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Late quaternary palaeoclimates of western India : A geoarchaeological approach

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सार - पश्चिमी भारत के अंतर्गत राजस्थान, गुजरात और महाराष्ट्र राज्यों के भाग आते हैं। यह क्षेत्र विभिन्न प्रकार की जलवायु और धरातल वाला है। उत्तरी पश्चिमी राजस्थान का भाग रेत के टीलों, पोखरों और पत्थर वाले पहाड़ों से युक्त आंतरिक अपवाह प्रणाली वाला क्षेत्र है इस क्षेत्र के दक्षिणी भाग की लूनी, साबरमती और माही नदियों के बेसिनों में वातोढ़ और नदीय दोनों प्रकार की प्रक्रियाओं के लक्षण मिलते हैं। नर्मदा, ताप्ती, गोदावरी तथा भीमा के बेसिनों में वातोढ़ स्थल रूपों का अभाव है तथा जलवायु की अपरदन क्रिया के प्रभाव के कारण नदीय भूआकृतियों परिवर्तित होती रहती है। इस समूचे क्षेत्र में पूरे चतुर्थ महाकल्प में अर्द्धशुष्क से शुष्क जलवायु की प्रधानता से इस बात का पता चलता है कि चतुर्थ महाकल्प में भूआकृतिक प्रक्रिया की गति मंद रही जिसके फलस्वरूप, वर्तमान धरातल रूपों में तृतीय युग की बहुत सी विशेषताएं सुरक्षित रह सकी हैं। धरातल बनाने वाली भूआकृतिक प्रक्रियाओं की भिन्नता तथा भूआकृतिक प्रक्रियाओं और जलवायु के मध्य प्रगाढ़ संबंधों से यह पता चलता है कि पश्चिमी भारत की पुराजलवायवी के विषय में हमारी जानकारी अधूरी है। मूलतः राजस्थान और महाराष्ट्र के लेखकों के हाल ही के लेखों के आधार पर पश्चिमी भारत की उत्तर चतुर्थ महाकल्प की पुराजलवायवी के विषय में इस शोध पत्र में संक्षेप में जानकारी दी गई है। यहाँ पर भूवैज्ञानिक अभिलेख की पुराजलवायवी व्याख्या से संबंधित कुछ मामलों की चर्चा की गई है। विभिन्न प्रकार के धरातल रूपों में पुरातन बंजरपन प्लीस्टोसीन होलोसीन संक्रमण अवधि के दौरान जलवायु में होने वाले परिवर्तन, पुरातन होलोसीन आर्द्र जलवायु और मध्य काल में बंजरपन में हुई वृद्धि के लक्षण, विविध रूपों में दृष्टिगोचर होते हैं।

ABSTRACT. Western India comprises parts of the states of Rajasthan, Gujarat and Maharashtra. This region has varied climate and landscape. Northwestern Rajasthan is an area of internal drainage, with dunes, playas and rocky pediments. The Luni, Sabarmati and Mahi basins to the south of this zone show the influence of both aeolian and fluvial processes. Aeolian landforms are absent in the Narmada, Tapi, Godavari and Bhima basins and fluvial aggradation has alternated with erosion in response to climatic change. Dominance of semi-arid to arid climate throughout the Quaternary in the entire region has meant that Quaternary geological processes have been weak, preserving many features of the Tertiary in the present landscape. The variation in the geomorphic processes shaping the landscape and the complex links between geomorphic processes and climate mean that our understanding of palaeoclimates in western India is far from complete. This paper gives an overview of the Late Quaternary palaeoclimate of western India, based primarily on recent work by the authors in Rajasthan and Maharashtra. Some issues in the palaeoclimatic interpretation of the geological record are discussed. Signatures of Late Pleistocene aridity, fluctuating climate during the Pleistocene Holocene transitional period, early Holocene humid climate and increased aridity from the middle Holocene onwards are reflected in different ways in the different landscape settings.

Key words – Late quaternary palaeoclimates, Western India, Geoarchology.

1. Introduction

It is well established that the Quaternary was a period of frequent, rapid and dramatic environmental changes. In any study of the Quaternary, palaeoclimate is a major theme. This is in contrast to other geological periods when climate was less variable and where longer time spans are considered. Most geological studies therefore give pre-eminence to tectonic forces in shaping the landscape. In India, geologists studying the Quaternary, also have a tendency to emphase the role of tectonics over climatic change in explaining the geological record. However, this role has probably been over stressed at the expense of the palaeoclimatic factors, partly due to a failure to recognise relict Tertiary features in the landscape. While tectonics is the dominant factor over long timespans, it is less important over the short time considered here, where climatic change is pre-eminent (Mishra *et al.* 1999c).

