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# Late Quaternary Environmental History of the Horton Plains, Central Sri Lanka

**T. R. Prematilake**
Postgraduate Institute of Archaeology, University of Kelaniya
**D. S. Epitawatta**
Department of Geography, University of Sri Jayewardenepura

**Abstract**

Pollen and mineral magnetic analyses performed on two peat sequences from the elevated area at 2300 m above above sea level (a.s.l.) in the central part of Sri Lanka provide an almost continuous succession of data on the vegetation, climate and land-use history of the area since 18,000 BP. An amelioration of the arid Late Pleistocene environment is indicated by the development of herbaceous and summer forest communities. Xerophytic woodlands predominated at the termination of the Pleistocene, about 13,000 BP. At the very end of the Pleistocene an increase in precipitation is identified by the predominance of a montane rain forest (12,000 - 11,000 BP). The Holocene vegetation changes reflect two significant phases of expansion and diversification in the rain forest, in 8000 - 7000 - and 4000 - 3000 BP. Suggesting iparcases in precipitation. In addition an arid climatic phase from 6000 to 5000 BP was observed, and a short wet phase around 600 BP.

The first indications of human impact in the pollen diagram, dated to approximately 14,000 BP, may be the result of severe deforestation, forest clearance and grazing. A pre-farming/pastoral culture existed from 14,000 to 10,000 BP, and changes in both human subsistence strategies and climate, and be recognized around 9000 BP, with the start of the first agricultural land-use (Hordeum sp. and Avena sp.). These activities continued until 6500 BP, whereas only limited agricultural activities and be identified during the period 6500 to 3000 BP. Thereafter, the area was abandoned until small-scale triticum cultivation started around 800 BP, lasting until 200 BP.

## Introduction

The Horton Plains, located between 6°46'- 6°52' N and 80° 46'-80°51' E in the central hilly region of Sri Lanka, were designated a National Park in 1969 for the preservation of natural montane ecosystems and habitats (Fig. 1). The area is characterized by a rolling landscape with mires, plains, forested hill tops, grassy slopes, precipices, brooks and waterfalls. Located at 2100-2600 m (a.s.l.), it covers and area of some 3200 ha. The bedrock of the Horton Plains was formed during the Archaean, underwent folding on vast scales in the Precambrian (Cooray 1984) and was later uplifted during post-Jurassic times. The bedrock of the area studied here mainly consists of high grade metamorphic rock belonging to the charnokite-metasedimentary series, largely garnetiferous gneisses, quartz, granulites and sillimanite (Coory 1991; Mosley and Pitfield 1997)

The climate of the Horton Plains ranges from extreme wet to dry. During the driest period, in February, the mean temperature is 12°C and the night temperature drops to 5°C in February, the mean temperature is 12°C and the night temperature drops to 5°C (Balasubramaniam et al. 1993). The area is affected by the monsoons, mainly as a consequence of differential heating between the Asian continent and the Indian Ocean, causing an atmospheric circulation over the Indian Ocean. The rainfall, which averages about 2150 mm per year, is determined to a great extent by the south-west monsoon (SWM), which reaches its peak in June and August. The north-east monsoon (NEM) brings considerably less precipitation. Because of its strategic geographical location, the organic accumulations in the Horton Plains area are thought to contain information on variations in rainfall and temperature with time. The vegetation of the area mainly consists of upper montane rain forest and grasslands.

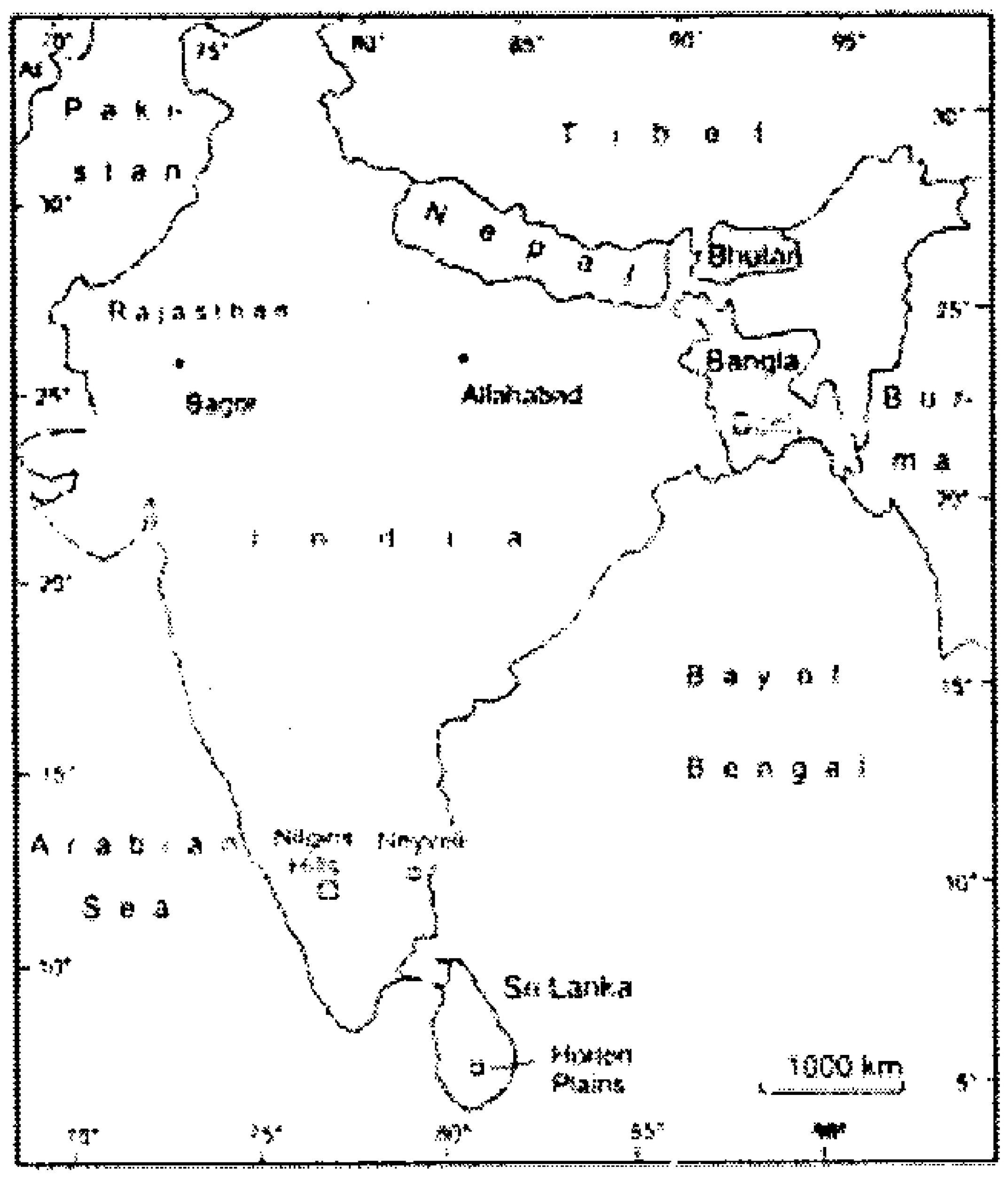


FIGURE 1: Location of the Horton Plains in central Sri Lanka. Sites on the Indian peninula that mentioned in the text are ahown.

The purpose of the study is to reconstruct the vegetation, climate and land-use history during the Late Quaternary from pollen records and mineral magnetic analyses obtained for two peat sequences taken from the Horton Plains area.

## Sites

The two mires selected for lithostratigraphic and biostratigraphic investigations (Fig. 2) are located at 6° 49' 58" N-80° 48' 48" E (Site 1) and 6° 48' 20" N-80° 49' 05" E (Site 2).

Site 1 constitutes a valley approximately 2km long extending in a north-west to south-east direction (Fig. 3). Its sides are steep, and bedrock outcrops are occasionally visible on the slopes. The eastern side is dominated by wooded hill tops, and the western side by grassy slopes. The ground vegetation consists mainly of grasses (Poaceae), sedges (Cyperaceae) and dwarf bamdoo. The peat thickness does not in general exceed 3m (Fig. 3), although the figure at the sampling site was 5.3 m.

