highly resistive basement rocks. The techniques applied here were however insufficient to locate lineaments, which were indicated in the area from satellite imageries.

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Liquefaction features of the 2005 Muzaffarabad–Kashmir earthquake and evidence of palaeoearthquakes near Jammu, Kashmir Himalaya

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We have studied the earthquake-induced ground deformation features like fractures and landslides associated with the 2005 Muzaffarabad–Kashmir earthquake. During the study we observed well-developed liquefaction features at Simbal camp, about 20 km south of Jammu. We excavated small trenches for palaeoseismological study at the site. We recorded two palaeoearthquake events (I and II) of sand injections prior to the sand blows of the 2005 earthquake. Two palaeoearthquakes events have been interpreted in the trench. Event-II is assigned an age of 2000 yrs BP (i.e. beginning of the first millennium) and the event-I occurred during AD ~1100. The Main Boundary Fault, locally called the Riasi thrust, lies along the southeastern extension of the Balakot–Bagh Fault. The liquefaction features are located around ~240 km SE of the epicentre of the 2005 event, and may have been produced due to favourable ground conditions and dynamic stress transfer, as the rupture and stress are reported to have propagated to the SE from the epicentral area.

Keywords: Fractures, landslides, liquefaction features, palaeoseismology, sand blows.

THE 8 October 2005 Muzaffarabad–Kashmir earthquake (Mw = 7.6) was the deadliest in the history of the Indian subcontinent that killed more than 80,000 people. The earthquake occurred on a rupture plane 75 km long and 35 km wide[1,2] with strike of 331° and dip angle of 29°. The epicentre of the event was located north of Muzaffarabad (34.493°N and 73.629°E) within the Hazara Syntaxis and about 120 km WNW of Srinagar (USGS, NEIC WDCS-D; Figure 1). A surface rupture called the Balakot–Bagh Fault (BBF), 75 km long with variable slip of 3–5.5 m has been recorded and mapped in the field for an Himalayan earthquake[3–5]. Based on surface displacements deduced from GPS observations and locations of aftershocks, it has been suggested that the earthquake may have originated from multiple fault planes[6]. The post-earthquake field observations and general hazard assessment associated with the October event in the eastern part of the line of control (LOC) has been reported recently[7].

During a field survey undertaken two weeks after the earthquake, we mapped the surface ground fractures in the Tangdhar–Titwal, Uri and Punch–Rajouri sectors and liquefaction features in Jammu areas. The orientations and displacements recorded in the fractures reflect pronounced strike-slip together with some tensile component[8]. The Tangdhar–Titwal area, lying on the hanging wall of the causative fault show left-lateral strike-slip motion, and the Uri region showing right-lateral strike-slip movement is located towards the southeastern extension of the causative fault zone (Figure 1). The shear fractures are related to static stress that was responsible for the failure of the causative fault. In Jammu area, located ~240 km southeast of the epicentre, the fractures and the liquefaction features were produced as a result of favourable ground conditions and may be due to propagation of dynamic seismic waves[8].

Jammu city is located within the outermost part of the Sub-Himalaya in the Siwalik range made of conglomerate and sandstone of upper Siwalik. South of the range front,