Western Rajasthan, Gujarat and western Maharashtra comprise a large area with a diversity of landforms. A common factor is the dry climate (arid, semi - arid and dry sub - humid) in most of the region. In western Rajasthan, the degree of aridity increases from east to west and from south to north. Gujarat forms the margin of this semi-arid to arid zone. In western Maharastra, on the other hand the aridity increases from west to east with the western ghats forming a humid catchment for the Godavari and Bhima drainages. The Narmada and Tapi rivers which flow from east to west also originate in the humid areas of central India. Thus while the Luni-Mahi-Sabarmati basins have virtually no catchment from the humid zones, the Narmada, Tapi, Godavari and Bhima do. The two regions have contrasting responses to Late Quaternary climatic change due to the differing geological terrains and the influence of humid catchment in Narmada, Tapi, Godavari and Bhima basins. The differing climatic records of the two regions therefore in combination give a more complete record of Late Quaternary climatic change.

2. Relict features of western India

One of the common features of all the regions of western India is the "relict" nature of much of the landscape. This has resulted from the long-term semi-aridity of the region dating back to atleast the Late Tertiary period. The Indian continent has been drifting northwards since the break-up of the Gondwana supercontinent and after passing through the equatorial belt, during which period, it experienced a humid equatorial climate, it has been entering into more arid climatic zones. In addition, there has been a global trend towards aridity, especially during the last 5 million years. The rates of weathering and denudation were much higher during the period of humid climate in the Early Tertiary and the present day landscape retains the imprint of these relict processes due to the inability of present day processes to modify the landscape on a large scale.

Thus, the rocky upland of western Rajasthan or of the Thar desert seems to have been affected by tectonics/uplift and the developement of grabens in which surficial fluvial deposits upto 300 m thickness have been deposited during the Late Tertiary/Early Quaternary (Neogene).

Western Rajasthan and Gujarat are regions where ancient rocks are exposed over a large area. Rocky uplands alternate with basins. (Wadhawan and Sural 1992, Wadhawan and Kumar 1996, Wadhawan 1990). The age of the rocks forming the uplands decreases from east to west and the elevation of the basins reduces in the same direction. In western Rajasthan three rocky uplands - the Aravallis, the Jodhpur-Nagaur plateau and the Jaisalmer plateau have been identified. Five basins separated by these plateaus have also been identified. These five basins are the coastal dunefield of southern Kachchh , the Phalsund-Shergard-Phalodi area, Merta-Degana-Sanju tract and the Shahgarh-Kishangarh tract. This classification can be extended to Gujarat with the Saurashtra and Kutch Peninsulas forming prominent uplands and the north Gujarat plains an additional basin.

The rocky uplands of Aravallis, Jodhpur Nagaur plateau, Jaisalmer plateau and Saurashtra plateau, being areas subjected to processes of denudation over a long time do not provide a good record of Late Quaternary climatic change. Nevertheless, there are a few interesting observations to be made. The first is that the nature of the regolith appears to be different in different upland zones. While the Nagaur Jodhpur plateau has massive calcrete development (Dhir 1995), the Jaisalmer plateau preserves ferricrete crusts, some of which have been also calcretized (Achyuthan 1999). These differences could be due to differing climatic zones, different parent materials and different lengths of time. Some evidence for the weathering processes undergoing changes with the changing Quaternary climate is provided by surface archaeological material. This could be seen in the different weathering of artefacts of different ages on the surface reported by Deotare *et al.* (1998) from a rocky pediment surrounding the Bap-Malar playa. Although the artefacts are few, after assigning them to different groups based on their manufacturing technology, it was seen that these different groups had different surface modifications. The handaxe (Lower Palaeolithic) showed a lustrous desert varnish, while the scrappers and flakes from multi-directional cores (Middle Palaeolithic) showed wind abrasion and the flakes from single platform cores (Mesolithic) were unmodified. While the Lower Palaeolithic artefact, which might pre-date the last interglacial had the desert varnish the Middle Palaeolithic artefacts which pre-date the Last Glacial Maximum showed the imprint of Last Glacial Maximum wind abrasion and the probably post LGM artefacts were remarkably unmodified.

The Quaternary fluvial, aeolian and playa records of western Rajasthan and Gujarat are confined to the "basin" areas. In all basins 100's of metres of sediment underlie the dunes, playas and rivers. These sediments are predominately fluvial and have been mostly taken to belong to the Quaternary. However, inspite of abundant indicators of semi-arid climate in the form of calcrete development, poor sorting *etc.* all workers have noted the contrast with the present day processes. Shridhar *et al.*(1994;1996) have labelled these deposits in northern Gujarat as "Super Fluvial" and have noted that the present day Sabarmati and Mahi rivers are not related to them. Sareen *et al.* (1993) also note the different characters of these gravels with the present Sabarmati.

Wasson *et al.* (1983) also note the presence of fluvial sands/gravels beneath the sand dunes throughout the Thar desert. Tiwari and Ramachandran (1995) have assigned an Early to Pre-Quaternary age to these units in the Luni valley and Gangadhar and Tiwari (1995) to the Jayal gravels near Didwana. Wadhwan (1999) has suggested that all the basins in the region have similar such anomalous units and noted that stratigraphically they are post Eocene and pre-Late Pleistocene in age. He also notes that they represent a radically different environment from that of the present. The presence of these units is however one reason for a persistent idea that the desert environment in the Thar is recent.

