Spread of loess and march of desert in western India

R. K. Pant

Physical Research Laboratory, Ahmedabad 380 009, India

Recent studies on loess deposits and deserts have provided clues to climatic change in the Quaternary period in the Indian sub-continent. The palaeoclimatic record in the Thar Desert apparently dates back to ~200 ka., while the loess-palaeosol succession in the Kashmir Basin in NW Himalaya parallels deep-sea oxygen isotope record up to Stage 9. The desert lakes have preserved record of climatic fluctuations from Terminal Pleistocene onwards. Loess deposits in the basins of the Son and the Belan rivers in north-central India are good indicators of the areal extent of the Quaternary aridity in the sub-continent.

Introduction

Loess, desert sands and other dust mantles are the manifestations of aeolian processes prevailing both in cold arid (cold desert) and hot arid (hot desert) regions (Figure 1). The Quaternary glaciation amplifies aridity resulting in the deposition of loess and expansion of deserts. With the amelioration of climatic conditions, deposition of loess ceased and the desert margins shrank as the sands stabilized and soils started forming. Hence the emphasis on the study of loess profiles with intercalated palaeosols (buried soils) for Quaternary palaeoclimatic reconstructions. Considerable effort has been made during the past couple of decades to understand the genesis of loess[1,2] and deserts[3] and their palaeoclimatic implications[4,5]. The loess record of the Kashmir Basin extends down to mid-Pleistocene while the Rajasthan desert lake-deposits have preserved an account of climatic changes from the Terminal Pleistocene till today. The Thar or the Great Indian Desert itself may be of the mid-Pleistocene antiquity. The calcareous bands within the desert sands/soils possibly developed in response to the Quaternary climatic changes as in the case of the Kashmir loess-palaeosol succession. However, details of the palaeoclimatic record in the desert have yet to be worked out. The Kashmir loess-palaeosol sequences have been studied in order to glean information on the Quaternary palaeoclimates, and thus to supplement the little information that is available on the history of the Thar desert.