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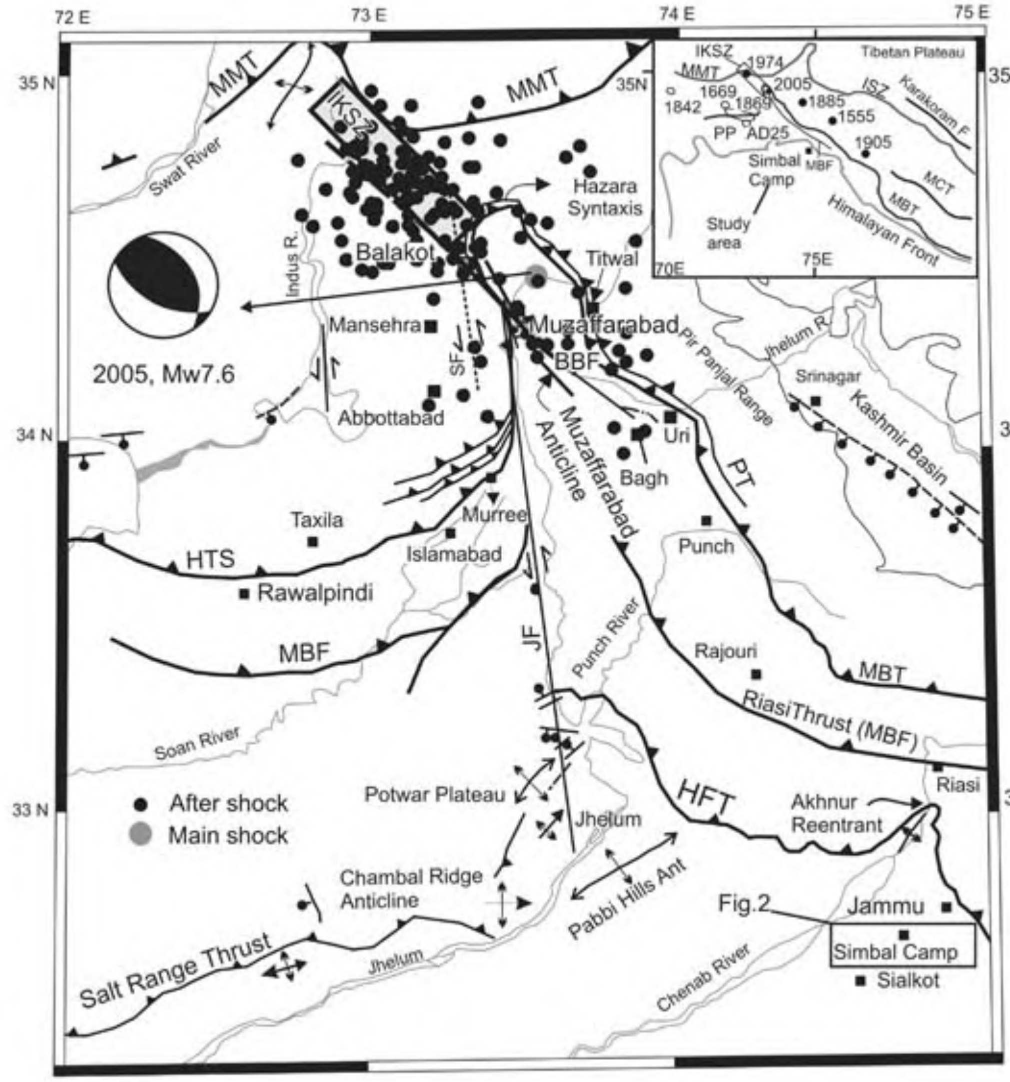

Figure 1. A simplified active tectonic map of NW Pakistan and Kashmir Himalaya, India, modified from Yeats *et al.*[23]. Major thrusts are shown by thick lines with solid barbs on the up-thrown side. Active faults are indicated by thick line with ball on the down-thrown side and solid–dashed line with sense of shear. Faults and fold marked in the map are from Kazmi and Qasim Jan[10]; Bossart *et al.*[24] and Kumahara and Nakata[4]. Dark grey oval outline indicates epicentre of the 2005 event, dark circles correspond to the aftershocks (USGS) aligned along IKSZ. USGS–CMT Harvard fault plane solution shown in middle as inset. MMT, Main Mantle Thrust; HTS, Hazara Thrust System; IKSZ, Indus Kohistan Seismic Zone; PT, Panjal Thrust; MBT, Main Boundary Thrust; MBF, Main Boundary Fault; HFT, Himalayan Frontal Thrust; SF, JF and BBF; Shinkiari, Jhelum and Balakot–Bagh faults respectively. (Inset, top): A simplified tectonic map showing locations of historical earthquakes (after Ambraseys and Douglas[13] and Yeats *et al.*[23]).

~20 km SW of Jammu, liquefaction features are located at the foot of the Simbal Camp Ridge within the piedmont zone of the foreland basin (Figures 1 and 2).

