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LATE QUATERNARY HISTORY OF VEGETATION AND CLIMATE OF THE RAJASTHAN DESERT, INDIA

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The results from stratigraphy, radiocarbon dating and pollen analysis of three salt-lake deposits at Sambhar, Lunkaransar and Didwana in western Rajasthan, and one freshwater lake deposit at Pushkar in the Aravalli Hills, are described in conjunction with pollen analysis of some archaeological soil samples from the Indus Valley site at Kalibangan in northern Rajasthan. The salt-lake deposits studied are stratigraphically divisible into (*a*) pre-lacustrine, (*b*) lacustrine and (*c*) post-lacustrine sections. The pre-lacustrine section is characterized by a thick bed of aeolian sand underlying lacustrine sediments, while the lacustrine and post-lacustrine sections are broadly circumscribed by laminated clay and non-laminated silt respectively.

The pollen record from the four lake profiles studied is divided into local pollen zones. Four regional pollen assemblage zones are delineated for the area west of the Aravalli Range in Rajasthan. The environmental history deduced from the pollen record is divisible into phases I–V, of which phases II–V follow the regional pollen assemblage zones. Phase I is stratigraphically determined, and is representative

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of severe arid environments under which the sand dunes, now stabilized, are suggested to have been active. The plant microfossils first appear in phase II with the deposition of lacustrine sediments dated to around 10000 B.P. The vegetation comprises an openland steppe which is rich in grasses, *Artemisia* and sedges and poor in halophytes. *Artemisia*, *Typha angustata*, *Mimosa rubicaulis* and *Oldenlandia*, which now grow under areas of comparatively higher average annual rainfall (above 50 cm), appear to have flourished in the semi-arid belt, while the first two plant taxa had encroached even as far as the arid belt, both suggesting that a general westward shift of the rainfall belts had taken place. Vegetation destruction through burning by man is suggested to have started together with the first occurrence of Cerealia-type pollen at about 7500 B.C. and continued thereafter throughout phases III and IV. The increase in swamp vegetation and the intensification of vegetation cover inland together with the maxima of all mesophytic elements in phase IV (*ca.* 3000 B.C. to *ca.* 1000 B.C.) indicate an increase in the rainfall, apart from a short relatively drier time about 1800–1500 B.C. at Sambhar which correlates with the decline of the Indus culture in northwest India. Phase IV is immediately followed by aridity for which there is stratigraphic evidence that the salt lakes started drying. At Pushkar, there is evidence that the vegetation showed a marked change in the Aravallis. The onset of this aridity is suggested to have been widespread. The climate did not ameliorate until about phase V (? early centuries A.D. to present) at which time the Rangmahal culture perhaps flourished in Rajasthan, the remains of which imply good water supply.

In conclusion it is suggested that the Rajasthan desert is primarily natural, its history punctuated by at least one more vegetated, humid period during the Holocene, the climatic control of which as indicated by the vegetation history is consistent with climatic events elsewhere in the world.

Introduction

The Rajasthan desert in northwest India, otherwise known as the Rajputana Desert, and apparently an eastward extension of the Saharo-Arabian Desert in the west, centres on the very dry area (less than 10 cm annual rainfall) known as the Thar (figure 1). Seen in the context of the overall climate of the northern states of the Indian subcontinent, the Rajasthan desert assumes an anomalous position in the sense that its climate is just the opposite to that of the high rainfall area in east and northeast India, even though the two regions have so many similar climatic controls (Trewartha 1961). This contrasts, however, with the situation during the Early Tertiary when the Rajasthan territory is known to have harboured tropical rainforest taxa such as *Mesua*, *Garcinia* and *Cocos* (Lakhanpal & Bose 1951; Kaul 1951; Singh 1969). Obviously this raises the question as to how and when the Rajasthan desert originated and whether it is 'man-made' or is the result of natural phenomena, or both. Geographically, however, the Great Indian Desert, most of the western part of which is now in Pakistan, and of which the Rajasthan desert is the Indian counterpart, is situated in the normal latitudes of the subtropical winter anti-cyclones and the deserts associated with them. The shallow monsoon current of humid air crossing the area in the summer months fails to register itself in the form of any significant precipitation because the main body of the monsoon current from the Bay of Bengal barely reaches the arid west after having shed most of its moisture along the Himalayan belt and the adjacent plains, and the southwestern current from the Arabian Sea meets no major obstruction, as the Aravalli range is alined parallel with the direction of the monsoon current. Recently, it has been suggested that if the atmospheric subsidence over the desert area were less, the moist monsoon layer would be deeper and the slight summer rainfall maximum would be considerably higher (Trewartha 1961; Bryson & Baerreis 1967). This is in line with Sawyer's earlier observations that the desert coincides with the extent of divergent, sinking air at about 320 m (10000 ft) (Sawyer 1947). Bryson, Wilson & Kuhn (1964), who measured the radiation divergence in the troposphere and also carried out aerosol studies over northern India, suggest that the high density of atmospheric dust over Rajasthan leads to a rise in the mid-tropospheric subsidence rate by perhaps 50%. They therefore conclude that, in the absence of dust, there would be less subsidence and a deeper monsoon layer and in turn more rainfall in the Rajasthan desert. It is argued by the same authors that if the source of the dust is the desert itself, the desert would appear to be self-sustaining and steps taken to inhibit the raising of dust would help to reverse the entire cycle and lead to the reclamation of the desert (Bryson & Baerreis 1967). In order to test the above hypotheses it was necessary to find out whether any wetter conditions existed in the recent past in this region and also whether the raising of the dust had in some ways been influenced by the progressive destruction of vegetation by man since the introduction of agriculture in the area. It was also essential to know whether the onset of aridity was in any way synchronous with a period of intensive devegetation during the sub-recent times.

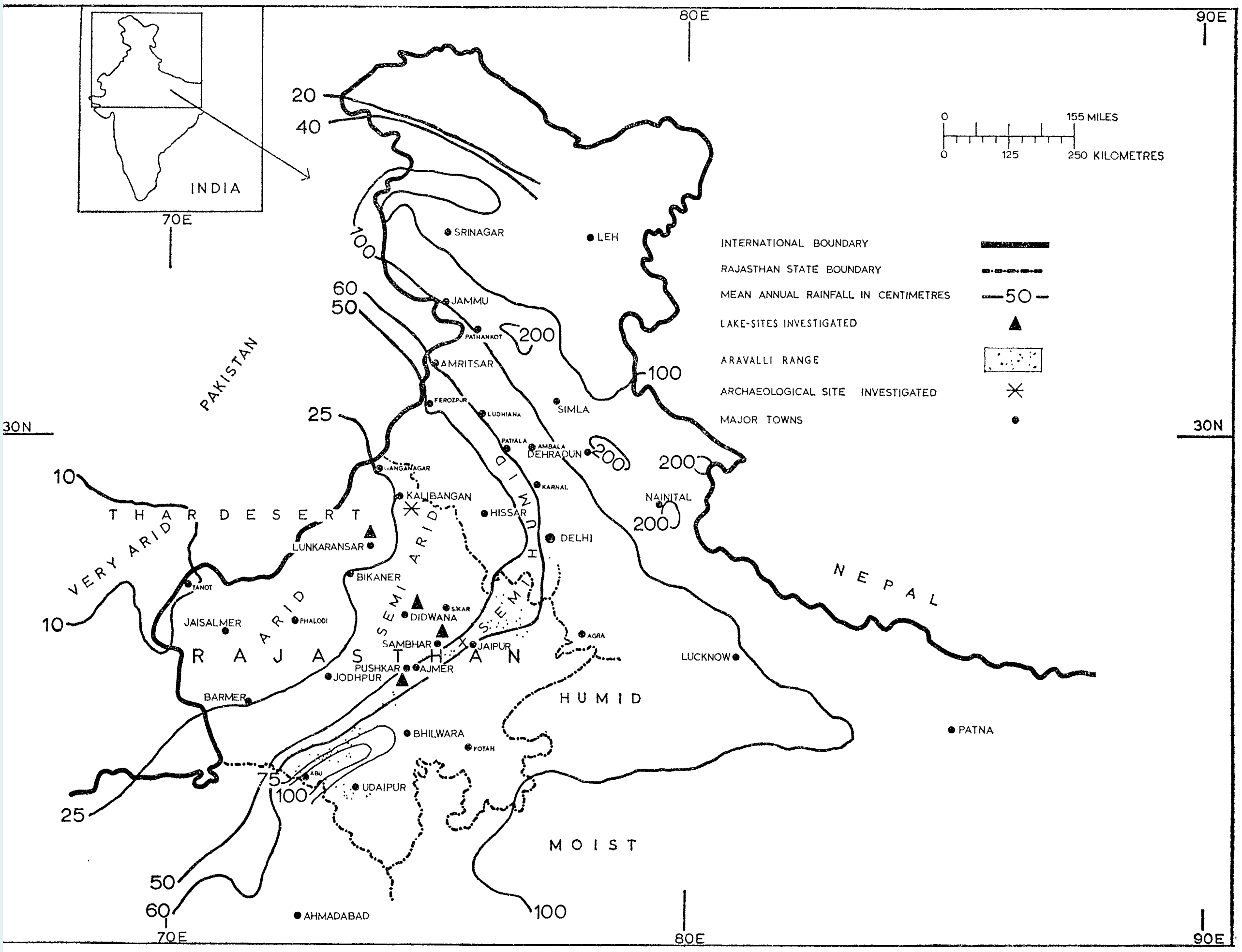

Figure 1. Map of northwestern India, showing broad climatic belts based on mean annual rainfall, and the location of sites investigated. The belts shown are 'very arid' (below 10 cm), 'arid' (10–25 cm), 'semi-arid' (25–50 cm), 'semi-humid' (50–60 cm), 'humid' (60–100 cm), and 'moist' (above 100 cm). The four lake sites investigated lie astride the arid, semi-arid and semi-humid belts.

A set of three dry salt-lakes at Sambhar, Lunkaransar and Didwana in western Rajasthan, and one freshwater lake at Pushkar in the Aravalli Hills in eastern Rajasthan, located approximately along a transect running in the NW–SE direction through arid, semi-arid and semi-humid belts of northwestern India, were selected for pollen analysis (figure 1). A few soil samples from pre-Harappan levels of the excavated Harappan site at Kalibangan, in Rajasthan, were also pollen-analysed. Besides, studies on surface samples were undertaken all over northwest India (Singh, Chopra & Singh 1973) with a view to fixing broad criteria for marking changes in vegetation and climate. Some results of the investigations have been reported briefly without the pollen diagrams (Singh 1967, 1971; Singh, Joshi & Singh 1972).

Description of the area

The territory covered by the present investigations consists of the State of Rajasthan, 20° 3′ N to 30° 12′ N and 69° 30′ E to 78° 17′ E, which is broadly subdivided into two large geographical units by the Aravalli Range running in the northeast–southwest direction (figure 1) (see Singh 1971).

The solid rocks of the area are mostly hidden under a mantle of desert sand. Those rising above the sand dunes are mostly ascribed to the Pre-Cambrian and Vindhyan systems. At a few sites are exposures of the Talchir boulder-beds, and sandstones of the Damuda and Mahadeva Series (Krishnan 1952). Most extensive of all, however, is the unconsolidated veneer of the Quaternary deposits. The sand-hills are alined parallel with the direction of the monsoon running SW–NE and ENE–WSW, and rise to a height of *ca.* 150 m and more. They are higher in the west than in the east, where they spread out into a thin veneer to produce the extensive semi-arid transitional plain known as the Pat (Pithawalla 1952). This section, which is broadly delimited by the 25 cm and 50 cm isohyets in the west and east respectively (figure 1), is characterized by the occurrence of several salt lakes. The salt lakes remain dry during the summer months, when the superficial crust breaks into a network of polygonal areas and the seasonal horizontal layering of the sediment is obliterated. The process of drying also results in the more or less complete oxidation of the organic content in the sediment including the pollen grains.

The Aravalli Range bordering the area in the east does not form a continuous range and has a number of wind gaps as near the Sambhar Salt-lake, east of Sikar and between Ajmer and Beawar. The sand from the west, which normally piles up high against the southwestern flanks of the Aravalli Range, blows right through these gaps to the other side (Misra 1967). The range acts as the watershed in the region but also forms an effective boundary between the western desert flora on one hand and the largely Indo-Malayan eastern flora on the other (Singh *et al.* 1973). During prehistoric times the range appears to have acted as a divide between the ancient cultural regions of the Indus and the Ganges. Its height varies from 460–920 m above sea-level, with the highest peak reaching 1720 m at Gurushikhar near Mt Abu. The Aravalli Range, because of its comparatively higher rainfall, is endowed with a number of freshwater lakes which in most cases have now been transformed into artificial reservoirs.

The climate of Rajasthan has been discussed in some of the earlier publications (Singh 1971; Singh *et al.* 1972, 1973). The mean annual rainfall gradually drops towards the core centring on the Thar desert, which has less than 10 cm annual rainfall (figure 1). The northern parts of Rajasthan, receiving comparatively more rainfall in the winter months, show a correspondingly higher relative humidity than the southerly placed localities. This has partly resulted in a slight amelioration of winter aridity in northern Rajasthan and southern Punjab as compared to the areas situated in the south and southwest. The whole of northwest India is visited by periodical dust storms and large concentrations of atmospheric aerosol are seen over the area, especially during the pre-monsoon season (Kendrew 1942). Reconnaissance flights over Africa, Middle East and northwest India have revealed that a thick layer of deep dense dust over North Africa

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and Arabia, during the spring months, appears to thin eastward along the southern coast of Iran and Baluchistan but becomes very dense and deep over the Rajasthan desert; from there it appears to diminish southward and eastward (Bryson & Baerreis 1967).

The vegetation has already been described in relation to the present pollen rain of the region (Singh *et al.* 1973). The vegetation of the Rajasthan desert and its surrounding areas has so far been described solely on the basis of edaphic variables (Blatter & Hallberg 1918–21; King 1879; Agharkar 1920; Sarup 1952; Puri *et al.* 1964) and there is little information on the precise geographical limits of the species growing there. Besides this the large-scale decimation of the natural vegetation through the agency of man from times immemorial has obliterated the original conditions. Forests are lacking and open woodlands are confined to the uplands in the Aravallis, or the river courses in the north. Herbaceous vegetation is overwhelmingly dominant in the very arid, arid and the semi-arid belts though there is a progressive increase in the tree vegetation accompanying a rise in the rainfall (Singh *et al.* 1973). Among the woody plants, shrubs are dominant in both the very arid and arid belts whereas trees dominate in the semi-arid, semi-humid, humid and moist belts. The trees, however, are mostly heavily lopped. The natural occurrence of aquatic freshwater species is confined to areas north and east of the 50 cm isohyet except under artificial conditions.

King (1879) divides the vegetation of this territory into the generally mesophytic east of the Aravalli and the mostly xerophytic west of the Aravalli. The vegetation of the dividing range itself is considered to resemble that of the eastern rather than that of the western tract. In general terms, a western (Perso-Arabian), an eastern (Indo-Malayan) and a more general element (including purely Indian species) can be distinguished occupying the two parts (Biswas & Rao 1953). The western is constituted of nearly 200 species and the eastern of only 30 species resulting in the overall preponderance of the western element in the flora of Rajasthan. The line dividing these two major phytogeographical units, the Perso-Arabian and the Indo-Malayan, passes along the Aravalli Range (Drude 1890); it also roughly follows the 50 cm isohyet (figure 1); the line in approximate terms. In view of the critical nature of this boundary, any recognizable shift of it recorded in the history of the vegetation, and defined by the two floras, is diagnostic of a change of climate. The choice of the sites selected for investigation was clearly influenced by the above considerations.

Methods

Field work

Stratigraphical studies in the salt lakes were carried out by digging pits in the dry bed of the lake basins. The profiles thus exposed were sampled for pollen analysis at 2.5–10 cm intervals. For radiocarbon datings, short monoliths, measuring 10–15 cm in thickness, were obtained from the same face as the samples for pollen analysis. At Pushkar, the only freshwater lake studied, the sampling was carried out by means of a 'Hiller' borer, equipped with a 50 cm long chamber. The levelling was done by means of an ordinary dumpy level.

Laboratory techniques

The samples were prepared for pollen analysis following the usual techniques of Erdtman (1943), slightly modified. In each case about 10 g of material were used. Each sample was first boiled in 10 % potassium hydroxide solution for 5 min. After washing the material several times with water, the coarser sand was eliminated by decantation after settling for about 10 s. The finer fraction was then transferred to polythene tubes and treated with 40 % hydrofluoric acid for 5–10 days, depending on the amount of silica present. This was followed by washing the residue once with dilute hydrochloric acid (1 part concentrated HCl in 2 parts of water) and twice with water. After this the sample was acetolysed as usual. The material was mounted in 50 % glycerine.

The material for radiocarbon dating consists mostly of charred wood fragments embedded in the sedimentary profile. A bulk sample from the monolith was first freed of carbonates, if any, by dilute hydrochloric acid and then washed twice with water. After the removal from coarse sand by decantation, the residue was treated with 40 % hydrofluoric acid for 10–15 days in large polythene jars. This was followed by washings, once with dilute hydrochloric acid (1 part HCl in 2 parts of water) and several times with water. Afterwards the material was dried to form cakes in large-size petri dishes.

At least 400 land-plant pollen grains were counted from each sample; the number was reduced to 300 in the case of the Lunkaransar pollen profile where pollen was rare and very occasionally to 150. All percentages are based on total land-plant pollen excluding Cyperaceae. The box in the middle of each pollen diagram, besides the a.p./n.a.p. curve, also includes a curve each for the combined pollen of freshwater aquatics and Cyperaceae. In the latter case the percentages are based on total land-plant pollen including Cyperaceae. In order to perceive small-scale changes in the curves of elements represented in low frequencies, an exaggerated curve ($\times 5$) has been provided for each, the original curves being filled in black and the exaggerated curves by a line connected by horizontal lines to it; the horizontal lines represent the levels of the samples taken from the profile.

A curve showing frequency of carbonized wood fragments, measuring individually between 10 and 100 μm per unit area of the pollen slides for each sample, has been provided from samples at 20 cm intervals in the pollen diagrams from Sambhar, Lunkaransar and Didwana, with a view to estimating the relative frequency of scrub burning during the time span of each of the three pollen sequences.

Zonation of pollen diagrams

Pollen-analytical studies of Late Quaternary sediments in north India have so far been confined mainly to temperate and subtropical montane areas in the Himalayas whose pollen sequences have little in common with the Rajasthan pollen diagrams. The zonation of the present diagrams is therefore independent of other areas in India, and is based on the recognition of biostratigraphic units (pollen assemblage zones) from the pollen stratigraphy of each of the profiles studied. The divisions from each site are independent of one another and have been termed local pollen zones, prefixed with the site initials SM, LK, DW and PS, and numbered from below upwards (figures 4, 6, 8, 9). Later on an attempt has been made to compare and correlate the different pollen sequences on the basis of broadly identical vegetation shifts and radiocarbon dating of the individual profiles investigated resulting in the delimitation and description of a series of regional pollen assemblage zones for the area west of the Aravalli Range. At Pushkar, where there is no radiocarbon evidence available from the sedimentary profile pollen analysed, the local pollen zones established in the pollen diagram have been compared with the regional pollen assemblage zones from western Rajasthan on the basis of regional parallelism (Godwin 1956), in the Discussion. In accordance with the common practice (following the American code of stratigraphic nomenclature (American Commission on Stratigraphic Nomenclature 1961), the regional pollen assemblage zones have been termed after particularly outstanding or diagnostic pollen types and they have been defined at a specific type locality and section. The zones drawn are, however, informal in the strictest sense of the code.

The present system of zonation replaces the tentative zonation of pollen diagrams followed in the earlier publications (Singh 1971; Singh *et al.* 1972).

The local pollen zones at Sambhar (*figure* 4)

Zone SM-1 (325–355 cm). Pollen is seen for the first time in this zone, which is also the lowest. Cyperaceae and Gramineae pollen occurs in high frequencies, 20–115 % and 60–85 % respectively. Chenopodiaceae–Amaranthaceae, hereafter mentioned as Cheno–Ams, show low pollen values (1–5%). *Artemisia* is well represented (15–40 %). *Mimosa rubicaulis* pollen is seen up to 7 %. *Oldenlandia* and *Typha* pollen occurs up to 5 % and 12 % respectively, from about the middle of the zone. The total tree and shrub pollen values do not exceed 6 %.

The age for the lower zone boundary, which also coincides with a stratigraphical change from loose sand to laminated clay, is extrapolated at *ca.* 10300 B.P. from two radiocarbon dates, 9250 ± 130 B.P. (TF-887) and 8835 ± 140 B.P. (TF-698) (figure 4), obtained from levels above the stratigraphical break.

Zone SM-2 (165–325 cm). Cyperaceae pollen frequencies fall and remain mostly between 20 and 30 %. Gramineae pollen values decline whereas those of *Artemisia* rise; the latter remaining mostly steady around 40 %. The pollen of Cheno–Ams shows an overall rise and its curve stays mostly between 5 and 10 % in the lower half but declines thereafter. *Oldenlandia* pollen forms a continuous curve and its frequencies rise up to 4 %. *Typha* also forms a continuous pollen curve in the lower half but later on its curve shows frequent breaks. *Maytenus* and *Mimosa rubicaulis* form almost continuous curves but their frequencies do not rise above 2 %. The pollen frequencies of total tree and shrub pollen stay below 6 %.

The age for the lower zone limit is extrapolated at *ca.* 9500 from the two radiocarbon dates mentioned earlier (TF-887 and TF-698) (figure 4).

This zone has been subdivided into two subzones:

Subzone SM-2*a* (220–325 cm). The Cyperaceae pollen values remain consistently low in this subzone whereas those of Cheno–Ams remain at a high level.

Subzone SM-2*b* (165–330 cm). The pollen curve for Cheno–Ams shows a steady decline whereas that of Cyperaceae exhibits an overall rise. The date for the base of the subzone is interpolated at *ca.* 7000 B.P. from two radiocarbon dates 8300 ± 135 B.P. (TF-738) and 6235 ± 315 B.P. (TF-884) (figure 4).

Zone SM-3 (105–165 cm). The upper zone limit is determined by the lack of pollen in the sediment above the 105 cm level. The zone begins with a sudden rise in the pollen values of Cyperaceae and the tree and shrub pollen ratios. The pollen frequencies of Gramineae show an overall decline. The Cyperaceae values remain very high, ranging from 100 to 500 %. There is a general increase in the pollen frequencies of *Capparis*, *Prosopis cineraria* and *Acacia*, and the pollen of *Syzygium* occurs for the first time in this zone.

