Reconstruction of buried channel-floodplain systems of the northwestern Haryana Plains and their relation to the 'Vedic' Saraswati

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Based on the collection of subsurface lithofacies data from well logs, this study attempts to map the buried channel-floodplain systems of a part of the northwestern Haryana Plains and provides evidence of buried major sand bodies at various depths; these belong to at least two separate phases of fluvial activity. The younger phase of fluvial activity includes the previously mapped palaeochannel segment between Tohana and Sirsa that was considered as a part of the 'lost' Saraswati[1]. The recognition of major palaeochannel belts in the subsurface provides definite proof of the presence of a strong fluvial regime sometime in the past. Based on OSL dating, it is inferred that these relatively older palaeochannel belts pre-date the Last Glacial Maximum and are related to the later part of the wetter MIS 3; and the younger fluvial activity, recognized in a limited part of the area, is dated between ~6.0 and ~2.9 Ka BP. The analysis of these subsurface data suggests the existence of integrated drainage networks in the northwestern Haryana Plains in the 20–30 Ka time interval.

Keywords: Buried fluvial systems, northwestern Haryana Plains, OSL dating, 'Vedic' Saraswati.

THE evolutionary processes resulting in the accumulation of the >400 m thick sediment succession under the modern plains of Haryana are poorly understood, especially because of the limited availability and access to subsurface data. These plains represent the alluvial surface of the post-Siwalik sedimentary sequences that have aggraded in a southerly shallowing basin, demarcated by the Siwalik hills in the north and by the Aravalli ranges in the south. From a preliminary analysis of the subsurface lithological data collected from the exploratory bore holes of the Central Ground Water Board and the geophysical investigations of the Geological Survey of India, it is estimated that the Quaternary sedimentary succession is a few kilometres thick near the Himalayan front (Ambala area) and reduces to few hundred metres in Sirsa, Hissar area, about 200 km south from the Himalayan front[2] (Figure 1). The drill core data further show that more than 80% thickness of this succession is made up of alluvial deposits, despite the fact that presently no large perennial river exists in the terrain. The Yamuna flows in the eastern part with no direct link to these plains. The Ghagghar river, which traverses the Haryana plains, is a narrow, degrading channel originating in the Siwalik

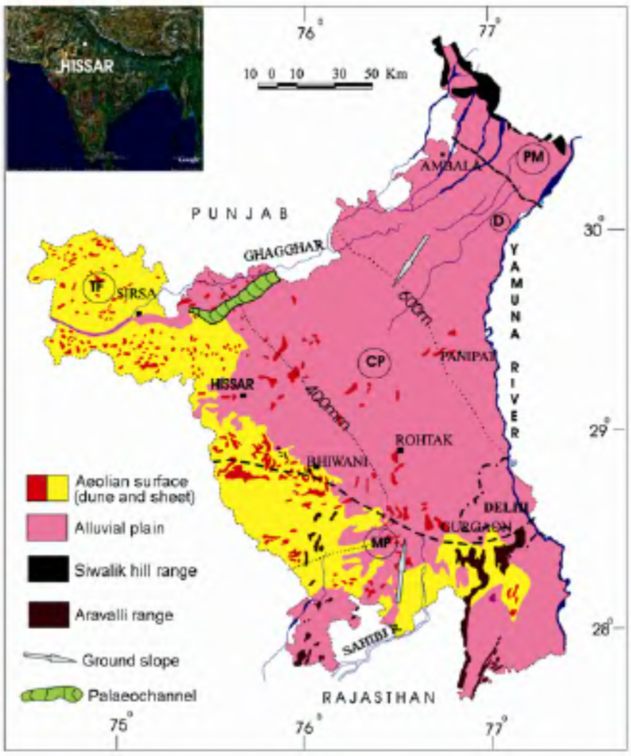

Figure 1. Geomorphological map of Haryana showing four geomorphic units namely piedmont (PM), central alluvial plain (CP), marginal alluvial plain (MP) and Thar fringe (TF). Bedrocks are exposed in the north (Siwalik Group) and in south (Delhi Supergroup). Note the flow of Ghaggar drainage towards SW and Yamuna towards SE with no visible drainage divide (labelled D) in between. The northern and southern parts have opposing slopes. The aeolian deposits occupy the western and southern border and are limited by ~400 mm isohyet. Isolated sand mounds are present in alluvial plain up to Panipat in north and Delhi in SE. A palaeochannel segment, previously mapped by Yashpal *et al.*[1] and related to the 'lost' Saraswati river is shown for ready reference.

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hills. These two rivers are about 100 km apart at their exits at the Himalayan front, and this separation between the rivers increases to 200 km further south in the plains as they diverge in opposite directions. The contributions of these two rivers and/or any other river system as major sources of sediment to the Haryana plains are not understood. A second related issue regarding these plains is about the role and influence of the Saraswati river which is believed to have existed in the Vedic period[1,3–8] and subsequently became dysfunctional due to causes not yet understood comprehensively. Therefore, it is important to obtain integrated surface and subsurface data of the Haryana plains from which processes and events of the past could be reconstructed.

Geomorphology and drainage

The major geomorphological units in Haryana south of the Siwalik front include a piedmont, central alluvial plain, marginal alluvial plain and desert fringe (Figure 1). The piedmont is a southerly sloping, 20–40 km wide zone of rudaceous dominated sediments along the Siwalik front. It lies between 360 and 240 m elevations and has the highest drainage density among all units. Several short, narrow, incised, seasonal water courses originate on this surface and disappear at the northern margin of the central alluvial plains or join the fourth order trunk streams. Besides Ghagghar, Markanda and Dangri are the main ephemeral streams of this unit which disappear on entering the central alluvial plain (Figure 1). The Ghagghar river originates in the outer Siwalik belt north of the Morni hills. After debouching in the piedmont, it flows in a southwesterly direction with wide and shallow, degrading floodplains in the piedmont zone and 5–10 m deep floodplain constrained by prominent bluffs near the junction of the piedmont and the central alluvial plain. Downstream in the central alluvial plain, the river has a 300 to 1000 m wide, 3–6 m deep valley with the development of a patchy, upper erosional terrace. Between Tohana and Sirsa, the Ghagghar channel has a non-meandering and entrenched form with 30–100 m wide and 3–6 m deep channel. Downstream of Sirsa, the river has 4–6 km wide floodplain whose northern limit is defined by a sharp palaeobank while the southern limit is buried under aeolian deposits. Between Tohana and Ellenabad (Figure 2), the river floods a 2–10 km wide stretch on its southern side which also includes a palaeochannel segment of ‘Vedic’ Saraswati river of previous workers[1,8].

