PALAEOECOLOGY OF THE RAJASTHAN DESERT DURING THE LAST 10,000 YEARS

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ABSTRACT

In the light of fresh and exhaustive information now available on the ecology of vegetation of the Rajasthan desert, the reinterpretation of the published pollen diagrams reveals that there was increasing trend towards dryness until 5,000 years ago and thereafter between 5,000-3,000 years ago the environment was characterized by maximum warmth and dryness and by high velocity winds and dust storms. The precipitation which was within the range of 150-400 mm showed a gradient from the extreme west of the desert to its east. The renewed sand dune activity during the hypsithermal period had encroached upon the eastern tracts of the desert.

The salt lakes which had originated about 10,000 years ago had already high salt content in their waters and during a continuous phase of recession in the entire Holocene rose once between 6,000-5,000 years B.P.

The vegetation had comprised of *Calligonum* series and *Prosopis-Capparis-Ziziphus* series in the vicinities of Lunkaransar, Didwana and Sambhar and of *Anogeissus-Acacia* series in the vicinity of Pushkar lake.

The earliest farming episode did not precede 5,000 years B.P. though inexplicable evidence of burning and disturbance of vegetation preceded it perhaps caused by natural means and grazing of animals.

The subsequent desertification was caused by combined effect of climatic and biotic factors.

INTRODUCTION

THE reconstruction of palaeoecology of a region through pollen analysis is largely dependent upon the ecological requirements of modern representatives of the fossil plant species identified from their remains. It becomes highly imperative therefore that the investigator posts himself fully with the ecological information of the modern plant life of the region under investigation. Luckily the ecology and mapping of modern vegetation of the Rajasthan desert exhaustively accomplished by the French Institute, Pondicherry (Gaussen *et al.*, 1972) if properly made use of, valuable information can be had of the former plant life and the climatic, biotic and edaphic factors governing its distribution. Further it can provide information on the origin and history of the desert, past meteorological conditions, origin and history of the lakes and their salinity and aspects of human and animal influence upon the desert vegetation towards land-use and agriculture. The technical excellence of the recovery and presentation of the palaeobotanical and palynological data often becomes offset if the inference therefrom is based upon inadequate knowledge of the factors governing the distribution of the plant life. It is intended in this paper to infer information of palaeoecology of Rajasthan desert from the recently published palaeobotanical work by Singh *et al.* (1973, 1974) in the light of information now available on the ecology and vegetation of the Rajasthan desert by Gaussen *et al.* (1972), the information which was not available to Singh *et al.* (1973, 1974).

The writing of this paper was also prompted by the glaring anomaly between the hitherto inferred Holocene climatic sequence in Rajasthan (Singh *et al.*, 1974) with global climatic fluctuations. For instance between 5,000 B.P. to about 2,760 B.P. (the Sub-Boreal Period), a recognized hypsithermal interval during which maximum warmth and dryness prevailed all over the world (with rare exceptions of course) and minor cool oscillations did occur in some parts of the world (Wendland & Bryson, 1974), wet climate turning dry about 1800 B.C. has been inferred in Rajasthan (Singh, 1971; Singh *et al.*, 1974). Nearer home the chemical analysis of Indian ocean cores in the Gulf of Aden has revealed that not only the pre-Boreal was the driest and a time of great wind erosion, the first millennium of the sub-Boreal was drier than the Atlantic and thereafter about 1800 B.C. a slight increase in precipitation did occur. Thereafter, between 750 B.C. to 500 B.C., a new and gradual decrease in rainfall had occurred (Olausson, 1972).

In western Iran dry climate prevailed until 6,000 B.P. and there was either fall in temperature or rise in precipitation but the pollen stratigraphy of lake Mirabad in the same region suggests that the summers during 5,000-4,500 B.P. were drier causing intermittent desiccation of the lake (Van Zeist, 1967). Macrofossil study at this site suggests that the lake level during 5,000 B.P. did not fluctuate much rather it was lower than today (Wasylikowa, 1967). The arid period in Sahara began at about 4,300 B.P. (Zinderen Bakker, 1972). The sub-Boreal optimum temperature was secular in nature in Europe, S. America and Tropical Africa though Central Africa was slightly warmer and wetter during 4,700 B.P. (Zinderen Bakker, 1972). Although synchroneity in global fluctuations of temperature has to a large extent been proved than in fluctuations in moisture, most amazingly the sub-Boreal has been found to be secularly dry with rare exceptions.

