New insights on the geological evolution of palaeorivers and their relationship to Indus Civilization and Early Historic settlements on the plains of Haryana, NW India

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Abstract

The Quaternary sediments and landscapes of the plains of north-western Haryana and the ancient settlement mounds distributed across them have great potential to reveal the history of the evolution and disappearance of palaeorivers and their relationship to the Indus Civilization and Early Historic periods in northwest India. There are numerous palaeochannels in Haryana, and their distribution and burial in the subsurface creates difficulties for accessing the archives and proxies necessary for developing insight into the timing of river flow and shift, and its relationship to settled populations. This paper investigates the deep and shallow subsurface sedimentary lithology of an area around Sirsa that is close to the course of the modern Ghagghar River. The paper presents additional age constraints provided by dates from the site of Rakhigarhi and examines a sedimentary substrate of a new archeological mound situated on the palaeochannel identified at a mound near Dhir village. New AMS radiocarbon dates of drifted charcoal from natural and cultural strata suggest human activity and/or natural burning in this region as early as 10405 to 10190 cal BP (8455 to 8240 cal BC). The substrate sediments recorded at Dhir mound indicate flooding events after the urban phase of the Indus Civilization.

Keywords

Palaeorivers, Indus civilization, Haryana plains, Harappan settlements, radiocarbon dates

1. Introduction

Tracing and validating the course of buried palaeorivers in the Quaternary fluvio-aeolian plains of NW India has been attempted for more than a century (Oldham 1893; Ghose et al.

1979; Yashpal et al. 1980; Wilhelmy 1999; Sahai 1999; Radhakrishnan and Merh 1999; Malik et al. 1999; Kar 1999; Rajawat et al. 2003; Gupta et al. 2004; Bhadra et al. 2009; Saini et al. 2009; Valdiya 2013). Many studies suggest that one major river, which is often identified as the ancient Saraswati, traversed three morpho-climatic terrains: from the humid and tectonically active Himalaya, across the semiarid plains of northwest India and the arid Thar desert margins, before emptying in the Arabian Sea. Interest in the buried channels of northwest India was renewed after the demarcation of palaeoriver courses from aerial photos and satellite imagery, particularly a major channel in Fatehabad area of Haryana, which was argued to be part of the disappeared Saraswati River (Yashpal et al. 1980; Sahai 1999). Subsequently more palaeocourses were identified through refined digital remote sensing data and analysis. Some of the channels appear to be related to the major channel while others were detached ones. In large areas of Haryana and Rajasthan, to the north of the Thar desert, three major palaeochannels and several minor channels have now been inferred suggesting that the palaeohydrology of this region comprised of a network of channels (Mehdi et al. 2016; Van Dijk et al. 2016; Orengo and Petrie 2017). Disorganization of such a river may not be so abnormal phenomenon in view of its course through the climatically sensitive semiarid region and an active Himalayan orogen. In semiarid and arid regions, rapid development of dunal landscape can mask the drying up of river courses easily, leaving few or no surface expression. Similarly, tectonic disturbances in catchments can also cause shift in river courses, starving them of water. Besides, climatic and tectonic implications of the disappearance of these palaeorivers, their relationship to the ancient Indus (or Harappan) Civilization has also been extensively explored. Some scholars have argued that the Indus Civilization thrived on the plains of northwest India when the palaeochannels were active (Sahai 1999; Radhakrishnan and Merh 1999; Valdiya 2013), while others have argued that there was no link between the two and suggested that the major palaeorivers had dried up much earlier than the Indus Civilization (e.g., Singh et al. 2016, 2017; Dave et al. 2019). Like its existence, the cause of the drying up of the palaeoriver and the decline of the urban period of the Indus Civilization has also been intensively debated, though several studies have suggested that weakened rainfall and increasing aridity was a major factor in this process (Clift et al. 2012; Giosan et al. 2012; Dixit et al. 2014b, 2018; Petrie et al. 2017). It is also pertinent to mention here that recent archaeological evidence suggests that there were relatively fewer settlements along the major palaeoriver that is considered to have been the Saraswati river during pre-urban, urban and post-urban periods of the Indus Civilization (Petrie et al. 2017; Singh et al. 2018, 2019; Green et al. 2019; Neogi et al. 2019). A complex climate-landscape interaction with highly variable fluvial activity suggesting the dynamic nature of Holocene has also been proposed based on a new set of OSL dates (Durcan et al. 2019).

The main reason for the lack of consensus amongst these issues is paucity of surface signatures and subsurface geological data in the nearly two-thousand-kilometer-long Quaternary landscape from the Himalaya to the Arabian Sea. Today the plains are intensely cultivated and access to the subsurface is extremely constrained even though several studies have attempted to fill data gaps (Saini et al. 2009; Saini and Mujtaba 2010; Clift et al. 2012; Sinha et al 2013; Singh et al. 2016,2017). Earlier work, based on the study of more than 100 shallow wells, riverbank and quarry litho-sections coupled with remote sensing and field-based tracing of the drainages, has provided a framework of the shallow subsurface stratigraphy and chronology of the major events during last ~30 ka BP (Saini et al. 2009; Saini and Mujtaba 2010; Mehdi et al. 2016). Though several scholars have traced the tentative course of the major palaeoriver in the area of Fatehabad, ground validation for the entire course is yet to be done. Despite conflicting opinions on the path and ages of the channel courses, the presence of a prominent palaeochannel zone near Fatehabad is universally accepted. A NE-SW aligned 5-15 km wide high moisture zone which can be traced from Tohana to Ottu for a length of approximately 80 km (Saini and Mujtaba 2010) is the remnant of a major river. However, understanding of climate versus tectonic dynamics in its degeneration and its relationship with the growth/demise of the spatially and temporally related Indus Civilization is rather sparse. Archeological mounds dating to the pre-urban, urban and post-urban periods of the Indus Civilization are scattered along the palaeochannels (Kenoyer, 1991). Several important mounds belonging to pre-urban and urban period lies close to the bank near Banawali, Bhirrana, Kunal, Fatehabad, Sirsa and Hoshanga, whereas a mound belonging to post-urban period is located within the palaeochannel at Dhir, and a substantial number of settlements are located far away from this channel near Tohana, Agroha, Bhuna and Hisar. Interestingly, the famous Rakhigarhi mound complex is located away from the main palaeochannel documented at Fatehabad and appears to be on a subsidiary palaeochannel that is not visible on the surface (Mehdi et al. 2016; Orengo and Petrie 2017).

The complex linkage of the palaeochannel network and the settlements of the Indus Civilization and the Early Historic periods in northwest India will only be resolved by integrated studies that combine radiocarbon and other chronological dating approached with geoscientific investigation of the sediment and their sources, and consideration of the processes of climate evolution. This study provides important linkages between the shallow subsurface geology of the palaeodrainage, mineralogical constraints on the provenance of sediments, and contribution of new age data to fill the proposed gap.

2. Area and the work done

The study area lies along the present day Ghagghar River, between the major palaeochannel near Tohana in the northeast to Ottu in southwest, on the alluvial plains of northwestern Haryana (Fig.1). Two of the authors (HSS and NCP) conducted systematic Quaternary geological mapping at a regional scale in 1980s when human interference to the landscape was less. These plains are underlain by 200 m to >400 m thick Post Siwalik Quaternary sediments deposited by the Himalayan rivers over a northerly deepening basin (Saini and Anand 2003; Saini et al. 2009). The area is significant in context of its sensitive semi-arid climate and its location on the Indus alluvial plain at the northeastern fringe of the Thar desert. The alluvial plain abuts the ENE-WNW oriented Himalayan ranges in the north and is delimited by the Yamuna River on the east. Major geomorphic zones in the region from north to south include a piedmont, a central alluvial plain and an aeolian zone (Fig.1). The Piedmont zone lies adjacent to the Himalayan front and comprises a clayey surface with southward slopes and high drainage density. The central alluvial interfluve plain between the Yamuna and the Sutlej rivers has a silty clay surface with imperceptible slope and low drainage density consisting of seasonal piedmont rivers as well as the perennial Himalayan rivers like Sutlej. It has faint impressions of palaeodrainage on the ground, and they take the form of subtle elongated depressions and occasional sand dunes. The structure of this drainage has been reconstructed using processed remote sensing imagery and digital elevation models (van Dijk et al. 2016; Orengo and Petrie 2017, 2018). Amongst the numerous impressions of palaeochannels, two are most prominent: one with a course from Tohana to Fatehabad to Sirsa (TFS), which is near the modern Ghagghar River; and a second from Jind to Hansi to Bhadra (JHB) (Fig. 1, Saini et al. 2020). The TFS channel has a perceptible depression near Fatehabad and continues to be flood prone, which was referred as the Palaeo-Ghagghar and Palaeo-Chautang channels by Dave et al. (2019). The aeolian zone represent the sand ridges and plains and palaeolake depressions.

Through carefully selected sections in the present study, we have attempted to: (a) work out the shallow subsurface lithology of the unexplored areas in the palaeochannel around Ottu; (b) carry out the provenance fingerprinting through monazite (Th-U-Pb chemical geochronology) and zircon ages (U-Pb isotopic ages); (c) provide new age constraints using Accelerator Mass Spectrometry (AMS) radiocarbon dating of the samples from a natural substrate of an archeological mound at Dhir village situated within the main palaeochannel of Saraswati; and (d) obtain new AMS radiocarbon dates from the samples collected from the top and the middle parts of the mounds at Rakhigarhi (sample locations are marked in Fig. 2).