The central alluvial plain is a ~200 km wide stretch that attains 240 m elevation in the north and 210 m in the south. Its southern margin occurs along the NW–SE Bhiwani–Rohtak–Delhi axis which nearly defines the northern flank of the subsurface Delhi–Sargodha ridge. The marginal alluvial plain forms the southern part of Haryana and unlike the northern part has a northerly slope and drainage. There are only two seasonal, plains-fed streams namely Krishnawati and Dohan (Figure 1), which have wide floodplains in this unit. These streams carry little sediment load from the local plains and disappear in the contact zone with the central alluvial plain. The contact zone is a broad NW–SE trending subtle depression prone to flooding by drainage from the southern and northern sides.

The Thar Desert fringe in Haryana is the northeastern extension of the Thar Desert and comprises sand dunes and sand sheets (Figure 1). The dunes are 0.4–10 m in height, few metres to 5 km long and stabilized to active in nature. The stabilized dunes are longitudinal and oval in shape while active dunes are transverse and barchanoidal. The latter show easterly, westerly and southeasterly trends of sand migration. Sand sheets are present in the dunal plain areas adjoining the Thar Desert. These are 0.5–2.0 m thick and consist of very fine-grained sand attaining elevations between 190 and 200 m above msl. East of 400 mm isohyet, the aeolian morphology is replaced by an alluvial surface with relict stabilized sand dunes (Figure 1).

Geological setting

The area is covered by Quaternary aeolian and alluvial deposits which unconformably overlie the quartzites and granites of the Delhi Supergroup, Nagaur sandstone of Cambrian age and Tertiary clays[9,10]. The pre-Quaternary topography is in the form of a NW–SE trending ridge occurring at about 200 m below the ground[1,9,10]. The Quaternary succession is 200 to more than 400 m thick and consists mainly of brownish silt-clay, grey micaceous sand with thin lenses and layers of brown sand. The silt-clay shows strong carbonate enrichment at various levels, and in places forms hard pans. On the surface, the aeolian deposits in the form of sand dunes and aeolian sheets make up the western and southern parts while alluvial silt-clay is dominant in the eastern part (Figure 1).

Shallow subsurface Lithofacies

This analysis is based on the subsurface study of about a 100 lithosections located throughout the area (Figure 2). These include both shallow well sections (8 m) and relatively deeper bore hole records (~25 m). Based on physical characters, the lithology was classified into four sedimentary facies. A log was prepared at each site. Two-dimensional subsurface lithological organization and spatial correlation is attempted by studying geological cross-sections along different transects. From them, the facies association and depositional environments were interpreted, and these data were converted into reconstructions showing the interpreted subsurface organization of buried channel networks.

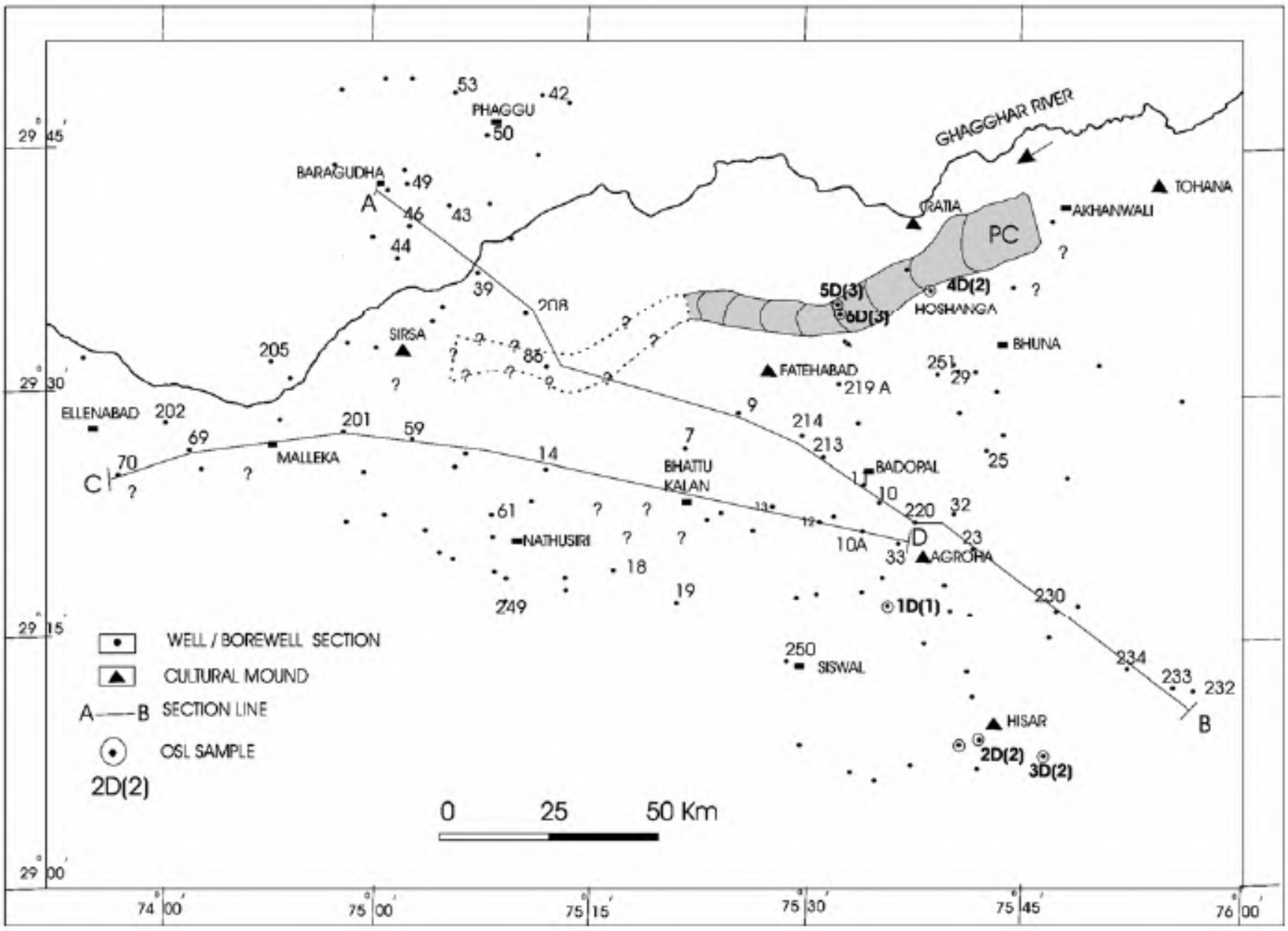

Figure 2. Location map of the studied lithosections (well and borehole) in northwestern part of Haryana. Lithosections used in constructing the subsurface sections and logs (Figures 3–5) have been numbered. The section lines (A–B and C–D) have been selected to provide a representative sub-surface visualization from the available data. Low concentration of well sections in some areas indicates absence of sand bodies in the subsurface. The palaeochannel segment (PC) mapped by previous workers[1] between Fatehabad and Hoshanga, and some important cultural mounds (Thers) are also shown.

