J. Ind. Geophys. Union (Jan. 2004)
Vol.8, No.1, pp.15-25

Late Quaternary geomorphology, palynology and magnetic susceptibility of playas in western margin of the Indian Thar Desert

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ABSTRACT
Multidisciplinary studies of Bap-Malar and Kanod playas in the arid western margin of the Thar desert have been carried out to understand past climate changes in this region. These studies are well supported by AMS ^{14}C dates and archaeological material preserved on dunes and pediments surrounding the playas. Present investigations show that the playas originated during the Last Glacial Maximum (>15 ka) and survived with fluctuating hydrology till 5 ka. The lake full stage is suggested by rarity of gypsum, increased proportion of paramagnetic minerals and relative increase in organic material in playa sediments. On the other hand, predominance of gypsum, decrease in paramagnetic minerals and organic material indicate ephemeral stage of these playas. Though lake full stage was between 8 ka and 6 ka, these playas remained brackish to saline throughout their existence. Biomass was predominantly C4 type and overall vegetation was grass dominated. Peak of aridity affected human life in the area, as indicated by rarity of upper Palaeolithic sites. On the other hand, there is prolific development of human occupation during the Mesolithic cultural stage between 8 ka and 6 ka when the climate was relatively wet. Even after drying of playas around 5 ka, pastoral human activity continued in the Thar till about 1.5 ka in favourable ecological niches in otherwise water starved western margin of the Thar.

INTRODUCTION

In the last two decades considerable progress has been made in palaeomonsoon studies in the Indian sub-continent. Micropalaeontological studies, well supported by absolute dates on marine cores in northwestern part of Arabian sea, geological and palynological studies of lake sediments in the Himalayas and in Nilgiri highlands of southern peninsular India have brought out interesting new data. These high-resolution investigations have produced centennial scale palaeomonsoon results (Sirocko et al. 1993, Sarkar et al. 2000, Gupta et al. 2003, Kale et al. 2003). Briefly, the summer monsoon shows high variability in its strength and also demonstrates cyclicity of 700 yrs in both wet and dry phases, which are part of global geophysical and climatic factors. It appears that the summer monsoon was extremely weak around 20 ka, moderate to weak between 3-2 ka and between 1300-1870 AD. Both summer as well as winter monsoon was strong during 8 ka and 5 ka. The summer monsoon was by and large moderate to weak during the last 5000 yrs while the winter monsoon was insignificant. Reasons for such a change during the Late Holocene[1] needs further detailed investigations on the local as well as regional and global scales.

The Thar desert (69° to 73° E and 25° to 28° N) is the most populated desert of the world. It is an easternmost extension of mid-latitude desert belts of Africa and western Asia. It primarily receives 90 % of its annual rainfall from southwest summer monsoons and is by and large semi-arid to arid (100 to 500 mm range). Contribution from northwesterly winds for winter rains is little less than 10%. Evapotranspiration is around 2000 mm/annum and wind activity is strong between May and June, with wind speed reaching 25-30 km/hr. Droughts are frequent due to high variability of rainfall.

1 The Holocene period is not well defined in India and there is considerable ambiguity in the stratigraphic sub-division of the same due to lack of precise chronology. We have followed stratigraphic sub-division suggested by Wayne and B'elcher (2000) for Pakistan. The Early Holocene covers 10 ka to 7 ka, the Early middle Holocene lies between 7 ka and 5 ka, Middle Holocene ranges from 5 ka – 3 ka and the late Holocene begins around 3 ka BP.

Hard rocks of Proterozoic age dominate the eastern side of the Thar, while the Permo-Carboniferous and Jurassic sediments dominate in the western part. Tertiary sediments rich in bentonetic clay and lignite occur as pockets in southern and northern part of the Thar. Morphologically, pediments, inselbergs and unintegrated low order bedrock channels carrying water discharge only for a few days during exceptionally strong intensity rains of the SW monsoons are seen. Overall drainage is autochthonous except that of the river Luni in the southern part of Rajasthan.

Quaternary alluvial and aeolian deposits covering the pediplained rocky landscape of western Thar are up to 300 m thick in structurally formed basins. Exposures of Quaternary deposits are not more than 30 m deep, usually of 5 to 8 m depth. These deposits have at times preserved cultural materials (stone artifacts and pottery pieces) and rarely fossil animal bones. Recently Paliwal (2003) has discovered fossil bones of *Elephas sp*. in gypsum deposit (petrologically designated as petrogypside) in fluvio lacustral deposits at Bhadwasi, 20 km north of Nagaur on Nagaur – Bikaner highway.

In the last 20 years multidisciplinary studies including geology, geomorphology, geochronology, palynology and archaeology have been carried out (Wasson et al. 1983, 1984; Misra & Rajaguru 1989; Singh et al. 1990; Sinha-Roy et al. 1998; Kajale & Deotare 1995; Deotare & Kajale 1996; Deotare et al. 1998) in central and southern parts of the Thar desert. In order to resolve the problem of different responses of playas in the Thar, we employed newly emerging and promising technique of 'mineral magnetics' for the first time at two playas – Bap-Malar and Kanod in the western margin of the Thar.

