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## Geo-archeology at Khaj nawar in Western Uttar Pradesh plain

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**Khaj nawar village in Saharanpur district of western Uttar Pradesh is inhabited over the remains of an ancient archaeological settlement. Field observations and archaeological investigation reveal two periods of settlement: settlement I with grey ware and iron objects and settlement II with painted red ware.**

**Radiocarbon and optical stimulated luminescence (OSL) dating indicate 2600a–1400a age for settlement I and 850a–350a for settlement II. A hiatus of ~550a between the two settlements may have been caused either by an earthquake or climate change. A south-facing and NW–SE trending scarp on the southern end of the Khaj nawar has been interpreted as a tectonic scarp that is a continuation of the Piedmont Fault with right-step. The scarp should have formed due to an earlier earthquake that may have caused the hiatus. Climate change can be another possibility for the hiatus, because periods of settlement and occupation seem to coincide with drier and wetter conditions recorded in the subcontinent. Collapsed and tilted walls with brick rubble and infilling by sands in the settlement II layers was probably caused by a later earthquake post-dating 350a (OSL age), suggesting that this most likely corresponds to the large  $M_w > 7$  1803 earthquake of Garhwal Himalaya.**

**Keywords:** Active tectonics, grey and painted red ware, historical earthquake, Piedmont Fault.

HIMALAYA is a seismically active orogenic belt that has suffered several large magnitude earthquakes  $M_w > 7$  in the past. Of these, three earthquakes (viz. 1905 Kangra, 1934 Bihar and 1950 Assam) with magnitude  $M_w > 7.8$  occurred within the last 105 years<sup>1,2</sup>. Unlike Himalaya, the Indo-Gangetic plains have no historical record of large earthquakes. However, records of some moderate earthquakes of magnitude  $\geq 5$  during 1720 (Delhi), 1956 (Bulandshahr) and 1966 (Moradabad)<sup>3</sup> are available. The Indo-Gangetic plains have also been impacted by the Himalayan earthquakes. The 1803 Garhwal Himalaya earthquake damaged structures in Delhi, and the 1999 Chamoli earthquake in Garhwal Himalaya produced cracks in buildings in Delhi. Palaeo-seismological studies in recent years have lead to discovery of surface rupture earthquakes, dating at AD ~1450 in northwest Himalaya<sup>4</sup> and AD ~1100 in central Nepal<sup>5</sup>. These earthquakes occurred along the Himalayan Frontal Thrust (HFT), which is a physiographic and tectonic boundary between the Himalayan front and the Indo-Gangetic plains, and a plane of active displacement<sup>6</sup>. Evidence of active deformation propagating further south of the Himalayan front to the Indo-Gangetic alluvial plains has also been presented<sup>7</sup>.

In the piedmont zone (south of the Siwalik range front between the rivers Ganga and Yamuna), an active fault has been identified and designated as the Piedmont Fault (PF)<sup>8</sup>. Located ~15 km south of the HFT, the NW–SE trending PF has been interpreted as a footwall imbricate of the HFT. This uplifted the piedmont zone during its southward propagation. During the geomorphic surface mapping of PF and extending it to northwest towards the river Yamuna, we found an archaeological site towards the southern termination of the piedmont zone at Khaj nawar (Figures 1 and 2). This site had collapsed dwelling

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structures, ash layers with burnt charcoal, pottery fragments and bones. A NW–SE trending, 3–4 m high scarp is exposed on the southern end of the Khaj nawar village. The scarp lies on the right-step northwest extension of the PF (Figure 2*b*). A NE–SW ground penetrating radon (GPR) profile across the scarp shows a flexure break, suggesting it to be a tectonic scarp produced by a low angle NE dipping fault<sup>7</sup>. The Archaeology Department, H.N.B. Garhwal University at Srinagar excavated a trench on top of the outcrop site at the southern part of the village. This study integrates observation on active tectonics with archaeology, radiocarbon and OSL dating results. The demise of the early settlement and reoccupation by the later settlement is examined in terms of climate change and disruption of settlement structures as being due to an earthquake.