The date for the lower limit for zone SM-3 has been interpolated at *ca.* 5000 B.P. from two radiocarbon dates, 6235 ± 315 B.P. (TF-884) and 4665 ± 115 B.P. (TF-739), from below and above the zone boundary respectively (figure 4).

The zone has been subdivided into three subzones:

Subzone SM-3*a* (130–165 cm). The pollen of Cyperaceae, *Artemisia*, *Mimosa rubicaulis*, *Syzygium* and that of the trees in general attains highest values and that of Gramineae the lowest.

Subzone SM-3b (120–130 cm). The pollen values of Cyperaceae, *Artemisia* and tree and shrub fall whereas those of Gramineae rise once again. The date for the base of the subzone has been extrapolated at *ca.* 3800 B.P. from two radiocarbon dates, 4665 ± 115 (TF-739) and 4510 ± 110 (TF-883) (figure 4), from below the lower boundary

Subzone SM-3c (105–120 cm). Cyperaceae, *Artemisia* and *Capparis* frequencies rise and those of Gramineae decline. The dates for the lower and the upper boundaries of the subzone have been extrapolated at *ca.* 3450 B.P. and *ca.* 3000 B.P. respectively from the two radiocarbon dates mentioned above (TF-739 and TF-883, figure 4). The upper limit of subzone SM-3c at 105 cm is determined by the lack of pollen in the sediment above that level.

The local pollen zones at Lunkaransar (figure 6)

Zone LK-1 (230–255 cm). Pollen occurs for the first time in this zone. Cyperaceae and Gramineae pollen frequencies rise and reach up to > 115 % and 79 % respectively. Cheno–Ams pollen is lowly represented (3–10 %). *Artemisia* rises to 25 % at the beginning but falls off to a steady 12–13 %. *Typha* pollen occurs from 2–4 %. The total tree and shrub pollen frequencies do not exceed 10 %.

The date for the lower zone boundary, which is also determined by a change in the stratigraphy from loose sand to laminated clay, has been extrapolated at *ca.* 10300 B.P. from the subsequent radiocarbon-dated horizons in the profile (WIS-405, WIS-386 and WIS-387) (figure 6).

Zone LK-2 (130–230 cm). Cyperaceae pollen frequencies fall and maintain values between 50 and 85 %. Gramineae pollen values stay at a high level (50–80 %). *Artemisia* maintains a more or less steady pollen curve around 10 %. Cheno–Ams pollen shows an overall increase in its frequencies but follows a fluctuating curve. The pollen of *Typha* continues to occur mostly regularly attaining frequencies up to 8 %. The frequencies of total tree and shrub pollen do not exceed 10 %.

The lower border of zone LK-2 is dated at *ca.* 9260 ± 115 (WIS-405).

The zone has been subdivided into two subzones:

Subzone LK-2a (180–230 cm). The pollen frequencies of Cyperaceae are on the decline for most of this subzone. The values for Cheno–Ams pollen mostly remain comparatively high.

Subzone LK-2b (130–180 cm). The pollen curve for sedges starts to recover in this subzone. Cheno–Ams maintain comparatively lower frequencies than in subzone SM-2a.

The age for the lower subzone boundary has been interpolated at *ca.* 7000 B.P. from the three radiocarbon dated horizons in the profile (WIS-387, WIS-386 and WIS-405 (figure 6).

Zone LK-3 (100–130 cm). The pollen curve for Cyperaceae shows a consistent rise and attains its highest values. The curve for Gramineae declines temporarily. There is a sudden rise in the values of tree and shrub pollen. *Artemisia* shows some rise in its pollen frequencies.

The age for the lower limit of zone LK-3 has been interpolated at *ca.* 5200 B.P. from two radiocarbon dates 5420 ± 70 B.P. (WIS-386) and 5060 ± 70 B.P. from below and above the zone boundary respectively (figure 6). The date for the upper limit of the zone at 100 cm, which is determined entirely owing to the lack of pollen in the sediment above that level, is extrapolated at *ca.* 4000 B.P. from the radiocarbon dates mentioned earlier.

Zone LK-4 (0–30 cm). The beginning of this zone is determined by a resumption in the occurrence of pollen at the 30 cm level in the Lunkaransar profile. The pollen frequencies of Cheno–Ams, *Calligonum*, *Capparis* and *Aerva* show a prominent rise. The tree-pollen frequencies are extremely low but those of shrubs remain high (15–30 %). The Cyperaceae pollen curve rises but remains at a comparatively lower level than in the earlier zones. *Artemisia* and *Typha* pollen occurs in extremely negligible numbers.

The date for the lower limit of zone LK-4 is unknown. But if it can be assumed that the rates of deposition did not vary significantly since the times of zones LK-1–3, then the date for the boundary can be extrapolated at about 1200 B.P. from the radiocarbon dated levels in the lower part of the profile (WIS-387, WIS-386 and WIS-405) (figure 6). The zone is divisible into two subzones.

Subzone LK-4a (20–30 cm). The pollen curve for Cheno–Ams attains its highest level (38 %). Gramineae declines whereas Cyperaceae, *Aerva* and shrub pollen maintain low frequencies.

Subzone LK-4b (0–20 cm). The pollen frequencies for *Calligonum*, *Capparis*, *Aerva*, Cyperaceae and shrubs in general rise whereas those of Cheno–Ams decline. The date for the lower boundary can be extrapolated to *ca.* 800 B.P. provided the rates of sedimentation remained the same as in the previous zones.

The local pollen zones at Didwana (figure 8)

Zone DW-1 (195– 315 cm). This is the first zone in which pollen is found preserved from the base upwards. The pollen frequencies of both Gramineae and *Artemisia* are high remaining between 29–45 % and 18–38 % respectively. Cheno–Ams pollen values are high at first but later decline. The Cyperaceae pollen curve is low but shows a gradual upward trend. *Typha* and *Oldenlandia* pollen is present in significant numbers from the beginning of the sequence. The tree and shrub pollen frequencies remain extremely low (< 5 %).

The date for the lower limit of zone DW-1 is unknown. There is only one radiocarbon date 2970 ± 65 (WIS-415), from the entire pollen sequence (figure 8). Assuming, however, that the top surface of the lake deposit represented the zero date and that the rate of sedimentation remained the same as between the surface and the radiocarbon dated horizon, the date for the base of the pollen sequence could be estimated at about 7550 B.P.

The zone is divisible into two subzones.

Subzone DW-1a (230–315 cm). Cheno–Ams pollen values fluctuate between 3 and 15 %. Cyperaceae pollen remains less than 58 %.

Subzone DW-1b (195–230 cm). The pollen curve for Cheno–Ams declines and that of Cyperaceae rises further to 80 %. The tree and shrub pollen curve shows a slight improvement. The date for the beginning of the subzone is unknown.

Zone DW-2 (110–190 cm). The pollen curve for sedges shows a rapid rise and attains its highest values reaching to 514 %. The tree and shrub pollen frequencies increase progressively and achieve their maximum extent and importance. *Artemisia* declines.

The date for the base of the zone is unknown. The zone ends at 110 cm where the pollen ceases to be preserved in the sediment.

The local pollen zones at Pushkar (figure 9).

Zone-PS-1 (310–390 cm). Among the trees and shrubs the pollen of *Anogeissus* is by far the most dominant. The tree pollen curve shows up to 15 %. The pollen of *Calligonum*, *Maytenus*, *Ephedra*, *Capparis*, *Ziziphus*, *Prosopis cineraria* and *Salvadora* is seen only sporadically.

The date for the base of the zone is unknown.

The zone is divisible into three subzones.

Subzone PS-1 a (370–390 cm). The *Anogeissus* and tree and shrubs pollen frequencies are at a high level.

Subzone PS-1 b (335–370 cm). The curve for *Anogeissus* drops to < 5 %. Similarly the tree and shrub pollen values fall to < 5 %.

Subzone PS-1 c (310–335 cm). The *Anogeissus* and the tree-pollen frequencies rise once again together with a rise in the frequencies of desert shrubs, such as *Calligonum*, *Maytenus* and *Capparis*.

Zone PS-2 (150–310 cm). The *Anogeissus* pollen curve declines and follows a broken course. The pollen of *Calligonum*, *Maytenus*, *Capparis*, *Prosopis cineraria* shows a corresponding rise in its frequencies. The total tree and shrub pollen curve remains at a low level. The Gramineae pollen curve attains its maximum extent and importance.

The date for the base of the subzone is unknown.

Zone PS-3 (0–150 cm). *Anogeissus* pollen frequencies start to rise once again together with a rise in the values of *Ficus* whose pollen hitherto occurred only sporadically. The pollen of *Calligonum*, *Maytenus*, *Ephedra*, *Capparis* and *Prosopis cineraria* declines in the upper half of the zone. The total tree and shrub pollen curve rises in comparison to zone PS-2.

The date for the base of the zone is unknown.

The zone is divisible into two subzones:

Subzone PS-3 a (70–150 cm). The pollen of desert elements *Calligonum*, *Maytenus*, *Ephedra*, *Capparis* and *Prosopis cineraria* continue to occur uninhibited by the rise in *Anogeissus* and *Ficus* pollen frequencies.

Subzone PS-3 b (0–70 cm). All the above-mentioned desert elements, except *Ephedra*, fall and later almost disappear from the pollen sequence. Both *Anogeissus* and *Ficus* attain almost their highest pollen values in this subzone.

The date for the base of the subzone is unknown.

Regional pollen assemblage zones

The local pollen zones delimited in the pollen diagrams from the salt lakes at Sambhar, Lunkaransar and Didwana, all situated within the xerophytic flora to the west of the Aravalli Range in Rajasthan (figure 1), are broadly similar and form a basis for the delimitation of a series of regional assemblage zones for the area.

As the time synchroneity of the subzones of the various pollen diagrams is comparatively less certain than those of the zones, the correlations between the subzone are limited by the local site differences.

The regional pollen assemblage zones for western Rajasthan are defined below.

*Cyperaceae–Gramineae–*Artemisia *assemblage zone*

Type site. Sambhar Salt-lake, District Jaipur; zone SM-1, 325–355 cm (figure 4).

Zone characteristics. Non-arboreal pollen excluding Cyperaceae exceeds 90 %. Gramineae and Cyperaceae are by far the most dominant pollen types. *Artemisia* is the next most important pollen type found.

Contacts. Where known, this zone is the lowest in the sequence of pollen bearing sediment. The upper zone limit is placed where the sedge curve finally begins to fall to lower frequencies and the curve for Cheno–Ams, rises consistently. The lower boundary is associated with a stratigraphical change in the sediment from loose sand to laminated clay.

Other known sites. The Cyperaceae–Gramineae–*Artemisia* zone is also found at Lunkaransar, zone LK-1 (figure 6), where the frequencies for *Artemisia* are comparatively less prominent whereas sedges hold the second most dominant position after Gramineae.

Age. The date for the lower boundary, as extrapolated from the available radiocarbon dates (TF-887, TF-698, figure 4; WIS-405, WIS-386, WIS-387, figure 6) from both Sambhar and Lunkaransar, falls at *ca.* 10300 B.P.

*Gramineae–*Artemisia*–Cheno–Ams assemblage zone*

Type site. Sambhar Salt-lake, District Jaipur; zone SM-2, 165–325 cm (figure 4).

Zone characteristics. Gramineae and *Artemisia* become the most dominant pollen types and these are followed by Cyperaceae and Cheno–Ams in the next order of importance. Whereas the pollen frequencies of Cyperaceae decline with respect to Cyperaceae–Gramineae–*Artemisia* zone, those of Cheno–Ams rise. Non-arboreal pollen frequencies continue to exceed 90% as in the earlier zone.

Contacts. The upper boundary is placed where the Cyperaceae curve begins to show a consistent rise once again and is accompanied with a progressive rise in the tree and shrub pollen curves.

Other known sites. The Gramineae, *Artemisia*–Cheno–Ams zone, but for some local difference also occurs at Lunkaransar, local pollen zone LK-2, and Didwana, local pollen zone DW-1 (figures 6, 8). At Lunkaransar, the *Artemisia* pollen curve occurs in a rather subdued form than at the other two sites. At Didwana the lower boundary of the zone is not seen as the deposits pertaining to Cyperaceae–Gramineae–*Artemisia* zone are not preserved at this site.

Age. The date for the lower boundary, as extrapolated from two radiocarbon dates from immediately above the zone boundary at Sambhar, 9250 ± 130 (TF-887) and 8835 ± 140 (TF-698) (figure 4), falls at *ca.* 9500 B.P. At Lunkaransar, the radiocarbon date of 9260 ± 115 (WIS-405) from the zone boundary is close enough to warrant a broad synchroneity in the zone boundary at the two sites. At Didwana the estimated date for the base of the pollen sequence falls at *ca.* 7550 B.P., which shows that perhaps the lower part of the deposit referable to Gramineae–*Artemisia*–Cheno–Ams zone had not been preserved at this site (for further details see Discussion).

Cyperaceae tree and shrub assemblage zone

Type site. Sambhar Salt-lake, District Jaipur; zone SM-3, 105–165 cm (figure 4).

Zone characteristics. Cyperaceae are the most abundant pollen types. The tree and shrub pollen curves show a prominent rise for the first time and, later on, attain their maximum extent and importance. The non-arboreal pollen frequencies frequently reach below 85% and occasionally below 80% for the first time in this zone.

Contacts. The upper boundary of Cyperaceae tree and shrub assemblage zone is influenced by the lack of preservation of pollen above that level; therefore no firm criteria based on pollen can be established for this zone boundary.

Other known sites. The Cyperaceae tree and shrub assemblage zone is also found at both Lunkaransar, local pollen zone LK-3 (figure 6), and Didwana, local pollen zone DW-2 (figure 8). At Didwana the rise in the trees and shrubs curves is comparatively more gradual than at the other two sites.

Age. The interpolated date for the lower boundary at Sambhar falls at *ca.* 5000 B.P. (figure 4).

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At Lunkaransar the date for the same boundary is interpolated at *ca.* 5200 B.P., which is close enough to the Sambhar date. At Didwana, the estimated date for the zone boundary, calculated from the rate of sedimentation based on the only date available from the site (WIS-415, figure 8), falls at *ca.* 4600 B.P. The estimated dates for the upper boundary at Didwana, Sambhar and Lunkaransar, which, in each case is determined by the lack of preservation of pollen in the sediment above that level, fall at *ca.* 2650 B.P., 3000 B.P. and 4000 B.P. As the above boundary is based on artificial grounds, the boundary cannot be taken to be synchronous over a wide area.

*Gramineae–Cheno–Ams–Cyperaceae–*Calligonum *assemblage zone*

Type site. Lunkaransar Salt-lake, District Bikaner; zone LK-4, 0–30 cm (figure 6).

Zone characteristics. Gramineae and Cheno–Ams are the most abundant pollen types and these are followed by Cyperaceae and *Calligonum* respectively in the next order of importance. *Capparis* and *Aerva* attain their highest pollen frequencies.

Contacts. The lower boundary is determined by a resumption in the preservation of pollen in the sediment and therefore the boundary cannot be taken to be synchronous over a wide area.

Other known sites. None in western Rajasthan. Later on broad comparisons have been made with the local pollen zone PS-3 from Pushkar.

Age. No definite age can be assigned to the lower boundary. Locally at Lunkaransar the date for the boundary has been estimated at *ca.* 1200 B.P.

Sites

Sambhar Salt-lake

The location and stratigraphy of Sambhar Salt-lake (figure 1) has been described briefly in Singh *et al.* (1972) without the detailed map (figure 2) and the stratigraphical reconstruction of the lake basin (figure 3) included in this paper.

The lake, once described as a hollow in sand by Hackett (1880), has a number of low hill features, rising to about 500 m a.s.l. (above sea level) in its vicinity in the south, north and northeast (figure 2). A narrow range of hills, forming an arm, penetrates far into the lake basin in the extreme northwest. The lake is fed mainly by two flood streams, namely the Bandi and the Nandana (or Mendha), entering the lake from the southwest and the northeast respectively, and several other small streams draining an area of about 5710 km^2 (figure 1). Apparently there is no present outlet to the lake basin. The dry bed of the lake lies at about 360 m a.s.l. but the lake sediments, consisting mainly of silt and clay, extend some 6.1 m above the general surface in raised beaches formed on the slopes of the promontory jutting into the basin in the extreme northwest. A detailed geomorphological study of the raised beaches is still wanting and would be needed to estimate the precise maximum lake level in the past. The present incomplete evidence indicates that the lake level rose to at least 366 m a.s.l. at its maximum (figure 2). The town of Sambhar, with its long but largely undocumented history, lies on a sand-dune overlooking the lake in the southeast (figure 2). The sand-dune provides a continuous seepage of a small quantity of freshwater into the salt-lake and this accounts for the growth of *Cyperus laevigatus* in a narrow belt bordering the margin of the basin at certain points. The lake surface when dry is encrusted with salt drawn up through capillary action; the surface develops polygonal mud-cracks and the brine-table sinks to about 3 m below the surface in the summer months.

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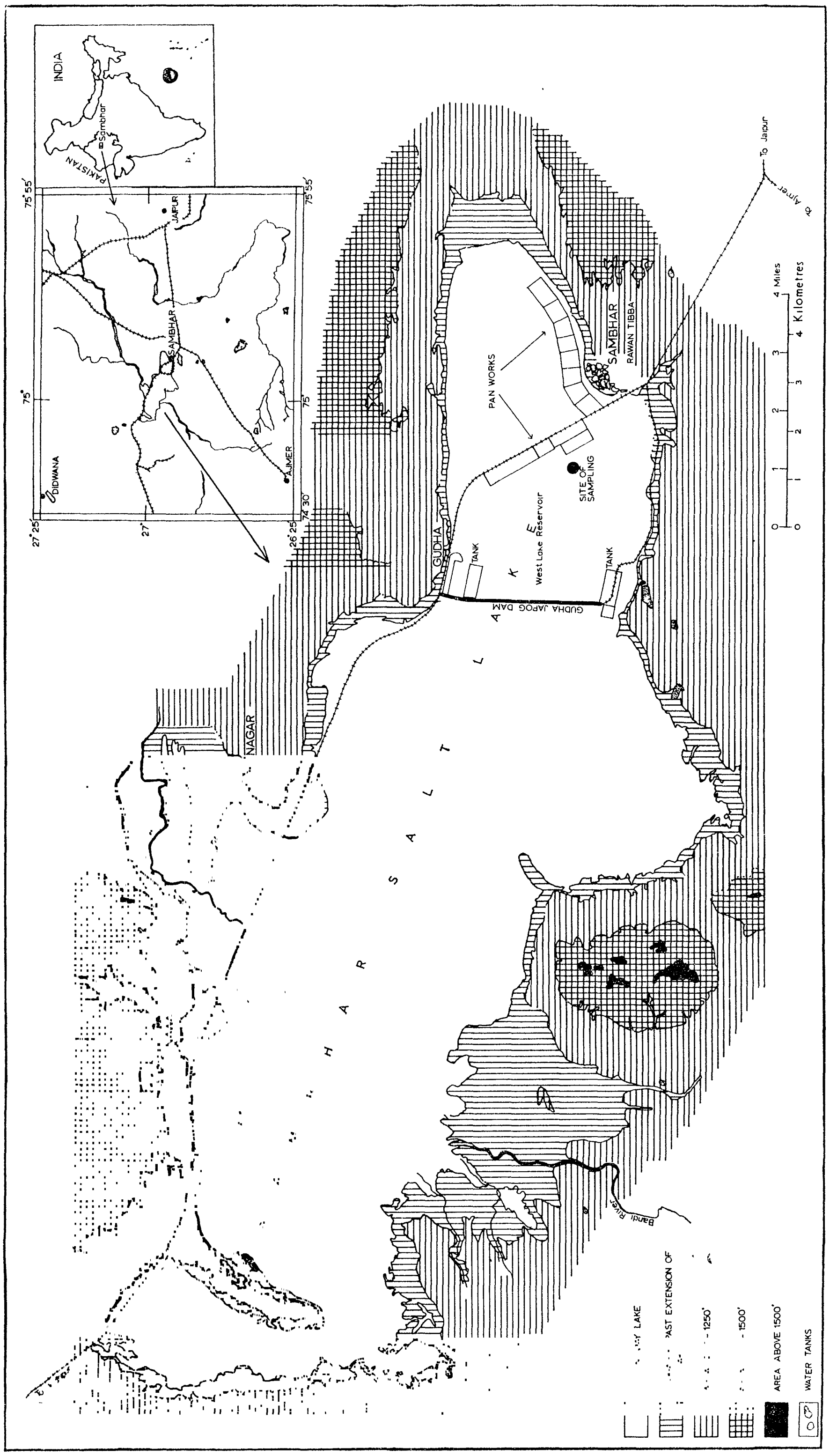

FIGURE 2. Map of Sambhar Salt-lake with inset map of the surrounding area. The point of sampling for pollen analysis and radiocarbon dating is shown in the extreme right-hand section of the lake basin. The stratigraphical section given in figure 3 follows approximately the railway line from Sambhar to Gudha shown in the map. The probable past extension of the lake is shown by vertical lines.