Site 2 constitutes a topographically well defined valley (Fig. 4) with its sides undulating so as to create segments with alternating wide and narrow parts. In the northern narrowing, a thin layer of peat covers about 50cm of sand superimposed on the bedrock while in its southern equivalent the bedrock is exposed. A brooklet runs close to the southern side of the valley. The ground vegetation consists mainly of Poaceae, Cyperaceae and Sphagnum sp. The peat thickness does not usually exceed 3m.

## Materials and Methods

The lithostratigraphy was investigated by means of 50 cores, 36 taken at Site 1 and 14 at Site 2 (Figs 3 and 4, Tables 1 and 2) using a Russian peat corer (diameter 5cm). Preliminary sediment in the field and detailed determinations in the laboratory on the basis of macroscopic observations. The coring revealed sequences consisting of partially decomposed plant remains and humus, occasionally mixed with fine and/or coarsegrained minerogenic material. The material is characterized below as

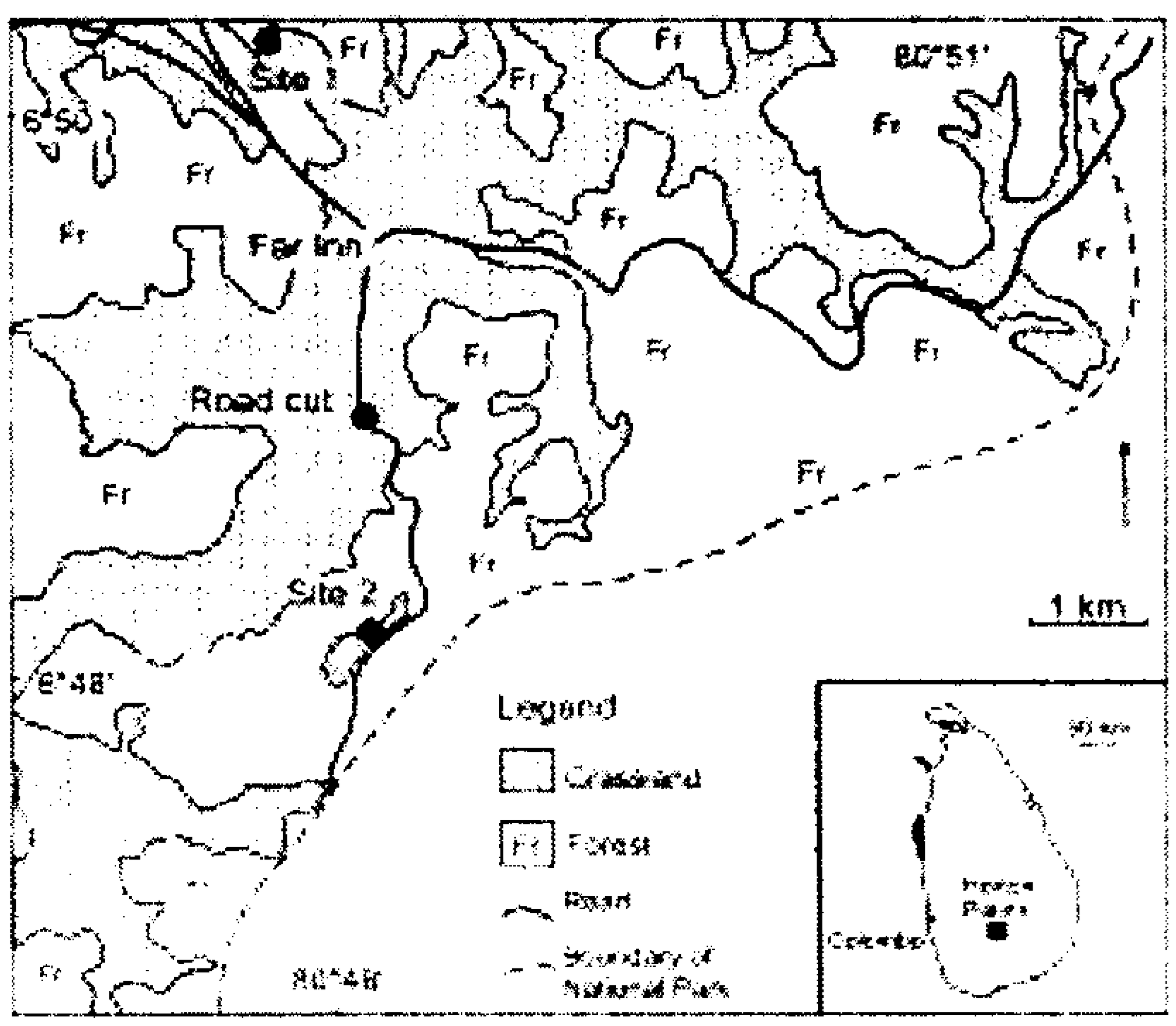


FIGURE 2: Generalized map of the present day relations between grassland and forest in the central part of the Horton Plains. Locations of the sampling sites the indicated.

herbaceous peat, underlain in most cases by weathered kaolinite bedrock. A clayey, siltyo organic-rich layer occurring bedrock at Site I could either be a sediment produced outside or within the valley or an unknown clay mineral produced by in sim bedrock weathering. i.e. inwashed weathered bedrock.

## Radiocarbon dating

Ten bulk samples were collected from the cores and dated at the Ångström Laboratory, Uppsala University, Sweden, by the AMS technique (Possnert 1990). Three samples were collected from a road cutting about 1km NW of Far Inn (Fig. 2) and dated by the conventional technique at the Laboratory of isotope Geology, Swedish Museum of Natural History (Table 3). The pre-treatment procedures were begun by pouring distilled water over the samples and removing any coarse plant remains such as coarse roots, and rootlets manually. The samples were then treated with 1% HCI to dissolve carbonate and the rest of the material was wet sieved through a sieving cloth of mesh size 63 microns using a water-driven suction pump. The material passing through the sieve was separated by centrifugation into two parts: an insoluble fraction (INS) and a soluble fraction (SOL). Humic acids were removed using 1%. NaOH. Ages are stated with $\pm\sigma$ and a normalization of $\delta^{13}$ C = -25 per mille against PDB was carried out. The half-life ($T_{1/2}$) is 5570 years. All ages stated refer to uncalibrated $^{14}$C years BP.

