The River Saraswati was a Himalayan-born river

K. S. Valdiya

Giosan and co-workers contend that the 'mythical' Saraswati River was not a glacier-fed Himalayan river. Questioning the findings of Indian archaeologists and geologists, they postulate that the Saraswati was a monsoonal river originating in the foothills of the Siwalik Hills and did not water the heartland of the Harappan Civilization. Reduction in its discharges due to weakening of the monsoon rains resulted in its drying up, leading to the demise of the Harappa Civilization. I have put forth a number of evidence gathered in the last 10–15 years to show that their arguments are not acceptable and by giving eloquent examples have asserted that the climate is not the only cause of all changes occurring on the surface of the Earth, and that there are other factors, some more powerful, which bring about changes.

Keywords: Channel fills, climate change, glacier-fed and monsoonal rivers, neotectonic movements.

GIOSAN *et al.*[1] have come out with their findings based on their 10-year work, using Shuttle Radar Topography Mission data combined with fieldwork and radiometric and optically stimulated luminescence (OSL) dating that 'mythical Saraswati' 'was not a large glacier-fed Himalayan river'. In their e-mail letter to S. Kalyanaraman at Chennai, forwarded to me on 19 June 2012, they have taken strong exception to my putting the Indian findings and perceptions in the books I have written. Questioning the Indian deductions that the Saraswati 'watered the Harappan heartland' they postulate – with an air of finality – their views that 'only monsoonal-fed rivers were active during the Holocene. As the monsoon weakened, monsoonal rivers gradually dried or became seasonal'. This development 'affecting the habitability along their courses' was detrimental to the Harappans 'who relied on the annual floods to sustain their economy'.

In support of their contention they cite the Pb–U dating of zircon grains in the sediments done by them[2] indicating (i) that the channel-fill sand bodies close to the Harappan settlements show little affinity with those of the present-day Ghagghar–Nara; (ii) that there are two groups of sediments showing similarities – both to the Beas River in the west and to the Yamuna and the Satluj rivers in the east and (iii) that the channels were active until after 4.5 ka and were covered by dunes before 1.4 ka. Clift *et al.*[2] however, postulate that the loss of the Yamuna from the Indus likely occurred as early as 49 ka and no later than 10 ka.

K. S. Valdiya is in the Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 560 064, India.
e-mail: valdiya@jncasr.ac.in

The main planks of the arguments of Giosan *et al.*[1] are: (i) upstream of the alluvial plains there is lack of large-scale incisions in the Ghagghar–Hakra and (ii) downstream sedimentation slowed on the distinctive megafluvial ridge, simply because of 'fluvial quiescene' resulting from gradual decrease in flood intensity.

Before addressing these points, I wish to dwell on four aspects – the reality of topographic situation, the action of the wind, the neotectonic movements of the terranes through which the Saraswati flowed and, the great thicknesses of channels fills.

Hydrogeomorphic analysis

If the Saraswati were just a monsoonal river fed by springs and seepages in its upper reaches during non-monsoon months – as the Hindan River in western and the Gomati River in central Uttar Pradesh (UP) are – then it would be necessary to establish this assertion by GPR survey – by a comprehensive study of groundwater elevation in relation to topographic lows combined with hydrogeological studies on the quantum of 'spring loading to the streams' that make the Saraswati River. There is no mention of this kind of study and no relevant data provided by Giosan *et al.*[1] in support of their thesis.

Landscape obliteration by desert storms

The Thar Desert which came into existence approximately 200,000 years ago[3,4] advanced nearly 1500 km eastward in the last 8000 years. In a short period of 50 years between 1930 and 1980, the desert encroached up to 30,000 ha of land in Haryana and UP to its east, the rate of desert march being on the average 0.8 ha/yr (ref. 5). On the average, five to eight major dust storms per year sweep the desert domain during May and June, the dust cloud rising to the height of 6000–10,000 m. These storms spread dust hundreds of kilometres eastward up to central UP. A dust storm having 1 km diameter, according to Strahler[6], is capable of lifting on an average 870 tonnes of dust, so that the dust storm having 500 km diameter can sweep away 90 million tonnes (mt) of fine sediments. Western Rajasthan is one of the dustiest places in the world, lifting great amount of fine sediments and blowing them far and wide, as evident from the dust storms that have been sweeping over the Indo-Gangetic Plains year after year almost daily in May–June for more than 3500 years.

If the wind scrapes off sediments from one area, it deposits them elsewhere, covering forests, grasslands, farmlands, water bodies (including rivers) and thus concealing all kinds of landforms, including the channels and floodways of rivers and streams. This explains why even later historical places, forts, temples, mosques, monuments and settlements in western UP – the eastern extremity of the Ganga floodplain – are concealed deep under heaps of sand that look like knolls or small hillocks.

The widespread occurrence of aeolian sediment mounds in the vicinity of stream channels called Bhur[7] – the youngest unit of the Ganga Plain – bears unambiguous testimony to the blowing dry winds piling up as much as 6–7 m thick deposit of yellow–brown fine sand in the western extremity of the Ganga flood plain[8], Haryana and Panjab plains.

Under such a circumstance how can one expect the pre-3500-year-old river-formed landforms in the Saraswati domain to be visible today on the surface to the geologists–geomorphologists and to the satellite-borne cameras, no matter how high their resolution is, in the region that fell under the sway of recurrent desert storms? In my humble submission the geomorphology and landscapes of the Saraswati basin from the foothills of the Siwalik to its point of discharge into the sea are bound to look different from those of the Indus and Ganga systems that are free from dust storms.

Influence of neotectonic movements

The larger part of the Saraswati domain cut by many faults across the river from its source to the sea (Figure 1) experienced neotectonic movements with attendant uplift, subsidence and displacement of ground, including those of the hill ranges and rivers as a number of lines of evidence of geomorphic, structural and seismological (including palaeoseismological) studies unambiguously demonstrate[9–18]. The higher-than-normal seismicity along the roughly NW–SE trending subsurface (hidden) Lahore–Sargodha and Barwani–Jaisalmer Ridges that trend across the upper and middle reaches respectively, of the Saraswati River demonstrates that tectonic movements continue to take place along the limits of these ridges. The Aravali, delimited by NE–SW trending major faults, is even more active seismically in its northeastern expanse.

To what extent the faults of the neotectonically resurgent terrain influence the flow regime can be gauged from effects of the NNW–SSE trending Daudpur–Bibipur lineament (fault) identified on Landsat image[19]. This fault is supposed to be responsible for distribution – rather diversion – of more water to the Yamuna in the east

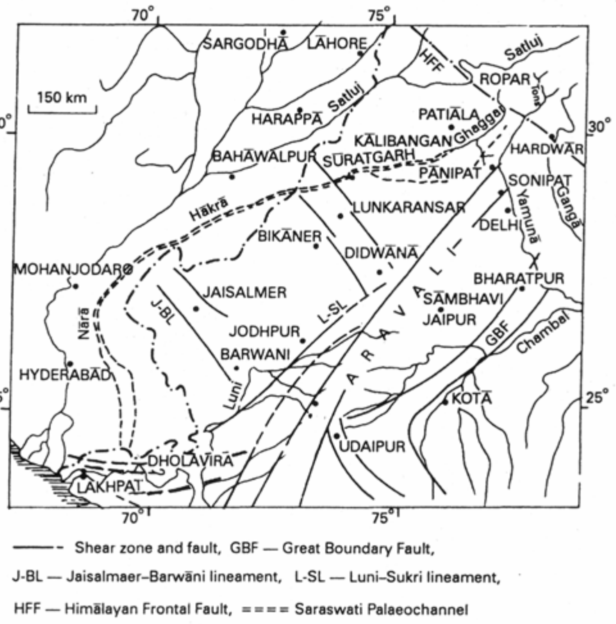

Figure 1. Simplified structural map of the terranes through which the Saraswati River flows in northwestern India. The faults shown by thicker lines have influenced the course of the Saraswati. Broken double lines show the ancient course of the Saraswati. (From Valdiya[20], based on works of S. Sinha Roy, A. B. Roy and S. K. Biswas.)

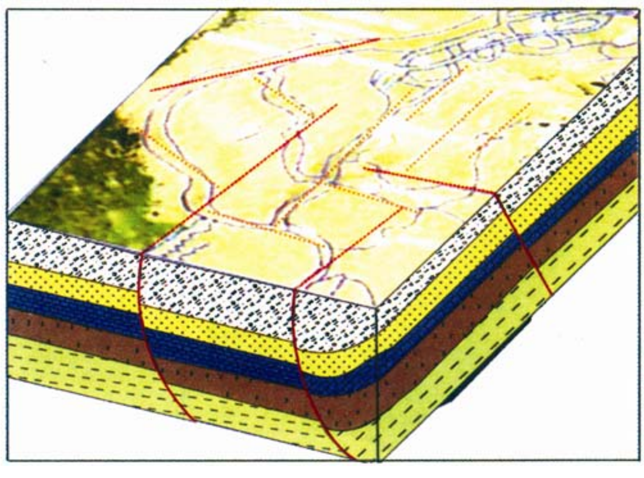

Figure 2. Block diagram showing faults affecting the course of the Saraswati River and its many channels. (From Mitra and Bhadu[12].)

