Quaternary fluvial systems in Upland Maharashtra

S. N. Rajaguru, Vishwas S. Kale* and G. L. Badam

Department of Archaeology, Deccan College, Pune 411 006, India
*Department of Geography, University of Poona, Pune 411 007, India

Detailed geomorphic, stratigraphic and chronologic data reveal that major aggradational episodes in the Upland Maharashtra were associated with flow-regime changes. Four major alluvial formations and one colluvial formation reflect the spectrum of fluvial activity at different discharge stages of the Upland rivers during the Quaternary period. The alluvial sequences exhibit signatures of changing fluvial regime from meandering to non-meandering channels or from bed-load to suspended-load channels. The fluviatile evidence points to a synchronous pattern of depositional events associated with the Quaternary climatic changes for these geomorphologically stable channels, during the last 1.4 m.y.

Introduction

ARID and semi-arid regions of lower latitudes, have strong imprints of humid tropical climate of the Neogene. The Quaternary climatic changes in these areas, therefore, have superimposed certain geomorphic elements on relict landforms of the Neogene. Some of the index features of the Quaternary are documented for the correct evaluation of the fluvial processes, dominated by highly fluctuating discharge.

The measure of effectiveness of the geomorphic process is generally the sediment transport, for the transportation and deposition of sediments change the landscape drastically. Indeed the fluvial forms and processes are closely associated with the morphogenetic regions[1]. The fluvial systems in the semi-arid and arid areas are subject to wide fluctuations in discharges. Although river channels can be classified as meandering or non-meandering or bed-load or wash-load or mixed-load dominant[2], the nature of the semi-arid rivers is complex because the rivers are subject to marked fluctuations in water (Qw) and sediment (Qs) discharge[3–5]. The rivers are, thus, characterized by more compound channel configuration and load characteristics[6,7]. Nevertheless, owing to abrupt changes in the form and load characteristics of the rivers, the regime models developed for the perennial rivers of temperate regions cannot be applied to the semi-arid rivers.

The general predominance of coarse sediments in the semi-arid rivers is responsible for less stability and more mobility of sediments[7,8]. Such channels are, therefore, unstable and dynamic and are characterized by constant channel migration. Further, the semi-arid rivers respond fast to the changes in the hydraulic regime because of the high average rate of motion of coarse sediments. The cut-and-fill sequence in response to rapid changes in the regime leads to stratigraphic relationships characterized by erosional surfaces. Studies have shown that wet-dry environmental changes in the semi-arid areas have a noteworthy effect on the nature of sediments.

A two-stage analysis is presented here as part of a study of the semi-arid rivers of Western Upland Maharashtra. The main Quaternary formations are described according to their facies transition sequence, textural characteristics and age. An attempt has also been made to understand the relationship between lithological units and vertebrate fossils found within them. Depositional environment and the channel configuration have been deduced on the basis of the sedimentological characters of the fluvial deposits. A lithofacies classification similar to that developed by Miall[8,9], Markov chain analysis of successions[10] and architectural elements[11] have been adopted for the present purpose, of course with minor changes (Appendix I).

Major formations

The rivers (Figure 1) originating in the Western Ghat (750–1400 m ASL) flow through wide open valleys towards the drier east. The land is made up of Cretaceous–Eocene basalts of various types. Tertiary laterites and tephra of the early Pleistocene locally occur between the basalts and the mid-to-late Quaternary alluvial formations. There are two types of fluvial systems in the Upland region: (i) The rivers such as Krishna, Godavari and Bhima have their sources in the high-rainfall Ghat zone, and (ii) rivers such as Manjra, Sina, Karha and Man have their sources in the semi-arid tract. Consequently the hydromorphic characteristics of the two drainage systems are different.