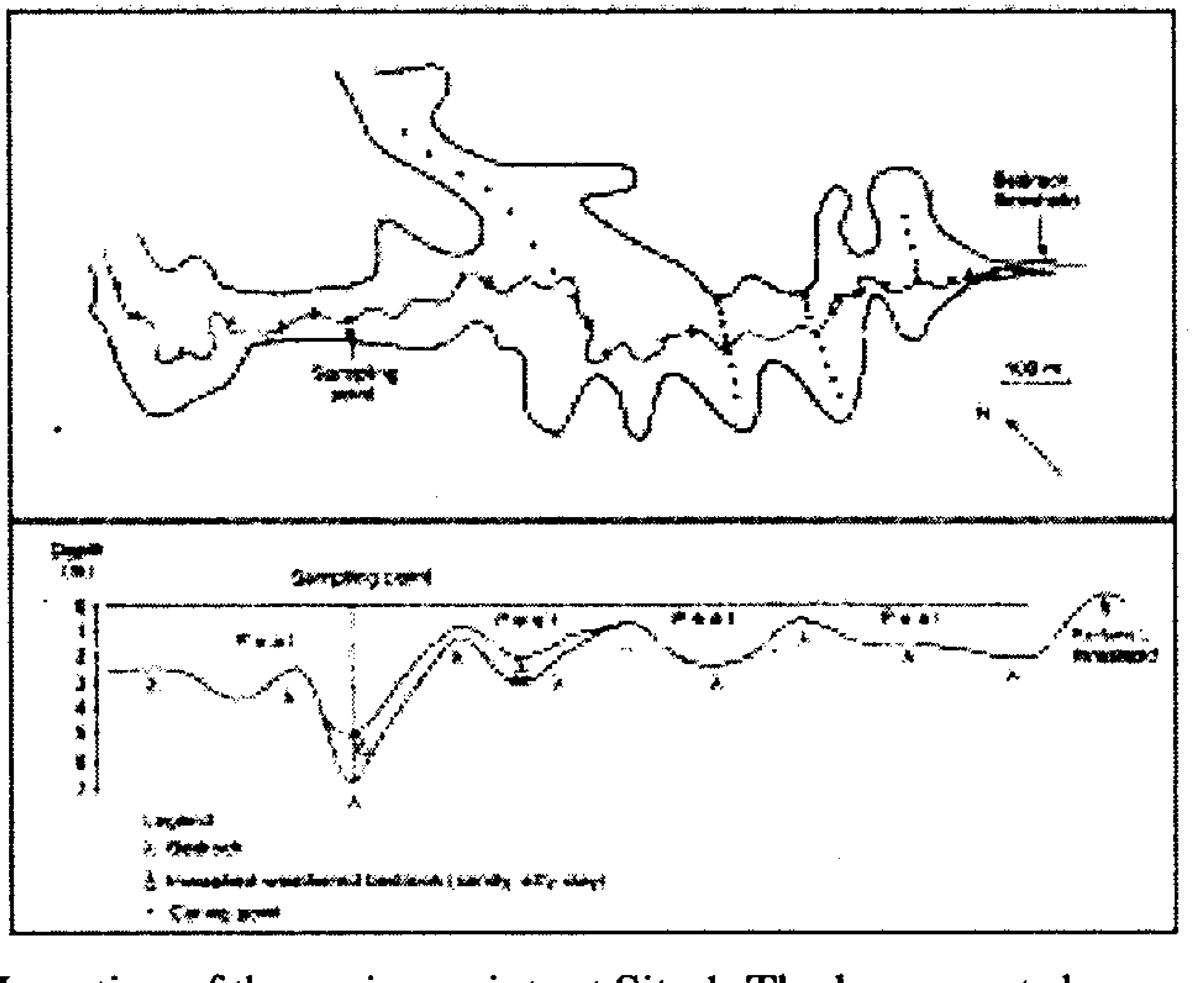

FIGURE 3: Location of the coring points at Site 1. The lower part shows a generalized longitudinal section from northwest to southeast indicating peat thickness. Coring along all four cross-sections revealed a similar stratigraphy, with an undulating bedrock topography. The in-weshed weathered bedrock is believed to have been transported only short distances.

**Pollen and spore analysis**

Sub-samples for the analysis of pollen and spores were treated by conventional methods as described by Berglund and Raiska-Jasiewiczowa (1986). Two Lyopodium tablets were added to the volume-specific samples (1cm$^3$), and chemical treatment included 10%Hci, 10% NaOH and 40% HF, acetolysis with 1 part of $H_2SO_4$ to 9 parts $C_4H_6O_3$ and final mounting in glycerine. Pollen and spore analyses were carried out at 10 cm (Site 1) and 20cm (Site 2) intervals, with counting taking place under a magnification of x 500 (standard), with x 1250 phase contrast for critical identifications. Between 400 and 1800 (mean value) pollen grains were counted in each sample. The number of microscopic charcoal particles with a maximum diameter > 25 μm.

Table 1: Lithological description of the material analyzed from Site 1.

| **Depth (cm)** | **Lithology** |
|---|---|
| 000-139 | Peat, BL/VDB (10YR 2/1 : 2/2): 1. 2. 3 & 4 |
| 139-165 | Sandy peat, BL/VDB (10YR 2/1 : 2/2): 1. 2. 3 & 4 |
| 165-172 | Peat, BL (10YR 2/1): 1. 2. 3 & 4 |
| 172-200 | Sandy peat, BL (10YR 2/1): 1 & 4 |
| 200-216 | Peat, BL (10YR 2/1): 1. 2 & 4 |
| 216-228 | Sandy peat BL (10YR 2/1): 1 & 4 |
| 228-353 | Peaty sand, BL/VDB (10YR 2/1: 2/2): 1. 2. 3 & 4 |
| 353-367 | Peat, BL (10YR 2/1): 1. 3 & 4 |
| 367-373 | Sandy peat, BL (10YR 2/1): 1 & 4 |
| 373-405 | Peat. GA/BL (10YR 5/1 : 2/1): 1. 2 & 4 |
| 405-432 | Sandy peat, GB (10YR 5/2): 1.2 |
| 432-460 | Peaty sand, BL/VDB (10YR 2/1 : 2/2) |
| 460-529 | Sandy silty clay (org.) GB (10YR 5/2): 1. 3 & 4 |
| 529 -560 | Sandy silty clay (org.) BL/YE/WH/OYE (10YR 2/1:5Y 8/6, 8/1, 6/8): 3 &4 |
| 560-600 | Sandy silty clay, WH/OYE/YE (5Y 8/1, 6/8, 8/6): 1. 3. & 4 |

**Remnant:** grass (1), wood (2), charcoal (3), non-identified (4), moss (5). Colour: black (BL); very dark brown (VDB); dark brown (DB); greyish brown (GB), yellow (YE); olive yellow (OYE); white (WH); greyish (GA), Colours are determined according to the Munsell Soil Color Charts (1988). and fungal spores were also counted on the same slides as used for the pollen analyses.

Table 2: Lithological description of the material analyzed from Site 2. Abbreviations are according to Table 1.

| **Depth (cm)** | **Lithology** |
|---|---|
| 000-050 | Peat, DB(10YR 2/2): 1. 4 |
| 050-100 | Peat, DB (10YR 2/2): 1. 4. 5 |
| 100-150 | Peat, with fine sand DB (10YR 2/2): 1. 4. 5 |
| 150-200 | Peat, with fine sand. DB (10YR 2/2): 1. 4 |
| 200-224 | Peat. DB (10YR 2/2): 1. 2. 3 |
| 224-230 | Peat, with fine sand. BL (10YR 2/1): 1. 2. 4 |
| 230-255 | Peat, BL (10YR 2/1): 1 |
| 255-260 | Sand, BL (10YR 2/1): 1. 4 |
| 260-270 | Peat, BL (10YR 2/1) |
| 270-300 | Sand, coarse sand and pebbles. BL (10YR 2/1) 1. 4 |
| 300-315 | Peat with sand, BL (10YR 2/1): 1. 4 |
| 315-325 | Pebbly sand. BL, (10YR 2/1): 1. 4 |
| 325-335 | Silty sand with clay, pebbles BL (10YR 2/1): 1. 4 |
| 335-350 | Clay. kaolinite (?). WH (10YR 8/1) |

Table 3. Radiocarbon dates obtained for Sites 1 and 2, and from a road cutting about 300 m south of Far Inn.

| **Depth (cm)** | **Lab. Nr** | **Fraction** | **Age yrs BP** | **$\delta^{13}C$** | **Material** |
|---|---|---|---|---|---|
| **Site 1** | | | | | |
| 80 | Ua-16393 | INS | 1025±70 | -24.2 | Peat |
| 160 | Ua-16394 | SOL | 2675±60 | -23.0 | Sandy peat |
| 230 | Ua-16395 | SOL | 3120±70 | -25.7 | Sandy peat |
| 305 | Ua-16396 | SOL | 7935±80 | -18.1 | Sandy peat |
| 420 | Ua-16397 | SOL | 9125±80 | -18.6 | Peat |
| 487 | Ua-16398 | SOL | 12.970±115 | -25.5 | Peaty sand |
| 540 | Ua-16399 | SOL | 15.045±140 | -25.5 | Org.clay |
| **Site 2** | | | | | |
| 170 | Ua-11126 | SOL | 3865±80 | -26.2 | Peat |
| 245 | Ua-11127 | SOL | 4550±90 | -25.9 | Peat |
| 310 | Ua-11128 | SOL | 6610±45 | -21.3 | Peat sand |
| **Road cut** | | | | | |
| 40-43 | ST-14039 | INS | 1320±60 | -12.5 | Sandy peat |
| 40-43 | ST-13783 | SOL | 2125±70 | 13.4 | Sandy peat |
| 53-56 | ST-13782 | SOL | 6970±80 | -14.6 | Sandy peat |

## Water content

A known volume of bulk material in a plastic container was used for the determination of water content by weighing before and after freeze-drying. The results are shown as percentages of dry weight.