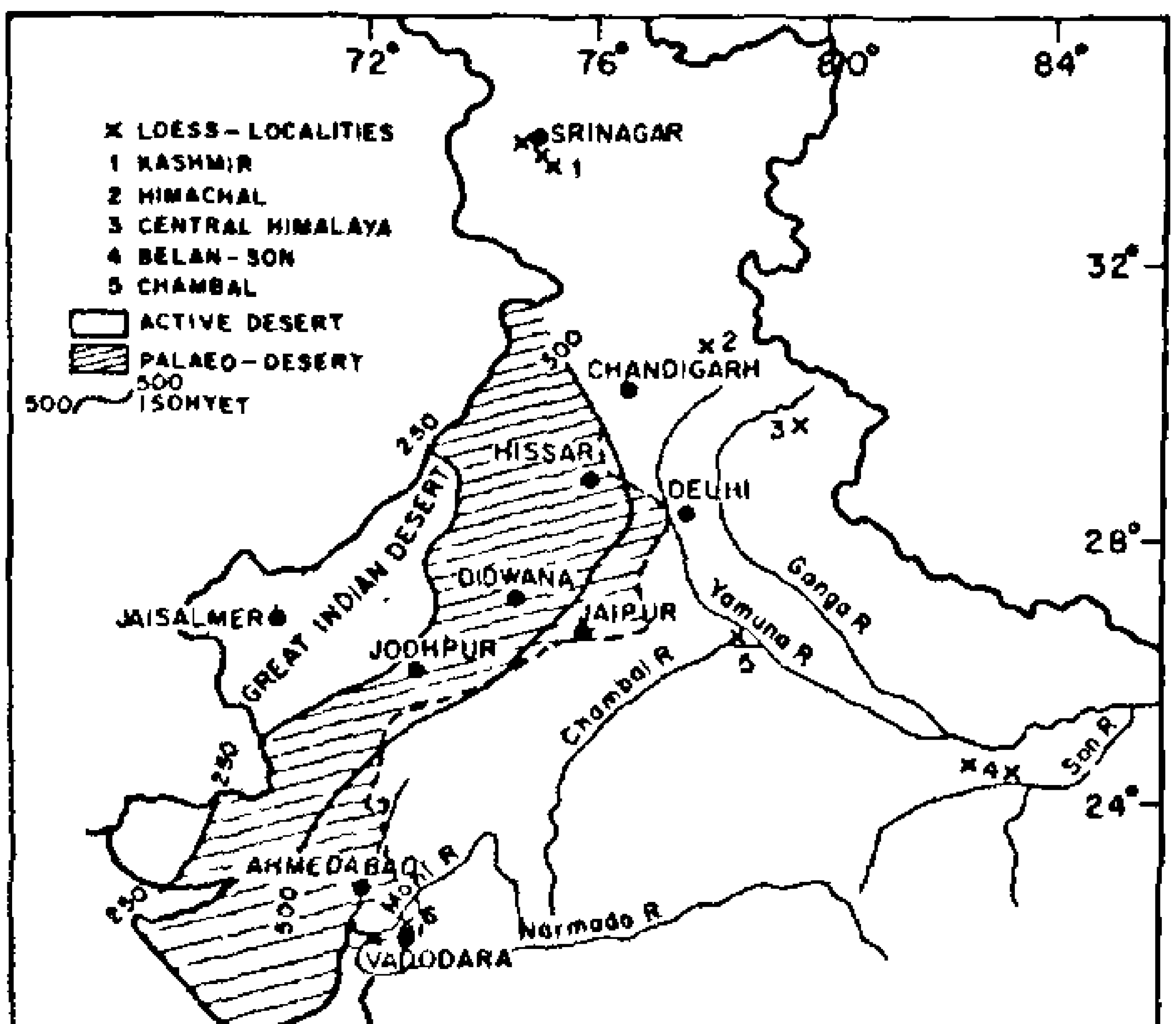

Figure 1. Loess localities and desert extension.

Loess-palaeosol in Himalaya and palaeoclimatic changes

Loess, is a structureless, homogeneous, calcareous silt of aeolian origin. The loess deposits have preserved by far the longest and almost uninterrupted climatic record in terrestrial situations, next only to the isotope record of the deep-sea oxygen[6]. Such deposits have been reported from the Potwar region in Pakistan[7,8], the Balen and Son valleys in north-central India[9,10] and the Kashmir Basin[1,2]. The loess deposits have also been reported from the Mahi river basin in Gujarat underlying aeolian sands[11,12]. It is not unlikely that such deposits also occur within the Thar and in the areas peripheral to it.

Kashmir Basin

The loess forms the topmost member of the Kashmir intermontane Plio-Pleistocene basinal fill (Figure 2 *a, b, c*), known as the 'Karewas' or the 'Karewa Group'[7,13]. The Lower and Upper Karewas, are essentially fluvio-lacustrine in origin. However there were controversies regarding the origin, distribution and age of the loess deposits forming the Upper Karewa. The excavations carried out by De Terra and Paterson[7] at a Neolithic site near village Burzahom (34° 10′ N, 74° 53′ E) led them to conclude that these externally derived silt deposits were of Holocene age. Later workers[14,15] redesignated these deposits as 'loam' and 'loam member' of the Upper Karewa, of the Holocene age, overlooking the palaeoclimatic significance of these deposits. On the basis of field observations and SEM study of the quartz grain characterized by pinprick pores[16,17], backed up by detailed sedimentological and mineralogical investigations[16], Pant *et al.*[1] concluded that these deposits are loess and exhibit typical box-shaped valleys or dells.

Mineralogical studies further suggest that the loess is derived from local rocks[16]. Thick loess deposits are found in the valley where these were deposited by the northerly winds during the glacial times and not by the southerly or the present-day monsoonal winds as envisaged by De Terra and Paterson[7]. The Karewa sediments are rich in clay fraction and the Katabatic or the gravity winds blowing down mountain slopes during the glacial times[18] had picked up fine materials and redeposited them on the valley floor.