Examination of bore-hole data collected by the Groundwater Department and the Irrigation Department of Maharashtra reveals that the total thickness of the Quaternary alluvial and colluvial deposits is less than 50 m and rarely exceeds a few kilometres laterally

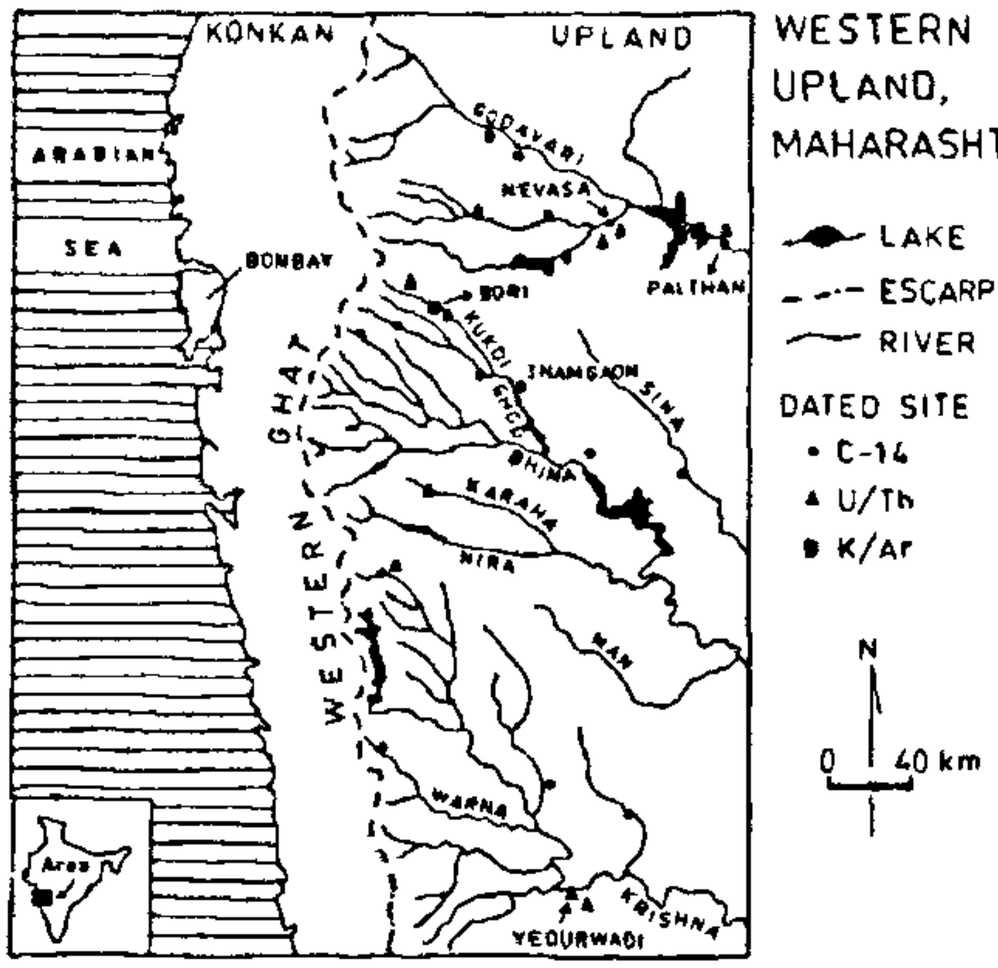

Figure 1. Location of the study area. The map also shows the location of dated sites and some of the important Quaternary sites.

on either bank of any river. The thickness of the exposed alluvium generally varies from 10 to 20 m. The lateral extent of the Quaternary deposits increases to about 10 to 16 km where colluvial deposits intergrade with the alluvial deposits, as is the case with the Upper Pravara Valley near Sangamner and Akola.

The Quaternary deposits in Upland Maharashtra are thin as compared to those of the Extra-Peninsular India. However, this is the only region in India where about 100 absolute dates have been obtained in the context of archaeological and palaeontological materials recovered from the alluvial deposits. Although alluvial formations have been recognized for the Upland rivers[12,13], the earlier interpretations need revision in the light of new U/Th and K/Ar dates together with archaeological and faunal evidence.