## Organic carbon measurements

Organic carbon content was determined using an ELTRA, CS 500 simultaneous carbon sulphur determinator at 121 levels representing the whole core from Site 1 and at 21 levels between levels 319 and 239 cm at Site 2. Approximately 300mg aliquots of the freeze-dried samples were combusted at 550°C and the loss-on-ignition results shown as percentages of dry weight.

## Mineral magnetic analysis

Sub-sampling for mineral magnetic analysis was performed at 1cm intervals over the entire length of the core. The measurements were carried out at the Department of Quaternary Geology, Land University. Magnetic susceptibility ($\chi$), was measured using an air-coiled susceptibility bridge (Kappabridge, KLY-2), with pulse magnetic charges employed for artificial magnetization of the samples. Anhysteretic remanent magnetization (ARM) was induced un an AC demagnetizer with a peak alternating field of 100 mT and a steady direct field of 0.1 mT and the remanence was measured on a Molspin spinner magnetometer. Saturation isothermal remanent magnetization (SIRM) was achieved by placing the samples in a high magnetometer. ARM and SIRM were determined using the Molspin anhysteretic remanent magnetizer and molspin "Minispin" fluxgate magnetometer. After the saturation procedure, the samples were placed in a weak negative field of 0.1 T (isothermal remanent magnetization; $IRM\text{-}_{0.1T}$) using a Molspin pulse magnetic charger and the remanence was measured on the spinner magnetometer. The S-ratio was calculated as $IRM_{-0.1T}$/SIRM. After completion of the magnetic analysis, the samples were dried and weighed to allow calculation of the mass specific concentration parameters (Thompson and Oldfield 1986). All the above parameters were measured on the palynological core from Site 1.

## Identification of pollen and spores

Pollen and spores were identified using the pollen atlases of Huang (1972), Wang *et al.* (1995), Zheng (1982) and Reille (1998) together with two reference slide collections, one made at the Playnological Laboratory, Museum of Natural History, Stockholm, Sweden, and the other at the Postgraduate Institute of Archaeology, University of Kelaniya, Sri Lanka. The works of Erdtman (1952), Nair (1961, 1962 and 1963), Chaubal (1966, 1986) Huang (1981), Gupta and Sharma (1986) and Tissot *et al.* (1994) were also used. Critical identification of cultivated *Hordeum* and *Triticcum*-type pollen was based on measurements of the annulus diameter (anl-D), the largest diameter of the pollen grain (D) and the diameter (d) perpendicular to D, all made after preparation with glycerine. The actual pollen size was taken to be the average of D and d (*cf.* Andersen 1979). The phase contrast facility was also used to determine surface features and the arrangement of columellae. The key used as aide to identification were chiefly those of Beug (1961), Kohler and Lange (1979), Faegri and Iversen (1989) and Moore *et al.* (1991)

### Diagram construction

The pollen diagrams were constructed using the TILIA program (Grimm 1992). The basic sums include pollen of trees, shrubs, herbs and woody twines, but exclude pteridophytes (triletes and monoletes), bryophytes, fungi spores and charcoal particles. The local pollen assemblage zones/sub-zones were differentiated on the basis of fluctuations in pollen and spore frequencies, using the CONISS contrained cluster analysis which operates on the incremental sum of squares (Grimm 1987). The result of the cluster analysis is presented as a dendrogram at the right-hand end of the pollen diagram.

## RESULTS AND INTERPRETATION

### Pollen and spores

The results for the core sequences from Sites 1 and 2 are shown in simplified diagrams in Figs. 5 and 6, and full pollen diagrams are provided as fold-outs from the back cover. In general, both sites feature a high diversity of pollen types, more than 200 taxa being identified, most of them occurring at low frequencies. Unknown pollen types make up 1-2% of the count at any given level. Pollen preservation is generally good throughout both sequences, except for two intervals at Site 1. Pollen concentration values are calculated for both sites as an additional indicator, and these together with organic carbon curves are also shown in Figs. 5 and 6. The key features of the local pollen assemblage zones (LPAZ) at Site 1 and 2 are detailed below, and their age intervals are deduced from linear interpolations and extrapolations of lines fitted to the dates (Figs. 7 and 8).

**Site 1**

The pollen evidence for the coniferous taxon *Cunninghamia* sp. and the deciduous taxa *Terminalia* sp. and *Grewia* sp. in the lowermost sample representing LPAZ 1 (17,500 - 15,000 BP, 600-540cm) indicates a cool climate and low precipitation. An interpretation that is supported by the occurrence of xerophytic taxa, *e. g. Drymaria diandra* and *Erythroxylum* sp. Pollen grains of aquatic-hygrophyte taxa, *e. g. Commelina undiflora* and *Laurembergia zeylanica,* reveal that the valley temporarily material emanating from the weathered bedrock and bare soil over short distances. Pollen grains were incorporated into the material during these processes.

The scarcity of pollen grains, the lack of arboreal taxa and the few occurrences of xerophytic taxa, *e. g.* Chenopodiaceae/*Suaeda* spp or Amaranthaceae/*Digera* sp., suggest that dry conditions prevailed during the period represented by the uppermost part of the zone. The organic carbon content (Fig. 5) and the pollen concentration values are low, also indicative of an oxidizing depositional environment in which pollen rains were destroyed. The high values for microscopic charcoal particles (90%) point to natural fires in the open vegetation just close to the coring site. Since there is no conclusive evidence in the pollen record of human activity in this period, it is believed that these fires were natural. A sample from 540cm yielded at date of 15,045±140 $^{14}C$ yrs BP.

The pollen concentration values in LPAZ 2 (15,000 - 12,500 BP, 540-478cm), are fairly high relative to LPAZ 1. The appearance of arboreal taxa, *e.g. Elaeocarus* spp, *Symplocos* spp and *Meliosema simplicifolia,* at the lower boundary indicates a slight increase in precipitation, and this interpretation is supported by the occurrence of an aquatic taxon, *Erioculan brownianum,* and cysts of *Pseudoschizaea* sp. (at 517cm). It is also possible to correlate the initiation of the fairly wet conditions with an increase in the amount of sand. The aquatic and hygrophytic taxa, e.g. Limnophyton sp., suggest the presence of a temporary shallow water body just close to the coring site. The occurrence of ericaceous taxa, *e.g. Rhobodendron arboreum, Gaultheria fragrantissima* and *Vaccinium symplocifoloum,* indicates a cool climate.

In the upper part (517 - 478 cm), the decrease in Poaceae and the occurrence of xerophytic tree, shrub and herb taxa, *e.g. Cassuarina montana, Pemphis acidula,* and *Zygocactus truncatus,* indicate a change in the composition of the vegetation from an open forest to xerophilous woodlands. This interpretation is confirmed by the low percentages of the pollen of