Lithological facies

Brown sandy facies

It includes the brown, loose, well-sorted, very-fine grained sand that occurs as lenses, mounds and sheets in the subsurface, and as dunes and sheets on the surface (Figure 3). The dune and sheet sediments on the surface show variations in colour, cohesiveness, and the variable development of carbonate nodules. Based upon field relations, the deposits can be organized into four units. The youngest unit ($u - 1$) occurs as small active dunes, the next older unit ($u - 2$) as stabilized, sand dunes and mounds and the third unit ($u - 3$) as sand sheets. The remaining older deposits occurring in the subsurface are tentatively classified together as unit 4. Except ($u - 1$), other brown sands contain carbonate nodules. The ($u - 1$) sediments are coarser, better sorted, platykurtic and more negatively skewed than the sediments of other units[11]. Mineralogically, the sediments of ($u - 1$) to ($u - 4$) are predominantly composed of quartz (~70%) followed by feldspar (~25%) and heavy minerals (2–10%). Monocrystalline quartz contains inclusions of tourmaline, rutile and zircon. Feldspar includes sodic plagioclase, microcline and orthoclase. The dense mineral suite is dominated by green, blue-green and greenish brown amphibole, garnet, sillimanite, kyanite and minor biotite, tourmaline, ilmenite, zircon, rutile. Based upon the textural and mineralogical similarities of the ($u - 4$) sediments with the surface aeolian deposits, the brown sandy facies is considered to be of aeolian origin.

Brown silt facies

This is the most common lithology on the surface as well as in the subsurface. It includes massive, moderately cemented brown silt (Figure 3). In places, fragments of gastropod shells, decayed rootlets and mica flakes are present. The facies is usually associated with small, disseminated carbonate nodules in poorly defined 20–40 cm thick zone just below the ground surface. The facies forms a prominent bed ranging in thickness from 1 to 8 m at the top of the sedimentary succession and constitutes the main agricultural surface except in the dunal areas. It is underlain by grey sandy facies, brown mud facies and brown sandy facies with gradational contacts at different places. The facies is interpreted to represent the distal floodplain deposits modified by aeolian action under semi-arid to arid conditions.

Grey sandy facies

This facies consists of greyish, loose, fine to very fine, micaceous sand occurring at different depths (Figure 3). The grey sediments are similar to the modern day sediments of mountain-fed rivers[12] like Ganga and Yamuna. The facies occurs at varying depths from 2 to 10 m below the ground. Usually, the shallow sediment bodies (2–5 m deep) are thin layers, ribbons and lenses of cross-bedded, very fine grained to silty, micaceous sand which pass upward to brown sand or mud. Their mean size varies between 3.48 and 3.82 ϕ, and are poor to moderately sorted, very platykurtic to leptokurtic and positively skewed. Quartz is the major mineral followed by feldspar which is generally partially altered. The dense mineral fraction includes amphiboles followed by kyanite, sillimanite, garnet, muscovite, pyroxene and biotite. The grey sandy facies represents fluvial channel deposits.

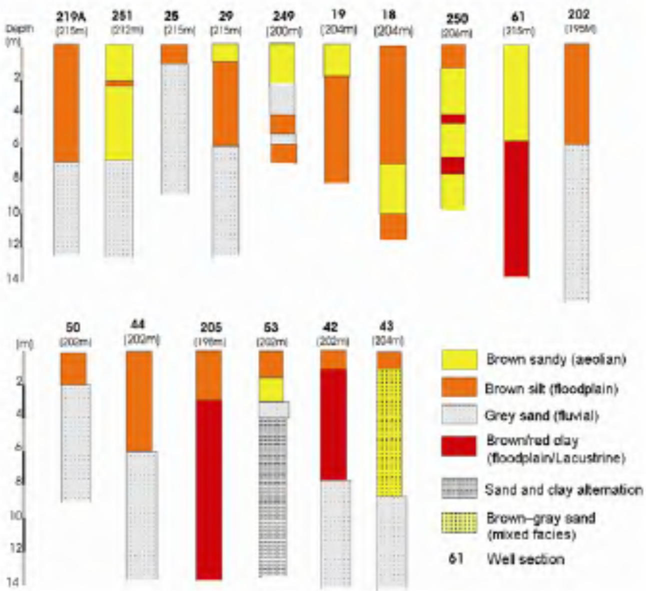

Figure 3. Lithologs of some important well-sections to show the lateral and vertical variations in lithology of buried channels and adjoining floodplains. For location of sections refer to Figure 2. The ground elevation in metres of each section is shown in parentheses above each log.

Brown clay/mud facies

It comprises brown to red and light khaki mud (silt-clay and clay) of lensoidal and sheet-like habit that occur in the surface and subsurface (Figure 3). The khaki mud is laminated in places, and contains worm tubes and partly decayed vegetation filaments. The brown and red muds are pedogenically calcretized and at places associated with thin pods of fine sand. The hard pink mud forms a thick bed at the surface in the eastern side, east of Hissar (Figure 1). The bed merges with the brown silt facies in the western side. This facies represents alluvial environment of the distal floodplain with local development of lacustrine conditions.

Shallow subsurface lithological architecture

Using the above mentioned facies, two main and one subsidiary channel courses, their associated floodplains and dunal tracts have been demarcated (Figures 4 and 5). Channels have been inferred wherever the grey micaceous sand is more than five metres in thickness and its continuity traceable in several adjacent well sections. Floodplains are inferred where bioturbated silt-clays are dominant and alternate with grey sand layers (0.3–1 m thick). The dunal upland is identified on the basis of brown well-sorted sand similar in characteristics to the surface dunes.