3. Dunes

The Thar desert, in western Rajasthan has an extensive aeolian cover (Dhir *et al.* 1992). Most of the dunefields occur in the "basin" areas of the desert. There are a number of dune forms (Verstappan 1970, Wassan *et al.*1984, Wadhawan and Kumar 1996, Raghav and Sinha 1999). The forms of the dunes depend on the supply of sand, vegetational cover and amount and direction of the wind. Verstappan (1970) was one of the first to map the dune types in the Thar desert. Goudie *et al.* (1973) and Allchin *et al.* (1978), in their study of the Thar desert, interpreted the presence of dunes as indicators of past aridity. Using the assumption that formation of dunes indicates the absence of vegetation, Goudie *et al.* (1973) argued for a shift of the 200 mm rainfall isohyet from its present position west of Jaisalmer to the region of Ahmedabad and Baroda. The presence of foraminifera in the dune sands in the heart of the desert region was attributed to transport from the coast many hundreds of kilometres away (Sperling and Goudie 1975). Wasson *et al.* (1983) however argued that dune accumulation did not necessarily imply the absence of vegetation. Ash and Wasson (1983) had shown that dunes could form with a vegetational cover of upto 30% given sufficient sand supply and wind speeds. Large areas of the Thar desert are covered by parabolic and irregular dunes, which form in the presence of vegetation. Little movement of the dunes could be seen as the dunes are confined to areas of sedimentary rocks or fluvial sediments, which provide a supply of sand to the dunes. Local mineralogy of the dune sands also argue against long distance transport of the dune sand. A local source for the foraminifera was suggested given the fresh appearance and large size of some of the specimens observed by Wasson *et al.* 1983.

The most important new methodological development in the study of desert dunefields of the world is the development of optical dating techniques, which can date the depositional time for the dune sand (Thomas 1999, Singhvi *et al.*, 1982).

It was widely assumed, prior to the dating of the dunes that the peak of dune mobilisation occurred during the peak periods of aridity. Chawla *et al.* (1992) however, concluded, after dating a number of dunes in the Thar desert that the mobilisation of dunes did not co-incide with the LGM, but with the re-establishment of the monsoon wind system around 14 kyr. Wasson *et al.* 1983 showed that dune accumulation of a few metres occurred along with pedogenesis and human occupation of the dunes at Langhnaj, Bagor and Tilwara during the most humid phase of the Holocene between 4-8 kyr. Andrews *et al.* (1997) dated an aeolian sequence with colluvial intercalcations at Shergarh and concluded that a phase of less arid climate existed between 60-30 kyr, based on the isotopic compositions of the calcretes in the colluvial layers. Relatively arid phases are identified at 69 and 33 kyr. At Puskar aeolian episodes are centred at 25 kyr and 11-14 kyr (Dhir *et al.*, 1994).

The longest aeolian record has been obtained by a 20 m excavation of the 16 R sand dune near Didwana. Here archaeological horizons are associated with periods of dune stability when sheetwash/pedogenesis occured. Dating of these horizons was attempted by Th/U and C14 on the carbonates and TL of the sand. Uncorrected Th/U dates from the calcretes and one TL date from the aeolian sand are reported by Raghvan *et al.* 1989. This shows that a prominent pedogenic horizon associated with Middle Palaeolithic artefacts dates to the last interglacial. The lower part of the dune is beyond the range of Th/U dating (>400 kyr).

Raghav (1992), Raghav and Sinha (1998) and Wadhawan and Kumar (1996) identify three major aeolian episodes based on mapping dunes from satellite imagery and field checks by the Geological Survey of India. While the oldest of the dunes belong to the Late Pleistocene the youngest are actively forming, showing that there are a number of aeolian episodes within the Holocene. Kar *et al.* (1998) have shown that the dune surfaces were stable at 2000 and 6-700 bp, with the major phase of dune building during the 11-14 kyr period. Thomas *et al.* (1999) have presented some evidence for a phase of aeolian activity during the post Harappan period. At Manawara, on the Luni river near Balotra, Mishra *et al.* (1999a) have studied an early Holocene palaeochannel of the Luni which was occupied by Late Harappan pastoralists around 3.4 kyr. This shows that upto 3.4 kyr the palaeochannel remained free of any aeolian cover. The palaeochannel and archaeological material was covered by a sand dune sometime between 3.4 to 2.8 kyr. This dune was only stripped of during the catastrophic Luni flood of 1979.

The major findings of the studies of aeolian landforms in the Thar desert and its margins can be summarised as follows:-

(*i*) Aeolian activity can be dated beyond 100 kyr by luminescence dating techniques. Additional evidence for long term semi-arid to arid climate is found in the well developed calcrete regoliths in some of the upland areas.

(*ii*) Early correlation of the peak of aridity with the peak of dune accumulation has been shown to be erroneous. Present data suggests that the last major phase of dune accumulation was between 14-11 kyr. A number of earlier episodes of dune stability and accumulation have been dated from a few localities.

(*iii*) Within the Holocene a phase of dune re-activation in the post Harappan period and of landscape stability at 2,000 and 700 bp have been identified from a few localities. Sand accumulation continued with moderate intensity along with pedogenesis and human occupation of dunes during the most humid period of the Holocene at some localities.