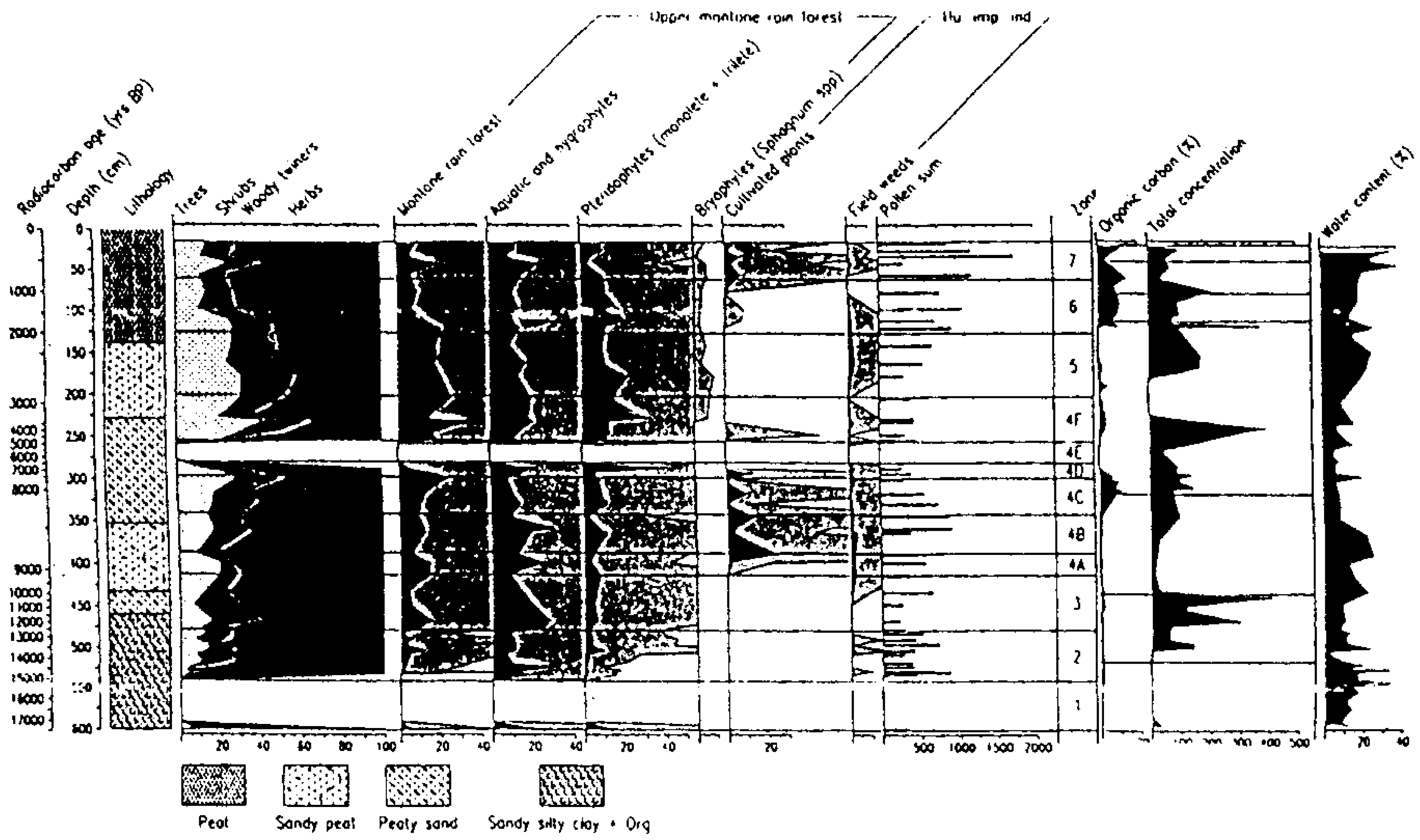


FIGURE 5: Simplified pollen diagram for Site 1, together with values for organic carbon, charcoal particles, and water content.

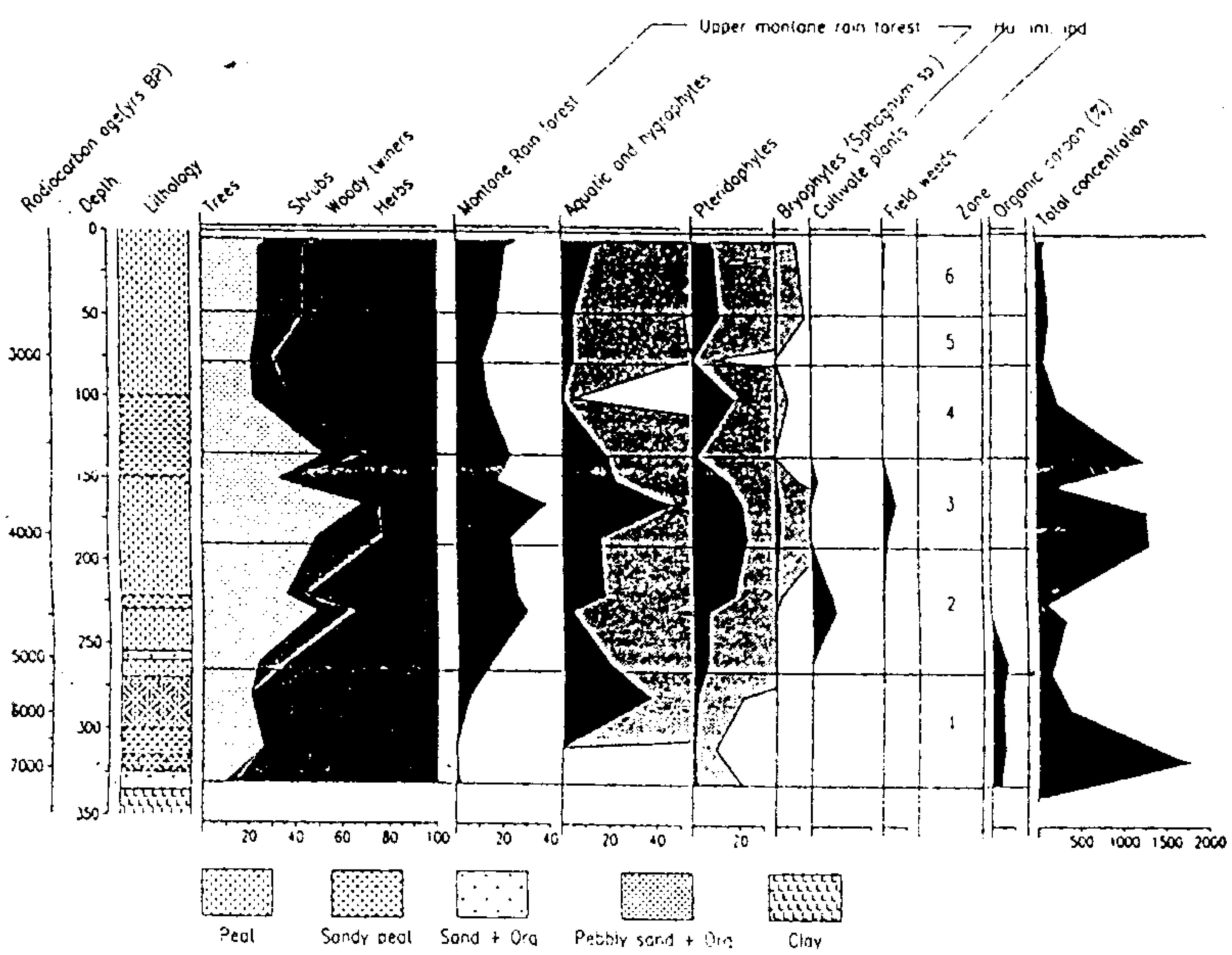


FIGURE 6: Simplified pollen diagram for Site 2, together with organic carbon values for the interval 225-330 cm.