The liquefaction features include sand blows and fissures on the ground. The sand blows were composed of fresh, white sand oozed out from the subsurface and deposited on the green grass background of an abandoned field (Figure 3). Local villagers were the first to observe the sand blows as a sand and water fountain about a metre high, ejecting out from the ground during the October 2005 earthquake. We observed sand blows at five locations within the field area of 250 m length and 110 m width. The largest sand blows in the southwestern part of the grass field showed an elongated area of 11 m length and 2–3 m width, with a fissure in the central part extending along the length. Adjoining this, a set of three sand blows, spaced a few metres apart for a length of 4.5 m and aligned in the direction of the largest sand blow. Five more sand blows with crators measuring few metres up to 8 m in diameter were observed in the northeastern part of the grass field, each with a central linear fissure (crack) that ejected white sand. The sand blows are oriented with a common NE–NNE trend of the fractures. Two sets of fissures trending NNE and NW were also observed along

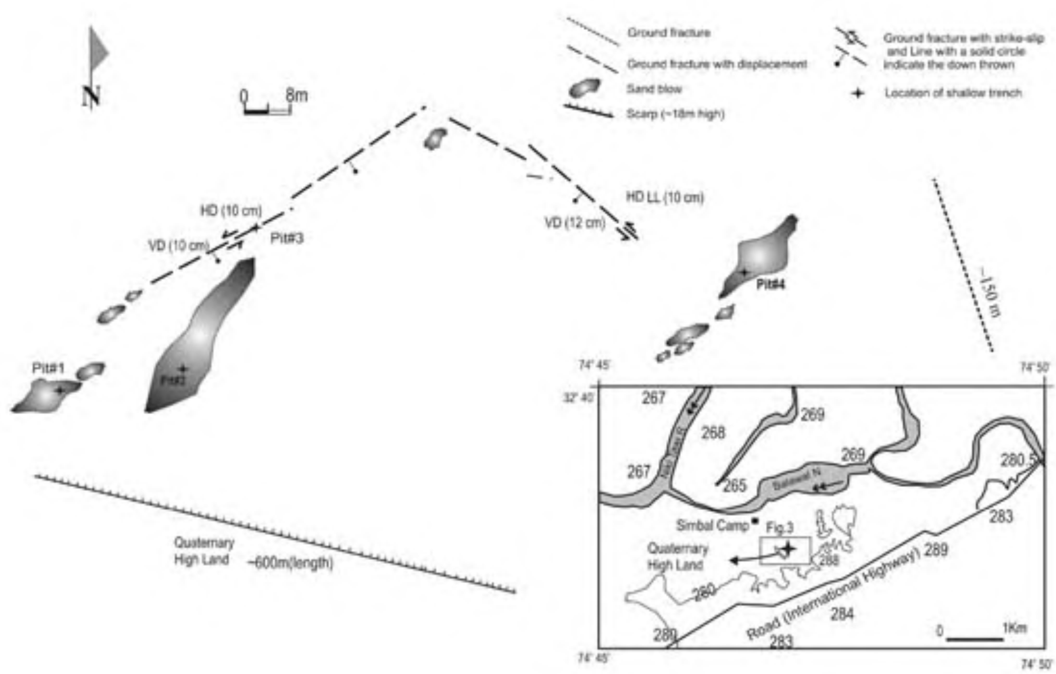

Figure 2. Map showing ground fractures and distributions of sand blows in the abandoned floodplain of Balawal River at Simbal Camp near Jammu. (Inset) Location of sand blows and fissures (solid star) at the foot of the Simbal Camp Ridge.