In the NW–SE section (Figure 4), two buried channel bodies (BCH-1 and BCH-2) and two floodplain domains (FP-1 and FP-2) were demarcated. Buried channel BCH-1 is indicated by a 10–30 m thick semi-lensoidal loose, grey micaceous sand (grey sandy facies) occurring 4–10 m below the ground. The sand is overlain by light brown silt-clay which is covered by a thin apron of brown aeolian sand ($u - 3$) of variable thickness. The channel body has a convex base and concavo-convex top and pinches out to the south-east in a floodplain domain (FP-1). The FP-1 comprises ~50 m thick section of brown to red silt-clay and clay with minor lenses of grey sand (1–2 m thick). It is strongly calcretized at 30 m depth. This area does not have any shallow wells because of the non-availability of sandy aquifers. The second channel body, BCH-2, appears east of FP-1 (Figure 4). It consists of two vertically stacked sand bodies separated by a 2–6 m thick silt-clay at ~25 m depth. The upper sand body is ~20 m thick and the lower sand body is about ~16 m thick. Another subsidiary channel body, BCH-2A, exists in the east at the stratigraphic level of the upper sand body of BCH-2 from which it is separated by a narrow floodplain sediment package of brown silt-clay and aeolian sand. The extreme southeastern part of the study area represents a floodplain domain (FP-2) with a uniform facies package of inter-layered brown sand ($u - 4$) and brown mud. There are four beds of brown aeolian sand up to 18 m depth, each around 2 m in thickness. The domain represents a

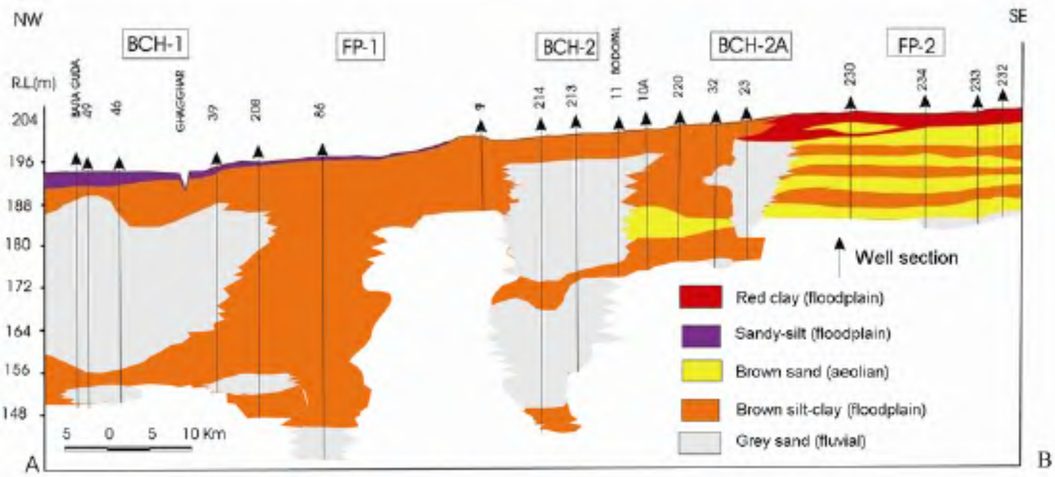

Figure 4. NW–SE subsurface cross-section along A–B of Figure 2 showing spatially distinct buried channels BCH-1 and BCH-2 separated by mud-dominated floodplain regimes. Channel BCH-2A is a subsidiary loop of BCH-2 as shown in Figure 6. Note the alternating layers of silt-clay and brown sand under floodplain FP-2 which is distinctly different from FP-1.

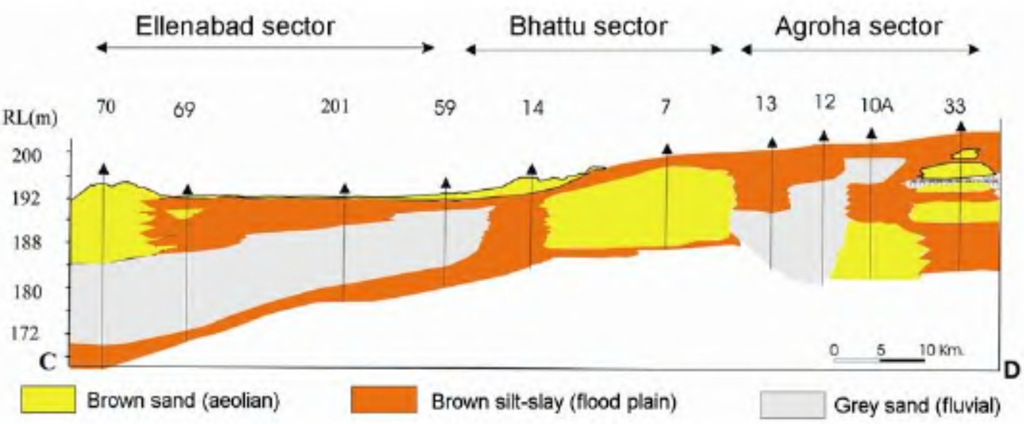

Figure 5. East–west subsurface cross-section along C–D of Figure 2 showing a prominent buried channel below Ellenabad sector and a subsidiary channel, the meander BCH-2A of Figure 6, below the Agroha sector. The intervening area is made up of aeolian sand representing a dunal upland. In Ellenabad sector (well no. 70) the grey channel sand gradually passes upsection to the brown aeolian sand, indicating a gradual change in depositional environment. The Ellenabad sector has an aeolian landscape and ground surfaces about 5 m lower than the Agroha sector which is an alluvial plain.

prominent ephemeral floodplain deposited by alternating overbank and aeolian accumulation. There is a conspicuous absence of grey sandy facies up to 18 m depth. The equal prominence of aeolian and silt-clay sediments suggests the accretion of floodplain sediments under fluctuating arid conditions. Such aeolian facies become prominent around Siswal area (well no. 250, Figure 3) where the upper 8 m succession is constituted by brown sand and brown silt, and the grey channel sand appears below 20 m.

