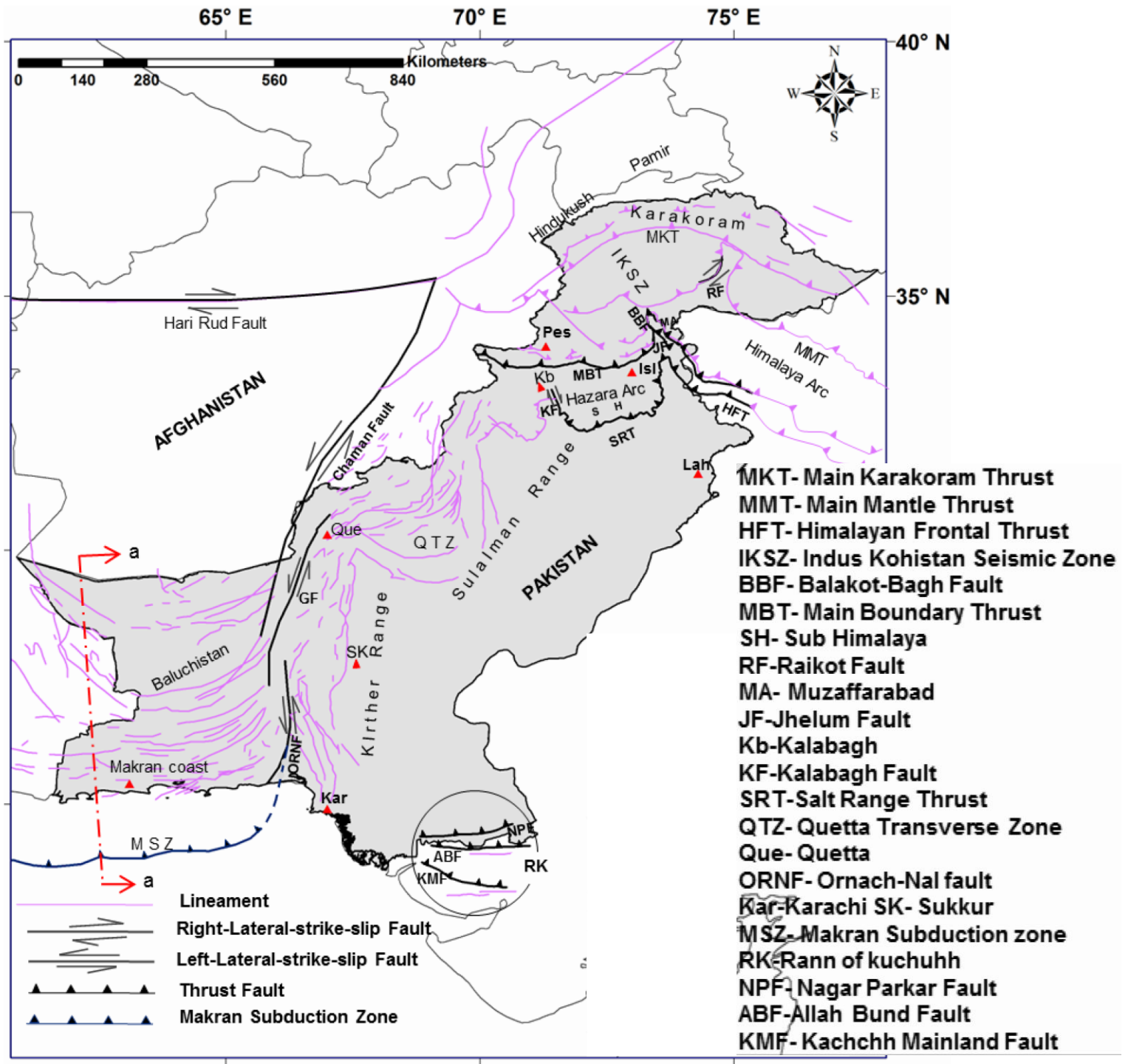


Figure 4-3. Modified Mercalli Intensity distribution of Muzaffarabad earthquake, based on the survey of the near-field made immediately after the mainshock

