

Kidd *et al.*<sup>15</sup> also state that much of the variation observed today arose some time ago and was present in the ancestral African population from which modern populations descended, and that all of these populations have had large effective population size, allowing them to maintain all the different haplotypes. This is consistent with the single migration of modern *Homo sapiens* out of Africa, and additional loss of variation as that initial non-African founder populations grew and expanded to the east and later into the Americas. Using nuclear DNA markers, Majumder *et al.*<sup>32</sup> also found that a major population expansion has taken place in India. It is also clear from the recent reports on Indian populations that India has played a vital role of being a major corridor in the out-of-Africa migration<sup>24,39</sup>. By and large, the present study using the same set of markers is concordant with the global survey of DRD2 locus<sup>16</sup>, affirming that India might have been in the path of this eastward migration. Since the gene investigated in the present study is expressed in the brain and has been associated with the risk for psychiatric illness, our findings may also provide some insight into complex issues of behaviour adaptations.

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## A note on early earthquakes in northern India and southern Tibet

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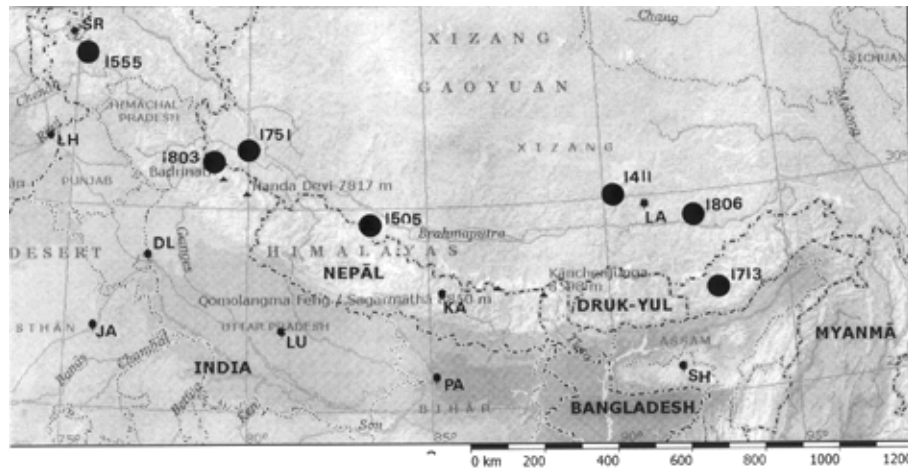
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**The scientific contribution in this communication is threefold: (i) the presentation of new evidence or early, pre-19th century large earthquakes in the Himalaya, (ii) the preliminary interpretation of data that have been identified up to now and (iii) that currently no forecast for the timing and magnitude of future large events is possible.**

THIS communication records a number of large, pre-1810 earthquakes in southern Tibet and northern India that are little known or do not appear in Western earthquake catalogues that are widely used for the assessment of seismic hazard and for the recurrence of large events in the region. The study area extends along the Himalayan arc, between 27–35°N and 78–95°E, i.e. from Bhutan in the east to northern Pakistan in the west (Figure 1).

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**Figure 1.** Location map of the study area showing general location of earthquakes described in this communication. DL, Delhi; JA, Jaipur; KA, Kathmandu; LA, Lhasa; LH, Lahore; LU, Lucknow; PA, Patna; SH, Shillong and SR, Srinagar.

It is not our intention at this stage of our research to undertake a detailed analysis, but rather to provide information to help further studies of the seismicity of the Himalayan arc. Extended summaries of these accounts which are based chiefly on primary information retrieved from the various sources quoted are given in Appendix 1.

Since we are obliged to study the seismic activity of southern Tibet and surrounding areas almost exclusively in terms of macroseismic effects, in order to assess intensities it is important to have an idea of the similarities and differences in environmental and building conditions with occidental regions, against which intensity scales have been calibrated.

Tibet is the highest country in the world; its inhabited areas vary from 3000 to 5000 m in height, and throughout most of the country, the extreme climate and high altitude decree a thin population based mainly on subsistence agriculture and herding, supplemented by trading.

The region where Tibetan dialects are spoken stretches in a band beginning in northern Pakistan, extending along the Himalayas and beyond, all the way to the western borders of China. In the western Himalayas, most of the main settlements, which seldom exceed the size of a small town, are situated in a series of widely separated valleys in which the river flows north to south, such as Purang, Mustang and Kyirong. Elsewhere people live in scattered villages wherever fertile fields can be irrigated and cattle grazed.

The further east one goes, the more plentiful do rainfall and trees become, and the more productive the land becomes. Most people live in villages, with only an occasional small town of a district governor's seat or market. Areas in the southern borderland such as Bhutan and Kongpo receive sufficient rains for heavy forestation, allowing more wood to be used for house building. Tribes of nomads lived to the north of the settled strip in

the vast 'Northern Plain' (Changthang) and at higher elevations above the southern arable areas.

The vulnerability of the building stock exposed to earthquakes in the region, which is needed for the assessment of intensities, varies enormously in space and time.

In the central provinces of Tibet, a few larger towns exist in alluvial valleys, such as Lhasa in Central Tibet, and Shigatse and Gyantse in southwestern Tibet (Tsang). Before the annexation by the Chinese in the 1950s, there were no paved roads to speak of throughout most of Tibet. People travelled mostly along footpaths, routes of local trade or long-distant east-west caravan routes to Kham and Tachienlu, the great entrepôt for the importation of Chinese tea.

A typical village house in many districts had two storeys, with the ground floor used as a stable for domestic animals; often an open courtyard was included on the ground floor. The flat roof above the first floor functioned as a third storey, used in the summer as a place to work. For a structure of this size, the four outer walls were normally made of adobe, atop a stone foundation. Windows only existed on the second storey and above.

Most of Tibet was dry enough to use roofs made from 10 to 15 cm of beaten and polished, sun-dried clay spread on fine brushwood and supported by split sticks that lay on poles 7 to 10 cm in diameter. These poles were spaced out upon cross-beams 20 to 30 cm thick, that ultimately rested on wooden pillars 20 to 30 cm in diameter. Metal nails were not used and wooden pins only rarely, with all joints dove-tailed. Since walls and wooden framework were largely independent, such a house could remain standing even after the collapse of one wall. The collapse of inner pillars would bring down the heavy central roof made of clay.

In some places near great monasteries, houses were limited to one storey in height for religious reasons.

Elsewhere, one-storey homes of rubble stone or adobe that could be made by a single person were inhabited only by the poorest classes in most districts. Village houses typically clustered together for mutual defence.

Monasteries are fortress-like, sited on hilltops, built with thick walls of stone laid in mud without many external windows, with internal sun-dried bricks walls. They are built mostly on rock with skyscraper-like sloping external walls and their down-slope facing walls rise precariously to tens of metres. A few special ornamental roofs are covered with heavy clay tiles, but much more commonly with beaten clay resting on a sequence of twigs, slats and rafters, as in normal houses.