4. Playa studies

Studies of the playas in the desert were initiated earlier as the earlier availability of radiocarbon dating made it feasible to develop a chronology for the playas. Singh's (Singh *et al.* 1972, 1974) work in the 70's made a very big impact and continues to dominate the interpretation of the playas to date. In this early work, three lakes of Didwana, Lunkarensar and Sambhar were studied. This work showed that these lakes filled with water at the beginning of the Holocene, based on dates of about 9.2 kyr from the base of the lakes at Lunkarensar and Didwana. A number of vegetational changes were reconstructed based on the studies of pollen from the lake sediments, and this was used by Bryson and Swain (1981) to suggest that the rainfall was upto three times more than that at the present during the most humid phase. These lakes dried up around 3 kyr. It is also suggested that charcoal and large cereal pollen found in the lake sediments from about 8 kyr suggests the presence of agriculture in the area surrounding the lakes and that the humid phase coincides with the Harappan civilization.

The new studies of the Didwana lake yielded a record stretching back to the Late Pleistocene and also revised the date for the lake drying from 3 - 4 kyr, making the drying of the lake prior to the Harappan civilization (Wasson *et al.*, 1984, Singh *et al.*, 1990). A halite layer with thin clay laminae was found to underlie the laminated silty clays, which represent the main phase of lake filling. The base of the laminated clay gives radiocarbon date of 12,820+370-350 bp (PRL 650). Below the halite layer is a silty fine sand containing 50% chemical precipitates. This represents a moderately shallow saline lake and must date to the late Pleistocene based on the date of the overlying layers. Singh *et al.*(1990) identifies six pollen zones. From 22 to 13 kyr the lake was hypersaline and the surrounding area had a steppe vegetation, with sand dune vegetation and salt tolerant grasses among the species identified. From 12.8 to 9.3 kyr a short grass vegetation existed. The third pollen zone sees a rise in the local swamp vegetation at the expense of the regional pollen, which Singh interprets as a consequence of a rise in water level and increase in freshwater. The fourth pollen zone dating between 7.5 to 6.2 kyr is the most humid in the sequence with species present from the present sub-humid zone. The fifth pollen zone indicated a falling and shallowing of the lake and the top part of the lake did not preserve pollen. Wasson *et al.* 1984 also note fluctuating lake levels early in the lake sequence with the most humid phase of the lake directly preceding the drying of the lake at 4 kyr.

More recently a sedimentological study of Lunkarensar has been made by Enzel *et al.* (1999). This study shows that the most humid phase of the lake was from 6.3-4.8 kyr when it is probable that winter rainfall contributed to the lake. The drying at 4.8 kyr was abrupt and preceded the Harappan culture. Deotare *et al.* (1997, 1998) provide interesting palaeoclimatic and archaeological data from the shallow playa at Bap-Malar in the arid core of the desert in Jodhpur district. Their studies show that the playa existed even during the LGM, and had a short (~1000 years) perennial phase during 8 kyr -7 kyr and dried around 5.5 -6.0 kyr, almost 1.5 kyr earliler than the playas on the eastern margin of the Thar. Like Lunkaransar, Bap-Malar playas also show increased winter rains during the Early Holocene. Microlithic cultures flourished on the surrounding stable dunes around 7 kyr. In the Late Holocene (~1.5 kyr) the playa was flooded by ephemeral streams for a short period and agro-pastoral communities camped in the braided channels of these ephemeral streams. Rai (1990) has studied the playa near Pokaran.

5. Fluvial studies

5.1. *Luni-Sabarmati-Mahi rivers*

The Luni, Sabarmati and Mahi rivers along with a few other minor rivers such as the Rupen, Banas and Saraswati drain the north Gujarat plain and the adjoining southwestern parts of Rajasthan. These rivers, have very little catchment in the humid zone. Nevertheless huge thicknesses of alluvial sediments are found in all the basins. Shridhar *et al.* (1994; 1996) have argued that these huge piles of sediments are unrelated to the present day drainages and belong to a more dynamic "super-fluvial" systems. The exposed sequence of the different river basins have a number of similarities as pointed out by Chamyal and Merh (1993). More recently Tandon *et al.* (1999) have made a number of basin wide correlation between the three river basins. The earliest units are mottled clays which recently have been conclusively shown to be of marine origin by Raj *et al.* (1998). A series of coarse cemented gravels are found at the base of the section. These have been labeled as "Waghpur formation" by Sareen and Tandon (1995). A prominent rubified horizon in many of the sections has been proposed as a marker horizon, first correlated to the last interglacial by Chamyal and Merh (1992) but now, on the basis of some luminescence dates to 50-30 kyr (Tandon *et al.* 1999). Above the rubified horizon, aeolian and fluvio-aeolian units are found. Recent work by Malik *et al.* 1999 and Khadikikar *et al.* 1996 have tried to place more emphasis on the palaeoclimatic aspects of the sequence.