The spatial distribution of loess profiles (Figure 2) showed variation in the number of palaeosols and thickness across the valley. Loess deposits occurring on the plateau situations are ideal for reconstructing lithostratigraphy and palaeoclimates, as these preserve full record and are correlatable in different exposures.

The most complete stratigraphical records have been observed on the Tsrar Sharif and Martand plateaus. These profiles show ten to eleven intercalated palaeosols.

Three palaeosurfaces were available for loess deposition at various intervals of time which may have developed in response to the continuously developing outer Himalayan schuppen-structure[13]. The process ultimately culminated in a major upliftment of the Pir Panjal between 1700 and 3000 m around 350 ka[13] which generated extensive gravel fans forming the first surface for loess deposition. At least two more such episodes were marked by erosional phases in the loess stratigraphy and the terrace formations.

Soil micromorphological[4] and clay mineralogical[19] studies have helped to delineate the past climatic fluctuations. The topmost Holocene soils (Lithounit-VII, Figure 3) have a typical A-B-C profile and genetically have an Ah(t)-Bwt-Ck horizon sequence[4]. These soils appear to have developed under the tall grass prairie during the first (warmer) half of the Holocene which changed to deciduous forest (cooler) during later Holocene. The last interglacial soil (Lithounit Va; Figure 3) could be recognized mid-way in the profiles. It represents climatic conditions comparable with the modern or slightly warmer conditions in which flourished deciduous forest in a 'xeric' moisture regime[4]. The thermoluminiscence date is 110 ka (Figure 3). The underlying loess has been dated 130 ka. The soil horizon can, therefore, be equated with substage 5e of the oxygen isotope stratigraphy[20]. On the Tsrar Sharif plateau, a pedocomplex could be recognised below the last interglacial soil (Figure 2*a*) representing yet earlier interglacial stages. On the Martand plateau however, there are four distinct palaeosols (Lithounits I, II and III; Fig. 3) stratigraphically comparable with the Tsrar Sharif pedocomplex. The loess profiles, at places, have also recorded hiatuses in the form of relict but well-developed Ck horizons. These evidences, therefore, suggest that the loess-palaeosol succession in the Kashmir valley was punctuated intermittently by erosional episodes.

Clay mineralogical parameters were used to further understand the fluctuating Quaternary climatic conditions in the valley[19]. Crystallinity parameters of illite turned out to be very sensitive to climatic change (Figure 3). During interglacial epochs, when the pedogenic processes were at the maximum, many elements were rendered mobile by the breakdown of primary minerals. Though the illite has degraded during the pedogenesis as indicated by poor crystallinity in the A horizons, it progressively improves in well developed B horizons (Figure 3). The improved crystallinity in the authigenic phase suggests an incorporation of the potassium released from the breakdown of feldspars and mica of the coarse fraction[19].

The profile is compared with the deep sea oxygen isotope curve on the basis of loess chronology provided by Bronger *et al.*[4] The crystallinity curve and the soil micromorphology results show concordance up to Stage 9 (ref. 20) (Figure 3). This is in keeping with the age of 350 ka assigned to the marker gravel[13] which forms the first palaeosurface for loess deposition in the valley.

Potwar Basin

Potwar loess extends east to the Jammu region. Levallois tools besides fossils of horse, dog, camel and oxen have been recovered from the basal part of the loess. Thermoluminescence dating suggests 135 ka as the lower limit for the commencement of loess deposition[8] during the glacial stage preceding the Last Glacial Maxima (LGM). It continued to deposit during the LGM with punctuations during interglacial times.