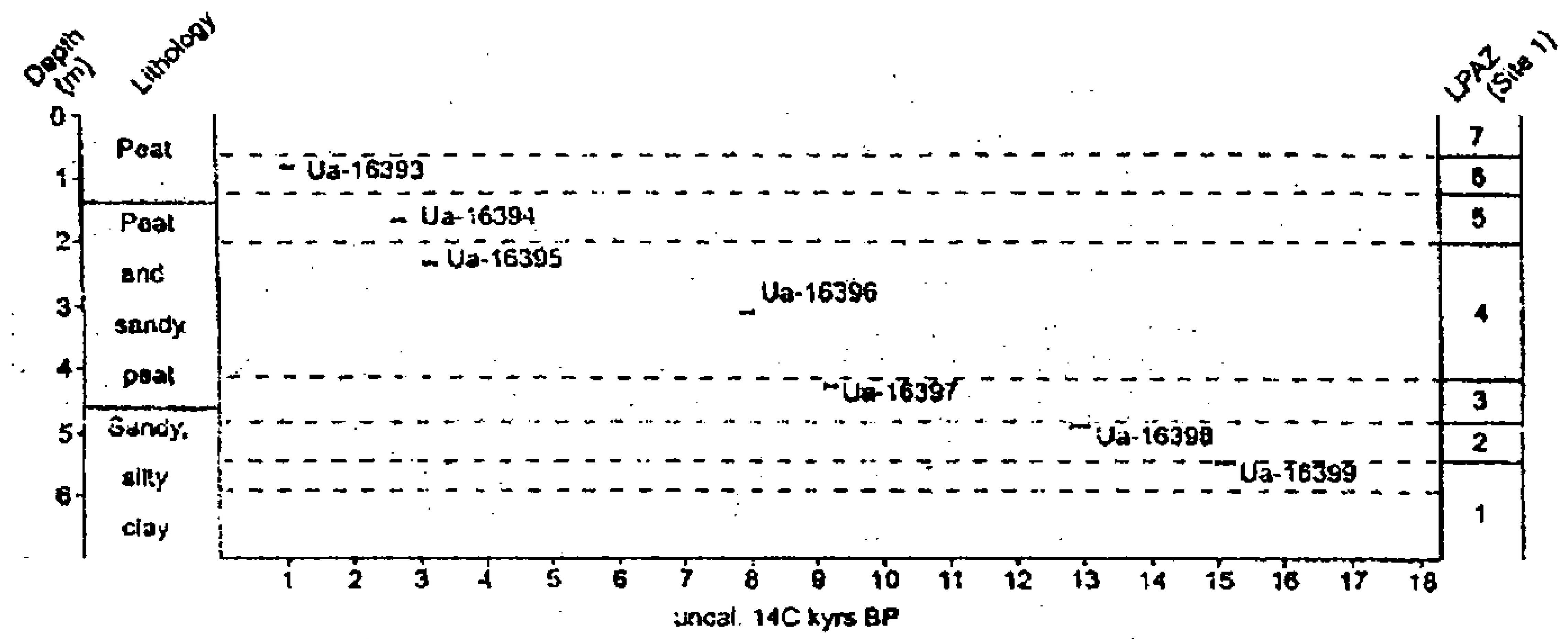


FIGURE 7: Age-depth relationship for Site - 1.

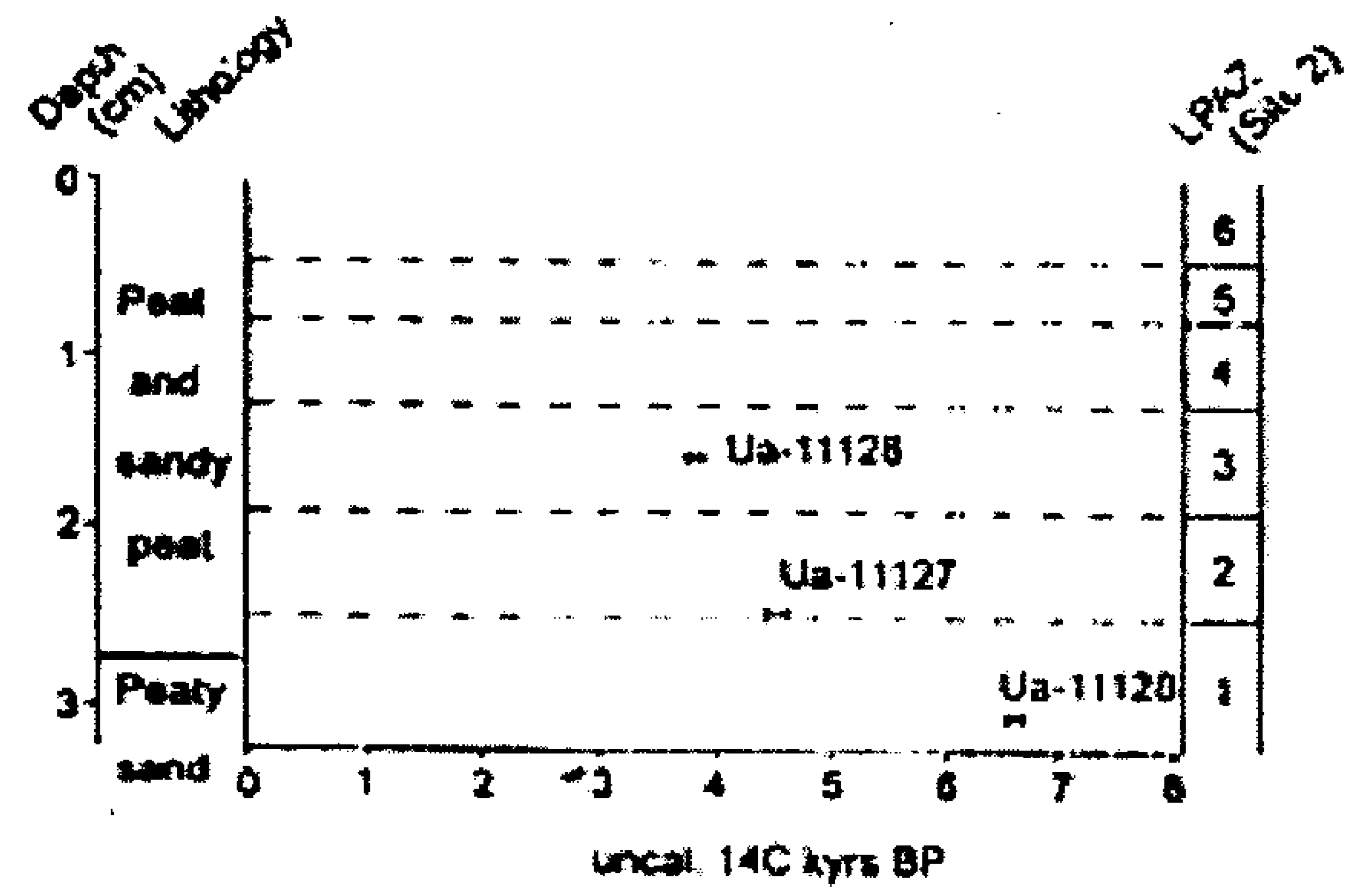


FIGURE 8: Age-depth relationship for Site - 2.

aquatichygrophytic species and appearance of xerophytic shrub taxa. The presence of taxa such as Michelia nilagirica, Acer caesium and *Terminalia* sp. indicates that the climate was dry and cool from about 14,200 to 12,200 BP, while the occurrence of low and upper montance deciduous tree taxa, e.g. Prunus sp., suggests that the regional vegetation contained a diversity of (evergreen-deciduoud) ixed forest elements indicating low precipitation.

The observations of "uncertain" cereal pollen types around 14,000 BP do not necessarily point to cereal cultivaion, as the grains may have been derived from wild progenitors of potential domestic Poaceae. Alternatively, these may have grown as a (weed) component among other grrasses. The sharp fluctuations in the curve for woody forest taxa indieate a succession in the vegetation, which might be the reslt of a close relationship between prehistoric humans and the prevailing climate. The appearane of seccondary forest taxa, *e.g. Olea* sp., and *Ligustrum* spp, indicates severe deforestation, and members of the *Impatiens* spp, *Rubus* spp and *Cardamine african* group will have profited from the forest clearance. *Crotalaria* spp, *Polygonum chinese, Ocinum* spp and Labiatae (*Leucus* spp) represent evidence of grazing, while Buchanania axillaris, which is edible, was probably introduced by humans. The occurrence of *Plumbago zeylanica,* the field weeds

Amarantaceae/*Achyranthes aspera* and Drymaria diandra emphasize the anthropogenie signal (Dassanayake and Clayton 1997). The high percentage of microscopic charcoal particcles may have orginated from domestic fires. The 487cm level is dated to 12,970 ± 115 $^{14}C$ yr BP.

LPAZ 3 (12,500 - 9000 BP, 478-41cm) features relatively low pollen concentration values are as compared with zone 2. The increase in Syzygium spp, Adinandra Iasiopetala, Oldelandia sp., Gaultheria sp. and Strobilanthes spp marks an abrupt rise in precipitation from around 12,500 to around 11,750 BP. This interpretation is in good sgreement with the high values for aquatichygrophytic plants (30%)

During the period 11,750 - 10,500 BP the woody forest plants decrease, indicating a cooling phare of the climate. The pollen evidence, with significant occurrences of Rhodoendron arboreum, Poaceae and Scrophulariaceae, and the aquatic and hygrophytic taxa also decrease, suggesting a dry environment. Then, from 10.500 to around 9000 BP, the rain forest taxa increase, suggesting an expansion of the woody vegetation under humid climatic conditions. The significant occurrences of Laurembergia spp, Cyanotis spp, Impatiens walkeri, Erioculon brownianum and Anotis spp support this.

The relatively high values for the pollen of field weeds may indicate human activities of either local or extra-local origin, while the low but significant percentages of *Indigofera* spp probably reflect grazing. A slight decrease in the woody vegetation in the lowermost part of the zone indicates small-scale forst clearance in the vicinity of the sampling site. The minor occurrences of *Rubus* spp and *Osbeckia* spp suggest that human influence is of limited character, but the high values for microscopic charcoal (65%), togerther with the comparison of the pollen spectra, indicate that there was some human presence in the area. The 420cm level was dated to 9125±80 $^{14}C$ yrs BP.