Interpreting this sequence in terms of climate is problematic in the absence of good dating control. The enormous thickness and extent of the fluvial sequences and their mismatch with present processes places a doubt as to the Quaternary age of the sequence. Lower Palaeolithic artefacts have been found in some of the localities on the Sabarmati which shows a Quaternary age. However many of the classic localities, such as Mahudi have never yielded artefacts while nearby localities such as Pitambli have yielded them in abundance. Distinguishing between a Quaternary gravel derived from local reworking of a Pre-Quaternary gravel could be difficult. However it is the presence of artefacts in part of the sequence which probably led to the assumption of a Quaternary age inspite of the other anomalous features noticed by most of the present workers.

Recent work on the Luni between Bhuka and Sindari has resulted in the identification of three units labeled as type I, type II and type III sequences (Jain *et al.* 1999, Tandon *et al.* 1999) The type I sequence is of the relict type and beyond the range of dating by luminescence techniques. It does not contain artefacts. The type II sequence shows many features of ephemeral arid zone fluvial systems and could be dated to about 80 kyr, indicating an older Quaternary fluvial system. It is not necessary that all the type II units belong to the same fluvial phase and dating is so far available from only one locality (Karna). Artefacts, although undiagnostic do occur in some of these units. The most prominent unit is a well preserved Early Holocene palaeochannel (type III sequence), probably reflecting the enhanced fluvial processes during the period of re-establishment of the monsoon between 14-8 kyr (Mishra *et al.* 1999 a).

5.2. *Narmada-Tapi-Godavari-Bhima Basins*

The Narmada, Tapi, Godavari and Bhima basins only partly come in "Western India." The lower parts of the west flowing Narmada and Tapi rivers and the upper parts of the east flowing Godavari and Bhima basins are included here in the discussion. These rivers have a number of significant contrasts to the basins of western Rajasthan and Gujarat. The first is the bedrock which is almost entirely Deccan Trap basalt which is the youngest major geological unit in the Indian sub-continent. The second is that all the rivers have a source region which is humid, providing a more regular discharge to the rivers. Sea level change would have had an important impact on the Mahi, Sabarmati and Luni, as well as Narmada and Tapi rivers, while the Godavari and Bhima rivers are far from the sea. While in the Mahi, Sabarmati and Luni basins, large areas are covered with alluvial sediments, in this region, bedrock is exposed in most of the landscape, with alluvial sediments occupying a very narrow area close to the present day perennial drainage. The thickness of the alluvium is also typically 15-20 m with greater thickness only in a few structural basins.

Mishra *et al.* 1998b suggest that while the rivers having a catchment from the humid zone responded to aridity by aggradation, the rivers without a humid zone catchment aggraded in response to relatively humid climate. The sediments deposited during periods of aridity are dominantly sandy silts with small gravels lenses 14-30 cm thick and having lateral extent of 5-15 m. These gravels are made up of granule sized material, with transported calcrete nodules and local basalts being the main components. Bivalves shells found in these gravels are unabraded and usually in the growth position. Ostrich eggshells and microliths are found in many of these gravels, often showing little or no abrasion. The sediments deposited during the humid periods on the other hand are floodplain type fining upward sequences with rare gravels. Prior to 25 kyr dating methodologies are not available which allow correlation between different localities. A major phase of arid climate occurred during the Late Pleistocene between 25 -14 kyr, when rivers having catchment from humid zones aggradated. This phase is prominently seen in the Narmada, Bhima and upper catchment of the Godavari basins. Shortly after 14 kyr a major phase of incision is seen at a number of localities. The period between 14-8 kyr was one of fluctuating climate with records from a number of semi-arid zone tributaries. A record spanning this period is found on the Sindhphana at Shakshal Pimpri. Between 8-

TABLE 1

Radiocarbon dates from Western India

Site Name	River	Material	Lab No.	Date
Mehtakheri	Narmada	Bivalve shells	A 6518	30,680+1040/- 920
Nandur/Madhmeshwar	Godavari	Bivalve shells	Bs 163	27,435
Morgaon	Karha	Bivalve shells	Bs 1230	26,370±710
Patne	Ad nala	Ostrich eggshell	GRN 7200	25,000±200
Dharampuri	Narmada	Bivalve shells	BS 286	25,160±850
Bhedaghat	Narmada	Bivalve shells	A 6619	25,160±550
Sangamner	Pravara	Bivalve shells	BS 78	25,390±710
Morgaon	Karha	Ostrich Eggshell	A 8846	22,485+320-310
Kalas	Pravara	Bivalve shells	BS 1260	22,090±430
Shirdhan	Krishna	Bivalve shells	BS 661	21,780±460
Inamgaon	Ghod	Bivalve shells	TF1177	21,110+615-5702
Sangamner WW	Pravara	Bivalve shells	BS 1258	19,420±410
Inamgaon	Ghod	Bivalve shells	TF 1177	19,290±360
Paithan	Godavari	Bivalve shells	TF 891	17,075±660
Nevasa	Pravara	Bivalve shells	BS 575	16,420±420
Khapardkhera	Narmada	Charcoal	A 9446	15,680+440-415
Sangamner	Pravara	Bivalve shells	PRL 470	14,840±350
Sakshal Pimpri	Sindhphana	Bivalves and gastropods	AA 2174	14,200±90
Chandoli	Ghod	Bivalve shells	BS 1227	13,510±200
Nevasa	Pravara	Bivalve shells	BS 576	13,220±190
Sashtewadi	Mulamutha	Bivalve shells	BS 1226	13,020±190
Sangamner	Pravara	Bivalve shells	PRL 470	12,890±350
Inamgaon	Ghod	Bivalve shells	BS 146	12,040±150
Talegaon	Vel	Bivalve shells	BS 1228	9,420±90
Talegaon	Vel	Gastropod shells	BS-1427	10,390± 130
Talegaon	Vel	Gastropod shells	BS-1428	6,930±120
Ranjegaon	Sindphana	Bivalve shells	BS 1256	7,800±130
Sakshal Pimpri	Sindhpana	Bivalve shells	BS 1259	7,800±130
Apegaon 6	Godavari	Charcoal	A 7638	6,600±1001
Apegaon3	Godavari	Charcoal	A 7637	6,280+210-205
Apegaon2	Godavari	Charcoal	A 7636	4,250±95
Manawara	Luni	Gastropods	BS 1412	6,520 ±150
Lohida	Luni	Gastropods	BS 1419	6,900±120

