
Origin and history of tropical deciduous Sal (*Shorea robusta* Gaertn.) forests in Madhya Pradesh, India

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Chauhan MS 1995. Origin and history of tropical deciduous Sal (*Shorea robusta* Gaertn.) forests in Madhya Pradesh, India. *Palaeobotanist* 43(1) : 89-101

The paper embodies the results of pollen analysis of three soil profiles at Bastua, Chhui Stream and Amgaon, district Sidhi, Madhya Pradesh revealing the shift in vegetational development since 10,000 years B.P. till date. The study has envisaged that between 10,000 - 8,700 years B.P. open grassland type of vegetation with cool and dry climate was present in the area. Around 8,000 years B.P. the grasslands were succeeded by shrub-savannahs through the invasion of Oleaceae indicating first step in climatic amelioration. Later between 6,720--5,010 years B.P. few deciduous trees such as *Emblica officinalis*, *Terminalia*, *Haldina cordifolia*, *Lagerstroemia*, *Anogeissus* succeeded and consequently shrub-savannahs transformed into tree-savannahs. During 4,500-3,800 years B.P. the most significant event was the establishment of tropical deciduous forests by the further invasion of several other trees, viz., *Sterculia urens*, *Mitragyna*, *Buchanania*, *Diospyros*, *Madhuca indica*, *Flacourtia*, etc. Thereafter, around 1,200 years B.P. the Sal (*Shorea robusta*) forests were established.

Key-words — Palynology, Tropical deciduous forests, *Shorea robusta*, Palaeoenvironment, Madhya Pradesh (India).

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सारांश

मध्य प्रदेश (भारत) में उष्णकटिबन्धीय साल (*शौरिआ रोबस्टा* गेयर्टन) के वनों का इतिहास और उत्पत्ति

मोहनसिंह चौहान

इस शोध-पत्र में मध्य प्रदेश में सिधी जनपद में बस्तुआ, छुई प्रवाह एवं अमगाँव से एकत्रित तीन मिट्टी की परिच्छेदिकाओं के परागकण-विश्लेषण के परिणामों की विवेचना की गई है। इन परिणामों से पिछले 10,000 वर्ष पूर्व से अब तक इस क्षेत्र में वनस्पतिकीय विकास में परिवर्तन इंगित होता है। इस अध्ययन से यह भी व्यक्त होता है कि इस क्षेत्र में 10,000-8,700 वर्ष पूर्व शीत एवं शुष्क जलवायु वाली खुली घास-भूमि वाली वनस्पति विद्यमान थी। 8,000 वर्ष पूर्व के लगभग यह घास-भूमि ओलिगोसी कुल के पदार्पण के साथ-साथ झाड़ीदार पौधों एवं सबाना प्रकार की वनस्पति में परिवर्तित हो गई, जिससे जलवायु में सुधार का संकेत मिलता है। बाद में 6,720-5,010 वर्ष पूर्व कुछ पर्णपाती वृक्ष जैसे *एम्बलिका ऑफिसिनेलिस*, *टर्मिनेलिया*, *हेल्डीना कोर्डिफोलिया*, *लेगरस्ट्रूयमिया* एवं *एनागाइसस* उग आये और इस प्रकार यह क्षेत्र झाड़ीदार सबाना से वृक्षीय सबाना में परिवर्तित हो गया। 4,500 से 3,800 वर्ष पूर्व के मध्य इस क्षेत्र में *स्टर्कुलिया यूरेन्स*, *मित्रागाइना*, *बुकनानिया*, *डायसपायराँस*, *मधुका इन्डिका*, *फ्लेकोर्शिया* आदि वृक्षों के और अतिक्रमण से इस क्षेत्र में उष्णकटिबन्धीय पर्णपाती वनों का विकास एक महत्वपूर्ण घटना है। इसके बाद लगभग 1,200 वर्ष पूर्व साल (*शौरिआ रोबस्टा*) के वनों का प्रभुत्व हो गया।

THE forests in Madhya Pradesh are chiefly deciduous type, which are either dominated by Sal (*Shorea robusta*) or Teak (*Tectona grandis*). This floristically rich phytogeographical province of the country has not received any attention so far, as regard the origin, developmental history, temporal and spatial distribution of these tropical forests in the Indian subcontinent. In the present paper an attempt has been made

to reconstruct the vegetational succession of tropical deciduous Sal (*Shorea robusta*) forests distributed in Sidhi District, Madhya Pradesh through the palynostratigraphical studies deciphering various seral stages till the forests attained the climax and also simultaneously to ascertain the corresponding climatic oscillations in chronological order during Quaternary Period.

PHYSIOGRAPHY

The three sites of investigation, viz., Bastua, Chhui Stream and Amgaon are situated in the north-eastern part of Sidhi District, Madhya Pradesh between $81^{\circ}19''$ and $81^{\circ}51''$ Longitude and $23^{\circ}43''$ and $24^{\circ}43''$ Latitude.

Bastua, about 62 km south-west of Sidhi town, is situated in Bastua Forest Range, whereas Amgaon and Chhui Stream are located about 73 km and 95 km south-west of Sidhi town in Pondi Forest Range, respectively (Text-figure 1).

CLIMATE

The area of district Sidhi is characterized by seasonal climatic fluctuations. Summer season is marked by high temperature with average mean minimum and maximum being 24°C and 30°C , respectively. The temperature in May seldom shoots up to 48°C . Winter season is short and average mean temperature varies from 7°C to 20°C . However, the temperature goes down to 1.5°C to 1°C during

December-January. The average annual rainfall is approximately 1,100 mm. For Sidhi town the average annual rainfall is 961.7 mm.