Regional tectonic setting of Pakistan

Source: Zaman 2016 (modified from Sarwar et al., 1979)



Regional tectonic setting of Pakistan

Source: Zaman 2016 (modified from Sarwar et al., 1979)

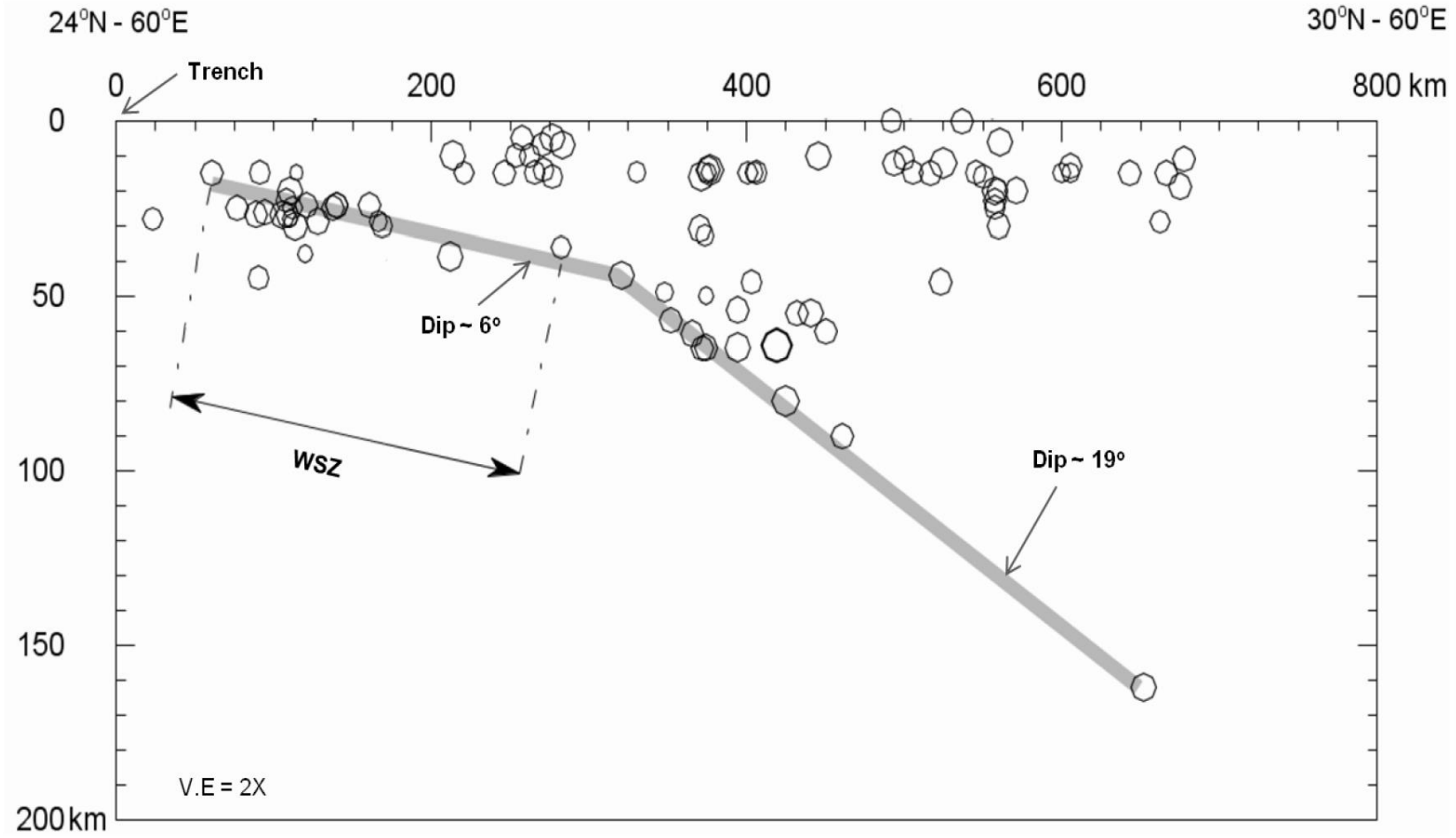
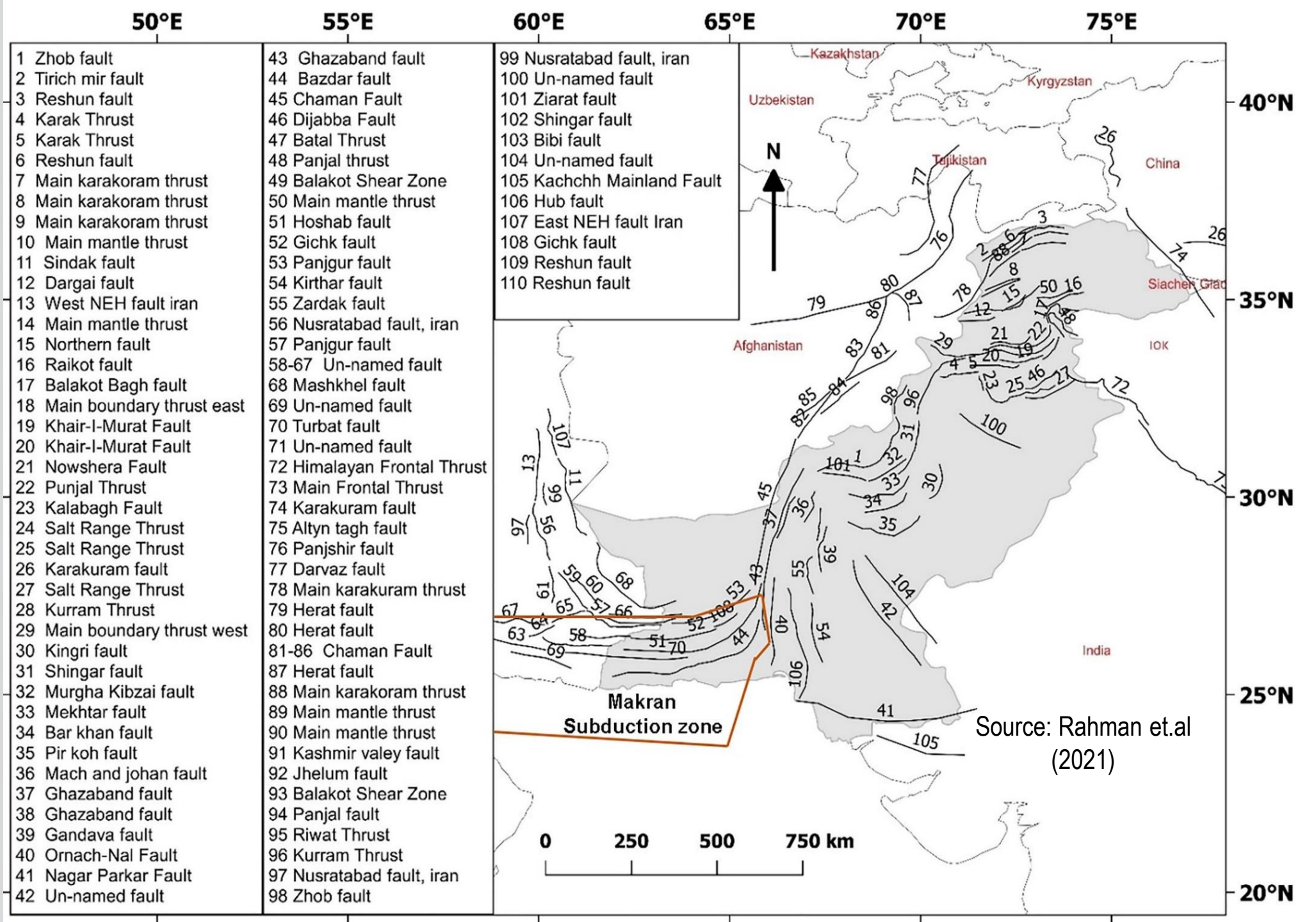