In southeastern Tibet, near the borders with India in Arunachal Pradesh and Bhutan, Sikkim and Nepal, more wood was used in houses, chiefly to support the roof structure, with non-bearing walls of rubble masonry filling in the space between wooden supports, a method widely used in other parts of the Himalaya and the Northwest Frontier area in Pakistan<sup>1</sup>.

The main cause of earthquake fatalities for sedentary Tibetans was collapsing walls and roofs of their houses and monasteries. The danger of fatalities greatly increased after dark, when people locked themselves and their animals inside their houses as a precaution against robbers. During daytime they had a better chance to escape outside, or even if caught inside, survivors could be dug out from the rubble.

Nomads lived in tents and hence were immune to the usual threat posed by earthquakes in settled areas, though they could face fatal accidents if caught on a steep hill or from rockfalls or landslides.

In India, along the south-facing slopes of the mountain ranges, houses were made of rubble stone masonry or adobe walls, a construction similar to that in Tibet.

In the plains, rural houses were mostly *kuccha*, built chiefly of sun-dried mud, adobe bricks and lath. The usual type of bungalow was of poorly burnt bricks, very thick, with thatch roofs, which become particularly heavy during the monsoon period. After the 1870s, kiln brick structures laid in lime mortar were limited to churches, government, railway buildings and, in rural centres, chiefly to factories and tea estates.

At the turn of the 19th century, in towns, and to a lesser extent throughout rural areas, *pukka* or better built constructions were of kiln brick, and occasionally of stone, laid predominantly in clay mortar and plastered. The term *pukka* was generally used for more substantial houses, covered with corrugated sheets or thatch. However, in most cases, heavy damage to brick buildings was due either to weak construction or to differential settlement of their foundations. In villages in the plains, brick was used sparingly only for external walls, up to the window sill; the rest of the wall consisting of bamboo and lath or adobe, covered with corrugated sheets or thatch.

The preceding discussion shows that the vulnerability of the building stock exposed to earthquakes varies enormously. Tibetan style of buildings is not included in any of the intensity scales, which are chiefly designed for European conditions. There are few standard types of buildings over the area, and that such as did exist vary greatly in vulnerability, making it difficult to map out intensity according to any modern scale. This is compounded by the fact that macroseismic information is rather poor and subject to misinterpretation. This regional problem regarding intensity assessment is discussed elsewhere<sup>2</sup>.

For the period before ca. 1900, documents in Tibetan are almost the only sources that record earthquakes north of the Himalayas. References to individual earthquakes are strewn throughout the entire Tibetan historical literature, though the most detailed accounts are given in full-length autobiographies or biographies of religious masters affected by them.

Like the country, Tibetan literature too was only partly accessible to interested foreign scholars until the middle of the 20th century, though by the 1940s sizable collections of Tibetan manuscripts and block-printed books did exist in St. Petersburg, Patna, Rome, London and Paris.

The interpretation of traditional references to earthquakes has its own peculiarities because of the religious significance of the phenomenon within Tibetan hagiographical literature. The sole prior attempt to collate such historical references<sup>3</sup> was made in Tibet itself in the early 1980s, before many now standard works were available.

Macroseismic epicentres in our region are an approximate indication of the general location of an earthquake. For the few well-reported earthquakes, they are defined as the centre of the area mostly affected by the shock.

For shallow earthquakes, which have source dimensions sufficiently small, there is little difference between an epicentre and the source of the earthquake. As the magnitude of an earthquake increases, the epicentre loses its meaning as the site of seismic source. Bearing in mind that earthquakes of  $M_S$  between 7.0 and 8.0 will have ruptured faults from 80 km to more than 350 km in length, epicentres are necessarily approximate but adequate, indicating nothing more than the general location of an event.

The surface wave magnitude  $M_S$  of a historical earthquake can be inferred indirectly from the length of the associated surface fault break we have

$$M_S = 5.13 + 1.14 \log(L), \quad (1)$$

with the length of rupture  $L$  in km, and a standard deviation of 0.15, derived for events in the Middle East between 20 and 70°E (ref. 4).

Alternatively, we may use the calibration relation of Dizhen Xuejichu<sup>5</sup>,

$$M_S = 5.75 + 1.06 \log(L), \quad (2)$$

in which  $L$  is in km, assuming that the associated slip is  $0.5 \times 10^{-5} \times (L)$ . Equations (1) and (2) are similar, the latter overestimating  $M_S$  by 0.4.

Magnitude may be estimated from the radii  $r$  of isoseismals of intensity  $I$ , from

$$M_S = -1.54 + 0.65(I) + 0.0029(r) + 2.14 \log(r) + 0.32p, \quad (3)$$

which was derived for the Balkans and Turkey in which  $I$  is the intensity in the Medvedev–Sponheuer–Karnik (MSK) scale at a site which is at a distance  $r$  (km) from the assumed surface projection of the fault rupture, with  $p=0$  for mean values and 1 for 84 percentile, and  $r = (r^2 + 9.7^2)^{0.5}$ , provided intensity  $I \leq VIII$  (MSK). This last condition excludes sites of high intensity for which the criteria are of limited value and irrelevant when applied to vulnerable structures, particularly in the historical period. It also reduces the error which is associated with uncertainties in the inferred location of the fault rupture<sup>6</sup>.

Quite often, in the absence of other relevant information, the length of an active fault, which is not always known, is the best guide to the maximum earthquake that might occur along it, although any such guide is a gross approximation at best, particularly for little-known or 'blind' faults for which any assumption regarding their location and length, is little more than an arbitrary judgement.

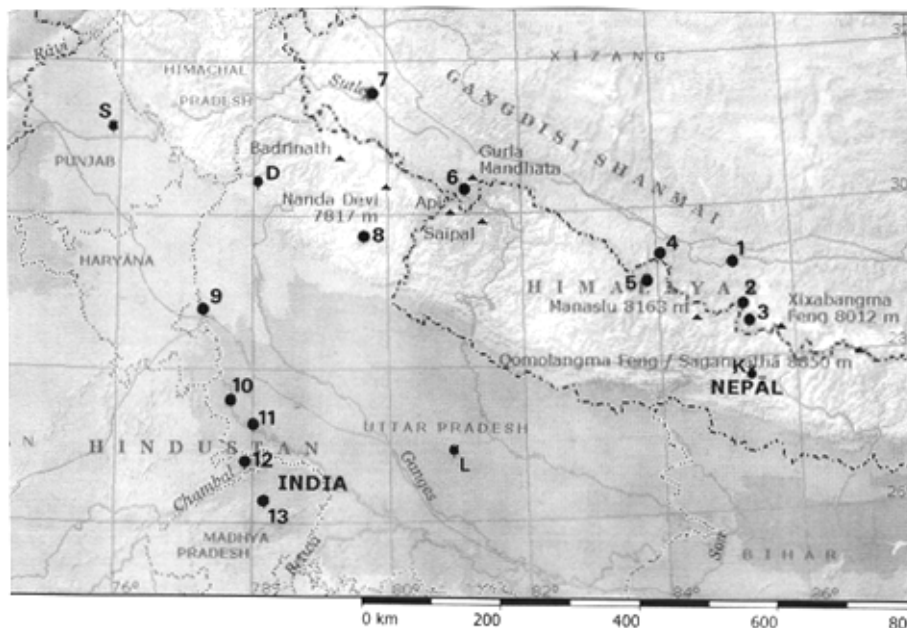
The recurrence of large magnitude earthquakes along the India–Tibet border zone is the result of the northward movement of India, which is also responsible for the great height of the Himalayan peaks. Measurements, such as GPS and re-levelling, show that India and southern Tibet converge at about  $20 \pm 3$  mm/yr on average, of which only a small fraction of the strain accumulating within the Himalaya is inelastic<sup>7,8</sup>. Earthquakes, therefore, must release most, if not all, of India's 2 m per century of convergence with southern Tibet.