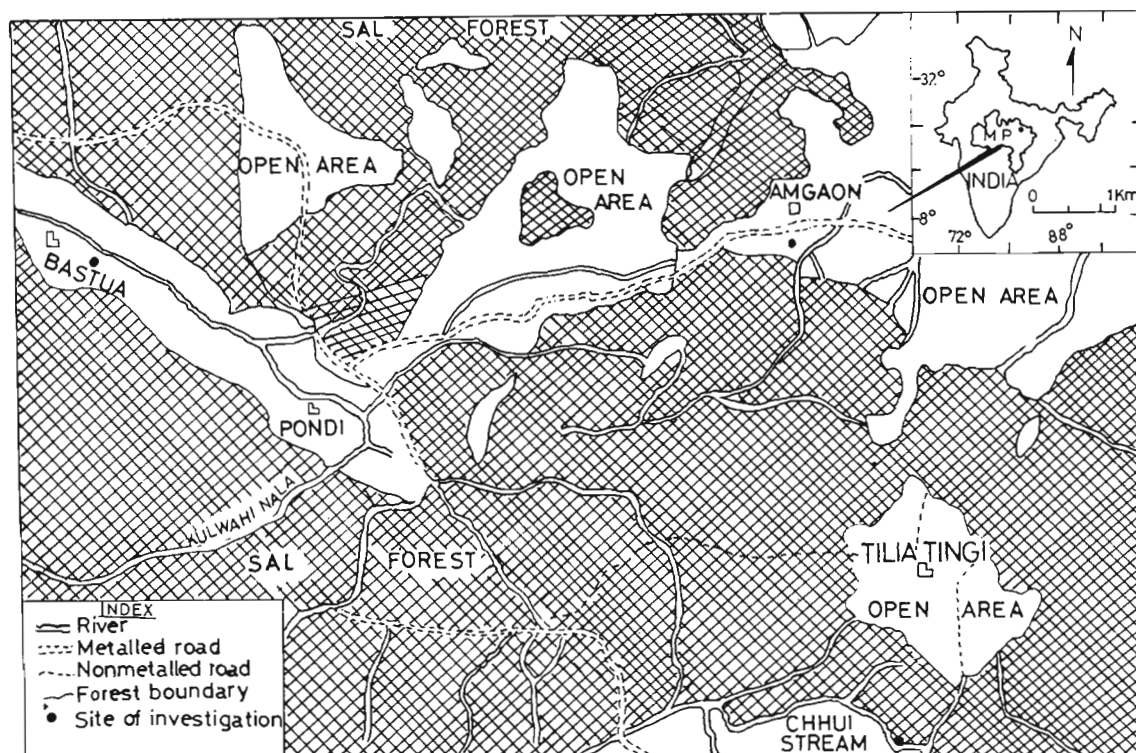
VEGETATION

The district is mostly dominated by the tropical deciduous Sal forests which are chiefly confined to better rainfall areas such as south, south-east and south-west regions of the district. *Shorea robusta* constitutes 20-90 per cent of the forest wealth in the region and generally found on northern hills, cooler valleys and water courses. It attains luxuriant growth on well-drained sandy loam and deep acidic soils.

Champion and Seth (1968) have classified these Sal forests into two recognizable types:

- i. Tropical dry deciduous Sal forests : mean annual rainfall 1,000 mm (from 900-1,155 mm).
- ii. Tropical moist deciduous Sal forests : mean annual rainfall above 1,200 mm (1,100-1,300 mm).

The usual associates of dry deciduous Sal forests



Text-figure 1 — Map showing the sites of investigation in Sidhi District, Madhya Pradesh.

are : *Boswellia serrata*, *Sterculia urens*, *Buchanania lanzan*, *Lagerstroemia parviflora*, *Diospyros melanoxylon*, *Madhuca indica*, *Embllica officinalis* and *Lannea grandis*. Other frequent elements seen in these forests are *Mitragyna parvifolia*, *Semecarpus anacardium*, *Haldina cordifolia*, *Syzygium cuminii*, *Terminalia alata*, etc.

The floristic composition of moist deciduous Sal forests is almost the same as seen in dry deciduous type, but for the luxuriance and more pronounced presence of *Anogeissus latifolia*, *Syzygium cuminii*, *Careya arborea*, *Mitragyna parvifolia*, *Haldina cordifolia* and *Terminalia tomentosa*.

In both these forest types, shrubby elements are more or less identical, though it is seen that in dry deciduous type *Ziziphus mauratiana*, *Helicteres isora*, *Carissa spinarum*, *Woodfordia fruticosa* are more common, whereas *Strobilanthes angustifrons*, *Nyctanthes arbor-tristis*, *Murraya koenigii*, *Clerodendron viscosum*, *Holarrhena antidysenterica*, *Gardenia turgida*, etc. have a better frequency in moist deciduous forests.

Apart from the above two main forest types, mixed dry deciduous forests are also found on southern and western aspects of hills. *Boswellia serrata*, *Sterculia urens*, *Terminalia bellerica*, *Ziziphus xylopyrus*, *Gardenia latifolia*, *Diospyros melanoxylon*, *Flacourtia indica*, *Lannea grandis* and *Anogeissus latifolia* are the major constituents of these forests.

STRATIGRAPHY OF THE SITES AND RADIOCARBON DATES

In all, three profiles were collected from the region. Of them, two profiles collected with the help of Hiller's peat auger from Bastua and Amgaon swamps are 1.90 and 2.48 m deep, respectively, whereas the third profile is from a 3.45 m thick section exposed along the left bank of Chhui Stream.

Bastua Swamp— This swamp is situated between 81°45" Longitude and 23°9" Latitude at the right bank of Patipara Stream. The swamp area is flat with patches of black cotton soil and is surrounded by hillocks around. A 1.90 m deep profile collected from this swamp comprises four conspicuous lithozones. The details are as under:

Depth	Lithology
0-18 cm	Water column
18-124 cm	Coarse organic mud with rootlets
124-171 cm	Fine organic mud
171-181 cm	Sandy clay
181-190 cm	Coarse sand

The radiocarbon dates for the above profile are as below:

Depth	Lithology	Radiocarbon dates
93-150 cm	Organic mud	BS-439 8, 710 ±150 yrs B.P.
170-190 cm	Sand and coarse sand	BS-440 11, 550 ±240 yrs B.P.

Chhui Stream— This site situates about 25 km south-east of Pondi Forest Rest House, close to the Tingi Village. The area is hilly having undulating plains and gorges.

A section extending over 200 m in length and 3.45 m in thickness is exposed along the left bank of the stream. From top to bottom it has four distinct strata, viz., silty loam, sand, black clay and mottled clay. Amongst them, black clay stratum is thickest in the column. The stratigraphical details are as under:

Depth	Lithology
0-40 cm	Silty loam with rootlets
40-190 cm	Sand
190-290 cm	Black clay
290-345 cm	Mottled clay

The radiocarbon dates for this profile are as below:

Depth	Lithology	Radiocarbon dates
250-280 cm	Black clay	BS-409 5,010 ±100 yrs B.P.
290-310 cm	Mottled clay	BS-410 6,720 ±110 yrs B.P.