3. Methods

Lithological logging of active drill and well sites was carried out and stratigraphic logs were prepared for each location. Keeping in view the constraint of dry drilling, non-contaminated fluvial sediment samples were collected from a bore-well near Sirsa for zircon and monazite dating to infer the provenance of buried river channel. The two cultural mounds at Dhir and Rakhigarhi were studied and sampled to understand their geoarchaeological context. The mound at Dhir is situated within the Fatehabad palaeochannel (TFS) and the mounds at Rakhigarhi are located near a buried drainage (JHB) identified by Mehdi et al. (2016) using remote sensing imagery. At Dhir the natural sedimentary platform forming the base of the mound was logged and sampled, while at Rakhigarhi exposed sections of mounds were logged and uncontaminated charcoal samples were collected for radiocarbon dating. For subsurface lithological evaluation, sediments recovered from the under construction bore wells (up to 120 m depth) and dug wells (up to 7 m depth) were studied, logged and depositional environment was inferred as per our earlier study (Saini et al. 2009) (Fig.2). The logs were used to draw cross-sections from which local and distant shallow subsurface lithological variations were evaluated. Four deep boreholes show the different types of subsurface lithology (Fig. 3) over a large area up to 120 m depth while shallow data of closely spaced wells show detailed variations in the lithology (Fig.4).

Zircon is a weathering resistant mineral whose age represents cooling time at or above 750° C. For U-Pb isotopic dating of zircon and electron probe micro analyzer (EPMA) total Th-U-Pb chemical dating of monazite, grains were separated from two grey micaceous fluvial sand samples from Sirsa and one from the Bhagirathi catchment from Gangotri and were processed. Though, Zircon dating has been widely used for provenance fingerprinting of sediments in Indo-Gangetic plains (Alizai et al. 2011; Gehrels et al. 2011; Clift et al. 2012;

Singh et al. 2016) monazite has generally not been targeted. Using both of these minerals, this study was carried out to target the provenance of fluvial sand of Sirsa area (TFS).

Zircon grains were mounted on glass slides together with the zircon standard FC1 (^{207}Pb/^{206}Pb age of 1099.0 ± 0.6 Ma; Paces and Miller 1993). Photomicrographs of the zircon grains were taken in transmitted and reflected light using an optical microscope and back-scattered electron (BSE) and cathodoluminescence (CL) images were taken using the JEOL JSM-7500F scanning electron microscope at the Hiroshima University. U–Th–Pb isotopic analyses were performed at National Museum of Nature and Science, Japan. Zircon U–Pb analyses were conducted using an Agilent 7700x inductively coupled plasma mass spectrometer (ICP-MS) equipped with ESI NWR213 laser ablation system. Detailed analytical procedures and work conditions are described in Tsutsumi et al. (2012). A Nd-YAG laser (213 nm wavelength and 5 ns pulse), with a 25 μm spot size and 4–5 J/cm^2 energy were used in this study. All measurements were carried out using time resolved analysis. Common Pb corrections for the Concordia diagrams and each age were made using ^{208}Pb based on the model for common Pb compositions proposed by Stacey and Kramers (1975). Age data and plots were processed by using the Isoplot software (Ludwig 2003).

A total of 45 monazite grains from three samples in the sample mounts were analyzed for U-Th-total Pb by EPMA (JEOL JXA-8200 Super probe) at the Natural Science Center for Basic Research and Development (N-BARD), Hiroshima University. The analytical procedures followed were fundamentally the same as those of Fujii et al. (2008) following the methodology of Suzuki and Adachi (1991). The beam current was fixed at 200 nA, whereas the acceleration voltage was 15 kV throughout the analysis with a beam diameter of 5 μm. Fifteen characteristic X-ray lines were measured for each element (Si–Kα, Sm–Mβ, Gd–Mβ, Dy–Mβ, Th–Mα, U–Mβ, Ca–Kα, La–Lα, Ce–Lα, Y–Lα, P–Kα, S–Kα, Pr–β1, Nd–Lβ1, Pb–Mβ). All the analytical results were monitored using data of a monazite age standard from Namaqualand, South Africa (ca. 1033 Ma; Hokada and Motoyoshi 2006).

Radiocarbon determinations were obtained from the Inter University Accelerator Centre, India. A total of 13 samples were first microscopically inspected and then chemically processed using Acid-Base-Acid (ABA) protocol as discussed in Sharma et al. (2019). Chemically treated and freeze-dried samples were combusted and graphitized using automated graphitization equipment (AGE). Thus, obtained graphite powder samples were loaded into the ion source of AMS system for isotopic analysis of carbon ($^{14}C/^{12}C$) to estimate the radiocarbon age of the samples (Table 1).

Radiocarbon ages were converted into calendar ages using OxCal 4.3 online (Reimer et al. 2020), and the IntCal13 calibration curve for northern hemisphere. Standard (OX II) and blank samples (Phthalic anhydride, Sigma Aldrich, Purity 99%) prepared in the same lot as that of archeological samples were used for AMS system calibration and background correction, respectively. Results were corrected for delta ^{13}C, which is taken (-25.00±2.000) ‰ for all the samples. Background value during the measurement was (0.455±0.018) pMC (Percentage modern carbon) which corresponds to the $^{14}C/^{12}C$ ratio of (4.3543± 0.0168) x 10^{-15}, which was much below than that for the archaeological samples dated for this study. Data quality was monitored with a secondary standard sample (IAEA-C8) and its consensus values (pMC = 15.03±0.17) was matched with its experimental result (pMC= 14.96±0.09) and was found to be within the error. The AMS system description and measurement procedure is explained in detail in Sharma et al. (2019).

4. Results

4.1. Shallow lithostratigraphy:

The upper part of the Quaternary sediment column in NW Haryana representing the regional alluvial/aeolian plains consists of horizontal layers, beds and lenses of grey micaceous, medium to poorly sorted, coarse silt and fine sand (GF); brown, well sorted, fine sand (BF); brown, greenish silt clays (SC), brown, pinkish, reddish clays (CF). The GF represents channel deposit, the SC and CF represent flood plain deposits and the BF represent aeolian deposits (Saini et al., 2009). In western part, near Ottu-Sultanpuria (OS) (Fig. 3), there is dominance of pinkish and greenish silt-clay (SC) with one bed of GF at around 18 m and a hard bed of calcretised clay at ~55m depths. The hard clay is typical of this area and farmers use this clay as a roof of the cavity type bore-wells. The litholog near Rasulpur Ther (RT) (Fig. 3) displays four beds of channel sand (GF) alternating with pinkish clay (CF). The aeolian sand (BF) appears at around 100 m depth. In Sirsa log (SR) (Fig. 3) the aeolian sand (BF) appears prominently between 10-30 m depths followed by silt-clays (SC) with two thin beds of channel sand (GF) at around 52 m and 70 m depths. The subsurface lithology of a 120 m deep bore hole, about six km west of Bhuna (WB) (Fig. 3), shows two levels of channel sand (GF) at about 10 and 85 m depths and two prominent lenses of aeolian sand (BF) below 90 m depth and silt-clays (SC) in the remaining part, with thin lenses of aeolian sand in between. These four logs were from the silt-clay alluvial surface of central alluvial plain. From a bore-hole in the aeolian surface Saini and Mujtaba (2012) recorded and dated 28 ± 2 ka channel sand (GF), six meter below ground. Similarly, channel sand is also noted at several places between 10 and 30 m depths. These occurrences suggest a vigorously flowing channel system that disappeared due to aridity close to the interface of MIS 2 and MIS 3.

Though these distant logs provide a clue of the subsurface geological set up over a large area, a better perception of the subsurface litho-architecture of the fluvio-aeolian deposits can be obtained by considering the closely placed litho-sections inferred from combination of several bore hole logs. Three such sections, within and across the palaeochannel were prepared (Fig. 4) and are described below.

Section A'-A: This 10 km long NE-SW section is located across the palaeochannel and shows equal dominance of grey micaceous channel sand (GF) and silty-clays (SC) of flood plain (Fig. 4A). There are two thin and impersistent layers of brown aeolian sand (BF). The lithological set up is indicative of a fluvial regime briefly interrupted by aeolian activities indicating short lived aridity.

Section B'-B: Across the Ghagghar River, the grey micaceous channel sand (GF) reduces in thickness and the upper bed present in section A-A" also disappears in this section (Fig. 4B). The flood plain silty clays (SC) gain prominence and the aeolian sand (BF) also appears at three levels. A lens of reddish clays (CF), possibly representing a flood plain lake deposit is also developed along this transect. The red clay is similar to the modern clay being transported by the Ghagghar River from the Siwalik ranges.

Section C'-C: This 11km long section also lies in the palaeochannel zone about 4 km downstream of B'-B (Fig. 4C). It has thick layers of brown sand (BF) in the middle, suggesting prominent aeolian activity in the region. The river channel deposit (GF) is less with thinner bands while the aeolian sand (BF) and flood plain clays (CF) are prominent, suggesting, either the channel migrated outside this zone or was considerably reduced at the expanse of aeolian activity.