The amount of slip rate can be inferred indirectly from the size of past larger earthquakes in the region. This permits one to estimate the slip potential across the Himalaya arc, which depends on size and elapsed time since the last great earthquake and the convergence rate of 20 mm/yr.

Taking the known large earthquakes say in the last 200 years, we find that less than 50% of the Himalayan arc has ruptured in major earthquakes, and that 50% of the arc may currently be ready to rupture in  $M_S = 8.0$  events. If we assume that the approximately 200-year record of known earthquakes is relatively complete, these estimates lead to the serious conclusion that destructive events in the region are today overdue.

But the new earthquakes discussed below show that the record of historical earthquakes is incomplete and that a realistic appraisal of hazard from Himalayan earthquakes cannot be developed from existing catalogues without the retrieval of new data and the thorough re-evaluation of the already-known events.

The earthquake of 6 June 1505 in southwestern Tibet was a major event (Figure 2). It was strongly felt, with



**Figure 2.** Location map of the earthquake of 6 June 1505. 1, Gungthang; 2, Kyirong; 3, Nubri; 4, Globo; 5, Sirib; 6, Purang; 7, Guge; 8, Almora; 9, Delhi; 10, Mathura; 11, Agra; 12, Dholpur; 13, Gwalior; D, Dehra Dun; K, Kathmandu; L, Lucknow and S, Simla.

damage to local houses along the northern part of the Great Himalaya, from Guge in the northwest to Lo Mustang and Kyirong in the southeast, along a distance of about 700 km. If it be assumed that the radius within which these effects of intensity VI (MSK) or greater were confined is about 250 km, eq. (3) gives a magnitude of about 8.2, which is consistent with the value of 8.3 that one obtains from observations that the shock was clearly felt with intensity IV (MSK) as far as Gwalior and Delhi, 500 km away. Geodetic data suggest that present convergence between India and southern Tibet of 16–18 mm/yr is developing as elastic strain in the Greater Himalaya. Should this have prevailed since 1505, the so-called Central Himalayan Gap may have accumulated as much as 9 m of slip, sufficient to drive a  $M_w = 8.2$  earthquake<sup>8</sup>.

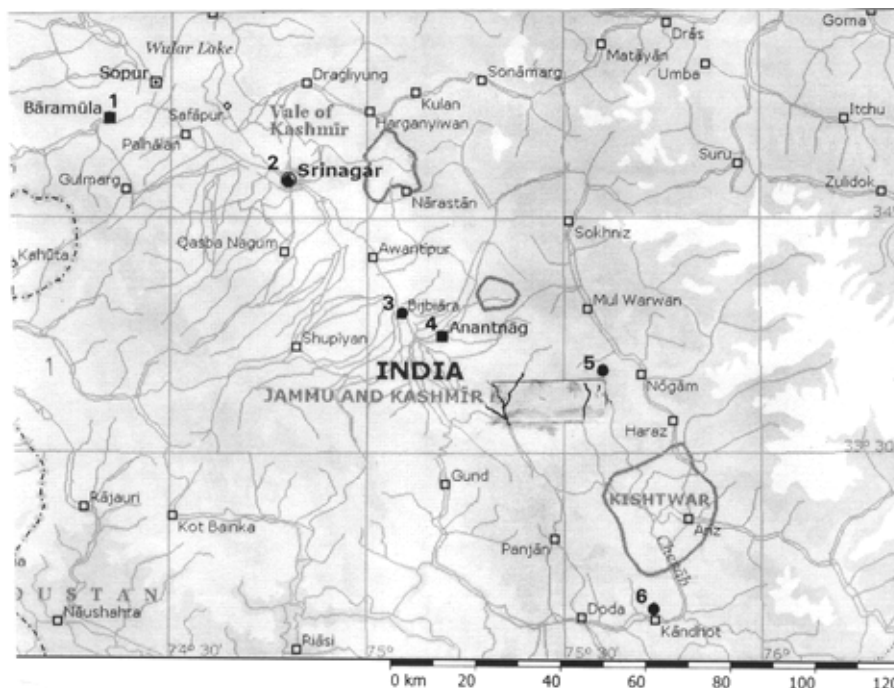
The earthquake of 1555 in Kashmir is the westernmost earthquake dealt with in this communication (Figure 3). The very long duration of aftershocks, its damaging effects (VII MSK) which extended for more than 100 km southeast from Srinagar, and the fact that the event is mentioned by so many contemporary and near-contemporary writers suggest that it was a shallow, large-magnitude earthquake of  $M_S = 7.6$ .

The earthquake of 1713 was located east of the 1806 event, somewhere in Bhutan or in Arunachal Pradesh, and there are no data from which to assess its magnitude. However, the survival of the information over such a long period also suggests the significance of the event, the magnitude of which cannot be estimated, probably approaching  $M_S = 7$ .