Amgaon Swamp— Amgaon swamp, 3 km east of Pondi Forest Rest House, is situated at the base of a hillock, adjacent to cultivated fields. Its water source is a perennial spring flowing at the base of hillock. This swamp is not very large in expanse. A 2.48 m deep profile collected from this swamp comprises six lithozones. Underneath the 72 cm water column begins the organic mud zone characterized by em-

bedded rootlets. Below this a sandy clay zone is present followed by distinct zones of the silty sandy clay, dark sandy clay, sand and coarse sand.

Depth	Lithology
0-72 cm	Water column
72-93 cm	Organic mud with rootlets
93-124 cm	Dark sandy clay
124-155 cm	Silty sandy clay
155-186 cm	Dark sandy clay
186-217 cm	Sand
217-248 cm	Coarse sand

Of the four samples collected for radiometric dating, only two have yielded the dates as under:

Depth	Lithology	Radiocarbon dates
85-95 cm	Organic mud with sandy clay	BS-407 1,200 \pm 110 yrs B.P.
100-125 cm	Dark sandy clay	BS-408 1,000 \pm 200 yrs B.P.

The inversion of dates could be due to contamination of sediments with foreign material and reworking of sediments.

POLLEN ANALYSIS

The usual technique of pollen analysis (Erdtman, 1943) through the use of KOH, HF and acetolysing mixture, was employed for the recovery of pollen/spores from the sediments.

The profile samples from Bastua and Amgaon are rich in pollen content and for both, the pollen counts varied from 260-300 which includes the pollen/spores of terrestrial and aquatic plants. The samples from Chhui Stream section yielded low pollen and it was not possible to raise the pollen counts beyond 150. The samples from upper as well as lower parts of the section were palynologically barren. In the pollen diagrams the encountered plant taxa are grouped as herbs, shrubs, pteridophytes, trees and drifted ones and thus have been arranged accordingly.

MODERN POLLEN/VEGETATION RELATIONSHIP

Prior to investigation of soil profiles from tropical deciduous Sal forests distributed in district Sidhi, a large number of surface samples have also been collected and analysed (Chauhan, 1994) from three sites—Amgaon, Bastua and Tingi. The pollen analysis of surface samples from the area reveals that Sal (*Shorea robusta*), the chief ingredient of forest floristics, does not exhibit its correct picture in the modern pollen rain and only its average 14 per cent pollen represent approximately 90 per cent Sal forest, irrespective to its being an enormous pollen producer. It declines severely at the edge of forest and remains extremely sporadic in the adjoining open area. The under representation of Sal could be inferred to poor pollen dispersal efficiency as well as microbial degradation of its pollen in the sediments. Likewise, the prominent associates of Sal such as *Madhuca indica*, *Terminalia*, *Anogeissus*, *Embllica officinalis*, etc. are also not represented in accordance to their occurrence. The irregular representation of all these taxa could be attributed to their low pollen productivity since majority of them shows a strong tendency of entomophily. While translating the pollen diagrams in terms of past vegetation and climate all these limiting factors have been taken into consideration.