ENVIRONMENTAL HISTORY OF THE THAR – A BRIEF OVERVIEW

After the recession of sea during the early Eocene, the Thar witnessed moderate tectonic movements and climatic changes mostly in the form of strengthening and weakening of monsoonal rains. Reactivation of basement faults and epeirogenic movement led to the development of uplifted rocky uplands and graben like depressions. The rocky uplands were subjected to the development of pediment surfaces with classical inselbergs. On the other hand, the graben like structures facilitated thick (>300 m) accumulation of fluvial and fluvio-lacustral sediments. Ferricretes and calcretes represent weathering regolith of Neogene and Early Pleistocene age (Achuthan 1999). Stable isotope data, a few ESR dates on calcretes indicate initiation of monsoonal climate in the Thar during the Neogene around 0.8 Ma and with relatively higher rainfall, yet remaining in the semi-arid climatic ambit. However, there is no evidence of human habitation during the Early Pleistocene.

The first sign of the existence of Stone Age hunter-gatherers is observed in the form of Stone artifacts preserved in fluvio-colluvial gravels, at times highly calcretised, in calc-pan clays, and within fossil dunes, particularly in the eastern margin of the Thar Desert (Kajale et al. 2003). ESR and TL dates on calcretes and aeolian sediments indicate that the antiquity of Stone Age Man goes back to Early Middle Pleistocene (approximately around 400 ka or even earlier) (Singhvi et al. 2001). The climate was distinctly semi-arid to arid, at times drier than the present climate. Thus, the desert conditions and human existence date back to the Early Middle Pleistocene. The fluvial system was braided and weak. Dunes and playas also existed in the pediplained landscape (Misra & Rajaguru 1989).

Around 100 ka, aeolian sedimentation got accentuated and the fluvial system turned extremely weak. Aeolian sand accumulation in the form of varieties of dunes such as parabolic, longitudinal, irregular linear and sand sheets was not continuous (as indicated by the presence of weak calcareous palaeosols within aeolian sand) and was for a short period (~1000 yrs.) (Kar et al. 1998; Thomas et al. 1999). Rapid sand accretion took place during the transitional climatic phase from relatively dry to less dry climate. A major wet phase during 60-40 ka has been detected in the semi-arid/arid zone of Thar Desert and northern Gujarat (Andrews et al. 1998). Aeolian sedimentation was rapid between 14 to 11 ka and tapered after around 10 ka in southeastern margin of the Thar (Juyal et al. 2000). On the other hand, it continued in pulses up to 5 ka in the central core of the Thar and more or less came to an end around 700 BP (Kar et al. 1998). The present increased aeolian activity is more of anthropogenic origin rather than climatic. By and large, the Thar was dry, without adequate water resources during the LGM (~20 ka) and hence there are hardly any Stone Age sites belonging to this dry climatic phase.

PLAYAS OF THE THAR AND CONTROLLING FACTORS

In this paper, we have adopted the definition of playa by Rosen (1994) as an "intercontinental basin where the water balance of the lake (all sources of precipitation, surface water flow, and ground water flow minus evaporation and evapotranspiration) is negative for more than half the year, and the annual