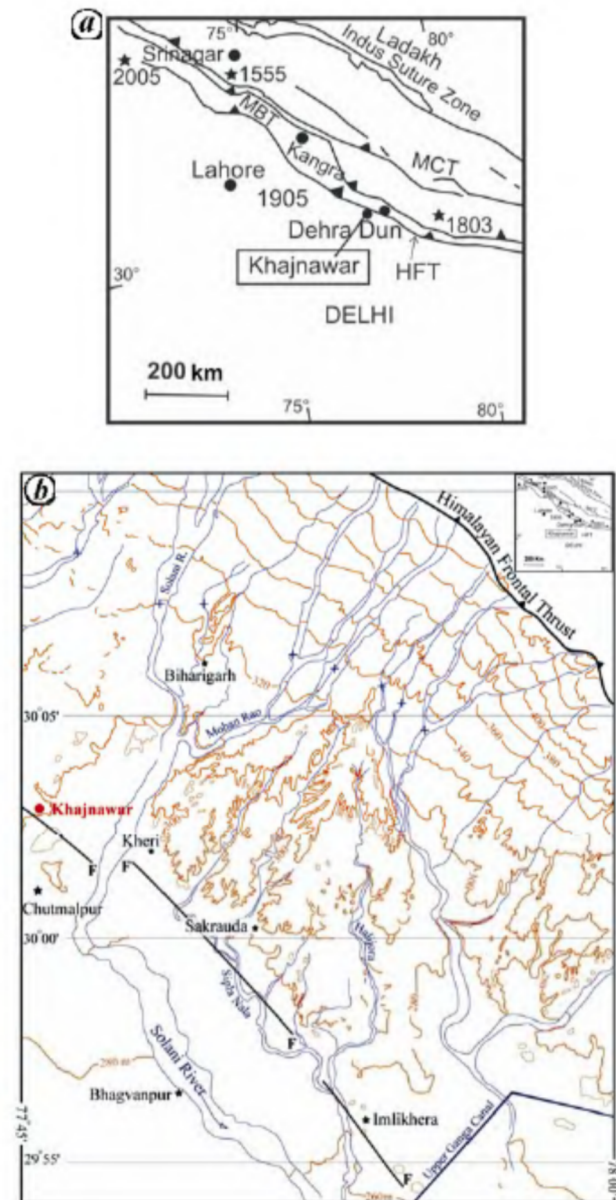
The piedmont zone comprises coalescing alluvial fans from the Siwalik range front to the Indo-Gangetic plains and is characterized by weakly undulating topography dissected by gully erosion, giving a semblance of badland topography. Incised stream sections across the piedmont zone show stratified silt, sand and gravel in the proximal part, poorly consolidated clay, silt and sand in the middle part, and mud and silt with concretion in the distal part of the fan. HFT is an abrupt physiographic boundary and tectonic contact between the frontal Siwalik range and the piedmont zone of the Indo-Gangetic plains. Remnants of isolated raised geomorphic surfaces stand out as topographic highs at elevation 8–12 m from the ambient alluvial plain. Such raised geomorphic surfaces are exposed at Imlikhera, Sakrauda, Kheri, left bank of Mohan Rao, Biharigarh, Fatehpur and Khaj nawar (Figure 2*b*).

Raised surface of the piedmont zone abruptly terminates against the recent alluvial plain and, in the past it formed scarps that are preserved in isolated outcrops.



**Figure 1.** Khaj nawar village resting over an old archaeological site with the west-facing fluvial scarp along Chacha Rao seasonal stream. Horizontal white double-direction arrows are locations of remains of red brick layers. Casing of an old well is exposed due to stream incision.

South facing scarps exposed at Imlikhera, Sakrauda, Kheri, Fatehpur and Khaj nawar are aligned along the NW–SE trending lineament and were identified using the IRS-IC LISS III and IRS-IC PAN images and areal photos. The drainage pattern also suggests the presence of a PF<sup>8</sup>. Thus for example Solani river flowing southwest takes a knee-bend turn from near Chhutmalpur to southeast towards Roorkee (Figure 2*b*). The second set of streams like Halijora and others flows southwest and join south-



**Figure 2.** *a*, Map showing location of the study area, epicentral locations of major  $M_w > 7$  earthquakes, and principal faults. *b*, Piedmont zone, south of HFT, Solani river taking knee-bend turn. Piedmont Fault (PF) trending parallel to Sipla stream. Khaj nawar scarp trending NW–SE right-step of the PF. PF largely blind with modified tectonic scarps (modified after Thakur and Pandey<sup>8</sup> and Yeats and Thakur<sup>7</sup>).



east running Sipla Nala which lies parallel to the alignment of the lineament of the PF. All the major streams in the piedmont zone originate north of the HFT in the frontal Siwalik range. The second set of streams originate within the rolling topography of the piedmont zone and show 8–12 m incision. This suggests uplift and upwarp associated with the southward propagation of the PF. As HFT propagated southward uplifting the frontal Siwalik range, the imbricate PF propagated further south raising the incipient elevation of the piedmont zone<sup>8</sup>. The PF may remain a blind fault forming scarp or may emerge on the surface. The Najiabad Fault and the Sarda Fault delineated in the piedmont zone<sup>9</sup> represent southeastern extension of the PF. Two local earthquakes were recorded in the piedmont zone neighbourhood of Roorkee: 6 November 1975, 4.9 mbgs, 78.08°–29.50° and 8 November 2007, 3.7 mbgs, 78.41°–29.28° (USGS; personal communication Sushil Kumar, WIHG, Dehradun). The epicentres of these earthquakes lie in the piedmont zone south of the HFT and suggest active tectonic activity.