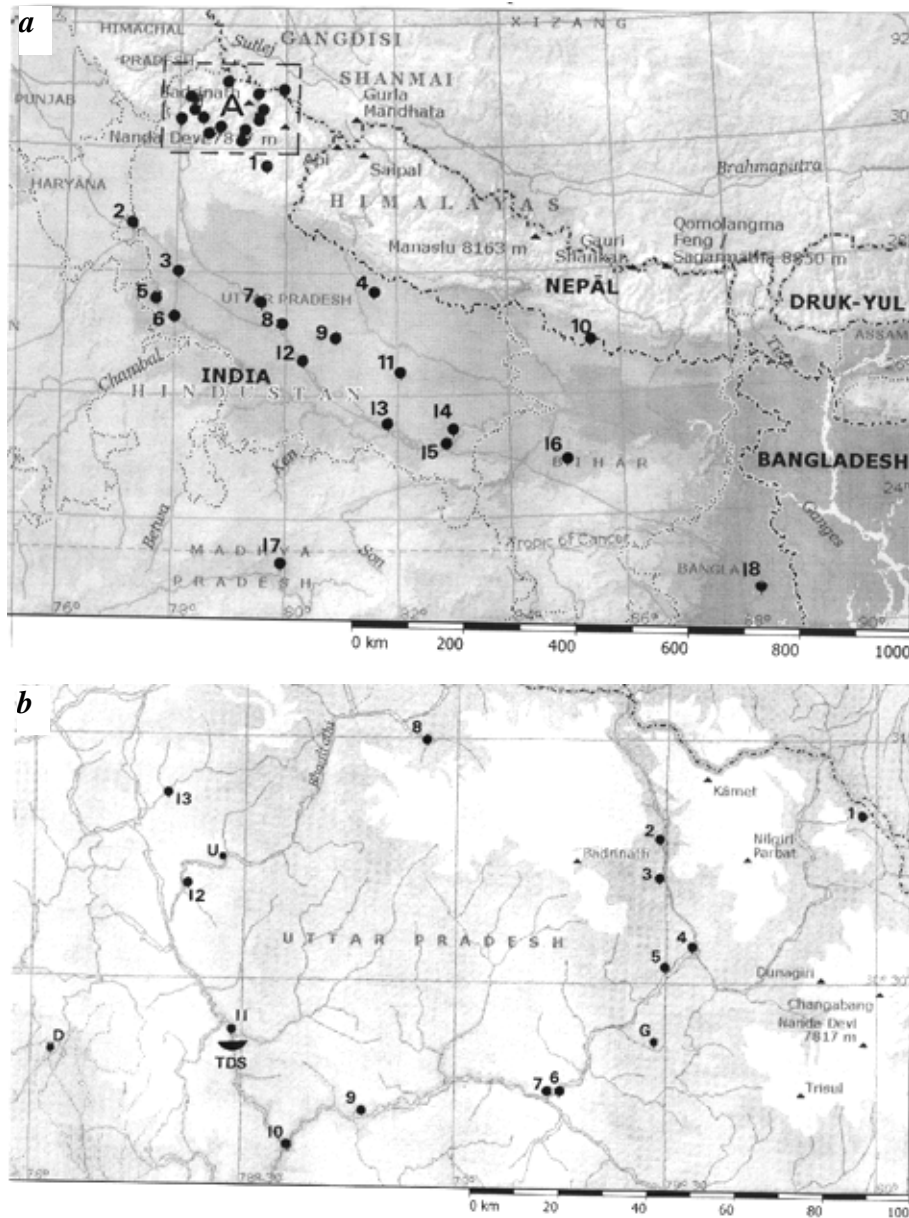
The earthquake of 1751 occurred in the upper reaches of Sutlej river in Tibet. Data retrieved so far are insufficient to allow an estimate of its magnitude, which could be about 7.0. Using only two sites, Toling and Daba, Chen<sup>3</sup> drew an isoseismal map of the earthquake to which he assigned an epicentral intensity of X and a magnitude of 7.25. The occurrence of snow slides in the Ali province, 1100 km northwest of Guge, should not be associated with the event.

The earthquake of 1 September 1803 occurred in northern Kumaon-Tibet. Data are insufficient to assign intensities in locations that can define without ambiguity the extent of the epicentral area, which must be sought between Pali, Devprayag, Garhwal and Barahat, an area of about 75 km radius. In this mountainous region the collapse of old, dilapidated local structures, damaged by previous earthquakes and neglect, and the collapse of rock faces are known to have occurred before and after this event, without help from earthquakes. For example, towards the close of the rainy season, on 6 September 1893, two enormous landslides from the mountains in the upper reaches of the Alakandá River, not far from Ghona, dammed the river, 13 km west of Ghona on the Birihi Ganga valley. The slide formed a lake which, after heavy rains, together with further slips, created a dam 360 m high, 1.6 km long and 450 m wide of a volume of 400 million cubic metres of rock<sup>9</sup>.

Also, information from the far-field is biased: much of what has been reported comes for sites on the Ganges plains where intensities are enhanced by the thick allu-



**Figure 3.** Location map of the earthquake of 6 June 1555. 1, Baramula; 2, Srinagar (shahr-i; Kashmir); 3, Bilarah (Bijbehra); 4, Anantnag; 5, Mareg and 6, Maru Petgam?



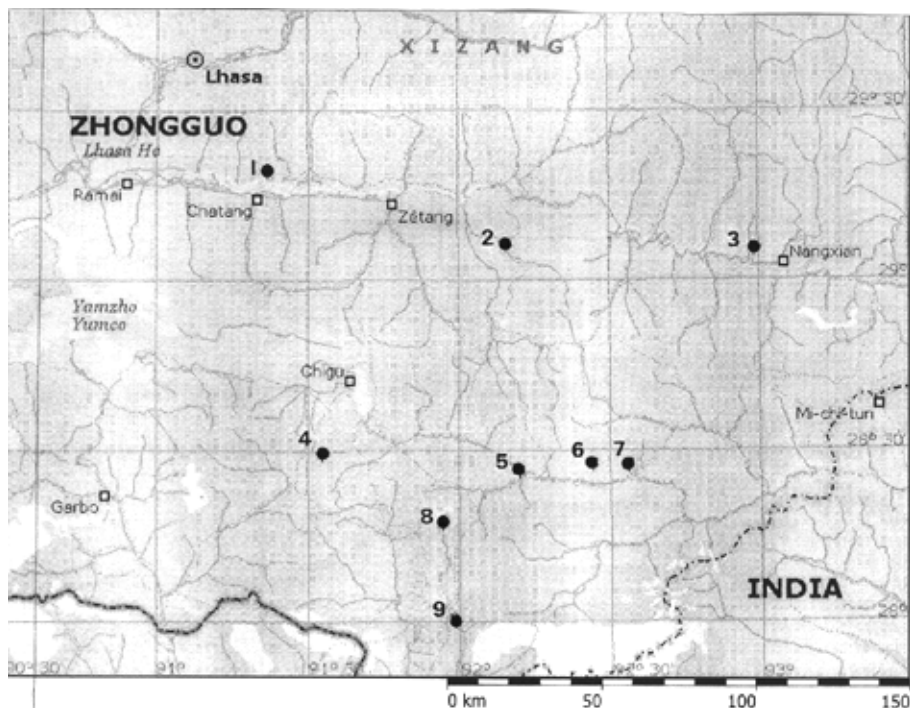
**Figure 4.** *a*, Location map of the far-field region of the earthquake of 1 September 1803. Inset A is shown (*b*). 1, Almora; 2, Delhi; 3, Aligarh; 4, Bagraich; 5, Mathura; 6, Agra; 7, Farrukhabad; 8, Kanauj; 9, Lucknow; 10, Meer-ka-Serai; 11, Sultanpur; 12, Kanpur; 13, Allahabad; 14, Banares; 15, Chumar; 16, Gaya; 17, Jabalpur; and 18, Calcutta. *b*, Location map of epicentral region of the earthquake of 1 September 1803. 1, Barahat; 2, Manah; 3, Badrinath; 4, Joshimath; 5, Kalpa Gram; 6, Karnaprayag; 7, Panha; 8, Gangotri; 9, Srinagar; 10, Devaprayag; 11, Tehri; 12, Phali; 13, Kutnaur; D, Dehra Dun; G, Ghona; TDS, Tehri Dam Site and U, Uttarkashi.

vium, with little or no information of where the shock was not felt (Figure 4). The magnitude of the earthquake estimated from the size of the area over which the shock was clearly felt is about  $M_s = 7.5$ .