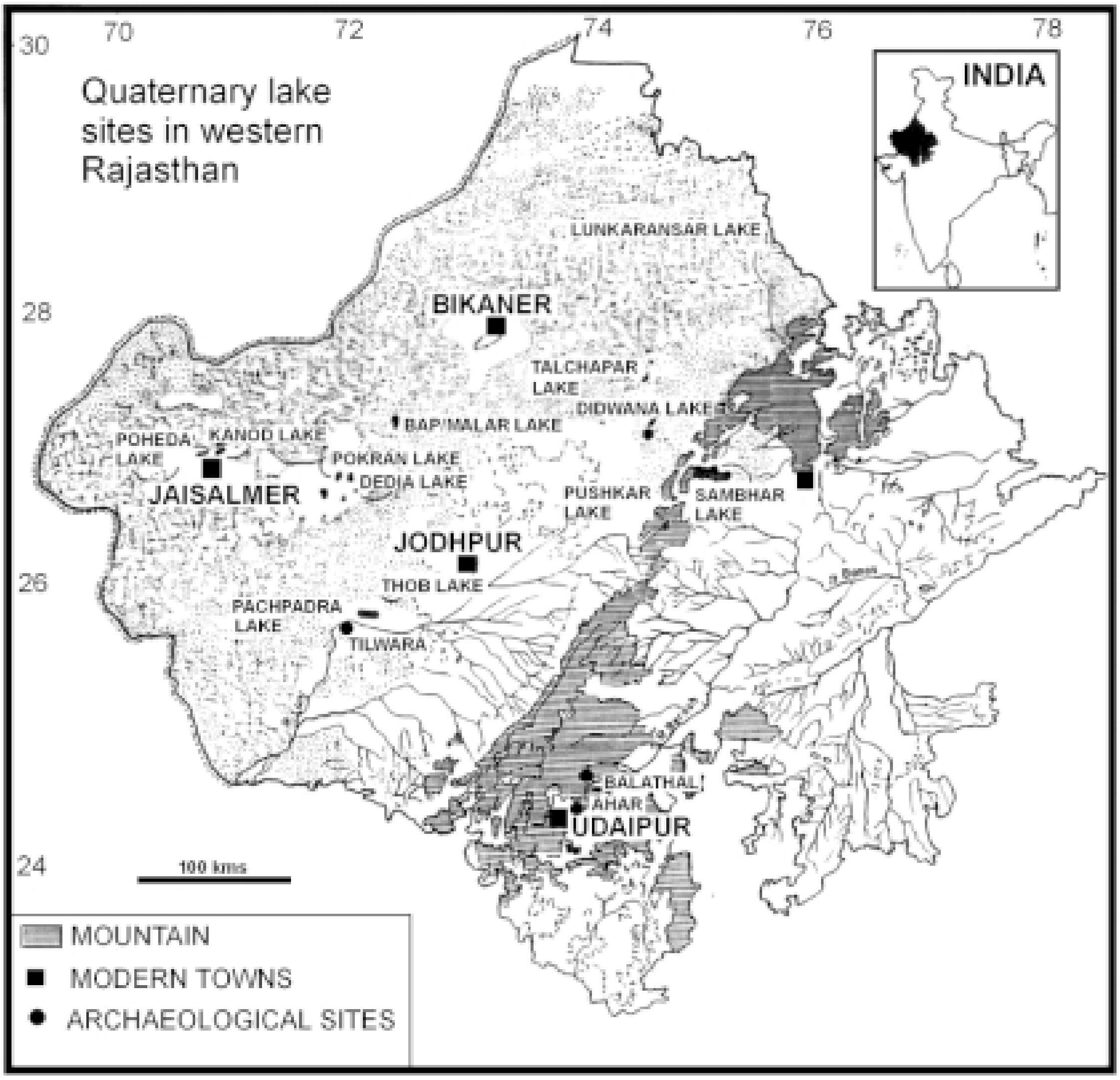

Figure 1. Quaternary lake sites in western Rajasthan.

water balance is also negative" (Rosen 1994, p.1). Playas started forming in suitable depressions either due to tectonic factor or due to obstruction of ephemeral streams by advancing dunes or due to strong wind deflation even during the LGM, and became the major source of surface water since 13-14 ka (Kar 1995).

Our multidisciplinary studies including geology, geochronology, evaporite geochemistry, palynology, stable isotope and archaeology of some of the playas like Sambhar, Didwana, Kuchaman in the eastern margin, Lunkaransar and Thob in the central part and Bap-Malar and Kanod in the western margin of the Thar (Fig.1) have brought out interesting data on palaeomonsoon, palaeolandscape vegetation and human encampments during terminal Pleistocene to Early Mid Holocene. In the following paragraphs some of the important features of playas (excluding Bap-Malar and Kanod) have been summarized. The latter two playas have been described and discussed in detail after reviewing the other important playas.

Amongst the various factors which influence dynamics and lithostratigraphy of playas, the most important are the local morphology and ecology of both basin and catchment areas. Owing to these complex factors, playas of the same age respond differently even in the same climatic conditions. Playas in the Thar demonstrate the complex response in terms of age, causes of formation and preservation of clay minerals and microfossils. Depth of playa sediment at Didwana, Sambhar and Kuchaman in the eastern margin is around 20 m, while the thickness of playa sediments is generally less than 7-8 m in the central and western parts of the Thar. Variation in thickness of playa sediments is thus related to local geological and geomorphic factors.

The playas like Sambhar, Didwana and Kuchaman have most probably formed due to tectonic factors related to the basement rocks (Roy 1999). The Sambhar and the Didwana (Wasson et al. 1983) definitely existed during the LGM. The Kuchaman also may have survived during this cold dry period, though the dating is yet uncertain. Other playas like Thob, Pachapadra, Pokaran seem to have formed due to complex geomorphic factors like obstruction of palaeochannel by dunes (Wadhavan & Sharma 1997), in wind-deflated basins during the end Pleistocene/ Early Holocene. The playas like Sambhar, Didwana, Kuchaman, Lunkaransar and Pokaran were brackish to saline (as indicated by the presence of evaporite minerals like halite, gypsum etc) during the end Pleistocene/Early Holocene. These playas on the other hand turned perennial and fresh water during Early Mid Holocene (Singh et al. 1990). Presence of pollen of *Prosopis cineraria*, *Oldenlandia* and *Artemesia* in playa sediment of Didwana also support the hypothesis of fresh water phase during 6 ka and 5 ka. Thob does not show any fresh water phase during this period as indicated by pollen studies (Deotare & Kajale 1996).

Playas in the eastern margin (Fig. 2a) differ in their response to climatic changes of the late Quaternary from those in the central part of the Thar. All these playas, however, show evidence of gradual drying around 5 ka and almost complete drying by 3 ka. Irrespective of local factors, none of the playas have preserved any evidence of high strand line during the perennial and of fresh water stage.

Bap-Malar and Kanod Playas

Against this brief background of ecological history of the playas in the Thar, the following are the salient findings of Bap-Malar (Dist. Jodhpur) and Kanod (Jaisalmer Dist.) in the arid area of the western margin of the Thar together with backdrop on human settlements in this region of arid core.

The Bap-Malar (Fig. 2c) and Kanod playas (Fig. 2b) occur as depressions formed on pediment surfaces, developed at elevation from about 250 to 150 m above mean sea level. These pediments have developed over Proterozoic and Mesozoic sediments comprising limestone, sandstone, shale and conglomerate (boulder beds) (Sinha Roy et al. 1998). These hollows are possibly structural depressions (Roy 1999), disorganized palaeochannels (Anand Prakash 1980) or the result of strong wind erosion (Kar 1995). In both playas, channel gravel beds and fossil dune sediments or any other non-playa sediments were not found over the weathered bedrock. However, the precise age and origin of the depressions remain uncertain at this stage of research.