The distribution and ecology of the Rajasthan flora reveal that distinct plant species fall into ecological groups such as halophytes, xerophytes, mesophytes, etc. the temperature, moisture and soil requirements of the individual constituents of each group will not permit, for instance the members of the mesophytes to occur with those of the xerophytes (planted or introduced plant species excepted). Further the plant societies in Rajasthan desert constitute a mosaic of plant associations having particular edaphic preference. Thus pollen grains may be derived from several plant societies. For proper palaeoecological inference it would be profitable to group the pollen grains in the societies they may be derived from. Likewise pollen grains transported from plants in different climatic regimes within or outside the Rajasthan desert too be grouped together for any palaeoecological indication they may suggest. From the published data of which details are also preserved with us the inferences drawn here are based upon such recognizable ecological groupings.

PALAEOECOLOGY OF THE RAJASTHAN DESERT

Temperature, Precipitation and Sand Dune Activity

Gaussen *et al.*'s (1972) ecological survey of the Rajasthan flora brings to light climatically and edaphically controlled series of vegetation occurring in the desert. Finding the inadequacy of the rainfall isohyets as determiners of the distribution of plant societies in Rajasthan, Gaussen *et al.* (1972) have derived bioclimates from temperature, duration of dry months, number of biologically dry days (i.e. xerothermic index) besides precipitation. Their painstaking work suggests that the series *Calligonum polygonoides* and the series *Prosopis-Capparis-Ziziphus* occur under the same climatic conditions: annual precipitation 150-400 mm, dry period extending over 9-11 months a year, xerothermic index over 250 and mean temperature of the coldest month being 15-20°C or less than 15°. However, the *Calligonum* series occurs on sand dunes (active & stabilized) and the *Prosopis-Capparis-Ziziphus* series especially on old sandy alluvium. Likewise the other series are characterized by increase in annual precipitation and less number of dry months and slightly higher winter temperature. The *Acacia-Capparis* series for instance occurs under a rainfall of 400-700 mm with 8-9 dry months, 15-20°C mean temperature of the coldest month. *Maytenus emerginata* of which pollen grains constitute an important curve in pollen diagrams belongs to the shrubby savannah in the *Prosopis-Capparis-Ziziphus* series. It occurs abundantly with *Calligonum* and *Prosopis* in the Rajgarh area and Bikaner in the Bikaner District (Joshi, 1956). *Capparis* and *Maytenus* constitute dominant vegetation in the sandy areas in the Shekhawati region in Jaipur District (Joshi, 1957). It also occurs in other series under higher rainfall but the associated constituents are entirely different.

Singh (1971) and Singh *et al.* (1974) based the inference of climatic fluctuations upon the pollen curves of Cyperaceae, grasses, *Artemisia*, *Mimosa rubicaulis*, *Oldenlandia* and *Typha* as indicators for wet climate and it has already been suggested elsewhere (Vishnu-Mittre, 1974a, b) that these pollen indicators for wet climate have not been judiciously chosen. Granted for a moment that they are, a comparison of the three pollen diagrams would reveal that during 9,500 B.P. to 5,000 B.P. Sambhar and Didwana areas were much wetter than Lunkaransar (the curves of most of them show a progressive decrease from east to west) suggesting that the moisture belts remained much the same as today. And this would be contrary to the conclusion of Singh *et al.* (1974, p. 494) that the westward shift of the rainfall belts took place during phases II-IV. Amazingly the behaviour of Cyperaceae and *Artemisia* as shown below has been found to be inversely related at the two sites, Lunkaransar in the driest belt and Sambhar in the least dry belt. The declining *Artemisia* pollen curve at Didwana, a site in between the two, remains enigmatic.

revealed that the pollen grains of *Mimosa rubicaulis* and *Mimosa hamata* are indistinguishable from one another (Saxena & Vishnu-Mittre, 1976) and so are those of *Oldenlandia* species.

The Lunkaransar pollen diagram shows during the last 10,000 years the development of the desert vegetation from *Ephedra-Maytenus-Calligonum-Capparis* to *Maytenus-Ephedra-Capparis* with little *Ziziphus* to *Calligonum-Maytenus-Ephedra-Prosopis-Capparis* and eventually to *Calligonum-Capparis* Society*. During the same period of time Sambhar Lake pollen diagram shows *Mimosa-Acacia-Ephedra* developing into *Maytenus-Capparis-Acacia* to *Capparis-Prosopis-Acacia-Maytenus* and eventually to *Capparis-Prosopis-Acacia* and *Euphorbia*. The sequence in Didwana is ± similar to that of Sambhar with the difference that *Calligonum* appears here in the middle of

Cyperaceae and *Artemisia* pollen percentage during 9,500-5,000 B.P.

