A note on the Kangra $M_s = 7.8$ earthquake of 4 April 1905

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Although most recent Himalaya seismic hazard studies adopt the $M_s = 8.0$ magnitude assigned to the 4 April 1905 Kangra earthquake in 1954 by Gutenberg and Richter, subsequent investigators have proposed magnitudes in the range $7.5 < M_s < 8.6$. On his worksheet Gutenberg calculates a magnitude of $M_s = 7.7$ using data from 15 teleseismic Milne records, yet he notes inexplicably at the base of the page, $M = 7.8$, and in a marginal note $M = 7.9$, a value that is rounded upwards by Gutenberg and Richter to $M_s = 8.0$. We confirm his original analysis, but find that the inclusion of 4 additional Milne data reduces the magnitude to $M_s = 7.54 \pm 0.23$. A more refined magnitude analysis using data from 6 stations for which we may estimate station corrections confirms a M_s magnitude of 7.83 ± 0.18. The reduced magnitude for this event suggests that more of the western Himalaya plate boundary remains unruptured than hitherto supposed.

THE Kangra earthquake of 4 April 1905 in the north-west Himalaya was the first of several devastating 20th century earthquakes to occur in northern India. The Punjab Government estimated that more than 20,000 of its ≈ 375,000 epicentral population were killed, and that 100,000 buildings were destroyed by the earthquake[1]. Farming was disrupted by the loss of 53,000 domestic animals and extensive damage to a network of hillside aqueducts that had been constructed over many generations. The economic costs of recovering from the earthquake were estimated at 2.9 million (1905) rupees.

Although this earthquake is not the only severe event known in the western Himalaya, it has the largest death toll[2] and is the first to have occurred since the development of instrumental seismology. Gutenberg and Richter[3] published a magnitude of $M_s = 8$ for the 1905 event and Richter[4] characterized it further as one of the four great Himalayan earthquakes to have occurred in the past 200 years. Subsequent estimates for the magnitude of the event range from $M = 8.6$ (ref. 5) to $M_s = 7.5$ (ref. 6).

The severe human and economic effects of the earthquake, combined with its inferred $M = 8$ status have uniquely influenced our understanding of seismic hazard in the western Himalaya. For example, Seeber and Armbruster[7] interpret the earthquake to have ruptured a 280×100 km^2 area, that when combined with the inferred rupture areas of the 1897, 1934 and 1950 earthquakes implies that half of the 2000-km-long Himalayan arc has been ruptured by these great earthquakes. The rupture of the remaining half of the Himalayan Arc in future $M = 8$ earthquakes to the west and east of the Kangra rupture zone poses a significant seismic hazard to the greatly increased population that now inhabit the plains fronting the Himalaya. However, were the instrumental magnitude of the earthquake to have been overestimated, a yet larger area of the Himalaya would potentially remain unruptured.

The estimated magnitude of the Kangra earthquake has also influenced seismological thinking on the largest credible earthquake that might occur in the western Himalaya. Moderate earthquakes occur every few decades along the small circle that defines the southern edge of the Tibetan Plateau[8], but no historical earthquakes have ruptured the surface along the Main Frontal Thrusts bordering the Himalayan foothills. The 1905 event produced no frontal rupture, raising concerns that yet larger events may be responsible for surface ruptures that have caused surface slip on the main frontal faults[9].

Much of what is known about the location and effects of the 1905 earthquake comes from the detailed reports of Middlemiss[10,11]. His epicentral intensity distribution shows two regions separated by about 200 km, one around Kangra and another around Dehra Dun, to which he assigns maximum intensities of X and VIII on the Rossi–Forel (RF) scale, respectively. These two regions have been interpreted by later writers either as the rupture of a 300 km long fault zone along the NW-SE trending boundary of the Himalaya, or as the rupture of two smaller segments that broke sequentially. A reappraisal of Middlemiss'[12] data, that is still in progress, and new macroseismic and instrumental information, however, suggest that (i) much of the evidence for this double epicentral

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region is an artifact arising from the way macroseismic observations have been interpreted; (ii) Middlemiss' intensities are inflated, and (iii) the magnitude of the event did not exceed $M_s = 7.8$. In what follows we shall be concerned here only with the general problems relating to the assessment of intensity of historical earthquakes in India, with the use of intensity distribution for the estimation of magnitude, and with the calculation of the surface-wave magnitude of the Kangra earthquake.