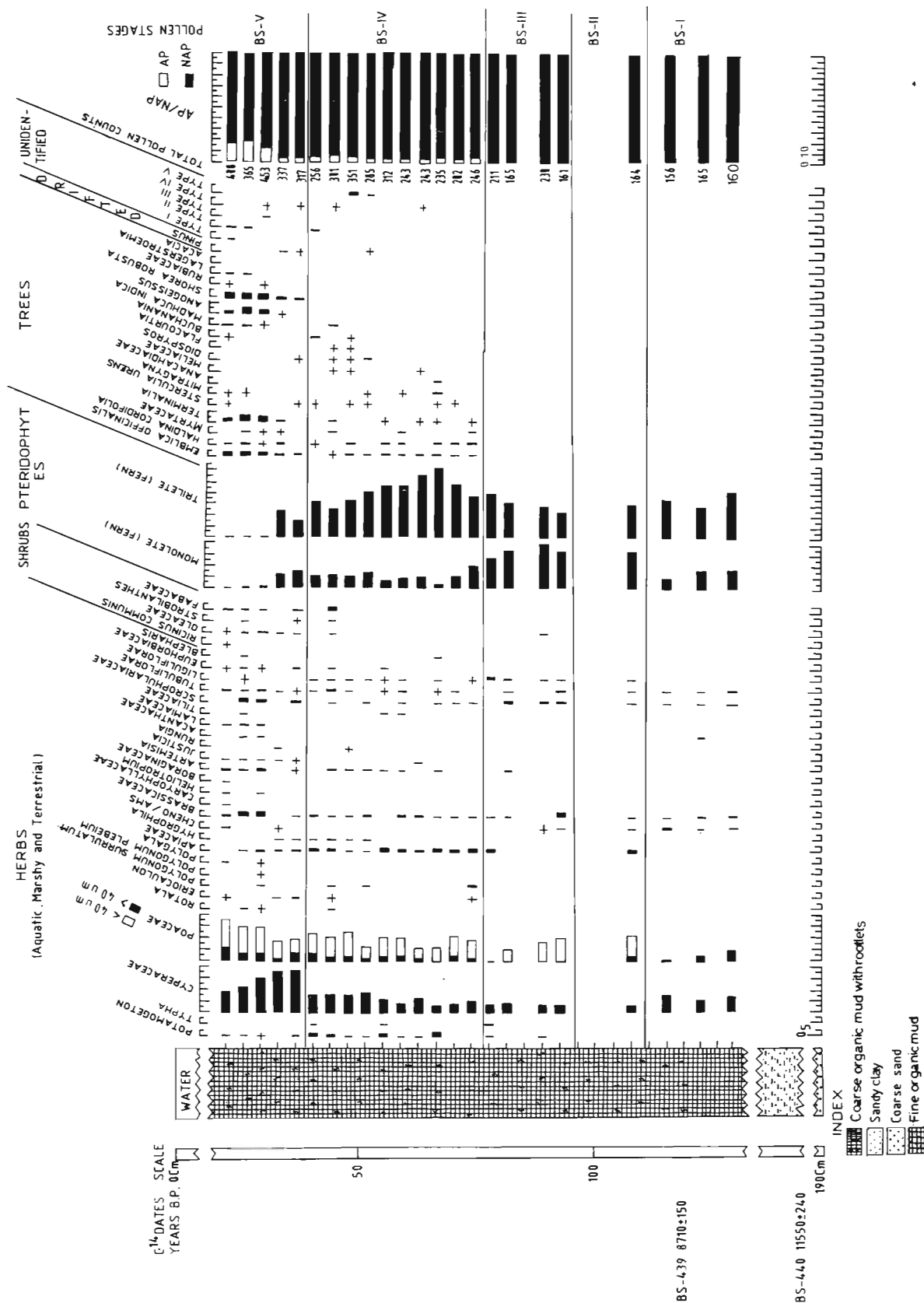
DESCRIPTION OF POLLEN DIAGRAMS

For the convenience of description, discussion and correlation of pollen diagrams based upon the changes in pollen/spores content, each pollen profile has been divided into pollen stages. They are numbered from oldest to youngest and prefixed for each pollen diagram after the name of site such as BS for Bastua, CH for Chhui Stream and AM for Amgaon.

BASTUA SWAMP POLLEN DIAGRAM

Five pollen stages (BS-I to BS-V) have been recognised in this pollen diagram (Text-figure 2).

Pollen Stage BS-I : *Poaceae-sedges-ferns-assemblage*— This pollen stage, between 134-111 cm with a date of 8,710 \pm 150 years B.P., is marked by the



Text-figure 2 --- Pollen diagram from Bastua, Sidhi District, Madhya Pradesh (percentages calculated in terms of total pollen counts).

dominance of non-arborescences and total absence of arborescences. Poaceae (34-74%) and Cyperaceae (11-16%) are the chief components of vegetal cover, whereas Brassicaceae, Chenopodiaceae, Tubuliflorae, Scrophulariaceae and Acanthaceae (2% each) are sporadic. Fern spores (monolet 10-15% and trilete 29-35%) are recorded in high values.

Pollen Stage BS-II : Poaceae-sedges-Apiaceae-fern assemblage – Between 111-96.7 cm, this pollen stage differs from the preceding one in comparatively low values of Poaceae (23%) and Cyperaceae (7%). Apiaceae and Liguliflorae (2% each) are met with for the first time in this stage, whereas Brassicaceae, Chenopodiaceae, Tubuliflorae and Scrophulariaceae pollen are quite stray. Monolet spores (30%) and trilete spores (35%) maintain their high frequencies.

Pollen Stage BS-III : Poaceae-sedges-Oleaceae-fern assemblage – This pollen stage, between 96.7-75.5 cm, portrays the first appearance of Oleaceae (1%) or advent of shrubby vegetation. Poaceae (14-21%) shows a declining trend, whereas Cyperaceae (7.9%) exhibits a rising trend. Scrophulariaceae (3%), Brassicaceae (5%), Liguliflorae (4%) and Tubuliflorae (2%) show much improved values than the Pollen Stage BS-II. *Artemisia* and the aquatic taxa *Potamogeton* and *Typha* (2% each) appear for the first time. Ferns (monolet 24-40% and trilete 22-40%) too show increased values.

Pollen Stage BS-IV : Emblica officinalis-Haldina cordifolia-Myrtaceae-Terminalia-fern assemblage – This pollen stage (75.5-39 cm) depicts the abrupt appearance of several arborescences among which *Emblica officinalis* and *Haldina cordifolia* are consistently represented. *Buchanania*, *Flacourtia*, *Diospyros*, *Terminalia*, *Sterculia urens*, *Mitragyna*, *Madhuca indica*, Myrtaceae, Meliaceae and Anacardiaceae together with shrubby elements of *Strobilanthes*, Oleaceae and Fabaceae, 2 per cent each, are recorded in low values.

The non-arborescences, Poaceae (11-25%), Cyperaceae (18%) and Apiaceae (4%) maintain their high values, whereas Brassicaceae, Scrophulariaceae, Tubuliflorae and Liguliflorae show reduced values. *Potamogeton* 4 per cent and *Typha* 1 per cent represent the aquatic vegetation.

Pollen Stage BS-V : Shorea robusta-Terminalia-Anogeissus-Emblica officinalis-assemblage – This

uppermost pollen stage (39-19 cm) shows prominent occurrence of tree taxa, viz., *Emblica officinalis* (3%), *Terminalia* (1-6%), *Madhuca indica* (5%), *Haldina cordifolia*, *Diospyros*, *Buchanania*, *Mitragyna*, *Sterculia urens* and Myrtaceae (2% each). *Shorea robusta* 5 per cent and *Anogeissus* 6 per cent appear with increasing trend along with sporadic pollen of *Acacia* and *Lagerstroemia*. The shrubby taxa, viz., Fabaceae, Oleaceae and *Strobilanthes* show increased values. *Ricinus communis* turns up for the first time.

Poaceae (18-39%), Scrophulariaceae (5%), Brassicaceae (4%) and Apiaceae (3%) exhibit rising trend, whereas Cyperaceae (38-18%) shows a declining trend. Fern spores decline to 1 per cent at the top of this stage.