The fluvial deposits can be divided into the ones deposited in either channel or overbank environments or those deposited in the foothill zones. The present reconstruction is based on detailed geomorphological, sedimentological and geoarchaeological studies. About two dozen C-14 dates, several U/Th dates and relative dates based on fluorine-phosphate ratio are now available for reconstructing the chronology of the fluvial sediments.

There are five major Quaternary formations* in the Western Upland Maharashtra as follows: Bori formation (BRF), Godavari formation (GDF), Upper Bhima formation (UBF), Post-black soil formation (PBF) and Chandanapuri formation (CPF).

*The term formation is not used here according to strict definition of International Stratigraphic Code. These are essentially different litho units associated with certain fluvial processes and flow power.

Bori formation (BRF)

This formation (with a maximum thickness of about 2–8 m) represents mainly the high-sinuosity lithofacies sequence (element OF) in the Kukdi Valley near Bori. Sediments are fine-textured, dark blackish brown silty-clays (Fm). Bedding is poor but the deposits are massive, with thin and discontinuous lenses of pebbly gravel. A subangular pebbly gravel (<1 m thick) occurs at the base of the Bori formation and rests unconformably over the Deccan Traps. The deposits are associated with thick (ca 1–1.5 m) volcanic ash. The tephra has been dated by K-Ar at 1.4 m.y.[14], which suggests that the sequence is of early Pleistocene period.

The oldest known palaeo-channel (>1.4 m.y.) associated with this formation has been reported from Bori[5]. The palaeo-channel is very narrow (17–24 m) and more sinuous (>1.5) than the modern channel of the Kukdi (w = 150 m & P = ca 1.3). It suggests a low-energy environment (low gradient) and a very different hydraulic regime than from the present[5], as evident from thick clay and ash deposits. The general absence of thick gravel deposits and dominance of fines at the base is characteristic of tropical sub-humid rivers. Preliminary geochronological studies indicate that the volcanic ash associated with the dark brownish silty clays is about 1.3 m.y. (personal comm. Dr. B. L. K. Somayajulu). At Morgoan in the Karha Valley, V. S. Kale and D. N. Patil discovered volcanic ash in dark brownish silty clays.

Godavari formation (GDF)

This 2–3 m thick formation consisting of entirely coarse-grained deposits in the Upper Godavari Valley (Figure 2), unconformably rests on a rocky bench 3–20 m above the present bed of the river. The sequence comprises rounded to sub-rounded pebbles and cobbles of basalt, chalcedony, agate, chert and quartz set in a matrix of granular sand and silt showing cross-bedding and local inverse grading.

The deposits are complex in nature and might have resulted from vertical stacking and amalgamation of a number of low-sinuosity (non-meandering) channels dominated by facies Gm. The characteristics suggest a braided system of low-sinuosity channels[13]. The high proportion of cobbles indicates high-energy river, with wide shallow channel and prevalent bedload transport.

A few stone artefacts have been recovered in the older gravel beds in the Godavari Valley near Paithan. A U/Th series date of the cementing material in a sandstone facies of the reworked gravel-bed indicates an age of about 1,45,000, yr[15] BP.