4.2. Zircon and Monazite geochronology and provenance

Studies utilizing extensive detrital zircon data have been carried out in context of the palaeochannels of northwest India (Alizai et al. 2011; Clift et al. 2012; Singh et al. 2016) but have produced some confusing results. For example, comprehensive sampling of the detrital zircons from the Indus River and all its tributaries, as well as the Ghagghar and the Yamuna Rivers and the bedrock of the Sutlej River was supplemented with age data from the zircon chemistry to establish provenance markers (Alizai et al. 2011). The paucity of younger Himalayan data (<15 Ma), distinctions between the zircon populations of the upper Indus (<200 Ma most prominent) and rest of the Indus and the separation of Higher and Lesser Himalayan sources were the significant conclusions derived from this study (Alizai et al. 2011). Alizai et al. (2011) also used modelling of modern delta zircons with the past to suggest that there were contributions from the then westward flowing Yamuna River. Using zircons from the established palaeochannel sand lenses, Clift et al. (2012) also supported the contention for a contribution from the Yamuna (which now flows south and east), to the sediments of the major palaeoriver that flowed west. However, presence of an active channel has been inferred even after 4.5 ka BP and its aeolian covering after 1.4 ka BP (Clift et al. 2012). Contrastingly, using another set of extensive zircons U-Pb data, Singh et al. (2016) suggested that the major palaeochannel was not active after ~8ka BP.

In view of existing large U-Pb zircon age data in these studies and a general consensus on contribution from the Ganga basin, at least when the major palaeochannel was active and perennial, we devised a focused provenance testing strategy to prove higher Himalayan sourcing (or not) of the sediments in the TFS channel. A two-pronged approach was adopted in obtaining a control sample away from the Indus basin and utilizing monazite along with zircon for this study. The control sample (representing higher Himalayan source) was collected from the riverbed sand at Gangotri town and the samples from palaeochannel was collected from undisputed and well-described grey sand lenses of the main TFS palaeochannel from Sirsa (Fig. 2). The geological log of the Sirsa location is described above (Fig. 3).

Representative back scattered electron (BSE) and cathodoluminescence (CL) images of some of the analyzed zircon and monazite are shown in Fig. 5A. Most of the zircons are euhedral and show magmatic signatures in form of oscillatory zoning in the CL images. Monazite grains (brighter grey tones in BSE images) may represent a metamorphic component as well in being subhedral to anhedral (Fig. 5A).

A total of 119 zircon grains were measured (data in supplementary table S-1) from fluvial sand at ~72 m depth within the Sirsa palaeochannel and the Concordia diagram for these grains is plotted in left-side diagram of panel A of Fig. 5B. Near concordant data from 82 of these measurements are shown in the central histogram plot of panel A (Fig. 5B) (data in supplementary table S-2). Similarly, plots of the Concordia diagram of 128 zircon grains from the same borehole at ~52m depth and histogram plot of near-concordant data of 106 grains from amongst this dataset is given in panel B of Fig. 5B. Panel C in this diagram is that of the control sample from Gangotri where 52 grains were measured, of which 43 represented near-concordant data (Panel C, Fig. 5B; data in supplementary table S-3). Corroborating the zircon U-Pb isotopic ages, the monazite total Th-U-Pb chemical geochronology results (right-side panels in Fig. 5B) also depict the Tertiary age signatures in both the samples as well as in the control sample. Even though these samples are from deeper levels which is unlikely to have any bearing on the settlements in the area, this data is relevant to establish that the palaeorivers in late Quaternary was a robust hydrological system.

In the control sample (sample C), a bimodal age population for zircon U-Pb data (Palaeozoic as well as Tertiary or younger) and a unimodal (Tertiary and younger) age of monazite is observed (Fig. 5). In combination, this is considered as evidence of sourcing from the Higher Himalayas (above MCT) with the Tertiary or younger signal of monazite and zircon indicative of peak Himalayan metamorphism and associated Tertiary and younger granite magmatism (monazite analysis and age data in supplementary table S-4).

Samples at Sirsa both depths (52 and 72 m respectively) which are older than 64$\pm$3 ka as compared to the study of Dave et al. (2019), show representation of Paleoproterozoic, Mesoproterozoic as well as Palaeozoic ages besides the younger “higher Himalayan” signals in the zircon U-Pb ages. Interestingly, monazite ages from these samples shows nearly a unimodal population characteristic of Higher Himalaya source. Thus, higher Himalayan or glacial sourcing of the palaeoriver in Sirsa area is well established.

4.3. Geoarchaeology

The Dhir Mound

An excellent composite geogenic and archaeological section was exposed at Dhir village, which is located well within the bounds of the TFS palaeochannel (Fig. 2 and Fig. 6). The eastern face of this exposure shows a 2 m thick basal natural flood plain deposit, which is overlain by a 4 m thick archaeological deposit. The natural deposit comprises of thin and crude layers of laminated to massive silty clays and sandy silt with rare lenses of very fine sand (Fig. 6A and Fig. 6B). Most of these layers contain small pieces of soft charcoal, brick and pottery pieces and broken bones that have been transported along with sediments. Just below the contact with the archaeological deposit, whitish dusty salt precipitates of calcium carbonate are present in the silt-clayey sediments. The archaeological deposit exhibits a horizontal fabric due to clay beds and is replete with bird-hole weathering (Fig. 6A). The deposit is mainly comprised of buff clays with pieces of baked bricks that post-date the Indus Civilization. Some brick structures within the section are still intact. We dated four samples of charcoal from these deposits (Table 1 and Fig. 6B). Although the oldest date was 10405-10190 cal. BP (DH3), and there was a date of 5595-5300 cal. BP (DH5), the ages are not in stratigraphic order. This reflects the fact that these charcoal pieces may have been transported from different parts of the catchment along with sediments during flood events. The charcoal in the basal strata gives an age of 2860 - 2735 cal. BP (DH1), which is younger than the two dates mentioned above, and must be used as a *terminus post quem* for the age of the basal part of sediment layer. All other materials must have been deposited subsequently, irrespective of radiocarbon age. To corroborate this dating, a sand sample at 1.5 m above the base (near DH-7 of this study; Fig. 6B) was dated independently which gave a quartz OSL age of 1.5$\pm$ 0.1 ka BP (Raza et al. 2020). The bricks in the archeological deposit are akin to bricks of the Early Historic period, and possibly belong to Kushan period in the age bracket of 2000-1500 yr BP (pers comm., S.J. Hasan, Former Director Archeological Survey of India). A coeval mound ~2000 years old has been discovered near Kunal village.

Rakhigarhi Mounds

The major site of Rakhigarhi represents one of the five major cities of the Indus Civilization**,** and it is the largest Indus settlement in northwestern India (Kenoyer 2008; Neogi et al. 2019). Presently there is no river or channel visible on the surface near the site, but impressions of a drainage have been mapped by Mehdi et al. (2016) through satellite imagery and the reconstruction of this course was extended by Orengo and Petrie (2017, 2018) using a combination of vegetation indices and micro-topographic analysis. Some scholars have linked this channel to the now defunct Drishadwati river (Nath 1998). The site of Rakhigarhi comprises of six mounds forming the city and a seventh towards the north marking the cemetery (Nath 1998; Shinde et al. 2018) (Fig. 7). All these mounds are partially occupied by modern villagers. Mound 4 has a ~12 m high cliff section (Fig. 7C) of stratified archaeological material consisting of poorly sorted pottery fragments, bricks and kanker in muddy matrix. The basal two meters is finer, the middle 8 m is coarser and the upper 2 m is gritty in nature. The sediments are compacted and hardened. The beds in the basal parts are

1-5 cm thick and laminated. Thin beds and lenses of ash are common in the basal part. No evidence of natural stratification by water or any other natural agencies was observed.

Nine AMS radiocarbon ages were obtained from various locations in Rakhigarhi. The sample locations and median calendar ages are shown in Fig. 7. A sample from the upper part of mound 3, collected near the temple, gave a calendar age of 5890 – 5595 cal. BP (RGR32). From the middle part of mound 2 we obtained three ages which gave a range of 5915 – 5660 to 3375 – 3080 cal. BP (RGR21, 22, 23; Fig. 7B, Table 1). These three dates are in stratigraphic order but span almost 3000 years and come from deposits of spanning 10 cm of cultural material, which is problematic. From the lower part of the ~12m section of mound 4 (Fig. 7C) five measurements have given a range of 4570 – 4295 to 8520 – 8335 cal. BP, with the oldest date being the youngest stratigraphically. The stratigraphically earliest of these dates, which should be used as the *terminus post quem* for the sequence, falls within the span of the Mature or urban phase of the Indus Civilization (c. 4600-3900 BP; Shinde et al. 2018; Vahia et al. 2016), but all other ages are older, suggesting that they originated in material that has been redeposited higher up on the mound. One OSL age at two metres above the base of stratification has shown an age of 7.5±0.5 ka BP (Raza et al. 2020).

5. Discussion

Today, the large arid to semi-arid plains between the Ganga on the east and Indus on the west is drained by a short piedmont, monsoon and groundwater fed Ghagghar River and a range of tributaries. This area is important as it was habited by population of the Indus Civilization (c. 4600-3900 BP/2600-1900 BC) and the Early Historic period (c. 2500-1500 BP/500 BC-AD 500), and it was traversed by a range of palaeorivers, which were potentially important for the ancient inhabitants.