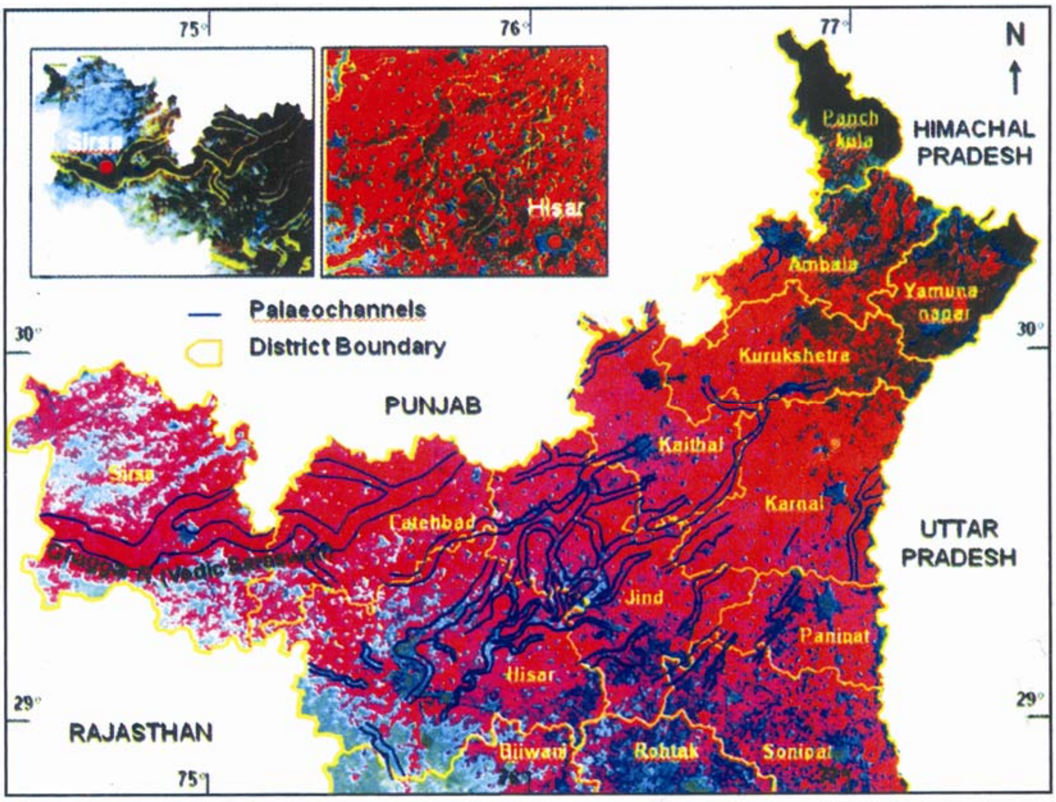

Figure 3. In the upper middle reach of the Saraswati the satellite photographs show many abandoned channels of the river. (Photograph Courtesy: Gupta *et al.*[67,68].)

compared to that of the Markanda–Sarsuti to the west, culminating in the reduction in discharge of the Markanda–Sarsuti towards southwest and west and increased water in the Yamuna towards south and southeast[19].

In the lower middle reach, deep drilling for exploration of oil and gas and water, together with analysis of aerial photos and Landsat TM Band imagery by the Oil and Natural Gas Corporation[12] have demonstrated existence of deeper lineaments and faults – including active faults registering sideways and up-and-down movements to various extent, resulting in uplift and sinking and horizontal displacement of ground. Under such tectonophysiographic upheavals the rivers and streams were frequently forced to change their courses, sometimes gradually and sometimes abruptly (Figure 2) as clearly seen in the satellite imagery[12]. Important is the finding that the NW–SE trending Jaisalmer–Mari Arc passes through the point near Shahpur where the meandering nature of the river abruptly ends and the river follows a linear course with change in directions and steep gradient (Figure 2). Deep drilling has established that the faults recognized on the surface extend to considerable depth. ‘The entire Saraswati Basin is riddled with a multiplicity of long reactivated and deep faults.’[12]

This is what I have explained and emphasized in all my works[20,21].

Not only the Saraswati (Figures 3 and 4), but also the Indus shifted westwards up to 160 km, primarily due to the effect of the northward drifting Indian plate[22], which must have caused subsidence of the belt adjacent to the Kirthar–Sulaiman mountain front. The Indus also flowed through its many channels in different times as evident from the existence of multiple palaeochannels (figure 3.12 in ref. 20).

In our time great Himalayan rivers like the Brahmaputra, the Tista, the Kosi, the Gandak, the Ganga and the Yamuna have been changing their courses[23–27]. In the Indo-Gangetic Plains underlain by fault-delimited Munger–Sahara Subsurface Ridge, the ground surface of the northern part is subsiding at the rate of 0.20–0.3 mm/yr, as indicated by Survey of India benchmarks[28]. The consequence – the Kosi migrated 112 km westwards in 238 years – between AD 1736 and 1964, and the Gandak moved 105 km westward in 100 years[24]. Significantly, in 2008 the westward-migrating Kosi suddenly changed its course eastward and flowed through its abandoned valley in the middle of its megafan.

The Tista that used to flow straight south to join the Ganga, suddenly deflected southeastwards in 1787 and became a tributary of the Brahmaputra, presumably because the Barind area rose up – and continues to rise up. In Bangladesh, the Brahmaputra flowed eastward south of the Meghalaya Hills delimited by the E–W trending Dauki Fault and met Meghalaya in eastern Bangladesh. Between AD 1720 and 1830 it abandoned its eastward course and carved its course straight south to join the Ganga. This is the region which is cut by the NW–SE trending active fault which lifted up the Madhupur Jungle by at least 20 m (ref. 29). Even today the Sylhet plain is sinking at the rate of 2.04 mm/yr and the Khulna region at the rate of 4.00 mm/yr (refs 30 and 31) and the Brahmaputra continues to cut its bank at the rate of 50 m/yr and migrating at the rate of 100 m/yr (ref. 32).

In the Saraswati–Yamuna domain some parts sank as happened in the place where the Yamuna descends onto the plain – the land to the eastern side of the transverse fault cutting across the Siwalik and dextrally displacing it – sank 14–22 m (ref. 14). This fault showed strike–slip movement of 30 cm within a short period of 4 years between 1962 and 1966 (ref. 33) and 0.7–5.7 cm between 1951 and 1976 (ref. 34).

To the west, the KalaAm Fault along which the Markanda enters the Haryana Plains and which had caused dextral displacement of about 5 km 'displays evidence of two large surface-rupture related to earthquakes – 1294 AD and 1423 AD and possibly the third at 260 AD' with resultant 'displacement during the last two earthquakes of minimum 4.6 m and 2.4 to 4.0 m respectively'[35].

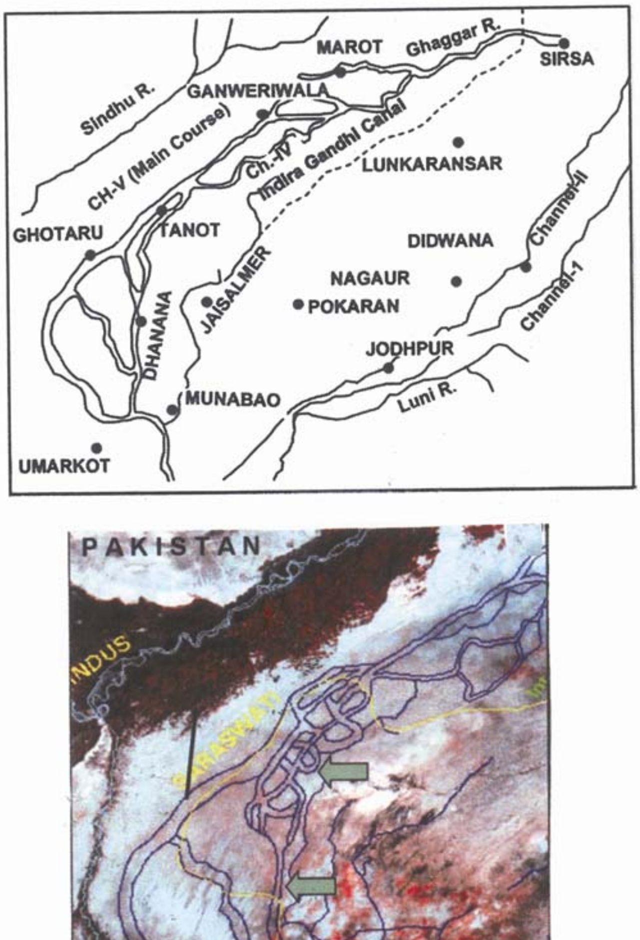

Figure 4. The many courses of the Saraswati in its lower middle reaches, as revealed by the analysis of latest techniques of remote sensing. (Top: After Gupta *et al.*[68]; Bottom: From Mitra and Bhadu[12].)

Not only the Saraswati basin but also the Indus Plain experienced tectonic resurgence many a time. According to L. Flam (p. 326 in Shroder[36]), 'the morphology and dynamic behaviour in the present (Indus) river in that reach support the conclusion that the ancient city of Mohenjodaro was abandoned as a result of river behaviour. Avulsion was a function of tectonically controlled subsidence and aggradation.' 'A period of increased flooding and sediment deposition followed by avulsion of the river away from the city is a reasonable explanation for its abandonment.'

This is exactly what I have been pleading all along in case of the Saraswati.