The Bap-Malar playa is a closed dry basin with an area of about 78 km^2 located ~150 km northwest of district town of Jodhpur in western Rajasthan. The basin is fed by a few insignificant ephemeral streams, particularly on the southwestern side. The source of water to the lake basin is rainfall and ground water. The water table is currently 8 to 10 meters below the dry surface of the playa (rann). The possible source of the sediments to the rann is aeolian sand from the surrounding dunes, and silt and sand from the ephemeral streams. Ten pits were dug at different locations for sediment sampling and employed them for testing pollen potential, AMS ^{14}C dating, XRD analysis etc. W10 pit was selected for detailed laboratory studies, because it is representative and is in the deepest part of the Bap-Malar playa. Chemical studies show that these sediments are organic carbon deficient and low in clay content, as a result AMS dates were obtained on fossil pollen concentrates.

The lithostratigraphy as given in Table 1 indicates that lithounit IV is a brownish coloured sediment which overlies lithounit III. Unit II is relatively rich in gypsum (surface as well as sub-surface) and unit I is sand dominated with alternations of silt with sub-surface gypsum. In view of limited dates from the lower portion of the Bap-Malar playa, it is difficult to precisely suggest a tentative date for the initiation of the playa. Yet, if the rate of sedimentation of ~ 0.25 mm/year is assumed for the pre- 15 ka lake sediments, the playa seems to have been initiated around 25 ka and its final drying is certainly later than 7 ka, probably around 6 ka (Fig.3).

The XRD studies show a predominance of detrital minerals like quartz, feldspar, muscovite, and chlorite and evaporites like gypsum, halite, calcite and dolomite. An inverse relationship in proportions of gypsum and halite, and gypsum and calcite, exists. Thus, gypsum in samples from 0-120 cm depth of W10 is in trace amounts, while halite is predominant and calcite occurs in moderate amounts. Between 120 and 225 cm depth of W10, gypsum is dominant and halite and calcite are in minor amounts. A similar relationship of gypsum, halite and calcite is noticeable in samples from the K5 trench at the Kanod playa. Enzel et al. (1999) examined gypsum concentrations