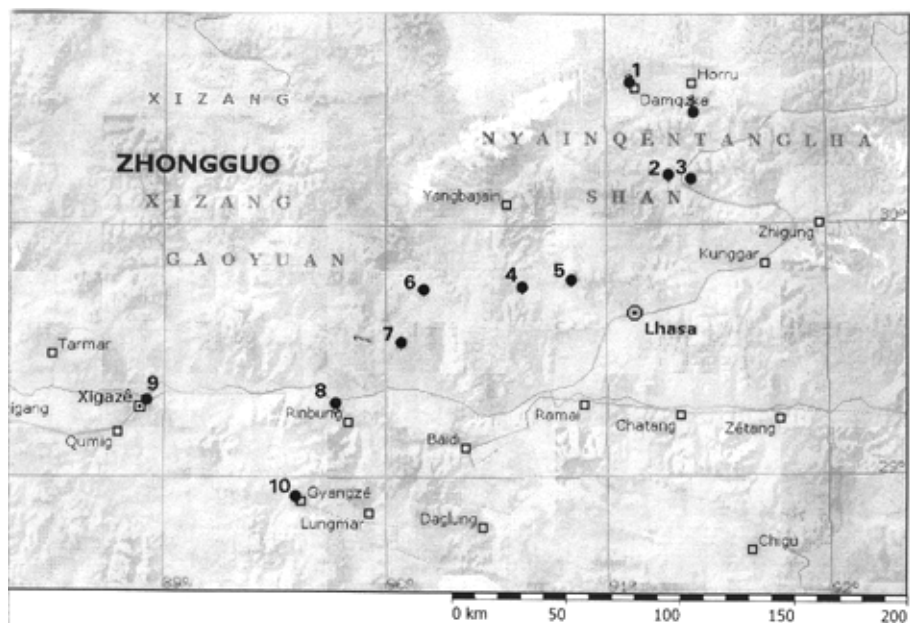
The earthquake of 11 June 1806 occurred in the region between Samye and Cona in Tibet, near its border with eastern Bhutan (Figure 5). Chen<sup>3</sup>, and Yang and Zhang<sup>10</sup> place its epicentre close to Dunxu (Lhun-rtse ?) and assign to them intensities XI and X, and magnitudes 8.0 and 7.5 dating the earthquake to 1 June and 11 June re-

spectively. An isoseismal map in Chen shows intensities at a number of localities which are not mentioned in the sources quoted by these authors.

The earthquake of September 1411 occurred about 100 km north of Lhasa in Tibet (Figure 6). We have included this early, large earthquake which happened outside and to the north of the Himalayan arc, because it confirms that a substantial fraction of the displacement of the NNE movement of India towards Asia is manifested in southeastern Tibet.



**Figure 5.** Location map of the earthquake of 11 June 1806. 1, Samye; 2, Qusun; 3, Gurabnam-gyai; 4, Damxoi; 5, Ritang; 6, Gytang; 7, Nyaimai; 8, Dunxu and 9, Cona.



**Figure 6.** Location map of the earthquake of 29 September 1411. 1, Dam-gzhung; 2, sTag-lung; 3, Lhun-grub; 4, mTshur-phu; 5, bDe-chen; 6, Mor-rdzong; 7, sNye-mo; 8, Rin-spungs; 9, Shigatse and 10, Gyantse.

This is a large event, only recently recognized to have been associated with a 136-km long oblique surface fault rupture of the Nyaqing fault in northern Ü (dBus) which extends from Damshung southwestward to Nasguo, then turning south to Yangyingxiang<sup>11,12</sup>. Tree-ring and lichen

dating confirm that the observed ruptures are associated with the 1411 earthquake, displaying average horizontal and vertical displacements of 5.2 and 4.1 m respectively, predominantly oblique right-lateral. Maximum slip reached 13 m with the largest throws exceeding 8 m (ref. 13).

**Table 1.** Estimated parameters of earthquakes in this study

Y	M	D	T	N°	E°	$M_S$	Epicentral region
1411	09	29	0500	30.0	90.2	7.7	Danxung
1505	06	06	0500	29.5	83.0	8.2	Lo Mustang
1555	09	00	2200	33.5	75.5	7.6	Srinagar
1713	00	00	2000	27.5	93.0	–	Arunachal
1751	00	00	0000	31.3	80.0	7.0	Guge
1803	09	01	0130	31.0	79.0	7.5	Kumaon
1806	06	11	0000	28.5	92.0	7.7	Samye

Note, Locations and magnitudes are approximate.

Yang and Zhang<sup>10</sup> date the event to 8 October 1411 and assign to it a magnitude 8.0. A similar magnitude is given by Wu *et al.*<sup>13</sup> and Huang<sup>14</sup>. Using eq. (1) and a length of rupture of 136 km, we calculate  $M_S = 7.6$ , compared with 8.0 from eq. (2). On the other hand, heavy damage corresponding to an intensity of VIII (MSK) appears to have occurred within a radius of about 70 km which, from eq. (3) gives  $M_S = 7.8$ . With the exception of the 1411 earthquake, there is no clear evidence in the sources that other events, in spite of their large magnitude, had been associated with surface ruptures.

From the foregoing, it appears that the historical record for the Himalayan arc can be improved with the addition of new large events which happened as far back as the 15th century, as well as with the refinement of other large but little-known earthquakes. The implication is that destructive events in the region today may not be all that overdue.

Tibetan literature underwent unprecedented re-printing in the last 30 years, first in India from the late 1960s, and then from the mid-1980s onward also in Tibet and China. Many histories have yet to be combed for seismological purposes. When this is done, the number of historical earthquakes is likely to increase substantially, though not for the thinly inhabited areas west of Lo Mustang, which possess relatively few histories. From about Lo Mustang eastward, however, the situation looks more promising, especially for the 12th through 16th centuries, for which data are scanty.

## Appendix 1

### Case histories

This appendix describes some earthquakes that occurred in the Himalayan arc and adjacent regions. These events have been selected partly because of their individual destructiveness, but chiefly for their general illustration of the effects of earthquakes in this part of the world. They contain the essential data available and an assessment of this material in the light of the relevant seismological factors, thus illustrating some of the problems associated with evaluating seismicity.

### 28–29 September, 2 October 1411 (Damxung/'Damgzhung, Figure 6)

The earthquake of 29 September 1411 occurred in the province of dBus in south-central Tibet. It affected the region southeast of lake Namtso and the Nyenchen Tanghla range, about 100 km northwest of Lhasa. Much of what is known about this event comes from Tibetan documents (see references) and their Chinese translation<sup>3,15</sup>.

Preceded by a foreshock on the 11th day of the 9th lunar month at about midnight (ca. 28 September 1411), the main shock occurred at dawn the following day, 29 September 1411. Five days later, on 3 October 1411, there was a strong aftershock which did not add much to the damage already done<sup>3</sup>.

Much of the damage caused by the main shock occurred in Ü (dBus) province, and at Rin-spungs in eastern gTsang, decreasing in other parts of gTsang province such as in the upper Nang valley to the south, including the environs of Gyantse and nearby Nenyang<sup>16,17</sup>.