If this is happening to the Himalayan rivers in central and eastern Indo-Gangetic Plains in the sub-recent and recent historical time, we have all the reasons to believe that similar fate may have befallen the Himalayan-born Saraswati during the middle Holocene time. If Giosan *et al.*[1] can *speculate* (p. 5) on the basis of their 10-year work, mostly in Pakistan, what is wrong with the hundreds of Indian geologists working for over 50 years in putting forth their findings and deductions or perceptions? More so, because we have worked in all the geological terranes through which the Saraswati flowed – the Great Himalaya, the Lesser Himalaya, the Siwalik (each demarcated by boundary thrust), and the plains from the foothills to the border of Cholistan.

Sediment fills in multiple channels

Vertical resistivity sounding applying Wenner configuration technique with maximum electrode spacing up to

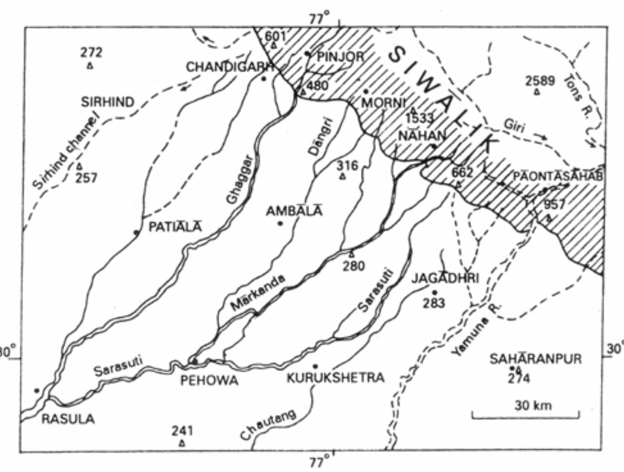

Figure 5. The dry channels of the Siwalik-born Sarsuti (corruption of Saraswati) and its tributaries Markanda met the Ghagghar, another ephemeral system coming from the Siwalik. Downstream of Rasula the river is called Ghagghar. (From Valdiya[20].)

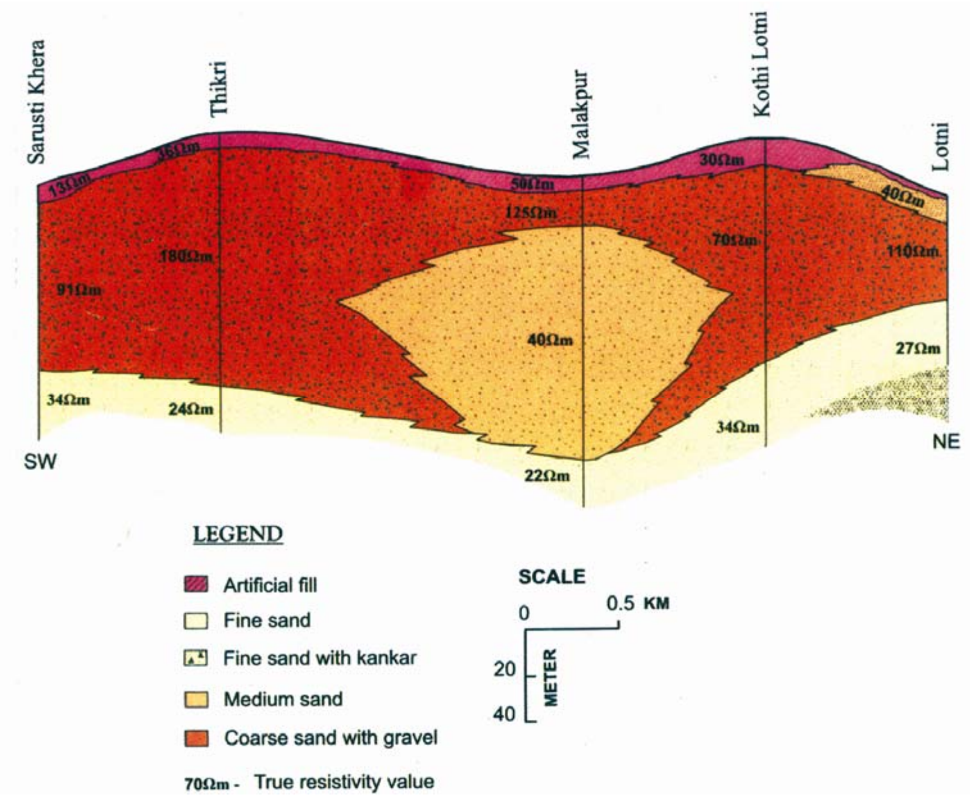

Figure 6. Resistivity log section between the Markanda River and the Sarsuti 'River'. Note the great thickness and lateral extent of the sand body. (From Kshetrimayum and Bajpai[37].)

1 km together with the study of IRS 1D LISS-IV (scale 1 : 250,00) imagery by Kshetrimayum and Bajpai[37] in the upper reaches of the Ghagghar system (Figure 5) just south of the Siwalik front brought out a number of facts. The buried sand bodies (Figure 3) are aquifer horizons composed of coarse sand with gravel at the depth between 10 and 100 m and having an average thickness of 90 m and lateral extent of 12 km (Figure 6). Another aquifer horizon at a depth of 45–148 m connects the Markanda and the Sarsuti (corruption of Saraswati) rivers. The lower course of the Markanda is hydraulically connected with the palaeochannels of the Saraswati Nadi. The archaeological sites found in the study area belong to the Late Harappan period, suggesting that the buried sand bodies at different places have the same historical time in terms of age[37].

It is obvious from the study that only a large perennial river could have filled the channel with such thick deposits of sands with gravels of the Sarsuti and the Marakanda in the Late Harappan time (3900–3300 yrs BP).

Saini *et al.*[38] carried out extensive geological fieldwork, together with analysis of subsurface lithological data collected from exploratory bore-holes dug by the Central Ground Water Board, and of geophysical studies and OSL dating of sediments in the central reach of the Ghagghar within Haryana done by the Geological Survey of India (Figure 7). This comprehensive work demonstrated that (i) More than 80% of the thickness (varying between 10–30 m and in some places more than 50 m) of the channel fills is made up of alluvial deposits in spite of the fact that presently no large perennial river exists in the terrain; (ii) Recognition of the major palaeochannel belt in the surface provides definite proof of the presence of a strong fluvial regime sometime in the past; (iii) The subsurface architecture of the palaeochannels and their floodplains in the Sirsa–Phaggu sector (Figure 7) is approximately 10–25 km wide, the palaeochannel with 9–29 m thick sediments being oblique to the present-day Ghagghar River (Figures 8 and 9). This points to the existence of multichannel, multilateral systems[38].

The OSL dating shows that the older sediments are 26.0 ± 2 to 21 ± 2 ka old and the younger fluvial activity recognized in the limited part of the region between 5.9 ± 0.3 and 2.9 ± 0.2 ka (ref. 38) – that is, between 6000 and 2900 yrs BP. The period of the Harappa Civilization is 5000–4600 yrs BP (Early Harappa), 4600–3900 yrs BP (Mature Harappa) and 3900–3300 yrs BP (Late Harappa). There is thus OSL dating proof that the river that watered the Harappan settlements did flow through the land. In all our works we have been stating that the discharge of the once mightly Saraswati had diminished after 3700 yrs BP when its eastern branch swung south to join with the Yamuna. And when the western branch also shifted westward near Ropar, around