Indo-Gangetic Basin

Extensive loess deposits have been reported from the Son and Balen river basins[9,10] in the north-central

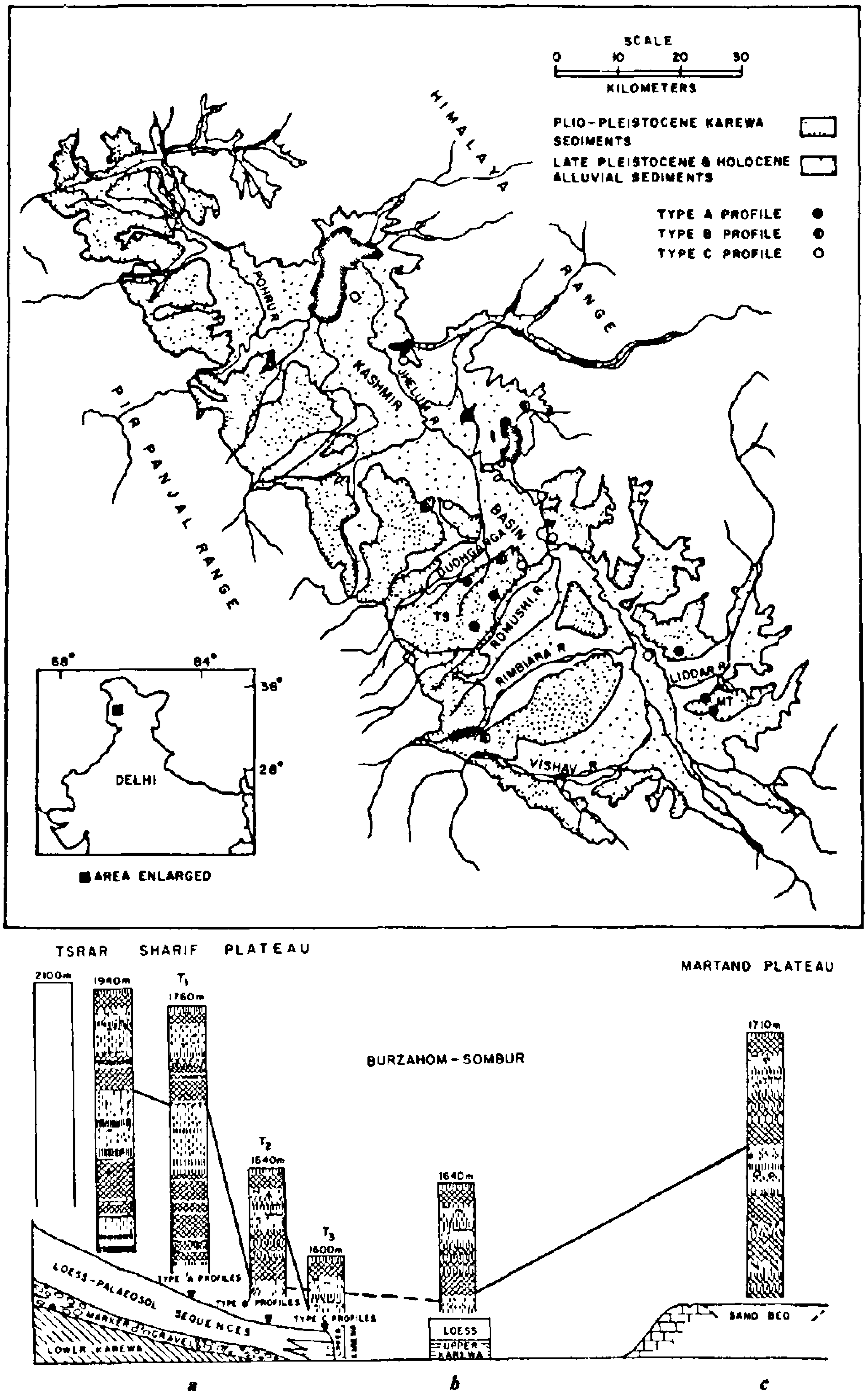

Figure 2. Kashmir Basin showing Karewa infillings and location of loess profiles studied. **Upper**: TS Tsrar Sharif Plateau, MT-Martand Plateau. **Lower**: Section and columns show stratigraphical correlation between loess profiles. T_1, T_2, and T_3 represent loess sequences on river terraces in descending order. For symbols, see Figure 3.

