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Pollen evidence of late-Quaternary vegetation and climate change in Northeastern Madhya Pradesh, India

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ABSTRACT

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Pollen analysis of 1·5 m deep sediment core from Jagmotha Swamp, Sidhi (M.P.), India has shown that between 6,500 to 4,250 yrs BP, the tree-savannah vegetation chiefly comprising, grasses, sedges, Cheno/Ams, *Artemisia* together with scattered trees such as *Emblica officinalis, Terminalia* and *Syzygium* existed in the region under cool and dry climatic regime with an ameliorating trend. Between 4,250 to 2,900 yrs BP, the tree-savannahs transformed into open mixed deciduous forests with the invasion of some more deciduous trees viz., *Adina cordifolia*, *Holoptelea* and *Lagerstroemia*, indicating the onset of warm and moist climate. Subsequently, between 2,900 to 1,050 yrs BP the mixed deciduous forests became dense and diversified as evidenced from the improved frequencies of most of the tree taxa as well as immigration of *Shorea robusta* (sal) along with *Lannea coromandelica, Bauhinia, Helicteres*, etc. Such a change in the floristic composition suggests that warm and moist climate with increased precipitation prevailed in the region. *Shorea robusta* (sal) assumed dominance over other forest constituents around 1,050 yrs BP in response to prevalence on more moist climate in the region.

Key-words—Palaeovegetation, Palaeoclimate, Late-Quaternary Period, Madhya Pradesh.

भारत के उत्तर-पूर्वी मध्य प्रदेश में अन्तिम क्वाटरनरी युगीन वनस्पतियों के परागाणविक प्रमाण तथा जलवायुविक परिवर्तन

मोहन सिंह चौहान

सारांश

भारत के मध्य प्रदेश के सीधी जिले के जगमोथा अनूप से प्राप्त 1·5 मीटर गहरे अवसादी क्रोड के परागाणविक विश्लेषण से प्रदर्शित होता है कि 6,500-4,250 वर्ष पूर्व के बीच परिक्षिप्त वृक्षों, जैसे-*एम्बलिका ऑफिसिनेलिस, टर्मिनेलिया* एवं *साइज़ीजियम* के साथ-साथ प्रमुखतः घास, प्रतृणों, चीनो/एम्स, *आर्टीमीज़िया* से युक्त सवाना वृक्ष वनस्पतियाँ सुधरे हुए रूझान के साथ शीत एवं शुष्क जलवायुविक परिस्थितियों में क्षेत्र में विद्यमान थीं. 4,250 से 2,900 वर्ष पूर्व के बीच सवाना वृक्ष कुछ अन्य पर्णपाती वृक्षों, जैसे- *एडीना कॉर्डीफोलिया, होलोप्टीलिया* एवं *लेजरस्ट्रोएमिया* के आ जाने से विवृत-सम्मिश्र पर्णपाती वनों में परिणत हो गए, जिससे उष्ण एवं नम जलवायु के प्रारम्भ होने के संकेत मिलते हैं. कालान्तर में 2,900 से 1,050 वर्ष पूर्व के बीच सम्मिश्र पर्णपाती वन सघन तथा वैविध्यमय हो गए. इसके प्रमाण अधिकांश वृक्ष वर्गकों की बेहतर आवृत्ति तथा *लैनिया कोरोमण्डेलिका, बाउहाइनिया, हेलिक्टेरीज़* इत्यादि के साथ-साथ *शोरिया रोबस्टा* (साल) के आप्रवासन से प्राप्त हुए हैं. वनस्पतिजातीय संघटन में ऐसा परिवर्तन क्षेत्र में वृद्धिमय वर्षण युक्त उष्ण एवं नम जलवायु

को प्रस्तावित करता है. क्षेत्र में अधिक नम जलवायु की प्रमुखता के कारण 1,050 वर्ष पूर्व के आस-पास यहाँ अन्य वन संघटकों की अपेक्षा *शोरिया रोबस्टा* (साल) की प्रभाविता हो गई थी.

संकेत शब्द—पुरावनस्पतियाँ, पुराजलवायु, अन्तिम-क्वाटरनरी कल्प, मध्य प्रदेश.

INTRODUCTION

A large number of sediment cores have so far been investigated from the tropical region of the country in order to reconstruct the vegetational succession and corresponding climatic events of the Quaternary period. Such studies from the tropical region have remained restricted mainly to south Indian mountains (Vishnu-Mittre & Gupta, 1971; Gupta, 1973; Gupta & Prasad, 1985; Vasanthy, 1988), western India (Singh *et al.*, 1972, 1974; Vishnu-Mittre & Sharma, 1975, 1979) and plains of Uttar Pradesh (Gupta, 1978; Chauhan *et al.*, 1990). However, central India which possesses approximately 26% of the total forest cover of the country has yet not received adequate attention to understand the antiquity of the tropical deciduous forests. Additionally, the climatic fluctuations affecting these forests are poorly known, except for some sporadic information available from northeastern part of Madhya Pradesh (Chauhan, 1996).

In the present paper an attempt has been made to study another part of central India with the intention of reconstructing the palaeovegetational succession of the tropical deciduous forests as well as their temporal and spatial distribution in the region during the Quaternary Period. This is being done through the pollen analytical investigation of a 1·5 m deep sediment core from Jagmotha Swamp, Sidhi (M.P.).