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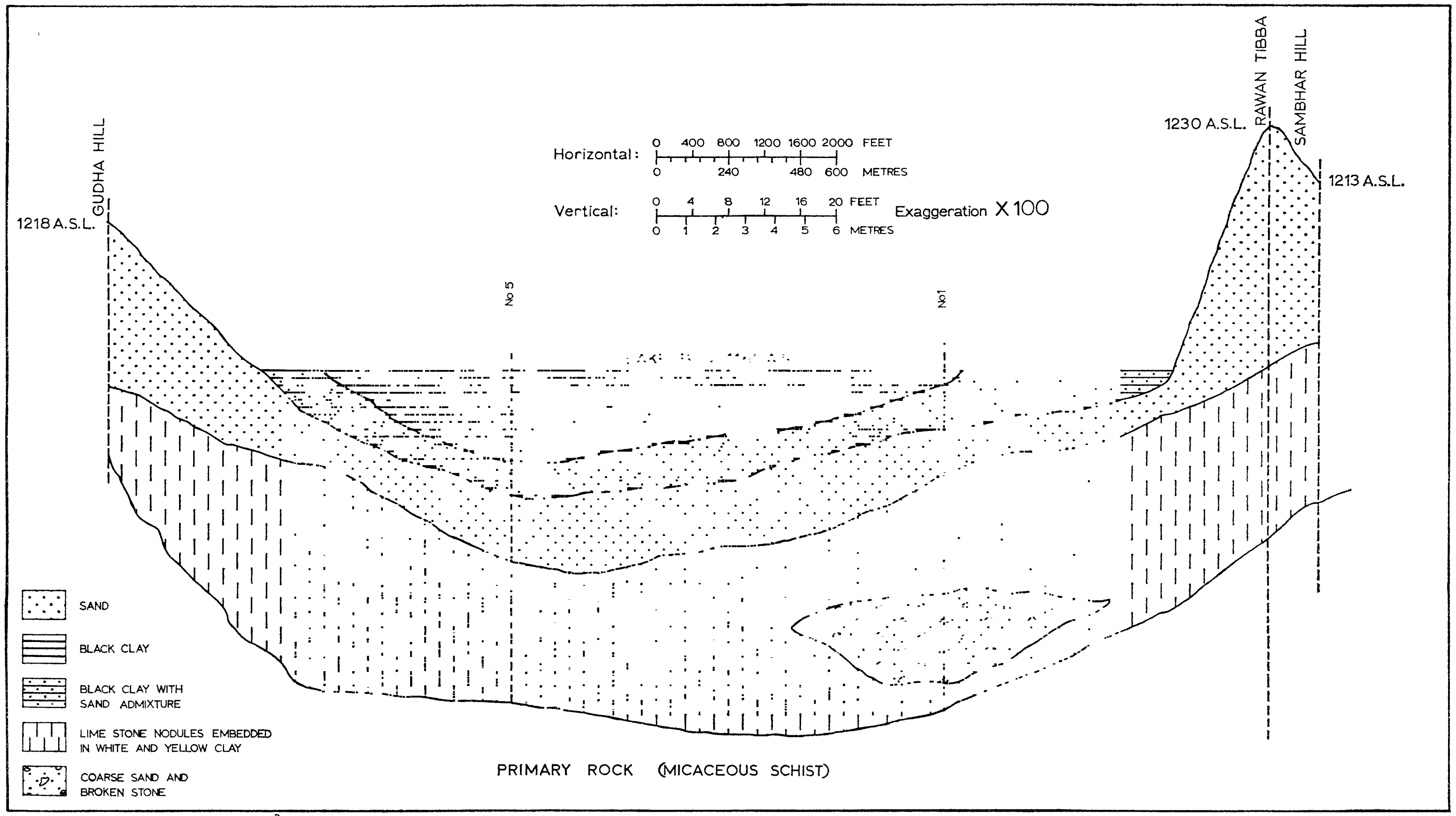

FIGURE 3. A generalized semi-diagrammatic stratigraphical section of Sambhar Salt-lake deposits redrawn from Aggarwal (1951), with slight modifications in the symbols used to denote the different layers. The lens of coarse sand and gravel seen in the section appears to be the remnant of an ancient stream course traversing the valley. The section follows approximately the railway line from Sambhar to Gudha shown in figure 2.

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The lake surface at large is devoid of vegetation; the marginal areas, however, support a number of halophytic herbs, such as *Sueda fruticosa*, *Salsola foetida* and *Cressa cretica* and, on higher ground, the halophytic tree *Tamarix dioica*.

The general sequence of deposits revealed in sections down to a depth of 4 m, and described earlier in Singh *et al.* (1972), wholly corroborated the findings of earlier workers (figure 3; Aggarwal 1951; Auden 1952). A sedimentary profile from the site of sampling (figure 2), which was later studied pollen-analytically as well as from the point of view of the occurrence of carbonized wood remains, showed the following sequence (cf. Singh *et al.* 1972):

cm
0–115 greyish brown unlayerd silt; carbonized wood remains common below 100 cm
115–360 dark grey laminated clay; carbonized wood remains very common between 115 and 320 cm
- 120–125 one pollinium of *Calatropis*, one *Carex* nut
- 182–185 change in colour to brownish grey
- 205–357 layers predominantly brownish in colour
- 210–225 one *Carex* nut
- 225–240 one *Carex* nut
- 255–270 one *Carex* nut
- 326–328 calcareous soft sandstone
- 340–345 calcareous soft sandstone

360 ± 600 loose grey sand, the grains well rounded; thin layers of calcareous soft sandstone intercalated at irregular intervals

In the reconstructed section of the basin deposits (figure 3) the underlying micaceous schist rock is overlain by a bed of 'alluvial valley fill'. The lens of coarse sand and broken stone seen in the southeastern half appears to be a remnant of an old stream channel passing through the valley. The alluvial deposit is covered by aeolian sand which merges laterally with the sand ridges surrounding the basin (figure 3). Several thin bands of carbonate cemented soft sandstone varying in thickness from 2 to 30 cm are intercalated in the sand-bed, showing thereby that the lake had occasionally filled with water before the final infilling of the lake. No definite date can, however, be suggested for these earlier short-term incursions. It has been pointed out earlier (Singh *et al.* 1972) that the aeolian sand in the basin was perhaps laid down while the sand-dunes, now stabilized, were still active in the area. Overlying the aeolian sand is a thick bed of lacustrine laminated clay and non-laminated silt. The laminations break down at 115 cm from the surface, roughly the level above which the sediments are completely depleted of fossil pollen (figure 4). In view of the paucity of organic content in the sediment very few macro-remains, mainly nuts of *Carex*, have been encountered. Nevertheless, carbonized remains of wood, cuticle, etc., have been found in great abundance in the sediment at the 105–320 m levels. Their relative frequency in the profile can be gauged from the separate curve given at the right-hand extreme end of the pollen diagram (figure 4).

Pollen diagram. Zone SM-1 begins at 355 cm, immediately above the stratigraphical change from aeolian sand to lacustrine clay (figure 4). But for the pollen of *Pinus*, *Betula* and *Alnus*, all the other plant taxa represented in the pollen diagram appear to have come from the Rajasthan area (Singh *et al.* 1973). The pollen sequence starts with low values of tree and shrub pollen (6 %), high values of sedges (110 %), grasses (60 %), *Artemisia* (22 %) and *Mimosa rubicaulis* (6 %), and low Cheno–Ams (1 %) and Tubuliflorae (3 %). The pollen of *Acacia* (polyads), Palmae and Leguminosae occur to the extent of 1 % each. Later on the curves for sedges, *Mimosa rubicaulis*, *Artemisia*, and Tubuliflorae decline while those of grasses and Cheno–Ams rise. The grass curve rises to 82 % in the lower half but later falls to below 40 %. The curve for *Artemisia*, after a short fall, rises in the upper half to nearly 60 %. *Ephedra* rises to about 2 % in an isolated sample and single grains of *Maytenus*, *Capparis* and Boraginaceae occur sporadically. Pollen of *Typha angustata* makes its first appearance at 345 cm and rises to 12 %, declining thereafter to lower values. *Oldenlandia* develops a curve at the same level as that of *T. angustata*. The curve for carbonized wood remains shows extremely low values.

The picture presented by the pollen assemblage of zone SM-1, on the whole, is that of an open land grassland-*Artemisia* steppe in which *Artemisia* grew in great profusion together with grasses, *Mimosa rubicaulis*, *Oldenlandia* and some herbs. The tree and shrub vegetation is low, but it is likely that both *Acacia* and Palmae and, later, *Maytenus* and some *Capparis* occurred in the area. Both Cyperaceae and *Typha angustata* are likely to have been represented locally, suggesting that freshwater swamp conditions prevailed in the lake basin.

Subzone SM-2a begins at 325 cm. The curve for sedges suffers an irreversible fall and that of Cheno–Ams begins to rise. *Maytenus* starts a continuous curve for the first time and the frequencies of *Capparis* rise. The grass curve falls to comparatively lower values than in zone SM-1, but *Artemisia*, after suffering a temporary decline in the lower part of subzone SM-2a, maintains high values, mostly above 40 %. *Mimosa rubicaulis*, *Oldenlandia* and *Typha angustata* form almost continuous curves and the pollen of *Ephedra*, Boraginaceae, Tubuliforae, *Typha latifolia* (tetrads) and ferns (spores) either form short curves or occur sporadically. Pollen grains of *Tecomella*, *Acacia* (polyads), Palmae, *Morus*, *Grewia*, *Ailanthus*, Acanthaceae, *Cleome*, *Corchorus*, *Indigofera*, Leguminosae, Liguliflorae, *Neurada*, *Solanum*, *Tephrosia*, *Trichodesma*, Umbelliferae, *Withania*, *Nymphaea*, *Polygonum*, *Spergula*, *Convolvulus* and *Potamogeton* occur either singly or form short curves in this subzone. Three grains assigned to Cerealia-type pollen (grass pollen > 40 μm) were recovered separately from 285, 277.5 and 255 cm levels. In the first two cases the Cerealia-type pollen was found together with a single grain of *Spergula rubra*, a weed of fallow lands growing in northwest India.

There is a definite increase in the number of taxa represented in subzone SM-2a as compared to zone SM-1. The shrub vegetation marks a slight increase in what appears to be largely a grassland–*Artemisia* steppe vegetation. From the steep rise in the frequencies of carbonized remains in the sediment it would appear that some sort of scrub burning was initiated in subzone SM-2a and that the practice continued thereafter. The frequent breaks in the curves for shrubs may have probably been influenced by this. But this cannot be said with absolute certainty considering the small size of the curves; nevertheless, the possibility cannot be ruled out. The occurrence of Cerealia-type pollen soon after in this subzone does not appear to be a mere coincidence as similar evidence is also found at the two other sites in western Rajasthan (figures 6, 8), suggesting either that some sort of primitive cereal cultivation had started or that an invasion of the area with wild grass species producing large-sized pollen took place at that time (Singh 1971). The horizon at which the first Cerealia-type pollen occurs in the profile is dated at 8300 ± 135 B.P. (TF-738) (figure 4). There is as yet no archaeological evidence for cereal agriculture before Harappan times (2300–1750 B.C.) in northwest India (Singh 1971).

Subzone SM-2b begins at 220 cm. There is a fall in the Cheno–Ams values and a progressive but gradual rise in the curve for Cyperaceae. The curve for Gramineae starts declining in the

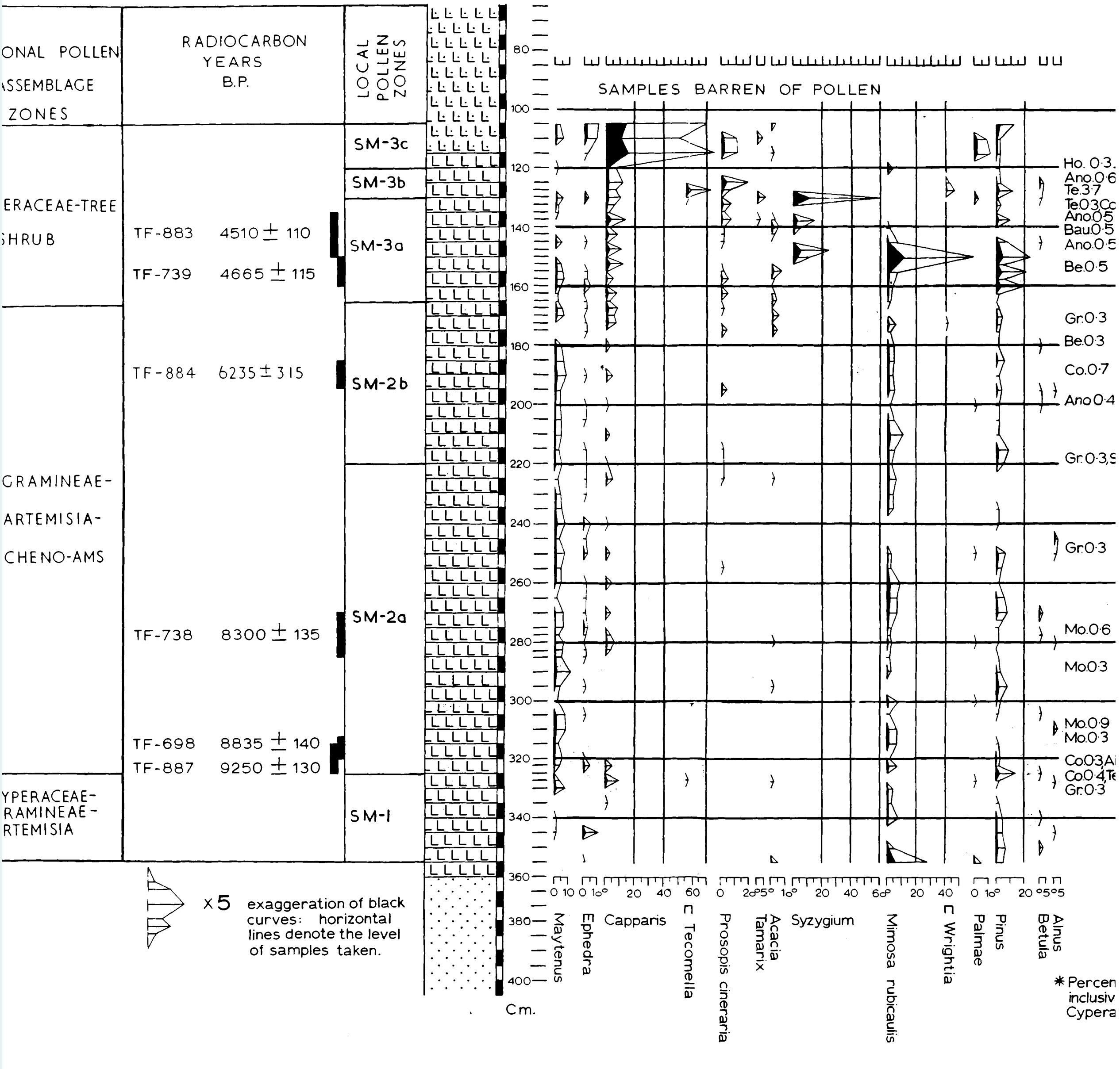
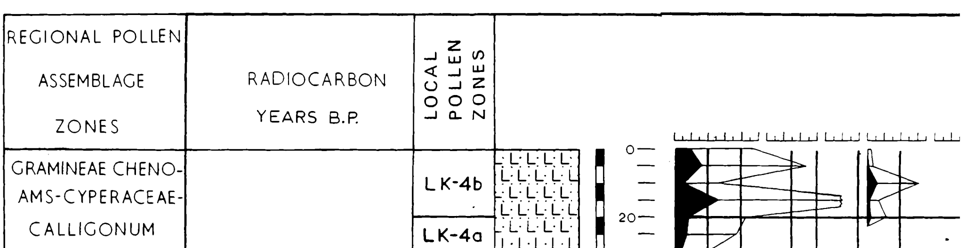
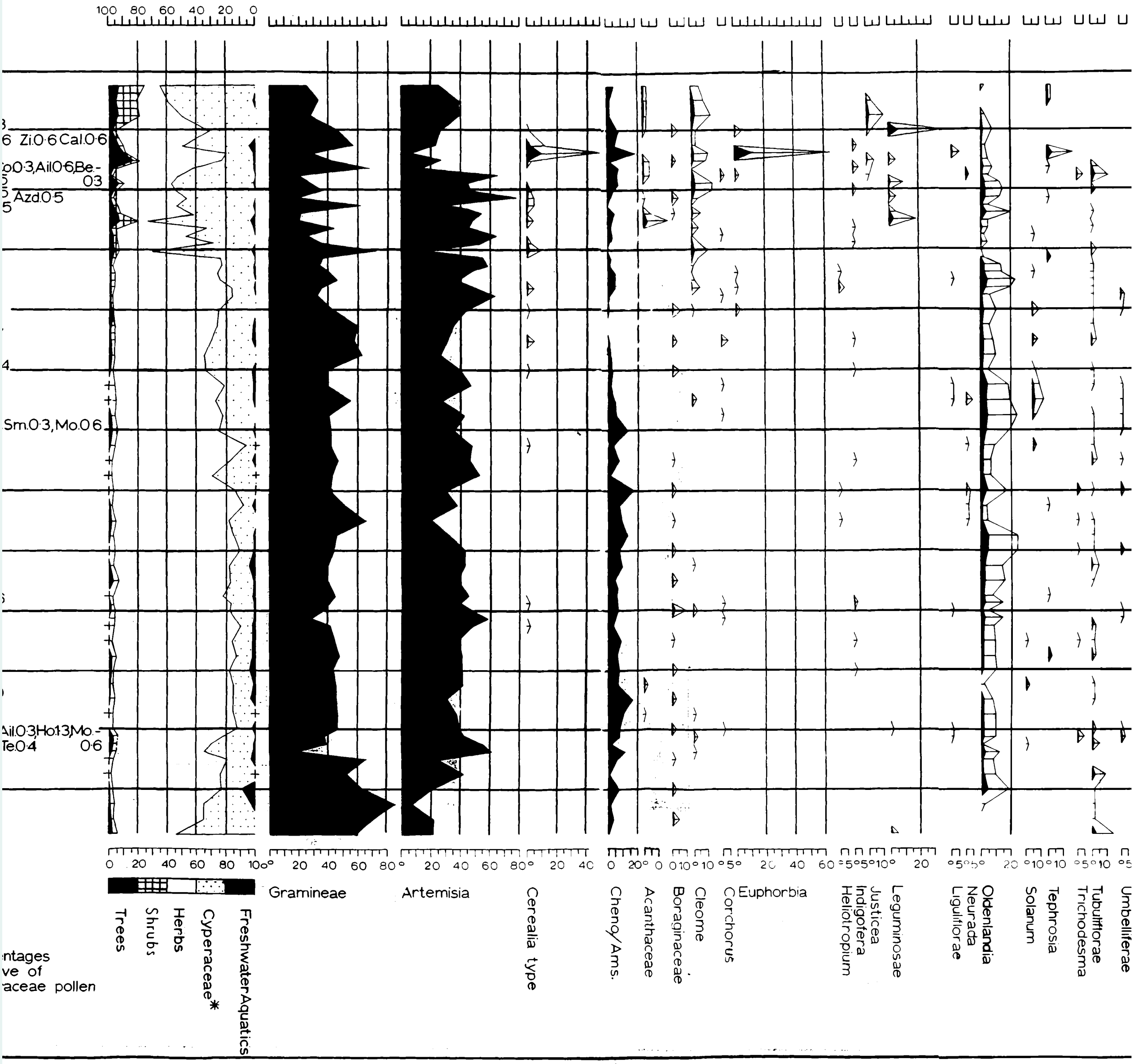
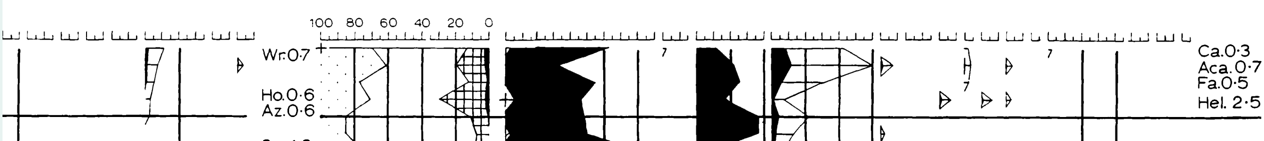


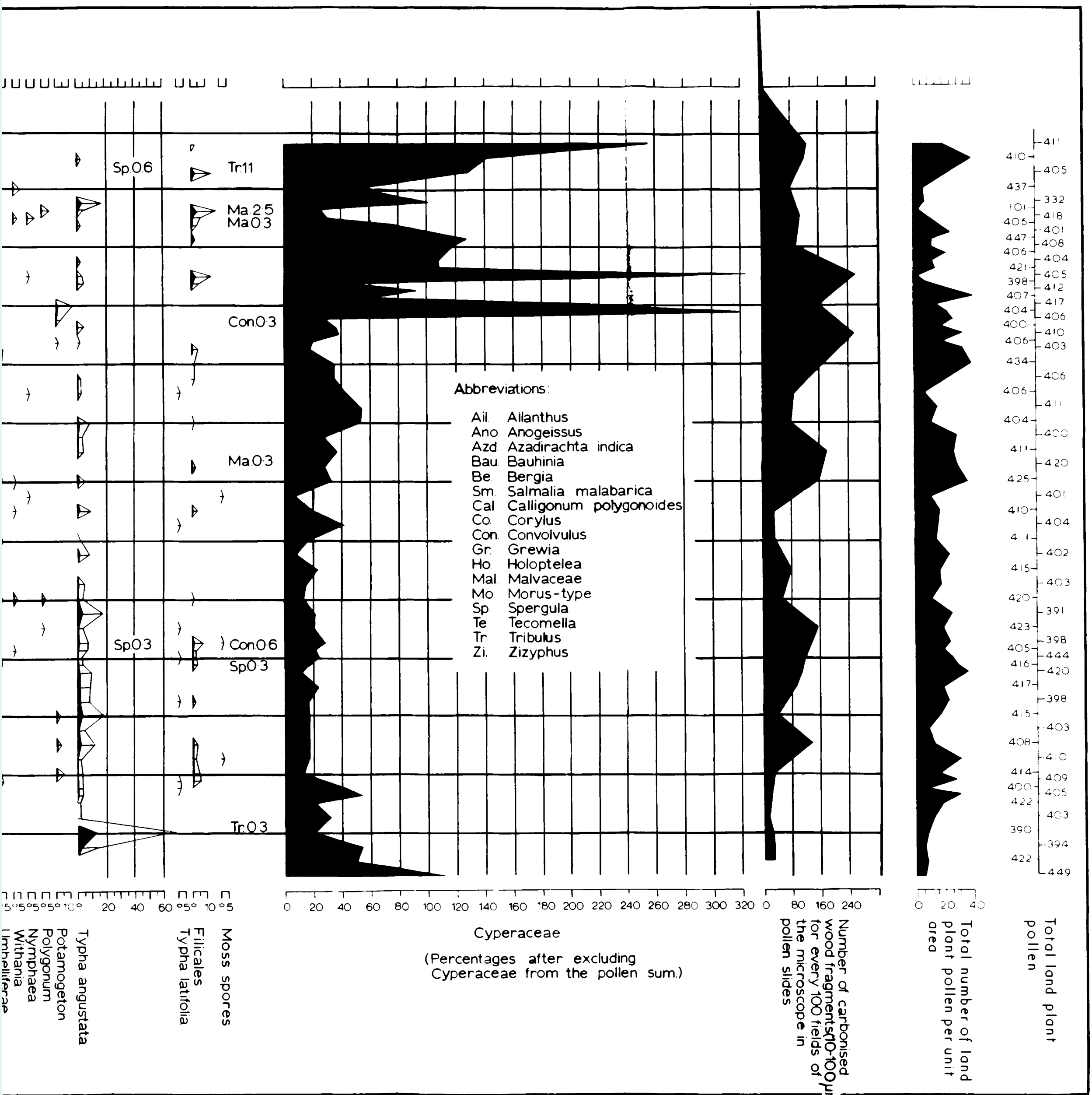
FIGURE 4. Late-Quaternary pollen
additional curve for Cyperacea
from samples taken at 20 cm i