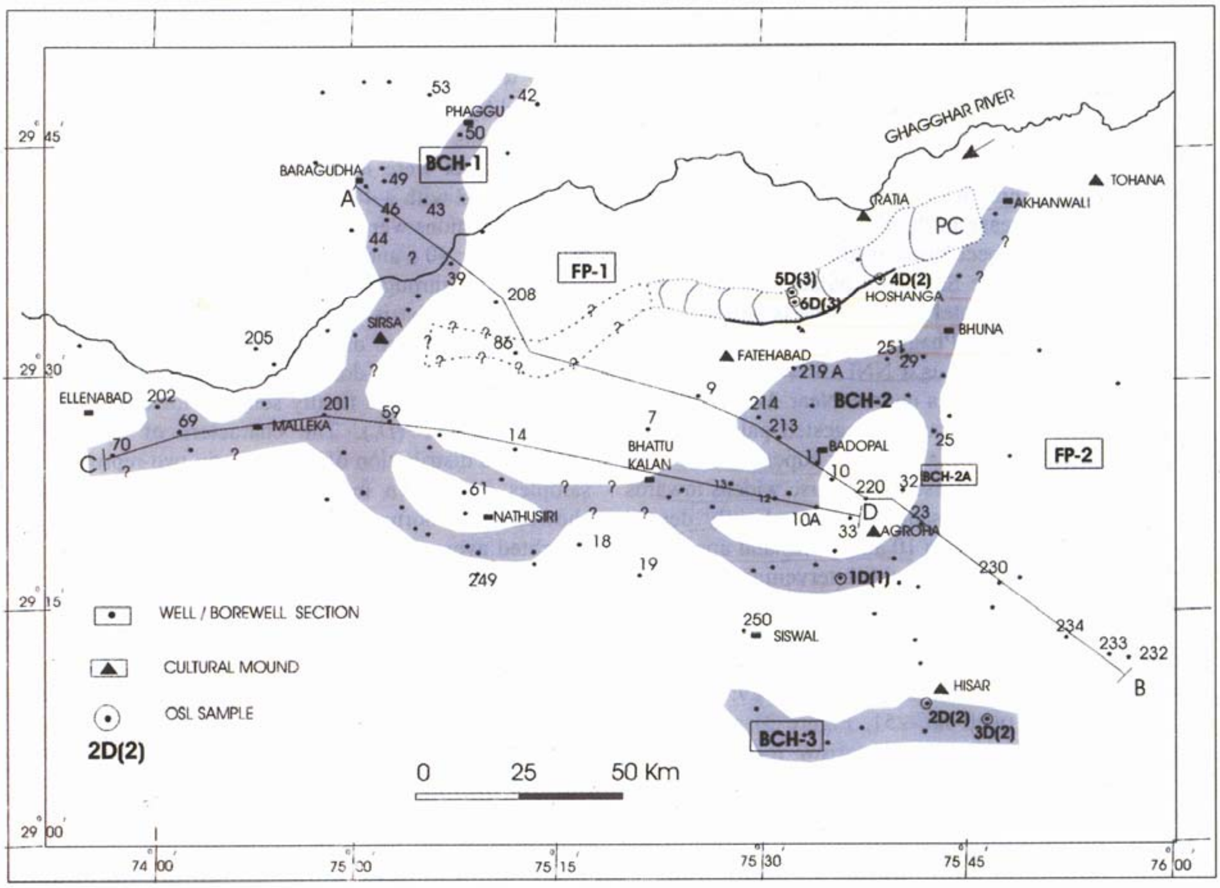

Figure 7. Subsurface reconstruction of northwestern Haryana (mid-central reaches) of the Ghagghar Basin showing identified courses of buried channels (BCH-1, 2 and 3) and floodplains (FP-1 and 2). (From Saini *et al.*[38]).

2500 yrs BP (refs 39 and 40), the Saraswati degenerated into a petty stream characterized by a chain of pools and swamps.

Where have we gone wrong in our descriptions and deductions?

Although one would be skeptical of the worth of the epic *Mahabharat* penned by Krishna Dwaipayan Vyas sometime after 3500 yrs BP (ref. 41), it does describe the Saraswati drying up and vanishing for long stretches under the desert sands (*Mahabharat*, Van Parv, Chapter 25; Shalya Parv, Chapter 37) and occurrence of waterlogged terrain adjoining a pool, swarming with snakes (*Mahabharat*, Shalya Parv, Chapter 37). In other words, the *Mahabharat* clearly states the Saraswati started declining before it was written 3500 yrs BP.

According to Saini *et al.*[38], the brown sandy facies of sediments contain mineral constituent, heavy minerals such as tourmaline, greenish-brown amphibole, garnet, sillimanite, kyanite, ilmenite and biotite. The grey fine-grained micaceous sands that occupy different depths are *similar to modern-day sediments of mountain-fed rivers like the Yamuna and the Ganga*[38].

A recent comprehensive geoelectrical study by Sinha *et al.*[42] across very crucial reaches of palaeochannels – including the valley abandoned by the Satluj River (Figure 10) when it swung west to join the Beas River of the Indus System/has unravelled the large-scale geometry and architecture of the palaeochannel system adjacent to the Harappan sites and proved the presence of a thick and extensive band of sand body more than 12 km long and 30 m thick in the subsurface part of northern Haryana, Panjab and NW Rajasthan. They have demonstrated that the dimension of palaeochannel bodies *represents deposits of a large river system*. Significant is the finding that the channel abandoned by the Satluj River is filled with 40–50 m thick sedimentary succession overlying a gravel bed[42]. The authors emphasize that 'first-order relationship between the postulated surface trace of a palaeochannel belt in satellite imagery and the subsurface sand body has been established beyond doubt and the dimension of the palaeochannel complex as *a large long-lived fluvial system*' (Figure 10).

A monsoonal river originating from the foothills plain of the Siwalik could not have been large and long-lived enough to build the kind and dimension of sand bodies in the multiplicity of palaeochannels, particularly in its uppermost reaches.

Now I address the main points of Giosan *et al.*[1].

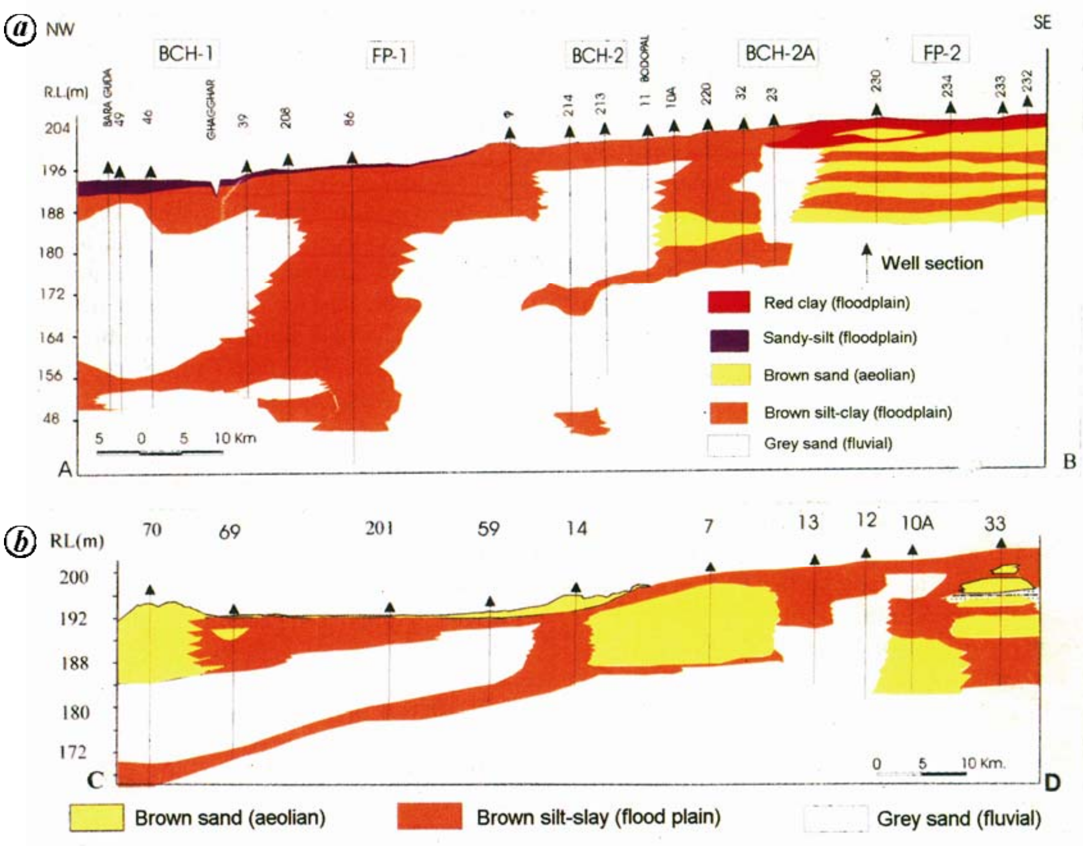

Figure 8. ***a***, NW–SE cross-section along *A–B* in Figure 6 shows spatially distinct buried channels separated by mud-dominated floodplains. Note the alternating layers of silt-clay and brown sand under flood plain FP-2, which is distinctly different from FP-1. ***b***, E–W subsurface section along *C–D* of Figure 6 showing prominent buried channels. The intervening area is made of aeolian sand. (Both from Saini *et al.*[38].)

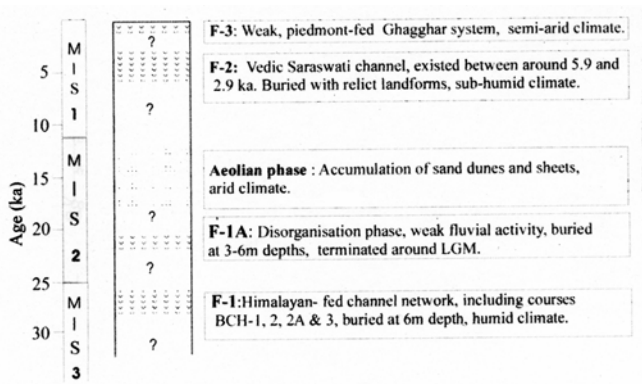

Figure 9. Summary of three phases of fluvial activity (F-1, F-2, F-3) in the Ghagghar Basin in the Haryana reaches, as revealed by the records of sediments of buried channels. (From Saini *et al.*[38].)

Incisions in interfluve

Giosan *et al.*[1] assert that while strongly incised valleys characterize the Indus and its tributaries in Panjab as well as in the westernmost rivers of the Ganga system in UP, there is lack of large-scale incisions in the interfluve in the Ghagghar–Hakra region, demonstrating (according to them) that larger glacier-fed rivers did not flow in this part.

Srivastava *et al.*[17] – who explicitly deny that the River Yamuna ever flowed southwest to join the Indus system at least during the Holocene – on the basis of Digital Elevation Model (SRTM and ASTER) satellite data and Digital Elevation Model and field work describe 'terminal fan' with 'diverging abandoned channels and fan morphology of the Haryana plain'. The surface of the fan dips southwards, its distal part having a gradient of 20–30 cm/km in contrast to 70–85 cm/km in the upper part close to the Siwalik hills. And this wide, large ancient fan surface is superimposed by piedmont surface of coalescing fans made up of gravels. Interestingly, the triangular area between Ropar (where the River Satluj abruptly turns west) and Ferozpur and Bathinda in the south represents an ancient fan deposit.