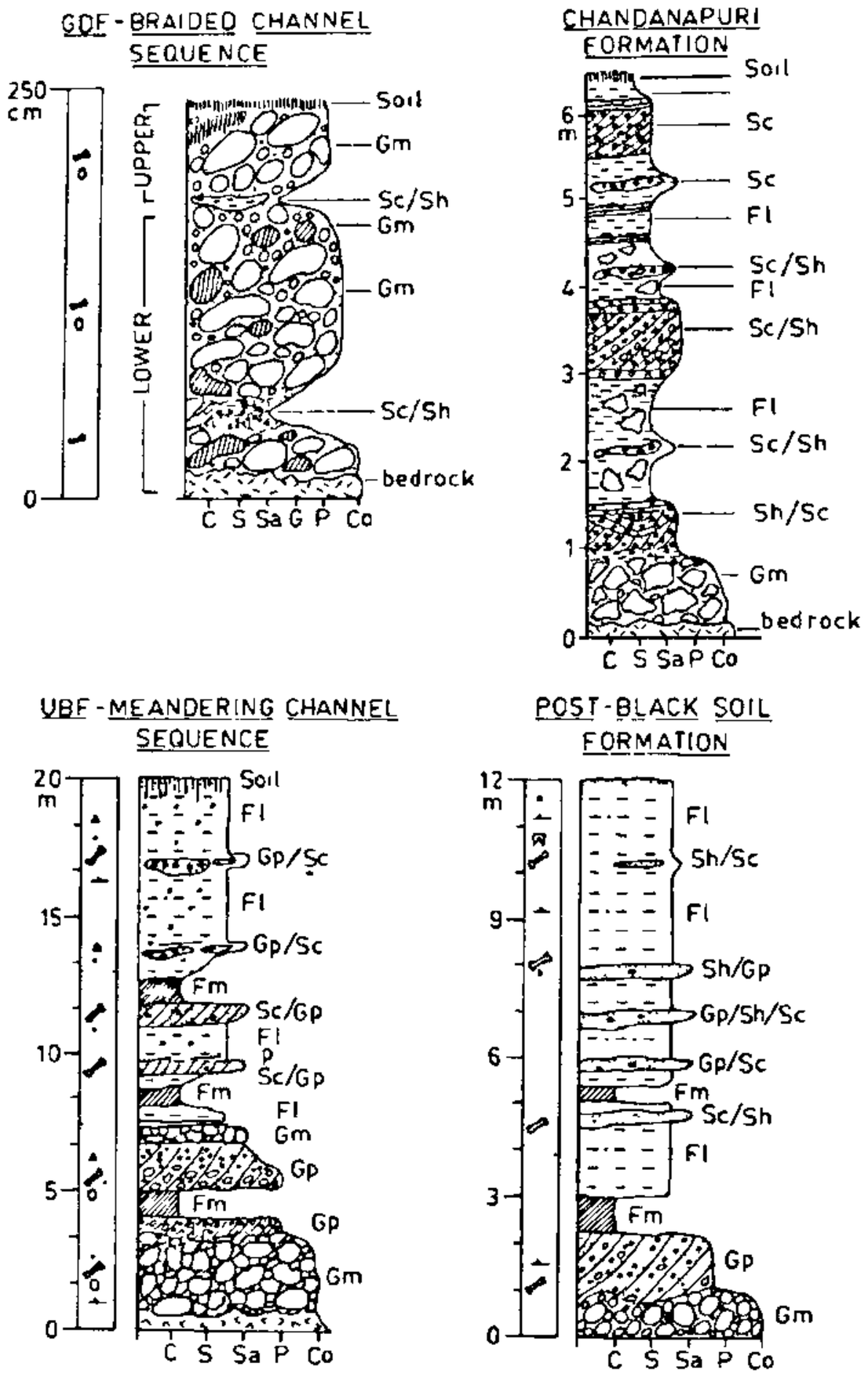

Figure 2. Composite lithosequence of Quaternary formations.

Upper Bhima formation (UBF)

This is the ubiquitous Pleistocene formation in the Godavari, Bhima and Krishna valleys. About 5 to 30 m thick in the study area, it can be separated into two major members (Figure 2)[12,13]: The lower succession, consisting of pebbles and cobbles with high proportion of sandy matrix, comprises vertically stacked and laterally adjacent channel deposits (Gp, Gm), upto 2 m thick, and at places with erosional bases and containing trough shaped as well as tabular cross-strata. Fossils of *Equus*, *Elephas* and *Bos* are frequently found and fossil wood has only been reported at Chirki in the Pravara Valley[16–18]. The frequently occurring fossils in the lower member of UBF are *Bos namadicus*, *Equus namadicus*, *Hexaprotodon* spp., *Stegodon insignis ganesa*, *Elephas (Palaeoloxodon) namadicus*, *Elephas* sp. and Chelonia[16–18]. The U/Th dates of indurated sandstones from Nevasa, Bori and Yedurwadi have given ages between 30 and >350 ka[15]. The upper succession is, made up of predominantly yellow-brown bedded sandy silt (10 YR 5/4, 10 YR 7/4), with discontinuous 50 cm thick lenses of sand (Sc/Sh), mud (Fm), planar cross-stratified sandy-pebbly gravel (Gp) occurring within it. Nodular and bedded calcrete (P) is common. The member has yielded Upper Palaeolithic and Epi-palaeolithic stone artefacts and fossilized animal bones, shells and driftwood. About a dozen C-14 dates of shells and bones indicate that the member is of Terminal Pleistocene period (10–17 Ka)[12].