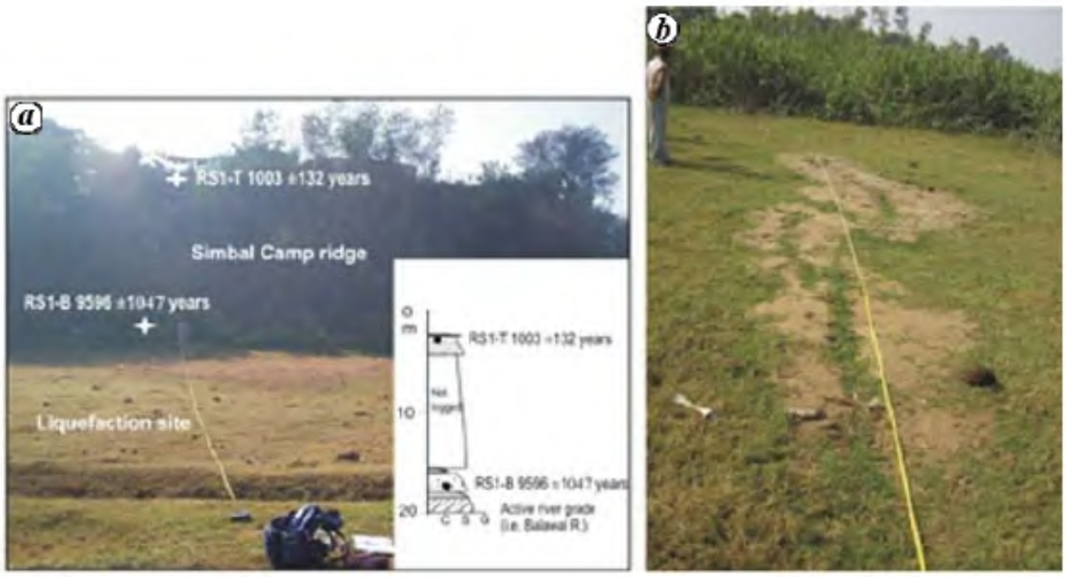

Figure 3. Photographs of (***a***) Simbal Camp Ridge with north-facing scarp together with litholog showing location of optically stimulated luminescence ages of top and bottom units and (***b***) sand blow oozing out white sand with fissure at the centre.

with the sand blows (Figure 2). The rhomb-shaped fissures (cracks), devoid of ejected sand blow with width (aperture) 8–15 cm, indicated 10–20 cm of horizontal displacement from east to west and 5–10 cm vertical displacement, and showing left-lateral strike-slip motion[8].

The Simbal Camp ridge represents a remnant of the raised piedmont zone. It is ~600 m in length and ~400 m in width, oriented WNW–ESE and has an elevation of ~18 m from the Balawal river plain (Figures 2 and 3). The fractures, sand blows and associated fissures were observed on the flat surface of the abandoned floodplain of Balawal river, which lies on the northern margin of the Simbal Camp Ridge scarp. The Simbal Camp Ridge is made largely of unconsolidated sand and silt.

One OSL (optically stimulated luminescence) sample, RS1T was collected from the top of the ridge of the scarp section at 32°38′46.2″, 74°46′45.1″. The sample was extracted from a pit 1 m deep comprising 70 cm sand-silt

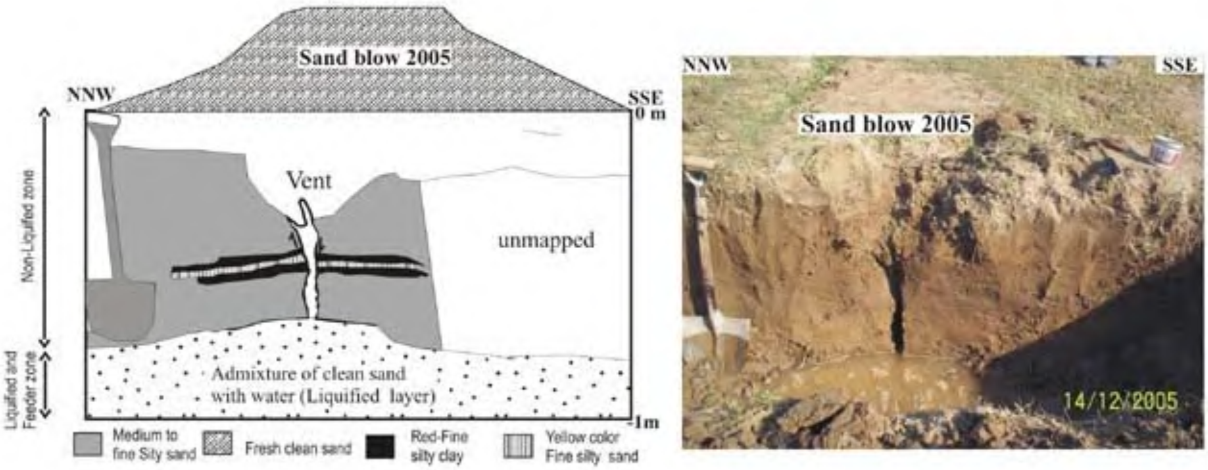

Figure 4. (Right) West-facing wall of a shallow (1.5 × 2 × 1 m) trench made across 65° trending sand blow at Simbal Camp pit #1 (right). Location of the shallow trench is shown in Figure 2. (Left) Details of litholog of trenched pit shown on the right-hand side (location: 32°38′48.1″, 74°46′43.3″).