India. Four loessic episodes are separated from each other by fluvial gravels. The topmost loess belongs to the Holocene while the lower three are of the late Pleistocene age. Radiocarbon dating on mollusc shells from the gravels range from 26 ka through 18 ka to 10 ka. The Holocene loess has been dated between 5 ka and 3 ka.

The source of the loess has been attributed to the

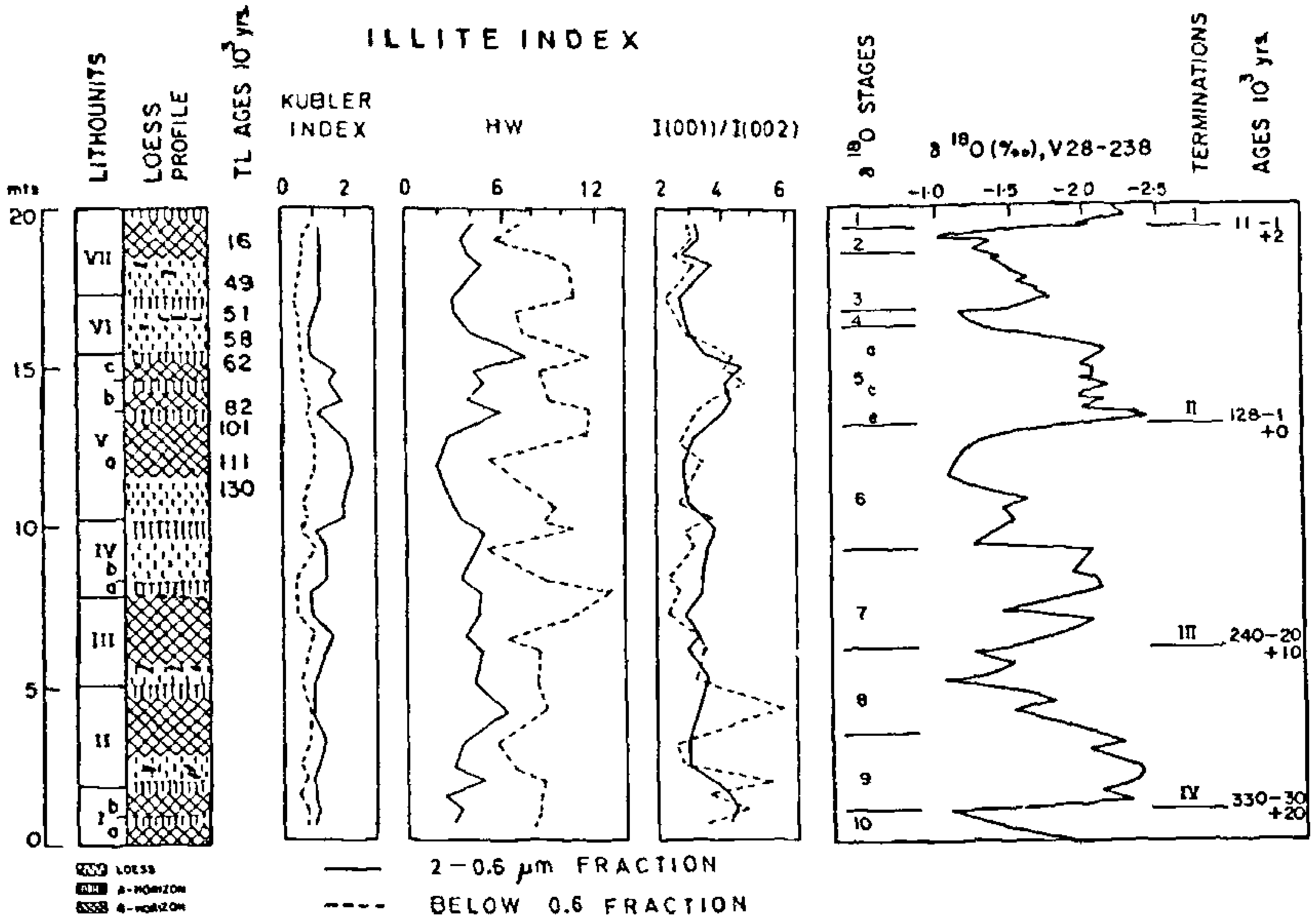

Figure 3. Loess profile in the Kashmir valley showing illite index and correlation with deep sea core V 28–238.

alluvial plains of the Indo-Gangetic Basin as the deposits have yielded pollens of the Himalayan pine. It has also been postulated that the Thar Desert contributed some dust. This is significant and implies that the processes, which were responsible for the desertification of western India, contributed equally to the deposition of loess in the northern and central India and Himalaya. Thus the Quaternary aridity had larger spatial manifestations.

Origin of Thar Desert

The aeolian activity capable of sand mobilization in the Thar or the Great Indian Desert is presently confined to the zone having a precipitation regime <250 mm yr^{-1} whereas the relict dunes extended into the zone which presently receives rainfall upto 900 mm (see ref. 24) (Figure 1). In the past the desert occupied nearly 320,000 km^2 between 24° N and 30° N latitude and 69° 30° E and 76° E longitude. The conditions leading to such dramatic changes in precipitation regime are complicated. However, it is obvious that the desert margins fluctuated in response to the variation in the behaviour of south-west monsoon during the Quaternary times.

The basinal configurations in the Thar evolved as a result of neotectonism, which also created conditions favourable for the abundant supply of sand from the defunct alluvia of the now vanished rivers of Himalayan origin and described in Vedas and mythologies[21–23]. Subsequent aeolian processes reworked alluvia to give rise to dunes over vast expanses, now known as the Thar dunefield. The source of sands is considered to be local as these contain the mineral derivatives of the surrounding rocks. This negates long-distance transport from the Saurashtra coast[24]. Rao *et al.