PHYSIOGRAPHY

Jagmotha Swamp (81°40' Long. and 24° Lat.) lies in the vicinity of the small village of Khuderia, about 25 km south of Majhouli township, district Sidhi (M.P.). Topographically, this area is characterised by the presence of moderate and flat topped hillocks and undulating plains with ravines and gorges (Fig. 1). The average elevations of the hillocks vary from 400-600 m a.s.l. Most of the hillocks and adjoining plains are occupied with huge boulders. The swamp is situated amidst the open pasture, which is surrounded by dense sal forest. It is circular in outline and measures approximately 100 m in circumference. The subterranean water makes the swamp highly water logged throughout the years. The soil is generally sandy, although the patches of black cotton soil can be seen in certain areas.

CLIMATE

This area experiences a warm and moist climate. The average annual mean temperature is 25·4°C with an average summer maximum temperature of 32°C and an average minimum temperature is ca. 18·5°C. During extreme cold months of December and January the temperature descends to 7°C. The mean annual rainfall recorded is 1,144·8 mm. About 80% rainfall out of the total annual precipitation occurs during rainy season.

VEGETATION

Most of the area around Jagmotha is occupied by dense tropical deciduous sal (*Shorea robusta*) forests. These sal forests are very luxuriant in well drained sandy loam and acidic soils. Better quality sal forests are found along the water courses, but they progressively degenerate in quality and growth on the higher hill slopes.

Following the classification of Champion & Seth (1968), mainly two types forests are recognisable in the area:

I. Tropical dry deciduous sal forests : mean annual rainfall 1,000 mm (900-1,155 mm)

II. Tropical moist deciduous sal forests : mean annual rainfall above 1,200 mm (1,100-1,300 mm)

The major associates of *Shorea robusta* in dry deciduous forests are: *Boswellia serrata, Sterculia urens, Buchanania lanzan, Lagerstroemia parviflora, Diospyros melanoxylon, Madhuca indica, Emblica officinalis* and *Lannea coromandelica*. Other less frequent associates are *Mitragyna parvifolia, Semecarpus anacardium, Adina cordifolia* and *Syzygium cumini*.

The general floristic composition of moist deciduous sal forests is more or less alike as in the dry deciduous sal forests. However, *Anogeissus latifolia, Terminalia tomentosa, Adina cordifolia, Syzygium cumini, Careya arborea* and *Mitragyna parvifolia* occur very frequently in the moist deciduous forests.

The comprehensive floristic study conducted by Sengupta & Ram Lal (1973) has shown that certain dry slopes possess dry mixed deciduous forests, which are chiefly composed of *Boswellia serrata, Ougeinia oogeinensis, Cochlospermum religiosum, Sterculia urens, Ziziphus xylopyrus, Nyctanthes arbor-tristis* and *Gardenia latifolia*.

The shrubby constituents are almost alike in all the above mentioned forest types. Nevertheless, *Ziziphus mauritiana, Helicteres isora, Carissa spinarum* and *Woodfordia fruticosa*