LPAZ 4 (9000 - 3000 BP, 412-200cm) is characterized by an almost continuous curvw for Poaceae pollen of the cultivated type. There are several significant variations in the composition of the natura, vegetation within this zone, however, and therefore it has been divided into six sub-zones (A-F).

The appearance of *Euodia* sp., *Lithocarpus* spp and deciduous taxa, *e.g. Celtis cinnamomea,* in LPAZ 4A (9000 - 8,750 BP, 412-386 cm) suggests that the regional vegetation consisted of a high diversity of mixed evergreen-deciduous forest elements, *i.e.* a temperate rain forst. The organic carbon content increased, displaying a peak of about 10%.

Major forest elements, e.g. *Syzygium* spp, decrease in this sub-zone, indicating forset clearance, while the ccultivated *Hordeum*-type pollen (25%) and field weeds provide the oldest signs of cereal cultivation, dated to approx. 9000 BP. The high percentages of microscopic charcoal particles probably originate from fires used for foreset clearance, an interpretation supported by the occurrence of secondary forset taxa. As a result of the forest clearance, *Ocimum* spp and *Asparagus* sp. indicates grazing.

In LPAZ 4B (8, 750 - 8000 BP, 385-340 cm), the first appearances of *Eugenia maboides, Isonandra montana, er caesium* and *Amentotaxus* sp. indicate an expansion of montane temperate rain forests. This interpretation is supported by the first immigration of *Atalantia rotundifolia, Smilia* spp, *Piper* sp. and *Cuscuta* sp. Aquatic and hygrophytic taxa increase to 30% confirming high preipitation. The increased precipitation can be correlated with the inwash of sand to the sampliing site. In the uppermost part of the zone, aquatic and hygrophytic plants show an abrupt decrease, suggesting a dry climatic event.

The occurence of *Hordeum*-type pollen indicates cereal cultivation, and the concurrent high values for this and microscopic charcoal suggest that the land area had was used for cultivation around 8000 BP. The mirosccopic charcoal particles probably originated from forest clearance, or alternatively from domesti fires situated far away from the coring site. This interpretation is supported by the secondary forst. The minor *occurrences of Osbeckia* walkeri, Labiatae (*Leuca* spp), *Cardamine african* and *Polygonum chinese* indicat that forst clearance had taken place, while *Ocimum* spp, *Urena* sp. and meadow plants are evidence of grazing.

The increases in *Syzygium* spp, *Eugenia mabaeoides, Symplocos* spp, *Elaeocarpus spp, Glochidion coreaseum* and *Psychotria* spp, Glochidion coreaseum and Psychotria spp in LPAZ 4C (8000 - 7000 BP, 340-296cm) indicate a rise in precipitation, an intepretation supported by the significant occurrence of mallotus walkeri, Strobilanthes spp and Rapanea robustata. Aquatic and hygrophytic pollen values increase, confieming the wetness of the environment. As a result of the high-energy environment, pollen concentration and the organic carbon content decrease significantly.

The occurrence of *Hordeum*-type pollen and the high values for microscopic charcoal are inerpreted as resulthing from cultivation. Likewise the occurrence of *Indigoferra* sp., *Rubs* spp, *Sarcococca zeylanica* and *Mimosa* sp. indicates grazing and forest clearance. The 305cm level was dates to 7935 ± 80 $^{14}$C yr BP.

Pollen concentration values decrease rapidly in LPAZ 4D (7000 - 6000 BP, 296-278 cm), indicating a ry climate. The gradual decreases in *Syzygium* spp, *Eugenia mabaeoides, Psychoria* spp, *Symplocos* spp and *Adinandra lasiopetala* suggest a reduction in prcipitation, whicch is supported by the decreases in *Ilex* spp, *Strobilanthes* spp, *Oldelandia* spp and ericaceous taxa, *e.g. Gaultheria fragrantissima.* The occurrence of *Acer caesium, Michelia nilagirica* and *Celtis cinnamimea* indictes cool, dry conditions. *Hordeum*-type pollen and high values for microcopic charcoal particles suggest that the land has been usedfor cultivation.

LPAZ 4E (6000 - 4500 BP 278-253 cm) has extremely low pollen concentration values. Only a few pollen grains (1-5 grains) of tree taxa such as *Ilex* spp *Elaeocarpus* spp, and *Adinandra lasiopetala,* and herbs such as *Stroblianthes* spp, *Phylanthes* spp, Poaceae, Asteraceae and Cyperaceae are observed. The surfacce characters of the exine on most of the pollen grains were not clear (*e.g.* very faint colour) and the exine fairly obviously ruptured and bent. The lack of pollen grains in this zone can probably be ascribed to aribity, causing unfavourable edaphic conditions for preservation. The organic carbon content is low, *i.e.* indicative of an oxidizing depositional environment in which the pollen grains would have been destroyed.

Montane rain forest taxa, *e.g. Syzygium* spp and *Elaeocarpus* spp predominate in LPAZ 4F (4500 - 3000 BP, 253-200 cm), indicating an increase in precipitation. The first appearances of *Canarium* sp., *Ixora* sp. and *Turpinia* sp. conditions, and the significant representation of shrubs, *e.g. Rapanea robustata* types, *Eurya japonica, Rhodomyrtus tomentosa* and *Chloranthes* sp., support this interpretation. The large amounts of pollen from aquatic and hygrophytic plants also show that wet conditions had prevailed. The first appearance of mosses (*Sphagnum* spp) clearly indicates that a change in chemical status within the mire, a lowering of the pH and a high groundwater table reaching close to the mire surface.

The minor occrence of *Hordeum*-type pollen and the high percenage of microscopic charcoal particles suggest that the land surface was used for cultivation. The appearance of *Osbeckia walkeri, Memecylon* spp, Labiatae (*Leucas* spp), *Polygonum* spp indicates forset clearances, while grazing is evidenced by the presence of *Crotalaria* spp and *Occimum* spp. One possible reason for the decrase in cereal cultivation may have been the high precipitation. The 230cm level was dated to 3120±70 $^{14}$ yr BP.

In LPAZ 5 (3000 - 2000 Bp, 200-125cm), the decrease in montane rain forest taxa (*Calophyllum walkeri, Isonandra montana, Ixora* sp. and

*Euodia* sp.) indicates a cooling trend, as supported by the first appearances of *Codiaeum variegatum* and *Microtropis* sp. The general reduction in shrubs, *e.g. Eurya japonica,* suggest a decrease in precipitation. There is a clear change in lithology (at 140cm) from sady peat to herbaceous peat, indicating a lowering of the temperature. The 160cm level has been dated to 2675±60 $^{14}$C yr BP.

The significant reduction of montane rain forest taxa (*Syzygium* spp, *Elaeocarpus* spp, *Euonymus revolutus* and *Adinandra lasiopetala*) in LPAZ 6 (2000 - 800 BP, 125-65cm) indicates a decrease in precipitation, and is in agreement with the significant occurrene of *Wikstroemia canescens, Andrographis* sp. and *Justica* sp. The first appearances of *Arisaema leshenautii, Bryophyllum* sp., *Oenothera* sp., *Agrimonia* sp., *Elatine* sp. and *Disacus* sp. suggest that have cooler climatic conditions have prevailed. The dryness of the environment is reflected by the marked decrease in shrub vegetation, *e.g. Strobilanthes* spp, *Eurya japonica* and *Viburnum coreaceun*, supported by a reappearance of Amoaranthaceae/*Acchyranthes aspera.* The minor occurrence of *Triticum*-type pollen in the lowermost part of the sub zone and the high values for microscopic charcoal are evidence for human activities, probably some distance away from the site. Evidence of forest clearance and razing spp, *Cardamine african* and *Indigofera* sp. The 80cm level was dated to 1025±70 $^{14}$C yr BP.