In 'Dam-gzhung, which is the northernmost locality for which we have information, a great lama's biography records that this was a large earthquake which caused 'mountains to run', an unusual expression presumably meaning 'to move rapidly'. Ground motions forced him to alight from his mount, and the severity relented as soon as he could be seated (ref. 18, vol. 1, p. 472.6 = vol. 236f).

Further south, sTag-lung and Lhun-grub were affected. The foreshock caused fairly serious damage to the sTag-lung temple building, while the main shock did tremendous damage elsewhere, in places which are not named<sup>19</sup>.

In Linzhou Dalong (=Lhun-grub sTag-lung) at the Dalong (sTag-lung) temple, numerous buildings collapsed as well as part of the wall by the east gate of the Sutra Hall, doors and windows also fell down. In other areas there were slides and burst lakes, and some villages were buried beneath the rubble. Large cracks also appeared on the level ground and numerous people and livestock were killed, (Chen<sup>3</sup>, based on the same Tibetan source of sTag-lung.)

The shocks caused damage in the sTod-lung valley where both bDe-chen and the monastery of mTshur-phu are located; we know that the monastery had to be repaired in 1412 after the earthquake (ref. 18, vol. 1, p. 474).

Duilong Deqing (=sTod-lung bDe-chen), east of Lhasa, was also damaged, probably less than other places, (Chen<sup>3</sup>, based on Si-tu and Be-lo.)

South of sNye-mo, all the structures of the fort of Mor-dzong collapsed<sup>20</sup>.

In Rin-spungs, the foreshock and main shock caused destruction of many towns, obliterating villages<sup>16</sup>. This seems to imply that Rin-spungs district was particularly badly hit.



Southeast of Shigatse in Renbu (Rin-spungs) a county government building collapsed and nearby village homes were severely affected<sup>3</sup>.

Damage at Gyantse should not have been serious as the ruler of Gyantse sent 500 large wooden beams to Rin-spungs to help rebuilding<sup>16</sup>.

There is no evidence that Shigatse or further west Lazi (Lha-rtse) suffered damage worth recording<sup>3</sup>.

### 6 June 1505 (*Globo/Lo Mustang, Figure 2*)

An earthquake which was felt in Agra in northern India, is known from late 16th-century Indian history. It records an earthquake in Hindustan on 3rd Safar 911 aH (6 July 1505) and says that as a result, mountains shook, large buildings were ruined, the ground was fissured at several places, and villages and trees were uprooted and 'slipped from their place'. It adds that *Agra*, in particular, was badly affected and that the earthquake was felt the same day beyond Hindustan and was just as powerful in Kabul and in the 'vilayat' (*sic*)<sup>21</sup>. For this information Bada'uni refers to the *Vaqi'at-i Baburi* which Ranking's translation (Calcutta 1898.i.421)<sup>22</sup>, renders as 'vilayet' in Persia. There is no doubt that here Bada'uni refers to a large earthquake that affected north-central India.

The date of the event is confirmed by Firishtah<sup>23</sup> who adds that the earthquake happened on a Sunday, which in 911 aH fell on 3rd of Safar or, on 6 July 1505 O.S. (old style). Firishtah says briefly that on that day there was a violent earthquake in Agra, so 'that the mountains shook on their bases, and every lofty building was levelled with the ground, some thousands being buried in the ruins' (Firishtah ii.155).

But Babur's memoirs, which are contemporary, do not mention Hindustan or Agra; instead, they say that on 6 July 1505, an earthquake affected the region of Kabul in Afghanistan, 1500 km to the west of Agra.

At first sight, these accounts suggest that on 6 July 1505 there was an earthquake which affected Agra and Kabul, and obviously the region between the two cities, its effects extending over an area of nearly 1200 km in length. Such an event should have been of unprecedented size.

However, careful reading of these texts shows that two separate events; one in Hindustan and another in Afghanistan, have been amalgamated. Babur's memoirs, which are also the basis of the information in 'Allami, at the end of the description of the Kabul earthquake add that in this year (911 aH) there was also another great earthquake which was widely felt in Hindustan<sup>24</sup>.

This implies, therefore, that there were two distinctly different events and also that if the date of the earthquake in Kabul is correct, the date of the earthquake in Agra and Hindustan, which is given by Bada'uni, Firistah and al-Alami, must be wrong. Apparently these authors con-

flated two separate events on the date of the earthquake in Kabul, where Babur was present the time of the earthquake.

The fact that there was a separate earthquake in Hindustan can be confirmed by a number of contemporary Tibetan documents. They show that the shocks which were felt in Agra were from a large earthquake which had its epicentral area in northwest Nepal and southwest Tibet, 1600 km from Kabul and 500 km from Agra<sup>25</sup>. According to Tibetan sources, the earthquake occurred at dawn on the fifth or the sixth day of the fifth lunar month of the wood-ox year in the 9th Tibetan sixty-year cycle, or on 6 or 7 June 1505. This date, in the Moslem calendar, corresponds to 6 Muharram 911 aH, which is almost exactly a lunar month before the Kabul earthquake.

We are told that the regions of Guge, Purang and the western Nepal hilly country between Tibet and India were devastated. In the district of Lo Mustang in north-western Nepal, from where we have eyewitness accounts, damage was very heavy. Monasteries and temples for the most part were destroyed; tens of thousands of 'sentient beings' were killed, and trees and forests were extensively damaged. Many manor houses collapsed completely. Damage extended south of Lo in the Thakali area of the Kali Gandaki river valley in Nepal, where many people were killed.

Further east, the Gungthang area was not quite as severely damaged, but in the region to the south and west of Kyirong, many houses were destroyed and the local ruler of Gungthang was killed. However, loss of life here was smaller than in Lo.

Damage in Agra, which at the turn of the 15th century was not an important urban centre, should not have been serious. Although Bada'uni<sup>21</sup> says that the city was particularly badly affected, he does not mention anything specific regarding damage or loss of life. Also, Firishtah<sup>23</sup> only says that the shock was violent in the city. Exactly the same information was repeated by later writers, i.e. Nizam al-Din, Ni'mat Allah al Harawi and 'Abd Allah. It may be significant, however, that Agra was rebuilt in 911 aH (1505) by Sikandar Lodi, who made it the seat of his government<sup>26</sup>.

Iyengar and Sarma<sup>27</sup> speculate that the earthquake mentioned without date in the contemporary Hindi novel, *Mrignayani*, written between 1486 and 1516, an event which damaged Delhi, Mathura, Agra, Dholpur and Gwalior, may have been the same earthquake.

Elphinstone<sup>28</sup> reports that the earthquake was also felt in Delhi, but he does not quote his source of information. The earthquake was followed by about 30 aftershocks, some of which were damaging. Allowing for some exaggeration in the sources, undoubtedly this was a major earthquake.

It is not clear whether this earthquake was the same as reported from Kashmir in the time of Sultan Fatikh Shah (c. 1500), aftershocks of which continued to be felt for three months<sup>29</sup>.

It is instructive to mention here, in some detail, about the earthquake in Kabul, which occurred on 3rd Safar 911 aH, or 6 July 1505, although this event occurred outside our study area. For this earthquake, we have an eyewitness account.