The E–W, Ellenabad–Agroha section (Figure 5) is representative of the subsurface of desert landscape in the west and alluvial landscape in the east. It can be tentatively divided into three sectors namely Ellenabad sector dominated by aeolian landforms, Bhattu Kalan sector with mixed Aeolian–alluvial landforms and Agroha sector with alluvial landforms in the modern landscape. The subsurface reconstructions bring out a E–W trending buried channel sand body of about 45 km length below Ellenabad sector. The channel body occurs at about 10 m depth in the west (well no. 70), and gradually rises to 4 m depth towards east (well no. 59, Figure 5). It is overlain by the brown sandy facies existing in a dunal form (WS-70) and a silt-clay facies representing channel mud or floodplain (well nos. 69, 201, Figure 5). In Bhattu Kalan sector, brown sand is the dominant lithology which may represent a dunal morphology (well no. 7, Figure 5). In Agroha sector, a 4–16 m thick body of channel sand, identified as BCH-2 (Figure 5) in the NE–SW section, reappears.

An isolated segment of a channel BCH-3 is also noted around Hissar (Figure 6), where the grey channel sand

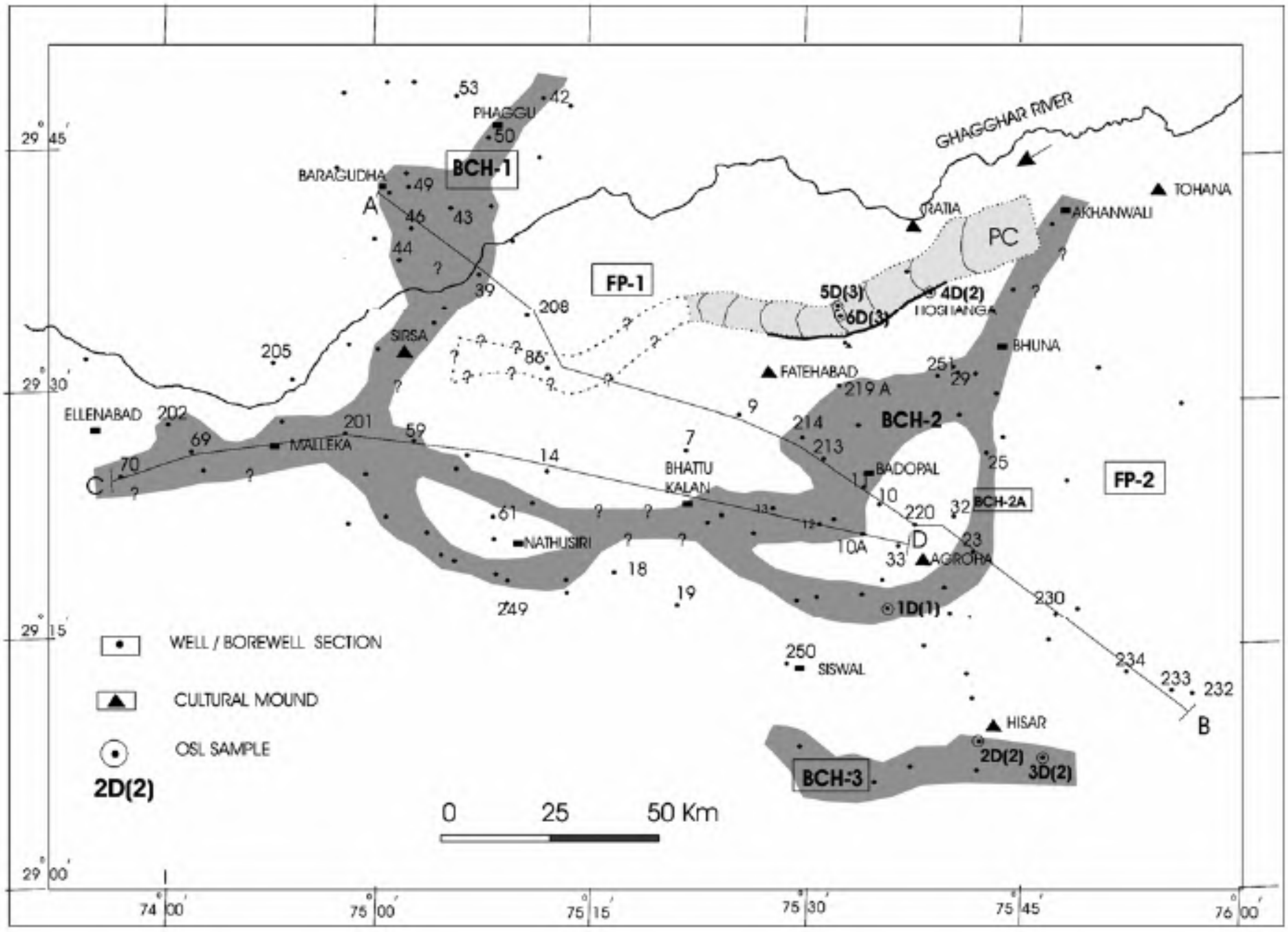

Figure 6. The subsurface reconstruction of northwestern Haryana plains showing the identified courses of buried channels (BCH-1, 2 and 3) and the associated floodplains (FP-1 and 2). Locations of sections with number of samples (in parentheses) dated by OSL are also shown.

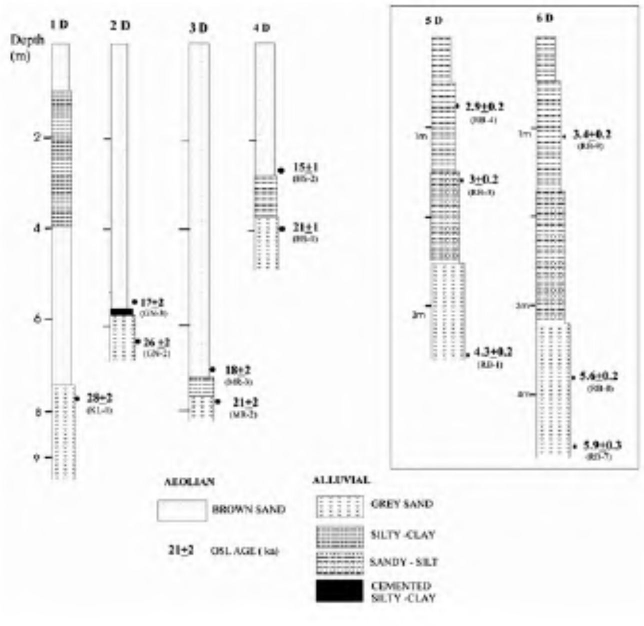

Figure 7. Selected subsurface sections with OSL ages in Ka of the channel sand and aeolian sand which have been used to constrain the ages of buried channels. Their locations are shown in Figures 2 and 6.

occurs below 6 m depth under the brown aeolian facies as well as alluvial facies (sections 2D and 3D in Figure 7).