Figure 3.4 Cross section *a-a* through the Makran Subduction Zone along longitude 62°E, between latitudes 24°N and 30°N and covering events from longitudes 58°E to 66°E using the EHB catalogue updated to 2004. The thick grey line is the inferred upper boundary of the oceanic lithosphere of the Arabian Plate. WSZ is the width for the seismogenic zone (modified from Aldama-Bustos 2009)

Active Crustal Faults

(GEM Database)



Source: Rahman et.al (2021)

Active Crustal Faults

(GEM Database)

ID	Name	Fault type	Length (Km)	Slip rate (mm/year)			Dip angle	Rake angle	M_{max}
				Min	Mean	Max			
1	Zhob fault	Reverse	335.41	1	2	3	65	85	7.9
2	Tirich mir fault	Sinistral-Reverse	189.41	0.3	1.6	3	80	60	7.5
3	Reshun fault	Reverse	111.45	0.15	0.6	1	45.5	85	7.6
4	Karak Thrust	Reverse	68.76	1	1.5	2	46.5	85	7.3
5	Karak Thrust	Reverse	43.77	1	1.5	2	62.5	85	7
6	Reshun fault	Sinistral-Reverse	135.29	0.15	0.6	1	67.5	37	7.4
7	Main karakoram thrust	Reverse	129.81	0.15	0.6	1	65	82	7.4
8	Main karakoram thrust	Reverse	105.28	0.15	0.6	1	65	82	7.4
9	Main karakoram thrust	Reverse	121.52	0.15	0.6	1	65	87	7.4
10	Main mantle thrust	Dextral-Reverse	109.80	0.15	0.6	1	70	120	7.3
11	Sindak fault	Dextral	245.25	1	1.2	1.5	85	180	7.6
12	Dargai fault	Reverse	105.28	0.15	0.6	1	55	85	7.5
13	West NEH fault iran	Dextral	204.50	1	1.2	1.5	85	180	7.6
14	Main mantle thrust	Reverse	51.64	0.15	0.6	1	65	85	7.1
15	Northern fault	Reverse	68.12	0.15	0.6	1	65	85	7.2
16	Raikot fault	Reverse	142.71	0.15	0.6	1	65	85	7.5
17	Balakot Bagh fault	Reverse	64.38	0.15	0.6	1	52.5	85	7.3
18	Main boundary thrust east	Reverse	279.79	1	1.5	2	65	85	7.8
19	Khair-I-Murat Fault	Reverse	128.03	1	1.5	2	55	85	7.5
20	Khair-I-Murat Fault	Reverse	143.64	1	1.5	2	65	85	7.5
21	Nowshera Fault	Reverse	123.83	0.15	0.6	1	65	85	7.4
22	Punjal Thrust	Reverse	227.01	1	1.5	2	65	85	7.7
23	Kalabagh Fault	Dextral	41.97	1	1.5	2	65	177	6.9
24	Salt Range Thrust	Dextral-Reverse	63.64	1	1.5	2	67.5	120	7.1
25	Salt Range Thrust	Reverse	169.44	1	1.5	2	65	85	7.6

Active Crustal Faults

(GEM Database)