Pollen grains	Climatic inference	Lunkaransar	Sambhar
Cyperaceae	wet	around 40%	around 20%
Artemisia	wet	around or less than 20%	around or less than 40%

This inverse relation between Cyperaceae and *Artemisia* and between *Artemisia* and grasses indeed deserves further ecological study.

In the modern pollen spectra from within the purely *Calligonum* series both Cyperaceae and Gramineae have 10% to 200% pollen and 15-60% pollen respectively, though *Artemisia* pollen is up to 5% and Chenopodiaceae pollen is from 5-30% (Singh *et al.*, 1973). These modern pollen spectra deserve detailed evaluation prior to attributing wet climate to Cyperaceae, Gramineae and *Artemisia*. The fact should not be over-looked that some sedges like *Cyperus arenarius* and the others and quite a few grasses occur gregariously on the sandy plains and sand dunes.

Artemisias in the Afro-Asian belt are mainly encountered in the dry climates with cool winters and with higher proportion of winter-spring precipitation than summer rains (Krinsley, 1972; Meher-Homji, personal correspondence). More data would indeed be welcome to ascertain this fact. Continued work at the Sahni Institute has

the successional development and continues to remain thereafter an important member of vegetation which is eventually dominated by *Capparis*.

A comparison of the shrubby members of the desert vegetation in the three salt lake pollen diagrams reveals that the desert vegetation comprised of the two series *Calligonum polygonoides* series, and *Prosopis-Ziziphus* series suggesting that the precipitation remained more or less the same (150-400 mm) with the number of dry months from 9-11 and the temperatures of the coldest months between 15-20°C. The succession in the series was largely governed by the local physiographical features, i.e. the old sandy alluvium and the formation of the sand dunes. No evidence of the occurrence of *Calligonum polygonoides* series has been found in the Sambhar Lake pollen diagram suggesting that no active sand dunes occurred here though the sandy plains were present around the eastern area of

*The reconstruction of these societies from pollen diagrams is based upon the relative abundance of the pollen grains of various constituents.

the Sambhar Lake during the Holocene until after the Iron Age. Both the sandy alluvium and sand dunes occurred around Didwana and the dunes were more prominent and widespread around Lunkaransar. Until about 3,000 B.C., the *Calligonum* series had not invaded the area around the Sambhar Lake. A marked increase in the *Calligonum* series (indicating sand dune formation) took place at Lunkaransar about 5,000 B.P. More or less at this time it is also observed though comparatively less around Didwana.

The Pushkar lake pollen diagram representing the top missing period at both Didwana and Sambhar suggests gradual and marked increase of the sand-dune formation until the recent times. Approximately dated as it is to the post-Harappan times, a marked increase in the sand dune formation here as well as towards the extreme top of the Lunkaransar pollen diagram suggests the extension of this series in the Sambhar Lake area in the post-Harappan times.

Wind and Dust Storms

A comparison of pollen diagrams (Singh *et al.*, 1974) with the modern pollen spectra (Singh *et al.*, 1973) and present distribution of plant species in the Rajasthan desert reveals that the shrubby and tree vegetation becomes comparatively more dense in the vicinities of these lakes from 5,000 B.P. to 3,000 B.P. Apart from the desert shrubs, tall artemisias and tufted perennial grasses perhaps also dominated the scene. Artemisias are extremely rare today and so are *Maytenus* and *Ephedra*. The significance of the density of vegetation in relation to environment in a desert is a problem in itself and needs to be examined carefully. Walter (1964) believes that bush encroachment in a desert is not a climatic phenomenon but is caused by overgrazing. Blagoveschanskiy (1968) has found that the density of *Prosopis cineraria* is directly related to precipitation as shown below.