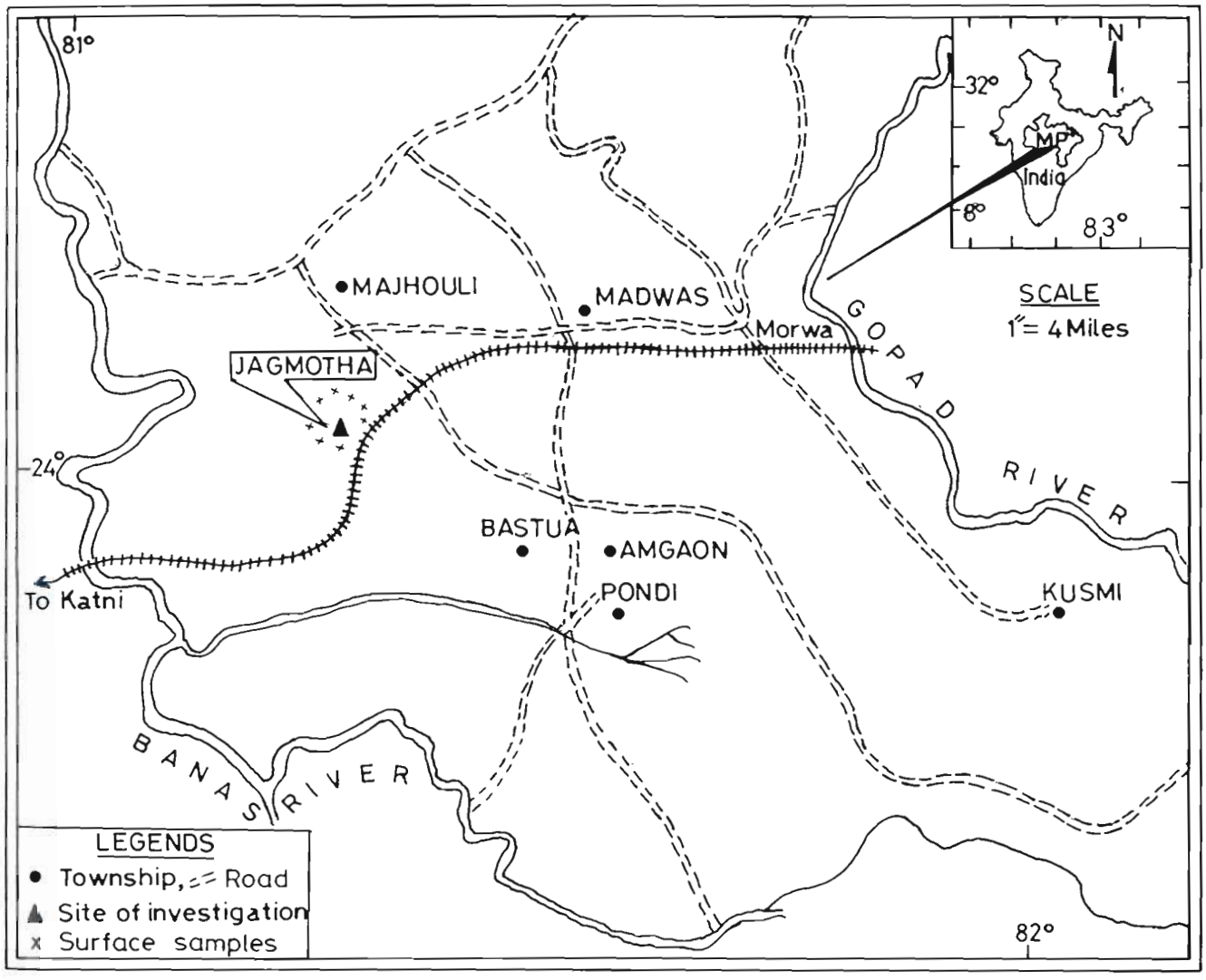

Fig. 1—Map showing the site of investigation in Sidhi District (M.P.).

are common in dry forests, whereas *Strobilanthes angustifrons, Clerodendron viscosum* and *Murraya koenigii* are quite frequent in moist forests.

The undergrowth on the forest floor includes *Grewia rothii, Indigofera cassioides, Campanula colorata, Oldenlandia affinis, Rungia pectinata, Micromeria biflora* and *Reinwardtia indica*. Marshy elements such as *Cyperus alulatus, C. compactus, Eleocharis acutangula, Rotala rotundifolia, Ammannia baccifera, Drosera burmanni, Eriocaulon quinquangulare, Polygonum plebeium* and *Hydrocotyle* sp. grow profusely in marshy habitats along the water courses and stream banks. *Monochoria vaginalis, Typha angustifolia, Potamogeton* sp. and *Nymphoides cristata* occur luxuriantly in ponds, pools and lakes.

MATERIAL AND METHODS

Material for the present investigation comprises both surface samples and sedimentary core. Eight surface samples (soil samples and moss cushions), consisting 4 each from open area and adjoining sal forest, were collected at an interval of 500 m from the vicinity of Jagmotha Swamp to study the modern pollen/vegetation relationship in the region. A 1·5 m deep sediment core was collected from this swamp using Hiller's peat auger. Beyond this depth, further coring could not become feasible owing to presence of inaccessible hard stratum. In total, 30 samples were collected from this core at an interval of 5 cm.

Five conspicuous lithozones are discernible in this core. The topmost zone is composed of fibrous peat with sand and rootlets of the vegetation growing over the swamp. Underlying

this is the zone of black organic mud with sand. This is followed by black organic mud zone, containing rootlets and it forms the thickest lithozone in the core. Below this is again organic mud with sand zone. The bottom most lithozone which is constituted of coarse sand and black organic mud, rests on the inaccessible hard stratum. The depth-wise lithostratigraphical details are as below:

Depth	*Lithology*
0-25 cm	Fibrous peat with sand and rootlets
25-50 cm	Black organic mud mixed with sand
50-100 cm	Black organic mud with rootlets
100-135 cm	Black organic mud with sand
135-150 cm	Coarse sand with organic mud

Two radiocarbon dates determined for this core are as below:

Depth	*Lithology*	*Lab. Ref. No.*	*Radio carbon dates*
35-50 cm	Black organic mud with sand and rootlets	BS-1488	2,950±80.yrs BP
135-150 cm	Coarse sand with organic mud	BS-1446	6,250±90 yrs BP

The sediment composition of the core does not exhibit much variation. Hence, on the basis of the available two ^{14}C dates the sediment accumulation rate for this core has been calibrated to 1cm/34 years. This accumulation rate has allowed to extrapolate dates at other depths in the core. The bottom of the core is dated to 6,500 yrs BP. Similarly, three more dates i.e., 4,250 yrs BP at 125 cm depth, 2,900 yrs BP at 80 cm depth and 1,050 yrs BP at 30 cm depth have been extrapolated for the precise demarcation of temporal changes in the floristic composition and corresponding climate in the region.

The conventional procedure of pollen analysis (Erdtman, 1943) through the use of 10% aqueous KOH solution, 40% HF and acetolysing mixture (9:1, acetic anhydride and conc. H_2SO_4) was employed to extract the pollen/spores from the surface and core sediments.

POLLEN ANALYSIS

The pollen sums vary from 150-350 for both surface as well as core samples, depending upon their yield. Pollen of aquatic plants and fern spores have not been included in the pollen sums. The percentage frequencies of the recovered palynomorphs have been calculated in terms of total terrestrial plant pollen. The plant taxa have been categorised as trees, shrubs, herbs and ferns and are arranged in the same order in the pollen spectra and pollen diagram.

Modern pollen/vegetation relationship

In order to study the modern pollen deposition pattern in the region, 8 surface samples comprising 4 each from open area and adjoining forests were pollen analysed from the vicinity of Jagmotha Swamp, Sidhi (M.P.). The comparative data-base generated from the study has been utilised for the factual appraisal of fossil pollen spectra in terms of past vegetation and climate (Fig. 2).