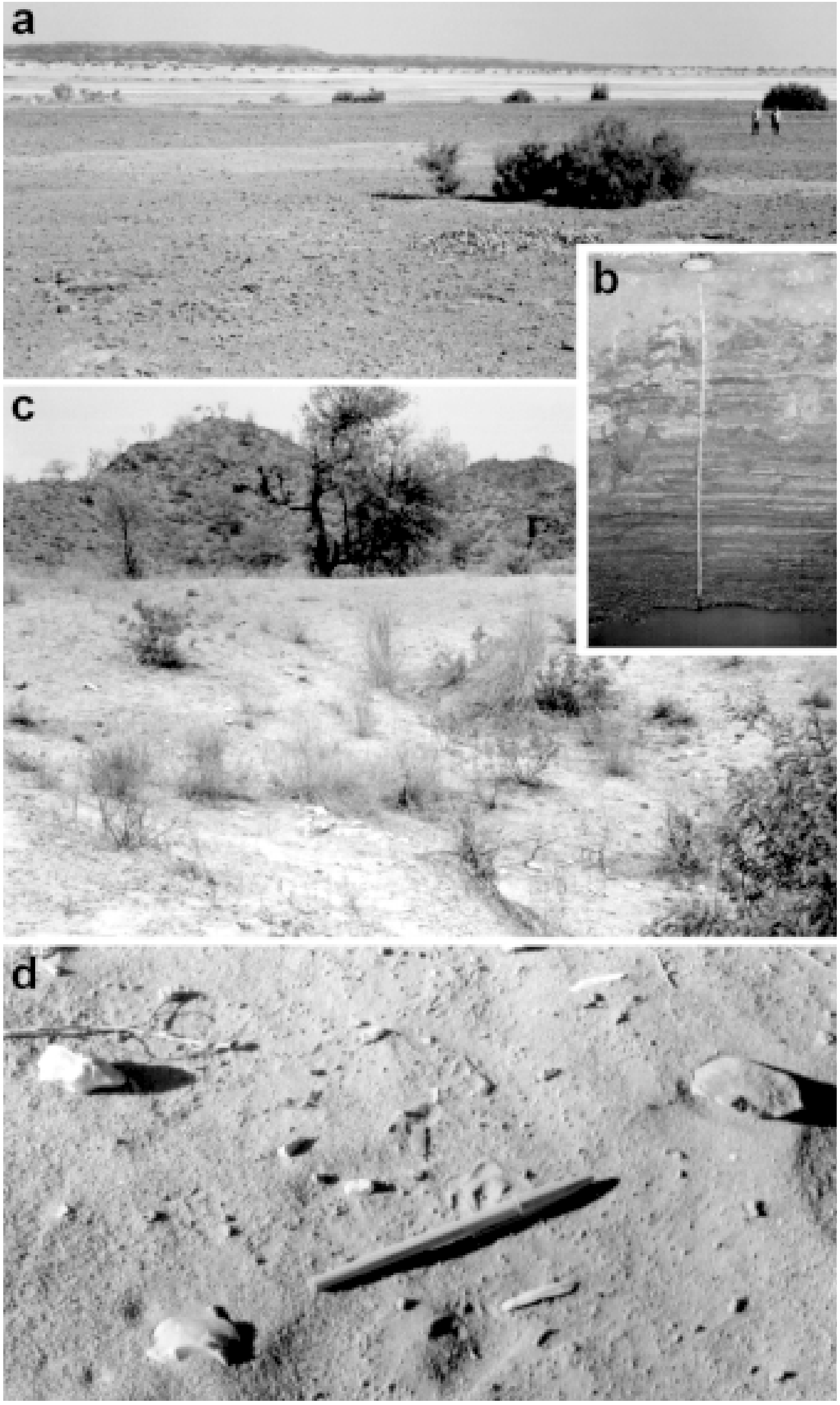

Figure 2. a) General view of playa in Rajasthan. b) Close view of sediment profile from Kanod playa. c) General view of Microlithic site near Bap-Malar playa. d) Close view of Microliths spread over the stable dune surface.

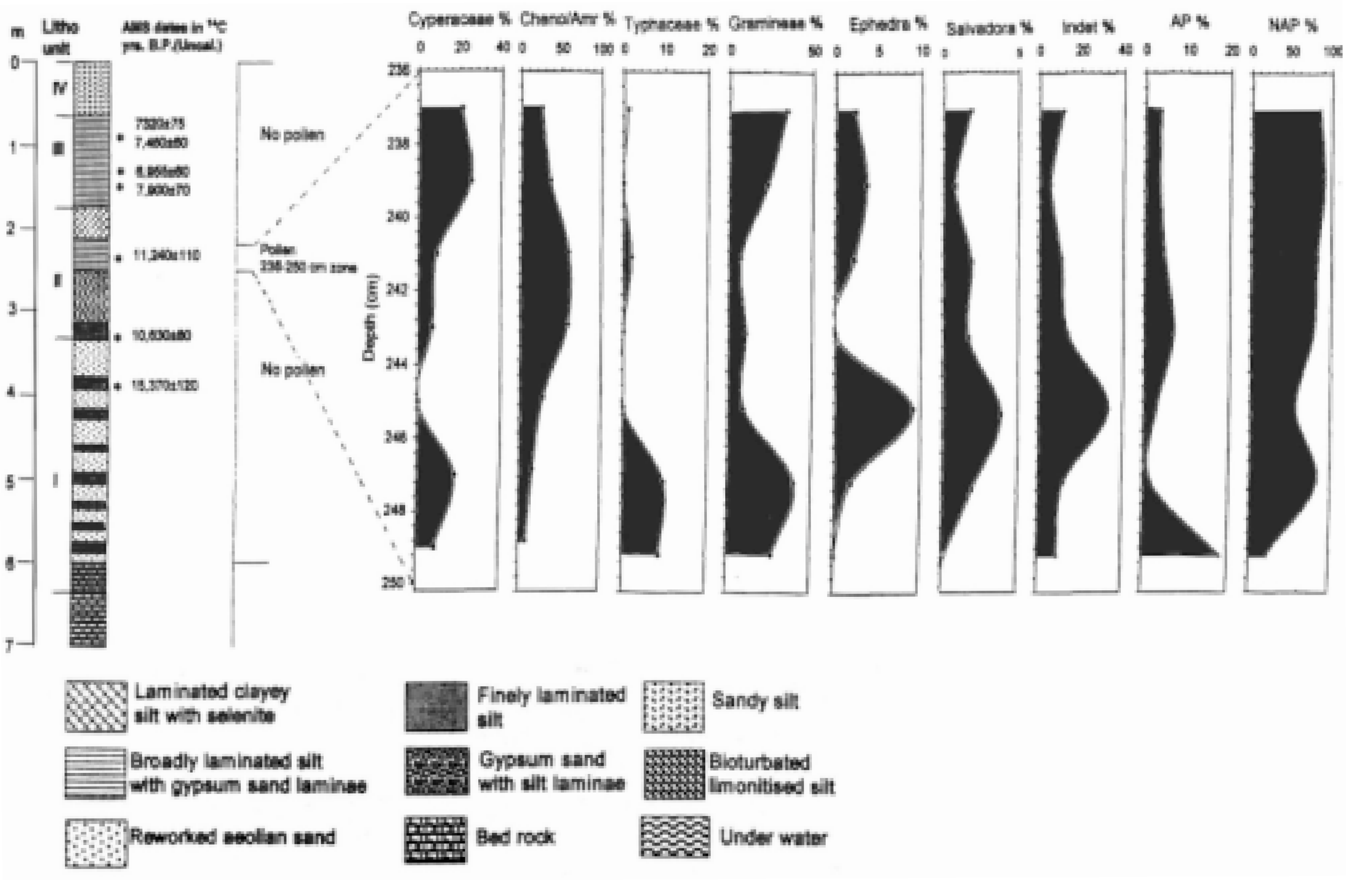

Figure 3. Pollen distribution in the profile from Bap-Malar playa.

Table 1. Lithostratigraphy and palaeoenvironments of Bap-Malar playa.