Macroseismic location

With historical earthquakes in India as elsewhere, reports from a few large towns provide most of the macroseismic information, with little additional data from rural areas. The larger the urban centre affected, the greater the detail with which damage is reported. This biases perceived damage towards urban centres and sites that suffered loss of life, and makes it difficult to assess the true extent and location of the epicentral region.

The macroseismic location of the epicentral region or regions of the Kangra earthquake was assessed by Middlemiss[10,11] and also by Christensen and Ziemendorff[13]. These authors selected the highest observed intensities to identify isoseismal intervals (Figure 1). A re-appraisal of these maps and the procedure used to draw them, which is still in progress, raises several reservations about the value of the intensities assigned, and the interpretation of the higher isoseismals drawn by these authors, reservations expressed earlier by Molnar[14]. Middlemiss' first account written within months of the earthquake in 1905 defines only isoseismals exceeding intensity VII. His second account published five years later provides additional details of these higher intensity observations but makes no attempt to revise his earlier contours. In this second account, Middlemiss extends the isoseismal contours to the limits of perception of the earthquake (an area of more than 3.8 million km^2) and includes a listing of macroseismic aftershocks.

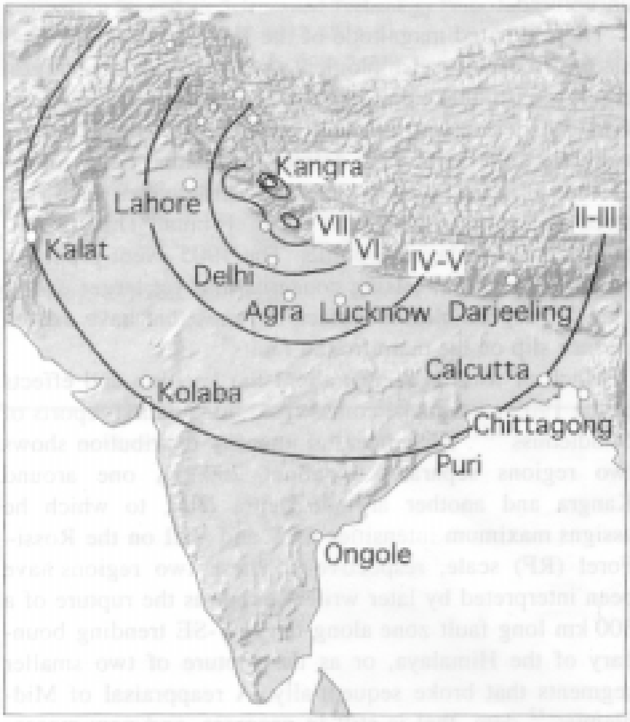


Figure 1. Location map and far field effects of the 1905 Kangra earthquake with Rossi–Forel isoseismal contours[10].

The higher isoseismals are important because they define the epicentral region of the event, and were drawn on the RF scale with a fine detail that we feel is not warranted by the volume and quantity of information available. Also, the intensities assigned appear to be grossly inflated. The reason for this is that in the RF scale most of the criteria for higher intensities are of limited value or are irrelevant, e.g. for intensity X the criteria are disturbance of strata, fissures in the earth's crust and rock-falls from mountains; for intensity IX, partial or total destruction of some buildings; while for intensity VIII, fall of chimneys and cracks in walls of buildings. For intensity VII, the criteria are overthrow of movable objects, fall of plaster, ringing of church bells and general panic without damage to buildings.