Pollen spectra (sample nos.1-4) from open area show the dominance of non-arboreals and poor representation of arboreals. Among the trees, *Madhuca indica* (7-11%) is the chief ingredient of the pollen rain. *Terminalia* (0·5-3%) and *Emblica officinalis* (1-2%) are recorded consistently in low frequencies, whereas *Lannea coromandelica* (1-2%). *Mitragyna* (1·5%), *Shorea robusta*, *Adina cordifolia*, *Dalbergia*, *Diospyros* and *Anogeissus* (1% each) have sporadically low values. The shrubby elements, Fabaceae (2-5%) and *Melastoma* (0·5-2%) have moderate values. The others such as *Grewia* and *Strobilanthes* are marked by their stray pollen. The ground flora exhibits high frequencies of Cyperaceae (sedges 12-44%) and Poaceae (grasses 15-35%). Tubuliflorae (1-3%), Cheno/Ams (2·5%), *Xanthium* and Ranunculaceae (1-5% each) are recovered in moderate values. *Artemisia*, Caryophyllaceae, *Justicia* and *Thalictrum* are poorly represented. Fern spores are encountered consistently in low frequencies.

Pollen Spectra (sample nos. 5-8) from the forested area demonstrate the better representation of arboreals in contrast to the adjoining open area. *Madhuca indica* (3-10%) and *Shorea robusta* (2-8%) are recorded in good frequencies. Likewise, *Emblica officinalis* (1·5-2%), *Butea* (2%), *Lannea coromandelica* (0·5-7%), *Xeromphis* (5%) and *Terminalia* (0·5-4%) have increased values than in the pollen spectra from open area. Except for Fabaceae (1-3%), the other shrubby elements viz., *Melastoma*, *Ziziphus* and *Strobilanthes* are extremely sporadic. Among the non-arboreals, Poaceae (15-30%) is better represented than Cyperaceae (5-15%). Cheno/Ams (1-4%), *Xanthium* (1-2·5%) and *Artemisia* (3%) are quite frequent. Monolete fern spores remain more or less same as in the open area, whereas trilete spores (2-28%) are recorded in increasingly variable frequencies.

In general, the modern pollen rain study from Jagmotha, Sidhi (M.P.) demonstrates the dominance of non-arboreals and reduced values of arboreals. *Shorea robusta* (sal), the major forest constituent, has only an average frequency of 3·5% in the forested area as compared to its good representation in the forest floristics. Furthermore, it shows extremely sporadic and low pollen counts in the adjoining open area (Chauhan, 1994). The under-representation of sal could be inferred to poor preservation of its pollen in the sediments as well as low pollen dispersal efficiency, irrespective to being a high pollen producer.

Madhuca indica, a close associate of sal, also portrays a similar behaviour, however, it is certainly better represented than *Shorea robusta*. The other associates such as *Emblica officinalis*, *Terminalia*, *Adina cordifolia*, *Lagerstroemia*, *Mitragyna* and Sapotaceae are meagrely represented. This

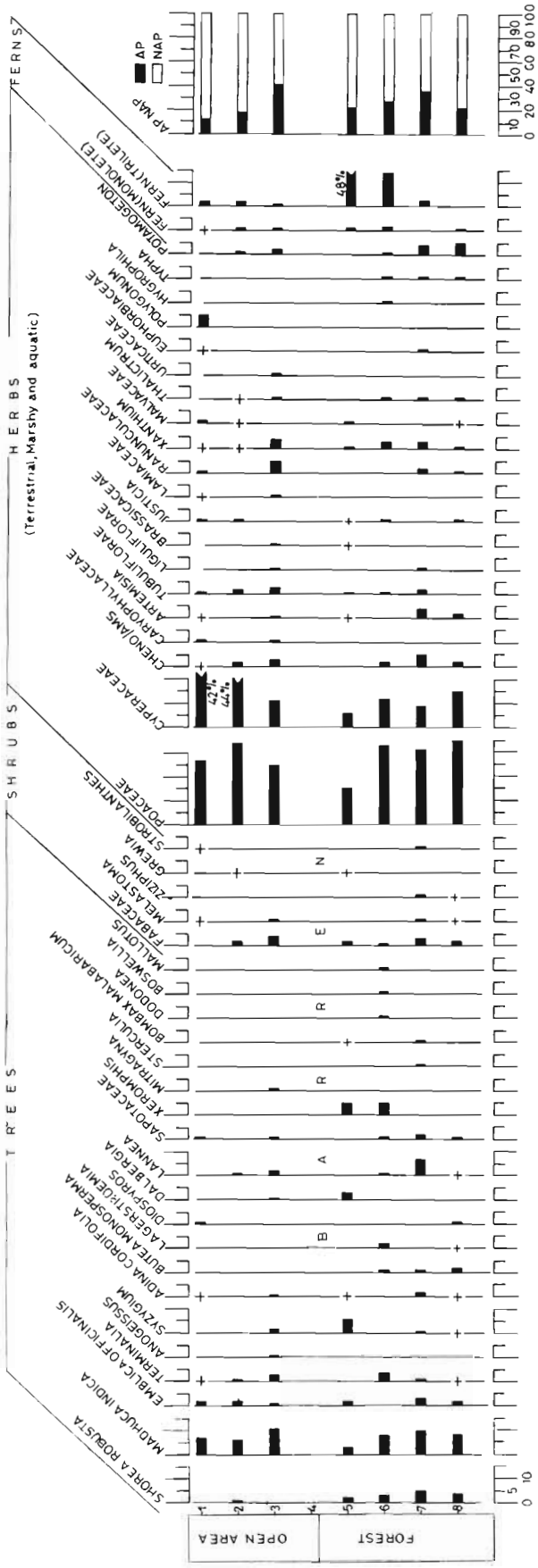

Fig. 2—Recent pollen spectra from Jagmotha, Sidhi (M.P.).

irregular feature of all these taxa, as compared to their actual proportion in the forest can be attributed to their low pollen production, since the majority of them exhibit a strong tendency towards entomophilly. The microbial degradation of the pollen in the sediments cannot be denied. A large number of deciduous elements viz., *Acacia*, *Buchanania*, *Semecarpus* and *Gmelina* remain solely unrepresented.