Table 1. OSL ages, elemental concentration, water content, dose rate and equivalent dose of late Quaternary deposits from Simbal Camp Ridge and palaeo-sand blow from the trench near Jammu, Kashmir Himalaya

Sample no.	U (ppm)	Th (ppm)	K (%)	Dry water content (%)	Dose rate (μGy/year)	Equivalent dose (Gy)	Age (years)
RS-1 B	2.90 ± 0.14	5.90 ± 0.29	1.61 ± 0.16	0.15 ± 0.03	2929 ± 170	28.11 ± 2.6	9596 ± 1047
RS-1 T	2.20 ± 0.11	10.40 ± 0.52	2.35 ± 0.23	0.97 ± 0.19	3806 ± 242	3.82 ± 0.44	1003 ± 132
RS-1 G	3.8 ± 0.19	13.5 ± 0.37	1.21 ± 0.12	7.35 ± 1.47	3044 ± 145	6.10 ± 0.53	2003 ± 199

capped by 40 cm modern soil. This yielded an OSL age of 1003 ± 132 yrs BP of the host sediment (inset, Figure 3 *a*; Table 1). The exposed bottom part of the scarp section of the ridge consists of 50 cm silty-sand unit underlain by 30 cm of fine silt-sand, followed by coarse sand probably related to overbank deposits. Another OSL sample RS1B collected from 30 cm fine silty sand unit at the bottom of the ridge yields an OSL age 9596 ± 1047 yrs BP of the host sediment (inset, Figure 3 *a*; Table 1).

Trenching was done at four places across the sand blows and ground fractures were recorded at the Simbal Camp locality. We describe here only two pits trenched across the freshly exposed sand blows and ground fractures. As we started digging the pits, water started oozing out from below at a depth of 1 m in all the pits, preventing further trenching. The water table may be at a shallow level because the site is located in an abandoned palaeochannel of the Balawal river, the effect of the earthquake may be another factor.

Among the four pits excavated to observe the subsurface manifestation of the sand blows, two pits, i.e. pit #1 and pit #3 showed promising results. Pit #1, which is 1.5 m wide and 1.0 m deep, was excavated across the sand blows trending 65° (Figure 2). In this pit the freshly ejected white sand layer on the surface is ~20 cm thick and linked through a vent, a few centimetres wide, to the base with an admixture of clean sand and water (Figure 4). The vent cuts across the pre-existing sediment comprising 40 cm thick, grey sand underlain by 2 cm of brownish sand and 2 cm red muddy clay, which in turn is underlain by 40 cm thick layers of sand and silt. Below this layer an admixture of white, loose sand with water is interpreted as the liquefied layer. The liquefied layer connected through the vent cuts across the pre-existing alluvial sediment and is ejected to the ground surface as white sand blow.

Pit #3 measuring 1.5 × 1 m was excavated across the NE-trending opened-up ground fracture (Figures 2 and 5 *a*). The 15–20 cm wide fracture shows 10 cm of vertical displacement of the ground surface. Figure 5 *a* shows the vertical, 10–15 cm wide vent, which represents the subsurface expression of the opened-up crack. Figure 5 *b* and *c* shows detailed lithologs of upper and lower parts respectively, on the exposed trench wall (their locations are given in Figure 5 *a*). We observed two levels of discontinuous layers and lenses of white sand 3–5 cm thick within the host sediments composed of sand, silt and clay. In the upper level (Figure 5 *b*) of the exposed wall, the medium-grained white sand lenses show 6 cm subvertical displacement along the vent with up-thrown side to the north. In the lower level (Figure 5 *c*) of the same section, white sand is distributed irregularly along the layered host sediment comprising silt, yellow and cherry-coloured muddy clay. Here also a vertical displacement measuring 3–5 cm is observed. The vertical displacement of 3–6 cm observed at both the levels along the vent cor-