4 kyr a major period of flood plain aggradation is seen on the Godavari river, while on the Bhima river this was a period of erosion. Agricultural settlements are first documented after 4 kyr when the climate has already taken a turn towards aridity. During the last 4 kyr a number of minor aggradational and erosional events are documented from some localities.

5.3. *Late Pleistocene aridity (~25 kyr to 14 kyr)*

The Narmada river has extensive evidence for this phase. The present Narmada channel is bordered by a few kilometre wide zone of alluvium which is dissected by flood erosion. This alluvium belongs primarily to the Late Pleistocene. Detailed lithologs of this Late Pleistocene alluvium at Bhedaghat (Mishra and Rajaguru 1989), Mehtakheri, Nawarkheda and Khapadkhera allow us to reconstruct the Late Pleistocene fluvial regime. Radiocarbon dates range from 30-15 kyr for this aggradational phase (see table 1, dates from Bhedaghat, Dharampuri, Mehtakheri and Khaparkheda) have been made. Our studies of this Late Pleistocene alluvium allow us to reconstruct some features of the Narmada fluvial regime during that period. While the present Narmada is flood dominated river, with a straight channel transporting pebble and cobble sized bedload, the Late Pleistocene Narmada was a floodplain river with a primarily suspension load material. Gravelly facies are extremely rare in this time period and the entire sequence is dominated with fine sand and silt grade material. Fining upward sequences, minor calcrete horizons, small fine sand channels and occasional aeolian reworking of the alluvium are seen in the sections documented in detail.

In the Godavari basin, this phase is represented by the Nandur Madhemeshwar locality (Kumar 1985, Joshi and Sali 1971) where the base of the section has been dated to 26 kyr, and Kalas and Sangamner on the Pravara river (Mishra *et al.* 1998b). At Sangamner town an extensive gravel is exposed on the surface. This gravel has developed a soil by the process of aeolian dust accumulation. Shells in this gravel date of 19 kyr. This gravel rests on brown fissure clays. Earlier, a thin gravel sandwitched between clays was dated to 14.6 kyr from another locality near the town of Sangamner. At Kalas, on the Pravara, some 10 km upstream, field leveling exposed a shell bed within clayey sediments. This shell bed was accumulated by humans with many of the shells being broken and charred. Microliths and burned mud were associated with the shell bed. One shell had been shaped into a disc. These shells were dated to 22 kyr. At Nevasa shells from an extensive silty fill with gravels lenses containing microliths was dated to 16.4 kyr. The Pravara river, therefore like the Narmada has an extensive late Pleistocene aggradational phase bracketed between 25-14 kyr.

On the Ghod river a gravel within a silty fill at Chandoli was dated to 19 kyr. At Inamgaon, also on the Ghod river, a second microlithic site was dated to 21 kyr.

The widespread nature of this aggradational phase is attested to not only from the dated sites but the numerous additional localities where sediments of the same type associated with Upper Palaeolithic artefacts are found.