In the Siwalik foothills huge alluvial fans extending 9–15 km radially from the immediate piedmont have been recognized. There are 'spectacular 30 to 100 m high vertical river-cut cliff faces of the frontal Siwalik Hills' abutting against the flat alluvial plains and 'wide flood plains with terraces in ephemeral streams in contrast to their very small water-discharge volume'[43].

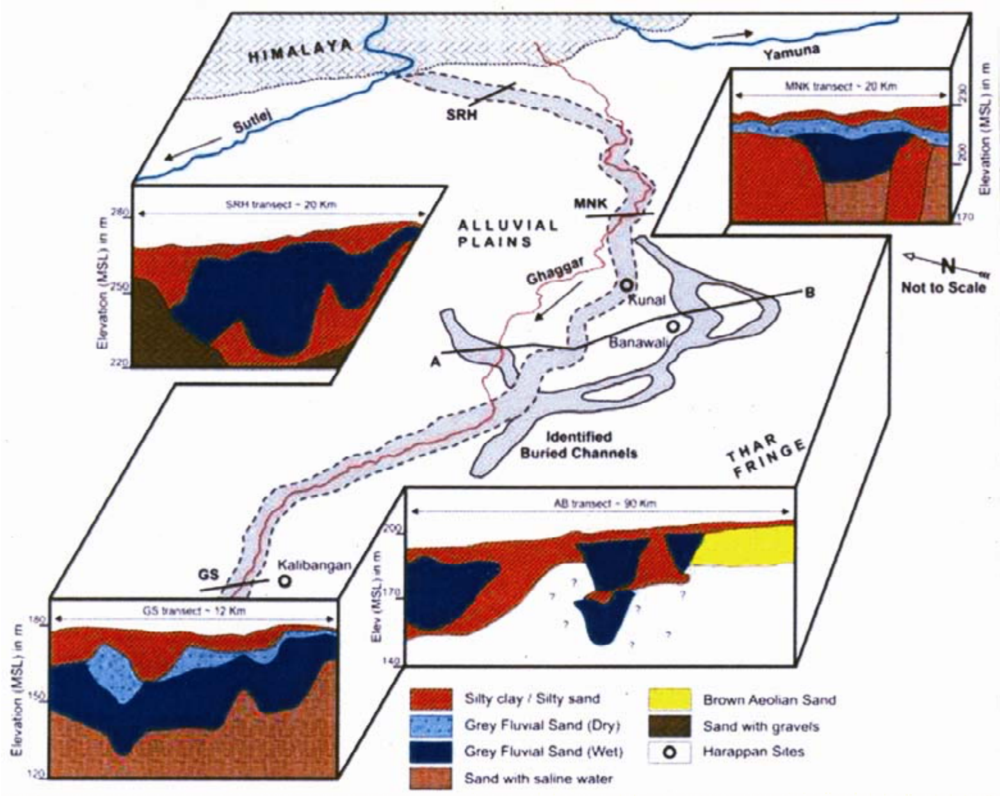

Figure 10. Block diagram by Sinha *et al.*[42] shows the palaeochannels of the Saraswati – including the one abandoned by the Satluj – and the extent of fluvial sediments filling their channels.

In northeastern Haryana, south of the Siwalik Range, there is a '20 to 40 km wide piedmont made up of predominant rudaceous sediments characterized by highest drainage density among all the units' of the study area 'and several short *narrow incised* seasonal water courses, the main one being the Ghagghar, the Markanda, the Dangri, the Sarsuti (≡Saraswati) and the Patiali Rau rivers'[38]. South of the piedmont, the floodplain (5–10 m deep) is 'constrained by prominent bank with steep cliff near the junction with the piedmont'. Downstream in the middle reaches 'between Tohana and Sirsa the Ghagghar has a non-meandering and *entrenched* form the latter with 30–100 m wide and 3–6 m deep channel'[38]. The width of the alluvial plain here is 200 km.

It is obvious that there are and must have been more prominent incisions before the piedmont and the floodplains were buried under colluvial deposits and the sands of dust storms blowing for over 3000 years. The neotectonic activities, including large earthquakes also obliterated the earlier formed landforms. It may be pointed out that in the Beas–Ravi interfluve to the west of the Saraswati, 0.5–5 m thick aeolian sands, representing subrecent 'Bhur' are intercalated with more than 150 m multicyclic sequence of the Holocene 'Bhangar' deposits – that is older alluvium[44].

Under such tectonic resurgence of the land and sway of dust storms, how can one expect the landscapes to remain in their original form?

Downstream slowing down of sedimentation

Giosan *et al.*[1] state that while the large Himalayan rivers (in the upper reaches in the floodplain) in Panjab (Pakistan) stopped incising, downstream the sedimentations slowed on the distinctive megafan ridge which the Indus built in Sindh. If the Indus, which was and is a Himalayan river, stopped incising and stopped depositing following 'intensification of aridification' after 5000 yrs BP, the other Himalayan rivers like the Saraswati must have also done the same. However, it did not stop doing so, as evidenced by relict incisions, entrenched valley and the very thick accumulation of sediments in the channel system as proved by Courty[45], Saini *et al.*[38] and Kshetrimayum and Bajpai[37] among others.

Giosan *et al.*[1] speculate that 'the development of Indus fluvial mega ridge was also a direct consequence of late Holocene aridity' and weakening of the monsoon after approximately 5000 years ago 'must have resulted in a reduction of sediment load compared to water discharge causing channel erosion and stabilization and leading to longer intervals of decoupling between channels and the alluvial plains'.

However, reduction in discharge in rivers is not the only cause of incision of the river valleys. I have walked and sometimes driven along more than two dozen of the Himalayan rivers from the foothill to across the Great Himalaya and the Tethys Himalaya – to the Indo-Tibetan border a couple of times. I have seen hundreds of spectacular incisions with nearly vertical to convex valley walls as deep as 1000–1500 m, practically in all these rivers wherever they crossed the active (reactivated) faults and thrusts[46,47]. It is the uplift of the mountain at a rate faster than the rate of erosion that caused the development of spectacular large-scale incisions, despite the abundant discharge of the Himalayan rivers. And this is an on-going process.

As already stated, all the Indian workers (archaeologists and geologists) have deduced (*not speculated*; p. 5) from a variety of pieces of evidence that following the deflection of the eastern branch of the Himalayan Saraswati (river Tamasa or Tons) to join the Yamuna River around 3750 yr (refs 19 and 38), there was considerable reduction in the discharge of the river in the plains, forcing the Harappans inhabiting the middle reaches to migrate *en masse* to the greener land in the foothills to the north and northeast. Likewise, there was another exodus of the people of the lower reaches southwards and southwestwards around 2500 yrs BP (ref. 40), when the western branch of the Saraswati (river Shatadru or Satluj) swung west to join the River Beas. If Giosan *et al.*[1] can speculate, they will concede that, we are also entitled to present our findings and perceptions based on solid evidence we have gathered.

Likewise, aggradation occurs also due to tectonic uplift of the ground downstream of the point under consideration. I have seen hundreds of massive aggradation at the river bends, upstream of active faults that lifted up the downstream blocks in streams, rivulets and rivers – in the Himalaya, in Sahyadri Mountain Range, in southern Karnataka and in the long coastal belt in Kerala and Karnataka[46–50].

Quoting again L. Flam (p. 326 in Shroder[36]), ‘channel pattern change, and lateral meander migration influence’… ‘rates of erosion and deposition’.

Then the change of the river-bed gradient, particularly if pronounced, leads to aggradation, as witnessed in all the Himalayan rivers, big and small, glacier-fed or not.

Testimony of heavy minerals and rock pebbles

The thickness of the sediment in the Ghagghar Basin in the western reaches between Sirsa and Kalibangan varies from 5 to 30 m, locally to 90 m (ref. 45) and in the Hakra reach as much as 150 m (ref. 51). The clay beds are composed of well-crystallized smectite, which is of Himalayan origin[45]. Saini *et al.*[38] found a suite of heavy minerals such as tourmaline, greenish-brown amphibole, garnet, sillimanite, kyanite, ilmenite and biotite in the brown micaceous sandy facies of sediments ‘similar to the modern-day sediments of the mountain-fed (Himalayan) rivers like Yamuna and Ganga’.

In the lower part of the basin the channel-fill deposits are characterized by lamination with abundant biotite, muscovite, hornblende, tourmaline, zircon and rutile within each layer[52]. The presence of these heavy minerals implies the schistose and gneissic rocks contributing to the fluvial sediments of the Saraswati. Needless to recapitulate, the schistone and gneissic rocks occur in the inner Himalaya. The Aravali provenance is ruled out, because the western flank of the Aravali is an undrained, riverless terrain. A few ephemeral petty streams that originate discharge into the Luni river flowing parallel to the Aravali slope independent of the Saraswati and discharging into the Rann of Kachchh, away from the Saraswati delta.

There is, however, no denying that a comprehensive provenance study is required to dispel all doubts about the source of the sediments that fill the channels and the floodplain of the Saraswati system.