CHHUI STREAM POLLEN DIAGRAM

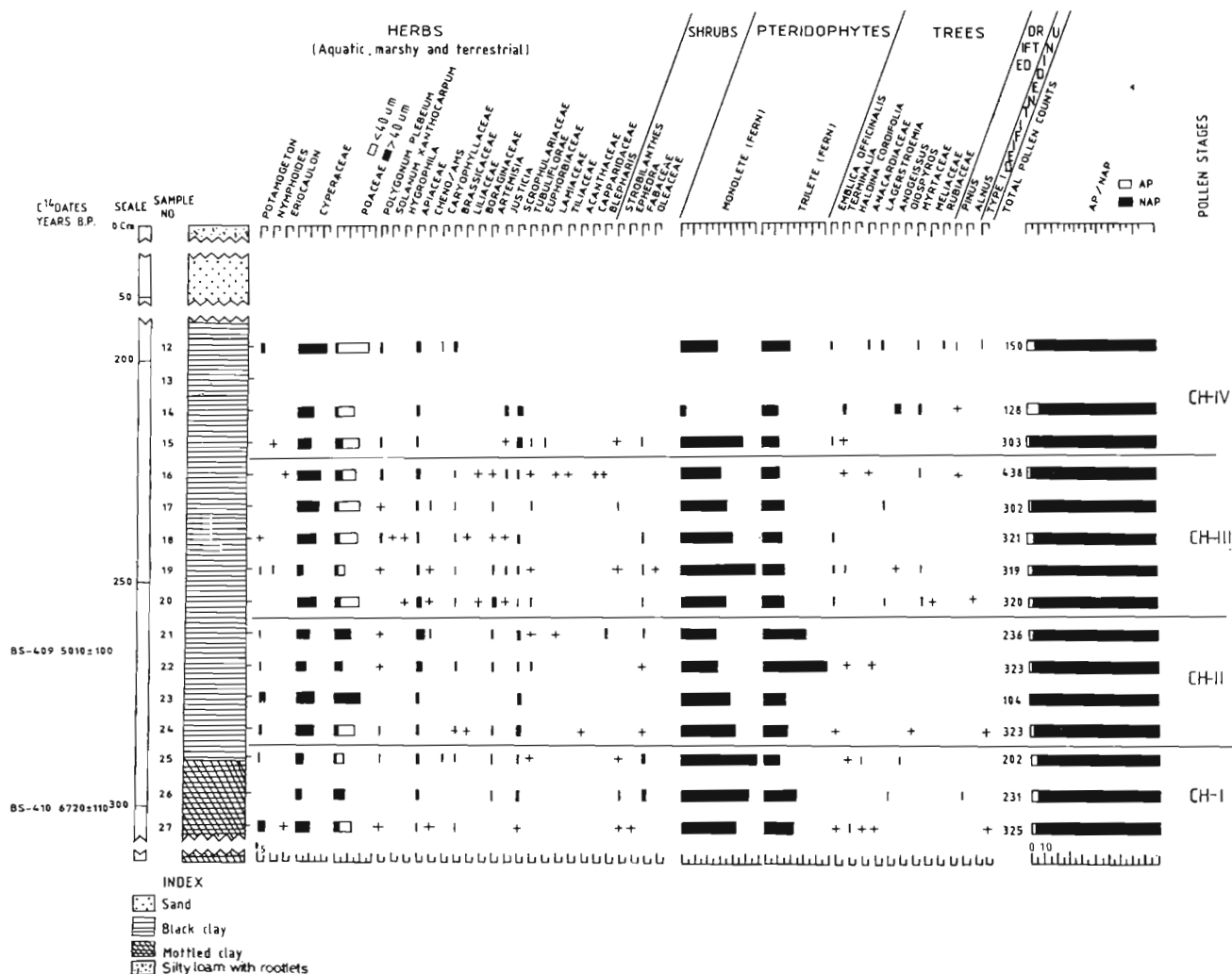
Following four pollen stages are demarcated in this pollen diagram (Text-figure 3).

Pollen Stage CH-I : Poaceae-sedges-Haldina cordifolia-Terminalia-fern assemblage – This bottom most pollen stage, between 308-286.5 cm and dated to 6720 ±110 radiocarbon years B.P., depicts the sporadic occurrence of tree taxa such as *Terminalia*, *Lagerstroemia*, *Emblica officinalis*, *Haldina cordifolia*, *Anogeissus* and Anacardiaceae as well as shrubby elements, viz., Fabaceae and *Strobilanthes*.

Among non-arborescences, Poaceae (8-14%) and Cyperaceae (4-11%) are the major elements. Scrophulariaceae and Apiaceae, 2 per cent each, are consistently represented in low values. *Potamogeton* (5%) is the only representative of aquatic vegetation. Fern spores (monolet 42-59% and trilete 12-24%) are recorded in high values.

Pollen Stage CH-II : Poaceae-sedges-Apiaceae-Emblica officinalis-Terminalia-fern assemblage – This pollen stage (286.5-258 cm) with a date of 5,010 ±100 years B.P. exhibits the decline in number as well as frequencies of arboreal taxa. *Terminalia*, *Emblica officinalis* and Anacardiaceae become more sporadic than in Pollen Stage CH-I. It is interesting that *Diospyros* makes its appearance in this stage.

The non-arborescences, Poaceae (2-16%), Cyperaceae (7-14%) and Apiaceae show improved values, whereas Scrophulariaceae, Brassicaceae, *Artemisia*, Chenopodiaceae remain low. *Potamogeton* (5%) is consis-



Text-figure 3 — Pollen diagram from Chhui Stream, Sidhi District, Madhya Pradesh (percentages calculated in terms of total pollen counts).

tently represented. Fern spores (monolete 30-40% and trilete 17-50%) are quite abundant.

Pollen Stage CH-III : *Emblica-officinalis-Myrtaceae-Lagerstroemia-Terminalia-fern assemblage* – This pollen stage, between 258.5-222 cm, shows better representation of tree taxa, viz., *Emblica officinalis*, *Terminalia* and *Anogeissus*, 2 per cent each. Also *Meliaceae* and *Myrtaceae* appear for the first time in this stage. The shrubby elements, *Fabaceae* (2%), *Strobilanthes* and *Oleaceae* (1% each) remain sporadic.

The non-arboreals, *Poaceae* 7-22 per cent, *Cyperaceae* 4-18 per cent, *Artemisia*, *Polygonum plebejum* and *Apiaceae* (3 per cent each) and *Brassicaceae* and *Tubuliflorae* (2 per cent each) show

improved values. *Potamogeton* and *Nymphaeae* are quite stray. The latter appears for the first time in this stage. Ferns remain prominent, but monolete spores (30-59%) predominate over the trilete spores (13-17%).

Pollen Stage CH-IV : *Anogeissus-Myrtaceae-Emblica officinalis-Terminalia assemblage* – This pollen stage, between 222-190 cm, depicts the improved values of *Anogeissus* (6%), *Terminalia* (3%), *Myrtaceae*, *Emblica officinalis* and *Anacardiaceae* 2 per cent each. The shrubby elements, viz., *Fabaceae* and *Strobilanthes* are scanty.