Khaj nawar village 30°05'44"–77°43'30", 8 km north of Chhutmalpur, is located over the remains of an archaeological settlement exposed on the west facing scarp along the eastern bank of the Chacha Rao seasonal stream (Figure 1). The fluvial scarp is incised by the stream and extends N–S for ~200 m. A charcoal sample KH-1 from the scarp located at an elevation of 5 m from the river bed has a radiocarbon age of 2130–2350 cal a BP (Table 1). This suggests an incision rate of 2.2–2.3 mm/y. The elevation of the west-facing scarp from the stream bed is 8 m at the southern end and decreases to 0 m to the northern upstream side becoming part of the flood plain. Such incised scarp shows a triangle shaped geometry and the calculated 2.2–2.3 mm/y incision rate, indicates an uplift of the surface as a result of a north dipping blind fault. This interpretation is supported by the GPR imaging of NW–SE trending south-facing tectonic scarp in a profile normal to the scarp<sup>7</sup>. The south-facing scarp at Khaj nawar lies as right-step northwest extension of the PF observed along Imlikera, Sakrauda, Kheri and Fatehpur (Figure 2 b). The tectonic scarp of the PF most possibly is related to an earthquake event.

The archaeological debris is recognized as layered bricks exposed on the west-facing fluvial scarp of the Chacha Rao stream and in an excavated large outcrop on the southern side of the road passing through Khaj nawar village. The brick layers occur in disrupted blocks within sand–silt deposits and show horizontal and lateral continuity. Layered brick blocks occur along the entire ~200 m length of the west facing scarp (Figure 1). In the excavated outcrop on the eastern end, red brick layers are in patches and are partially disrupted and deformed within the sediments (Figure 3). The sediments also enclose horizontally layered mud bricks. Two different levels of dispersed brick layers are recognized (Figures 3 and 4). The lower level is characterized by large red bricks (30–

35 cm × 20–25 cm × 5–6 cm size) embedded in sand containing pottery and bone fragments (Figure 5). The upper level is separated from the lower level by ~2 m thick sand layer. The red bricks of the upper level are of smaller size (22 cm × 10 cm × 7 cm), similar to the bricks used at present. The remains of two walls, one tilted (Figure 3) and the other hanging (Figure 4) occur within the rubble of bricks and sand in the upper level.

Excavation at Khaj nawar comprised a trench measuring 2 × 4 m (Figure 6 a). The trench was exposed to a depth of ~4 m. The excavation yielded a chronological sequence with a hiatus between two settlements. The excavated material like the ceramic industries, structures, terracotta objects, copper coins and other minor antiquities led the entire deposit to be divided into two occupational periods, viz. periods I and II.

At Khaj nawar, the charcoal occurs in the grey ash layers and within the sands. The charcoal samples were collected from the two outcrops located north and south of the road passing through the village Khaj nawar. Two samples, KH-1 and KH-2 were collected from the outcrop located north of the road near the old well-casing (Figures 1 and 5) and other two samples KH-8 and KH-9 were collected from the grey ash layers in the main outcrop south of the road (Figure 4 a). The radiocarbon dates were obtained using conventional liquid scintillation counting at the Birbal Sahni Institute of Palaeobotany, Lucknow and are given in Table 1.

Optical dating of the brick and pottery was carried out at the Wadia Institute of Himalayan Geology (WIHG), Dehradun, and the sediment samples were dated at the Physical Research Laboratory (PRL), Ahmedabad. Samples were processed by sequentially treating them with 10% HCl and 30% H<sub>2</sub>O<sub>2</sub> to remove carbonate and organic matter and sieved to obtain suitable grain size fractions.