ı diagram from Sambhar Salt-lake. Values are expressed as percentages of total land plant pollen excluding Cyperace
ıe shown within the same box as the a.p./n.a.p. ratios, where the values are inclusive of Cyperaceae pollen. A frequency curve
ıntervals of the profile is also included in the pollen diagram. A key to the stratigraphic symbols used is given in figures 5





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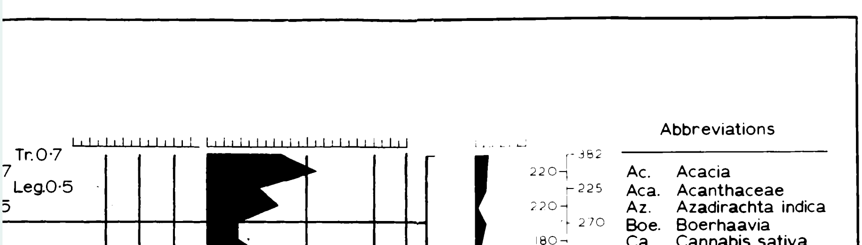


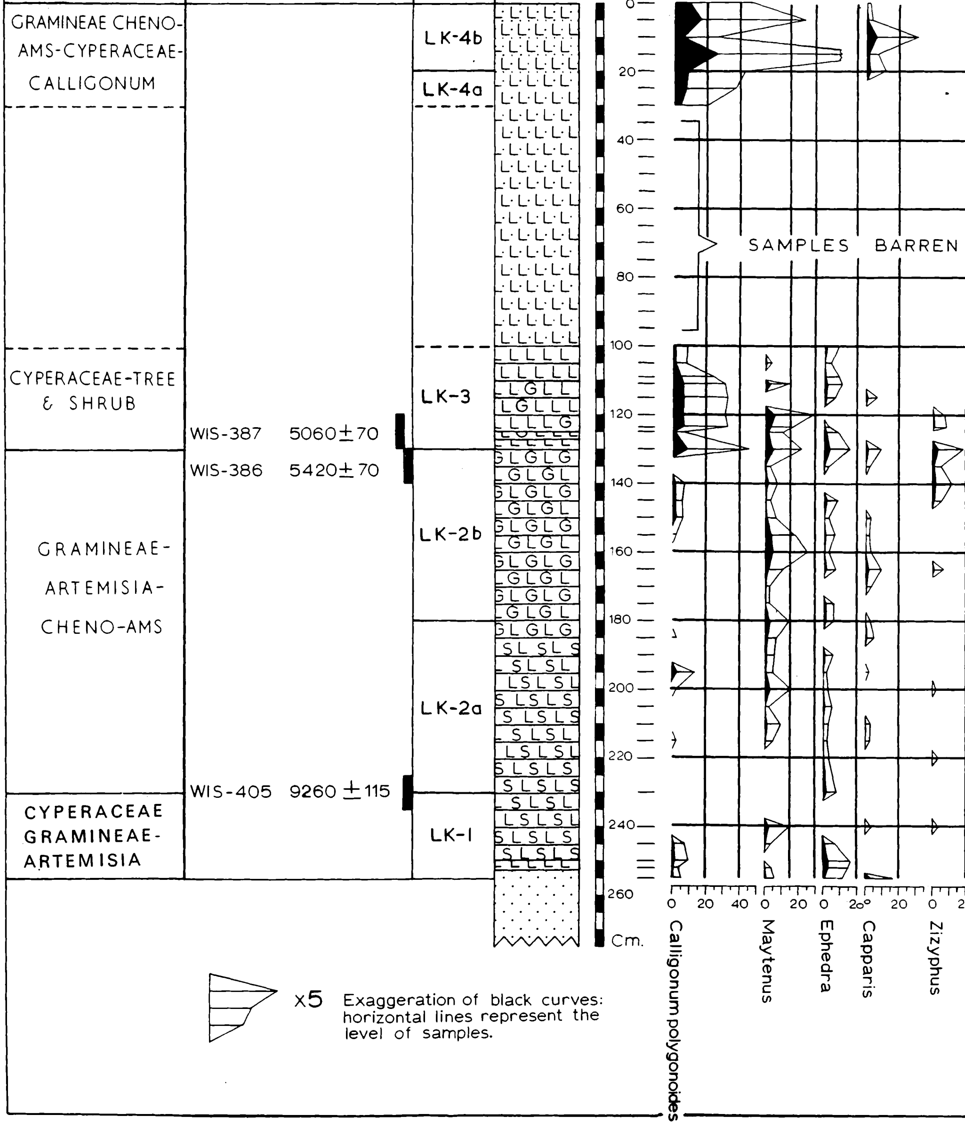
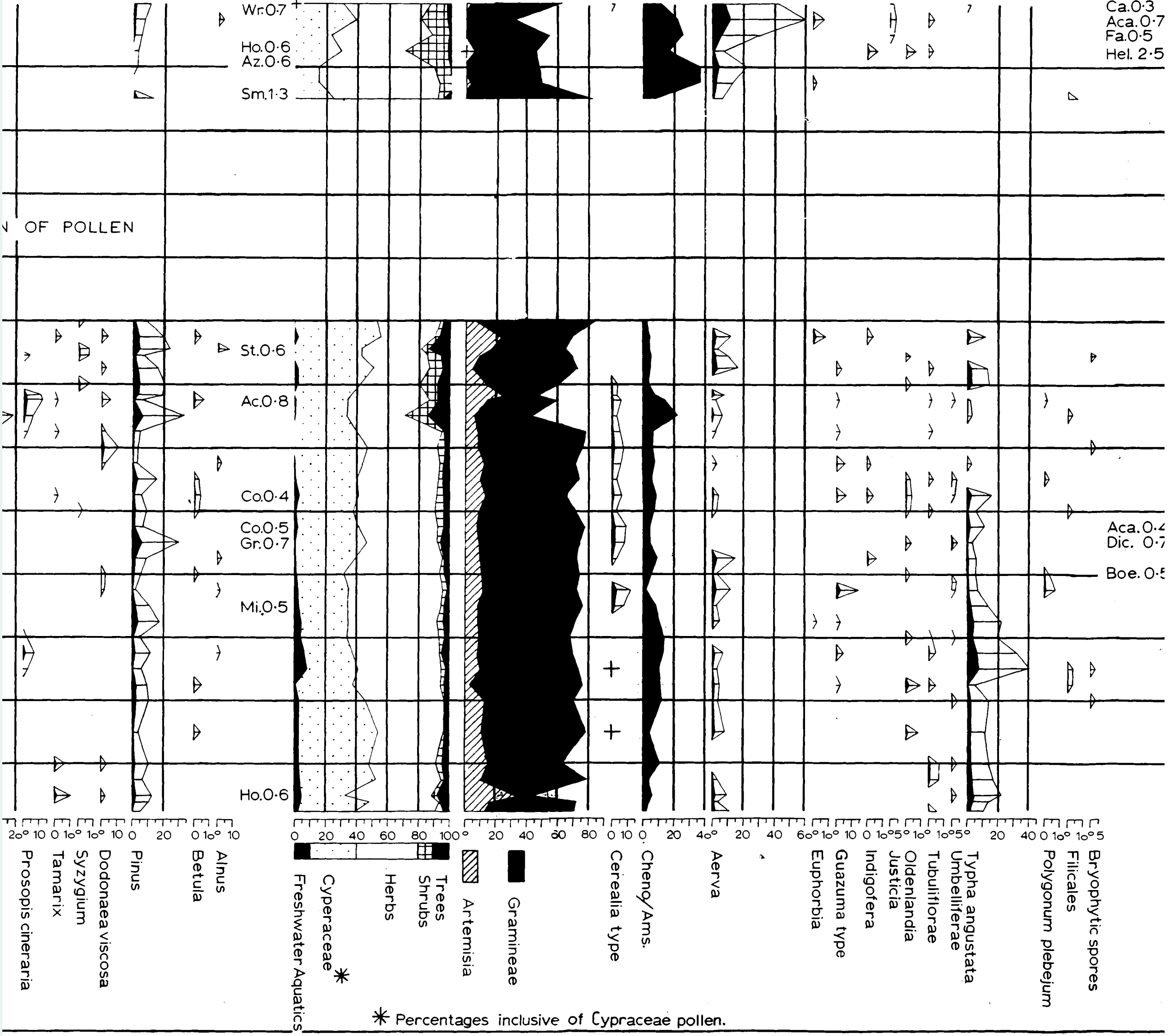
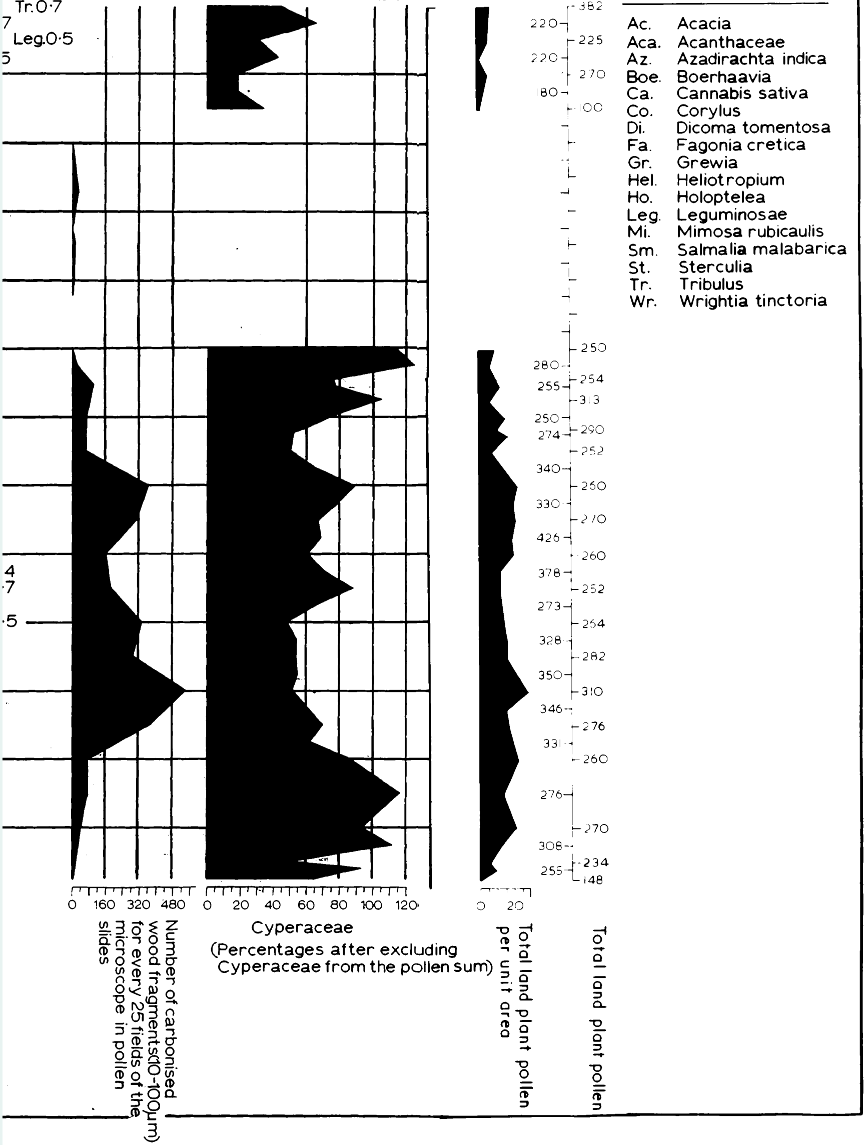


FIGURE 6. Late-Quaternary pollen di
additional curve for Cyperaceae sh
from samples taken at 20 cm inte



liagram from Lunkaransar Salt-lake. Values are expressed as percentages of total land plant pollen excluding Cyperace
shown within the same box as the a.p./n.a.p. ratios, where the values are inclusive of Cyperaceae pollen. A frequency curve f
tervals of the profile is also included in the pollen diagram.



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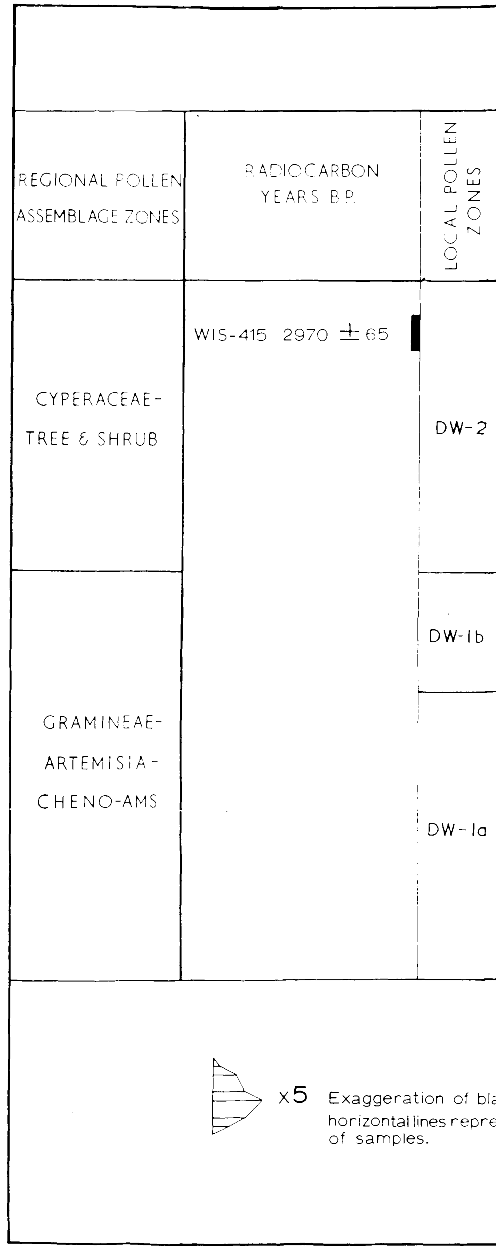

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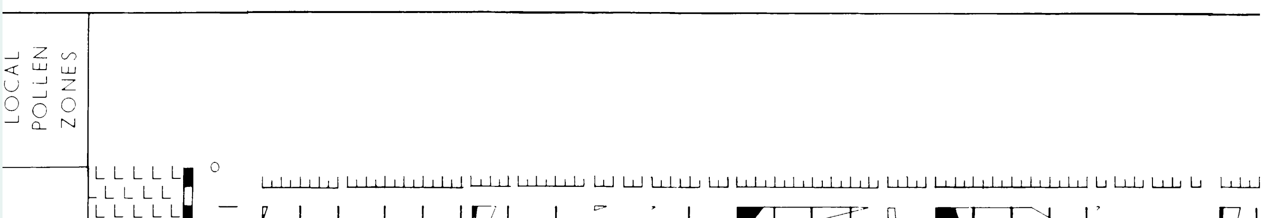


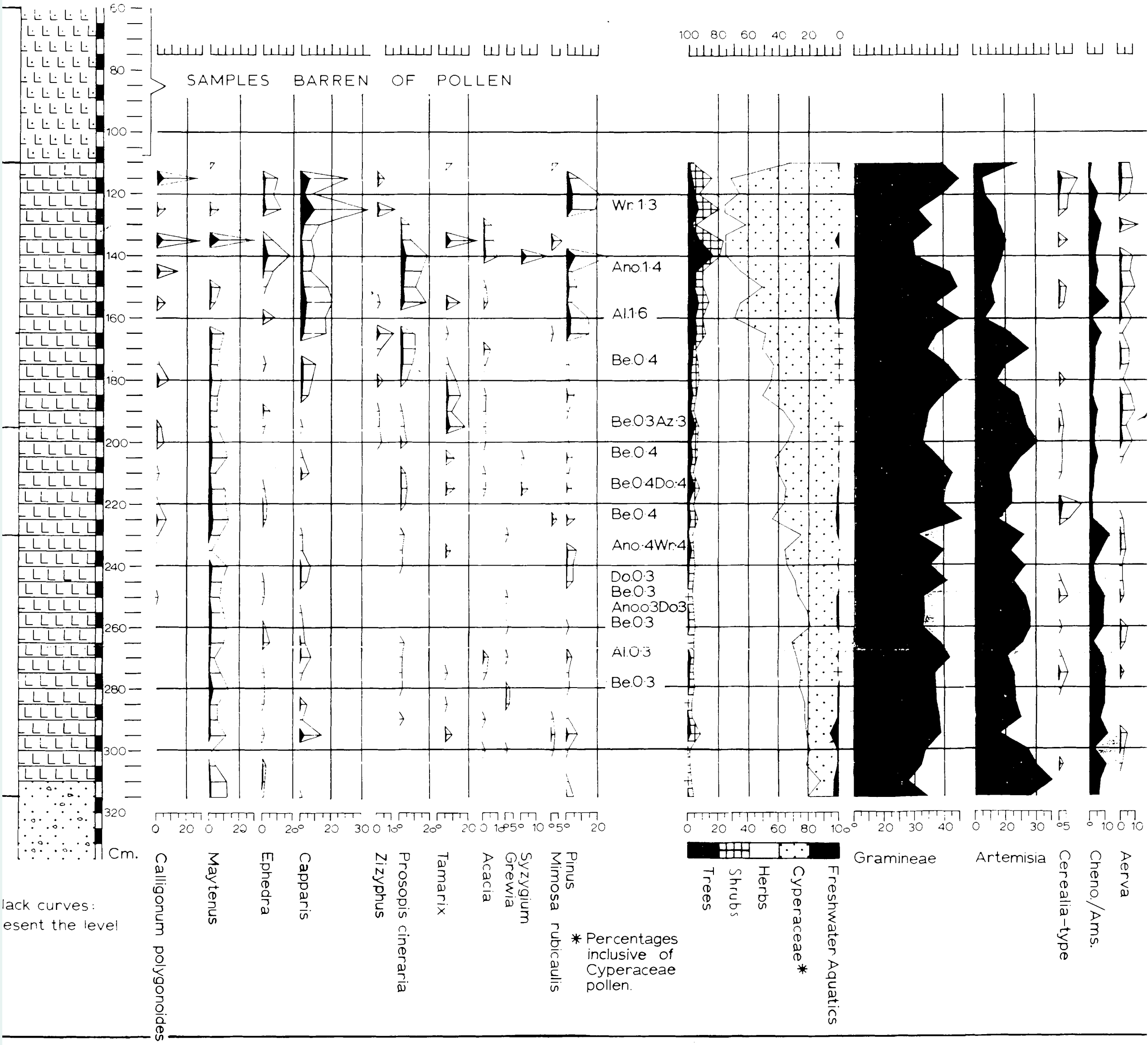
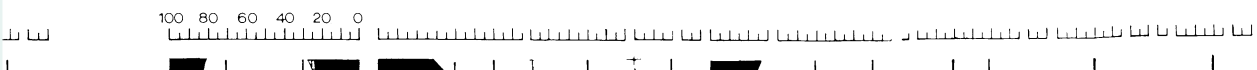
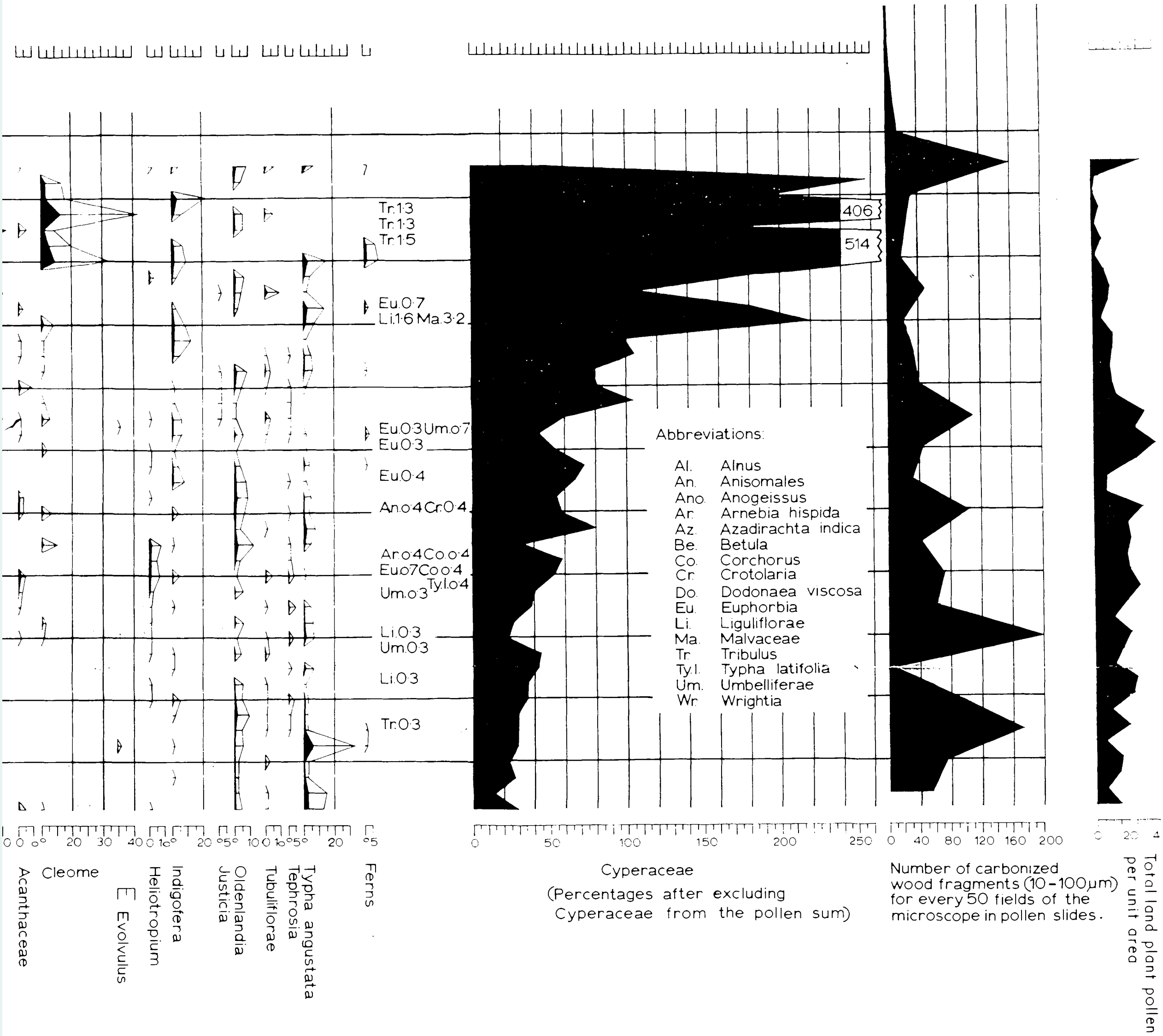
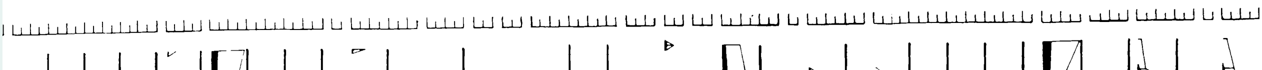


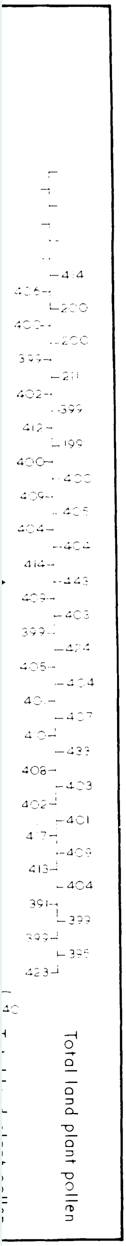
Figure 8. Late-Quaternary pollen diagram from Didwana Salt-lake. Values are expressed as percentages of
additional curve for Cyperaceae shown within the same box as the a.p./n.a.p. ratios, where the values are incl
from samples taken at 20 cm intervals of the profile is also included in the pollen diagram.