The modern Ghagghar River starts in the Siwalik hill ranges (rainfall ~1000 mm/year) and disappears into the northern part of Thar Desert (rainfall ~300 mm/year). The short, narrow and entrenched valley of the river corresponds well with the present-day climate but does not appear strong enough to have deposited the >400 m thick extensive sediment column that is known in the area. A palaeochannel (TFS) near Fatehabad, however, is much larger than the modern Ghagghar River and its sediments indicate its origin in Higher Himalaya as suggested by zircon and monazite-based provenance studies.

The shallow subsurface sediments at Sirsa dominantly represent deposition under channel and flood plain environments with fluctuating and noticeable interruptions by aeolian environment. The subsurface lithological data of this and earlier studies (Saini and Mujtaba 2012, Singh et al. 2016) show that the landscape development has progressed under humid and arid-semiarid conditions and the area has been prone to frequent climatic changes.

Lateral and vertical variation in the subsurface lithology (Fig. 3 and Fig. 4) suggests deposition by meandering and migrating rivers whose flows were controlled by a fluctuating SW monsoon. Presence of aeolian sediments at several horizon in the subsurface (Fig. 3 and Fig. 4) as well as in surrounding area (Saini and Mujtaba 2012) testifies to the weakened SW monsoon in the region several times during the period of alluviation. Now, there are several climate proxy records from the region that suggests that there were periods of weakened and/or fluctuating monsoon throughout the Holocene (Dixit et al. 2014a, 2014b, 2015, 2018). These fluctuations in time and space gave rise to variations in lateral facies from east to west, as shown by borehole logs and thus precludes the establishment of a regional stratigraphy. These fluctuations are the possible causes of problems in regional projections of localized subsurface studies (Shitaoka et al. 2012; Chatterjee et al. 2019; Dave et al. 2018). Our subsurface data (Fig. 3) shows that aeolian activities were relatively dominant in the western part near the Thar desert margin where a major phase of dune deposition took place during 18-12 ka BP (Saini and Mujtaba 2012). In eastern side towards Bhuna, this younger aeolian phase is sparse but an older aeolian phase can be seen at ~ 100 m depth which may be older than 96$\pm$5 ka BP in comparison to the aeolian sand reported at ~35 m depth in upstream (Singh et al. 2016). The channel sand occurs at various depths alternating with silt-clays and aeolian sand. The major fluvial activities now buried at ~ 6 m depth had ceased between 28-21 ka BP (Saini and Mujtaba 2012; Dave et al. 2019) in the alluvial plain and between 15-8 ka BP (Singh et al. 2017) in the palaeochannel. Variation in ages and architecture of grey micaceous sand (GF) is indicative of the lateral migration of channels as well as cessation of channel activities several times due to increased aridity in different sectors (Saini et al. 2009). Some scholars have argued that today's Ghagghar was the ancient Saraswati River (Chatterjee et al. 2019), however, present data is not sufficient to confirm the source from where the Ghagghar river originated, the course it followed, the precise timing of when it dried up and the reason of its disappearance. In section C-C' fluvial activities tend to weaken at shallow depths which is a signal of deteriorating climate and increasing aridity. It has been inferred that Yamuna River might have drained via this area probably till 49-10 ka BP (Clift et al. 2012).

These changes occurred much before the establishment of Indus Civilization in the region and has no direct relation to its subsequent deurbanization and decline. Studies have shown that at the beginning of Holocene, dry- aeolian conditions prevailed between ca. 9 and 7 ka BP followed by a lake phase during ~ 7-4.4 ka BP (Saini and Mujtaba 2012). However, fluvial activities continued in the region albeit with fluctuating strength throughout the Holocene and might have a role in Indus deurbanization. Saini et al. (2009) presented dates that showed that the Fatehabad palaeochannel was an active bedload river between 5.9 and 4.3 ka BP, and subsequently became a stream with weak suspended load transporting only silt-clay sized sediments. Chatterjee et al. (2019) consider 9-4.5 ka BP period as the rejuvenated perennial phase of Ghagghar/Saraswati River. As noted above, Singh et al. (2017) argued that the river was not perennial after 8.0 ka BP.

There is a striking unanimity on the origin and transportation of grey micaceous sand (GF) from the Himalaya by perennial rivers related to Indus and Yamuna drainage (Saini et al. 2005; Clift et al. 2012; Singh 2016, 2017; Chatterjee et al. 2019). The presence of Himalayan derived sediments in Kutch near the Arabian Sea could only be brought by large river from Himalaya (Khonde et al. 2017), but when was this deposited by river is still unclear.

Our approach of combining monazite along with zircon for provenance fingerprinting has shown interesting results. Monazite age data, even though not as precise as isotopic age data, is especially useful in its ability to uniquely characterize the Higher Himalayan source. The Tertiary and younger ages correlate well with both, the peak "Himalayan metamorphism" (Pant et al. 2020) as well as associated orogenic magmatism. Zircon age data corroborates this and shows both the higher Himalayan (Mesoproterozoic and Palaeozoic) as well as Lesser Himalayan (Paleoproterozoic) sourcing indicating that the main fluvial bedload of the river Saraswati? (Presently at ~50-70 m depth) was deposited by a robust long-flowing river.

In general, the Holocene fluvial activities correspond with the development and demise phases of the Indus Civilization as most of these palaeochannels are flanked with at least small numbers of cultural mounds. The Fatehabad and other palaeochannels which still shows some surface manifestations, including the one near Rakhigarhi (Mehdi et al. 2016), are likely to have been active in some form during this phase, though it is unclear whether any of these were perennial. The disappearance of those fluvial channels is attributed to various factors including river capture (Clift et al. 2012), monsoonal fluctuations (Enzel et al. 1999; Giosan et al. 2012; Dixit et al. 2014b) and tectonics (Valdiya 2013). The drying and shifting of the rivers has often been considered to be major factor in the decline of Indus Civilization urbanism and the dispersal of populations (Misra 1984; Mughal 1997; Wright et al. 2008; Sinha et al. 2013), as it is often claimed that perennial river systems were essential, but many settlements were not located close to the reconstructed hydrological system. It has generally been accepted that the Indus Civilization occupation in northwestern India was characterized by a rural phase (c. 5200-4200 BP), which was followed by the appearance of urban centers (c. 4600/4500-3900 BP), which in turn declined and there was another village-based phase (c. 3900-3000 BP), but many questions remain about the origin of the Indus Civilization in the region. Comprehension is complicated by inconsistent dating and contrasting dating evidence from sites including Bhirrana, Kunal, Girawad and Rakhigarhi (Dikshit and Mani 2012; Nath et al. 2019). While Banawali and Bhirrana are situated close to the Fatehabad palaeochannel, Farmana and Girawad are at some distance from any known palaeochannel, demonstrating that there was no straightforward relationship between water courses and settlement location. Our radiocarbon dates of the drifted charcoal pieces from Dhir indicate that burning was taking place in this region as early as ~10000 years ago, but it is not possible to confirm that this was related to human settlement (Fig. 7). Early dates from Rakhigarhi (Nath 2014) and Bhirrana have been published (Rao et al. 2005; Mani et al. 2008) but the associated cultural material was not included in each instance.

Some of our AMS radiocarbon dates from Rakhigarhi mounds RGR 2 and RGR 3 have shown age ranges that reaffirms the dating in the Mature Harappan period (Nath 2014; Vahia et al. 2016; Shinde et al. 2018). Several of the new ages from the exposed face of RGR 4 (Fig. 7) is considerably older than other published dates, but the ages are not in stratigraphic order, which suggests that this may be redeposited material and it is not certain that it was of anthropic origin. These dates provide indication of early activity, but they cannot be used to revise the chronology of occupation at the site, or more broadly in the region near Rakhigarhi.

The natural sedimentary platform of the Dhir mound consists of brown laminated silt – clay and greyish ash enriched patches with rolled charcoal and small pottery pieces (Fig. 6). The finer nature of sediments represents low energy flood deposits in the palaeochannel, and the radiocarbon ages suggest that the palaeochannel was flooded even up to 2145 –1885 years BP i.e., during the Early Historic period, and prior to the Kushan period. Presence of oxidized silt-clay and minute evaporates in the upper part suggest semi-arid climate. Absence of grey sediments indicate locally remobilized sediments.

Dhir mound is the only location yet assessed which preserves the post-Indus Civilization alluvial history of a palaeochannel up to 2145 –1885 years BP. Saini and Mujtaba's (2010) earlier study in the palaeochannel have shown that it was an active bedload stream during ~6-4 ka BP, which gradually degenerated during the period c. 3.4 - 2.9 ka BP due to weakened monsoon. The new radiocarbon dates, supported by an OSL age, show that although the river was not perennial, this channel was intermittently flooded during heavy rain episodes till 2145 –1885 years BP and such flooding events accumulated a 1.4 m high laminated sedimentary platform, which was subsequently occupied. It is interesting to note that heavy flooding was also recorded in recent times in this zone during monsoon of 1977, 1978, 1980, 1983, 1988, 1995, 1996, 2000, 2010, 2011 (Bishnoi, 2018). Water stagnates in the depressions for several days and recharges the aquifers and thereby has the potential to sustain agriculture for years, exemplifying the importance of geomorphic control for the availability of habitation sustaining moisture/water in semi-arid conditions. The interaction between human settlements and hydrology appears complex in this basin and needs to be investigated in depth to examine the simplistic view that Indus Civilization populations survived as long as the palaeohydrological system was alive.