Unit	Depth (in cm)	Character	Approx. Age and Environment
IV	60-0	Reddish brown thickly laminated silt-fine sand.	Mid to Late Holocene (<6 ka). Lake dry phase
III	180-60	Finely laminated grayish silt-fine sand without prominent gypsum.	Early Holocene (8-7 ka). Lake full phase, yet shallow and saline
II	320-180	Finely laminated grayish silt-fine sand with intercalations of powdery gypsum, rich in selenite crystals in upper part, pollen present.	Early Holocene (basal) (~ 11-10 ka). Shallow and seasonal, at times dry
I	650-320	Thickly laminated reworked aeolian sand with intercalations of silt and gypsum laminae.	Terminal Pleistocene (>15 ka). Shallow ephemeral lake
	>650	Reddish sandstone	Mesozoic

in sediments from Lunkaransar playa and observed that a fresh water phase of perennial playa datable to 6.3 to 4.8 ka was practically devoid of gypsum. Presence and/or absence of gypsum was used by them to interpret lake hydrology and palaeoclimate during the early to mid-Holocene.

The inverse relationship between halite and gypsum indicates that the playas remained saline from 15 ka to around 6 ka (in Bap-Malar), as sediments are rich in gypsum or halite. Observations by Deshmukh & Rai (1991) on the Sambhar, Kuchaman, Didwana playas in Rajasthan also suggest dry-wet phases based on presence/absence of the evaporites (gypsum and halite). Sinha & Raymahashay (2000) have also recently reported similar observations while examining absence of gypsum in near surface (<1.5 m) sediments of Sambhar salt lake in Rajasthan due to a low influx of calcium into the youngest lake sediments.

The W10 profile at Bap Malar yielded microfossils only at a depth of 235-250 cm (Fig. 3). Most of the facies did not yield adequate pollen and spores except a broadly laminated silt of zone II. The pollen grains are represented by morphotypes belonging to chenopodiaceae, gramineae, cyperaceae, compositae, mimosae, rhamnaceae, etc. and spores are mostly of fungal origin. These microfossils by and large indicate local ponds and stagnant water-bodies in the rann proper and also in the surrounding regions. This is further supported by stable isotope analysis. The stable carbon isotopic values on seven samples from W10 profile range from -15 to -18 ‰ (Table 2) suggesting predominance of C4 plant cover and arid climate.

Table 2. AMS radiocarbon dates and $\delta^{13}C$ on the deposits from Bap-Malar playa.

Sr. No.	Sample No.	Depth in cm	Lab code	$\delta^{13}C$ (‰)	^{14}C age (BP)
1	TR 63	380-384	V14192	-17.814	15,370±120
2	TR 61	318-322	V14191b	-16.547	10,630±80
3	MLR20	235-240	V14180	-18.399	11,240±110
4	MLR21	140-145	V14181	-15.654	7900±70
5	MLR23	130-140	V14183	-14.598	6955±60
7	MLR22	90-95	V14182A	-16.200	7460±60
6	MLR22	90-95	V14182	-16.194	7320±75

The perennial stage of the playa is represented by finely laminated silt and fine sand with low concentration of gypsum and a higher proportion of halite and calcite. Silt and fine sand laminae of unit I were deposited between 8 ka and 7 ka, around 11 ka and >15 ka (at a depth of 5.2 to 6.3 m). Though the playa was perennial with ground water above the surface, it was saline as indicated by the presence of calcite, halite and traces of gypsum crystallites. The perennial water playa of the early Holocene (8 ka and 7 ka) was the most conspicuous hydrological change in Bap-Malar playa, which by and large remained primarily saline and shallow with fluctuating ground water, particularly at 15 ka and 11 - 10 ka (Table 2).

Kanod playa having 32 sq km area is an elongated depression, which is located 35 km northeast of Jaisalmer in an area with mean annual rainfall of 160 mm and potential evapotranspiration in excess of 2000 mm/annum. Ephemeral channels cut through pediments surrounding the playa and drain into the playa. The playa surface remains practically dry throughout the year, except the monsoon months of August-September when occasional storm rains fill the playa with water up to about 0.5 m. The mean annual winter rainfall is ~30 mm and does not contribute effectively towards surface runoff. The Kanod playa is thus dependent more on groundwater discharge (brine with a salinity > 25g/l) than surface runoff during summer monsoons. Initial pollen analysis on Kanod was reported by Sharma & Chauhan (1991) with two conventional radiocarbon dates, on lake sediments: 8,701 ± 198 BP (180 cm) and the other 9,567 ± 159 BP (250 cm), suggesting the playa formed during the early Holocene.

The particle size analysis of the representative samples from Kanod shows that the sediments are mainly dominated by sand and silt fraction with very little clay. Sediments from K5 are alkaline in nature with pH ranging from 7.8 to 8.3. The distribution of calcium carbonate is erratic and does not show any specific trend. The organic carbon content (0.8 to 1.3%) is relatively high at 42 - 176 cm depth level as compared to lower and upper levels of the profile. The organic carbon content, which is one of the vital factors for the preservation of microfossils, is very low in Bap-Malar sediments as compared to Kanod, and may be one of the reasons for the better preservation of microfossils in Kanod playa. Six pits have been dug of which deepest is K5. It is 2.5 m in depth and reveals following major lithounits (Table 3, Fig. 2b).

The XRD pattern obtained on the samples from the K5 profile shows the presence of aragonite, calcite, gypsum, feldspar, halite, muscovite and quartz. Quartz is present in relatively significant amount in upper and lowermost samples, thereby indicating nearby dunes as a source of the sediments at the respective depth of 5-10 and 205-250 cms. Gypsum is present at a lower level (176 to 250 cm) while halite

Table 3. Lithostratigraphy and palaeoenvironments of Kanod playa.