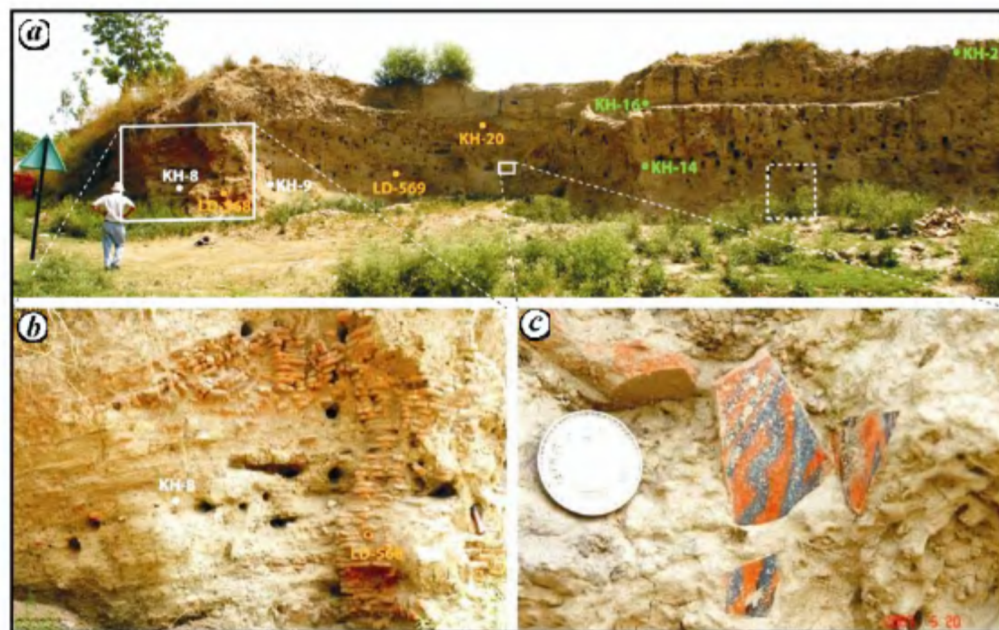
**Figure 3.** Eastern part of the main outcrop on south side of the road. Settlement I: a, the lower level with large red baked bricks and mud bricks with sand. b, Distorted red bricks. Settlement-II: c, In the upper level remain of tilted wall with rubble of bricks and sand, small size bricks. d, Dirty-white, unstratified, sand-silt containing pottery and bone fragments and red bricks.

**Table 1.** Radiocarbon dates of charcoal samples collected from the Khajnavar archeology site

Laboratory number	Sample number	$^{14}\text{C}$ date	Calibrated age (cal yr BP) One $\sigma$ range (middle)*	Calendric age (cal AD/BC)**
BS-2772	S-3597, KH-1	2240 $\pm$ 110	2120–2350 [2190]	Cal BC: 287 $\pm$ 128
BS-2773	S-3598, KH-2	2350 $\pm$ 110	2210–2710 [2460]	Cal BC: 479 $\pm$ 192
BS-2774	S-3599, KH-8	2580 $\pm$ 60	2360–2850 [2610]	Cal BC: 696 $\pm$ 198
BS-2775	S-3600, KH-9	1870 $\pm$ 80	1711–1892 [1800]	Cal AD: 142 $\pm$ 88

\*Calibrated ages (cal yr BP) are calculated using IntCal04.14c of Reimer *et al.*, 2004.

\*\*Calendric ages (cal AD/BC) are calculated using quickcal 2007 ver.1.5 of CalPal\_2007\_HU.



**Figure 4.** *a*, The full view of the excavated main outcrop on south side of the road. Two levels, settlements I and II are recognized. The lower level KH-8 and KH-9 locations of  $^{14}\text{C}$  samples, KH-569 brick sample, KH-568 pottery sample, and KH-14, KH-16 and KH-21 sand samples, and KH-20 small brick sample. In upper level, settlement II, the remains of the brick wall in the central part, and the tilted wall on the top left part of the outcrop (see detail in Figure 3). *b*, Detail of red brick wall an column distributed within layered mud bricks and sand. *c*, Painted red pottery fragment.



**Figure 5.** Outcrop on S-facing scarp near well-casing, north of the road, showing ash layers containing charcoal within the banded mud bricks. KH-1 and KH-2 location of charcoal samples for  $^{14}\text{C}$  dating and KH-7 sand sample for OSL dating. Enlarged rectangle on bottom right-hand corner with bone and pottery fragments.

In the coarse fraction, quartz and feldspar grain fractions were isolated using sodium–polytungstate ( $\rho = 2.58 \text{ g/cm}^3$ ). The magnetic grains were separated using Franz magnetic separator. Quartz samples were etched for 80 min in 40% HF with continuous magnetic stirring and then treated with 12N HCL for 30 min. Quartz was checked for purity using IRSL stimulation. The measurement of palaeodose was carried on Riso TL/OSL-DA-15 and 20 readers equipped with 470 nm blue light stimulation and  $^{90}\text{Sr}/^{90}\text{Y}$  beta irradiation source delivering a dose of 0.10 Gy/s. The etched grains of coarser samples were mounted as a monolayer on stainless steel discs using Silkospray<sup>TM</sup>. Single aliquot regeneration (SAR) protocol of Murray and Wintle<sup>10</sup> and for fine grains standard procedure of deflocculation and Stokes separation of 4–11  $\mu\text{m}$  fraction was followed. This was deposited on to aluminum discs and post IRSL, BLSLSAR was used for both coarse as well as and fine grains. In this method,