*[25] have suggested that foraminifera derived from the coast were transported in suspension possibly by buoyant convection, but rule out the same source for the sands. The general succession comprises fluvial, fluvio-lacustrine and aeolian deposits, though there is variation in thickness from profile to profile[21].

Misra and Rajaguru[3] summarized palaeoclimatic history. Powerful but shallow braided streams draining the pediments deposited the large volumes of gravel. Ferricretization of the gravels took place under hot-humid climate during the late Tertiary. The braided streams continued to flow over the ferricretized surface. However, the stream system became weaker and the gravel beds were exposed to post-depositional diagenetic changes. The sediments were highly calcretized, and hardpans or petrocalcic carbonate developed under semi-arid climate during the early Pleistocene. Neotectonic movements affected the braided drainage and associated fluvial processes so that the gravel plain was converted into Jayal Gravel Ridge.

One of the very well-documented dune-cutting 16R at Didwana, District Nagaur in Rajasthan[3] (Figure-4) has been divided into three litho-units on the basis of colour, texture and occurrence of palaeosols and calcareous-bands (calcretes). The presence of calcareous bands, palaeosols and colluvial washes at varying depths indicate that the dune building activity was not a continual process, but was interrupted by several humid phases. The climate seems to have fluctuated through the time. The Units II and III show semi-arid and arid phases several times during late Middle Pleistocene to Upper Pleistocene (i.e. 170 ka – 26 ka), whereas the sands of Unit I represent essentially an arid climate between c. 20 ka and c. 13 ka[3,26]. On the basis of archaeological evidence, dune stratigraphy and thermoluminescence (TL) dates, it has been inferred that the dunes were accumulating since the last 20 ka[5]. This was the time when the drainage system in the Thar got disrupted, the shallow lakes became hypersaline and dune building activities became vigorous.