Lithounit	Depth (in cm)	Character	Approx. Age/ depositional environment
V	20-0	Hard gypsum capped by yellowish brown sandy silt	Mid to Late Holocene (<5.5 ka). Lake dry phase
IV	140-20	Bioturbated, mottled, thickly laminated brownish gray silt with intercalated gypsum, and pollen.	Early to mid Holocene. Shallow lake, seasonal with occasional lake full stage
III	150-140	Finely laminated grayish silt with pollen and specks of charcoal, without prominent gypsum.	Early Holocene (~7.8 ka). Lake full phase
II	200-150	Gypsum sand with fine intercalations of grayish silt. Pollen present	Early Holocene (basal) (~ 9 ka). Shallow ephemeral lake
I	300-200	Reworked aeolian quartz sand. Pollen present	Terminal Pleistocene (?)
	> 300	Claystone	Mesozoic

is present in upper levels (5 to 148 cm), indicating the saline nature of the sediment throughout the course of deposition.

A few AMS ^{14}C dates (Table 4) suggest that the playa originated during the Pleistocene-Holocene transitional climatic phase. The playa was semi-perennial to ephemeral between 7.5 to 5.8 ka and was desiccated completely after 5.5 ka as revealed by a 10 cm thick hardened gypsum layer occurring between 10 and 20 cm.

Table 4. AMS radiocarbon dates and $\delta^{13}C$ on the deposits from Kanod playa.

Sr. No	Sample No.	Depth cm	Lab code	$\delta^{13}C$ (‰)	^{14}C age (BP)
1	K1/23	40-45	V14188	-14.701	5815±55
2	K1/22	140-145	V14184	-16.195	7885±60
3	K2/25	120-125	V14190	-16.192	9030±65
4	K2/24	160-162	V141898	-14.833	9355±75

The $\delta^{13}C$ values range from –14.7 per mil to –16.2 per mil for the last 9.4 ka (Table 4) suggesting predominance of C4 plants, mainly grasses, adapted to a dry environment. The blackish silty layer in Kanod yielded significant microfossils, and is also found in playas at Lunkaransar and Thob. Pollen and spores in litho units II, III and IV consist of cyperaceae, chenopodiaceae amaranthaceae, gramineae, pinaceae, typhaceae, etc indicating the dominance of grasses, sedges, and amaranthes in the region around the Kanod Lake. Presence of evaporites in units II to IV suggests that Kanod playa remained mostly saline all along early to mid-Holocene.

Both the playas remained brackish to saline throughout their existence from the end Pleistocene to early mid Holocene (~ 5 ka BP). They were ephemeral to semi-perennial during early Holocene (10 ka – 8 ka), perennial during Early mid Holocene (7 ka - 5 ka) and ephemeral to almost dry during the late Holocene (after 3 ka). In order to test the validity of these findings, the mineral magnetic technique was employed for the first time in the study of playas in the Thar.

MINERAL MAGNETIC DATA

The magnetic susceptibility of the Kanod playa core shows a progressive decrease down the profile (Fig. 4). XRD studies show that the mineralogy is dominated by diamagnetic (calcite, dolomite, gypsum) and paramagnetic (muscovite, chlorite) with some canted antiferromagnetic component in the form of hematite. The χ values vary between a restricted range of 4-16, which implies absence of significant pedogenesis either in the near provenance or on the body of the lake itself. This is in agreement with the hydrology and precipitation regime of the region.

The susceptibility values can be interpreted in light of the changing hydrology of the lake. During periods of high lake levels or rise in groundwater table, sediment composition is governed by the presence of paramagnetic minerals brought into the playa either by aeolian or wind activity. As the lake evaporates and ground water table goes down, the precipitation of evaporites and carbonates causes magnetic susceptibility to attain lower values. With progressive aridity and simultaneous drying up of the lake, precipitation of evaporite and carbonate minerals decline. Subsequently, aeolian sediments are deposited onto the lake surface, which appear to be rich in hematite as suggested by the reddish brown colour of the sediments. This increase in the canted antiferromagnetic component leads to slightly higher susceptibility values, around 16 (10^{-8} m^3kg^{-1}).

Hence in the Kanod profile, higher χ values encountered in the youngest phases testify towards progressive aridity and complete desiccation of the lake. Intermediate levels of susceptibility are interpreted to indicate higher groundwater tables and lake filling, while the lowest values suggest a shift to a evaporation > precipitation lake regime. Under such conditions, a dilution effect on the susceptibility signal is observed.

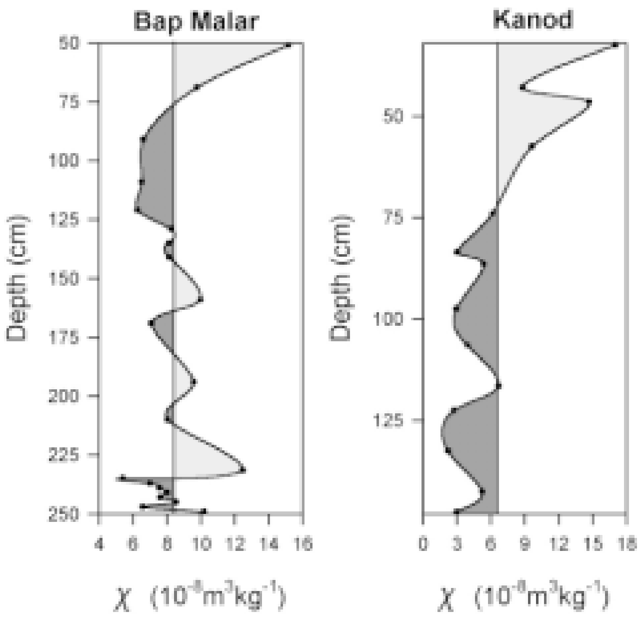

Figure 4. Variation in magnetic susceptibility (χ) in the Kanod and Bap Malar playas.