The herbaceous taxa, *Poaceae* (14-25%), *Cyperaceae* (13-14%), *Scrophulariaceae* (4%) and *Apiaceae* (3%) are better represented than in Pollen

Stage CH-III. The aquatic elements such as *Potamogeton* (2%) and *Nymphoides* (1%) remain static. Fern spores maintain their preponderance.

AMGAON SWAMP POLLEN DIAGRAM

Following five pollen stages have been demarcated for this profile (Text-figure 4).

Pollen Stage AM-I : Sedges-Poaceae-Myrtaceae-Haldina cordifolia-fern assemblage – This pollen stage, between 248-181.7 cm, is characterized by stray pollen of tree taxa, viz., Myrtaceae, *Anogeissus*, *Emblica officinalis*, *Haldina cordifolia*, *Terminalia* and Rutaceae as well as shrubby elements like, Fabaceae and Oleaceae. Poaceae (3-13%), Cyperaceae (8%) and Scrophulariaceae (5%) are the major constituents of ground vegetation. Aquatic elements – *Potamogeton* and *Nymphoides*, are sporadic. The monolete spores (47-60%) predominate over the trilete spores (11- 40 per cent).

Pollen Stage AM-II : Emblica officinalis-Haldina cordifolia-Myrtaceae-Lagerstroemia-fern assemblage – Between 181.7-155 cm, this stage is marked by the increased values of Myrtaceae, *Emblica officinalis*, *Terminalia* and *Haldina cordifolia* (2% each) and first appearance of *Lagerstroemia*, *Mitragyna* and Anacardiaceae (2% each). The shrubby elements such as Fabaceae and Oleaceae do not show any marked change.

Poaceae (9-14%) and Cyperaceae (17-20%) show improved values together with Brassicaceae, Lamiaceae, Tubuliflorae and Chen/Ams, 2 per cent each. Fern spores (monolete 27-42% and trilete 18-24%) show reduced values than in Pollen Stage AM-I.

Pollen Stage AM-III : Myrtaceae-Emblica officinalis-Haldina cordifolia-Terminalia-Anogeissus assemblage – This stage, between 155-112.5 cm, dated 1,000±200 years B.P., portrays further improvement in the frequencies of tree taxa, viz., *Anogeissus*, *Emblica officinalis*, *Terminalia*, *Haldina cordifolia*, *Lagerstroemia*, *Mitragyna* and Myrtaceae, though for a slight decline in the middle. *Shorea robusta*, *Buchanania*, *Diospyros* and *Lannea grandis* together with shrubby elements of *Strobilanthes* and *Ziziphus* appear sporadically for the first time. Among the non-arbores, Poaceae (6-18%) and Cyperaceae (7-23%) decline, but Scrophulariaceae

(6%), Brassicaceae (5%), Tubuliflorae(8%) and *Polygonum serrulatum* (2%) exhibit increased frequencies. The ferns remain preponderant.

Pollen Stage AM-IV : Emblica officinalis-Madhuca indica- Myrtaceae - Anogeissus assemblage – This stage between 112.5-89 cm is marked by the increased frequencies of *Emblica officinalis* and Myrtaceae (3 per cent each) as well as the addition of *Madhuca indica*, *Sterculia urens* and *Flacourtia* (1 per cent) for the first time. Fabaceae (4%) exhibits a rising trend, whereas *Strobilanthes*, *Ziziphus* and Oleaceae remain sporadic.

Poaceae 12-30 per cent, Cyperaceae 13-33 per cent, Scrophulariaceae 9 per cent, *Justicia* 5 per cent, Lamiaceae and Chen/Ams (2 per cent each) have increased values as compared to the Pollen Stage AM-III. *Potamogeton* (7%) reappears in high values together with *Typha* (1%). Ferns show considerable decline in this stage.

Pollen Stage AM-V : Shorea robusta-Emblica officinalis-Terminalia-Anogeissus-Madhuca indica-assemblage – The topmost stage (89-72 cm), dated to 1,200 ±110 years B.P., reveals a further improvement in arbores and a simultaneous decline in ferns. *Shorea robusta* (3 per cent) reappears in good frequencies after a lapse in Pollen Stage AM-IV. *Emblica officinalis*, *Madhuca indica*, *Anogeissus* and *Terminalia* are the other prominent associates.. The shrubby elements such as *Ricinus communis* and *Melastoma* also appear in this stage.

Cyperaceae 22-30 per cent followed by Poaceae 26 per cent attain maximum values, though latter declines towards the top. Other constituents, viz., Scrophulariaceae (7%), Lamiaceae (4%), *Rotala* and Tubuliflorae (3% each) together with aquatic elements such as *Potamogeton* (6-13%) and *Typha* (3%) show higher values than before. Ferns decline severely in this stage also.

CORRELATION AND REGIONAL POLLEN ZONATION

The pollen diagrams constructed from Bastua, Amgaon and Chhui Stream have been correlated on the basis of C-14 dates and the contemporary phases of vegetational development, so that a complete sequence of vegetational succession in the region could



Text-figure 4 — Pollen diagram from Amgaon, Sidhu District, Madhya Pradesh (percentages calculated in terms of total pollen counts).

be made in a chronological order (Text-figure 5). Of these pollen diagrams, the Bastua pollen diagram dated to $11,550 \pm 240$ radiocarbon years (BS-440), the Chhui Stream pollen diagram dated to 7,000 radiocarbon years (Pollen Stage CH-I is dated to BS-410 $6,720 \pm 110$ years B.P.) and the Amgaon pollen diagram may be contemporary with Chhui Stream pollen diagram as the top stages AM-III and AM-V date to $1,000 \pm 200$ (BS-408) and $1,200 \pm 110$ years B.P. (BS-407) respectively.