In Kabul, the shocks ruined the ramparts of the fort, even the walls of gardens. Paghman (Paghman) was particularly badly affected, all houses there being destroyed and 70 or 80 of their owners dying beneath the walls. Most of the houses at Tiba (Tibah) were levelled with the ground. Houses were destroyed in many towns and villages, which are not named, with numerous casualties.

Between Istarghach (Istarghij) and the plain (*maidan*) for about 6 or 8 farsakhs (31 to 42 km), in some places the ground rose as high as an elephant, in others, it sank as deep. It is not clear from the text whether *maidan* here refers to the plain or to the town of *Maidan* (*shahr*) which is at the southern end of the Paghman range, west south-west of Kabul.

Villages and groves slipped from their place and many rising grounds were levelled and dust rose from the tops of the mountains. Between Paghman and Begtut, the valley just north of Paghman, there was a landslide, where water springs emerged to the surface.

There were 33 shocks on the first day and shocks continued, two or three a day, for the next month.

At the time of the earthquake, Babur was outside Kabul, preparing for his campaign against Qandahar; it took him about a month of hard work to repair the fort (Bala Hissar) at Kabul (ref. 30, fols157r-158r, pp. 247-248).

A greatly abbreviated notice of this earthquake in Kabul is given also by al-Asafi<sup>31</sup>, who puts the event in 912 aH (1506) and says that destruction was general among citadels (*qal'at*) and houses in which many people perished, al-Asafi.

### September 1555 (Srinagar, Figure 3)

This was a destructive earthquake in Kashmir which ruined towns and changed the course of rivers. It is mentioned briefly by Burgess<sup>32</sup>. More recently Iyengar and Sharma<sup>27</sup> collected additional information.

The earliest account of the event comes from a contemporary, Suka, probably an eyewitness, who says that during the month preceding the earthquake, Kashmir was shaken by frequent shocks. The main shock occurred in Ashvina of the 30th Laukik year (September 1555) in the second watch of the night (4-8 h after sunset). It killed many people and caused the ground to open up, confusing the route of travellers. The shock caused houses to fall into openings into the ground, and elsewhere, wooden houses to fall into the Vitasta (Vesha) river and float downstream for seven 'krosas'. This, he says, could be seen at 'Hasainapura' and across the river, at 'Hosainpura'. He adds, that the shrines of Vijayeshvara Marttanda and Varahakshetra

were not affected by the earthquake and its aftershocks which continued for several days<sup>33</sup>.

Nizam<sup>34</sup>, who was writing late in the 16th century, dates the earthquake to 962 aH (26 November 1554 to 15 November 1555), which is consistent with the year Suka gives for this event. He says that in this earthquake in Kashmir, villages and towns were destroyed, and that two villages, 'Jalu' and 'Dampur', with buildings, trees and all, slid down the banks of Bihat (Jhelum) and swapped sites. He adds that the village of Mardar at the foot of a hill was overwhelmed by a landslide in which 60,000 peoples perished.

Firishtah<sup>23</sup>, who was writing in the second decade of the 17th century, repeats this information, and Haidar<sup>35</sup>, a contemporary of Firishtah, adds that these two villages were in the Miraj division, near Bilarah (Bijbehra), near the pass of Nandmarg, and that the same happened in other places in the Kashmir valley, where aftershocks continued for seven days. However, he dates these events two years earlier in 960 aH.

Narayan<sup>36</sup>, an early 18th century writer, calls the earthquake great and a Day of Judgement, in which many well-founded and strong houses were destroyed, copying earlier accounts, and dating the event to 960 aH.

Khawajah<sup>37</sup>, who was writing in the middle of the 18th century also dates the earthquake to 960 aH, copies earlier descriptions and adds that the town of Kashmir was shaken, the disaster continuing for weeks.

A later writer says that this earthquake in 960 aH was the fourth in the Kashmir valley during Ismail Shah's time. Houses were razed to their foundations and, in places, dwellings and people were swallowed up in cracks that appeared in the ground; springs of water disappeared and new ones started flowing, shocks continuing for a week but not stopping for two months. He mentions the story of the two villages near Advin, which were situated one mile apart on either side of Vesha, swapping sites, and adds that in the Pargana of the Kamraj district of Marvardan, a portion of the mountain fell killing 600 people<sup>38</sup>.

Trusting the earlier sources, the earthquake happened in September 1555. It is described as unprecedented because of the destruction it caused in the Kashmir valley, damage which was enhanced by massive landslides and rockfalls. No damage details are given for the town of Srinagar, but these perhaps have been included in the general description of the effects of the earthquake in Kashmir which, at that time, was also the name of Srinagar (*shahr-i Kashmir*).

We are told that divine protection saved the shrines of Martanda, 5 km east of Anantnag, Vijayeshwara and Varahakshetra at Baramula, but it is not known whether this protection extended to the towns of Baramula and Anantnag, near which the two villages on opposite banks of the Vesha, a tributary of Jhelum, slid into the river, damming it and diverting its course.

Damage extended to the southeast of the valley of Kashmir, about which little is known, except that the village of Maru Petgam or Mawar in the valley of Marvardan in Uttar Machhipura was completely destroyed by a landslide with the loss of 600 rather than 60,000 lives as reported by some later writers<sup>29</sup>. The exact location of Maru Petgam is not certain, but according to Iyengar it must be sought about 140 km southeast of Srinagar (private commun.).

### 1713 (*Arunachal*)

According to a Tibetan eyewitness account, in the spring of 1713 there occurred at night, a destructive earthquake in Bhutan which affected a large area, the extent of which is not given. It destroyed all houses in all districts causing many fatalities. The same earthquake is reported in numerous contemporary Bhutanese sources, but without any precise year<sup>25</sup>.

Probably this is the same earthquake in neighbouring Assam which occurred one night in the reign of Rudra Singh (r. 1696 to 1714). It was most severe and shattered several temples<sup>39</sup>. Damage to the temple structure at Tinkhang on Charaideo Hill, which is southeast of Sibsagar near 26.6°N, 94.5°E, may be attributed to this event<sup>40</sup>.

### 1751 (*Guge*)

This earthquake occurred in southwest Tibet in the district of Guge (31.5°N, 79.8°E), about 70 km northeast of the 1803 earthquake of Kumaon in Uttar Pradesh, India.

All we know about this event is that it is said to have been a very large earthquake. It consisted of four shocks which damaged beyond repair temples in Daba county on the Sutlej river. At Daba (31.28°N, 79.96°E), the Maitreya Hall, the main hall and another hall suffered great damage. Buildings and private houses collapsed in the area of the county government (m. Töling, 31.5°N, 79.8°E ?), and a minor temple belonging to the Zhashen Lunbu temple also collapsed. Following the earthquake snow slides destroyed two villages in Ali province (32.5°N, 80.1°E)<sup>3</sup>.

We could find no information for this event from Indian sources.

### 1 September 1803 (*Kumaon, Figures 4a and b*)

The earthquake of 1 September 1803 affected the mountainous districts of Kumaon and neighbouring provinces in northwest India. It was noticed briefly by Mallet<sup>41</sup>, Oldham<sup>42</sup>, Sieberg<sup>43</sup>, and Bapat *et al.*<sup>44</sup>, who place its epicentral region in Mathura, near Agra, and assign to it a magnitude of 6.5. More recently, this event has been discussed by Bilham *et al.*<sup>45</sup>.