Density of *Prosopis cineraria* in Rajasthan Desert Area is as follows:

Area	Precipitation (in mm)	Density	Ht. of trees (in m)
NE Rajasthan around Jaipur	500-600	150-200	7-8
Central Rajasthan around Ajmer	300-400	50-100	5-6
Western Rajasthan around Phalodi	200	25-30	3-4

The desert vegetation in the Pushkar Lake pollen diagram appears to consist of more than one series, the *Calligonum* series, *Prosopis-Capparis* series and *Anogeissus-Acacia* series. The gradual evolution of the desert vegetation here leads to *Anogeïssus-Acacia* series towards the top of the diagram indicating a change in annual precipitation in the region of the lake from 150-400 to 400-700 mm with the number of dry months from 9-11 to 8½-10 and without rise in temperature of the coldest month.

This extension of the sand dune formation from the west to the east of the Rajasthan desert commencing from 5,000 B.P. and gradually increasing until recent times is an interesting phenomenon in the history of the Rajasthan desert. It would be of interest to determine factors responsible for it.

We have no data about the other plant species distributed in the Rajasthan desert.

How far the percentage pollen frequency of a plant species is indicative of its density is yet to be determined for the Rajasthan flora, though in general abundance of pollen frequency is usually understood to reflect its density provided the phenomena of production and dissemination of pollen of particular species are well understood. Believing that the relative density of a taxon is directly related to its pollen frequency, the examination of the three pollen diagrams from the salt lakes reveals that:

1. The density of Cyperaceae during 9,500-5,000 B.P. was around 40% at Lunkaransar (the driest site) and it was about 20% (rising to 30% around 6,000 B.P.) at Sambhar (the least dry site). From 5,000 to 3,000 B.P. it was about 50% at Lunkaransar while

at Sambhar it fluctuated between 40-50%.

2. The frequencies of *Artemisia* in the Lunkaransar diagram continue to be just half of those in the Sambhar Lake diagram.
3. *Oldenlandia* was comparatively more widely spread at Sambhar where a low more or less continuous pollen curve is formed whereas its values at Lunkaransar are sporadic.
4. *Mimosa* (? *rubicaulis*) was comparatively more widely spread around Sambhar and almost absent in Lunkaransar (only 0·5% pollen is noted in a single sample during 9,500 B.P.-3,000 B.P.).
5. During 5,000 to 3,000 B.P. the shrubby vegetation did increase in the vicinity of these lakes. At Sambhar increase is observed in *Mimosa, Capparis, Prosopis, Acacia,* etc. whereas at Lunkaransar increase is noted in *Calligonum, Maytenus, Ephedra, Ziziphus, Prosopis,* etc. There is corresponding increase in ground vegetation also.
6. On the whole *Maytenus* was comparatively more frequent in the vicinity of Lunkaransar than of Didwana and Sambhar and there was more of *Ziziphus* too.

The relative decrease of the so-called wet climate indicators of Singh (1971) from Sambhar to Lunkaransar in the past 10,000 years reveals that the moisture gradient from Sambhar to Lunkaransar existed during the entire Holocene. From this it would appear that Lunkaransar area has always remained drier than Sambhar. The density of vegetation around each site did increase particularly during 5,000 to 3,000 B.P. and the increase observed is in the same desert species which had occurred there. Finding that the increase in the density of shrubby vegetation was a uniform feature from Sambhar to Lunkaransar and if it had resulted from increase in precipitation then the precipitation must have been uniform all over the area during 5,000-3,000 B.P. Obviously then the moisture belts as seen today or during 9,500-5,000 B.P. had ceased to exist. The decrease or absence of some of the so-called wet climate indicators such as *Mimosa ?rubicaulis, Oldenlandia* and *Typha* at Lunkaransar during 5,000-3,000 B.P. on the other hand suggests that the moisture gradient had continued to exist. Apart from this it would be important to determine if the increase was caused by increase in precipitation or decrease in summer temperature and if the increase as observed is factual or illusionary?

In the event of these conflicting inferences there is need to look into the views of Walter (1964) based on field work that the bush encroachment in a desert is the result of overgrazing rather than any change in climate. Very likely overgrazing has been responsible here too for the increase of bushy vegetation.

The increase in the density of shrubs and trees is usually accompanied by decrease in ground vegetation. Most amazingly the Rajasthan pollen diagrams exhibit increase both in the shrubs and trees and also in the ground vegetation comprising grasses, sedges and *Artemisia* suggesting that this visual increase may not either be factual or controlled by vegetational change but by a common factor affecting the enormous deposition of pollen of most elements comprising the vegetation. The significance of the occurrence of long distant pollen and that of ecologically incompatible plant species in the pollen diagrams may perhaps throw light on this common factor.