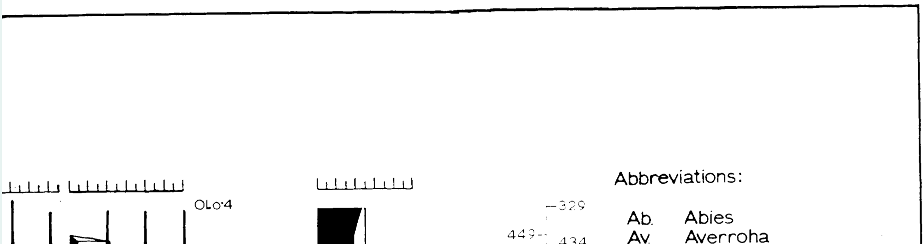




` total land plant pollen excluding Cyperaceae, except in the case of the
clusive of Cyperaceae pollen. A frequency curve for carbonized wood remains







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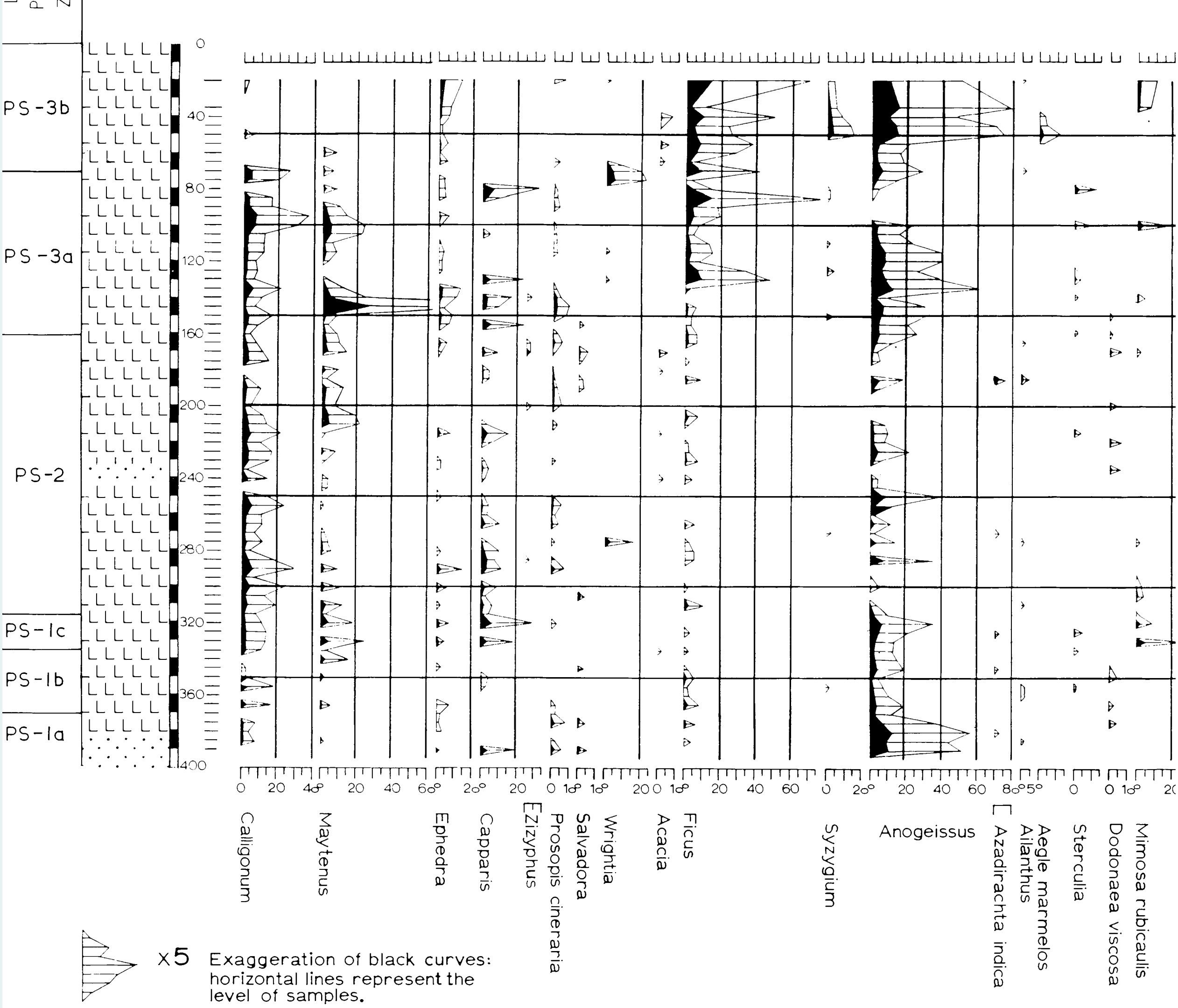
PS-3b
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360
400
Calligonum
Maytenus
Ephedra
Capparis
Zizyphus
Prosopis cineraria
Salvadora
Wrightia
Acacia
Ficus
Syzygium
Anogeissus
Azadirachta indica
Aegle marmelos
Ailanthus
Sterculia
Dodonaea viscosa
Mimosa rubicaulis
x5
Exaggeration of black curves:
horizontal lines represent the
level of samples.

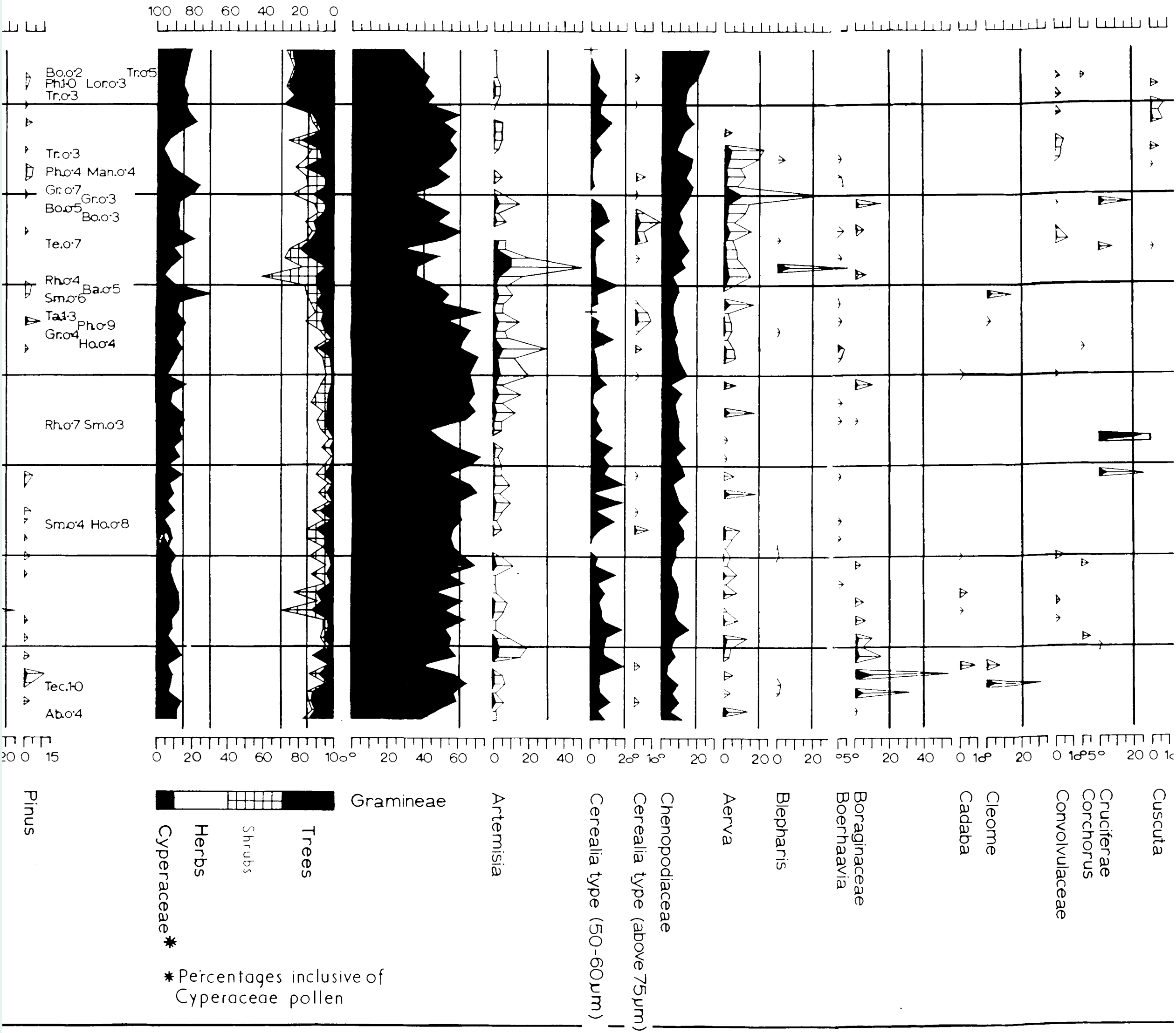
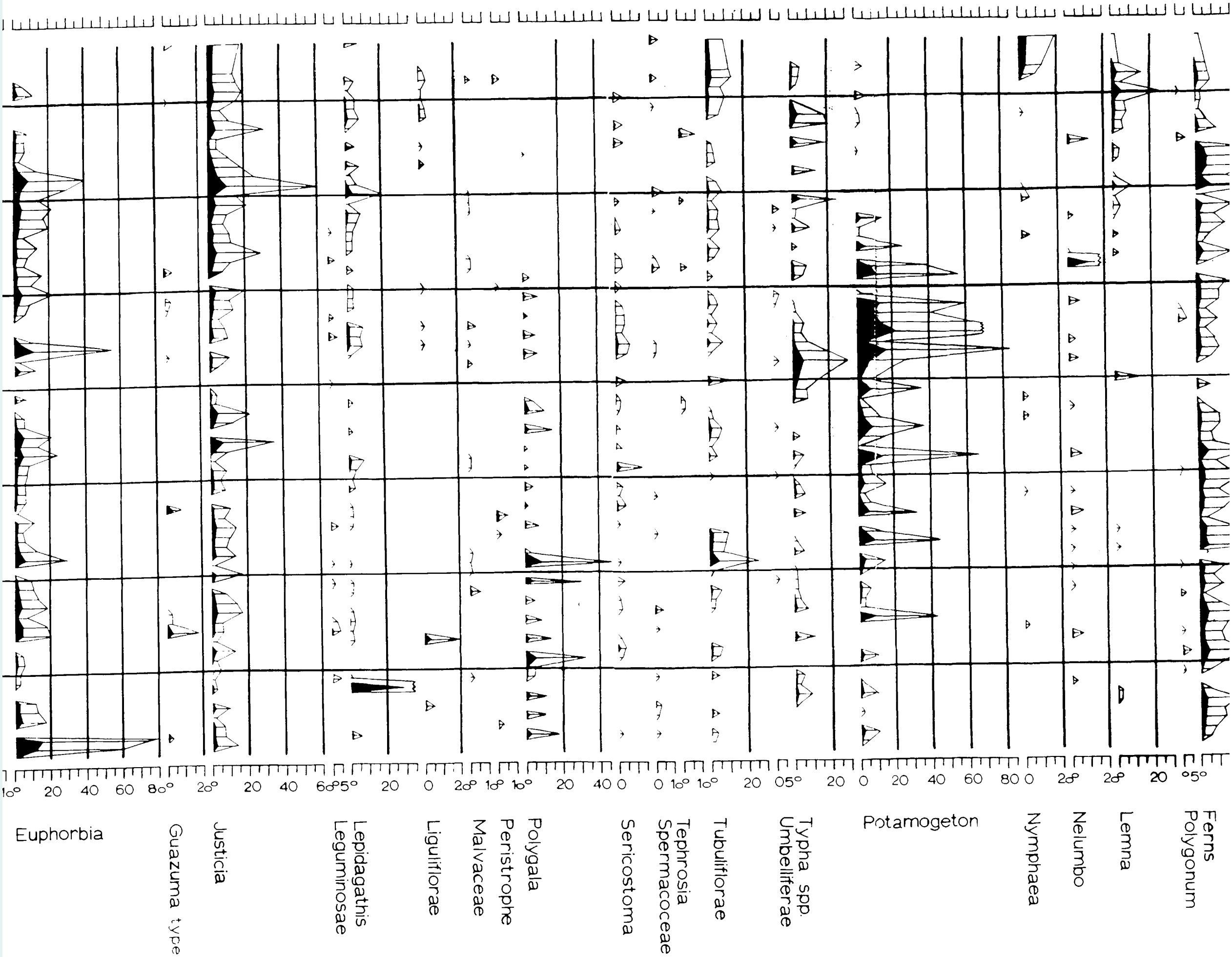
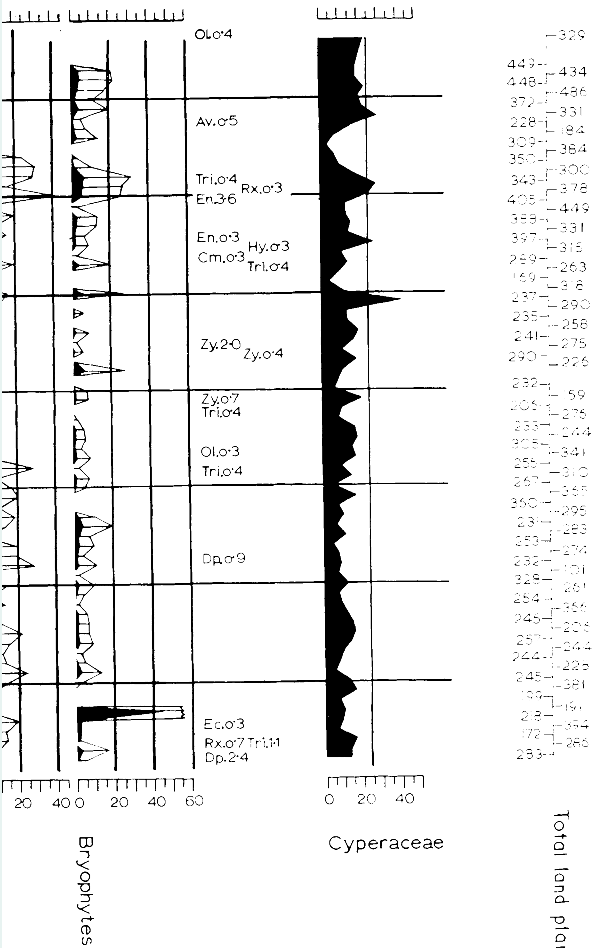


FIGURE 9. Late-Quaternary pollen diagram from Pushkar Lake. Values are expressed as percentages of total lar
curve for Cyperaceae shown within the same box as the a.p./n.a.p. ratios, where t



...nd plant pollen excluding Cyperaceae, except in the case of the additional ...the values are inclusive of Cyperaceae pollen.



Abbreviations:

Ab.	Abies
Av.	Averroha
Ba.	Bauhinia
Bo.	Boswellia
Cm.	Campanula
Dp.	Dipterygium
Ec.	Echinops
En.	Enicostoma
Gr.	Grewia
Ho.	Holoptelea
Hy.	Heylandia
Lor.	Loranthus
Man.	Mangifera indica
Ol.	Oldenlandia
Ph.	Phoenix
Rh.	Rhus
Rx.	Rumex
Sm.	Salmalia malabarica
Ta.	Tamarix
Te.	Tecoma
Tec.	Tecomella
Tr.	Terminalia
Tri.	Tribulus
Zy.	Zygophyllum

upper half but the pollen of Cerealia type begins to occur more frequently in this subzone. The curve for carbonized wood remains also increases farther to higher values, indicating an enhanced as well as sustained burning activity. The pollen of trees *Prosopis cineraria* and *Acacia* (polyads) is seen more frequently towards the upper border. A grain each of *Anogeissus pendula* and *Bergia* occurs for the first time in this subzone.

Subzone SM-3a starts at 165 cm. The curve for Cyperaceae rises suddenly to very high values (320 %). There is a collective rise in the tree-pollen ratios. The curve for *Capparis* becomes continuous for the first time and there is a definite increase in the frequencies of *Prosopis cineraria* and *Acacia*. The curve for *Mimosa rubicaulis* begins to rise and reaches its maximum (10 %) in this subzone. *Artemisia* and *Oldenlandia*, after a temporary decline at the beginning, return to and maintain considerably higher values. Cheno–Ams and Gramineae generally remain low. The pollen of the mesophytic tree species, *Syzygium* cf. *cuminii*, is seen for the first time, and its values rise sporadically up to 10 %, which in terms of the present-day pollen rain (Singh *et al.* 1973) denotes a rather heavy concentration of *Syzygium* trees at Sambhar. Single grains of mesophytic species, such as *Anogeissus pendula*, *Azadirachta indica*, *Bergia*, *Bauhinia* and *Ailanthus* are also found. The values of *Maytenus*, *Ephedra* and Boraginaceae remain low while those of Acanthaceae, *Cleome*, Leguminosae, Tubuliflorae and ferns rise. The pollen of *Typha angustata* occurs sporadically and there is slight rise in the values of *Potamogeton* at the beginning of the subzone. The curve for carbonized wood remains attains its maximum in the lower half and declines in the upper half of the subzone. The frequencies of Cerealia-type pollen mark a consistent increase. There is ample archaeological evidence for the existence of cereal agriculture in northwest India in the time period corresponding to the latter half of subzone SM-3a (Wheeler 1953; Singh 1971).

The vegetational conditions of subzone SM-3a mark a significant change towards an increase in the tree and shrub vegetation accompanied with a phenomenal rise in the occurrence of sedges and mesophytes such as *Syzygium* and *Mimosa rubicaulis*.

Subzone SM-3b begins at 130 cm. The curve for Cheno–Ams rises and those of Cyperaceae, tree pollen ratios and *Syzygium* fall. The values of *Maytenus*, *Artemisia*, Acanthaceae and *Oldenlandia* also decline. Gramineae, *Prosopis cineraria*, *Tecomella*, *Euphorbia*, *Typha angustata* and Cerealia-type pollen show comparatively higher values but in each case their rise is short-lived. Single grains of *Anogeissus pendula*, *Ziziphus* and *Calligonum* occur sporadically. On the whole, the tree and shrub vegetation, and especially the mesophytes and sedges, received a serious setback in this subzone.

Subzone SM-3c starts at 120 cm. There is a sudden rise in the values of *Capparis*, Cyperaceae, Acanthaceae and *Artemisia*. The values of Gramineae, Cheno–Ams and *Oldenlandia* fall. *Maytenus*, *Ephedra*, *Prosopis cineraria*, Palmae and *Justicia* form short curves. The values of *Cleome* rise. The pollen of *Tamarix*, Acacia (polyads), *Tephrosia* and *Typha angustata* occurs in very low values. The pollen of all mesophytes, *Syzygium*, *Mimosa rubicaulis*, *Anogeissus pendula*, *Morus*, *Bergia*, *Grewia*, *Salmalia malabarica*, *Bauhinia* and *Azadirachta indica* completely disappears from the pollen sequence in this subzone. The vegetation in subzone SM-3c evidently only incompletely reverted to its conditions in subzone SM-3a.

The Cerealia-type pollen curve ceases to be represented even though the curve for carbonized remains continues in a subdued form until the end of the subzone. It is quite likely that cereal agriculture had become less common in the area and that it may have even ceased for want of adequate climatic conditions. There is a change in the stratigraphy from laminated clay to non-laminated silt at the 115 cm level, and the pollen in the sediment above the 105 cm level is not preserved. It is likely that the lake surface started drying for a good part of the year, leading to the oxidation of pollen. The upper boundary of subzone SM-3c therefore remains undetermined pollen-analytically at this site. The curve for carbonized remains declines for good beyond this level, suggesting perhaps that either the people had migrated away from the area or that they could no longer practise burning to promote agricultural activity as a result of changed climatic conditions.

Lunkaransar Salt-lake

The location and stratigraphy of a section from the Lunkaransar salt-lake has already been described in Singh *et al.* (1972). In this paper details are given of the stratigraphical reconstruction of the basin together with an illustration of a reconstructed section of the basin deposits shown in figure 5. The village of Lunkaransar, situated to the southeast of the lake basin, lies on a sand-dune thought to be, partly, the debris of earlier habitations on the same site (Deb 1952). There are, however, no records of any archaeological excavations from the site. The lake has been used for the manufacture of common salt in the past but is now mined only for gypsum.