The fine sediments of the UBF have yielded fossils of *Bubalus palaeindicus*, *Bos namadicus*, *Leptobos* sp., *Bubalus* sp., *Elephas hysudricus*, *Canis* sp., *Sus* sp., *Hexaprotodon* sp., *Cervus unicolor*, *Cervus duvauceli*, *Axis axis*, *Antilope cervicapra*, *Crocodylus* sp., *Trionyx* sp., *Unio*, *Cerithium*[16–18], in addition to pollen grains of *Acacia*, *Eugenia* and *Holoptelea*[16–18].

Markov chain analysis of the UBF reveals an upward fining sequence. Two types of non-random fining upward sequences are observed (Figure 3): Massive cobbly-pebbly gravel to gravel (planar cross-stratified); and gravel (planar cross-stratified) to sand-silt-mud.

The nature of sediments and sedimentary structures in the coarser sandy facies of the UBF are similar to those observed in the modern point-bar deposits[13]. There is therefore little doubt that these deposits are like the point-bar deposits currently being built in incised channels and represent deposits laid down by a river in a degradational phase. This in turn implies that the morphological and hydrological conditions during the mid Pleistocene were similar to those observed today, in terms of kind if not in degree.

The upper fine member attains a thickness in excess of 3 m and covers a greater area than any of the channel facies. These deposits represent overbank deposition associated with high floods[19] and suggest low lateral confinement and a decrease in the stream power.

Geomorphic evidence suggests that the climate was dry during that period[12] (end of Pleistocene). The transition from Fm and S to Gp (coarsening upward) during the terminal Pleistocene[12] suggests a hydraulic differentiation of the system into distinct energy levels, coarser ones related to high and violent floods and finer ones recording medium discharge regimes. This differentiation may, therefore, reflect the spectrum of processes active at different discharge (sediment and water) stages of the rivers in the arid climate, with high floods associated with storms.

Palaeontological studies have helped in establishing local depositional features. At Dhanegaon, in the Manjra Valley, two species of elephants, viz., *Stegodon insignis ganesa* and *Elephas hysudricus* were predominant in the clayey deposits, which represent ox-bow lake sediments[18–20]. Evidence for perennial deep pools was found at Tadula in Manjra Valley, at Inamgaon in