6.Conclusions

A concise point-wise summary of outcome of this study can be stated as follows.

1. The NW Haryana plains have a long geo-archeological history of human occupation, and there is evidence for burning activity from c. 10405 – 10190 to 2145 – 1885 cal. BP.

2. The buried sediments of alluvial plains show strong affinity of higher Himalayan (Tertiary as well as Mesoproterozoic and Palaeozoic) as well as Lesser Himalayan (Paleoproterozoic) rocks.

3. The alluvial development of the area was mainly by the Himalayan rivers, which constituted a perennial source for some time.

4. The dried-up channel of the Saraswati continued to be intermittently flooded after the decline of Indus urbanism, and there is clear evidence that it continued into the Early Historic period, and this process continues to impact on the societies that continue to live in the region today.

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Figure Captions

Fig.1. A generalized regional geomorphological map of the study area and its surroundings showing major geomorphic units and palaeo and present drainage (after Saini et al. 2020)

Fig. 2. Map showing locations of regional bore holes and section lines with boreholes. Sample locations for radiocarbon AMS dating (Dhir and Rakhigarhi) as well as sample site of zircon-monazite dating is also shown in this map.

Fig.3. Lithologs of boreholes (WB: West of Bhuna, SR: Sirsa, RT: Rasulpur Their, OS: Ottu Sultanpuriya) for elucidating regional subsurface geology. Sand Sample from Sirsa borehole was used for zircon and monazite dating. Note variation in the grey fluvial sand indicative of migratory channel. Aeolian sand is indicative of episodic weakening of monsoon in the region.

Fig.4. Subsurface lithological sections along three transects shown in Fig.2. Location of boreholes, **1** (29.522N:74.837E), **5**(29.588:75.055E), **6**(29.610N0:7.668E), **7** (29.679N: 75.055E), **9** (29.525N: 75.131E), **14** (29.577N: 75.154E), **15** (29.661N: 75.168E), **28** (29.463N:74.865E), **31** (29.568: 75.058E), **37** (29434:74.882E).

Fig.5A. Representative Back Scatter Electron (SEM-BSE) and Cathodoluminescence (SEM-CL) images of zircon with a few monazite grains from the Sirsa palaeochannel (A at ~72m depth and B at ~52m depth) and Gangotri (C- control sample). These samples were mainly processed for zircon and only a few monazite grains were seen which can be identified by brighter greytone in the BSE images.

Fig. 5B. (Panel-A) **Left**: The Wetherill Concordia diagram for U-Pb isotopic data from zircon grains of sample D2 (from 72 m depth) of Sirsa palaeochannel. Total 119 grains were measured. **Centre**: The probability density age diagram for 82 near-concordant data. For ages older than 1000 Ma Pb/Pb age values are used, while U/Pb ages are used for younger age data for plotting this probability density diagram. **Right:** Total Th-U-Pb chemical geochronology plot of sample D2. Presence of Tertiary metamorphic signatures is prominently observed (Panel-B) **Left:** for the sample D5 (52 m of depth) of Sirsa palaeochannel. Out of 128 measured grains (left plot) 106 grains (**central plot**) yielded near-concordant data. Monazite yields signatures similar to sample D2 in the plot at the **right-side** of this panel. (Panel-C) **Same** for the control sample D7 from Gangotri River. Out of 52 measured grains (**left plot**), 43 were near-concordant data (**central plot**). Strong Tertiary Higher Himalayan metamorphic imprint is recorded in the **right-side** plot. Litholog of Sirsa (=Fatehabad) palaeochannel is given Fig. 3.

Fig.6. (A) Dhir composite mound located in a palaeochannel of the Saraswati(?) (Fig. 2) comprising of natural and archeological deposits with distinctive fabrics. (B) Detailed litholog showing median radiocarbon calendar ages which are not in stratigraphic order due to transported nature of carbon martial. The 10252 BP age is oldest reported age in the region and extend the age of habitation. (C) A closeup view of the natural deposit showing faint lamination, ash ribbon and charcoal further enlarged in the inset photographs.

Fig.7.Sampling sites on the Rakhigarhi archeological mounds and related details. (A) A pit at the top of Mound no RGR3. A-1 is the section exposed and A-2 is the closeup of sample point with radiocarbon calendar age. (B) Carbon samples sites and ages from the western flank of mound number RGR-2. (C) A section of archeological stratification exposed on the NE face of mound number RGR-2. The thinly bedded strata are laminated and show coarsening upward. The ages are in stratigraphic order in B but not in C. Latter is possibly due to the rolled nature of charcoal. (D). Plan of Rakhigarhi mound. All the carbon ages are median calendar ages.

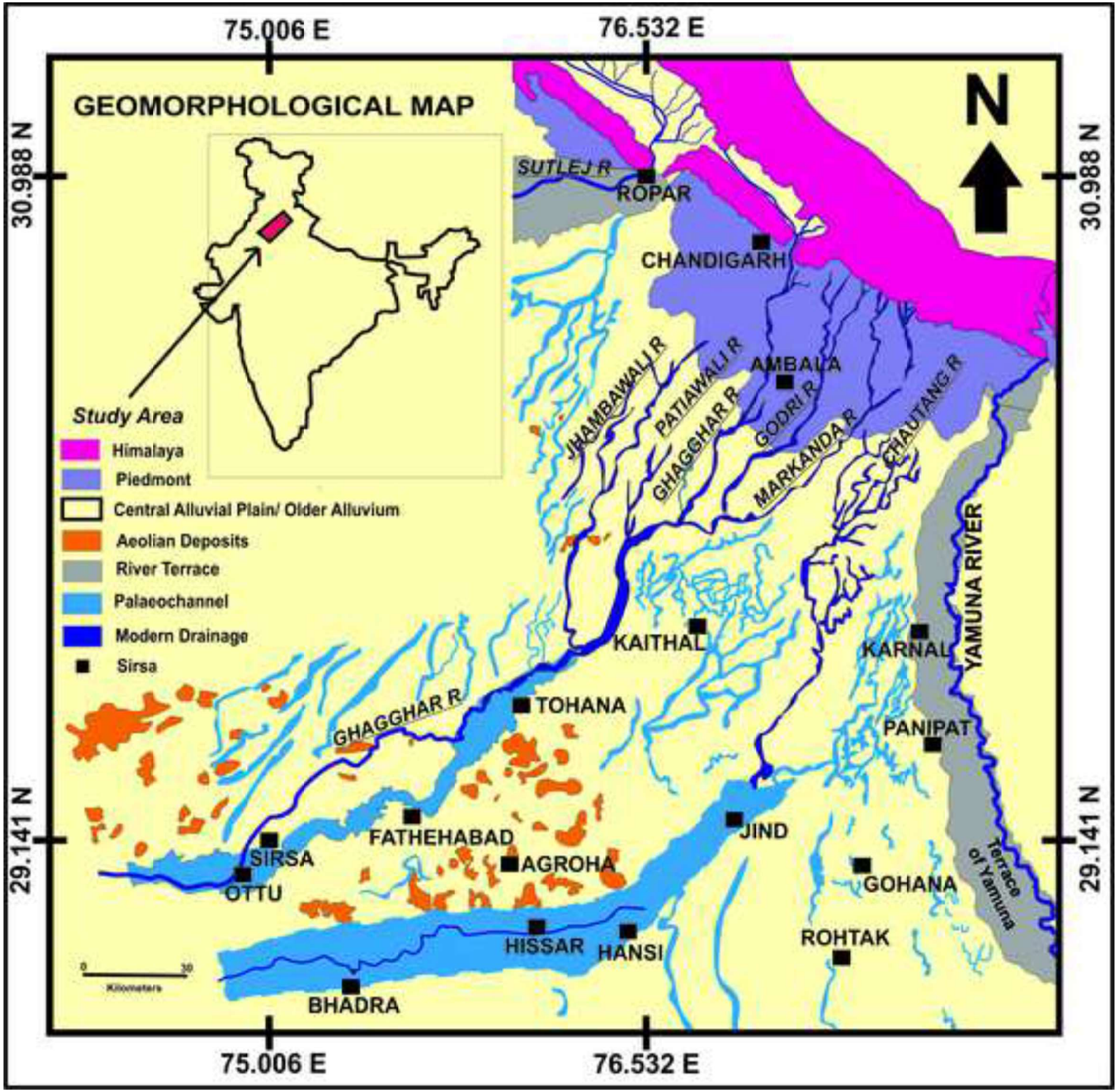
Table 1. AMS radiocarbon ages and calendar ages from the Rakhigarhi and Dhir area (sample locations shown in Fig. 6 and 7). In text and figures only the median ages are discussed.