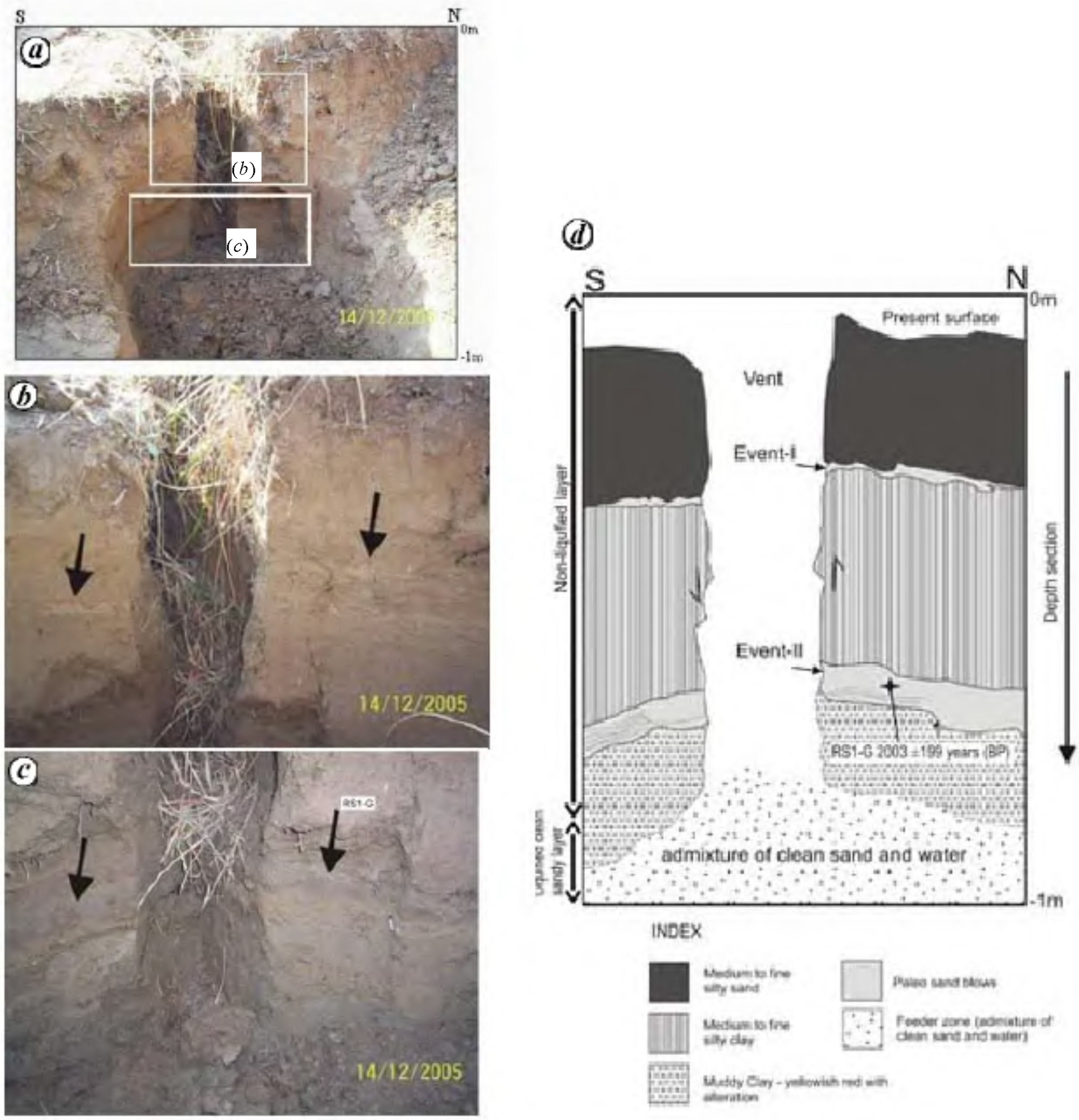

Figure 5. ***a***, Eastern wall view of a shallow trench measuring 1.5 × 2 × 1 m across the ground fracture in pit # 3 (see Figure 2 for location). White boxes represent locations of (***b***) and (***c***). ***b***, Photograph showing closer view of the upper part of the trench wall. White sand laminations indicated by black arrows, within the host sediment are interpreted as event-I. ***c***, Photograph showing a closer view of the lower part of the trench wall with contorted laminations within the altered host sediments related to event-II. ***d***, Composite litholog of (***b***) and (***c***) showing palaeoliquefaction features (events I and II) and OSL age of event-II. Palaeo-sand blows marker layers exhibit displacement along the vent (fissures).