The Unit I of the dune cutting a 16R com-

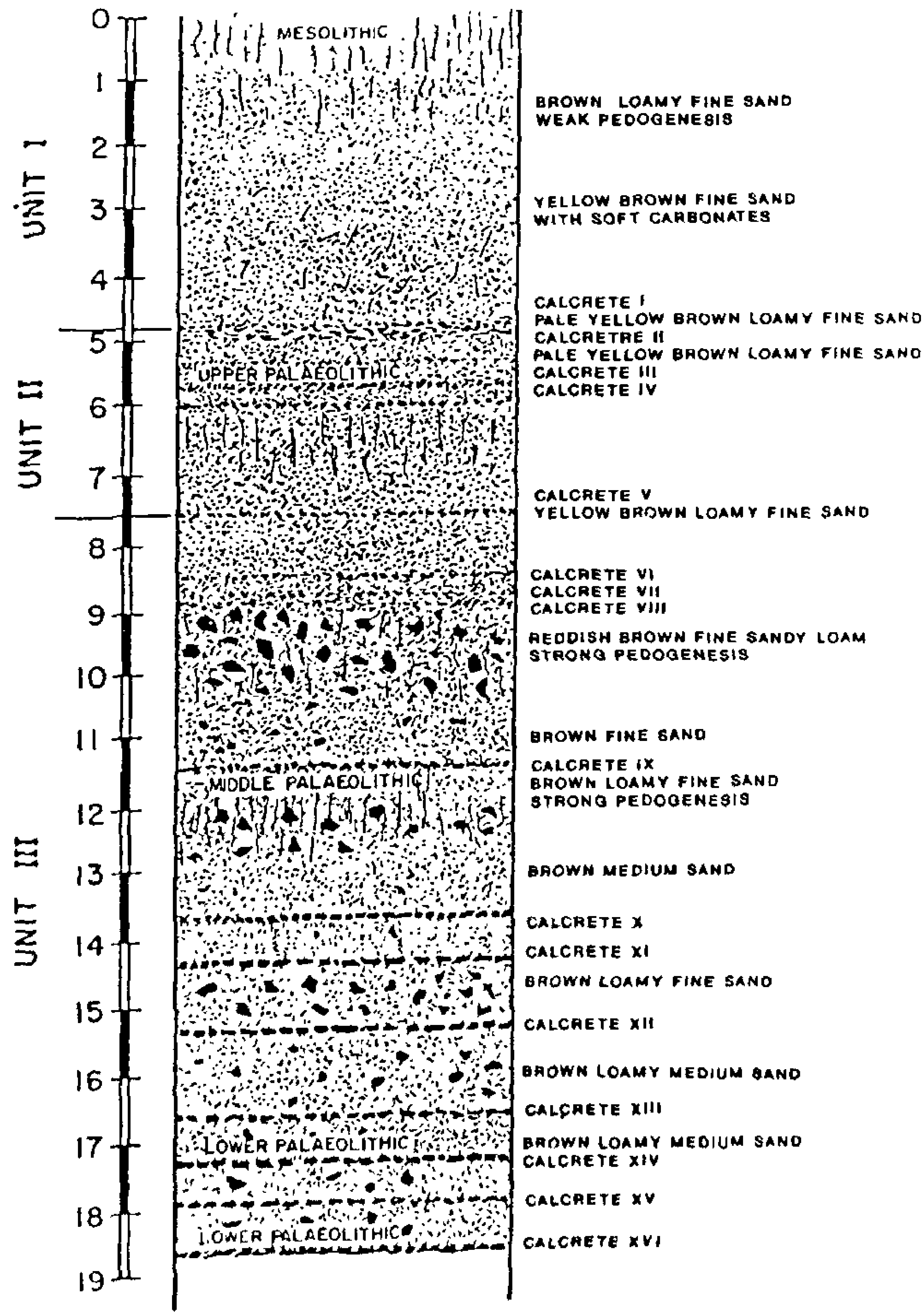

Figure 4. Cutting at 16R Dune, District Nagaur, Rajasthan. (After Misra and Rajaguru[3]).

pares well with the lithounit VII (Figure 3) of the Kashmir loess-palaeosol succession. Considering the number of calcareous bands and palaeosols exposed at the 16 R, one is inclined to believe that the record of aridity in Western India may be as old as that of Kashmir. The loess deposits in the Son, Belan and Mahi basins can be regarded as distal response to the climatic changes in the Thar.