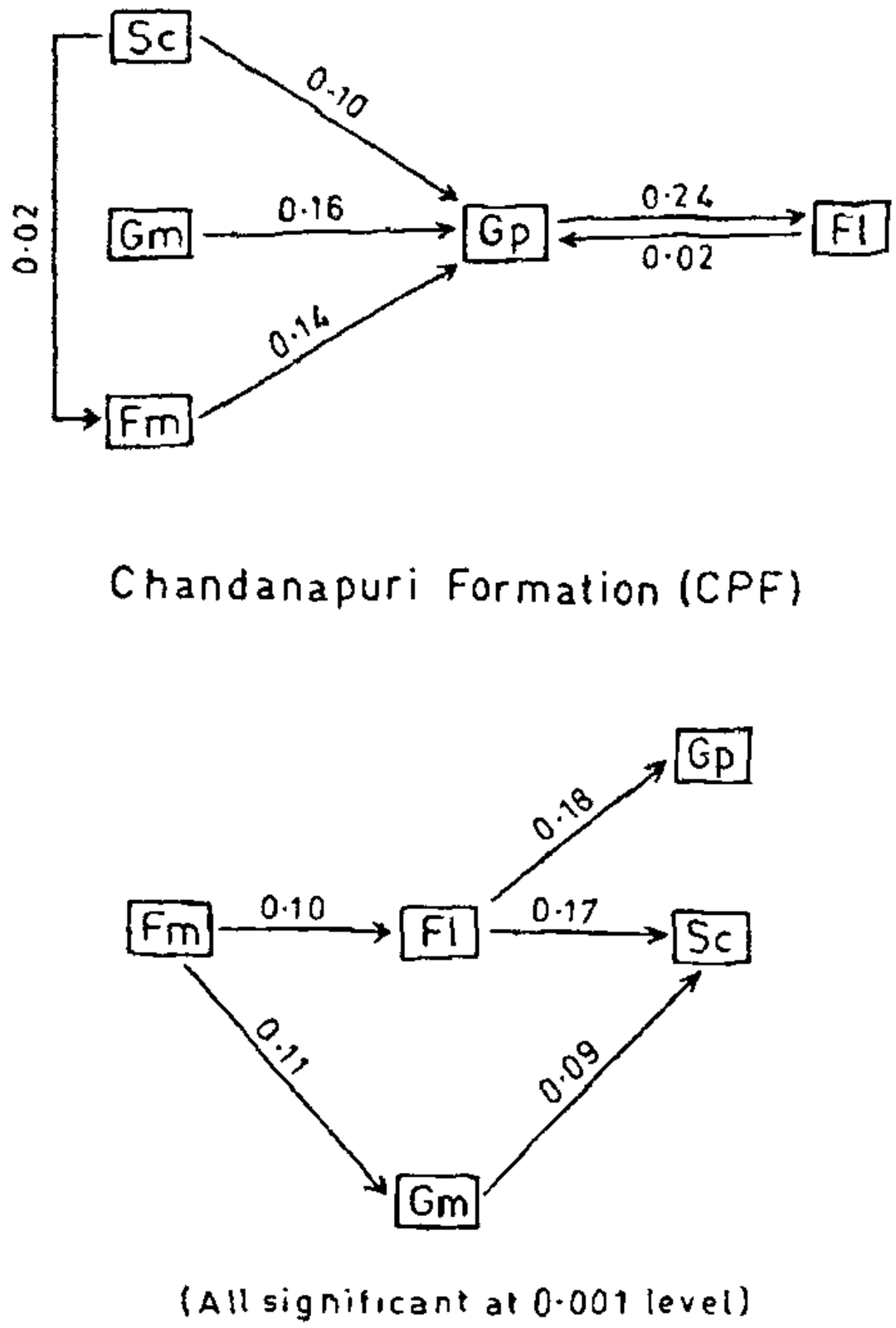

Figure 3. Facies transition sequence for UBF and CPF, based on Markov Chain Analysis.

Ghod Valley, at Yedurwadi in Krishna Valley and at Bori in Kukdi Valley. Fossils of turtles, crocodiles, hippopotamus, elephants, etc. have been discovered along the margins of such pools. Similar fossil sites have been reported from Sina and Hunsgi-Baichbal[21] Valleys in Maharashtra and Karnataka, respectively.

Post-black soil formation (PBF)

This lithologic unit, comprises overbank deposits laid down subsequent to a period of stream entrenchment. The sediments are fine-textured, non-calcareous massive dark brown (7.5 YR 4/2) sandy-silts, with gravelly lenses at the base[12,13]. The contacts between the basal gravel and upper sandy-silts vary from disconformable to fining-upward gradational interfaces. The upper part of the formation reveals fine alterations between sands and silts and represents over-bank accretion. Markov chain analysis of the PBF (Figure 2) reveals a complex inter-relationship between the various depositional environments. Two principal transition paths are: Upward fining—from gravel (Gm) to sandy-silt (F1) and Upward coarsening—from sandy-silt (F1) to sand.

The PBF has yielded bones, wood, charcoal, shells and artefacts ranging in age from mid to late Holocene (4.5 ka onward)[12].