The RF scale was designed at the turn of the 20th century for earthquakes in Europe affecting a built environment which differs considerably from that in northern India. Construction methods in northern India differ from those in Europe. Local houses in the plains were of mud-wall or adobe-brick construction covered with flat and heavy roofs, consisting of a rough boarding covered with tamped earth. In mountain villages houses were built with rubble-stone masonry, laid in clay mortar, often the roof of one house being the yard of the house above. In large villages and towns, the majority of houses, one to two stories high, were built chiefly of wood, while properly-worked stone masonry construction was used mainly for public buildings, places of worship and forts. Better houses on the outskirts of towns and in a few large villages were often detached and surrounded by a garden and a high wall. Elsewhere houses were built close together in clusters, separated by narrow, winding alleys, and in some cases on sloping ground.

For large earthquakes in India or in the Middle East, the assessment of intensity in the RF scale in the near-field becomes judgmental and quite often unduly subjective. With the majority of the rural building stock in India being highly vulnerable, damage is effectively the same at intensity VI, VII or VIII (RF), because at intensity VI (RF) all adobe and rubble masonry houses are damaged beyond repair. Damage to any village or town thus appears equally, but no more, damaged at the so-called higher intensity, despite Middlemiss reserving intensity X for total flattening of a village. Because of this saturation effect for low quality construction it becomes impossible to determine how strong or light a shock would be necessary to cause heavy damage or destruction. The same comment applies to secondary effects such as landslides, rockfalls and soil failure, criteria in the RF scale for higher intensities that are of limited value, and in the case of the Kangra earthquake, misleading. As a consequence, with damage statistics totally lacking and descriptions being brief and stereotyped any attempt to assess RF intensities VII or greater can be subjective. Intensity reports from areas surfaced by recent sediments are typically amplified by liquefaction effects that conspire to increment moderate intensity shaking towards the levels where the RF intensity scale saturates. A consequence of this saturation in the damage scale is that only for sites removed from the epicentral area are damage assessments suitable to assess RF intensities below VII.

The Medvedev–Sponheuer–Karnik (MSK) scale overcomes some of these problems by identifying intensity using a combination of construction methods, and by grading the severity of damage to those structures on a scale of 1–5. Direct comparison between intensities on the two scales must be made with caution because intensities greater than V are inflated by one unit on the RF scale with respect to the MSK scale. Moreover, rockfalls, slides and ground cracks, which in north-west India may occur without shaking during earthquakes, are not indicators of high intensity in the MSK scale.

A typical feature of the intensity distribution of shallow and intermediate depth earthquakes originating in north-west India is the southward extension of lower isoseismals by hundreds of kilometres to the south and their abbreviation to the north. That intensities attenuate slower southwards is attributable to the differing attenuation characteristics of ancient continental craton compared to tectonically complex Himalayan and Tibetan crusts. Consequently, calibration functions for magnitude must be derived separately for the two regions, although data from the north of the boundary zone are invariably sparse. The Kangra earthquake was felt within a SE-facing semicircular radius of 900 km, from Gilgit to Calcutta along the Himalayan arc, and from Ongole to Cambay and Kalat southwards. No felt reports are available for more than 50 km NE of Kangra.

A feature of the reported intensity distribution alluded to the above is the isolated RF intensity VIII contour near Dehra Dun. Official and newspaper reports were initially compiled by Middlemiss and his colleagues after the earthquake to estimate the extent of the damaged region, and these were supplemented by a inspection traverse over part of the identified region to verify the damage (Figure 2). Kangra town and its nearby European structures were severely shaken and many of the district administrators killed. The Dehra Dun region was also populated by a large European community who articulated the perceived effects of the earthquake in considerable detail to the press and to the investigative team in subsequent damage reports. The region between Kangra and Dehra Dun was not inspected in detail and was sparsely populated by buildings of variable quality suitable for distinguishing between RF intensity values. Few accounts of perceived shaking were elicited or offered in this