The kind of study carried out on the Luni river system by Bajpai *et al.*[53,54] would help understand better the Saraswati river system.

In the extreme northeastern Haryana at the foot of the Siwalik hills in the valley of the Somb at Adibadri Puri[55–57] and archaeologists found terraces (Figure 11) characterized by pebbles of metamorphic rocks (phyllites, mica schists, quartzites, metabasites) of distinct Himalayan affinity – derived from the rocks of the inner (northern) Lesser Himalaya. Very similar pebbles occur in the higher terraces lining the two banks of the anomalously wide and straight course of the east-flowing petty Bata stream, within the Siwalik terrane[58]. The Siwalik is wholly made up of softer sandstones, maroon claystones and shales. The remnant of the terraces can be seen at Garibnath and Sudanwala (Figure 11). I have seen the pebbles of metamorphic rocks at Sudanwala. One cannot imagine occurrence of pebbles of Lesser Himalayan rocks in a small tributary of stream originating in and flowing through exclusively in the Siwalik terrane unless the Himalayan-born Yamuna had once flowed through its

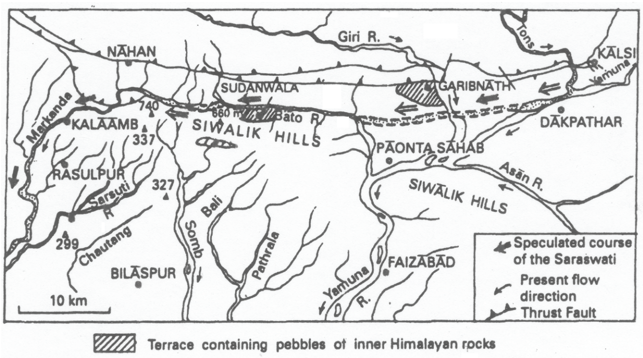

Figure 11. The east-flowing petty stream Bata, which joins the Yamuna a little north of Paonta Sahab, has a channel as wide as that of the Yamuna. Its two banks have relicts of high terraces at Garibnath and Sundanwala characterized by pebbles of metamorphic rocks of inner Lesser Himalayan origin. Similar occurrence is seen at Adibadri at the foothills of the Siwalik from where the present-day Somb-Sarsuti stream originates.

channel which is as wide as that of the Yamuna. Across a topographic high, the Markanda River flows to the west in its equally wide channel and past Adibadri immediately south of the foot of the Siwalik Hills.

Location of Harappan settlements in Saraswati Basin

It is commonly assumed that the Harappan settlements were located along the banks of the rivers, including the Saraswati. The Harappan people were worldly-wise (as testified by 'architecturally complex urban centres', showing 'excellent town-planning and short-text bearing 3000 seals' (ref. 1) and a wide range of archaeological finds[19]). They must have taken adequate precaution against recurrent floods. In the Indus Plain the archaeological evidence shows that the Mohenjodaro people built their houses in the floodplain on raised brick platforms as a measure of safety from floods.

In the Saraswati domain they must have built their houses away from them on the limits of the floodways instead of on the banks of the river channels prone to floods. A floodway is that part of the valley which experiences at least one-foot inundation by floodwaters at least once in a 100-year period (L. Palmer quoted by Coates[59]). The Saraswati being a wayward and wild river shifting its courses during floods, the limits of the floodway quite distant from the channels must have been the preferred location. This is borne out by the hundreds of brick-lined dug wells found within settlements and even within courtyards of houses.

The desert activities revived time and again after the intervals of wet spells as repeated occurrence of beds of wind-blown aeolean sediments with riverine and lake sediments in southwestern Thar[3] and in the Ghagghar bed near Sirsa[45]. The abandoned channels therefore must have been filled up with aeolian sediments. This explains the OSL dates 14,000 BCE and 10,000 BCE in the present Ghagghar–Nara reach of the Saraswati[60], and many other inconsistencies in the dates of channel sediments and of material of settlement.

Like Giosan *et al.*[1], I also speculate that they dated the sediments of channel abandoned by the Saraswati and filled with aeolian sediments long before the settlements came into existence.

Climate change

'Strong aeolian activity characteristic of the latest 200 to 300 ka period is marked by several episodes of the greater aridity, strong wind regime and sand dynamism followed by periods of stability implying climate amelioration and some pedogenesis'[61]. In a comprehensive review of palaeoclimate data collected from different parts of the Indian subcontinent based on studies carried out by palyaentologists, marine micropalaeontologists, sedimentalogists, glaciologists, geochronologists (including those who did OSL dating), Singhvi and Kale[4] demonstrate that between the arid dry phases there were intervals of *intense* aridity when hot dry wind blew in cyclic fashion during the time the humans lived there – 14,000 to 10,000 yrs BP, 5000–3500 yrs BP, 2000 yrs BP and 800–600 yrs BP (Figure 12). *Evidently, the pre-Harappan and Harappan people of the Saraswati floodplains were not only used to living under extreme climate condition, but also prospered and reached the climax of development in the period 4600–3900 yrs BP (Mature Harappa Phase).* Then there were spells of heavy rains at 15,300, 14,700 and 11,500–10,800 yrs BP and very heavy rains between 9500 and 5500 yrs BP (Figure 12). There were shorter intervals of weaker monsoon condition at about 8200, 6000, 5000–4300 and 200 cal yrs BP (ref. 4).

On the basis of carbon dating, Enzel *et al.*[62] had shown that in one of the lakes in the desert terrain – the Lunkaransar – the water rose to a maximum abruptly in 6300 ^{14}C yrs BP and dried up at 4800 ^{14}C yrs BP. In other words, *the people of the Mature Harappa Civilization lived and flourished several hundred years after the desiccation of the lakes due to onset of aridity*[62].

There is therefore no question of the Harappa Civilization meeting its demise around 5000 yrs BP. Our submission is that the Harappan people migrated *en masse* earlier to north, northeast and later to south and southwest when the water of the Saraswati diminished and when the Saraswati dried up due to tectonically induced river piracy and the people were forced to leave their homes[20]. Understandably, there was deterioration in the quality of life of the uprooted people wherever they settled down. *Those who remained in the desert terrain continue to enjoy life and multiply*.

Interestingly, Giosan *et al.*[1] concede that 'the Yamuna may have contributed sediment to this region…' (Hakra–Ghagghar) 'before the Mature Harappan Phase. For we recovered 5400-year-old sandy flood deposit at Fort Abbas (in Cholistan) Pakistan'… 'And on the upper interfluve, fine-grained floodplain deposition continued until the end of the Late Harappan Phase' … 'And at Fakirabad among the dunes of the expanding desert are seen even younger sediments approximately 3350 yrs BP'[1]. It may be pointed out that the Late Harappan Phase had the temporal span from 3900 to 3300 yrs BP.

On the basis of the OSL dates of sediments 'the younger fluvial activity recognized in a limited part of the area was between 5.9 ± 0.3 and 2:9 ± 0.2 yrs BP'[38] – that is 6000 and 2900 yrs BP. This is the time-span of the Early Harappa–Mature Harappa and Late Harappa Phases of the Harappa Civilization.

Which river deposited these younger sediments in the Hakra reach of the Ghagghar–Hakra river? We believe that it was the Saraswati River originating in the Himalaya.

What is wrong about our logic and our submission?

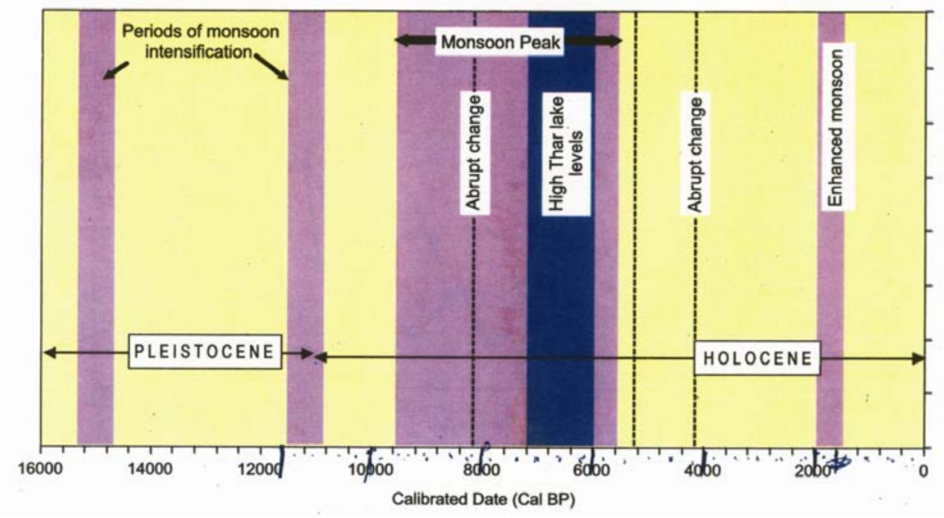

Figure 12. Summary of major changes in the monsoon conditions during the past 15,000 cal yrs BP. (From Singhvi and Kale[4].)

Rainfall changes not the only factor in the changes taking place

Changes that have taken place and are taking place on the surface of the Earth, are not all due to the increase and decrease of rainfall resulting from climate change. Rainfall is not the only decisive factor. There are equally, if not more powerful, factors that are working such as tectonic activities. The Saraswati domain experienced recurrent neotectonic activities, often very powerful.