Pollen of ecological misfits & long distance pollen — The easily recognizable long distance pollen belongs to Himalayan plant species. Of these, *Pinus*-pollen makes a consistent curve. The behaviour of this curve may not be without significance. It records an over-all relative increase in all the pollen diagram during 5,000-3,000 B.P. A slight increase has also been observed at Lunkaransar prior to it during the middle of 9,500 to 5,000 B.P. Transported as pine pollen is by wind currents in this area, its increase over the usual is highly suggestive of relative increase in wind activity during 5,000-3,000 B.P. in the area extending from Sambhar to Lunkaransar. If the wind velocity had not increased then the other possibility is that in its source area (the outer Himalaya) the population of pines had increased or their belt had been pushed further down along the foot hills and plains. The latter could only happen if the Himalayas were affected by a neoglacial advance during the sub-Boreal. This aspect indeed deserves investigation in the light of the fact that in other parts of the world Neoglaciation and cooler oscillations (Priora oscillation) have been recorded about 4,600 B.P. and 5,350-4,950 B.P. respectively and one around 6,000-6,400 B.P. (the late Atlantic oscillation in SW Wisconsin & the Misox oscillation in Europe). The earlier oscillations are dated to 6,910 B.P. and 7,740 B.P. respectively (Wendland & Bryson, 1974).

The glaring ecological misfit is the *Syzygium** pollen which is prominently present at Sambhar during 5,000-3,000 B.P., though comparatively rarer at the other sites, although appearing slightly earlier there. It occurs in the *Mangifera-Syzygium-Ficus* series of Mount Abu and also in the *Acacia catechu-Anogeissus pendula* series of Rathambor (dist. Sawai Madhopur) and in the *Anogeissus latifolia* series of the Aravallis mostly along the streams. Soils are red ferruginous loamy rich in humus; annual precipitation 700-1500 mm with 8 months dry in a year. In the region of Badgaon, extreme SW of district Jalor water table is shallow and water 1·5 m below even under sand dunes. Here in spite of low rainfall, the vegetation presents an oasis aspect with *Syzygium cumini* and *Phoenix sylvestris*, coconut, banana, guava, papaya, mango and *Ziziphus nummularia* are also grown (Gaussen *et al.*, 1972). The occurrence of its pollen among those of *Calligonum* and *Prosopis-Capparis-Ziziphus* series which require precipitation from 150-400 mm indeed raises doubt about its genuine occurrence as a member of the natural vegetation. We have to have a convincing evidence to prove that it was planted by the inhabitants of Rajasthan living during 5,000-3,000 B.P. Obviously then its pollen was transported by wind from the Aravallis including Mount Abu and or from outside Rajasthan where its natural forests might have occurred. Its transport must have been caused by the high velocity winds which were prevalent during 5,000-3,000 B.P. as inferred from high values of pine pollen during this period of time.

That the sub-Boreal in the Rajasthan desert was a time of violent dust winds and storms becomes apparent. It was obviously a period of intense dryness, summer temperatures being high so as to cause dust storms. Such an environment would indeed be conducive for transport of pollen in greater numbers from within and outside the desert. The overall increase in pollen frequency of shrubs, trees, grasses, sedges and *Artemisia* could have equally been caused by the violent dust storms prevalent then. This would suggest that there was no factual increase in shrubby vegetation, the increase in pollen frequency was caused by the environment of violent winds.

During the hot season extending from March to May under the present meteorological conditions in India, the high pressure system running from Upper Sind across Rajasthan to Chhota Nagpur prevailing from December to February gradually breaks down and vanishes completely by the month of April. Around March, a low pressure trough develops centering round Multan (Pakistan) and stretching up to Chhota Nagpur and is completed by May. This depression is caused by the high temperatures occurring in Rajasthan (over 48°C), Gujarat (38°-48°C) and Madhya Pradesh causing in this area of the lowest air pressure the inflow of NESW winds from the north and northwesterly winds from the south. These violent winds are the cause of dust storms today. Both, the Himalayan plants and *Syzygium* of which pollen grains have been found during 5,000-3,000 B.P. flower during February-June when these violent dust storms are frequent.