In the section (figure 5) the lacustrine deposit, overlying a bed of loose sand from below upwards consists of a sequence of laminated clay, selenite–gypsum, granular gypsum, clay, and silt. The gypsum layers become progressively thinner towards the margins and the sequence is dominated more by sandy material intercalated with thin bands of silt and clay (figure 5). The horizontal laminations in the sediment disappear in the upper 1 m or so of the deposit, and fossil pollen, except for the top 30 cm, also does not occur in this section (figure 5). Apart from a few unidentified seeds and fruits, no other recognizable macroremains were encountered in the lake sediment. The part of the deposit from 130–220 cm yielded high frequencies of carbonized wood remains shown as a separate curve in the pollen diagram (figure 6).

Pollen diagram. The pollen sequence from Lunkaransar should be viewed in the light of the natural conditions prevailing in the arid belt in which the lake is situated (Singh *et al.* 1973). The lower border of zone LK-1 is determined by a stratigraphical change from loose sand to lacustrine clay at 255 cm (figure 6); the underlying sand being completely barren of fossil pollen. At the beginning of the pollen sequence the curve for sedges is at a high level (65 %) and tends to rise farther in the later part of the zone, reaching to 115 %. The values for Cheno–Ams remain low. The curve for grasses rises to nearly 80 %. *Artemisia* is high and rises to more than 30 % but falls in the later half of the zone. *Artemisia* as now almost non-existent in the arid belt. *Calligonum*, *Maytenus*, *Ephedra*, *Aerva* and Tubuliflorae form short pollen curves. Pollen of *Capparis*, *Ziziphus*, *Tamarix*, *Dodonaea*, *Holoptelea* and *Umbelliferae* occurs sporadically. *Typha angustata* forms a well-developed continuous curve from the beginning of the sequence and, in all probability, the plant grew locally in the lake-basin.

On the whole, a grassland-*Artemisia* steppe type of vegetation, with freshwater swamps having sedges and *Typha*, grew in zone LK-1 at Lunkaransar in the present arid belt, contrasting sharply with conditions there now (Singh *et al.* 1973; see Discussion).

Subzone LK-2a starts at 230 cm. The curve for Cyperaceae begins a consistent fall and that of Cheno–Ams rises. Grasses maintain high-frequency values which remain mostly above 70 %. *Artemisia* values, however, stay at or below 10 %. *Maytenus*, *Ephedra* and *Aerva* form fairly continuous curves. The curve for *Typha angustata* attains its maximum frequency of about 8 % in the middle of the subzone. The pollen of *Calligonum*, *Capparis*, *Ziziphus*, *Prosopis cineraria*, *Mimosa rubicaulis*, *Oldenlandia*, *Euphorbia*, Tubuliflorae, Umbelliferae and fern and bryophytic spores

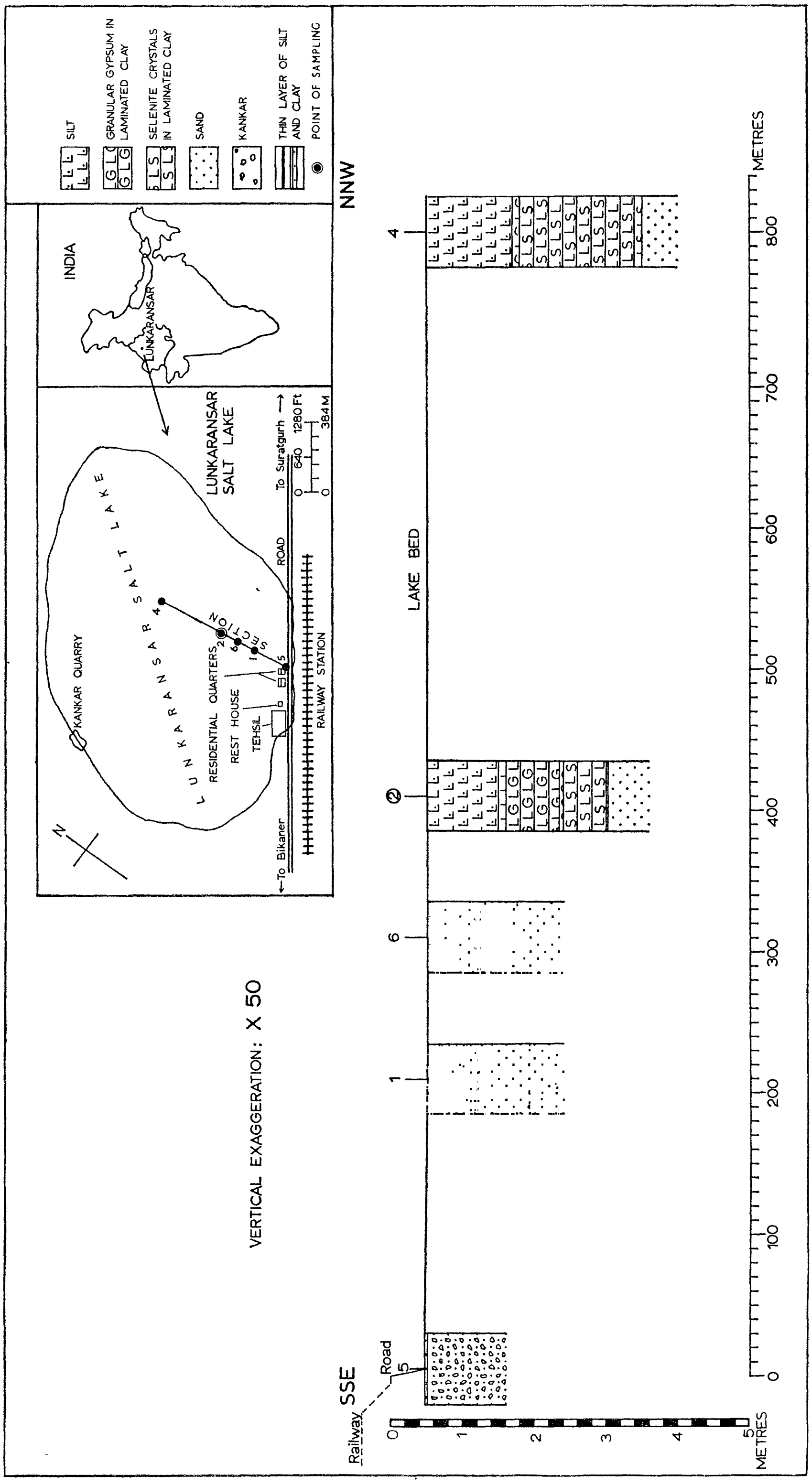


FIGURE 5. Stratigraphical section of Lunkaransar Salt-lake deposits with inset map of the lake basin showing the line of the section as well as the point of sampling for pollen and radiocarbon analyses.

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occur singly or form short curves. One grain of Cerealia-type pollen is seen at the boundary of zones LK-1 and LK-2 and another at 210 cm. Later on, a short curve is developed towards the top of the subzone. As the curve for carbonized wood remains also suddenly rises to high values at the 210 cm level, it is suggested that some sort of burning got underway together with the introduction of the Cerealia-type pollen in the pollen diagram.

Subzone LK-2b begins at 180 cm. The curve for sedges starts to recover. The values of Cheno–Ams maintain comparatively lower frequencies than in subzone LK-2a. There is a definite increase in the frequencies of *Maytenus*, *Capparis* and *Ziziphus*. *Calligonum*, *Ephedra*, *Dodonaea*, *Aerva*, *Oldenlandia*, *Umbelliferae* and *Polygonum plebejum* form short curves. The pollen of *Tamarix*, *Syzygium*, *Indigofera*, *Tubuliflorae*, *Grewia*, *Boerhaavia*, *Dicoma*, Acanthaceae, and fern and bryophytic spores occur singly in this subzone. Cerealia-type pollen forms a continuous curve and the curve for carbonized wood remains also maintains considerably high values except that the latter curve falls at the end of the subzone.

Zone LK-3 begins at 130 cm. The curve for Cyperaceae shows a consistent rise; Cheno–Ams and Gramineae values decline. There is a sudden rise in the values of tree and shrub pollen (*Calligonum*, *Maytenus*, *Ephedra*, *Ziziphus*, *Prosopis cineraria* and *Syzygium*), some of which, however, occur only sporadically, and the curve for *Artemisia* begins to rise. Two grains of *Acacia* (polyad) and one of *Sterculia* are also recorded. Gramineae remains low in the beginning but later rises again. The *Artemisia* curve fluctuates inversely with the rise and fall of the Gramineae curve. Both *Aerva* and *Typha angustata* recover to some extent. The curve for Cerealia-type suddenly ends in the first half of zone LK-3, following soon after the decline in the curve for carbonized wood remains. The *Maytenus* curve also breaks up in the upper half and the *Calligonum* curve declines towards the top of the zone. The tree and shrub pollen ratios attain their maximum representation together with those of sedges and mesophytic species such as *Syzygium* and *Artemisia*.

The section of the profile from 35 to 95 cm did not yield any fossil pollen. There is a stratigraphic change from laminated clay to non-laminated silt at 100 cm, and it is likely that the lake started drying during this period, a feature which perhaps led to the breakdown in the laminations as well as resulting in the oxidation of pollen in the sediment.

The curve for carbonized remains, which falls considerably in zone LK-3, declines further in the pollen-deficient layers of the profile and above (figure 6).

The top 30 cm of the profile, which once again contained fossil pollen, has been assigned to subzones LK-4a and LK-4b. The picture of vegetation presented in these subzones is closely akin to the present-day vegetation of the arid belt (Singh *et al.* 1973). Subzone LK-4a begins with continuous curves for *Calligonum*, Cheno–Ams and *Aerva*, which rise together in this subzone. The curve for Cyperaceae falls to its absolute minimum. Except for the pollen of *Pinus* and two grains of *Salmalia* (transported from a long distance in each case), tree vegetation remains unrepresented. Similarly the pollen of freshwater aquatics and that of Cerealia-type is completely absent. This is typical of the present-day almost dry, uncultivated, treeless, 'Sand Formation' type of vegetation prevailing in the area (Singh *et al.* 1973). Subzone LK-4b begins at 20 cm, where the curves for Cyperaceae, *Calligonum* and *Capparis* rise and that of Cheno–Ams falls. Single grains of *Wrightia*, *Holoptelea*, *Azadirachta*, *Alnus*, *Euphorbia*, *Indigofera*, *Oldenlandia*, *Tubuliflorae*, *Typha angustata*, *Cannabis sativa*, Acanthaceae, *Fagonia cretica*, Leguminosae and a few grains of *Heliotropium* are met with sporadically in this subzone (figure 6).

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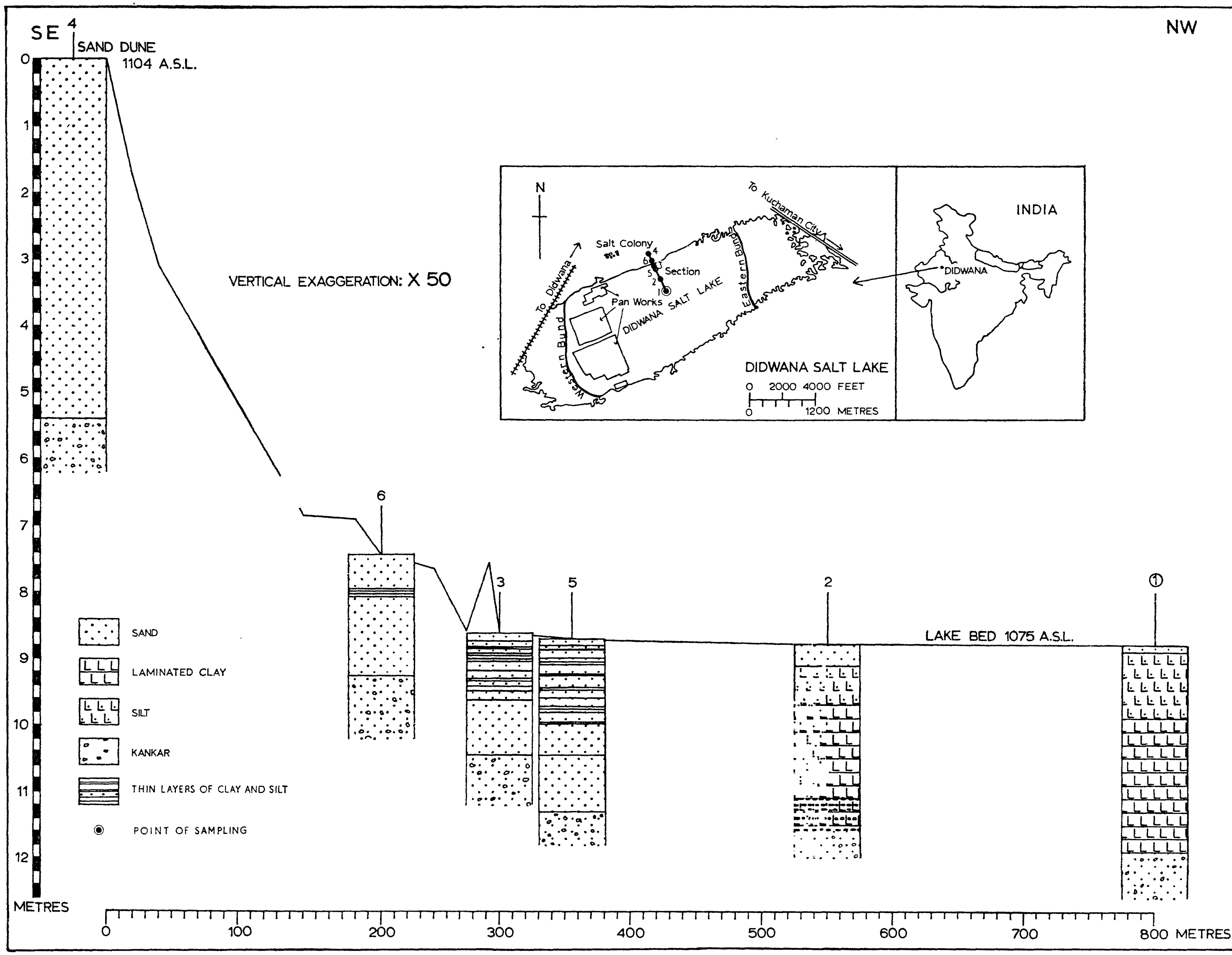

FIGURE 7. Stratigraphical section of Didwana Salt-lake deposits with inset map of the lake basin showing the line of the section as well as the point of sampling for pollen and radiocarbon analyses.

Didwana Salt-lake

The location and stratigraphy of a section from the Didwana Salt-lake has already been described in Singh *et al.* (1972). In this paper some aspects of the stratigraphical reconstruction of the lake basin are discussed along with an illustration of a reconstructed section of the basin shown in figure 7.

The lake basin is artificially dammed on each side of the longer axis by two bunds (dams) cutting across the width of the depression (figure 7) with a view to keeping the salt-works free of floods during the rainy season. The wells dug in sand on the outer edge of the depression contain fresh water and it is conceivable that a part of this wateı also finds its way into the lake basin through underground seepage. At present there is no recognizable outlet to the basin.

The dry bed is almost completely devoid of plant life except for the lake margins, where small mounds of sand support a variety of grasses. The halophytic vegetation is rather poorly developed at this site. The flora of Didwana in general consists mainly of a grassland savannah with scattered and heavily lopped trees of *Prosopis cineraria*, some *Tecomella undulata* and *Capparis decidua*. The sand-dunes are covered with an assemblage characteristic of 'Sand Formation' and the isolated spur of the Aravalli Range in the southwest of the lake-basin is overgrown with plants of 'gravel and rock formation' (Blatter & Hallberg 1918–21).

The southwestern end of the lake has been the site of the manufacture of common salt for a long time (Aggarwal 1956) and presently the area is, in addition, being exploited for sodium sulphate.

In the reconstructed section of the lake deposits (figure 7) it is revealed that the basin is lined by a kankar pan which is overlaid by loose sand at the margins. The sand as well as the kankar pan inside the lake-basin are overlain by a sequence of laminated clay, non-laminated silt and some fine sand. The non-laminated silt and sand did not yield any fossil pollen. As the lake sediments away from the lake margins lie directly over a kankar pan it is likely that the sand originally overlying the pan was eroded out in the initial stages while the early lake sediments were being laid down in the basin. This, as it will be seen later, is evidenced by the lack of deposits comparable to zones SM-1 and LK-1 at Sambhar and Lunkaransar respectively, in the pollen diagram from this site (figure 8). It is clear from the general stratigraphy that the lake basin was a hollow in sand prior to the deposition of lacustrine clay in the same manner as the other two salt lakes mentioned earlier.

Apart from the few macro-remains which could not be identified the part of the deposit from 110 to 315 cm yielded high frequencies of carbonized wood remains dispersed through the sediment (figure 8).

Pollen diagram. The pollen sequence starts with subzone DW-1a at 315 cm with low values of sedges and high *Artemisia*, grasses and Cheno–Ams. The curves of *Maytenus*, *Oldenlandia* and *Typha angustata* are well developed. In the later part of the subzone Gramineae rises, *Artemisia* falls to some extent and there is a gradual rise in the curve for Cyperaceae. *Capparis*, *Ephedra*, *Prosopis cineraria*, *Tamarix*, *Acacia*, *Grewia*, *Mimosa rubicaulis*, *Aerva*, Acanthaceae, *Cleome*, *Heliotropium*, *Indigofera*, Tubuliflorae and *Tephrosia* form short curves. Single grains of *Anogeissus*, *Wrightia*, *Dodonaea*, *Ailanthus*, Liguliflorae, *Arnebia*, *Corchorus*, *Euonymus*, Umbelliferae, *Tribulus*, *Evolvulus* and fern spores are also seen in the sequence. The pollen of Cerealia-type starts occurring from quite early on at 305 cm and the curve for carbonized wood fragments is well developed from the very beginning of the pollen sequence. The pollen of Cerealia type is seen more frequently in the upper part of the subzone.

Subzone DW-1b begins at 230 cm. The values of Cheno–Ams fall and there is a substantial rise in the curve for Cyperaceae. There is a slight rise in the tree and shrub pollen ratios. There is, however, little change in the other curves except that the pollen of *Calligonum*, *Prosopis cineraria*, *Tamarix* and *Acacia* (polyads) start occurring more frequently. The pollen of *Syzygium* is seen for the first time in this subzone. The curves for both trees and shrubs (excepting *Maytenus*) show frequent breaks which could have been caused through frequent burnings of the scrub vegetation as also evidenced at other sites.

Zone DW-2 begins at 195 cm. The curve for sedges shows a steep rise to very high frequencies in this zone. The *Artemisia* curve falls and the tree and shrub pollen ratios show a slight improvement and later attain their maximum values. In the zone, as a whole, a number of trees and shrubs, such as *Prosopis cineraria*, *Acacia*, *Syzygium*, *Capparis* and *Ephedra* attain their maximum frequencies. There is, however, a general decline in the *Maytenus* curve. The curves for *Cleome* and *Indigofera* also rise. The pollen of Cerealia-type continues to form short curves and the value of the curve for carbonized remains rises, once again, towards the end of the zone. The fern spores develop a short curve in the middle of the zone whereas the curve for *Typha angustata* breaks and its pollen becomes rare in the later half of the zone.

Subfossil pollen ceases to be preserved in the sediment above 110 cm where the horizontal laminae in the sediment also breaks down and the curve for carbonized wood remains plunges to extremely low values in the same manner as already seen at Sambhar and Lunkaransar (figures 4, 6). The lake appears to have started drying at this level.

Pushkar Lake

The freshwater lake at Pushkar (26° 29′ N, 74° 33′ 50 E), lies in the semi-humid belt about 11 km west of Ajmer about 382 m above sea-level in the Aravalli Range (figure 1). The lake occupies an inter-sand-dune hollow on the western flank of the Aravallis amid sand-dunes piled up against the Nag Pahar ridge rising to about 880 m. The Pushkar Lake is one of the most important holy shrines of the Hindus and has continued to attract hosts of pilgrims from times immemorial (Sarda 1941). Coins dating back to the fourth century B.C., and of even earlier age, have been discovered from the bed (Sarda 1941). In the ninth century A.D. the famous Parihar King, Narhar Rao of Mandar (Marwar), is said to have had embankments raised across the outlet, as well as on the three sides of the lake (Sarda 1941). The lake is fed mainly by a flood stream, the Gori Nadi, which rises only a few miles away in the south from the Nag Pahar mountain ridge. The lake extends itself southeastwards during the rainy season but shrinks to a small oval-shaped pond during the dry months, when it is fed by underground natural springs. A number of bore-holes was dug along the narrow isthmus connecting the perennial body of the lake to the extensive flood plains but no systematic stratigraphical reconstruction of the basin was attempted. The sampling for pollen analysis was carried out from a point close to the centre of the basin. The profile has not been dated by radiocarbon analyses for want of enough material. The stratigraphy at the point of sampling is as follows:

cm	
0–230	grey clay with occasional thin layers of silt and sand
230–240	sand
240–330	grey clay, rich in organic matter
330–380	same but with less organic content
380–390	sand.

Pollen diagram. The pollen sequence from the Pushkar lake (figure 9) is marked by the fact that, unlike the other sites investigated from western Rajasthan (figures 4, 6, 8), it represents a continuous record of vegetational change extending almost to the present day. The sequence exhibits changes in vegetation in the present semi-humid belt and, as might be expected, the taxa represented are markedly different from those of the pollen diagrams from the arid and semi-arid belts.

The pollen sequence starts with subzone PS-1a at 390 cm. The curve for *Anogeissus pendula*, a mesophytic species, is at a high level. The desert elements comprised of *Calligonum*, *Maytenus*, *Ephedra*, *Capparis*, *Ziziphus*, *Prosopis cineraria* and *Salvadora* are either absent or form very short curves. The curves for tree pollen and Cyperaceae rise to nearly 15% in each case; Gramineae and *Euphorbia* are high and *Artemisia* shows low values. The curves for both Chenopodiaceae and Cerealia-type pollen show frequencies exceeding 10%. *Justicia* pollen, together with fern and bryophytic spores, form continuous curves. *Potamogeton* is represented by a short curve. The pollen of *Ficus*, *Azadirachta*, *Ailanthus*, *Pinus*, *Dodonaea*, *Aerva*, Boraginaceae, *Lepidagathis*, *Peristrophe*, *Polygala*, *Sericostoma*, *Spermacoce* and Tubuliflorae occurs sporadically. Subzone PS-1a, which ends at 370 cm, is indicative of a relatively mesophytic phase in the Aravallis. Cereal cultivation was perhaps common in the area and was probably practised locally at Pushkar.