Among the non-arboreals, the dominance of grasses and sedges corresponds with their composition in the ground flora. However, the much higher frequencies of sedges in some of the pollen spectra indicate the prevalence of swampy conditions around the sites.

Description of pollen diagram

To better understand the sequential alterations in the vegetation and climate, the pollen diagram has been divided into four distinct pollen zones from bottom to top, on the basis of fluctuations in the values of some prominent arboreals and non-arboreal taxa (Fig. 3). These pollen zones (JS-I, JS-II, JS-III & JS-IV) are prefixed with initials 'JS' after the name of the site of investigation.

Pollen Zone JS-I (150-125 cm): Poaceae-Cyperaceae-Cheno/Ams-*Artemisia*-*Syzygium*-*Emblica officinalis*-Fern Assemblage

This pollen zone with a radiocarbon date of 6,250±90 yrs BP and covering a time span from 6,500 to 4,250 yrs BP, reveals the dominance of non-arboreals and poor representation of arboreals. The non-arboreals, Poaceae (38-55%) and Cyperaceae (10-38%) are recorded in high values. Similarly, *Artemisia* (3-7%), Cheno/Ams, Tubuliflorae, Liguliflorae (2-5% each) and Caryophyllaceae (1-4%) also have consistently good frequencies. Others such as Ranunculaceae, Lamiaceae (2% each) and *Hygrophila* (1%) are sporadically present.

Typha (1-3%) and *Potamogeton* (1-5%) are the representatives of aquatic vegetation. Fern spores (monolete 25-30% and trilete 5-9%) are quite frequent.

The arboreals are few and they are marked by extremely low values of *Emblica officinalis, Syzygium, Adina cordifolia* (1-2% each), *Holoptelea* and *Terminalia* (1% each).

Pollen Zone JS-II (125-80 cm): Poaceae-Cyperaceae-Cheno/Ams-*Artemisia-Emblica officinalis-Holoptelea*-Fabaceae-Fern Assemblage

This pollen zone encompassing a time span of 4,250 to 2,900 yrs BP also exhibits the dominance of non-arboreals. Poaceae (30-50%) retains its fluctuatingly high frequencies, whereas Cyperaceae (7-25%), after a sharp decline in the upper part has increased values at the top of this zone. Cheno/Ams (3-16%), *Artemisia*, Tubuliflorae, Liguliflorae (2-10% each) and Caryophyllaceae (1-6%) are encountered in enhanced values. *Justicia* (1-4%), Brassicaceae and Convolvulaceae (1% each) are sporadically recorded in this pollen zone. The aquatic elements, *Potamogeton* (2-12%) and *Typha* (1-4%) are present in higher values than in Pollen Zone JS-II. Fern spores (monolete 11-30% and trilete 6-20%) maintain their higher frequencies.

The tree taxa, *Holoptelea* (1-3%), *Emblica officinalis*, *Syzygium, Adina cordifolia* and *Terminalia* (1-2% each) remain more or less same as in Pollen Zone JS-I. However, *Lagerstroemia* (1-3%), *Madhuca indica* (1-2%), *Acacia, Diospyros*, *Mitragyna*, Anacardiaceae and Sapotaceae (1% each) together with shrubby elements viz., Fabaceae (2-5%), *Strobilanthes*, *Ziziphus*, Acanthaceae and Tiliaceae (1% each) appear sporadically for the first time in this pollen zone.

Pollen Zone JS-III (80-30 cm)-Shorea robusta-Emblica officinalis-Terminalia-Fern Assemblage

This pollen zone with a ^{14}C date of 2,950±80 yrs BP in the upper part and covering the time period of 2,900 to 1,050 yrs BP demonstrates the further increase in number and frequencies of tree taxa. *Shorea robusta* (2-3%), *Lannea coromandelica* (1-2%), *Helicteres* and *Bauhinia* (1% each) appear in the lower part of this pollen zone. *Emblica officinalis* (2-4%), *Adina cordifolia* (1-5%), *Terminalia*, *Syzygium, Lagerstroemia, Holoptelea* and Anacardiaceae (1-2% each) are slightly better represented than in the preceding zone, whereas *Diospyros*, *Acacia*, *Boswellia* and *Madhuca indica* occur extremely sporadically and in low numbers.

Among the shrubby elements, Acanthaceae (1-2·5%) has increased frequencies. Fabaceae (2-3%) and *Strobilanthes* (1%) show reduced values, whereas Oleaceae, *Melastoma* and Rutaceae appear for the first time, though sporadically.

Cyperaceae (18-57%) exhibits an increasing trend. On the other hand Poaceae (15-31%) declines considerably. Cheno/Ams (2-20%), Tubuliflorae (3-10%), *Artemisia* (0·5-10%) and Caryophyllaceae (1-5%) are also recorded in reduced values than in Pollen Zone JS-II. Liguliflorae (2-15%) and *Justicia* (1-4%) show enhanced frequencies. The aquatic taxa, *Potamogeton* (3-10%) and *Typha* (1-10%) are also present in increased values, but decline in the upper part of this pollen zone. Fern spores (monolete 8-30% and trilete 2-10%) are present in reduced frequency.