Chandanapuri formation (CPF)

The formation represents mainly colluvial deposits in the foothill zone of the valleys[13], having a maximum thickness of about 6 m. The unit comprises pale yellow-brown sandy carlcareous silts interlensed with silty sand and pebbly-sandy gravel. The basal part contains angular, unweathered rubble of basalt and tufa (20–30 ka)[15]. U/Th dates of the kankar nodules (75–14 ka)[15] occurring in the deposits, suggest that the sediments were laid down sometime during the late Pleistocene.

Trough cross-bedded gravels, represent channel-fills. These are commonly overlain or underlain by facies Gm or Gt. Markov chain analysis of the transitional sequence reveals a general upward coarsening sequence. Three types of non-random transitions are observed in this formation: a) sandy-silt (F1) to sand (S); b) sandy-silt (F1) to gravel (Gc); c) silty-clay (Fm) to gravel (Gm) or to sandy-silt (F1) (Figure 3).

The sequence does not fine upward and hence does not follow the established channel-fill model but represents deposits formed by gravity flows and sheet-floods (element SG). These characteristics suggest deposition of the coarse fraction by sheet-wash or debris-flow mechanism, with intermittent contribution from ephemeral gullies and streams. Intense precipitation associated with storms and reduction of vegetation density must have favoured the deposition of such sediments in the foothill zone, under dry climatic conditions[22].

Palaeofluvial environments

The fining-upward PBF and the UBF conform to the channel-fill model. Nevertheless, the occurrence of coarser facies in the upper part of the UBF indicates an increase in critical shear stress and stream power and thus reflects an abrupt change in the discharge and competence.

Mud is a major characteristic of the BRF. One would expect the clay to result from overbank floods in a system controlled by low-gradient and high-sinuosity meandering stream. However, the GDF in Godavari

indicates relatively high-energy streams, with prevalent bedload transport[13].

The general consistency of the mid-to-late Quaternary formations over a large part of the Upland Maharashtra suggests that palaeoclimate was the regional control rather than tectonic or baselevel control. The correlation between the climatic changes of the Quaternary and the changes in the fluvial regime indicates that the periods of river metamorphosis and major climatic changes were generally synchronous[12,13]. The transitional sequence in the case of UBF and PBF records a condition of decreasing fluvial energy resulting from decreasing pluvial activity. The UBF and CPF contain features indicative of periodic stage fluctuations, primarily associated with intense monsoon storms. Mud and fine sand beds and lenses associated with coarse member of UBF may be the result of settling of fine sediments during the waning flood stage.

Fossil evidences indicate that the distribution of animals during the Pleistocene was controlled by local ecological factors. The geomorphic situations and the fossils of ungulates (equids, bovids, cervids etc.), turtles, crocodiles, hippopotamus and elephants suggest that during mid to late Pleistocene the Upland valleys (including rivers like Manjra) had a relatively good vegetation cover, probably a mixture of grasslands interspersed with deciduous and bushy trees and also a distinct zone of galleria forest, with several deep water pools.

Conclusions

The main characteristics of the Quaternary deposits are as follows:

(a) The deposits are less than 30 m thick, and range in age from <10 ka to >1.4 Ma, with significant changes in the channel types, and several unrecognizable missing events.

(b) Due to the allochthonous and seasonal nature of the rivers, contribution from tributaries had considerably affected the process–morphology relationship in the parent streams[4].

(c) The radiometric dates and their stratigraphic position indicate that the net erosion in the valleys has been practically zero and the landscape was fairly stable[15].

(d) Climatic control is quite evident. Phases of erosion were linked to warm and wet periods, while the episodes of deposition were associated with cold and dry phases[12,15].

(e) The absolute dates also suggest that the Quaternary sediments having apparently similar textures, structures, geomorphic location and archaeological and palaeontological contents, may belong to different time stratigraphic units[23].