5.4. *Pleistocene Holocene Transitional period (14 kyr to 8 kyr)*

One of the most important findings of our work over the last few years was the dating of the beginning of the incisional phase to around 14 kyr. At Chandoli, Nevasa, and Sashtewadi gravels having an unconformable relationship to the underlying alluvial deposits, and without any associated silty sediments were dated to between 13-13.5 kyr. These gravel are about half to one metre in thickness. The gravel components are of small pebble grade and are have a higher proportion of well rounded basalt pebbles compared to the gravels found in the alluvium of the earlier phase. Bivalve shells in all the three gravels are single abraded valves in contrast to the unabraded shells found in growth position in the earlier gravels. The artefacts also show signs of abrasion, unlike those found in the earlier gravels. All these features support the hypothesis that these gravels were deposited as a response to high discharges rather than over supply of sediment. We have argued (Mishra *et al.* 1998a) that these gravels mark the initiation of the incisional phase which would co-incide with a rapid period of global warming documented from the ice and ocean cores. In the Narmada river the latest date for the Late Pleistocene alluvium of 15.6 kyr from an archaeological horizon covered by 7 m of alluvium and a soil >2 m thick could also imply that the end phase of the aggradation in the Narmada occured close to the same time. This also matches with the 14 kyr dating of the major dune building phase in the Thar desert found by Chawla *et al.* (1992). Our geoarchaeological studies of the Narmada (Mishra *et al.* 1999b) showed that the major phase of incision and gullying on the Narmada occured prior to the Chalcolithic period at 4 kyr. While the Narmada incisional phase is so far only constrained between the dates of 15.6 and 4 kyr, this is consistent with the more precise dating from western Maharashtra. The period between 14 to 8 kyr was one of rapid and frequent changes in global climate. In this period a number of tributaries on the Bhima show short periods of minor aggradation, such as at Talegaon and Inamgaon. At Shakshal Pimpri, on the Sindhphana, a tributary of the Godavari which originates near the arid

TABLE 2

Phases of Quaternary climatic change in Western India

	Period	Thar	Luni-Mahi-Sabarmati	Narmada-Tapi-Godavari-Bhima	Palaeoclimatic Inference
1	Neogene (Reliect features)	Hundereds of metres of gravels filling grabens, gravels with inverted relief. Calcretized and Ferricretized regolith.	"Super-Fluvial" systems represented by hundereds of metres of fluvial sediments filling grabens	Dedunational surfaces, high level gravels, weathered regolith and anomalous fills in source regions of major rivers.	Climate was more humid than today. Tectonic forces are a factor in the formation of these units.
2.	Pre Late Quaternary	Dune and playa facies are known which pre-date the Late Quaternary but absolute dating is so far scanty	Gravels containing Palaeolithic artefacts in the Sabarmati and Type II sequence from the Luni.	Many alluvial fills with Acheulian artefacts.	These units primarily reflect Quaternary climatic change, which could be either relatively humid or arid
3.	~50-30 kyr	Shergarh Trijunction shows evidence for reduced aridity	A "red soil" horizon has been identitifed and correlated from the three basins	Not well documented due to lack of dating inputs, but many aggradational records begin close to 25-30 kyr, implying incision in this period.	Relatively humid phase
4.	~25 kyr to 14 kyr	Dune system is relatively inactive, some playa show ephemeral shallow phases			Major phase of Late Pleistocene aridity
5.	14 kyr	Both dune and playa systems become active with re-establishement of monsoon	Major phase of Luni activity near Balotra begins at 14 kyr	A major change in fluvial behaviour documented from Bhima, Godavari and Narmada systems	14 kyr appears to be a very significant period for a rapid transition from glacial to post-glacial climate
6.	14-8 kyr	11-14 kyr is the major phase of dune building, while lake levels fluctuated from 14 to 8 kyr	The major activity of the Luni 14 to 11 kyr on the basis of luminessence dating	Short aggradational phases from Bhima tributaries. Major aggradational phase on Sindhphana. Major incisional phase of Narmada, Bhima.	A period of rapid and frequent climate changes
7.	8-4 kyr	Major phase of lake filling. Pedogenesis of dunes.	Gastropod date from Early Holocene Luni gravels near Balotra	Floodplain developement on Godavari seen at Nevasa, Dharangaon and Apegaon	Most humid phase of the Holocene, increasing aridity after 4 kyr when lakes dry in Rajasthan
8.	2.7-3 kyr "Dark Age"	Reduced number of settlements, wiht some being covered sand during this period	Chalcolithic site covered with sand at Manawara on the Luni	Little geological data. A reduced number of human settlements	The archaeological data does document a period of reduced settlements but the links with climate are controversial. More independant geological data needed.
9.	1.9- 2.2 kyr "Roman Optimum"	Dune stability	No data	Increased floods on Narmada and flood damage to settlements	Archaeologically a period with more settlements and some evidence for good rainfall from palaeoflood studies
10.	0.7 kyr "Mediavel Warm Period"	Dune stability	No data	Increased floods on the Narmada	A period of increased numbers of settlements. Evidence for dune stability and larger floods, indicates "good" monsoon
11.	.3 kyr "Little Ice Age"	Scanty data	Scanty data	Reduced floods on Narmada, aggradation in Godavari and Bhima rivers	Only palaeoflood data so far documents this phase.
12.	20th century little data	Flood of 1979 on Luni probably the largest in the last 4 kyr	Increased flood frequency on Tapi and Narmada	The present century shows increased floods on all the rivers studied, probably due to global warming.	

Ahmednagar plateau, a gravel from the base of an alluvial fill has been dated to 14.2 kyr while an archaeological horizon from the top of this terrace dates to 7.8 kyr. This terminal date was also found at a second site, Ranjegaon, on the Sindhphana for a similar context. The Sindphana therefore had a major active phase during the Pleistocene Holocene transitional period.