ID	Name	Fault type	Length (Km)	Slip rate (mm/year)			Dip angle	Rake angle	M_{max}
				Min	Mean	Max			
26	Karakuram fault	Normal	204.90	5.75	5	6.5	60	90	7.8
27	Salt Range Thrust	Reverse	158.90	1	1.5	2	65	85	7.6
28	Kurram Thrust	Reverse	72.39	1	1.5	2	65	85	7.2
29	Main boundary thrust west	Reverse	104.61	1	1.5	2	65	85	7.4
30	Kingri fault	Sinistral-Reverse	111.01	1	2	3	70	30	7.3
31	Shingar fault	Reverse	86.59	1	2	3	65	85	7.3
32	Murgha Kibzai fault	Reverse	124.22	1	2	3	65	85	7.4
33	Mekhtar fault	Reverse	202.56	1	2	3	65	85	7.7
34	Bar khan fault	Reverse	139.88	1	2	3	65	85	7.5
35	Pir koh fault	Reverse	236.83	1	2	3	65	85	7.7
36	Mach and johan fault	Reverse	96.68	1	2	3	65	85	7.4
37	Ghazaband fault	Sinistral	193.97	1	3	5	67.5	0	7.7
38	Ghazaband fault	Sinistral-Reverse	128.55	1	1.8	2.5	67.5	37	7.5
39	Gandava fault	Sinistral-Reverse	133.35	1	1.5	2	70	30	7.4
40	Ornach-Nal Fault	Sinistral-Reverse	247.78	1	3	5	67.5	37	7.8
41	Nagar Parkar Fault	Normal	540.70	0.15	1.6	3	65	272	8.1
42	Un-named fault	Normal	360.48	1	2	3	65	272	7.9
43	Ghazaband fault	Sinistral	285.16	1	3	5	67.5	0	7.9
44	Bazdar fault	Reverse	495.65	1	1.5	2	65	85	7.8
45	Chaman Fault	Sinistral-Reverse	429.21	4	6	8	67.5	37	8
46	Dijabba Fault	Reverse	107.44	1	1.5	2	65	85	7.4
47	Batal Thrust	Reverse	38.00	0.1	0.5	0.8	65	85	6.9
48	Panjal thrust	Reverse	54.43	0.15	0.6	1	65	85	7.1
49	Balakot Shear Zone	Sinistral-Reverse	21.09	0.1	0.6	1	67.5	37	6.6
50	Main mantle thrust	Reverse	107.32	0.15	0.5	0.8	65	85	7.4

Active Crustal Faults

(GEM Database)

ID	Name	Fault type	Length (Km)	Slip rate (mm/year)			Dip angle	Rake angle	M_{max}
				Min	Mean	Max			
51	Hoshab fault	Sinistral-Reverse	498.28	1	1.5	2	80	60	8
52	Gichk fault	Sinistral-Reverse	252.84	1	1.5	2	80	60	7.8
53	Panjgur fault	Sinistral-Reverse	253.56	1	1.5	2	80	60	7.7
54	Kirthar fault	Sinistral-Reverse	172.77	1	1.5	2	80	60	7.5
55	Zardak fault	Sinistral-Reverse	113.18	1	1.5	2	80	60	7.3
56	Nusratabad fault, iran	Dextral	172.66	1	1.2	1.5	85	180	7.5
57	Panjgur fault	Reverse	234.66	1	1	1	65	90	7.7
58	Un-named fault	Reverse	206.82	1	1	1	52.5	90	7.8
59	Un-named fault	Dextral	132.82	1	1	1	80	180	7.4
60	Un-named fault	Dextral-Reverse	104.11	0.69	0.8	1	70	150	7.3
61	Un-named fault	Dextral-Reverse	105.74	1	1	1	70	150	7.3
62	Un-named fault	Reverse	212.26	1	1	1	45	90	7.9
63	Un-named fault	Reverse	183.48	1	1	1	45	90	7.8
64	Un-named fault	Sinistral-Reverse	78.79	0.73	0.9	1	70	30	7.2
65	Un-named fault	Sinistral-Reverse	100.70	0.66	0.8	1	60	60	7.4
66	Un-named fault	Reverse	219.18	1	1	1	45	90	7.9
67	Un-named fault	Sinistral-Reverse	153.79	1	1	1	70	30	7.4
68	Mashkhel fault	Dextral-Reverse	348.89	1.5	1.9	2.21	70	150	7.8
69	Un-named fault	Reverse	180.82	1	1	1	45	90	7.8
70	Turbat fault	Reverse	358.20	1	1	1	45	90	8.1
71	Un-named fault	Reverse	173.92	1	1	1	45	90	7.8
72	Himalayan Frontal Thrust	Reverse	319.58	10	15	21	60	90	8
73	Main Frontal Thrust	Reverse	416.75	10	15	21	60	90	8.1
74	Karakuram fault	Dextral	403.04	1	6	11	60	90	8.2
75	Altyn tagh fault	Sinistral	692.52	4	7	10	60	90	8.4