DHIR

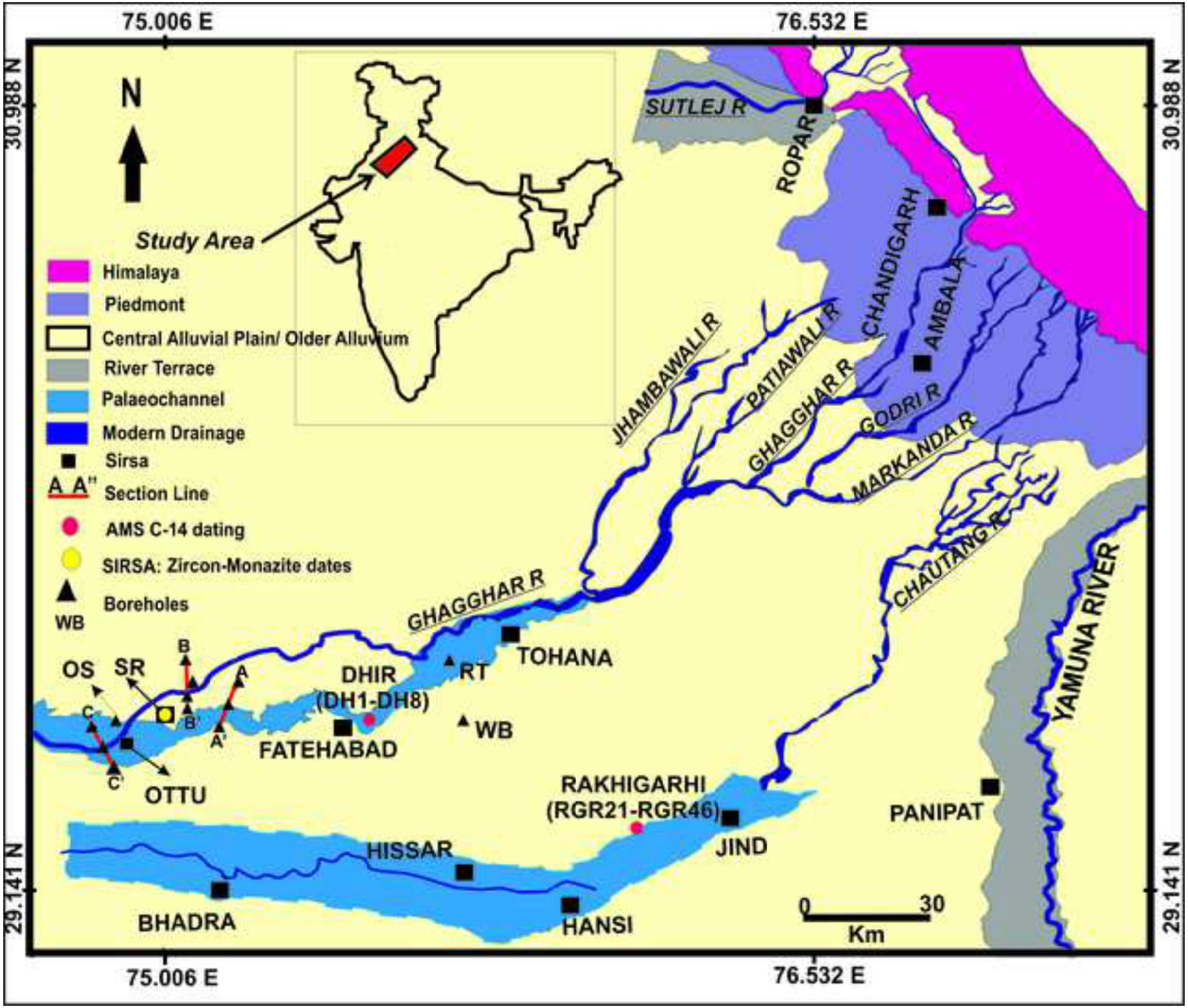
Sample ID	Lab ID	Radiocarbon age	Depth (cm)	Calendar Age (years BP)	Calendar Age (years BC/AD)
DH1	IUACD#18C1634	2668 ± 43	96	2860- 2735	910 – 785 BC
DH3	IUACD#18C1613	9103 ± 47	83	10405- 10190	8455 - 8240 BC
DH5	IUACD#18C1612	4779 ± 42	62	5595- 5330	3645– 3380 BC
DH7	IUACD#18C1631	2061 ± 45	10	2145 - 1885	195 BC –AD 65