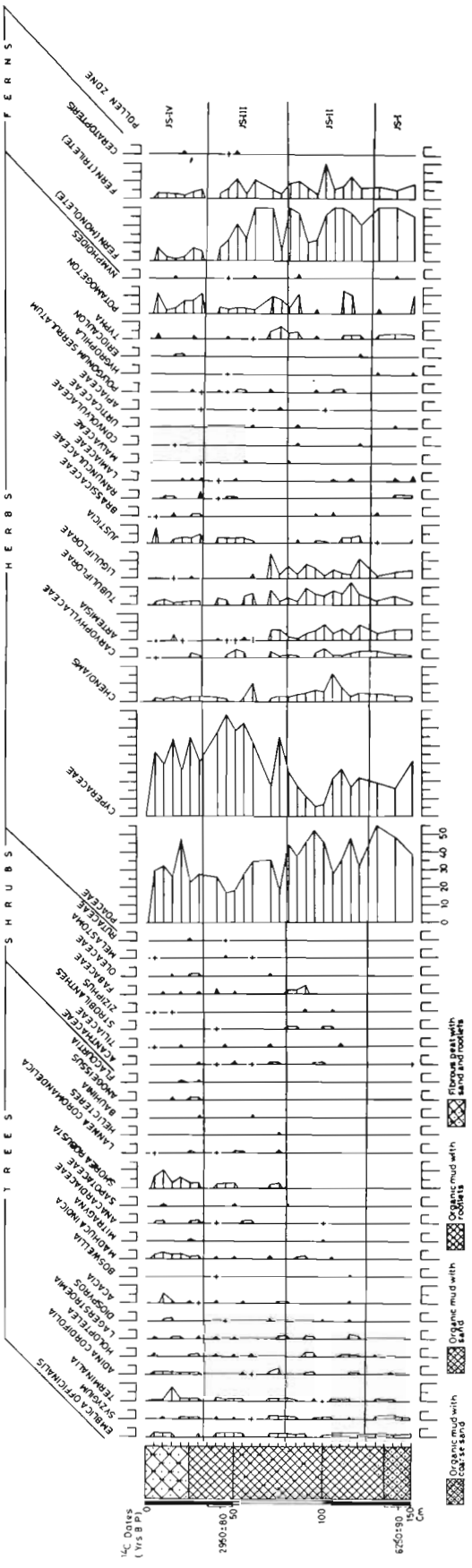

Fig. 3—Pollen diagram from Jagmotha Swamp, Sidhi (M.P.).

Pollen Zone JS-IV (30-0 cm): Shorea robusta-Madhuca indica- Terminalia-Poaceae-Cyperaceae Assemblage

This topmost pollen zone covering the time span from 1,050 yrs BP to present is characterised by the establishment of modern sal forests as indicated by further improved values and consistent representation of *Shorea robusta* (3-11%) together with its associates such as *Terminalia* (1-8%), *Madhuca indica* (1·5-5%), *Emblica officinalis* (1-3%) and *Adina cordifolia* (1-2%). Likewise, *Acacia* (1-5%), Anacardiaceae and *Diospyros* (2% each) are also encountered in increased values, though sporadically, whereas *Holoptelea* (3%), *Lagerstroemia* and *Syzygium* (2% each) do not show any marked change. *Schleichera*, *Anogeissus* (1-2% each) and *Flacourtia* (1%) appear rarely for the first time.

Poaceae (25-48%) and Cyperaceae (30-45%) along with Cheno/Ams (2-3%) and Tubuliflorae (2-5%) have reduced values as compared to Pollen Zone JS-III. *Justicia* (3-10%), Ranunculaceae (1-3%) and Brassicaceae (2%) are recovered in higher frequencies. *Typha* declines, whereas *Potamogeton* (2-12%) is recorded in fluctuatingly increased values. Fern spores (monolete 2-7% and trilete 3-5%) decline severely in this pollen zone.

DISCUSSION

The pollen data obtained from the investigation of 1.5 m deep sediment core from Jagmotha Swamp has provided some significant inferences concerning the vegetational development in the region during late-Quaternary Period. In general, the presently available pollen sequence has brought out more or less similar types of seral stages involved till the establishment