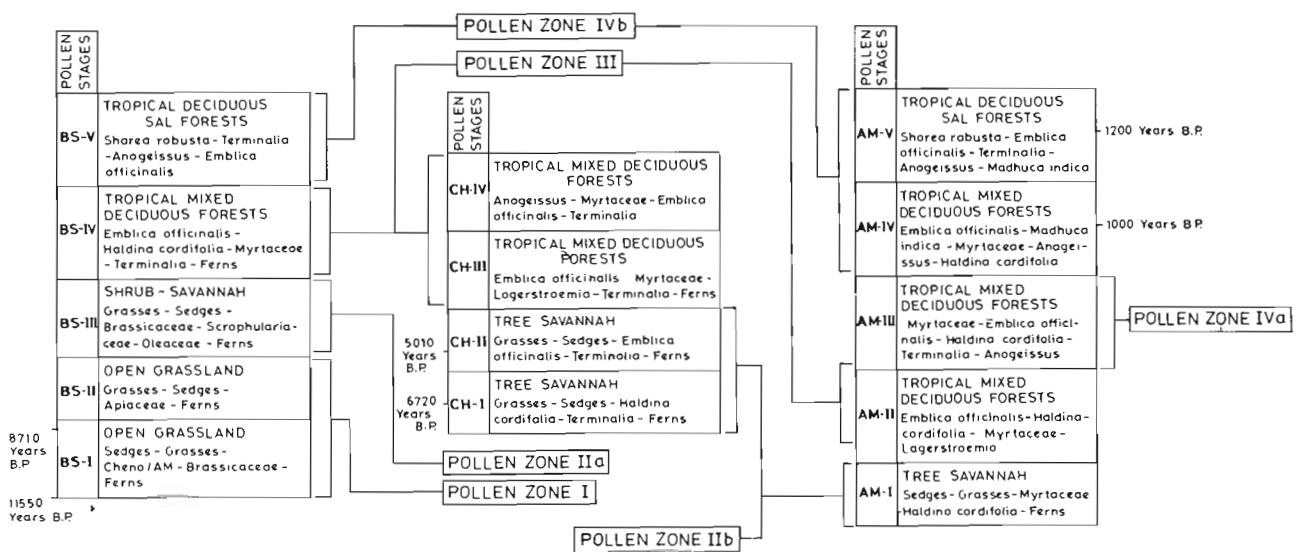
Utilizing the pollen data, the forest encroachment is dated to about 6,720-5,010 years B.P. in Chhui Stream pollen diagram (CH-I & CH-II) and the same is observed in Pollen Stage AM-I in Amgaon Pollen diagram. This is more or less comparable with Pollen Stage BS-III in Bastua Pollen diagram where shrub-savannah is indicated. Whereas the invading trees at Amgaon comprise *Terminalia*, *Embllica officinalis* and *Haldina cordifolia*, in the vicinity of Chhui Stream they comprise in addition to those of *Anogeissus*, *Lagerstroemia*, etc.

The development of tropical deciduous forests is observed in Pollen Stages CH-III and CH-IV in Chhui Stream pollen diagram (4,500-3,800 years B.P.), in Pollen Stage AM-II in Amgaon pollen diagram and in Pollen Stage BS-IV in Bastua Pollen diagram.

In these deciduous forests, Sal (*Shorea robusta*) appears at the top in Pollen Stage AM-III, but vanishes soon in Pollen Stage AM-IV when *Madhuca indica* and *Sterculia urens* turn up for the first time. However, it reappears and assumes prominence over other tree taxa in Pollen Stage AM-V. In the pollen diagram from Bastua, Sal (*Shorea robusta*), *Madhuca indica* and *Buchanania* appears during Pollen Stage BS-V.

In the absence of pollen grains of *Sterculia urens*, *Mitragyna*, *Madhuca indica*, *Lannea grandis*, *Buchanania* and Sal (*Shorea robusta*) in Chhui Stream pollen diagram may be interpreted to indicate lack of kind, diversity and density of forests or these taxa did not migrate to this region. Attention must be drawn to the fact that top sediments in Chhui Stream Section is covered by 190 cm modern alluvium, the possibility of erosion of top lake swamp deposit cannot be ruled out. It is therefore assumed that the top part of the profile which should have exhibited appearance of Sal and density of forests is missing in the section.

The correlation of these pollen diagrams from Bastua, Chhui Stream and Amgaon allows to recognize four periods of vegetational development in the region. These have been tentatively designated as regional pollen zones from base to top.



Text-figure 5 — Correlation of pollen diagrams from Bastua, Amgaon and Chhui Stream, Sidhi District, Madhya Pradesh.

Pollen Zones	Period	Vegetational sequence
	IVb since 1,200 years B.P.	Formation of Sal forests comprising local Pollen Stage BS-V in Bastua pollen diagram and Pollen Stages AM-IV & AM-V in Amgaon pollen diagram.
Pollen Zone IV	IVa prior to 1,200 years ago	First appearance of Sal pollen; Pollen Stage AM-III in Amgaon Pollen diagram.
Pollen Zone III	4,500-3,800 years B.P.	Formation of tropical deciduous forests comprising local Pollen Stage BS-IV in Bastua pollen diagram. Pollen Stage AM-II in Amgaon pollen diagram. Pollen Stages CH-III & IV in Chhui Stream pollen diagram.
	I Ib 6,720-5,010 years B.P.	Immigration of tropical deciduous forest constituents comprising local Pollen Stages AM-I in Amgaon pollen diagram and Pollen Stages CH-I & CH-II in Chhui Stream pollen diagram.
Pollen Zone II	II a 8,000 years B.P.	Shrub-savannah. local Pollen Stage BS-III in Bastua pollen diagram.
Pollen Zone I	10,000-8,700 years B.P.	Open vegetation or grass-sedge stage comprising local Pollen Stages BS-I & BS-II in Bastua pollen diagram.

DISCUSSION

Hitherto, some work has been carried out on the vegetational and climatic succession of tropical deciduous forests, in which Singh *et al.* (1974) worked out a detailed study on Rajasthan desert. Besides, Gupta (1978) investigated a single profile from the plain of Uttar Pradesh. However, no data is available on this aspect from Madhya Pradesh which possesses a diversified vegetational mosaic. Hence, in the present study a comprehensive attempt has

been made from the tropical deciduous Sal forests distributed in Sidhi District, Madhya Pradesh through pollen analysis of three soil profiles, one each from Bastua, Chhui Stream and Amgaon and consequently a complete sequence of vegetational and climatic alterations has been made in the region since past 10,000 years B.P.