Now, if the climate change was the sole cause of the evolution and collapse of civilization, how come that the people of Rajasthan desert *today* continue to enjoy life and grow. One would not believe, but it is true that the density of human population in this desert is highest anywhere in the deserts of the world – 57 persons/km^2. The Thar can be aptly described as world's most crowded desert[63]. Astoundingly, in the period 1909–1971 the population grew at the rate of 158% compared to 132% in the rest of India in the comparative period[64]. Not only the humans, but also the livestock population grew rapidly – from 72/ha in 1951 to 175/ha in 1971. The livestock population in 2003 was 49.14 million compared to 25.52 million in 1951 (ref. 64). The reason is obvious. At the very first shower, the desert is covered with green vegetation, which proliferates even when the rain is scanty. This is because, the soil of the once fluvial–alluvial deposits is rich in mineral nutrients, presumably brought down from the Himalaya, as all other rivers of the Himalaya have done and are doing in the vast Indo-Gangetic Plains.

Finally

If the 15-member team of Giosan *et al.*[1], using Shuttle Radar Topography Mission data with Digital Elevation *Models* to map the areas of study and the OSL and Pb–U dates of sediments of *some of the many* channels of the Saraswati, working as they did for 10 years, mostly in Pakistan, can speculate (p. 5), why cannot the hundreds of Indian archaeologists and geologists; the latter specializing in structural geology, tectonics, sedimentology, geomorphology, geochronology, geophysics and remote sensing and drawn from such varied organizations as the Geological Survey of India, Oil and Natural Gas Commission, Central Ground Water Board, State Ground Water Boards, Space Applications Centres of the Indian Space Research Organization and a number of universities who worked for more than 50 years throughout the domain of the Saraswati – in the plains, in the Siwalik, in the Lesser Himalaya and in the Great Himalaya, express their findings and views? What is the logic of Giosan *et al.*[1] thinking (in their letter to S. Kalyanaraman at Chennai), that 'A geological narration constructed without rigorous evidence has been promoted to support a theory of cultural evolution in northwest India.' When we have a mass of evidence collected from a variety of materials, why should our works 'now be revised or at the very least these geologists need to admit that their theory has been seriously challenged' (e-mail letter to S. Kalyanaraman, and made model in p. 1).

Yes, our conclusion (not theory) based on varied lines of evidence has been challenged, but not seriously, by those who themselves admit that they speculate (p. 5 of their paper).

Although I have attempted to address practically all points raised by Giosan *et al.*[1], I am skeptical if they would be impressed by this presentation of evidence collected by Indian workers mostly in the last 15 years. In an earlier e-mail letter to Kalyanaraman, forwarded to me on 12 June 2012, Giosan states that 'we studied quite a few material over the 10 years of project but considered seriously only the papers and authors presenting *reliable data and facts*'. In other words, most of the works of Indian workers (archaeologists and geologists) who have worked in the Saraswati Basin are not worthy of being cited by them – are not reliable. I wonder what criteria they considered to test or adjudge the reliability of evidence adduced by the Indians.

With my limited knowledge and capability, I believe that on the ground a human eye can see far better than the lens of even the most sophisticated camera mounted on satellite hundreds of kilometres high up in the sky. And there were hundreds of eyes looking closely at every patch of the ground for over 50 years, logging the events, walking long distances all over the Saraswati domain, living among the rocks and sediments, digging the ground, analysing the samples and cores of drill holes, but certainly not making models, nor speculating.

Giosan *et al.*[1] accuse us (Indians) of having a dogmatic approach in constructing a narration on the Saraswati prompted purely 'on emotional appeal'. It may be pointed out that the first geologists to write about it – in quite detail – in the *Journal of the Royal Asiatic Society of London* and *Journal of the Asiatic Society of Bengal* were two British stalwarts of the Geological Survey of India in 1886–1893 (refs 65 and 66). Surely they would not have been swayed by emotion on the 'cultural evolution in northwest India'. But insistence of Giosan *et al.*[1] on the belief that reduction of discharge in rivers resulting from diminished rainfall is the sole cause of incision and aggradation regardless of other factors playing roles, is nothing short of building a myth. Investing an aura of infallibility around the pet model 'climate change brings about all changes on Earth's surface' – may I state with all humility – is a dogmatic approach to such complex problems as river piracy, stream behaviour, persistent actions of dust storms, exodus of people from one area to another, etc.

1. Giosan, L. *et al.*, Fluvial landscapes of the Harappan Civilization. *PNAS*, 2012 (www.pnas.org/cgi/doi/10.1073/pnsas.1112743109) Early Edition.
2. Clift, P. D. *et al.*, U–Pb zircon dating evidence for a Pleistocene Saraswati River and capture of the Yamuna River. *Geology*, 2012, **40**, 211–214.
3. Singhvi, A. K. and Kar, A., *Thar Desert in Rajasthan: Land and Environment*, Geological Society of India, Bangalore, 1992, p. 186.
4. Singhvi, A. K. and Kale, V. S., *Paleoclimate Studies in India: Late Ice Age to Present*, Indian National Science Academy, New Delhi, 2009, p. 34.
5. Das, D. C., Soil conservation practices and erosion control in India – a case study. *Soil Bull. FAO*, 1977, **33**, 11–50.
6. Stahler, A. N., *Physical Geology*, Harper & Row, New York, 1981, p. 612.
7. Joshi, D. D., Late Quaternary climate events of the Gangetic plains. *Geol. Surv. India, Spec. Publ.*, 2001, **65**, 101–107.
8. Srivastava, P., Shukla, U. K., Mishra, P., Sharma, M., Sharma, S., Singh, I. B. and Singhvi, A. K., Luminescence chronology and facies development of Bhur sands in the interfluves region of Central Ganga Plain, India. *Curr. Sci.*, 2000, **78**, 498–503.
9. Kar, A., Climatic and neotectonic controls on drainage evolution in the Thar Desert. In *Geological Evolution of Northwest India* (ed. Paliwal, B. S.), Scientific Publishers, Jodhpur, 1999, pp. 246–259.
10. Bakliwal, P. C. and Ramasamy, S. M., Lineament fabric of Rajasthan and Gujarat. *Rec. Geol. Surv. India*, 1987, **113**, 54–56.
11. Bakliwal, P. C. and Wadhwan, S. K., Geological evolution of Thar Desert in India – issues and prospects. *Proc. Indian Natl. Sci. Acad., Part A*, 2003, **69**, 151–165.
12. Mitra, D. S. and Bhadu, B., Possible contribution of River Saraswati in groundwater aquifer system in western Rajasthan, India. *Curr. Sci.*, 2012, **102**, 685–689.
13. Ramasamy, S. M., Neotectonic controls in the migration of Saraswati River in the Great Indian Desert. *Mem. Geol. Soc. India*, 1999, **42**, 153–162.
14. Thusssu, J. L., Role of tectonics in drainage migration in Punjab–Haryana plain in recent times. *Geol. Soc. India Mem.*, 1999, **42**, 205–217.
15. Malik, J. N., Nakata, T., Philip, G. and Virdi, N. S., Preliminary observations from a trench near Chandigarh, NW Himalaya and their bearing on active faulting. *Curr. Sci.*, 2003, **85**, 1793–1798.
16. Srivastava, G. S. and Kulshrestha, A. K., Neotectonic movement of Markanda and Bata blocks, Himachal Pradesh: inferences from morphometric analysis. *Geol. Surv. India, Spec. Publ.*, 2005, **85**, 217–224.
17. Srivastava, G. S., Singh, I. B. and Kulshrestha, A. K., Late Quaternary geomorphic evolution of Yamuna–Satlej Interfluve: significance of terminal fan. *J. Indian Soc. Remote Sensing*, 2006, **34**, 123–130.
18. Virdi, N. S., Philip, G. and Bhattacharya, S., Neotectonic activity in the Markanda and Bata River basin, Himachal Pradesh, NW Himalaya. *Int. J. Remote Sensing*, 2006, **27**, 2093–2099.
19. Tripathi, C., Srivastava, A. K., Srivastava, V. C. and Iyer, R. V., Changes in the geomorphological setting of Yamuna river – a cause of ravine development. *Rec. Geol. Surv. India*, 1986, **113**, 1–10.
20. Valdiya, K. S., *Saraswati: The River that Disappeared*, Universities Press, Hyderabad, 2002, pp. 116.
21. Valdiya, K. S., *The Making of India: Geodynamic Evolution*, Macmillan, Noida, 2010, pp. 816.
22. Snelgrove, A. K., Migration of the Indus River, Pakistan in response to plate tectonic motions. *J. Geol. Soc. India*, 1979, **20**, 392–403.
23. Possehl, G. L., *Indus Age: The Beginning*, Oxford & IBH, New Delhi, 1999.
24. Bakliwal, P. C. and Sharma, S. B., On the migration of the Yamuna River. *J. Geol. Soc. India*, 1980, **21**, 461–463.
25. Mohinder, R. and Parkash, B., Geomorphology and neotectonic activity of the Gandak Megafan and adjoining areas, Middle Gangetic Plain. *J. Geol. Soc. India*, 1994, **43**, 149–158.
26. Parkash, B., Kumar, S., Rao, M. S., Giri, S. C., Kumar, C. S., Gupta, S. and Srivastava, P., Holocene tectonic movements and stress field in western Gangetic plains. *Curr. Sci.*, 2000, **79**, 438–449.
27. Gupta, R. P., Kumar, S. and Samadder, R. K., Palaeochannels as reservoirs for watershed management. In Proceedings of the 4th International Conference on Research in Watersheds, Fairbanks, UK, 2011, pp. 156–161.
28. Sinha, R. and Jain, K., Flood hazards of north Bihar rivers, Indo-Gangetic plain. *Mem. Geol. Soc. India*, 1998, **41**, 27–52.
29. Morgan, J. P. and McIntyre, W. G., Quaternary geology of the Bengal Basin, East Pakistan and India. *Bull. Geol. Soc. Am.*, 1959, **70**, 319–342.
30. Umitsu, M. O., Late Quaternary sedimentary environments and landforms in Ganges delta. *Sediment. Geol.*, 1993, **83**, 177–186.
31. Alam, M., Subsidence of the Ganga–Brahmaputra delta of Bangladesh and associated drainage, sedimentation and salinity problem. In *Sea Level Rise and Coastal Subsidence* (eds Milliman, J. D. and Haq, B. U.), Kluwer, Amsterdam, 1996, pp. 169–192.