Testimony of ocean sediments

The oxygen-isotope data from the Indian Ocean sediments indicate that the Asian summer monsoon was weaker during the Last Glacial Maximum (~18 ka)[27-30] but the winter monsoon was stronger than it is today[30]. The reversal of monsoon pattern has been attributed to the build-up of ice-cover over the Himalaya and the Tibetan plateau, which enhanced the land-sea temperature contrast in winter and reduced it during summer during the LGM[30]. On the basis of investigations on the Arabian sea cores it has been suggested that the winter monsoon was stronger upto 4 ka during the LGM between 20 ka and 16 ka[31], which is in conformity with the enhanced flux of aeolo-marine clay minerals between 15 ka and 27 ka[32]. However, a recent study shows that the last aeolian activity in the Thar post-dates the LGM and reached its peak by 14 ka on the basis of TL age estimate of sands from dunes and interdunal flats[33]. The fact remains that the northeast winds were strong during the LGM as evidenced by increased amount of quartz[34], dust plumes[32] and large flux of Asian pollen[27] into the Arabian Sea during the LGM. The salinity gradient in the Indian Ocean was much steeper during the LGM than today[30] which reflects a drastic reduction in fresh water input from the Himalayan rivers. This in turn may have exposed vast tracts of sparsely vegetated alluvia deflation by strong north-east winds, resulting in the formation of extensive loess deposits in most parts of north and central India, and the expansion of the desert[9]. The strong winter monsoon during the LGM may have had an amplifying effect on the Katabatic or gravity winds responsible for the loess deposition in the Kashmir valley and in other parts of the Himalaya. The age of the Kashmir loess-palaeosol succession (~350 ka) and the TL age of ~200 ka of the basal sands from the 16R profile at Didwana[35] further suggest climatic patterns in conformity with global Quaternary climates.

Records in lake deposits

The Holocene climatic history in the Thar is well documented in the lacustrine sediments[5,36]. The record of vegetational change enabled identification of five oscillations. Active dune development predates lacustrine conditions, with rainfall greater than at present between 10 ka and 6 ka. The wettest period was between 5 ka and 3 ka and dry conditions prevailed during the 3 ka–1 ka period. The alternating evaporite and non-evaporite succession of salt lakes imply fluctuating hydrology in response to climatic change[5]. This is in good concordance with the testimony of pollens[36]. The lake was hyper-saline prior to 12 ka, and fluctuated between hyper-saline and moderately fresh-water conditions between 12 ka and 6 ka. After 6 ka, fresh-water conditions gradually increased till the lake dried out around 4 ka. The lake survived after a short dry spell, and shallow water condition persists till today. Such a detailed account of climatic succession is not forthcoming from the Holocene soils of Kashmir, for the loess deposition apparently stopped with the onset of the Holocene.

Summary

The loess record of the Kashmir Basin conforms to the global climatic pattern upto 350 ka whereas the Great Indian Desert apparently dates back to 200 ka. The palaeoclimatic picture in the desert is far from clear, except for the Terminal Pleistocene and Holocene times. It has been suggested that the dune formation in the Thar has been going on for the last ~20 ka. This arid phase came to an end around ~6 ka, when high-lake level conditions prevailed until ~4 ka and the soils started forming. The evolution of the desert is a result of interaction between Quaternary neotectonism and climatic changes. The strong north-east monsoon conditions during the glacial times seem to have favoured the expansion of the desert and the deposition of the loess in most parts of north, central and west India.

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