Buried channel networks and their relation to the 'lost' Saraswati palaeochannel

The sub-surface architectural diagram shows the palaeochannel courses and their associated floodplains (Figure 6). BCH-1, named as Sirsa–Phaggu course, is an approximately 10–25 km wide buried channel belt (palaeo-valley) trending NNE–SSW, and runs oblique to the present day Ghagghar river. It has no corresponding trace on the surface. In the north, it widens with the development of intervening patches of floodplain deposits. The apparent high widths and the presence of silty clay and mixed sand (well nos 42 and 43, Figure 3) point toward the existence of multilateral channel systems. Between Baragudha and Phaggu, the channel sand is 9–29 m thick and appears usually at 2–5 m depths (well nos 50 and 44, Figure 3) and rarely around 10 m depth with thin sand layers between 5 and 10 m. The western limit of the course, at places, is confirmed by well sections dominated by floodplain deposits (well nos 205 and 53, Figure 3), and at other places this trace is yet to be delineated. The channel sand is fine to medium grained and grey in the lower part and very fine to silty and grey-brown in the upper part. They are overlain by layers of feebly calcretized silt-clay and brown sand. South of Sirsa, the channel sand shows increase in thickness to around 25 m and the upper silty part becomes conspicuous. The trend of the surface trace of the Saraswati palaeochannel delineated on the basis of remotely sensed data is oblique to the trend of the buried Sirsa–Phaggu course (Figure 7).

Buried Channel BCH-2 is a NNE–SSW feature which is named as Badopal–Bhuna course. Near Akhanwali, the northern end of the previously suggested palaeochannel trace of a part of 'lost' Saraswati[1,8] is superimposed over this subsurface channel/course. The course widens towards the south where channel sand becomes slightly deeper (~5 m) and thinner (between 10 and 13 m) and appears to form a multi-channel pattern with intervening floodplain packages (Figure 6). At places, the thickness of channel sand increases to 25 m with a layer of silt-clay in between (well nos 213 and 214; Figure 6). The channel is capped by silt-clay facies (well nos 219 A, 25 and 29; Figure 4) and aeolian facies (well no. 251, Figure 3) at different places. From the main trace, a narrow loop originates near well no. 25 and rejoins the course downstream (Figure 6). The main buried channel after widening near Badopal takes a westerly turn near Bhattu Kalan, and here its continuity is tentatively marked on the basis of absence of channel facies in the surrounding areas (well nos 18, 19 and 249; Figure 3). The course, however, reappears with an E–W trend, and is traced up to Ellenabad towards west through Malleka with an intervening patch of floodplain facies near Nathusari (well no. 61, Figure 3). In between, the buried channel BCH-1 also joins BCH-2 (Figure 6). Only a part of course BCH-3 could be traced in this study as an E–W course (Figure 6) near Hissar. The area between this course and BCH-2 is dominated by aeolian deposits (well no. 250, Figure 3). The continuity of BCH-3 needs to be traced further.

OSL dating

Thirteen strategically chosen samples from six sections were dated by optically stimulated luminescence (OSL) using Single Aliquot Regeneration (SAR) protocol[13–15]. Four samples were from the upper part of buried channels, three from the base of overlying aeolian facies and six from the previously mapped palaeochannel of 'lost' Saraswati[1] (Figure 7). The samples were collected from pit/well sections in 20×2.5 cm steel tubes and were processed under subdued red light by treating them with 1 N HCl to remove carbonates and 30% H_2O_2 to remove organic matter. The 125–150 μm grain size was sieved and quartz grains were separated using sodium polytungstate solution (2.58 gm/cm^3). The alpha affected layer of quartz was removed by etching with 35% HF for 40 min followed by a concentrated HCl treatment of 40 min. The quartz grains were mounted on 10 mm SS discs and all measurements were made on a Risoe TL/OSL 21 C-D Reader fitted with a 40 mCI Sr-90 calibrated source. Optical stimulations were made using blue LEDs (~470 mm) at 125°C for 40 s and the luminescence was observed in 250 channels through a Hoya UV filter. Other parameters selected on the basis of pre-dating experiments included pre-heat temperature of 240°C, recuperation <5%, recycling ratio ±10% and dose recovery ±10%. For each sample, 40–50 discs were finally selected for calculating the equivalent dose (D_e). The characters of shine down curves and distribution of D_e values in two representative samples are shown in Figure 8. Most of the samples showed a near normal distribution of D_e values and hence weighted averages were used for age calculation. In one sample (section 2D), the distribution was not normal, therefore a minimum D_e (ref. 16) was chosen for age calculation. Grunn age software was used for age calculation. The dose rates were calculated from the concentration of U and Th (analysed by ICPMS at GSI Chemical Lab, Hyderabad) and K (analysed by flame photometry at Chemical Lab, Faridabad) in the sediments (Table 1).

Discussion

The subsurface sedimentary architecture of the area shows that a network of river channels existed in the area that were much larger than the present surface drainage, and were subsequently buried under a superimposed landscape. The prominent river system demarcated in Figure 6 comprises two different courses. These courses joined to form a single channel course near Malleka (Figure 6) that had a westerly flow. The mineralogical characters, extent and style of the grey micaeous sand suggests that it was a Himalayan mountain-fed, multi-channel fluvial system. A sample KL-1 (1D, Figure 7 near Kalirawan village, 75°37″ : 29°18″) from the top part of the channel sand in buried course BCH-2 has given a minimum age of 28 ± 2 Ka and another sample GN-2 (2D in Figure 7 near Gnaguwana village, 75°42″ : 29°07″) in buried course BCH-3 provided an average age of 26 ± 2 Ka, suggesting that these channels were active during the interglacial period (i.e. MIS 3) when monsoon was relatively stronger and fluvial activities were prominent[16–18]. Two other samples MR-3 and HS-1 (3D, near Mirka village, 29°07″ : 75°42″ and section 4D near Hoshanga village, Figure 7) from the top part of the channel sand in BCH-3 have yielded OSL ages of 21 ± 2 and 21 ± 1 Ka respectively probably related to the disorganization phase of fluvial activity during the interval related to Last Glacial Maximum (LGM). Samples from the base of the overlying