Origin of Salinity and Fluctuations in Lake Levels

The problems concerning the history of the lakes, the fluctuations in their levels and the origin of salinity in them requires a detailed stratigraphical, geomorphological and geochemical studies. That in the same region there occur salt and fresh water lakes not far distant from each other (the sweet & salt water Ranns are the other groups of the sheets of water occurring not very far from one another in the Jaisalmer District), the attribution of salt in some of these to its aerial transport from the Arabian Sea does not appear convincing. Rather there is an indication of local haline deposits underlying these lakes and the origin of

*Its identity needs to be established.

some of these lakes as brine springs may not eventually prove off the mark. Deposits of halite at a depth of 541 m and more particularly between 553·3-556·4 m depth in Bikaner area (Sinha *et al.*, 1973) and at a shallow depth of 7·40 m in the Didwana salt lake area (Khandelwal, 1975) are highly suggestive of local source of salt below or around the salt lakes.

Exclusive pollen evidence in regard to the above problem howsoever of limited application may indeed be of ancillary importance. Pollen grains of plant species which thrive on saline soils (halophytes) do provide clues to the occurrence of saline conditions. However, more decisive information can be provided by their seeds and fruits if found in sediments as pollen can be derived from saline areas in the near and distant vicinity. Members of Chenopodiaceae, Tamaricaceae and of others distributed in Rajasthan today such as *Atriplex crassifolia*, *Chenopodium album*, *Cressa cretica*, *Haloxylon multiflorum*, *H. recurvum*, *H. salicornicum*, *Salsola foetida*, *Suaeda fruticosa*, *Tamarix dioica* and *T. troupii*, together with some salt tolerant grasses are indicative of salt concentration in soil. On less saline soils there occur *Salvadora persica*, *S. oleoides*, *Capparis decidua*, *Ziziphus* spp. and some grasses.

The curve for Chenopodiaceae may be safely taken to indicate the prevalence of salinity (strong concentration of salt or saline soils) and most probably around the margins of the salt lakes where these plants may have grown as they do today along the marginal areas of the Sambhar salt lake though poorly present around Didwana (Singh *et al.*, 1974, p. 481). The Chenopodiaceae curve therefore would reveal increasing marshy saline area around the Sambhar and Lunkaransar lakes from 10,000-9,500 B.P. At Lunkaransar the saline marsh increased between 9,500-6,000 B.P., a decrease occurred from 6,000 to 5,000 B.P. and another increase in saline marginal marsh took place after 5,000 B.P. The area exposed was much higher in the recent past. At Sambhar the exposed marshy area increased until about 6,000 B.P. when it declined to increase again about 4,500 B.P. The stray values of *Tamarix* at Lunkaransar occur before 9,500 B.P. and then from 5,500-4,500 B.P. In Sambhar they appear only after 4,500 B.P.

If the chenopods indeed grew along the shores of the lakes then the pollen evidence would suggest that the lakes receded to expose the marginal saline marsh which the chenopods had colonized but around 6,000 B.P. the lakes rose again. However, one cannot be certain of their growth immediately along the margins until their seeds have been recovered from the sediments. The inference from pollen would indeed remain plausible and tentative for fluctuations in lake levels.

Regarding the origin of the lakes the pollen evidence does suggest the occurrence and beginning of the lakes about 10,000 B.P. but how it had originated has to be discovered from detailed stratigraphy.

Among the aquatic plants in the Rajasthan pollen diagrams, *Typha angustata* constitutes a low pollen curve in all of them. Sporadic pollen grains of *Nymphaea* and *Potamogeton* have also been discovered though only in the Sambhar Lake pollen diagram. Of these, *Typha angustata* is both a fresh and brackish water species and the maximum salinity it can tolerate is 1·83% (Chapman, 1960). The species of *Potamogeton* remains unidentified. *P. pectinatus* which occurs in Rajasthan is also known to occur in shallow water along the shores of salt lake in the desert south-west of Baghdad (Chapman, 1960, p. 223). That *Nymphaea* can also occur in saline waters is not known to me. In view of the fact that water available in the desert of Rajasthan has a varying percentage of salinity and even drinking water in Barmer, Jodhpur, Jaisalmer, Bikaner in western Rajasthan and Bhilwara and Chittorgarh districts in eastern Rajasthan is saline, it would not be a surprise if *Nymphaea* may also be salt tolerant to some extent.

Thus, pollen grains of *Typha* and *Potamogeton* may at the same time indicate the former presence of saline conditions in these lakes. The case of *Nymphaea* needs further study. *Typha* is indeed more salt tolerant than the others. Its pollen has comparatively higher frequency than the sporadic occurrence of *Nymphaea* and *Potamogeton*. These are marshy plants though *Potamogeton* may occur in deep water. Apart from their indication of salinity howsoever limited it may be, their presence indicates the occurrence of a marsh with shallow or deep water.