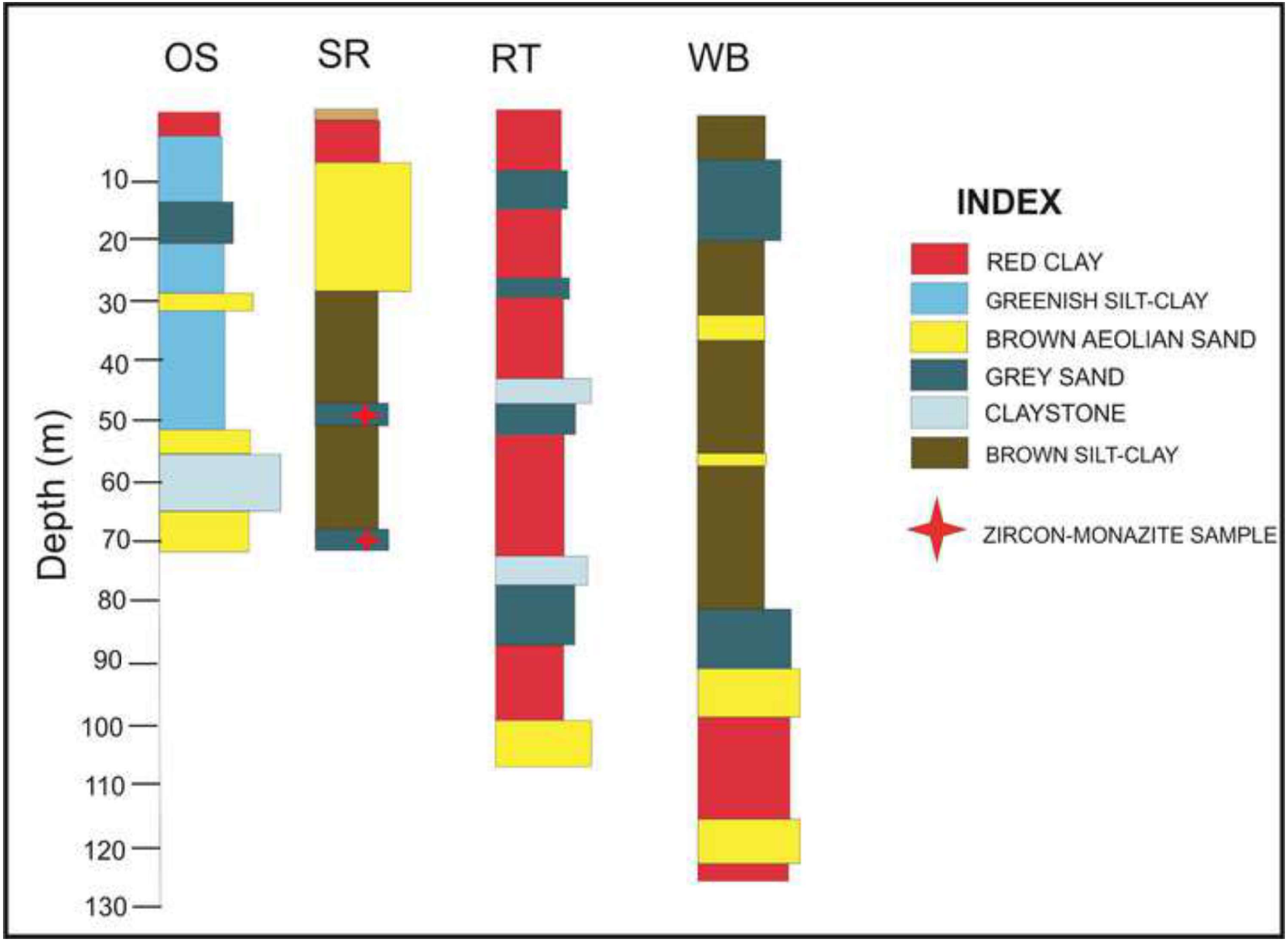
RAKHIGARHI

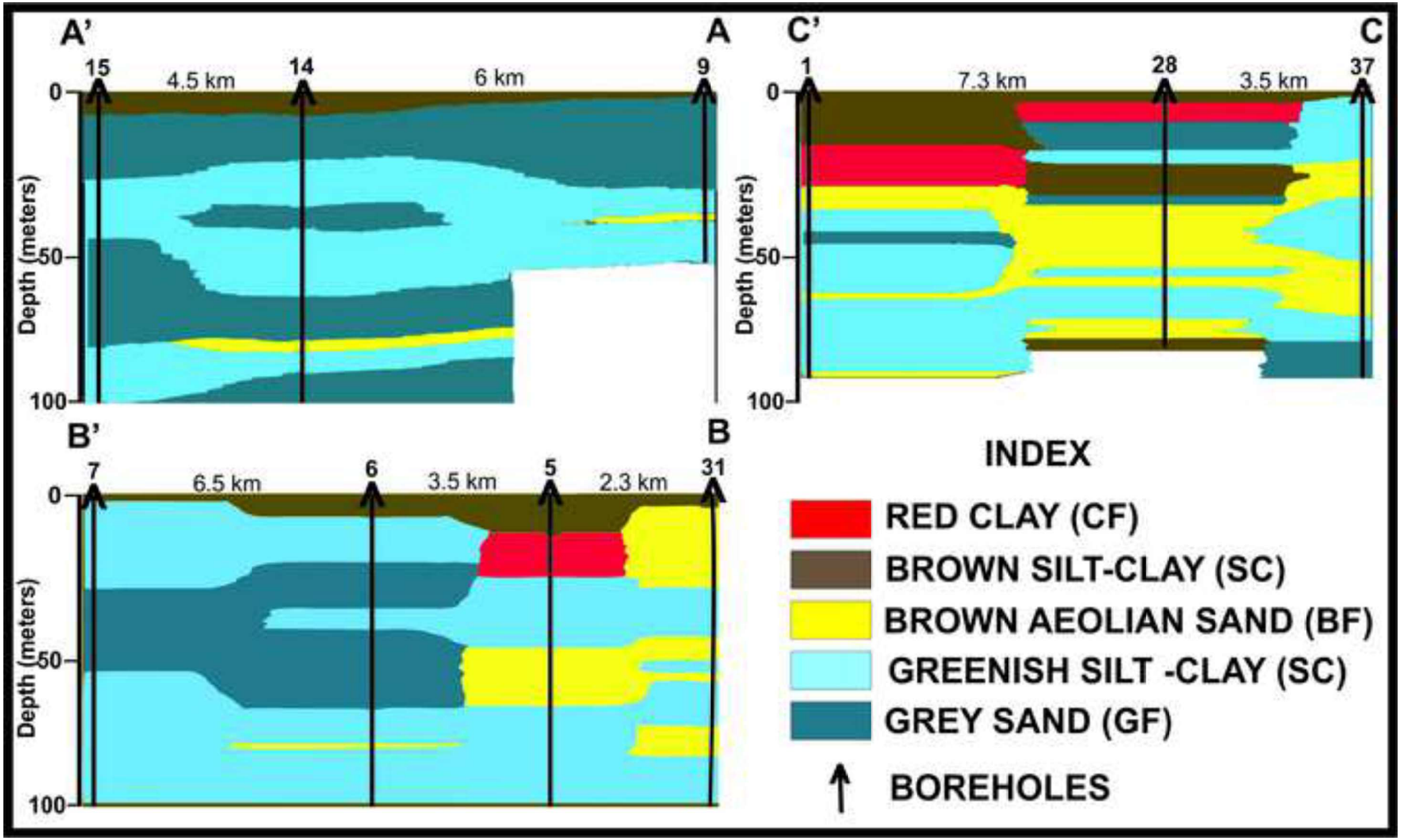
Sample ID	Lab ID	Radiocarbon age	Depth (cm)	Calendar Age (years BP)	Calendar Age (years BC/AD)
RGR21	IUACD#18C1617	5062 ± 44	35	5915- 5660	3965– 3710
RGR22	IUACD#18C1621	4049 ± 42	28	4795- 4415	2845 – 2465
RGR23	IUACD#18C1620	3054 ± 45	25	3375 - 3080	1425 – 1130
RGR32	IUACD#18C1611	4979 ± 42	25	5890 - 5595	3940 – 3645
RGR41	IUACD#18C1619	3988 ± 41	108	4570- 4295	2620 – 2345
RGR42	IUACD#18C1618	4468 ± 45	48	5305- 4890	3355 – 2940
RGR44	IUACD#18C1633	4371 ± 42	43	5215- 4845	3265 – 2895
RGR45	IUACD#18C1632	4234 ± 42	18	4865- 4620	2915– 2670
RGR46	IUACD#18C1615A	7600 ± 46	14	8520 - 8335	6570 – 6385

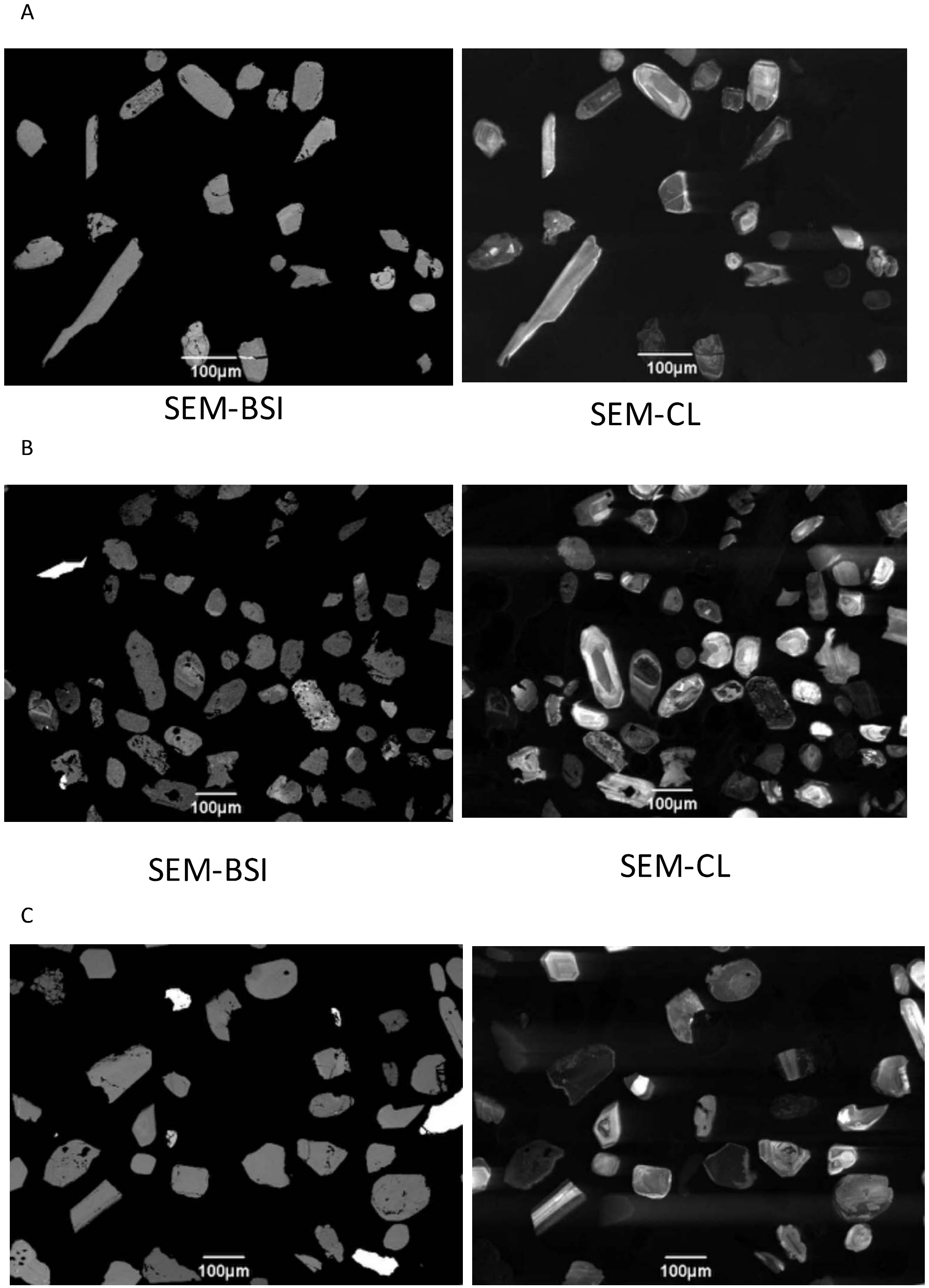


GEOMORPHOLOGICAL MAP
75.006 E
76.532 E
30.988 N
29.141 N
N
Study Area
Himalaya
Piedmont
Central Alluvial Plain/ Older Alluvium
Aeolian Deposits
River Terrace
Palaeochannel
Modern Drainage
Sirsa
SUTLEJ R
ROPAR
CHANDIGARH
AMBALA
JHAMBAWALI R
PATIAWALI R
GHAGGHAR R
GODRI R
MARKANDA R
CHAUTANG R
YAMUNA RIVER
KAITHAL
KARNAL
PANIPAT
TOHANA
GHAGGHAR R
FATHEHABAD
AGROHA
JIND
GOHANA
Terrace of Yamuna
SIRSA
OTTU
HISSAR
HANSI
ROHTAK
BHADRA