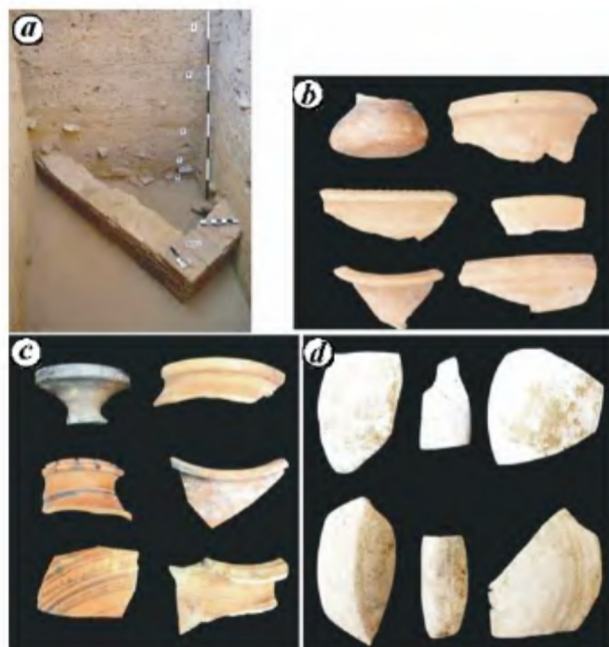


**Table 2.** Elemental content, ages (a) and dose rate ( $\mu\text{Gy/a}$ )

Sample name	U (ppm)	Th (ppm)	K (%)	A value	Dose rate ( $\mu\text{Gy/a}$ )	De (Gy)	Age (a)
KH-7*	$3.31 \pm 0.5$	$7.01 \pm 1.73$	$2.63 \pm 0.04$		$3657 \pm 284$	$5.92 \pm 0.13$	$1619 \pm 130$
KH-14*	$2.75 \pm 0.45$	$6.65 \pm 1.53$	$1.83 \pm 0.03$		$2763 \pm 226$	$2.74 \pm 0.13$	$992 \pm 93$
KH-21*	$3.23 \pm 0.56$	$3.86 \pm 1.92$	$1.81 \pm 0.04$		$2702 \pm 247$	$1.20 \pm 0.06$	$444 \pm 46$
KH-16*	$2.11 \pm 0.6$	$7 \pm 2.07$	$1.85 \pm 0.04$	0.05	$3655 \pm 257$	$3.14 \pm 0.03$	$859 \pm 101$
KH-20*	$3.34 \pm 0.62$	$5.25 \pm 2.12$	$2.42 \pm 0.04$	0.08	$4916 \pm 328$	$1.68 \pm 0.3$	$342 \pm 65$
LD568**	$2.2 \pm 0.02$	$19.1 \pm 0.19$	$2.65 \pm 0.03$		$4710 \pm 62$	$6.52 \pm 0.84$	$1384 \pm 179$
LD569**	$2.1 \pm 0.02$	$14.9 \pm 0.15$	$2.20 \pm 0.02$		$3930 \pm 54$	$6.68 \pm 0.50$	$1700 \pm 129$

\*Measured at the Physical Research Laboratory, Ahmedabad. The ages are least 10% SAR ages.

\*\*Measured at the Wadia Institute of Himalayan Geology, Dehradun.



**Figure 6.** a, Archaeological trench showing details of the log and remains of a part of the room wall. b, Red ware pottery pieces, not painted. c, Painted red ware pottery pieces. d, Grey ware pottery pieces.

estimation of palaeodose (De) was made on single aliquots by recording its natural luminescence and then the growth curve was reconstructed by successive beta doses. The growth curve was corrected for the sensitivity changes using a fixed test dose. The sensitivity corrected luminescence intensity from the sample was then read on this growth curve to estimate the palaeodose. The effective dose value (*a* value) of alpha radiation was calculated for fine grain sediments using Singhvi and Aitken<sup>11</sup>. At PRL, the dose-rate was estimated on thick source Zns(Ag) alpha counting for elemental concentrations of <sup>238</sup>Uranium and <sup>232</sup>Thorium using the Daybreak-582 alpha counters. The K concentration was estimated by measuring the <sup>40</sup>K gamma lines (1.46 MeV). A constant cosmic ray dose rate ( $150 \pm 30 \mu\text{Gy/a}$ ) and water content ( $10 \pm 5\%$ ) was used for age calculation. For samples analysed at WIHG, the U, Th and K concentrations (Table 2) were measured by X-ray fluorescence spectrometry.

The locations of the dated samples are shown in Figures 4 and 5: KH-7, KH-14, KH-21 and KH-16 are sand samples. The sample LD-568 is a pottery fragment, the sample LD-569 is from a large sized baked red brick, and the sample KH-20 is from a deep red small-sized brick.