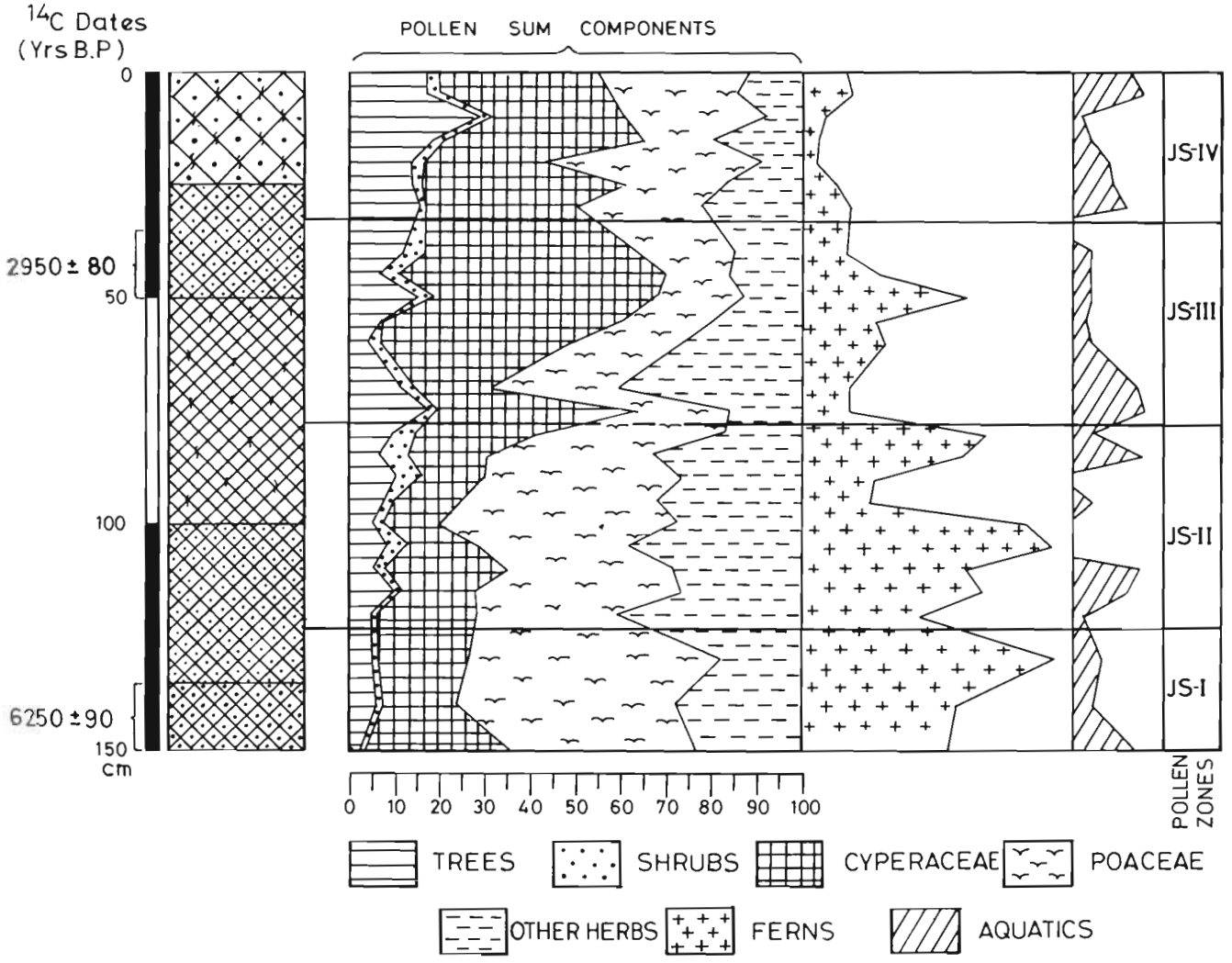

Fig. 4—Summary pollen diagram from Jagmotha Swamp, Sidhi (M.P.).

of modern forests, as have already been witnessed in the earlier worked out cores from Sidhi District (Chauhan, 1996), except for some temporal variations in the appearance as well as the time intervals for their existence in the region (Fig. 4).

The pollen sequence generated has demonstrated the vegetational shifts and corresponding climatic oscillations in the region prior to mid-Holocene Period. The study has revealed that during 6,500 to 4,250 yrs BP, the tree-savannah vegetation existed in the region, which was chiefly constituted of grasses together with *Artemisia* and members of Chenopodiaceae/Amaranthaceae and Asteraceae. A few deciduous trees such as *Emblica officinalis*, *Syzygium, Adina cordifolia, Holoptelea* and *Terminalia* were sparsely represented in the region. Hence, the overall vegetational scenario implies that a cool and dry climate prevailed in the region during this phase. The sediment composition of the core denotes that the enrichment of organic matter in the soil also commenced by this time to pave the way for the gradual incursion of the tree elements in the region. Locally, the swamp was wide in expanse as indicated by preponderance of sedges and frequent recovery of pollen of *Typha*. Ferns were also quite luxuriant in the moist and shady habitats in close proximity of the swamp.

Between 4,250 to 2,900 yrs BP, the tree-savannahs were invaded by a large number of deciduous arboreal elements viz., *Lagerstroemia*, *Diospyros*, *Acacia* and *Madhuca indica* successively one after another along with a few thickets of Fabaceae, *Strobilanthes*, *Ziziphus* and Tiliaceae. *Emblica officinalis*, *Syzygium, Adina cordifolia, Holoptelea* and *Terminalia* also grew more frequently than earlier. The