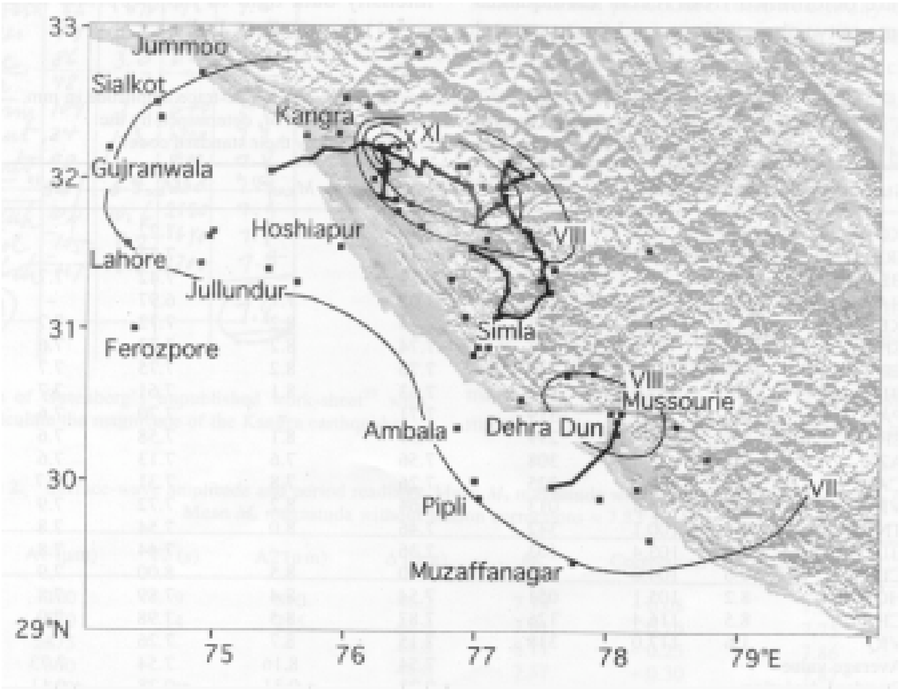


Figure 2. Location map of near-field intensity distribution[10]. Solid squares indicate locations where Rossi–Forel intensities were estimated, and bold angular discontinuous lines show paths followed by Middlemiss and corresponding authors in estimating epicentral damage.

region. We thus follow Molnar[14] in admitting that the basis for closing the RF VIII contour west of Dehra Dun is weak. Although we consider that intensities estimated within this contour are too high we do not consider this issue in detail here.

Instrumental location

Early instrumental locations on a global scale are necessarily inexact because readings in station bulletins were hampered by lack of accurate time and phase identification. For the Kangra earthquake there exist phase readings from 66 seismographic stations world wide which recorded the event, 33 stations operating Milne undamped penduli, 6 damped Wiecherts and the remaining stations operating a variety of lightly damped recorders[15,16]. Szirtes[16] calculated the epicentre at 32.10N, 76.30E, close to the town of Kangra, and Gutenberg and Richter[3] adopted an epicentre at 33.00N, 76.00E.

Intensity magnitude

The problem of epicentral location from intensity observations is intimately connected with that of assessing the magnitude of the earthquake. The intensity magnitude M_{i} of an historical earthquake may be assessed from the size of the areas over which the shock was felt with different intensities using an expression of the following form:

$$M_{\mathrm{i}} = \mathrm{A} + \mathrm{B}(I_{\mathrm{i}}) + \mathrm{C}(ri_{\mathrm{i}}) + \mathrm{D}\log(r_{\mathrm{i}}) + \mathrm{F}p, \qquad (1)$$

in which p is 0 for mean values and 1 for 84 percentile. Constants A to F are determined from recent earthquakes for which both intensity observations and instrumental determination of magnitude are available. In this equation, unlike in other empirical calibration formulae that have been derived for an attenuation model assuming a point source, I_{i} is the intensity at a source distance r_{i} and not at an epicentral distance (d) from the focus of an earthquake. At short distances from small magnitude, shallow earthquakes or at large distances from large ones, $r \approx d$ and the point source model is satisfied. For this reason the derivation and use of eq. (1) should be restricted to intensities (MSK) of less than VIII. For large earthquakes ($M_{\mathrm{s}} > 7$), the distance should be measured from the nearest point on the causative fault.