Using the OSL and radiocarbon ages described here, the settlements at Khajnavar provide a record from 600 BC onwards (Figure 7). This record comprises:

(a) *Period-I settlement:* The first settlers of Khajnavar established their settlement over the alluvial deposits of the river at ca. 2650a and remained till 1400a. They laid a well-arranged hard mud floor covering it with a sticky yellow loam. The contemporary people used large bricks ( $30\text{--}35 \text{ cm} \times 20\text{--}25 \text{ cm} \times 5\text{--}6 \text{ cm}$ ). In the excavation, a structure with burnt bricks was discovered and indicated the existence of a room (Figure 6a). A total of six courses of bricks were discerned and the occurrence of burnt mud, ash, potsherds, bones and charcoal indicates use of the floor for an extended period. The ceramic industry comprised red ware, black ware and painted grey ware (Figure 6b–d). The Khajnavar people smelted iron and copper. The iron objects included nails, hooks and knife, etc. indicating hunting and fishing. Other finds were copper rod, copper coin (not identifiable), terracotta bead, wheel, hopscotch, spinning wheel, and crucible and agate bead. Iron working in India began as early of 1000a BC<sup>3</sup>. The painted grey ware period has been associated with the common occurrence of iron, and has been found in Atranjikhara, Lal Qila and Jhakera in Uttar Pradesh. Radiocarbon dating suggests an age bracket of 650–200a BC for the period I of painted grey ware at Khajnavar.

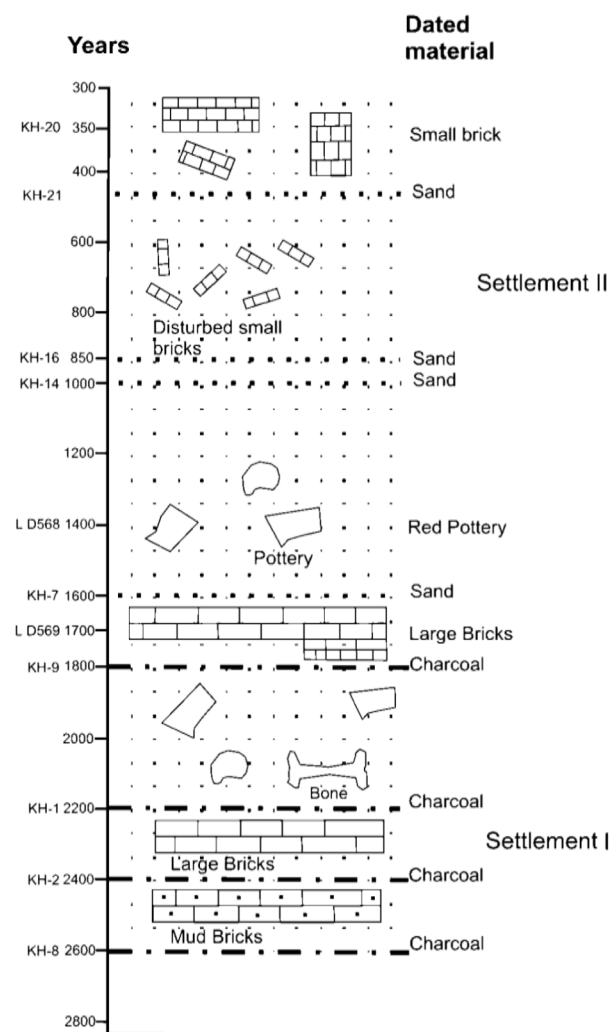
(b) *Period-II settlement:* This period (850a–350a) began in the 9th century AD after a gap of 550 years. The main ceramic industry included red and black ware. These include vases, jars, knife, edged bowls, dishes, basins, miniature pots, lamps, spotted pots and carinated handi. The red ware of this period was decorated with black paintings and incised decorations. Among the most important finds of this period are the terracotta ball, glass pendent, glass bangle, lac bangle, iron nail, hook, hopscotch and spindle.

Fault scarps affecting the late Quaternary–Holocene deposits occur along the HFT on the Himalayan mountain front. Trenches across the scarps provide evidence of surface ruptures by recent active faults showing displacement from a few metres to a maximum of 25 m. The fault traces in the trenches are interpreted as produced by the large earthquakes. Very large palaeoearthquake events  $M_w > 8$  have been reported along the HFT from Garhwal sub-Himalaya front and from Central Nepal sub-Himalaya front<sup>4,5</sup>. Dehradun region, which lies ~60 km northeast of Khajawar, also experienced an earthquake triggered by 1905 earthquake<sup>12,13</sup> of the Kangra reentrant<sup>14</sup>. Khajawar is located ~15 m south of the reactivated segment of the HFT, where a surface rupture earthquake has been inferred from evidence from trenches at Chandigarh, Kala Amb, Rampur Ganda, Lal Dhang and Ram Nagar<sup>4</sup>. The scarp profiles and trench relation indicate a single event dis-

placement of a fault 240 km in length extending from Chandigarh to Ram Nagar. Radiocarbon dates from the trench sediments give a wide range from AD 1200 to 1600 at different localities, and a mean AD 1450 has been assigned to the earthquake. In 1803, an earthquake of magnitude  $M_w > 7$  affected a large part of Garhwal<sup>1</sup>. In the main outcrop observation such as a settlement-II occurring as tilted brick wall, irregular dispersion of bricks rubble within sand, and remnant of a brick wall in the top central part of the outcrop suggest that the disrupted features in the brick layers were produced by an earthquake. Sands from uppermost level gave OSL ages of 450a (AD 1550) and the small brick gave an optical age of 350a (AD 1650). As brick walls were disrupted, the earthquake event at Khajawar should post-date AD 1650 and hence is plausibly related to the large 1803 Garhwal earthquake.