Much of the information we found about this earthquake comes from accounts of British officers who visited the region shortly after the event, supplemented by press reports. No information was found in Tibetan sources.

The effects of the earthquake are said to have been very destructive to houses and to human life, chiefly in the mountainous parts of the districts of Tehri Garhwal and Bashhar in the High Himalaya, and to the south in the alluvial plain of the Ganges<sup>46,47</sup>.

The northernmost point of the region for which we have information is Barahat on the Bhagirati river, where all the temples were more or less shattered, one collapsed and many of its houses were ruined with the loss of 200–300 lives, a significant number for this sparsely inhabited region<sup>42,48</sup>.

At Gangotri, in the mountains at an altitude of over 5500 m, the effects of the shock were very serious, and a great part of the population perished; whole villages having been buried by the fall of cliffs or sliding down of hillsides<sup>49</sup>.

At Kalapa Gram, around Manah and the Barsù Dhára waterfalls, an hour and a half march along the Mánah road, the earthquake caused collapse of large rocks that blocked the river<sup>50</sup>.

Badrinath, situated near the sources of the Alacnada river, one of the tributaries of the Ganges, was shattered and several settlements slid down the mountain slopes<sup>42,50,51</sup>.

At Jeni, the fort situated on a precipitous cliff, surrounded on three sides by the torrent was destroyed<sup>48</sup>.

In Páli and Kutnaur in Ojha Ghur, on the right bank of the Jumna at the foot of steep cliffs, the rocks hurled by the earthquake buried a small fort and village<sup>52</sup>.

Destruction is said to have been complete between Joshimath and Karnaprayage, but it is not clear whether this was due to shaking or rockfalls and slides.

At Panha, in the mountain above Karnaprayága, the temple of Mahadeva was ruined, having lost its cupola and roof in the earthquake<sup>50</sup>.

Srinagar, the capital of the province of Gurhwal, situated on the south bank of the Alacnada, about 20 miles above its junction with the Bhagirati at Deopragur, also suffered from the shock; many houses were ruined, the Rajah's palace was shattered and the spire of the Shah Hamdan Mosque fell off<sup>29,51</sup>. However, damage should not have been very serious as later travellers who visited the region before 1819 did not notice it here or in places along the Sutlej river up to its sources<sup>53</sup>.

Devaprayag, at the confluence of Bhágirat'hi and Alacnandá rivers, was ruined and many of the private houses, together with the terrace and cupola of the temple, were damaged as also those of Bhadrinát'ha to the north<sup>50</sup>.

The effects of the earthquake at Tehri, Dehra Dun and Simla are not known, but we know that damage extended

to the districts of Sirmur and Bashhar to the west, and as far north as Almora.

Further to the south, in Delhi it is alleged that the old cupola of the Kutb Minar was thrown down, and the whole pillar seriously damaged but later restored<sup>54</sup>.

At Alighar and in the camp outside the town, the earthquake was violent, lasting two minutes and destroying several adobe houses in the town<sup>55,56</sup>.

Also in Mathura the shock is described as violent lasting several minutes, awakening the inhabitants and causing general panic, but apparently with no loss of life. Many pukka houses were thrown down and the principal mosque, erected by Ghazi Khan, was ruined; its dome fell due to the opening of the ground. Extensive fissures were observed in the fields, through which water rose and continued to flow for some time. Several slighter shocks followed. The town which, at the time of the earthquake was under siege, was taken by British troops a few months after the event, in September 1803<sup>57,58</sup>.

The shock was felt at Farrukhabad (Fatehrath)<sup>59</sup>. In the camp at Meern-ka-Serai, about 10 miles southeast of Fatehgarh, the shock, which lasted a few seconds, was felt by every person and it was strong enough to awake an officer and allegedly to throw down his guard<sup>60</sup>.

In the cantonment at Mullye, in southern Nepal, the shock was very strong<sup>55</sup>. In Lucknow, the shock damaged a number of houses, but the only damage to public buildings was the dislodging of the upper turrets from the Minarets at the Mosque of the Imaumbareh, and of several other minarets in the city, including the Rome-kadarwasse in the Imambarah. The shock caused water to slosh out of tanks<sup>60,61</sup>.

At Sultanpur the shock awakened people, causing furniture to rattle. It did no damage in the town where it lasted 2 min (ref. 61). At Allahabad the shock stopped a clock but caused no damage<sup>60</sup>. The shock was felt at Prayag of Allahabad<sup>59</sup>, at Kashi (pur?) of Varanasi (Benares) and at Gaya<sup>59</sup>.

In Calcutta and its environs, the earthquake was distinctly felt. A church clock was stopped at 01 h 35 m and the river was considerably agitated. It is said that water of a tank in the Botanic Garden was thrown over its banks with many fish; the same happened to several other tanks in the neighbourhood of the city, which are the long-period, far-field effects typical of large earthquakes, not suitable for assessing intensity<sup>61,62</sup>.

To the west, the shock was generally felt at Chumar, and it was perceptible at Jabalpur in the south<sup>61</sup>. There is no evidence that the shock was felt in Bombay or Madras<sup>63</sup>.

### 11 June 1806 (Samye, Figure 5)

This earthquake in Tibet occurred in the first half of the sa-ga (fourth lunar) month of the fire-tiger year of the

13th cycle, i.e. in late May/early June 1806, and it was unusually strong in the vicinity of the ancient monastery of Samye (bSam-yas).

Damage was extensive in the Cona (Tsona), county, with the loss of 100 people and heavy loss of goats, donkeys and cattle. In the Longzi (Lhuntse) county many houses were destroyed, including government buildings and local temples. Parts of the Dezhu Riding temple collapsed.

Much further to the north, in Samye on the Brahmaputra, the shock apparently damaged the upper-storey temples of the 8th-century monastery, the walls of which collapsed sometime after the earthquake, about 17 August 1806.

Aftershocks were numerous, and in 1807 a strong shock caused the collapse of houses in the Longzi county. Small shocks continued into 1808 (refs 3, 15, 64, 65).

Nothing is known about this earthquake from occidental or Indian sources.

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## Early Oligocene non-geniculate coralline algal assemblage from Al Bayda Formation, Northeast Libya

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In northeast Libya the Al Bayda Formation of early Oligocene sequence is divisible into two members. The lower member, i.e. the Shahat Marl Member is characterized by the occurrence of foraminifera, ostracodes and echinoids. The upper Algal Limestone Member also contains foraminifera, bryozoa and few ostracodes. A rich assemblage of non-geniculate coralline algae has been recovered from the Algal Limestone Member of the Al Bayda Formation. The algal assemblage is represented by species of *Sporolithon* Heydrich, *Neogonolithon* Setchell and Mason and *Lithothamnion* Heydrich. Some forms are tentatively assigned to the genera *Mesophyllum* and *Lithophyllum*. At places some genera of coralline algae, viz.

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