Pollen profiles from Bastua, Chhui Stream & Amgaon (Chauhan, 1996)			**Pollen profile from Jagmotha Swamp**		
Period	**Vegetational Assemblage**	**Climate**	**Period**	**Vegetational Assemblage**	**Climate**
Present-1,200 yrs BP	**Tropical deciduous sal forests** (*Shorea robusta-Emblica officinalis-Terminalia-Anogeissus-Madhuca indica*)	Warm and more moist with high precipitation	Present-1,050 yrs BP	**Tropical deciduous sal forests** (*Shorea robusta-Terminalia-Madhuca indica-Emblica officinalis-Adina cordifolia*	Warm and more moist with high precipitation
Prior to 1,200 yrs BP	**Tropical mixed deciduous forests** (*Emblica officinalis-Madhuca indica-*Myrtaceae-*Anogeissus-Adina cordifolia)*	Warm and moist with further increase in precipitation	1,050-2,900 yrs BP	**Tropical mixed deciduous forests** (*Shorea robusta-Terminalia- Adina cordifolia-Lannea coromandelica)*	Warm and moist with further increase in precipitation
3,800-4,500 yrs BP	**Tropical mixed deciduous forests** (*Emblica officinalis-*Myrtaceae-*Lagerstroemia-Terminalia*)	Warm and moist with increased precipitation	2,900-4,250 yrs BP	**Open mixed tropical deciduous forests** (*Adina cordifolia-Holoptelea-Lagerstroemia--Madhuca indica*)	Warm and moist with increased precipitation
5,000-6,720 yrs BP	**Tree-savannahs** (Grasses-Sedges-*Adina cordifolia-Emblica officinalis-Terminalia)*	Cool and dry with ameliorating trend	4,250-6,500 yrs BP	**Tree-savannahs** (Grasses-Sedges-Cheno/Ams-*Syzygium-Emblica officinalis-Adina cordifolia-Terminalia*)	Cool and dry with ameliorating trend
6,720 -8,000 yrs BP	**Shrub-savannahs** (Grasses-Sedges-Asteraceae-Oleaceae)	Cool and dry			
10,000 yrs BP	**Open grasslands** (Sedges- Grasses-Cheno/Ams)	Cool and dry			

Fig. 5—Correlation of pollen profiles investigated from district Sidhi, (M.P.).

increased diversity in the arboreal vegetation envisages the transformation of tree-savannahs into open mixed tropical deciduous forests. Such an alteration in the palaeofloristic pattern signifies that a favourable environment with enhanced precipitation prevailed in the region which encouraged the further incursion and expansion of deciduous tree constituents. On account of prevalence of congenial climatic condition, the non-arboreal vegetation also thrived well as evidenced from the better representation of grasses, Chenopodiaceae/ Amaranthaceae, *Artemisia,* Tubuliflorae and aquatic elements, *Typha* and *Potamogeton*. Furthermore, the gradual increase of organic matter also enable the soil to sustain the growth and spread of arboreal vegetation.

Subsequently, between 2,900 to 1,050 yrs BP, the most remarkable feature was the immigration of *Shorea robusta* (sal) into the forest floristics in good frequencies as compared to its other associates such as *Lannea coromandelica*, *Helicteres* and *Bauhinia*, which also appeared sporadically during this time. In addition to *Shorea robusta*; *Emblica officinalis*, *Syzygium*, *Terminalia* and *Adina cordifolia* were also the major constituents of tropical deciduous forests. These mixed deciduous forests were not only varied in composition, but they were more dense than before. The increased complexity in forest composition coupled with the invasion of sal could have resulted from prevalence of warm and moist climate with further increased precipitation in the region. This is also corroborated by the expansion of swampy elements and simultaneous decline in grasses.

During 1,050 yrs BP to present, the most important event was the expansion of sal (*Shorea robusta*) as indicated by its increased frequencies as well as consistent representation. Gradually, *Shorea robusta* became dominant over other forest elements. Similarly, the other deciduous arboreals such as *Terminalia*, *Madhuca indica*, *Emblica officinalis*, *Syzygium*, *Adina cordifolia* and *Acacia* also became more prominent than before. *Anogeissus* and *Flacourtia* also appeared rarely for the first time in the forest floristics. Thus, by this time the extant sal forests were not only fully established, they were profuse and varied in composition too. This substantial rise in *Shorea robusta* as well as an overall change in the vegetational scenario could have occurred in response to further increase in precipitation, which ultimately resulted in the onset of a regime of warm and more moist climate than what prevailed earlier in the region. With the expansion of deciduous sal forests the ground vegetation and ferns also dwindled giving way to new immigrants into these forests.

CONCLUSIONS

When the present pollen sequence is correlated with the earlier investigated cores from Bastua, Chhui Stream and Amgaon areas in Sidhi District (M.P.), a more or less identical trend of floristics and climatic changes since 6,500 yrs BP to present is observed. However, the palaeofloristic pattern witnessed during 10,000 to 6,720 yrs BP from Bastua region (Chauhan, 1996) could not be deciphered in Jagmotha Swamp profile due to non-availability of deeper and older sediments. The comparative study has revealed that the tree-savannahs existed in Bastua and Jagmotha region during 6,720 to 5,000 yrs BP and 6,500 to 4,250 yrs BP respectively, under cold and dry climate with an ameliorating trend (Fig 5). An equivalent improvement in climate has also been recorded in Rajasthan desert, though for a wider temporal range i.e., from 9,000 to 5,000 yrs BP (Singh *et al.*, 1972, 1974). Subsequently, the mixed deciduous forests evolved between 4,500 to 3,800 yrs BP in Bastua region and between 4,250 to 2,900 yrs BP in the vicinity of Jagmotha Swamp region in response to further improvement in climate or increased precipitation. Similarly, during 5,000 to 3,000 yrs BP the Rajasthan desert also experienced 50 cm more rainfall than what prevailed earlier in the region. This contemporary and converging climatic trend witnessed from these two entirely different phytogeographical regions falls within the limit of Period of Climatic Optimum which has been recorded globally between 7,000 to 3,000 yrs BP. *Shorea robusta* (sal), the principal constituent of modern forests, appeared sporadically earlier i.e., around 2,600 yrs BP in Jagmotha region than in Bastua and Amgaon region. However, the formation of sal dominated tropical deciduous forests commenced simultaneously in both the areas between 1,050 to 1,200 yrs BP as a consequence of a more moist climate in the region.

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