The mechanism suggested for Kanod is equally applicable to Bap Malar playa (Fig. 4). Here too high χ values are seen in the uppermost portion and are followed down profile by very low values of χ. Between 150 to 225 cm depths intermediate values of c suggest lake full stage. Such conditions appear again at 250 cm depth and are separated by a short interval of high magnetic susceptibility at about 230 cm depth. This profile can be correlated with the Kanod playa in terms of regional drying events. Also these results confirm the utility of mineral magnetic studies on playa sediments for reaffirming palaeoclimate records from arid regions in conjunction with other methodologies such as stratigraphy, pollen analysis, geomorphology, etc.

ARCHAEOLOGY AROUND THE PLAYAS

The environmental conditions in the present desert are very harsh and inhospitable but they were much better in the past during the Middle and early part of Upper Pleistocene, and early to mid Holocene (Misra & Rajaguru 1989). Archaeological research has shown that the antiquity of human settlement in the Thar Desert goes back to the Middle Pleistocene. The first stone-age site was found at Baridhani near Bap-Malar (Mohapatra et al. 1963).

The association of Middle Palaeolithic sites with depressions in the desert, which at present hold saline water such as Lordiya, Sambhar, Thob and Baridhani and associated with present day streams, support for a humid climate during Middle Palaeolithic times (approximately around 100-125 ka). The extreme aridity during Terminal Pleistocene is marked by presence of relatively less Upper Palaeolithic sites. Towards the end of the Pleistocene, climatic amelioration took place, marked by increased rainfall during Early to mid Holocene. This can be clearly seen in the light of widespread distribution of microlithic sites in the Indian (Deotare et al. 1998; Kajale et al. 2003) as well as Pakistan occupied Thar desert (Biagi & Veesar 1998-99).

The majority of microlithic sites are located on stable surface of old sand dunes (Fig. 2c, 2d) all along the playa boundaries such as at Bap-Malar, Sambhar, Pachpadra and some on rocky pediments around Kanod. The extent of the sites is very small indicating short lived occupation by small groups. However, the higher density of sites during this period may also reflect a greater mobility necessitated during dry seasons due to restricted availability of water in the area. The microlithic sites of Jamba are dated by TL to 7 ka BP that matches reasonably well with the lake full stage of Bap-Malar playa (Deotare et al. 1998). Similarly, the occurrence of microliths (Fig. 2d) with pottery is also a very common feature of the sites around these playas. So, it can be surmised that Mesolithic occupants were primarily hunter-gatherers who adopted the pastoral way of life.

The archaeological sites in and around Phalodi and Bap-Malar playa are mostly located on old dune surfaces where pottery, microliths and bone fragments were recovered (Kajale et al. 2003). Similar type of evidence has been reported from the surrounding of Thari region in the Thar Desert of Sindh, Pakistan. Biagi & Veesar (1998-99) have surveyed the above area and discovered many sites on the surface of the sand dunes surrounding the salt water basins of Ganero and Jamal Shah Sim. The majority of these sites consist of microliths of different shapes and dimension belonging to Mesolithic period and some of the flint scatters are even older, may be attributed to the end of the Late Palaeolithic. Some of the sites have also yielded typical painted pottery in association with microliths. This aspect of Mesolithic sites with ceramic tradition in the Thar Desert of India and Pakistan opens a new avenue for further research on culture that existed around playas in Early Holocene. An Early Historic site dated to around 500 AD by ^{14}C method, around Bap-Malar in the western part of Jodhpur district, also focuses on Man land relationship during the Late Holocene (Deotare et al. 1999).

CONCLUSIONS

Our multidisciplinary studies of Bap-Malar and Kanod playas in the present arid semi-arid core of the Thar desert establish that these playas remained largely ephemeral to semi perennial over a long period of time ($\sim$>15 ka to $\sim$5 ka) with a short phase of perennial stage around 8 ka to 6 ka. Study of evaporite minerals, pollen analyses and of magnetic susceptibility clearly suggests that the climate during the late Quaternary fluctuated from arid to semi–arid. It was neither hyper-arid nor dramatically humid. Nomadic pastoralism was prominent during the lake full stage of the Early Holocene (8 ka to 6 ka). Variations in magnetic susceptibility in the playa deposits reflect changes in the lake hydrology, which led to dilution of χ through increases in diamagnetic evaporitic minerals. Higher χ values occur when aeolian detrital fluxes increase onto the playa surface. These results affirm the applicability of mineral magnetic techniques in reconstructing palaeoclimatological changes using the playa sediments of the Thar Desert. However, correlation based on χ records and development of χ as an environmental proxy requires an understanding of the magnetic mineral assemblage in the playa deposits. Therefore, we intend to undertake a detailed study to characterize the magnetic mineral assemblage in the playas, which is one of our prime objectives in the next few years.

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