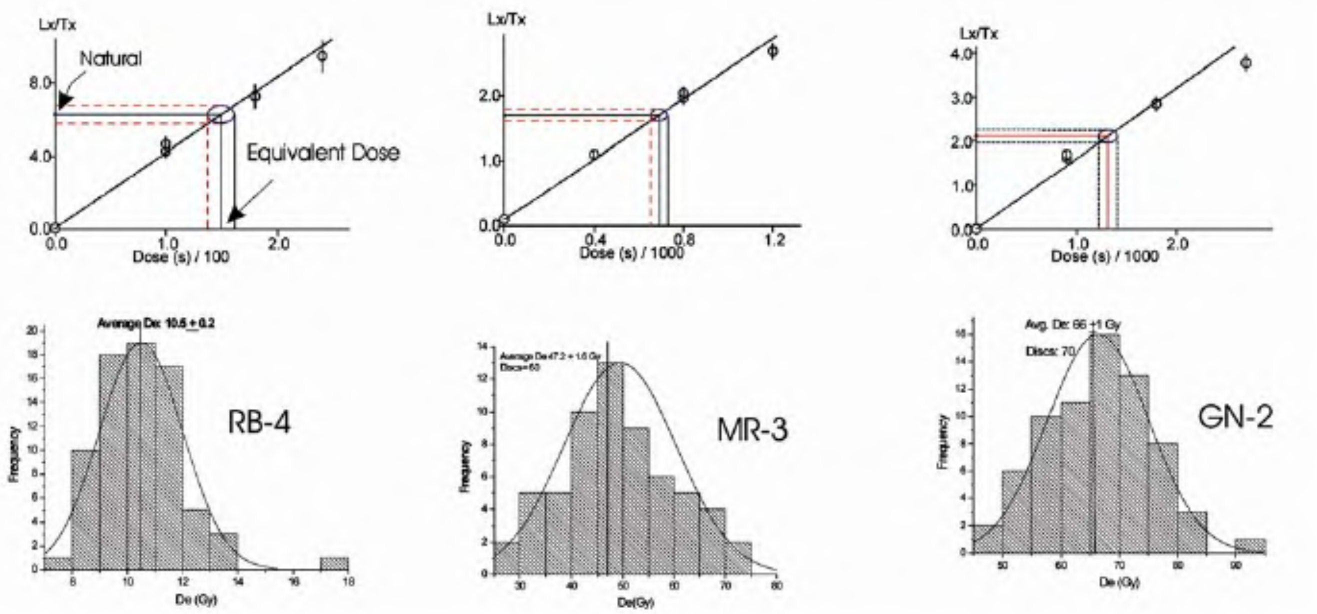

Figure 8. Growth curves (above) and frequency histograms of the equivalent doses (D_e) (below) of a representative sample of palaeochannel sand (RB-4), sample of aeolian sand (MR-3) and a fluvial sand sample (GN-2) representative of F1 – fluvial activity obtained from quartz using SAR protocol. In view of the near normal distribution of De values, weighted averages were used in age calculation except for sample no. KL-1 (section 1D, Figure 7) where minimum value of D_e (i.e. minimum value + (2 × standard deviation)) was considered to obtain the age of most bleached fraction. The growth curves show the natural and the regenerative equivalent doses (D_e). The points on the curved line represent the three regenerative doses, one zero dose and one repeat dose. The repeat dose was used to assess the recycling ratio while the zero dose was used for recuperation to test the suitability of samples for SAR protocol.

Table 1. OSL ages and other experimental results of samples used in this study

Sample no.	Depth (m)	K (ppm)	U (ppm)	Th (ppm)	Water contents (%)	Aliquot	Equivalent dose (Gy)	Dose rate (Gy/ka)	Age (Ka)
KL-1*	7.7	1.88	2.73	15.21	10 ± 5	49	89 ± 4*	3.2 ± 0.2	27.8 ± 2*
GN-3	5.5	1.48	3.14	17.8	10 ± 5	67	52 ± 2	3 ± 0.2	16.9 ± 2
GN-2	6.2	1.5	2.4	13.48	15 ± 5	69	65.8 ± 1	2.5 ± 0.1	26.4 ± 2
MR-3	7.2	1.35	2.37	14.06	10 ± 5	59	47.2 ± 1.6	2.6 ± 0.6	18.3 ± 2
MR-2	7.8	1.4	2.31	13.86	15 ± 5	42	51 ± 2	2.5 ± 0.1	20.8 ± 2
HS-2	2.5	1.75	3.06	13.1	10 ± 5	34	49.1 ± 1	3 ± 0.2	15.4 ± 1
HS-1	4.0	1.93	2.69	13.55	15 ± 5	24	62.3 ± 2	3 ± 0.1	20.6 ± 1
RB-1	0.8	1.7	2.36	12.56	10 ± 5	25	8.8 ± 0.3	3 ± 0.1	4.3 ± 0.2
RB-3	1.6	1.55	2.9	15.16	10 ± 5	57	9.06 ± 0.2	2.98 ± 0.1	3 ± 0.2
RB-4	3.6	1.2	2.44	12.54	10 ± 5	75	10.5 ± 0.2	2.4 ± 0.1	2.9 ± 0.2
RB-9	1.3	1.4	2.67	15.75	10 ± 5	41	9.8 ± 0.1	2.87 ± 0.1	3.4 ± 0.2
RB-8	3.6	1.05	2.44	12.1	10 ± 5	41	12.9 ± 0.3	2.27 ± 0.1	5.6 ± 0.2
RB-7	4.7	0.8	2.89	15.86	10 ± 5	44	13.7 ± 0.3	2.23 ± 0.1	5.9 ± 0.3

Age of sample KL-1* is based on minimum equivalent dose (D_e). Remaining ages are based on weighted averages of D_e.

aeolian facies in sections 2D, 3D and 4D (GN-3, MR-3 and HS-2) have yielded ages between ~20 and ~15 Ka (Table 1) suggesting the prevalence of arid conditions. Six samples from the previously mapped palaeochannel (sections 5D and 6D near Razabad: 29°31″ : 75°17″, Figures 6 and 7) considered as a part of 'lost' Saraswati[1] gave an age range between 5.9 ± 0.3 and 2.9 ± 0.2 Ka, suggesting a still younger phase of channel activity during middle Holocene.

The above data suggest that this part of the Haryana plain was affected by Himalayan-fed fluvial systems (F-1 fluvial activity) during the later part of MIS 3, and possibly through the Late Quaternary. Weakened fluvial activity is inferred during the LGM, on the basis of reduced thickness of the grey sandy facies, and its intercalation with brown sandy facies. Subsequently, aeolian accumulation became dominant and overlapped the fluvial system.