However, it remains to be settled if their pollen is of local origin or transported; they have their flowers above water. *Typha* is a high pollen producer and near its locale and surroundings its pollen should be found in much higher frequencies than recovered. This would also depend upon its population, whether thick or thin or just a few stray plants. These problematic difficulties limit our usage of its pollen for environmental deductions. The plausible inference that can be drawn is that the lake was shallower until about 7,500 B.P. at Sambhar and until about 6,000 B.P. at Lunkaransar. The waters of these lakes were moderately salty and this fact should be ascertained through chemical analysis of the salt lake sediments. Salt has been found in samples of the Sambhar Lake mud at 1-12 ft depth (Aggarwal, 1951, p. 15).

Former Land Use — Plant Husbandry

The human and animal influence upon vegetation, another important area to which palynology and palaeobotany can contribute, requires basic knowledge of the way the vegetation is affected and reacts under the impact of this factor. It also requires sound knowledge of the criteria which distinguish pollen grains of the culture plants such as of cereals, legumes, etc. and of the weeds associated with them. In a forested region clearance of a forest in a pollen diagram is easily discernible but in a savannah where tree and shrub vegetation is much less, it is indeed difficult to determine the clearance phase. Presence of charcoal at certain levels, an evidence of burning of vegetation, may be indicative of destruction of vegetation with the purpose of land use but the evidence of the kind of vegetation destroyed by fire ought to be there. This event may be offset by the high pollen production of the herbs (grasses) in a savannah particularly if the episode has not been a large scale burning of vegetation. Burning of dry savannah vegetation (grassland) by lightening, though rare, cannot be overlooked (Walter, 1964, p. 227).

In the hitherto published pollen diagrams from Rajasthan desert the charcoal fragments have been found spread over the entire profiles of the lakes investigated; the evidence for farming has been found in the cerealia type pollen which appeared first at 8,000 B.P. together with a pollen of a weed of fallow land. The practice of shifting cultivation has been inferred.

The charcoal fragments, 10-100 μm in size, have been counted in Rajasthan pollen diagrams and their curves show small and large fluctuations, which by no means can be taken to suggest the intensity of burning for the simple reason that a small charcoal piece if blown into the lake may disintegrate into numerous smaller fragments. What did they burn ? and was it a selective burning or indiscriminate burning ? If the lakes were fresh water, man may have chosen to live beside them for the potable water was available and if they were saline he would not have selected the environment of these salt lakes for his camping sites. Much positive information is needed to answer several such questions and other interdisciplinary evidence must be sought. The Mesolithic peoples — the hunters and food gatherers inhabited Rajasthan until 3,000 B.C. (Misra, 1970, 1971). Were they cattle breeders and graziers at the same time ? The animals grazing on a grassland prefer the young shoots of grasses, the old tufted grasses are usually spared which are burnt from time to time to enable the growth of young plants, the shoots of which are preferred by the grazing animals. Was this practice prevalent throughout the Holocene history of the Rajasthan desert ? If proven this may possibly explain the presence of charcoal fragments.

In the event of scarcity of vegetation during droughts even the unpalatable grasses may be eaten by cattle as it happens today in Rajasthan. The top feed may be obtained from the shrubs and trees such as *Acacia*, *Prosopis cineraria*, *Salvadora* and *Ziziphus nummularia* and several other trees and shrubs. Apart from grasses such herbs as *Atriplex* sp., *Suaeda fruticosa* (a halophytic plant), chenopods, and species of *Portulacca*, *Crotolaria*, *Indigofera*, *Tephrosia* and even *Calotropis* may not be spared. Sheep, cattle and goats are the ubiquitous consumers and amongst the wild artiodactyles, gazelle, black buck, blue bull, hares, rodents, bats, birds and insects are the consumers in Rajasthan today. It indeed needs a good deal of work to infer evidence in regard to the above and also to the more certain cause for the presence of charcoal fragments throughout the profiles. The impact of this on vegetation at the moment seems to be obscure in the pollen diagrams.

It may indeed be of interest to record that the charcoal fragments dominating 130-220 cm at Lunkaransar far outnumber those found at the other two sites (up to about 400% in Lunkaransar; up to 200% at Didwana, and upto 160% at Sambhar).