Himalayan frontal zone including HFT and piedmont zone is tectonically active. Foreland thrust system of the Himalayan front is propagating south of HFT<sup>7</sup>. The hiatus between the settlements I and II may be attributed either to climate or a natural disaster like an earthquake such that it took several centuries for people to settle down here. The tectonic scarp of the piedmont zone can be attributed to an earlier earthquake prior to the earthquake on the HFT recorded in palaeoseismology trenches<sup>4</sup>. Distortion of the remains of a wall and column observed in the settlement I (Figure 8) should have resulted in response to the earlier earthquake. The timing of the earlier earthquake can be bracketed between the upper limit of settlement I, i.e. pottery date 1400a and the lower limit of settlement II, i.e. 850a. If the hiatus of 550a was initiated by an earthquake than its timing was ~1400a. The earthquake should have raised the topography of the settlement I surface which later on provided a habitation surface for the settlement II, through incision and erosion. Khajawar area lies in the piedmont zone which is characterized by unstable drainage with changing courses of seasonal streams. Agricultural land at one place of time may be devoured by the changing drainage course leading to migration of the inhabitants. Because of such conditions, even at present, the practice of keeping revenue record of land in the piedmont area does not exist. The abandonment of settlement I may have been one such case related to climate change. Coincidentally, the hiatus gap between 1400a and 850a corresponds to failure of monsoon followed by wet conditions<sup>15</sup>.

Presence of a sterile layer dating 1700a–1400a and then <350a are correlatable to phases on weakened monsoon conditions. The inferences broadly correlate with fluctuating climate during the past 2 ka (ref. 16) and in particular correlate with climate reconstruction from peat deposits on the Himalaya. These attest to climate shift during 1570 cal a BP and 760 cal a BP (ref. 17). Despite this plausible coincidence of climate change and hiatus, it must be pointed out that the present average annual rain-



**Figure 7.** Stratigraphic log showing locations of dated materials and assigned ages. Constructed from main outcrop exposed on south side of road passing through Khajawar village (not to scale).



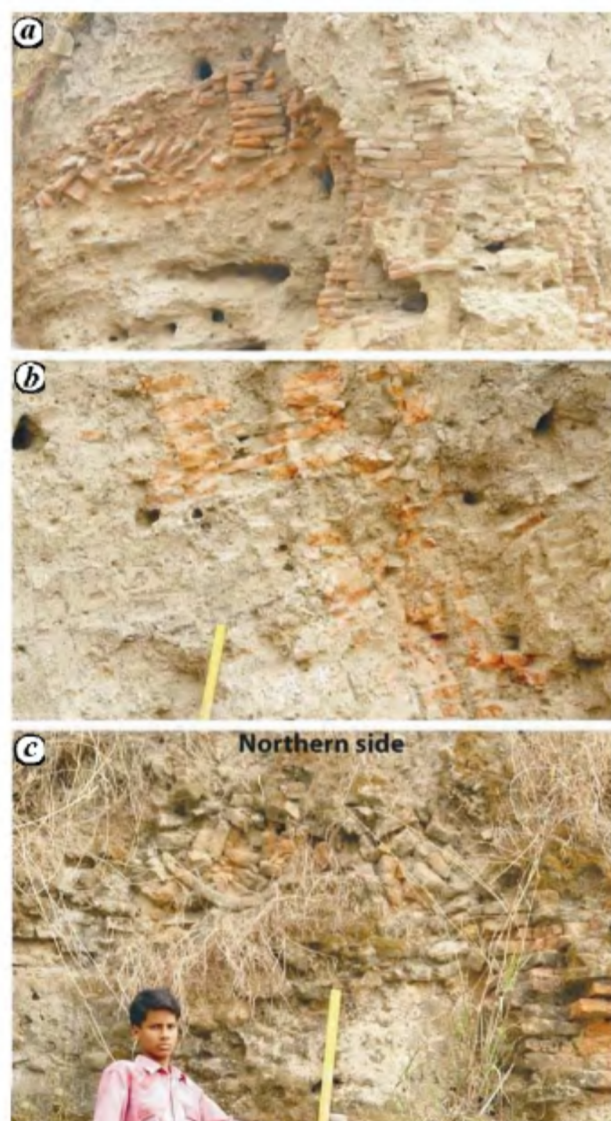
fall in the region is about 2500 mm and hence even a 50% monsoon performance is unlikely to have created sufficient hydrological stress to cause a crisis of survival for contemporary people. Any further elucidation of this premise will need a thorough investigation of the archaeology of the region and establishment of such an hiatus on a regional scale. Figure 7 summarizes the event chronology.