As far as we are aware, no regional calibration of the constants in eq. (1) is available for surface-wave magnitudes based on isoseismal information for northern India. Previous estimates of the size of the Kangra earthquake from its mapped isoseismal areas have been based upon assumptions about similarities between northern India and other cratonic areas of the world where these calibrations are available. Using the calibration constants derived for continental areas such as North America and Australia[17] a wide range of possible intensity magnitudes (M_{i}) have been obtained for the Kangra earthquake: Middlemiss' RF intensity VIII and VII regions yield magnitudes $7.5 > M_{\mathrm{i}} > 7$ whereas his RF intensity V to VII areas yield magnitudes $8 > M_{\mathrm{i}} > 7.5$ (ref. 18). The 1934 Bihar–Nepal earthquake and the 1897 Assam–Shillong earthquake do not exhibit this large variance in intensity magnitude. Hence, the spread in intensity magnitude for the Kangra event points more to potential errors in the estimation of intensity data than to inappropriate assumed constants in eq. (1) for northern India.

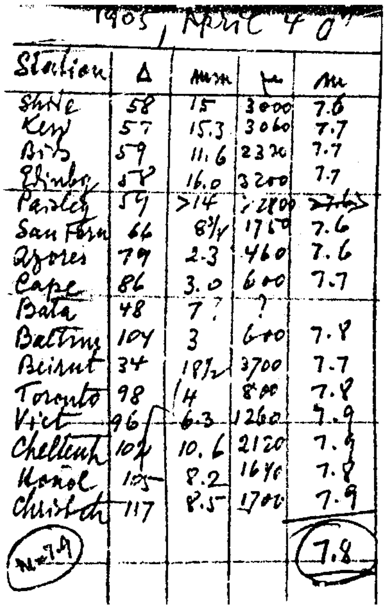
Table 1. Long-wave amplitude readings from Milne instruments. A is single-trace amplitude in mm, Δ is station distance in degrees, and Az is azimuth in degrees. M_{s} determined by the referenced method. The seismic stations are identified by their standard code

Station	A (mm)	Δ°	Az°	M_{Mln}[22]	M_{KAN}[20]	M_{abe}[21]	M_{G}[19]
KOD	> 22.0	22.8	179	7.40	–	7.22	–
IRK	> 20.0	28.0	038	7.47	–	7.33	–
BEI	18.5	33.6	283	7.54	–	7.42	7.7
BAT	3.5	48.9	137	7.02	7.7	6.97	–
KEW	15.3	56.7	313	7.74	8.2	7.72	7.7
SHI	15.0	57.4	313	7.74	8.2	7.72	7.6
EDI	16.0	57.4	319	7.76	8.2	7.75	7.7
BID	11.6	57.8	316	7.63	8.1	7.61	7.7
PAI	> 14.0	58.1	319	7.71	–	7.70	7.6
SFR	8.8	65.5	299	7.57	8.1	7.58	7.6
AZO	2.3	78.5	308	7.56	7.6	7.13	7.6
CAP	3.0	86.0	225	7.26	7.8	7.31	7.7
VIC	6.3	96.8	013	7.64	8.2	7.72	7.9
TNT	4.0	100.1	342	7.46	8.0	7.54	7.8
BLT	3.0	103.4	103	7.36	–	7.44	7.8
CLH	10.6	104.0	338	7.90	8.5	8.00	7.9
HON	8.2	105.1	051	7.54	8.4	7.89	7.8
CHR	8.5	116.4	126	7.87	8.5	7.98	7.9
VIQ	1.6	117.0	318	7.15	8.7	7.26	–
Average value				7.54	8.16	7.54	7.73
Standard deviation				± 0.23	± 0.31	± 0.28	± 0.11
Number of stations				19	14	19	15
Reference				This article	20	6	19