32. Barua, D. K., The characteristics and mobility of some major rivers in Bangladesh. *Water Nepal*, 1997, **5**, 109–127.
33. Krishnaswamy, V. S., Jalote, S. P. and Shome, S. K., Recent crustal movements in northwest Himalaya and the Gangetic foredeep and related pattern of seismicity. In Proceedings of the 4th Symposium on Earthquake Engineering, Roorkee University, Roorkee, 1970, pp. 419–439.
34. Rajal, B. S., Virdi, N. S. and Hasija, N. L., Recent crustal uplift in the Doon Valley. In Proceedings of the International Symposium on Neotectonics in South Asia, Survey of India, Dehradun, 1986, pp. 146–159.
35. Senthil Kumar, Wesnousky, S. G., Rockwell, T. K., Ragona, D., Thakur, V. C. and Seitz, G. G., Earthquakes recurrence and rupture dynamics of Himalayan Frontal Thrust. *Science*, 2001, **294**, 2328–2331.
36. Shroder Jr, J. F. (ed.), *Himalayas to the Sea*, Routledge, London, 1993.
37. Kshektrimayum, K. S. and Bajpai, V. N., Establishment of missing stream link between the Markanda river and the Vedic Saraswati river in Haryana, India – geoelectrical resistivity approach. *Curr. Sci.*, 2011, **100**, 1719–1724; Kshetrimayum, K. S. and Bajpai, V. N., Hydrogeomorphic classification and aquifer disposion in the Markanda river basin, northwestern India. *Hydrogenization Appl.*, 2012, **79**, 391–403.
38. Saini, H. S., Tandon, S. K., Mujtaba, S. A. T., Pant, N. C. and Khorana, R. K., Reconstruction of buried-floodplain systems of the northwestern Haryana Plain and their relation to the 'Vedic' Saraswati. *Curr. Sci.*, 2009, **97**, 1634–1643.
39. Thapar, B. K., A Harappan metropolis beyond the Indus Valley. *Expedition*, 1971, **17**, 19–32.
40. Mughal, M. R., *Ancient Cholistan: Archaeology and Architecture*, Ferozsons, Rawalpindi, 1996.
41. Valdiya, K. S., *Geography, Peoples and Geodynamics of India in Paranas and Epics*, Aryan Books International, New Delhi, 2012, p. 240.
42. Sinha, R., Yadav, G. S., Gupta, S., Singh, A. and Lahiri, S. K., Geo-electric resistivity evidence for subsurface palaeochannel systems adjacent to Harappan sites in NW India. *Quaternary Int.*, 2012, doi:10.1016/J.Quaint.2012.08.002.
43. Chaudhri, A. R., Active tectonics in the frontal Siwalik hills in the neighbourhood of Chandigarh, India – a case study. In International Association Gondwana Research Conference, 2008, Series 5, p. 5.
44. Rubi, B. S. and Punj, N. K., Quaternary geological studies in Amritsar district, Panjab. *Gondwana Geol. Mag.*, 1999, **4**, 33–42.
45. Courty, M. A., Late Quaternary environmental changes and natural constraints to ancient landuse (Northwest India), Museum of Technical University, Lubbock, Texas, 1995, pp. 106–126.
46. Valdiya, K. S., Trans-Himadri intracrustal fault and basement upwarps south of Indus–Tsangpo Suture Zone. In *Tectonics of Western Himalaya* (eds Malinconico, L. L. and Lillie, R. J.), Geological Society of America, Boulder, 1989, pp. 153–168.
47. Valdiya, K. S. and Pande, K., Behaviour of basement-cover decoupling in compressional deformation regime, northern Kumaun (Uttarakhand Himalaya). *Proc. Indian Natl. Sci. Acad*., 2009, **75**, 27–40.
48. Valdiya, K. S., Reactivation of terrane-defining boundary thrust in central sector of the Himalaya: implications. *Curr. Sci.*, 2001, **81**, 1418–1431.
49. Valdiya, K. S., Tectonic resurgence of the Mysore Plateau and surrounding regions in cratonic southern India. *Curr. Sci.*, 2001, **81**, 1068–1089.
50. Valdiya, K. S. and Narayanan, A. C., River response to neotectonic activity. Example from Kerala, India. *J. Geol. Soc. India*, 2007, **70**, 427–443.
51. Giyeh, M. A. and Ploethner, D., An applied palaeohydrological study of Cholistan, Thar Desert, Pakistan. In *Application of Tracers in Arid Zone Hydrology* (eds Aday, E. M. and Leibundug, C.), Proceedings of the Vienna Symposium, IAHS Publication No. 232, International Association of Hydrological Sciences, Vienna, 1995, pp. 119–127.
52. Malik, J. N., Mehra, S. S. and Sridhar, V., Palaeo-delta conplex of Vedic Saraswati and other ancient rivers of northwestern India. *Mem. Geol. Soc. India*, 1999, **42**, 163–174.
53. Bajpai, V. N., Saha Roy, T. K. and Tandon, S. K., Subsurface sediment accumulation patterns and their relationships with tectonic lineaments in the semi-arid Luni river basin, Rajasthan, western India. *J. Arid Environ.*, 2001, **48**, 603–621.
54. Bajpai, V. N., Saha Roy, T. K. and Tandon, S. K., Hydrogeomorphic mapping on satellite images for deciphering regional aquifer distribution: case study from Luni river basin, Thar Desert, Rajasthan, India, Preprint, UNESCO, Paris, 2001.
55. Puri, V. M. K., Origin and course of Vedic Saraswati river in Himalaya – its secular desiccation episodes as deciphered from palaeo-glaciation and geomorphological signatures. *Geol. Surv. India, Spec. Publ.*, 2001, **53**, 175–191.
56. Puri, V. M. S., Vedic Saraswati: scientific signatures on its origin from Himalaya. In *Vedic Rivier Saraswati and Hindu Civilization* (ed. Kalyanaraman, S.), Aryan Books International, New Delhi, 2008, pp. 14–35.
57. Dwivedi, I. D., Kesarwani, A., Manjul, S. and Bhosle, R., Archaeological investivation in and around Adi-Badri in Yamunanagar district of Haryana. *J. Hist. Hist. Archaeol.*, 2006, 54–63.
58. Puri, V. M. S. and Varma, B. C., Glaciological and geological source of Vedic Saraswati in the Himalayas. *Itihas Darpan*, 1998, **4**, 7–36.
59. Coates, D. R., *Geomorphology and Engineering*, Dawaden, Hutchison and Ross, Stroudsbury, Pennsylvania, 1976, p. 360.
60. Lawler, A., In Indus times, the river didn't run through it. *Science*, 2011, **320**, 1276–1285.
61. Dhir, R. P. and Singhvi, A. K., The Thar Desert and its antiquity. *Curr. Sci.*, 2012, **102**, 1001–1008.
62. Enzel, Y. *et al.*, High resolution Holocene environmental changes in the Thar desert, northwestern India. *Science*, 1999, **284**, 125–126.
63. Gupta, R. K. and Prakash, I., *Environmental Analysis of Thar Desert*, English Book Depot, Dehradun, 1975, p. 484.
64. Chaudhary, P., Bohra, N. K. and Chodhary, K. R., Conserving biodiversity of community forests and range lands of a hot arid region of India. *Land Use Policy*, 2011, **28**, 506–513.
65. Oldham, R. D., On the probable change in the geography of the Panjab and its rivers: an historical geographical study. *J. Asiat. Soc. Bengal*, 1886, **55**, 322–343.
66. Oldham, C. F., The Saraswati and the lost river of the Indian desert. *J. R. Asiat. Soc. London*, 1893, **34**, 49–76.
67. Gupta, A. K., Sharma, J. R., Sreenivasan, G. and Srivastava, K. S., New findings on the course of River Saraswati. *Photonirvachak*, 2004, **32**, 1–24.
68. Gupta, A. K., Bhadra, B. K. and Sharma, J. R., Saraswati drainage system of Haryana – Satellite based study. In *Vedic Sarasvati and Hindu Civilization* (ed. Kalyanaraman, S.), Aryan Books International, New Delhi, 2008, pp. 46–64.

Received 16 August 2012; accepted 13 December 2012