The cerealia-type pollen could as well belong to some wild grasses which as a result of natural mutations may have been transformed into polyploids producing large sized pollen rather than to primitive cereals of which pollen is not distinguishable from the wild grasses (Vishnu-Mittre, 1973). In regard to the cerealia type pollen, Singh *et al.* (1974) state that " either some sort of primitive cereal cultivation had begun or the area was invaded with wild grass species producing large-sized grass pollen ". The latter possibility may be correct or as suggested above natural hybrids of grasses might have emerged. No primitive cereals occur today nor the possibility of their former occurrence in India is borne out by geographical surveys of the cereals and their progenitors except that of rice which today does not grow in the desert of Rajasthan (Vavilov, 1951). Further their pollen as stated above cannot be distinguished by light microscopy from that of the wild grasses (Vishnu-Mittre, 1973).

The single pollen grain of *Spergula rubra* a weed of fallow lands along with the first cereal type pollen at 8,000 B.P. is not recorded subsequently even when cereal type pollen curve attains good frequency and particularly none from the levels dated from 5,000 B.P. to 3,000 B.P. which find correspondence with the Harappans culture when definite evidence of farming and of cultivated crops is known. It indeed casts doubt if the single pollen of *Spergula rubra* has been identified properly or else it may be dismissed as a contaminant.

Thus, the event of the earliest farming through palynology remains undemonstrated. The mystery of the charcoal fragments remains unsolved. It does indicate burning and there is nothing more that we can make of it, the evidence at hand being not clear and positive.

The earliest evidence of land-use in western Rajasthan comes from the Harappans who lived at Kalibangan in Bikaner District. They tilled the land (Lal, 1970-71) and grew barley and *Pisum arvense*. The barley discovered is the typical small sized grain suited to arid climate (Vishnu-Mittre, 1974c). We have no information of the plant economy of the Rangmahal culture (A.D. 700-800) in the north of Bikaner.

Pollen of *Cannabis sativa* (Bhang) has been recorded at 170-180 cm at Lunkaransar approximately dated to about 6,000 B.P. This stray pollen could have been blown in from elsewhere where *Cannabis* may have occurred as a wild plant, or perhaps it had occurred not far from the vicinity.

CONCLUSION

The discussions in the foregoing pages amply demonstrate that the exclusive pollen and other botanical fossil evidence if properly interpreted can provide useful information on biology, meteorology and climatology of the past on certain geomorphological problems and on land-use and agriculture — important aspects concerning the history and palaeoecology of the Rajasthan desert.

The Holocene history of the Rajasthan desert comprised of gradually rising temperature. Until 5,000 B.P. because of rising summer temperature slight humid climate had prevailed which showed an increasing trend towards dryness. The physiognomy of vegetation was of a shrub-savannah type — a grassland savannah with sprinkling of bushes and trees. From 5,000-3,000 B.P. maximum warmth and dryness had prevailed and the environment of high velocity winds and dust storms characterized the hypsithermal period. The rainfall was within the range of 150-400 mm, and from the extreme west of the desert to its east a moisture gradient had occurred. It is during this period that the formation of sand dune activity had encroached upon the eastern tracts of the desert.

The desert vegetation comprised of the *Calligonum* series and *Prosopis-Capparis-Ziziphus* series in the vicinities of Lunkaransar, Didwana and Sambhar, and in addition to these *Anogeissus-Acacia* series in the vicinity of Pushkar Lake.

The salt lakes which had originated about 10,000 years ago had most probably high salt content in their waters though perhaps less than they have today. A trend in the recession of lakes from 9,500-6,000 B.P. with a rise in lake level between 6,000-5,000 B.P. perhaps comprised the history of the lakes.

Evidence of disturbance and burning of vegetation and grazing of animals characterized the early part of the Holocene though much positive evidence remains to be brought out. The earliest farming episode did not precede 5,000 B.P., though pollen evidence is still obscure. The progressive evolution of vegetation towards the formation of *Calligonum-Capparis* series in the vicinity of Lunkaransar and of *Capparis-Prosopis-Acacia* and *Euphorbia* in the vicinity of Sambhar Lake is suggestive of increasing aridity, spread of aolian sand and extension of the dune formation activity ever since 5,000 B.P. or even earlier. This large scale desertification was caused not only by the climatic factors but also by the increasing biotic factor (human influence and overgrazing).

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