Surface-wave magnitude

Fortunately, an independent estimate of the magnitude of the Kangra earthquake is possible from a sparse set of global seismic stations. The surface-wave magnitude of the Kangra earthquake has been assessed by different authors between 7.5 and 8.6. The earliest magnitude determination was made by Gutenberg[19] from 15 Milne trace amplitudes. Figure 3 shows a facsimile of his unpublished work-sheet with the data he used to calculate M_G. The mean value of the 15 station magnitudes he used is 7.7, with a standard deviation of 0.1 magnitude units (Table 1). However, at the bottom of his table, Gutenberg writes $M_G = 7.8$, and in a marginal note $M = 7.9$. Neither the method he used to calculate M_G from Milne amplitudes nor the reason for which he increased his estimate is known. Gutenberg further increased the magnitude to 8, (probably a rounding off of 7.8) in his catalogue with Richter[3], and a value adopted by later workers.

A much larger magnitude of 8.6 was estimated by Duda[5]. This is the average value of long-period body (m_B P/S) and surface-wave (M_s) magnitudes calculated from amplitude readings of P, S, and L phases recorded by the Wiechert seismograph at Uppsala[5]. This estimate, obviously, is not a surface-wave magnitude.



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Station	Δ	mm	μ	M
Shide	58	15	3000	7.6
Kew	57	15.3	3060	7.7
Bid	59	11.6	2320	7.7
Edinbg	58	16.0	3200	7.7
Paisley	59	>14	2800	[illegible]
San Fern	66	8¾	1750	7.6
Azores	79	2.3	460	7.6
Cape	86	3.0	600	7.7
Bata	48	7?	?	
Baltim	104	3	600	7.8
Beirut	34	18½	3700	7.7
Toronto	98	14	800	7.8
Vict	96	6.3	1260	7.9
Chelten	104	10.6	2120	7.9
Honol	105	8.2	1640	7.8
Christch	117	8.5	1700	7.9
M=7.9				7.8

Figure 3. Facsimile of Gutenberg's unpublished work-sheet[19] with the data he used to calculate the magnitude of the Kangra earthquake.

Another estimate of 8.2 was made by Kanamori and Abe[20] (Table 1). This value was calculated from 14 maximum-trace amplitudes of surface-waves recorded by Milne penduli and from a global calibration formula derived by these authors. Abe and Noguchi[21], using an improved version of their calibration function and the same reading, calculated a rounded-off value of $M_s = 8$, a value that was further refined[6] and reduced to 7.5 (Table 1).

These diverse estimates of the magnitude of the Kangra earthquake are derived exclusively from readings of maximum trace amplitudes from undamped Milne recorders, using different calibration functions, and they vary between 7.5 and 8.2. The magnitude of the Kangra earthquake can be reappraised by two different methods and sets of instrumental data:

(i) In the first method, like Gutenberg, Kanamori and Abe we used Milne trace amplitudes, the values of which at different stations are given in Table 1, and a calibration formula derived exclusively from shallow earthquakes in the Middle East[22]. This procedure gives $M_{\mathrm{Miln}} = 7.54$ ($\pm$ 0.23) from 19 Milne stations, a value which is identical to the refined estimate by Abe and Noguchi[6].

(ii) In the second method, we used the original Prague formula together with ground amplitudes and periods of long waves recorded by six standard Wiechert seismographs operating at the time in Europe, following the same normal procedure followed today by ISC and NEIC to assess surface-wave magnitude. Table 2 gives the data used together with values for station corrections[23]. The resulting values for the surface-wave magnitude, with and without station corrections are $M_{\mathrm{Prag}} = 7.83$ ($\pm$ 0.18) and 7.83 ($\pm$ 0.05), respectively, which we believe to be the magnitude of the Kangra earthquake.