Active Crustal Faults

(GEM Database)

ID	Name	Fault type	Length (Km)	Slip rate (mm/year)			Dip angle	Rake angle	M_{max}
				Min	Mean	Max			
76	Panjshir fault	Normal	419.44	2	3	4	60	275	8.1
77	Darvaz fault	Sinistral-Normal	407.11	2	3	4	70	315	8
78	Main karakuram thrust	Normal	239.04	1	1.5	2	80	275	7.7
79	Herat fault	Dextral	401.70	0.75	1.9	3	70	170	8.1
80	Herat fault	Reverse	50.26	0.2	1.1	2	70	70	7.1
81	Chaman Fault	Sinistral-Normal	168.65	1	2.5	4	70	315	7.7
82	Chaman Fault	Sinistral-Normal	211.27	1	3.4	5.8	70	315	7.8
83	Chaman Fault	Sinistral-Normal	171.39	1	3.5	6	70	315	7.6
84	Chaman Fault	Sinistral-Normal	142.32	1	2.2	3.5	70	315	7.6
85	Chaman Fault	Sinistral-Normal	137.90	1	2.2	3.5	70	315	7.6
86	Chaman Fault	Sinistral-Normal	92.85	1	3.5	6	70	315	7.4
87	Herat fault	Normal	98.92	0.2	1.1	2	70	272	7.4
88	Main karakoram thrust	Sinistral-Reverse	111.68	0.15	0.6	1	67.5	37	7.4
89	Main mantle thrust	Sinistral	45.09	0.15	0.6	1	70	0	6.9
90	Main mantle thrust	Reverse	34.95	0.15	0.6	1	65	85	6.9
91	Kashmir valey fault	Reverse	48.68	0.15	0.6	1	65	85	7.1
92	Jhelum fault	Reverse	50.49	0.15	0.6	1	55	104	7.1
93	Balakot Shear Zone	Reverse	26.95	0.5	0.8	1	55	104	6.8
94	Panjal fault	Reverse	44.99	0.15	0.6	1	65	85	7
95	Riwat Thrust	Reverse	80.79	0.15	0.6	1	65	85	7.3
96	Kurram Thrust	Reverse	153.71	1	1.5	2	65	85	7.5
97	Nusratabad fault, iran	Dextral	80.92	0.5	0.8	1	85	180	7.2
98	Zhob fault	Reverse	92.71	1	1.5	2	65	85	7.3
99	Nusratabad fault, iran	Dextral	63.45	0.5	0.8	1	85	180	7.1

Active Crustal Faults

(GEM Database)

ID	Name	Fault type	Length (Km)	Slip rate (mm/year)			Dip angle	Rake angle	M_{max}
				Min	Mean	Max			
100	Un-named fault	Normal	202.26	1	2	3	65	272	7.6
101	Ziarat fault	Reverse	127.70	1	2	3	65	85	7.4
102	Shingar fault	Reverse	76.99	1	2	3	65	85	7.3
103	Bibi fault	Reverse	91.56	1	1.5	2	65	85	7.4
104	Un-named fault	Normal	323.91	1	1.5	2	65	272	7.8
105	Kachchh Mainland Fault	Normal	261.97	0.15	1.6	3	65	272	7.8
106	Hub fault	Reverse	324.27	1	2	3	65	85	7.9
107	East NEH fault Iran	Dextral	137.96	1	1.2	1.5	85	180	7.4
108	Gichk fault	Reverse	75.88	1	1.5	2	65	85	7.4
109	Reshun fault	Reverse	98.28	0.15	0.6	1	55	85	7.4
110	Reshun fault	Sinistral-Reverse	70.83	0.15	0.6	1	65	37	7.2

Thank you for your attention