5.5. *Early Holocene Humid period (8 kyr to 4 kyr)*

A number of localities on the Godavari river have been dated to this period in the last 5 years. At Apegoan, close to Sakshal Pimpri but on the Godavari river alluvium below the Chalcolithic mound was found to have a number of hearths. The dates from the lowest hearth was 6.6 kyr while from the top it was 4.2 kyr. As the alluvium continues below the dated horizon, the aggradational phase may extend to close to 8 kyr. The alluvium is a simple fining upward sequence with sandy facies at the base and clay facies at the top. A similar fill with numerous hearths was found at Dharangaon near Kopargaon some 20 km upstream of Apegaon. Here the lowest hearth could be dated to around 7 kyr. This phase of aggradation which is conspicous in the Godavari basin is less so in the Bhima basin where incisional mode appears to have continued. A few of the tributaries of the Bhima, however such as the Vel at Talegaon and the Nandi at Akoni have alluvial fills dating to this period.

The few sites so far identified for this period have abundant evidence of human activity. However so far the earliest agriculture dates not from this period but after 4 kyr when the climate had already become more arid. This holds true for the Thar desert also where although occupation of sand dunes by microlith using people is well documented, the first settlements are only identified from the period after the lakes have already dried up.

6. Late Holocene climatic changes

After 4 kyr the climate has fluctuated on a lesser scale. Some evidence has been found for a period of increased aridity at the end of the Harappan in Gujarat and Rajasthan and end of Chalcolithic in Maharashtra. Thomas *et al*. (1999) found a sand dune advanced over a Harappan settlement in northern Rajasthan, while Mishra *et al*. (1999 a) found a sand dune covering a late Harappan occupation of a gravel surface. The archaeologically documented break in the human settlements has also been used as evidence for environmental deterioration. A period of increased floods on the Narmada has been documented both by palaeoflood studies (Kale *et al.* 1997) and flood damage to settlements (Mishra *et al*. 1999b). Kar *et al.* (1998) find this period to be one of dune stability. The period between 400-900 A.D. is a second period of reduced settlements in western and northern India. The palaeoflood record from Sakarghat on the Narmada shows this to be a period of reduced large floods on the Narmada. An alluvial fill which post dates the early historical occupation at Navdatoli on the Narmada might also relate to this more arid phase (Mishra *et al.* 1999b). The medieval period (1000-1200 AD) again shows frequent large floods in the Narmada palaeoflood record while dune stability is found in Rajasthan by Kar *et al.* 1998. Ely *et al.* 1996 show an absence of large floods in the Narmada during the little ice age period with the recent floods being some of the largest in the last 4 kyr. This is also implied by the evidence from Manawara referred to earlier. Minor alluvial fills and channel shifting have been seen at a number of places in western Maharashtra, such as Songaon on the Karha river, Talegaon on the Vel river, Navgaon on the Virabhadra. Damori on a small tributary of the Godavari near Kopargaon and Nevasa on the Pravara. These changes might relate to Little Ice Age aridity or could be normal changes in the river processes.

7. Discussion

The diverse geological processes and varied response of these processes to climatic change give us richer reconstruction of Late Quaternary Palaeoclimates. The most interesting result of this review which compares the recent work mainly in the Thar and western Maharashtra is that inspite of the diversity of the geomorphic response to climatic change, the timing and nature of the climatic changes synchronise well given the limitations of the data. Thus a major phase of Late Pleistocene aridity is documented in different ways in the dune, playa and fluvial records between ~ 25 kyr+ to 14 kyr. Similarly, close to 14 kyr the processes in the dune, playa and fluvial systems undergo a dramatic shift. A major phase of dune mobilisation is seen in the Thar desert, while the playa lake phase begins. An incisional phase in the major fluvial systems such as Narmada and Bhima begins while the ephemeral fluvial systems such as the Luni in western Rajasthan and the Sindhphana in western Maharashtra have a major aggradational phase. The period 14-8 kyr is one of fluctuating lake levels, and short aggradational and erosional episodes in the fluvial environment. The most humid phase of the Holocene is between 8-4 kyr when most of the playas were full. The Godavari experienced floodplain development, while the Bhima and Narmada remained mostly in an incisional mode. Evidence supporting a relatively arid phase at 800-1200 BC, relatively humid phases during the Early Historic and Medieval periods has been reported, but is still scattered and scanty. Palaeoflood studies strongly support enhanced frequency of large floods during the 20th century (Table 2).

Arid and semi-arid climate in western India dates back to pre-quaternary times. This is documented in the massive hardpan and lithic calcretes seen in some of the upland areas. Association of Lower Palaeolithic industries with dune and playa facies at Didwana also shows the desert climate dating well into the Middle Pleistocene. Widespread fluvial sediments post-dating the local bedrock, found in the basin areas of the desert give an impression of a young age for the desert. However, an earlier date for these units may be considered. Many features of the landscape are relict due to the inability of weak arid zone processes to modify the effects of earlier dynamic humid systems.

In understanding the complex and variable response of all the geological processes to climate, absolute dating techniques remain essential. Progress in our understanding has depended on the development and application of dating methodologies, whether radiocarbon, luminescence or Thorium/ Uranium techniques.

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