Discussion and conclusions

The Kangra 1905 earthquake has hitherto been assigned a range of magnitudes $7.5 < M_s < 8.6$ based on instrumental data, and $7 < M_i < 8$ based on the areas of isoseismals estimated by Middlemiss[10,11]. A reappraisal of the instrumental data with station corrections available for the event

Table 2. Surface-wave amplitude and period readings. Mean M_s magnitude with station corrections = 7.83 ± 0.18; Mean M_s magnitude without station corrections = 7.83 ± 0.05

Station	T1 (s)	A1 (μm)	T2 (s)	A2 (μm)	Δ (deg)	M_s	Correlation	Corrected M_s	Instrument
UPP	9	300	9	310	46.2	7.74	+ 0.08	7.82	Wiechert
POT	14	570	14	725	48.4	7.91	− 0.16	7.75	Wiechert
OSA	28	2875	–	–	48.8	8.11	− 0.25	7.86	Omori
LEI	13	300	–	–	48.8	7.57	+ 0.30	7.87	Wiechert
POL	12	500	11	400	49.9	7.86	–	7.86	Vincentini
GTT	10	350	10	350	50.3	7.82	+ 0.05	7.87	Wiechert
Mean and standard deviation including all stations						7.83 ± 0.18		7.84 ± 0.05	
Mean and standard deviation excluding POL/Vincentini						7.83 ± 0.18		7.83 ± 0.05	

yields a surface-wave magnitude of $M_s = 7.83 \pm 0.18$. A preliminary re-assessment of the intensity data itemized by Middlemiss suggests that the areas of isoseismal contours drawn by him and by others using his data are inflated. Thus both instrumental and macroseismic data appear consistent with $M_s = 7.8$.

The downsizing of the event has important consequences for earthquake hazard estimates in the western Himalaya. The rupture area appropriate for a $M_s = 7.8$ lies in the range 100×120 km^2 to 80×50 km^2 with 3–8 m of average slip. The longest dimension available for slip normal to the Himalayan arc, assuming rupture between the zone of moderate earthquakes bordering the southern edge of the Tibetan Plateau and the Himalayan frontal thrusts, is 80–100 km. Hence the greatest along-strike dimension for this event is of the order of 120 km, significantly less than the 280 km proposed by Seeber and Armbruster[7], but similar to an interpretation of the data by Molnar[14]. This suggests that the main rupture in 1905 could not have extended continuously from the Kangra region to the second region of high intensity mapped by Middlemiss near Dehra Dun. A recent re-evaluation of coseismic levelling and triangulation data from the Dehra Dun region indicates[24] that no horizontal displacements were detected in 1905, and that severe systematic errors contaminate the vertical levelling data that have hitherto been interpreted as evidence for significant slip. The absence of significant deformation supports the notion that rupture did not approach within 50 km of Dehra Dun (78°E). Moreover, since the Kangra earthquake did not result in the surface rupture of the main frontal thrusts at 76°E, it is possible that a larger magnitude earthquake may be necessary to cause these to slip. An alternative explanation, that creep or moderate earthquakes cause the observed cumulative offset of the frontal thrusts, is not consistent with inactivity of the frontal thrusts in the past two centuries.

The abbreviated rupture dimensions of the 1905 earthquake imply that less than 10–13% of the 1000 km region of the Himalaya west of the 1833 and 1934 Nepal–Bihar earthquakes has ruptured in a great earthquake in the past 200 years, and several additional great earthquakes appear to be necessary to rupture the remaining region of the western Himalaya[25].

The recurrence interval for earthquakes that rupture the Himalayan frontal thrusts in the Dehra Dun region (78°E) has been estimated as 290–980 years[9], appropriate for 5–10 m slip events driven by a convergence rate of 18–21 mm/yr (ref. 26). If we assume a random occurrence of western Himalayan earthquakes we should anticipate at least one great earthquake each century west of 86 degrees, yet the historic record does not appear to support this.