responds to that seen at the surface along the opened-up fracture (vent). The basal part of the host sediment comprising rootlets, charcoal and stained silt is underlain by loose white sand and water. Sample RS1-G for dating was taken from the white sandy layer of the lower level (Figure 5 *c*) while yielded an OSL age of 2003 ± 199 yrs BP (Figures 5 *c* and *d*). This age is assigned to the lower level liquefaction event-II, and the upper level liquefaction is ascribed to event-I.

In the region east of the Northwest Syntaxis[9], now referred to as the Hazara Syntaxis[10], there are accounts of several past historical earthquakes affecting the Kashmir valley. *Akbar Nama* by Abu Fazal describes extensive devastation to life and property in the Kashmir valley[11] by an earthquake during September in AD 1555. The 1885 earthquake has been widely quoted by several workers[12], assigning an intensity of IX–X. More recently, magnitudes *Mw* 7.5 and *Mw* 6.3 have been assigned to the AD 1555 and AD 1885 events respectively[13]. The other historical earthquakes reported from Kashmir were in AD 1123 and AD 1501 (Figure 1)[14]. The epicentral locations of the earthquakes are not known. They are called

Kashmir earthquakes because the effects were reported from the Kashmir valley.

Trenching across the sand blows and fissures at Simbal Camp, Jammu has revealed two events (I and II) of sand injection prior to the event of the 2005 earthquake (Figure 5 *d*). We obtained one OSL age of 2003 ± 199 yrs BP of the lower liquefied layer of the sand blow ascribed to event-II. Two OSL ages were obtained from the base of the exposed scarp and the top surface of the Simbal Camp Ridge (Figure 3 *a* and Table 1). The Simbal Camp Ridge exposing 18 m scarp standing over the liquefaction site has yielded an OSL age of 9596 ± 1047 yrs BP at the base and 1003 ± 132 yrs BP at the top (1 m below the top ground surface). The liquefied sand layer of event-II dated 2003 ± 199 yrs BP represents a palaeoearthquake during the beginning of the Christian calendar. The sand layer of event-I liquefaction is younger than that of event-II (i.e. post 2003 ± 199 yrs BP) and older than OSL age 1003 ± 132 yrs BP of the top part of the Simbal Camp Ridge. This may imply that event-I occurred sometime during post 2003 ± 199 yrs BP and pre 1003 ± 132 yrs BP, suggesting that its correlation is more likely with the AD 1123 earthquake of the Kashmir valley[14]. Assigning these ages to palaeoearthquake events-I and II, suggests a recurrence interval of ~1000 years.

OSL dating of 18 m scarp of the Simbal Camp Ridge has also allowed us to determine the incision rate. The base of the scarp of the ridge gives an OSL age of 9596 ± 1047 yrs BP and top of the ridge yields an OSL age of 1003 ± 132 yrs BP. The 18 m incision of the scarp that took place during this time-span of 8500 years gives an incision rate of 2 mm/yr.

The rupture plane of the 2005 earthquake striking NW–SE and dipping NE 30° lies within the Hazara Syntaxis encompassing both the eastern and western limbs[1]. The surface trace of the 75–80 km long rupture plane corresponds to the active fault mapped by earlier workers[4,5,15]. The surface rupture of the causative fault of the 2005 earthquake extends from Balakot to Bagh and this mapped fault is referred to as BBF[3]. The transmission of stress is dominantly towards SE, along the regional Himalayan strike in the rupture propagation direction[16]. The liquefaction and fractures observed 240 km SE of the epicentre may have resulted due to dynamic stress transfer and suitable ground conditions. A similar situation occurred during the 1905 *Mw* 7.8 Kangra earthquake that produced intensity VIII isoseismal effects around Dehradun and ground deformation features like cracks near Roorkee, located ~ 300 km SE of the epicentral area[17]. However, this now has been interpreted as a triggered event[18]. Even in the case of the intraplate 26 January 2001 Bhuj earthquake (*Mw* 7.7), distant liquefaction features as far as 250 km from the epicentre were reported[19].