Subzone PS-1b begins at 370 cm. The curve for *Anogeissus* falls together with a decline in the tree pollen ratios. There is a small rise in the values of *Calligonum*, *Maytenus*, *Ficus*, *Artemisia*, Boraginaceae, *Polygala* and a fall in Gramineae and *Euphorbia*.

In subzone PS-1c (335–310 cm) there is a relative increase in the values of *Mimosa rubicaulis*, *Anogeissus pendula*, *Calligonum*, *Maytenus*, *Ephedra* and *Capparis*. The tree-pollen ratios rise once again and there is a relative rise in the frequencies of shrub pollen as well.

In zone PS-2 (310–160 cm) desert plants comprised of *Calligonum*, *Maytenus*, *Ephedra*, *Capparis* and *Prosopis cineraria* appear to have dominated the tree and shrub vegetation whereas *Anogeissus pendula* falls and remains low in this zone. The curves for Gramineae, *Artemisia*, Chenopodiaceae, *Justicia*, *Sericostoma*, Tubuliflorae, *Potamogeton*, *Typha* and fern spores mark a small overall increase in their frequencies in this zone. The pollen of *Ziziphus*, *Salvadora*, *Wrightia*, *Acacia*, *Syzygium*, *Azadirachta*, *Ailanthus*, *Sterculia*, *Dodonaea*, *Mimosa rubicaulis*, *Pinus*, *Salmalia*, *Holoptelea*, *Rhus*, *Grewia*, *Tamarix*, *Phoenix*, *Blepharis*, *Boerhaavia*, *Cadaba*, *Cleome*, Convolvulaceae, *Corchorus*, Cruciferae, Leguminosae, Malvaceae, *Nymphaea*, *Nelumbo* and *Lemna* occur sporadically. The curve for Cerealia-type pollen maintains mostly high values in the lower half but later falls to lower values.

Subzone PS-3a begins at 160 cm. The curve for *Anogeissus* once again shows a consistent rise and that of *Ficus* starts as an almost continuous curve. There is little change in the frequencies of desert species in this subzone; *Maytenus*, in fact, shows a further rise in its values. There is a rise in the values of tree and shrub pollen ratios and Gramineae shows an overall decline, even though its curve recovers to some extent in the later part of the subzone. *Artemisia*, after showing a sudden rise in the beginning of the subzone, declines. The values of Chenopodiaceae, *Aerva*, *Euphorbia*, *Justicia* and *Lepidagathis* show a definite rise. The curve for *Potamogeton* falls. There is a small rise in the values of Cyperaceae and fern and bryophytic spores. There is also a relative increase in the occurrence of the pollen of *Syzygium*, *Sterculia*, *Wrightia*, *Nelumbo* and *Lemna*.

Subzone PS-3b begins at 70 cm. The pollen frequencies of almost all the desert species, *Calligonum*, *Maytenus*, *Capparis*, *Euphorbia*, *Prosopis cineraria* and *Aerva*, decline to negligible values

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and the curves for mesophytic elements *Ficus* and *Anogeissus* rise consistently. In this subzone *Capparis* is no longer represented and the pollen of *Calligonum*, *Euphorbia*, *Maytenus*, *Aerva* and *Prosopis cineraria* occurs only very sporadically. The pollen of *Acacia*, *Syzygium*, *Anogeissus*, *Aegle marmelos* and *Mimosa rubicaulis*, all representing mesophytic species, reaches its maximum extent and importance. Similarly the tree-pollen ratios rise to their maxima and shrub pollen remains almost unrepresented. The values of Gramineae, *Artemisia* and *Aerva* and fern spores fall, whereas those of Chenopodiaceae, *Ephedra*, *Cuscuta*, Tubuliflorae, *Typha*, *Nypmhaea* and *Lemna* rise at one stage or another. There is little change in the *Justicia* curve. The curve for Cerealia-type pollen first rises but later falls to lower values.

There is clear evidence of an increase in the mesophytic tree forest cover and a recession of the western desert flora in the Pushkar area in zone PS-3 in general, and in subzone PS-3b in particular.

Kalibangan

The village of Kalibangan (29° 29′ N, 74° 8′ 15″ E), District Ganganagar, lies on the banks of the now dry river Ghaggar ('Saraswati' of Vedic times), and is the site of the ruins of a famous ancient town ascribed by archaeologists to the pre-Harappan and Harappan cultures in northwest India (*ca.* 2600–1700 B.C.). From the excavations carried out by the Archaeological Survey of India, a large number of samples of soil, loose earth, silt and sand were collected from deposits associated with different structural phases of the pre-Harappan and Harappan periods. The bulk of the material was found to be barren of pollen so the study was confined to only two samples, KLB/12 and KLB/13, collected from ash layer no. 20 in phase I of the pre-Harappan trench ZP 12/QDI.

The individual pollen spectra derived from the two samples are tabulated as follows:

name of taxon	percentages of total land plant pollen excluding Cyperaceae KLB/12	KLB/13	name of taxon	percentages of total land plant pollen excluding Cyperaceae KLB/12	KLB/13
Tamarix	1	—	Cheno–Ams	4	3
Capparis	—	1	Cerealia pollen type	1	58
Mimosa rubicaulis	8	—	Boraginaceae	23	4
Acacia	—	1	Compositae	25	7
Palmae	1	—	Cruciferae	1	—
Syzygium	—	3	*Cleome*	—	9
Pinus	4	—	*Justicia*	2	—
Wrightia	—	1	*Oldenlandia*	—	2
Cedrus	10	—	Leguminosae	1	—
Picea	—	3	Umbelliferae	—	1
Betula	1	—	total land plant pollen counted excluding Cyperaceae	87	101
Holoptelea	1	—			
Alnus	1	—	trees (%)	19	11
Gramineae	10	14	shrubs (%)	8	1
Cyperaceae	65	146	herbs excluding Cyperaceae (%)	72	87
Artemisia	1	—			

The two pollen spectra, even though dissimilar in several respects, broadly compare with subzone SM-3a of the Sambhar pollen sequence. Cyperaceae is high whereas Gramineae and Cheno–Ams are lowly represented. The occurrence of *Syzygium* and *Mimosa rubicaulis* pollen and the values of tree and shrub pollen ratios (after excluding the Himalayan long-distance wind-transported pollen) also compare with subzone SM-3a. The presence of Cerealia-type pollen in both the samples is probably suggestive of the occurrence of cereal cultivation during the pre-Harappan times at Kalibangan. It may be mentioned here that recent excavations at Kalibangan have indeed uncovered evidence of furrow-marks in the pre-Harappan levels, indicating some form of agricultural activity at that time in the area (Lal 1970–1). The values of Cerealia-type pollen up to 58 %, in sample KLB/13, are, however, exceptionally high and can only be explained in terms of very local representation; Cerealia pollen, on account of its size and low pollen productivity, is not recovered a long distance from its source (Singh *et al.* 1973). A variety of pollen types such as those belonging to *Pinus*, *Cedrus*, *Picea*, *Betula*, *Alnus* are derived through long-distance transport by wind and water from the Himalayan ranges.

Discussion and conclusions

Chronostratigraphical considerations

Some aspects of the stratigraphy, age and development of the three salt lakes investigated from western Rajasthan have already been dealt with briefly in an earlier publication (Singh *et al.* 1972). Barring the freshwater lake from Pushkar, whose overall stratigraphy is still undetermined, the deposits in the three salt lakes at Sambhar, Lunkaransar and Didwana provide a fair representation of the subrecent lake sedimentary history of the Rajasthan desert. The salt lakes vary both in size and the relative size of their catchments and occupy areas with differing mean annual precipitations as a result of which they are subject to dissimilar controls of level. Indeed, the lake deposits, seen in the light of the available radiocarbon dates, show variable rates of sedimentation. For instance, the Sambhar Salt-lake in the semi-arid belt exhibits a rate of 0.034 mm per year while that at Lunkaransar in the arid belt accumulated at only 0.025 mm per year. That the rates of sedimentation at each of the individual sites did not vary significantly during their sedimentary history is seen from the close agreement between the radiocarbon dates on one hand and those estimated by the simple application of a linear scale. It may in fact be suggested that there was little or no deflation of sediment during the course of the lacustrine period. The absence of lunettes, or any other deflationary deposit, on the leeward side of the salt lakes perhaps confirms this conclusion.

Stratigraphically the salt-lake deposits may be divided into three distinct parts, namely (*a*) pre-lacustrine, (*b*) lacustrine and (*c*) post-lacustrine. The early stages of the pre-lacustrine section are, however, least understood and need further elucidation. This section is constituted of mainly aeolian sands extending inwards from the margins of the encircling sand-dunes and underlies lacustrine deposits. At lower levels the sand grades into a kankar pan, having resulted from leaching as well as the cementing of sand particles by calcium carbonate. No firm date can be assigned to the beginning of this sequence.

The lacustrine section begins with a facies change from sand to dark-grey laminated lacustrine clay which was probably deposited under perennially submerged conditions. A date around 10000 B.P. is extrapolated for the beginning of this section. The lacustrine section ends at the upper limit of laminated clays. It is assumed that any layering broke down as a result of desiccation and that the resulting exposure of sediments also led to the destruction of organic matter, including fossil pollen. But as the local conditions governing the three salt-lakes differ from each other in several respects the desiccation is unlikely to have come simultaneously at all the sites and hence the non-laminated/laminated clay boundary cannot be regarded as synchronous. From the dates extrapolated for this boundary at Lunkaransar and Sambhar it is indeed evident that the boundary falls at *ca.* 4000 B.P. at Lunkaransar, in the arid belt, and at *ca* 3000 B.P. at Sambhar, in the semi-arid belt.

The post-lacustrine section is marked by greyish-brown non-laminated silty clays which are generally deficient in both organic matter and fossil pollen and constitute the top section of the salt-lake deposits. In view of the frequent limonitic stains seen in this section it is evident that the sediment was exposed to oxidation quite frequently during the dry seasons.

Late-Quaternary environments

Vegetation and climate

The vegetation history of the Rajasthan desert, as built from the combined pollen sequences from Lunkaransar, Didwana, Sambhar and Pushkar (figures 1, 4, 6, 8, 9), is broadly representative of the three major climatic belts, the arid, the semi-arid and the semi-humid, occurring in Rajasthan (figure 1), and may be viewed in the light of the corresponding vegetation as well as the prevailing patterns of modern pollen rain in these belts (Singh *et al.* 1973). Some inferences derived from the vegetation history from Sambhar, Lunkaransar and Didwana have already been discussed briefly in a different context, in two earlier publications (Singh 1971; Singh *et al.* 1972). The full discussion which now follows is presented, together with the relevant pollen diagrams, for the first time.

Based on the more or less parallel and certainly broadly synchronous changes observed in the stratigraphy and vegetational development at the lake-sites investigated, as exemplified by the four regional pollen assemblage zones described earlier, it is now possible to make certain deductions about the regional vegetation and climatic history of the area. The environmental sequence as deduced from the vegetation history and the stratigraphy of the lake basin deposits, has been grouped into five phases, I–V, four of which (II–V) are based on biostratigraphic units, that is, the regional pollen assemblage zones, which are also broadly time stratigraphic. Phase I has been delineated independently of biostratigraphical evidence, which is absent, and is based on lithostratigraphic criteria. The lower boundaries of phases I and V and the upper limit of phase IV are not time stratigraphic. A brief summary of phases I–IV has been reported in Singh (1971).

Phase I: before ca. 10000 B.P. It has been suggested earlier that the lacustrine deposit, at each of the three salt-lake sites lies directly above a bed of aeolian sand (Singh 1971; Singh *et al.* 1972). The base of the sand bed, which marks the lower boundary for phase I, has not been dated. The upper boundary is determined by the first consistent infilling of the lake basins, as exemplified by the first deposition of laminated clays, and by the beginning of the Cyperaceae–Gramineae–*Artemisia* pollen assemblage zone, as defined at Sambhar (figure 4), and dated at about 10000 B.P. At Sambhar, the presence of several thin layers of cemented sandstone in the otherwise loose sand is perhaps indicative of some earlier very-short-term inundations. This feature is, however, not seen at the other two sites. At Didwana, it has been already suggested that any evidence of the earliest sedimentation appears to be missing, perhaps through erosion at the point of sampling (Singh *et al.* 1972). Nevertheless, the stratigraphy of the Didwana lake basin, in general (figure 7), is closely similar to that of Sambhar and Lunkaransar salt lakes, and from the combined evidence it may be suggested that before about 10000 B.P., extremely severe arid conditions with perhaps strong winds prevailed in western Rajasthan, with the result that extensive sand-dunes were deposited which led to the choking of valleys with sand to give shape to inland basins, such as at Sambhar, Lunkaransar and Didwana.

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Phase II: ca. 10000 B.P. *to* ca. 9500 B.P. Phase II is broadly defined by a Cyperaceae–Gramineae–*Artemisia* assemblage zone whose upper limit has been extrapolated around *ca* 9500 B.P. (figures 4, 6). This zone is rich in sedges and grasses and poor in halophytes (denoted by Chenopodiaceae/Amaranthaceae). The vegetation can be considered as being comprised of an open-land steppe in which grasslands preponderated. While the tree vegetation was probably sparse it is very likely that some trees and shrubs, such as *Acacia*, Palm and *Maytenus* in the semi-arid belt (local pollen zone SM-1, figure 4), and *Calligonum*, *Maytenus*, *Ephedra*, *Capparis*, *Ziziphus* and *Tamarix* in the arid belt (local pollen zone LK-1, figure 6), were represented in this zone. The poor development of trees and shrubs in both the belts, may be ascribed to the slow migration of these plants into the area following the postulated aridity in phase I. *Artemisia*, an element of a higher rainfall regime (above 50 cm average annual rainfall) and which is now rarely seen in the Rajasthan desert (Singh *et al.* 1973), seems to have extended into both the present arid and semi-arid belts. Similarly, *Mimosa rubicaulis* and *Oldenlandia*, which now grow mostly east of the Aravalli Range, flourished in the semi-arid belt. The former species, unlike *Oldenlandia*, however, did not encroach into the contemporary arid belt. The desert vegetation was at its minimum in the semi-arid belt. As there was no further intercalation of sand layers in the lake sediments, it was suggested earlier by Singh (1971) that the sand-dunes had started to stabilize. That freshwater conditions prevailed in the lake basins is shown by the presence, in both the arid and the semi-arid belts, of *Typha angustata*, a freshwater swamp species no longer seen in the Rajasthan desert beyond the 50 cm isohyet except in the modern canal-irrigated tracts of the Punjab and Haryana (Singh *et al.* 1973). The evidence indicates that there was a general westward shift of the rainfall belts (figure 1) and that there was at least 25 cm more rain than at present in the arid belt in phase II provided that the rates of evaporation were not significantly different from those of the present.

Phase III: ca. 9500 B.P. *to* ca. 5000 B.P. This phase is broadly defined by the Gramineae–*Artemisia*–Cheno–Ams assemblage zone (figure 4, 6, 8). In this phase the development of grasses is the highest at Lunkaransar (local pollen zone LK-2, figure 6), in the present arid belt, and the lowest at Sambhar (local pollen zone SM-2, figure 4) in the semi-arid belt, with Didwana (local pollen zone DW-1), having values midway between Sambhar and Lunkaransar. Conversely, the values of *Artemisia* are the highest at Sambhar and the lowest at Lunkaransar, with again Didwana having medium values. At each of the three sites every rise and fall in the Gramineae curve mirrors the fall and rise of the *Artemisia* curve. There is no straightforward explanation for this behaviour but it is likely that the occurrence of relatively wetter or drier spells may have been partly responsible, though this explanation cannot be pressed too far on account of the lack of relevant basic ecological data. From the nature of the pollen assemblage, as well as the extent and importance of the various curves, the influence of the desertward location of Lunkaransar is unmistakable. Both the relative poverty of the flora and the subdued nature of the pollen curves for plants of comparatively higher rainfall zones is indicative of a comparatively poor plant cover in the present arid belt. Nevertheless the conditions appear to have been vastly different from those of the present day. For instance, the continued growth of *Typha angustata*, *Artemisia* and *Oldenlandia* in the present arid belt could have been sustained only as a result of a relatively higher rainfall (Singh *et al.* 1973).

Phase IV. ca. 5000 B.P. *to* ca. ?3000 B.P. Phase IV is defined by the Cyperaceae tree and shrub assemblage zone (figures 4, 6, 8). The upper boundary of the zone is unnatural and its date from the type site (Sambhar) cannot be taken to be synchronous over a wide area (see p. 492). The

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beginning of phase IV, which is marked by the zone boundary between the Gramineae–*Artemisia*–Cheno–Ams assemblage zone and the Cyperaceae tree and shrub assemblage zone is dated around *ca.* 5000 B.P. The phase starts with a sudden increase of sedges and a rise in the frequency of tree and shrub vegetation for the first time in the sequence. The trees and shrubs consisted mainly of *Syzygium cuminii*, *Mimosa rubicaulis*, *Acacia* sp., *Prosopis cineraria*, *Capparis* sp. and *Tamarix* sp. in the semi-arid belt, and of *Calligonum polygonoides*, *Ziziphus* sp. and *Syzygium cuminii* in the arid belt. The sedges reached their maximum abundance in both the semi-arid and arid belts. The present evidence would indicate that *Syzygium cuminii* (now growing naturally in India in areas with > 85 cm average annual rainfall (Troup 1921), seems to have grown not only in the semi-arid belt but perhaps also extended as far as the Lunkaransar area in the arid belt. Likewise, *Mimosa rubicaulis* rose to its highest pollen frequency values in the semi-arid belt. *Typha angustata* seems to have occurred in both the arid and the semi-arid belts as before. This suggests that precipitation over Rajasthan, in terms of annual average rainfall, was probably 50 cm (20 inches) greater than at the present time in the arid belt. In phase IV, as a whole, the tree vegetation appears to have increased to a greater degree than in any of the preceding phases but it cannot be claimed that trees formed a closed canopy. On the whole, a grassy steppe-savannah type of vegetation appears to have dominated the scene in most areas. However, trees seem to have been commoner in the east than in the extreme west, while the reverse was true for shrub vegetation. *Syzygium* appears to have grown wild around Sambhar in the local pollen zone SM-3a, and also perhaps occupied areas westwards as far as Lunkaransar in this phase. Both *Mimosa rubicaulis* and *Oldenlandia* probably grew in the east around Sambhar and Didwana, but of these, the former failed to reach Lunkaransar while *Oldenlandia* perhaps grew in a scattered form at this site. The grassland gave way to *Artemisia* steppe in the east, in the present semi-arid belt, but westwards it seems to have continued to dominate the landscape while *Artemisia* became less and less important. Sedges probably grew luxuriantly locally in the lake basins at each of the three sites and *Typha angustata* also perhaps continued to grow there.

At Sambhar the Cyperaceae tree and shrub assemblage zone is locally divisible into three sections which are best discussed under the headings of the local pollen subzones SM-3a, SM-3b and SM-3c. Whereas the general features of the three subzones at Sambhar are in close agreement with the diagnostic characteristics of the Cyperaceae tree and shrub assemblage zone, the vegetation sequence as a whole is marked by an oscillation which is clearly exhibited in the pollen curves. At the beginning of subzone SM3b (*ca.* 3800 B.P. to *ca.* 3400 B.P.) the sedges undergo a sudden decline. All the mesophytic plant species found in subzone SM-3a, such as *Syzygium cuminii*, *Mimosa rubicaulis* and the freshwater swamp species, disappear for good from the pollen sequence. At Lunkaransar, in the arid belt, the horizontal stratification of laminated clays breaks down at a level whose date is extrapolated at 4000 B.P. (figure 6), and pollen is no longer preserved in the sediment above that level, both factors indicating that the lake had started drying out. At Sambhar, with the disappearance of freshwater aquatic vegetation, it would appear that the lakes had started turning saline; indeed there is some increase in halophytic plants at this site (figure 4). Subzone SM-3c (*ca.* 3400 B.P. to *ca.* 3000 B.P.) represents a small and temporary revertence towards the conditions of subzone SM-3a. Cyperaceae, *Capparis*, Acanthaceae and *Artemisia* increased and the Cheno–Ams decreased. *Maytenus*, *Ephedra*, *Prosopis cineraria*, *Palmae* and *Justicia* reappeared fleetingly. The conditions of subzone SM-3c appear to have favoured the growth of shrub vegetation at Sambhar but were still insufficiently wet to allow the re-establishment of the mesophytic elements such as *Syzygium*, *Mimosa rubicaulis* and the swamp and aquatic flora in general.

At Sambhar the drying up of the lake surface appears to have been delayed in relation to Lunkaransar. From the extrapolated dates for the levels indicating this phenomenon, it seems likely that the period of drying, as evidenced by the break up of laminations and the lack of pollen in the sediment, was delayed for localities situated progressively eastwards. The dates suggested at Lunkaransar and for Sambhar are around 4000 B.P. (2000 B.C.) and 3000 B.P. (1000 B.C.) respectively. At all the salt-lake sites the nature of the sedimentary change from laminated clay to silt at the end of phase IV indicates that a lot of coarse material was beginning to be deposited and that the coarse silty deposit was perhaps derived through erosion during floods and through wind action on unstable soil surfaces resulting from arid environments. The level of salinity must have increased progressively during the earlier phases, as exemplified by the gradual declines in the frequencies of *Typha* pollen at all the sites, and the lakes would have turned saline at about the same time as the extinction of the aquatic flora from the respective lake basins (Singh *et al.* 1972). It has been already demonstrated that the crystallization of gypsum in the laminated clays ascribed to phases II, III and IV at Lunkaransar (figure 6) took place after their deposition, and this might well have happened after phase IV after the drying of the lakes (Singh *et al.* 1972).

Phase V: ? early centuries A.D. *to present*. Phase V is defined by the Gramineae–Cheno–Ams–Cyperaceae–*Calligonum* assemblage zone, which is separated from the Cyperaceae tree and shrub assemblage zone by a disconformity in the form of a pollen-less interval. The date for the lower boundary of phase V is thus uncertain as it is marked by the first renewed preservation of pollen in the lake sediment after the Cyperaceae tree and shrub assemblage zone (phase IV). Locally at Lunkaransar the date for the lower limit of phase V, as determined by the criterion mentioned above, can be estimated at about 1200 B.P. from the rate of sedimentation calculated for the deposits lower down. Phase V is known only from Lunkaransar. Broad comparisons have, however, been made later on with the local pollen zone PS-3 at Pushkar.