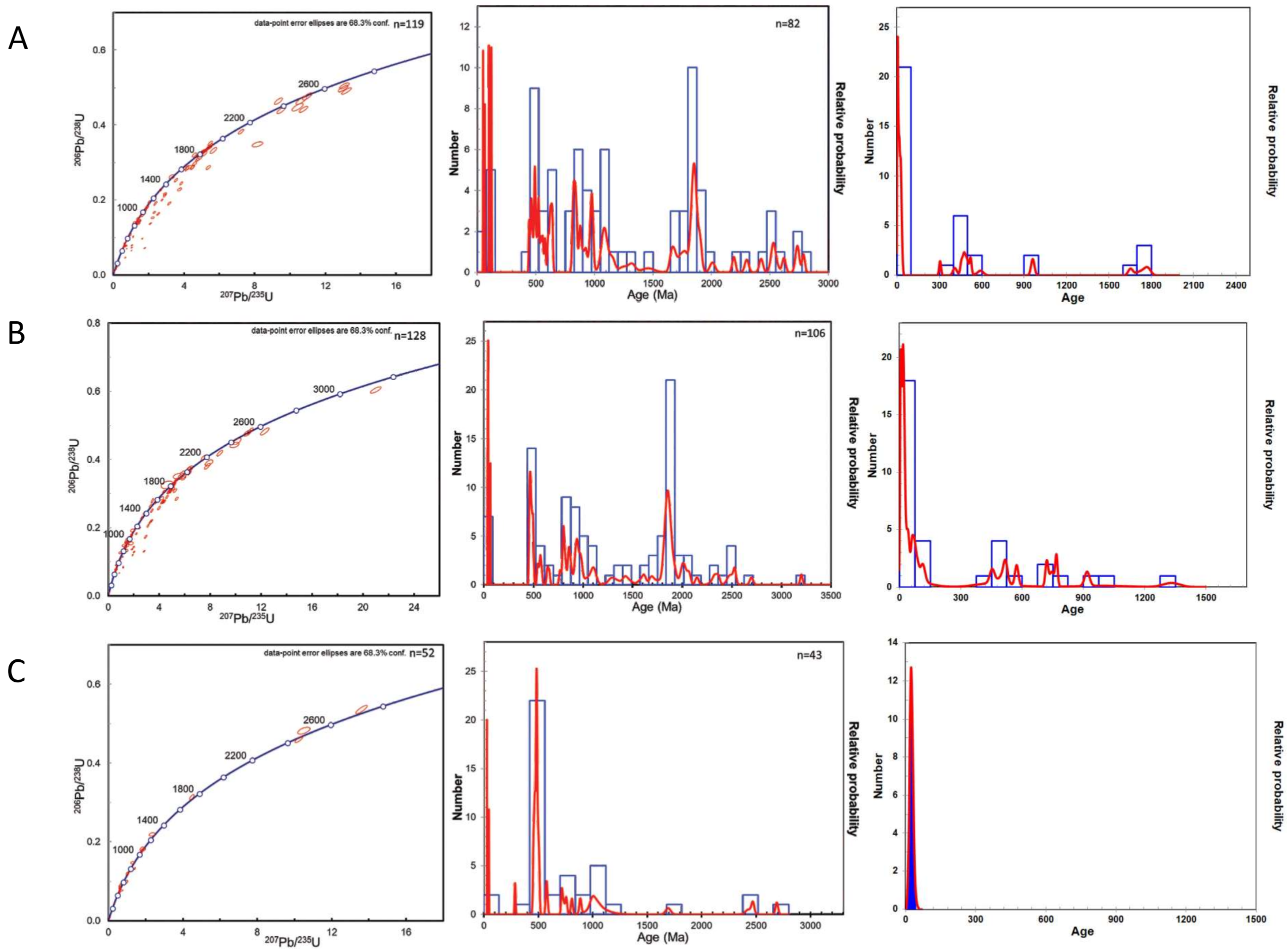

75.006 E
76.532 E
30.988 N
29.141 N
N
Study Area
Himalaya
Piedmont
Central Alluvial Plain/ Older Alluvium
River Terrace
Palaeochannel
Modern Drainage
Sirsa
A A'' Section Line
AMS C-14 dating
SIRSA: Zircon-Monazite dates
Boreholes
WB
SUTLEJ R
ROPAR
CHANDIGARH
AMBALA
JHAMBAWALI R
PATIAWALI R
GHAGGHAR R
GODRI R
MARKANDA R
CHAUTANG R
YAMUNA RIVER
GHAGGHAR R
TOHANA
RT
WB
DHIR
(DH1-DH8)
FATEHABAD
OS
SR
B
B'
A
A'
C
C'
OTTU
RAKHIGARHI
(RGR21-RGR46)
JIND
PANIPAT
HISSAR
BHADRA
HANSI
0
30
Km

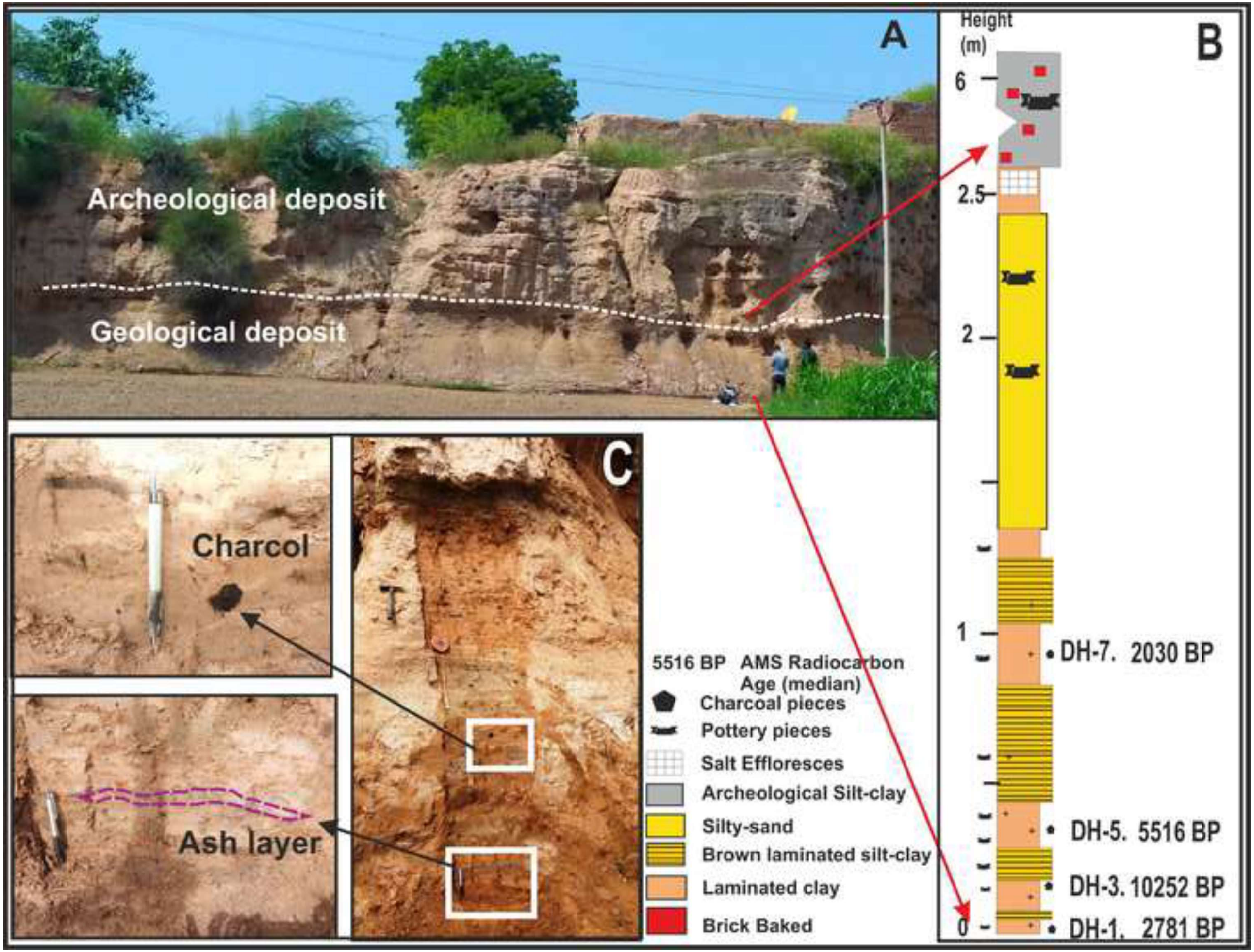

OS
SR
RT
WB
Depth (m)
10
20
30
40
50
60
70
80
90
100
110
120
130
INDEX
RED CLAY
GREENISH SILT-CLAY
BROWN AEOLIAN SAND
GREY SAND
CLAYSTONE
BROWN SILT-CLAY
ZIRCON-MONAZITE SAMPLE


A'
A
15
4.5 km
14
6 km
9
Depth (meters)
0
50
100
B'
B
7
6.5 km
6
3.5 km
5
2.3 km
31
Depth (meters)
0
50
100
C'
C
1
7.3 km
28
3.5 km
37
Depth (meters)
0
50
100
INDEX
RED CLAY (CF)
BROWN SILT-CLAY (SC)
BROWN AEOLIAN SAND (BF)
GREENISH SILT -CLAY (SC)
GREY SAND (GF)
BOREHOLES



SEM-BSI SEM-CL


A
B
C
data-point error ellipses are 68.3% conf. n=119
data-point error ellipses are 68.3% conf. n=128
data-point error ellipses are 68.3% conf. n=52
n=82
n=106
n=43
$^{206}Pb/^{238}U$
$^{207}Pb/^{235}U$
Number
Relative probability
Age (Ma)
Age


A
Archeological deposit
Geological deposit
B
Height
(m)
6
2.5
2
1
0
DH-7. 2030 BP
DH-5. 5516 BP
DH-3. 10252 BP
DH-1. 2781 BP
C
Charcol
Ash layer
5516 BP AMS Radiocarbon Age (median)
Charcoal pieces
Pottery pieces
Salt Effloresces
Archeological Silt-clay
Silty-sand
Brown laminated silt-clay
Laminated clay
Brick Baked

figure

Click here to access/download;figure;Fig-7_modified_29-05-21.jpg