The surface rupture of the 2005 Muzaffarabad–Kashmir earthquake, BBF, has been recently mapped in the field[5]. The rupture extends in en-echelon pattern with right step towards Punch on the Indian side of the LOC. In the older map of the Geological Survey of India (GSI), Wadia[9] defined a fault, known as boundary fault, between the Siwaliks and Murrees with inlier of Great Limestone (Sirban Limestone). This thrust was called the Riasi thrust in the geological investigation for the Salal hydro project by the GSI. Neo-active deformation features were described along the Riasi thrust in the Riasi and Katra areas[20–22]. We have undertaken traverses in the Riasi and Katra areas and confirm that the Riasi thrust is an active fault (manuscript under preparation). Based on correlation of the tectonostratigraphic and structural framework between the Balakot–Bagh region and the Riasi–Jammu area, we conclude that the BBF may be extending with right step to the Riasi thrust forming the same fault segment as postulated earlier by us[8].

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Synchronization of flowering in parental lines of sunflower hybrid TCSH-1 under north-Indian conditions

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Synchronization of flowering of parental lines is a prerequisite for successful hybrid seed production. In sunflower a gap of about a week in flowering between the seed and pollen parent was bridged by a simple seed hydration treatment with gibberellic acid (50 ppm) and a spray of urea (1%) at button formation thrice, on alternate days. The results suggested a perfect synchronization of flowering not only in terms of first flowering in both A and R line, but also a good match in frequency of plants flowered in both A and R lines on a given day during flowering.

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Keywords: Flowering, hybrid seed production, parental lines, sunflower, synchronization.

HYBRID seed production is a critical step to extend technology to the farmers. In sunflower among the many hybrids developed in the public sector, TCSH-1 is found promising following KBSH-1. TCSH-1 was recommended for cultivation only in Tamil Nadu during 2000 and there are many public-bred hybrids released at the national level in different states. Hybrid seed production in sunflower is mainly concentrated in the southern parts of the country. However, sunflower, in general, is cultivated in North India profitably. Our earlier studies indicated a higher possibility of successful hybrid seed production of sunflower in northern India. The hybrid seed being produced in North India during January–April can cater the demand of hybrid seeds in Tamil Nadu in the kharif season, avoiding the cost of storage of seeds. Major limitation in hybrid seed production of this hybrid is the non-synchronization of flowering of parental lines. A gap in flowering between the seed and pollen parent can cause a reduction of 43.2% hybrid seed production in cases where the seed parent flowers earlier than the pollen parent[1]. Therefore, an attempt was made to reduce the gap in flowering between parental lines through the use of seed treatment and nitrogenous fertilizer application for hybrid seed production. The results of this study are presented in this communication.

A field experiment was conducted with parental lines of sunflower hybrid TCSH-1 (CMS 234 A as female/seed parent and RHA 272 as male/pollen parent). Seeds of pollen parent were soaked with water and gibberellic acid (GA_3; 50 ppm) for about 18 h. Seeds of female line were soaked in water only for 18 h. Thereafter, seeds were dried under shade in ambient conditions for a few hours before sowing. The parental lines were sown on 15 February 2003 at the field of Indian Agricultural Research Institute, New Delhi. The experiment was laid out on six sets each in three replications, with a planting ratio of 6 : 2 (female : male) and row length of 5 m. The row-to-row spacing was 45 cm. After emergence of seedlings, a plant-to-plant spacing of 20 cm was maintained by thinning extra plants. All recommended packages of practice were followed to raise a normal crop.

At button formation stage the R-line plants were sprayed with urea (1%) thrice, on alternate days in the afternoon.

Data were recorded on days to button formation, flowering initiation, and 50% flowering in both A and R lines. The frequency of flowering was recorded on alternate days till completion of almost all the plants in a treatment. The data were analysed following usual statistical procedures.