Appendix 1

Lithofacies classification (mainly after Miall[9])

Facies code	Lithofacies
Gm	Massive or crudely bedded gravel
Gp	Gravel stratified planer crossbeds
Gt	Gravel stratified trough cross-bedded
Sh	Sand very fine to very coarse, may be pebbly horizontal lamination
Sc	Sand very fine to very coarse, may be pebbly cross-bedded
Fl	Sand, silt, mud fine lamination
Fm	Mud-silt massive with desiccation cracks
P	Carbonates

Architectural elements in fluvial deposits (Miall[11])

Symbol	Elements
CH	Channels
LA	Lateral accretion deposits
OF	Overbank fines
SG	Sediment gravity flows

1. Stoddart, D. R., in *Water, Earth and Man* (ed. Chorely, R. J.), Methuen, London, 1969, p. 43.
2. Schumm, S. A., *The Fluvial Systems*, John Wiley, New York, 1977.
3. Baker, V. R., Kochel, R. C. and Patton, P. C. (eds.), *Flood Geomorphology*, John Wiley, New York, 1988.
4. Kale, V. S., *Geomorphology*, 1990, **3**, 31–43.
5. Kale, V. S., *Mem. Geol. Soc. India*, 1990, **18**, 95–104.
6. Richards, K., *Rivers: Forms and Processes in Alluvial Channels*, Methuen, London, 1982.
7. Graf, W. L., *Earth Surf. Processes Landforms*, 1983, **8**, 125–139.
8. Miall, A. D., *Earth Sci. Rev.*, 1977, **13**, 1–62.
9. Miall, A. D., in *Fluvial Sedimentology* (ed Miall, A. D.), Can. Soc. Petrol. Geol. Mem., 1978, vol. 5, pp. 597–604.
10. Miall, A. D., *Sedimentology*, 1973, **20**, 347–364.
11. Miall, A. D., *Earth. Sci. Rev.*, 1985, **22**, 261–308.
12. Kale, V. S. and Rajaguru, S. N., *Nature*, 1987, **325**, 612–614.
13. Kale, V. S., in *Geomorphology and Environment* (eds. Singh, S. and Tiwari, R. C.), Allahabad Geographical Soc., Allahabad, 1989, vol. 1, pp. 171–202.
14. Korisettar, R., Mishra, S., Rajaguru, S. N., Gogte, V. D., Ganjoo, R. K., Venkatesan, T. R., Tandon, S. K., Somayajulu, B. L. K. and Kale, V. S., *Curr. Sci.*, 1989, **58**, 564–567.
15. Atkinson, T. C., Rowe, P. J., Kale, V. S. and Pawar, N. J., *Timescale of Landscape Development in the Deccan Plateau, India*, 1990, Unpub. Project sub. Natural Environmental Research Council, Swindon, UK.
16. Corvinus, G., *Curr. Anthropol.*, 1971, **12**, 383.
17. Badam, G. L., Working Document of Thematic Workshop, 1991, New Delhi, pp. 59–60.
18. Badam, G. L., in *The Evolution of East Asian Environment* (ed. Whyte, R. D.), Centre of Asian Studies, University of Hong Kong, 1984, vol. 2, pp. 746–775

19 Mujumdar, G G., Rajaguru, S. N. and Pappu, R. S., *Bull. D. C. R. I.*, 1969, 29, 118-134.

20 Sathe, V. G., Unpublished Ph D Thesis, Poona University, 1991.

21. Szabao, B J. MicKinney, C., Dalbey, T. and Paddayya, K., *Bull. D. C. R. I.*, 1990, 50, 317–321.

22. Watson, A., Price, W. D., Goudie, A. S., *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1984, 45, 225-249.

23. Kale, V. S., Pawar, N. J. and Rajaguru, S. N., *Bull. D. C. R. I.*, 1990, 49, 175–182.

ACKNOWLEDGEMENTS. We are grateful to Ms Veena Joshi for providing the sediment-sequence data of the colluvial sediments and to Dr Vijay Sathe for help in various ways. SNR thanks DST for financial assistance for carrying out fieldwork and laboratory studies between 1987 and 1990.