A 1000-year history of damaging earthquakes events is recorded in Kashmir[2] but recent events there appear to have been of moderate magnitude only[27]. Earthquakes in central Nepal in 1833 (ref. 18), and near 78°E in 1803 may have been similar to the 1905 event in Kangra. A possible conclusion is that earthquakes in the past two centuries have not been representative of infrequent great ($M_s > 8$) plate boundary events that could occur. Alternatively, it is possible that $M_s < 8$ events are characteristic of the mode of plate boundary slip, and that these events occur at 50–200 year intervals between 74° and 84°E. In view of the incompleteness of the earthquake record for this region, no final conclusion about recurrence periods and likely magnitudes can be made at this stage.

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1. Report, Punjab Government Press, 1907; Kaul, P. H., *Census of India*, 1911, p. 14.
2. Iyengar, R. N. and Sharma Devendra, *Earthquake History of India in Medieval Times*, Central Building Research Institute, Roorkee, India, 1998, p. 124.
3. Gutenberg, B. and Richter, C., *Seismicity of the Earth and Associated Phenomena*, Princeton Univ. Press, 1954, 2nd edn, 310 pp.
4. Richter, C., *Elementary Seismology*, W.H. Freeman, San Francisco, 1958, 768 pp.
5. Duda, S., *Tectonophysics*, 1965, **2**, 409–452.
6. Abe, K. and Noguchi S., *Phys. Earth Planet. Inter.*, 1983, **33**, 1–11.
7. Seeber, L. and Armbruster, J., in *Earthquake Prediction – An International Review* (eds Simpson, D. W. and Richards, P. G.), Maurice Ewing Series, Am. Geophys. Union, 1981, vol. 4, pp. 259–277.
8. Seeber, L. and Gornitz, V., *Tectonophysics*, 1983, **92**, 335–367.
9. Wesnousky, S. G., Kumar, S., Mohindra, R. and Thakur, V. C., *Tectonics*, 1999, **18**, 967–976.
10. Middlemiss, C. S., *Rec. Geol. Soc. India*, 1905 , **32**, 258–294.
11. Middlemiss, C. S., *Mem. Geol. Surv. India*, 1910, vol. 38, p. 405.
12. Ambraseys, N. and Bilham, R., A re-evaluation of the 4 April 1905 Kangra earthquake, 2000.
13. Christensen, A. and Ziemendorff, G., *Publ. Bur. Centr. Assoc. Int. Seismo. Ser. B.*, 1909, 121–128.
14. Molnar, P., *J. Geol. Soc. India*, 1987, **29**, 221–229.
15. Omori, F., *C. R. Seances 2me Reunion Commi. Perman. Assoc. Int. Seismol.*, 1907, 244–253.
16. Szirtes, S., *Publ. Bur. Centr. Assoc. Int. Seismol. Ser. A.*, Strassburg, 1909, 13–14.
17. Johnston, A., *Geophys. J. Int.*, 1996, **125**, 639–678.
18. Bilham, R., *Curr. Sci.*, 1995, **69**, 155–187.
19. Gutenberg, B., Work-sheets (NP/PG.106–116) (unpublished).
20. Kanamori, H. and Abe, K., *J. Geophys. Res.*, 1979, **84**, 6131–6139.
21. Abe, K. and Noguchi, S., *Phys. Earth Planet Int.*, 1983, **32**, 45–59.
22. Ambraseys, N. and Melville, C., *A History of Persian Earthquakes*, Cambridge Univ. Press, 1982.
23. Ambraseys, N. and Douglas, J., *Geophys. J. Int.*, 2000 (in press).
24. Bilham, R., *Geophys. J. Int.*, 2000 (submitted).
25. Molnar, P. and Pandey, M. R., *Proc. Indian Acad. Sci. (Earth Planet. Sci.)*, 1989, **98**, 61–70.
26. Bilham, R., Larson, K., Freymueller, J. and Project Idylhim members, *Nature*, 1997, **386**, 61–64.
27. Jones, E. J., *Rec. Geol. Surv. India*, 1885, **18**, 221–227.

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