F-2 fluvial activity, corresponding in age to the extinct river Vedic Saraswati of previous workers[1,3–8], is recognized in a limited part of the area (Figure 6) and is of much smaller scale as compared to the buried subsurface channel systems of MIS 3. Its extent is mainly limited to

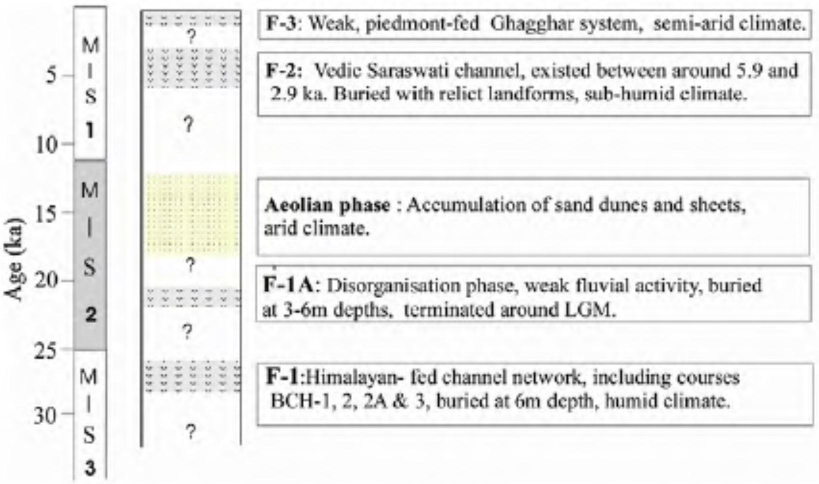

Figure 9. Summary diagram of the area showing three phases of fluvial activity (F-1 to F-3). F-1 and F-1A are buried, F-2 is mappable as a relict landform on aerial photos and imagery and has subtle expression on the ground. F-3 is represented by the present day Ghaggar river.

the area lying between Sirsa and Tohana, south of the present day Ghaggar system (Figure 6). The connectivity of the F-2 fluvial system with the upstream and downstream segments of the postulated Vedic Saraswati (Radhakrishna and Merh[3] and references therein) remains elusive and will need to be understood through integrated surface and subsurface geomorphic and stratigraphic analysis.

Earlier, the existence of the Vedic Saraswati river has been hypothesized based on its mention in the *Rigveda*, an ancient sacred collection of hymns whose composition is variously believed between 1700 and 1100 BC (ref. 19) and 8000 years ago[20]. It has been suggested that Saraswati was a mighty river system of Vedic period (between 6000 and 4000 BC) originating in the Har-ki-dum glacier in Garhwal Himalayas and after traversing parts of Punjab, Haryana, Rajasthan and Gujarat joined the Gulf of Khambat near Lothal[3–5]. The river dried up due to climatic and tectonic factors and the course was buried. The scientific work on the river commenced around 1874 (refs 21 and 22) and the first field mapping of the course undertaken in 1941 (ref. 23). After a gap, the subject re-emerged in late 20th century[24]; since then a number of workers have delineated the river course with the help of remote sensing data[1,3–8,25–28]. However, the ground validation of such a large river system in time and space especially the spatial continuity of channel segments still remain unconfirmed.

In the previously[1] delineated palaeocourse of the Saraswati, an important palaeochannel segment has been shown near Fatehabad in Haryana, south of the present day Ghagghar river (marked as PC in Figure 2). A number of archeological mounds are present in the area (Figures 2 and 6) which are assigned to the Harappan culture[23,29]. Our ground surveys confirmed parts of this segment based on the geomorphic and lithological signatures of a channel. These signatures include the southern bluff of a palaeochannel between Fatehabad and Hoshanga (Figures 2 and 6) defined by a 2–6 m sharp drop in elevation from the surrounding regional plain west of Fatehabad. The northern bluff of the channel is gradual and cannot be demarcated. Other evidences are (a) flood prone nature, (b) clayey topsoil, (c) flat topography, (d) absence of dunes. In contrast, the surrounding areas to the north and south have sandy soil, undulating topography, sand dunes and saline ground water. The sedimentary succession in the channel shows ~2.5 m thick red clay and sandy-silt at the top indicative of the desiccation phase, gradationally underlain by light greyish sand indicative of the channel activity (5D and 6D in Figure 7). Three OSL dates from this sand suggest that the channel was active before ~5.9 Ka and up till ~4.3 Ka. The dates from the sandy-silt suggest the desiccation of the channel between ~4.3 and ~2.9 Ka when the river became sluggish, and only red mud was being filled.

Although the above data set confirms the existence of channel activity during the mid-Holocene (i.e. F2 fluvial phase) in a part of the Haryana plains, it does not address the issue of upstream and downstream connectivity of the palaeochannel segment. Any confirmation of the 'Vedic Saraswati hypothesis', the lost river delineated by Yashpal *et al.*[1,8] based on their remote sensing based studies in this part of Haryana, requires a large scale concerted effort to establish the connectivity in lateral and vertical dimensions of this river segment to the postulated course of the Saraswati drainage system[3–5,26–28,30,31].

Conclusions

Including the present, three phases of fluvial activity (F-1, F-2 and F-3) are recognized in the area (Figure 9). The oldest fluvial activity, whose courses (BCH-1, BCH-

2 and BCH-3) are delineated in Figure 6, belonged to the <30 Ka phase of MIS 3. The second fluvial phase, F-2, is represented by a palaeochannel segment whose signatures are dated between ~6.0 and ~2.9 Ka. The third phase, F-3 is represented by the present day Ghaggar drainage. These integrated surface and subsurface data allow the following conclusions:

- The F-1 phase (subsurface) was the principal drainage network responsible for the alluvial development of the upper 40 m interval of this part of the northwestern Haryana plains.
- The F-2 phase, part of a relict landform, considered as a part of the 'lost' Saraswati drainage by previous workers[1,8] in this part of Haryana matches with the time span of the 'Vedic' Saraswati. However, the upstream and downstream connectivity of this segment to the postulated Saraswati course remains elusive and needs further exploration.

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ACKNOWLEDGEMENTS. We thank the Dy. Director General, GSI, Northern Region, Lucknow for providing facilities for the work. J. K. Bhalla, Director (Retd.), GSI, facilitated the collaboration between GSI and University of Delhi.

Received 28 April 2009; revised accepted 1 October 2009