The pollen analytical investigation has unravelled that during 10,000 to 8,700 years B.P. (Pollen Zone-I) this region was dominated by vast stretches of open grassland vegetation as evidenced by the preponderance of grasses and sedges and complete absence of arboreals. Other herbaceous elements such as Chenopodiaceae, Scrophulariaceae, Tubuliflorae, Liguliflorae, Brassicaceae, Acanthaceae and Apiaceae were scantily distributed in these grasslands. In totality, vegetational composition signifies that the region was under the impact of cool and dry climate and the soil was immature during the early part of Holocene Epoch.

Thereafter, around 8,000 years B.P. (Pollen Zone-II) in the vicinity of Bastua area these grasslands were invaded sporadically by the shrubby elements of Oleaceae in response to amelioration of climate and consequently a shrub-savannah vegetation developed. The vegetation was still dominated by grasses and sedges with other associates being almost alike as before except an addition of *Artemisia*. Thus, from this change in the vegetation pattern, it is quite apparent that the amelioration of climate and formation of suitable soil for the immigration of arboreal elements commenced during this time. Between 6,720 to 5,010 years B.P. in the vicinity of Chhui Stream area these grasslands were successively invaded by few tree taxa such as *Emblica officinalis*, *Terminalia*, *Haldina cordifolia*, *Lagerstroemia*, *Anogeissus* and Anacardiaceae one after the other together with shrubby elements of *Strobilanthes* and Fabaceae, though they were meagerly distributed. Simultaneously, a more or less similar type of vegetation also existed in Amgaon area, but in addition to all the above mentioned taxa there were also trees of Myrtaceae and Rutaceae. This slow and successive immigration of the tree taxa implies the replacement of shrub-savannahs by tree-savannahs during the subsequent part of this phase (Pollen Zone IIb),

which is indicative for further amelioration of climate and build up of suitable soil for the invasion of tree taxa. The vegetation was still open and it was in a state of reconstitution.

During 4,500 to 3,800 radiocarbon years B.P. (Pollen Zone III) in the vicinity of Bastua, the most significant event was the abrupt invasion of these grasslands by several deciduous forest constituents such as *Emblīca officinalis*, *Haldina cordifolia*, members of Myrtaceae followed by *Sterculia urens*, *Mitragyna*, *Diospyros*, *Flacourtia*, *Buchanania*, *Madhuca indica*, members of Anacardiaceae and Meliaceae successively one after the other. By this time the forests were not only established they were varied in composition and dense too. The shrubby vegetation was still scanty, but it became certainly better than before owing to immigration of *Strobilanthes* and Fabaceae. On the other hand, in Chhui Stream area the forests were enriched by the gradual immigration of some new tree taxa, viz., *Diospyros*, members of Myrtaceae and Rubiaceae as well as improvement in the frequencies of *Emblīca officinalis*, *Terminalia*, *Anogeissus*, *Lagerstroemia* and members of Anacardiaceae and Myrtaceae. Likewise, in Amgaon area, forests were also more or less alike in composition, however, expansion of forests took place due to considerable improvement in the representation of most of the tree elements as well as the appearance of some more taxa such as *Lagerstroemia* and *Mitragyna* in the forest floristics. The emerged out vegetational composition at all three sites reflects the establishment of mixed deciduous forests, which could perhaps be the consequence of increased precipitation coupled with the development of congenial edaphic condition for the encroachment and spread of most of the forest elements in the region.

Prior to 1,200 years B.P. (Pollen Zone IVa), the mixed deciduous forests continued to grow in the region, but they further became dense and diverse in composition as a consequence of improvement in the frequencies of prominent forest ingredients such as *Emblīca officinalis*, *Haldina cordifolia*, *Terminalia*, *Anogeissus*, *Mitragyna*, Myrtaceae and *Lagerstroemia* as well as immigration of some more taxa such as *Diospyros* and *Lannea grandis* into the forests, though sporadically. *Shorea robusta* also

turned up sporadically towards the termination of this phase, but vanished soon.

Thereafter, around 1,200 years ago in Amgaon area the most important event was the reappearance of *Shorea robusta* in these mixed deciduous forests and gradually became the dominant constituent as attested by its higher frequencies and consistent representation throughout this phase (Pollen Zone IVb). *Madhuca indica* together with *Sterculia urens*, *Flacourtia* and *Ziziphus* also appeared during this time. Besides, *Shorea robusta*, *Emblīca officinalis*, *Madhuca indica*, *Anogeissus*, *Terminalia* and Myrtaceae were the major components of these Sal forests. In Bastua area, Sal (*Shorea robusta*) also appeared together with *Acacia* and *Anogeissus* during this time and assumed dominance over other forest elements within a brief span of time. Thus, the establishment of Sal forests and increased diversity of forest floristics provides ample evidences for the further increased precipitation and prevalence of comparatively more moist climate in the region than before, since Sal prefers such type of climatic condition for its optimal growth. The shrubby vegetation was enriched by the invasion of *Melastoma* as well as increased in the frequencies of *Strobilanthes*, Fabaceae and Oleaceae. The sporadic record of *Ricinus communis*, a shrubby element, denotes the close proximity of cultivated land since it is a prominent indicator of anthropogenic activities. The maximum representation of herbaceous elements such as sedges, grasses and others including the aquatic taxa more particularly *Potamogeton*, signifies the expansion of swamp as well as profuse growth of ground vegetation in the adjoining open area in response to improved climatic condition.

CONCLUSION

Regarding the antiquity of Sal forests, it is indispensable to discuss here that the fossil woods (*Shoreoxylon*) resembling *Shorea robusta* have been described from the Tertiary of Assam, south India, West Bengal and Lower Siwalik beds (Prasad & Prakash, 1987). Besides, leaf-impressions of *Shorea* have also been described from the Siwalik sediments of West Bengal (Antal & Awasthi, 1993). However,

such reports are not available from the Tertiary or Quaternary of central India, where presently it is the major constituent of tropical deciduous forests spreading over a large area. The palynological findings have unravelled for the first time that this important forest ingredient appeared spontaneously in the mixed deciduous forests distributed in district Sidhi prior to 1,200 years ago as a result of improvement in climatic condition and subsequently assumed dominance over other associates within a short span of time.

For the reconstruction of spatial and temporal distribution as well as to trace out the route of migration of *Shorea robusta* in central India during Quaternary Period the palynological investigation of a series of cores from different parts is needed.

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