At Lunkaransar the quality of the pollen assemblage reflects more or less the present-day conditions of the area (figure 6). *Calligonum*, *Capparis*, *Aerva* and Cheno–Ams are at a high level whereas Cyperaceae is poorly represented. There is hardly any evidence of either cereal cultivation, tree vegetation or the existence of any aquatic species in the area. *Artemisia* pollen is almost absent. The vegetation, on the whole, thus seems to comprise of a typical 'Sand Formation' type, as presently seen in the Lunkaransar area (Singh *et al.* 1973).

That the renewed preservation of pollen in the lake sediments in phase V was to any extent influenced by a change in the weather pattern is not certain because no such evidence is seen at either Sambhar or Didwana. On the other hand there is some evidence from Pushkar (discussed later) that the conditions had turned wetter in the local pollen zone PS-3 after a protracted dry interval (figure 9). It is thus quite likely that the conditions had also improved marginally in the Lunkaransar area in the more recent times dating from about the early centuries A.D.

Comparisons with the pollen diagram from Pushkar (*figure* 9). At Pushkar there are no radiocarbon dates available from the profile, but it is reasonable to assume that the pollen sequence (figure 9) extends to the present day. This assumption is strengthened by the fact that the pollen spectra from the top layers of the profile are analogous to the vegetation pattern now prevailing in the area (Singh *et al.* 1973). The pollen sequence from Pushkar (figure 9), from the bottom upwards, exhibits a vegetation change from a mesophytic type, consisting of mainly *Anogeissus* in the local pollen zone PS-1, to a xerophytic assemblage comprised of desert elements such as *Calligonum*, *Maytenus*, *Ephedra*, *Capparis* and *Prosopis cineraria* in the local pollen zone PS-2, after which the vegetation reverts to its original mesophytic character in the local pollen zone PS-3 (figure 9). Assuming that the movement of the western Rajasthan xerophytic flora into the Pushkar area, in the Aravallis, in the local pollen zone PS-2, had resulted from a period of aridity in the area, it would not be unreasonable to suggest that the period was representative of the pollenless interval seen after phase IV in the pollen diagrams from Lunkaransar and the other two sites, Sambhar and Didwana, investigated from western Rajasthan. If the above correlation is correct then the local pollen zones PS-1 and PS-3 may be compared to phases IV and V respectively. The salt lake at Sambhar, which is the nearest to Pushkar, from amongst the three salt lakes studied, is suggested to have dried about 3000 B.P. (Singh 1971; Singh *et al.* 1972). Assuming that the local pollen zone PS-1, at Pushkar, ended about the same time, the date for the end of the local pollen zone PS-2, marking the end of an arid period in the Aravallis, can be estimated around A.D. 400, which is some 350 years ahead of the estimated date for the resumption in the pollen preservation at Lunkaransar, in the arid belt.

Long-distance correlations

Verstappen (1970) suggests that the sand-dunes in Rajasthan were formed under arid conditions, presumably during the cold, early Holocene, but is unable to give direct evidence for their age. Allchin & Goudie (1971), from a study of the sand-dunes in central Gujarat south of the Rajasthan desert, suggest that precipitation amounts in central Gujarat before the arrival of microlithic man were certainly low. Earlier, Zeuner (1963), concluding his studies on Gujarat, had arrived at a similar result: 'we come to the conclusion that here the Upper Pleistocene is, broadly speaking, represented by an arid phase instead of a pluvial'. From the present evidence it is abundantly clear that the sand-dunes were active for the most part in phase I, before *ca.* 8000 B.C., and that a similar situation has not recurred since that time in the Rajasthan desert. In the stratigraphy of the lake at Sambhar there is some indication of rather short-term oscillations of the lake level in the form of thin cemented sandstone layers in the otherwise loose sandy deposit below the lacustrine sediments before 10000 B.P., but no definite date can yet be assigned to these fluctuations. While the date of the beginning of phase I is uncertain, the upper limit coincides with the Late Weichselian/Flandrian boundary (8000 B.C.) of Western Europe. The nearest parallel to the situation in Rajasthan is seen in Iran where the pre-Holocene arid phase has been equated with the last full-glacial times (Van Zeist & Wright 1963; Van Zeist 1967). Recently it has been suggested (Butzer *et al.* 1972) that, between 10000 and 8000 years ago, the lakes in many parts of tropical Africa were greatly enlarged and that transgressions leading to this high stand began about 12000 years ago with an indication of a pause or a minor recession just at or before 10000 B.P. Farther afield in Australia, a sudden rise in precipitation (or a fall in temperature) is indicated at about 10000 B.P., following a long protracted dry interval, in places as far apart as north Queensland and south Victoria (Kershaw 1970; Bowler & Hamada 1971).

Phases II and III, in Rajasthan, range between *ca.* 8000 B.C. and *ca.* 3000 B.C. and can be broadly equated chronologically with the combined pre-Boreal to Atlantic periods of Europe (Godwin 1960), when temperatures are known to have remained high throughout the world, including northwest India (Singh 1962, 1963), following the final recession of the last glacial (von Post 1946; Godwin 1956; Iversen 1954). Eriksson (1959) is of the view that, along with the lowering of temperatures in Europe during the later part of the post-glacial period, 'there seems to have been a certain lowering of temperature in the same period in Rajputana' (that is, approximately the present-day Rajasthan). The area, according to Eriksson, 'has become more arid and the amount of wind-borne sand has increased'. Singh's (1962, 1963) evidence of a decreasing warmth from the Kashmir Valley pollen diagrams in the western Himalayas during the later part of the post-glacial period is conformable with the European evidence and lends some support to Eriksson's views mentioned above. It can now be postulated that the onset of aridity in the Rajasthan desert perhaps went hand in hand with the lowering of temperatures in northwest India, although positive correlation must await the radiocarbon dating of the Kashmir diagrams. Moreoever, the extent to which the lowering of temperatures was compensated by a resultant fall in evaporation is not known.

A reconsideration of Bryson & Baerreis's hypothesis

The idea that the Rajasthan desert is largely man-made dates more seriously from about 1952 (Hora 1952). Wheeler (1966) repeats the theme: 'The untiring consumption of major vegetation implied by the firing, age after age, of millions of bricks may, even with aid of hill-timbers, have helped to bare the land, and by reducing the transpiration of moisture have impaired the climate without drastically altering it.' Bryson & Baerreis (1967) take this idea a step farther and, on the basis of archaeological evidence derived from the northern portions of the desert within India, suggest that devegetation by man has been important in making the desert from about Rangmahal times (early centuries A.D.) onwards. They maintain that the progressive deterioration of the vegetation and perhaps of the structure of the soil surface led to increased deflation in the area during this period: 'If the source of the dust is the desert itself, then the desert would appear to be self-sustaining, for the presence of a vegetative cover would inhibit the raising of dust by wind and thus the development of the desert climate which is inimical to the vegetative cover.' Bryson & Baerreis (1967) therefore suggest that steps taken to inhibit the raising of dust would help to reverse the entire cycle and lead to the reclamation of the desert.

The present account suggests that while, on one hand, climatic change has been more or less contemporaneous with climatic events elsewhere in the world, on the other hand there is evidence that man has played havoc with the natural vegetation from quite early times. If increase in the vegetation cover is associated with soil stability and lack of deflation, phases II and IV, comparatively wet intervals, must have been times of great soil stability and low deflation. Vegetation destruction through burning by man started at about 7500 B.C. and continued throughout phases III and IV (figures 4, 6, 8) (Singh 1971). The increase in swamp vegetation and the intensification of vegetation cover inland, together with the maxima of all mesophytic elements in phase IV, indicate an increase in the rainfall, apart from a short relatively drier time from about 1800 to 1500 B.C. indicated at Sambhar (SM-3b) which correlates with the period of the decline of the Harappan culture in northwest India (Singh 1971). Phase IV is immediately followed by aridity for which there is stratigraphic evidence that the salt lakes started drying. At Pushkar there was a marked change in the vegetation from which it would appear that the onset of this aridity was widespread.

During phase IV, in spite of burning and the prevalent agriculture (Lal 1970–1), the natural vegetational cover actually increased despite the great expansion of the Neolithic–Chalcolithic way of life in northwest India (Allchin & Allchin 1968). It is hardly likely therefore that human activity was responsible for the desertification. This dry period, a already pointed out, was perhaps responsible for the wide cultural gap between the decline of the Harappan culture and the beginning of the succeeding Painted Grey Ware culture, generally put between 1000 and 600 B.C. and tentatively associated with the colonizaton of impoverished land (Ghosh 1952). The weight of analytical and stratigraphic pollen evidence favours a climatic determination of the events of this period.

The climate did not ameliorate until about phase V, at which time the Rangmahal culture perhaps flourished in Rajasthan, the remains of which imply a good water supply (Ghosh 1952).

Bryson & Baerreis (1967) are of the opinion that the Rangmahal culture, which was seemingly the most extensive in the region, may have made the greatest impact on the natural environment, implying the destruction of vegetation and intensive cultivation leading to instability of soil and deflation. The pollen diagrams do not favour such an interpretation. It is possible, however, that the nomadic graziers who followed the Rangmahal people (A.D. 700–800; Ghosh 1952) at a time too recent to be represented in the pollen diagrams were the agents through which the recovery of the vegetation was arrested. Grazing is still prevalent in Rajasthan and doubtless leads, amongst other things, to a lot of dust in the atmosphere. Nevertheless, the Rajasthan desert is primarily natural, its history punctuated by at least one more vegetated, humid, period during the Holocene, the climatic control of which, as indicated by the vegetation history, is consistent with climatic events elsewhere in the World.

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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

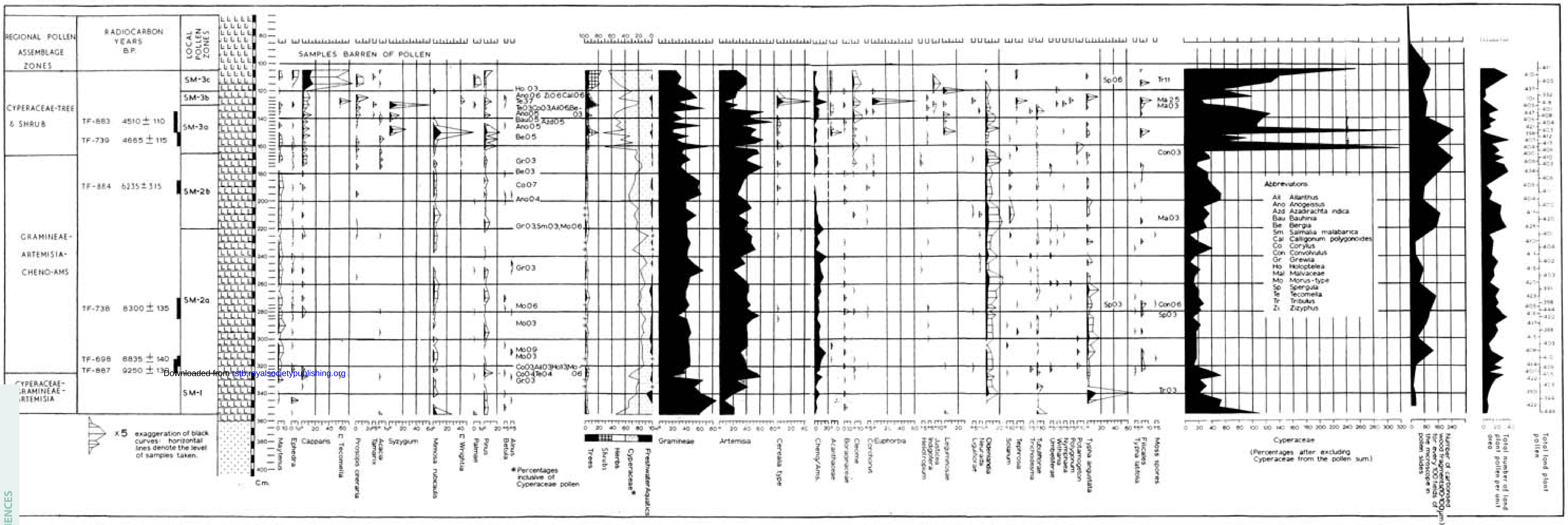

FIGURE 4. Late-Quaternary pollen diagram from Sambhar Salt-lake. Values are expressed as percentages of total land plant pollen excluding Cyperaceae, except in the case of the additional curve for Cyperaceae shown within the same box as the a.p./n.a.p. ratios, where the values are inclusive of Cyperaceae pollen. A frequency curve for carbonized wood remains from samples taken at 20 cm intervals of the profile is also included in the pollen diagram. A key to the stratigraphic symbols used is given in figures 5 and 7.

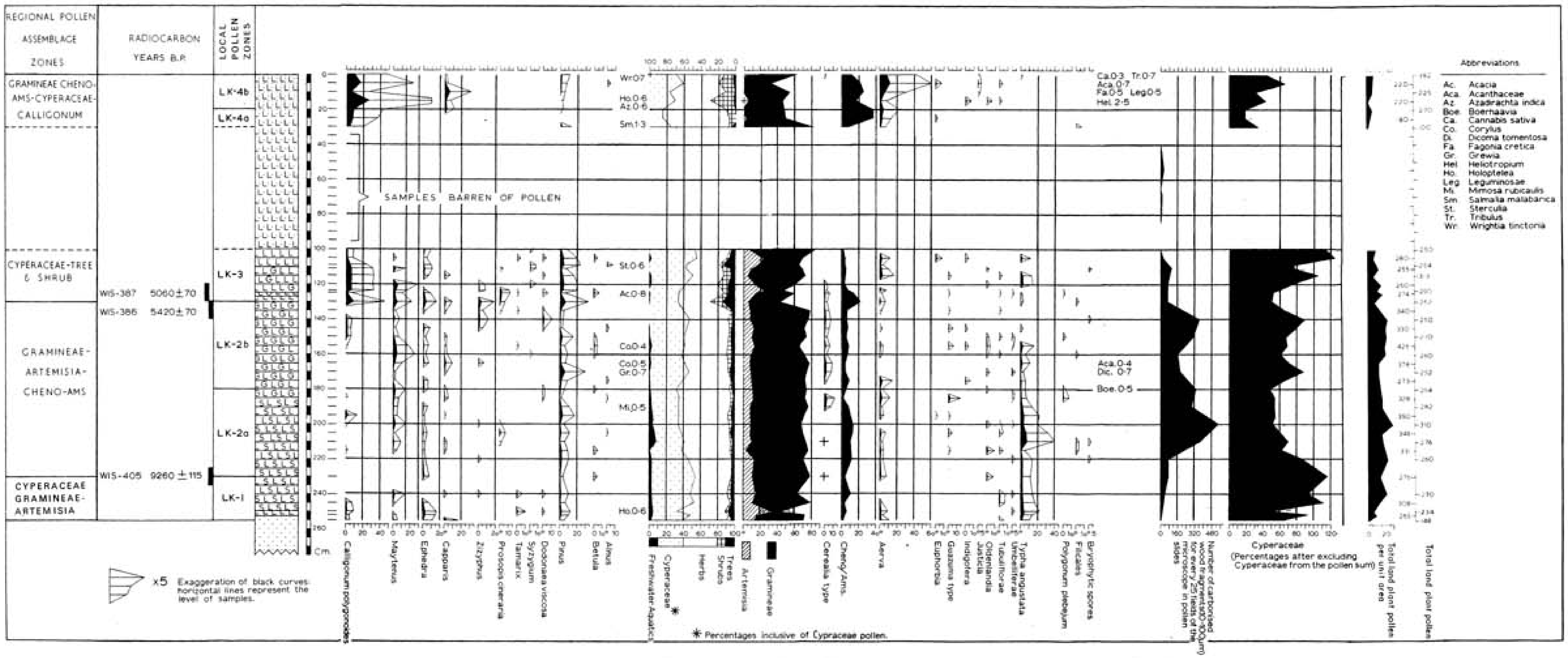

FIGURE 6. Late-Quaternary pollen diagram from Lunkaransar Salt-lake. Values are expressed as percentages of total land plant pollen excluding Cyperaceae, except in the case of the additional curve for Cyperaceae shown within the same box as the a.p./n.a.p. ratios, where the values are inclusive of Cyperaceae pollen. A frequency curve for carbonized wood remains from samples taken at 20 cm intervals of the profile is also included in the pollen diagram.

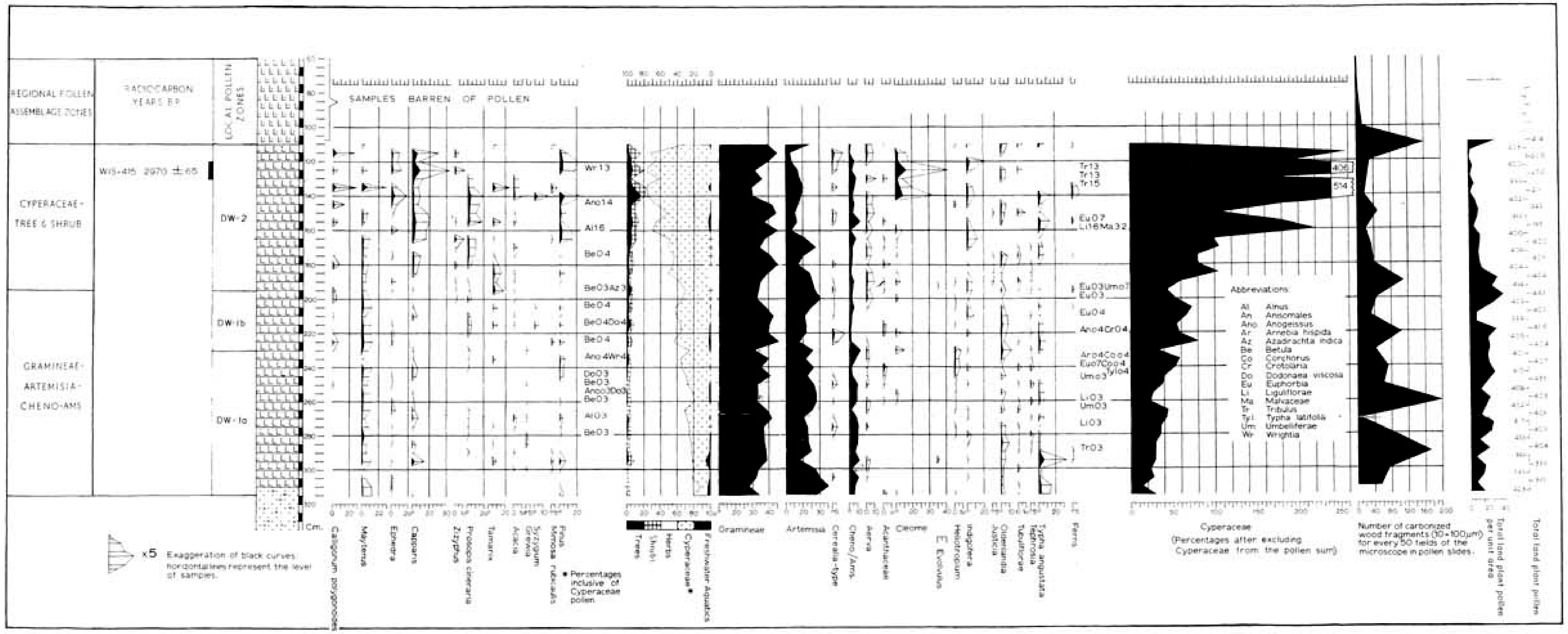

FIGURE 8. Late-Quaternary pollen diagram from Didwana Salt-lake. Values are expressed as percentages of total land plant pollen excluding Cyperaceae, except in the case of the additional curve for Cyperaceae shown within the same box as the a.p./n.a.p. ratios, where the values are inclusive of Cyperaceae pollen. A frequency curve for carbonized wood remains from samples taken at 20 cm intervals of the profile is also included in the pollen diagram.

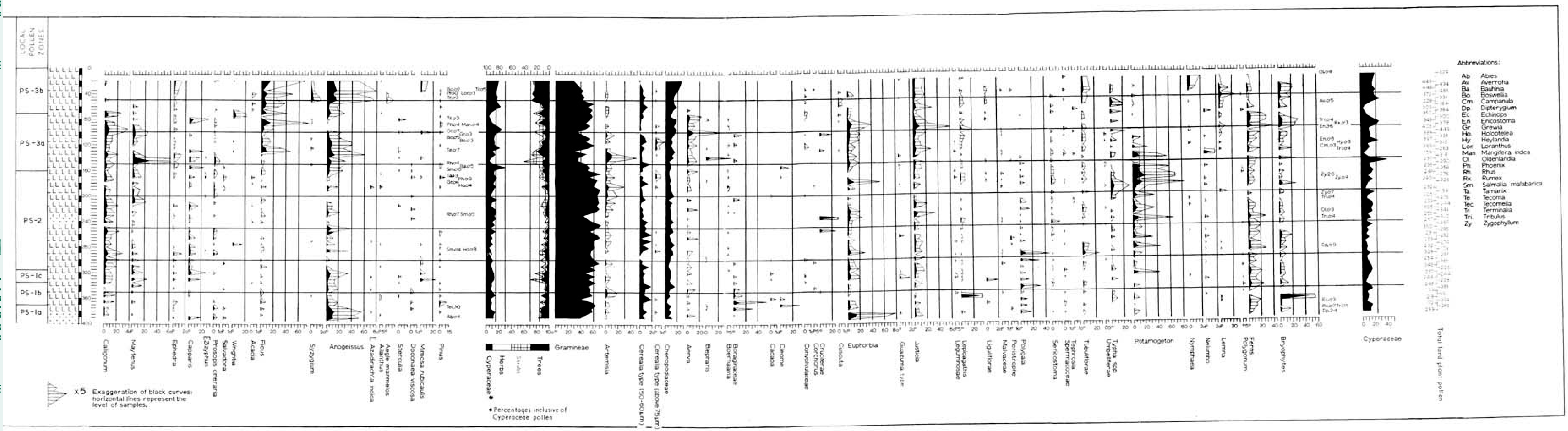

FIGURE 9. Late-Quaternary pollen diagram from Pushkar Lake. Values are expressed as percentages of total land plant pollen excluding Cyperaceae, except in the case of the additional curve for Cyperaceae shown within the same box as the a.p./n.a.p. ratios, where the values are inclusive of Cyperaceae pollen.