The  $^{14}\text{C}$  and OSL dating confirm the archaeological finding of two periods of settlement but has revised the dates. Settlement I with an age ranging from ca 2600a to ca. 1400a corresponds to the Iron Age that succeeded the Late Harappan (Cemetery H) and the final phase of Indus Valley tradition<sup>18,19</sup>. In the Gangetic plains, ca. 2600a was the time of rising Magadha empire with the reign of

Chandragupta Maurya and Ashoka during 2324a–2230a. This accords with the peat record of wetter phase between 3000a and 2500a. Settlement II ranging in age from 850a to 350a belongs to Islamic Sultanate and Mughal empire of historical period. A gap of ~550 years between the two periods of settlement is inferred. The gap indicates a hiatus and abandonment of the period-I settlement. The hiatus may be explained either by an earthquake or climatic factor. The remains of distorted and collapsed walls and columns are observed in settlement I, which may have resulted from an earthquake. Further, the hiatus between 1400a and 850a corresponds to a SW monsoon failure that occurred during ca. 1500a–1300a, interpretation<sup>15</sup> based on historical records of construction of large water bodies for rainwater harvesting. The arid phase was followed by wet phase indicative of strengthening of monsoon in several parts of India during ~1200a–800a of medieval warm period<sup>15</sup>. Settlement II, overlying the settlement I came after a time gap, encompasses remains of two walls within the rubble of bricks and sand. The wall on the eastern side is tilted and the wall on the western side is hanging within the rubble of bricks in the main outcrop. This is interpreted as the collapse of the walls due to shaking by an earthquake. The earthquake post-dated 350a dated brick from the disrupted wall. The earthquake destruction at settlement II may be related to the large 1803 Garhwal earthquake.

The principal inferences of this study are:

- An archaeological site at Khajnavar experienced two phases of occupation with a time interval.
- The site experienced two earthquakes that can be dated <1400 to >850a and at <350a.
- A hiatus in the occupation of the site. This break could have been caused by seismic event and or climate. Though chronometrically the events accord with climate change, the regional nature of occupation destruction/migration needs to be established.
- If the settlements are destroyed by seismic activity with older event at ~1400a and the next event past ~350a, it is reasonable to suggest an interval of ~1000 years between seismic events.



**Figure 8.** In settlement I: *a*, Distorted wall and subhorizontal column. *b*, Remains of a tilted wall. *c*, Collapsed bricks rubble of structure.

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## A ground-dwelling rhacophorid frog from the highest mountain peak of the Western Ghats of India

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**A new rhacophorid frog is described from Eravikulam National Park in the Western Ghats of India. The species is morphologically dissimilar from any known member of this family in having a bright orange to reddish colouration, multiple macroglands on the body and extremely short limbs. Phylogenetic analyses of mitochondrial genes indicate that this new frog is nested in a radiation of shrubfrogs that had its origin on the Indian subcontinent, and which is here recognized as a distinct genus, *Raorchestes* gen. nov. The new species, *Raorchestes resplendens* sp. nov. is likely restricted to less than 3 sq. km on the summit of Anamudi, and deserves immediate conservation priority.**

**Keywords:** Endotrophic development, macroglands, mitochondrial phylogeny, *Raorchestes* gen. nov., *Raorchestes resplendens* sp. nov., Western Ghats.

THE Rhacophoridae constitute a radiation of about 300 species of frogs<sup>1</sup> with a distribution in the tropical regions of Asia and Africa. A large part of their taxonomy has traditionally been based on the variety of reproductive strategies, such as the use of foam nests or development without going through a free-swimming tadpole stage. Molecular evidence has recently solved the phylogenetic position of many rhacophorid species<sup>2–7</sup> and has resulted in the erection of new genera, such as *Gracixalus*<sup>3</sup>, *Feihyla*<sup>4</sup>, *Liuixalus*<sup>5</sup> and *Ghatixalus*<sup>6</sup>. Although rhacophorids find breeding microhabitats from the soil to the forest canopy, calling males are often found in vegetation layers<sup>8</sup>, and the family as a whole is therefore usually considered arboreal. Here we describe an exceptional glandular rhacophorid with extremely short limbs from Anamudi summit (2695 m asl) in the Western Ghats of India. We performed molecular analyses to infer its phylogenetic position within the family and studied its reproduction and development.

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