In PPAZ 7 (800 - 200 Bp, 60-14cm), the vegetation composition (*e.g. Syzygium* spp, *Calophyllum walkeri, Symplocos* spp and *Adinandra lasiopetala*) reflects a slight increase in precipitation *Strobilanthes* spp, *Rapanea robustata, Rhodomyrtus tomentosa, Smilax* spp and *Juncus* spp are dominant in the middle of the zone, indicating relatively high precipitation. This is supported by the abrupt increase in aquatic and hygrophytic taxa, *e.g.* Cyperaceae, *Laurembergia* spp and *Cyanotis* spp The composition of the vegetation in the uppermost part of the zone (*Acer caesium, Lithocarpus* sp. and *Elatine* sp., *Achyranthes aspera* and *Mollugo* sp.) suggests a decrease in precipitation.

The occurrence of Triticum-type pollen (6%) and the high percentage of microscopic charcoal particles (around 85%) are evidence of human activity. The significant appearance of *Berberis* sp. and *Nandina domestica* together with *Triticum*-type pollen could be interpreted as an *Triticum* cultivation. The woody components of the forest vegetation decrease in the middle of the zone, reflecting a consequence of interaction between humans and the forest. *Sarcococca zeylanica, Rubus* spp and *Indigifera* sp. are evdence of forest clearance and grazing.

**Mineral magnetic analyses**

The low ARM/SIRM rations, remaimning at 0.05 for the entire ccore apart from the uppermost 40cm. where the values reach approx. 0.075, indicate that all the material is of detrital origin. Similarly, the low SIRM/$\chi$ ratios point to a coarse, multidomain character for the magnetic grains (Fig. 9). The core can be divided into three main magnetic units based on variations in magetic concentration (as reflected by $\chi$, ARM and SIRM) and variations in magnetic mineralogy (as reflected by the S-ratio).

Unit 1 (600-529cm). The lowermost unit, which consists of clayey, silty sand, is characterised by extremely low magnetic concentrations. This could probably be ascribrd to various degrees of dissolution of hardr magnetic grains, as reflected in the low S-ratios, indicating that ferrimagnetic minerals (e.g. magnetite) are dominant (fig 9, lower part of unit 1). These minerals are likely to from under dry/arid conditiond, when a low groundwater table allows oxygen to penetrate deep into the soil. The lithological change from kaolinite to black organic-rich silty clay at 560 cm and the increase in the S-ratio from -0.8 to 0 are suggestive of anti-ferromagnetic minerals, i.e. hematite. This unit corresponds to a natural environment with little or no anthropogenic activity in the vicinity.

Unit 2 (529-87cm). This unit consists of alternating layers of peat and sandy peat and has higher overall magnetic concentrations than the previous one. It has very consistent S-ratios, confined to an interval of 0.03, with only a few outlying values, indicating the presence of a hard magnetic component in the magnetic assemblage. The unit has been divided into three sub-unit (2a-2c, from older to younger). Periods with low or relatively low magnetic concentrations are marked with a grey shade in the sediment, whereas periods with high value, or relatively high values, are white. in sub-unit 2a higher and lower magnetic concentrations alternate over relatively long periods, while in sub-unit 2b the periodicity seems to be considerably shorter and a number of prominent short, high peaks can be identified sandwiched in between periods with lower concentrations. The uppermost sub-unit, 2c differs from the previous two in that magnetic concentrations are generally stable but at a lower level, with only two shorter periods of slightly higher values.

Unit 2a corresponds to the phase of prefarming activities as deduced from the pollen analyses. The initial increase in $\chi$ ARM and SIRM is probably the result of major forest clearance, resulting in an increase in the inwash of minerogenic particles. Unit 2b corresponds to the cultivation phase, when the variations in SIRm in oarticulture pattern. When these activities come to an end, at the 2b/2c boundary, all the concentration curves display a uniform pattern.

Unit 3 (87cm - top of core)

The magnetic concentrations are again higher in this unit than in sub-unit 2c. Particularly prominent is the significant increase in the values of the ARM parameter, which is also reflected in the ARM/SIRM ratio. This most probably reflects a change in the magnetic soure, as is also represented by the gradual drop in the S-ratio within this unit. The increase in ARM may have been caused by sub-recent potato cultivation. In general, it seems as if the variations in magnetic concentrations reflect human activities and not variations in precipitation. This is seen as only one possible correlation between increased precipitation, as deduced from the pollen assemblages, and enhanced magnetic concentrations (at 430 cm).

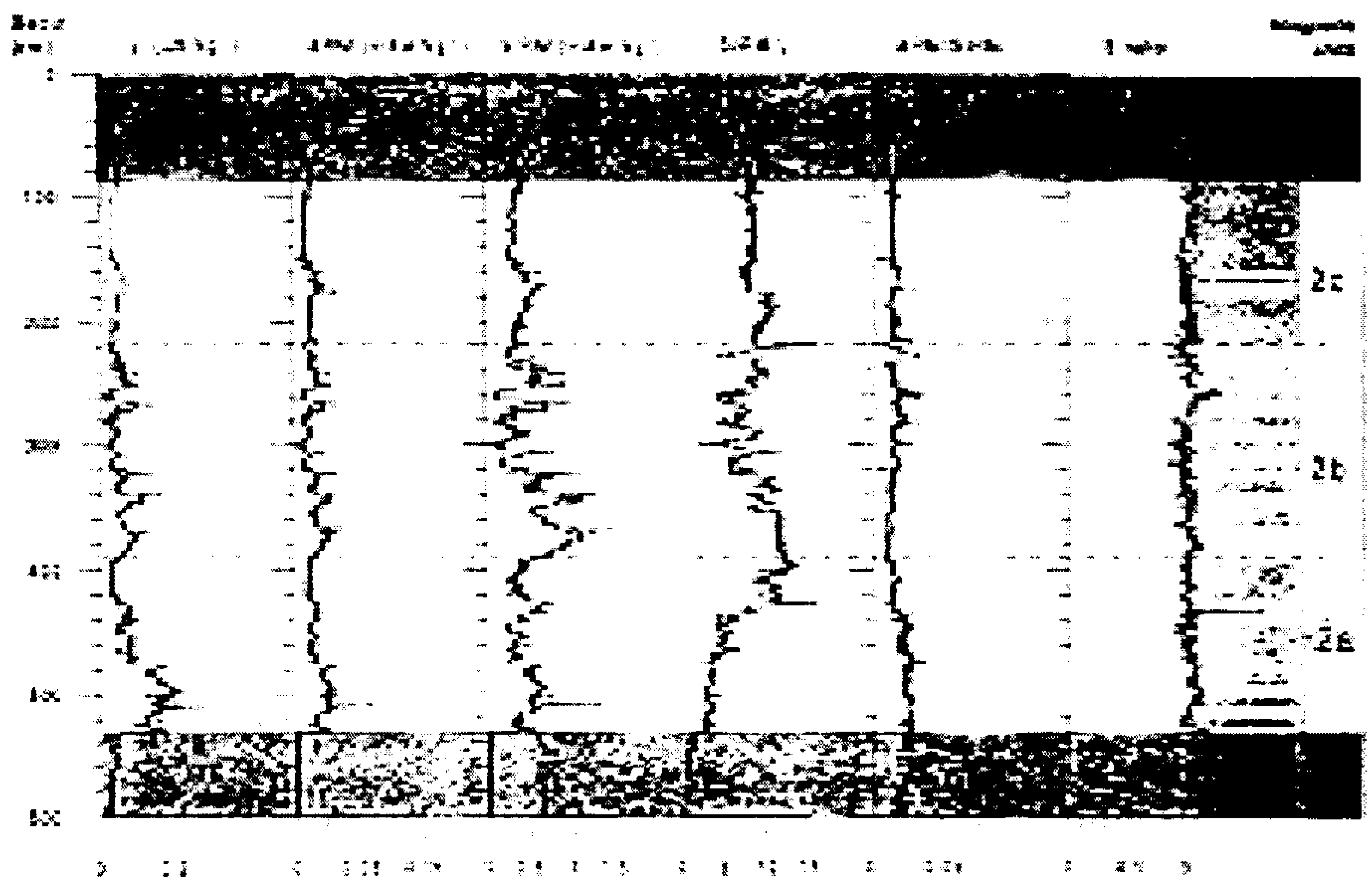

FIGURE 9: Mineral magnetic concentrations and ratios for Site 1. Magnetic unit 2a corresponds to the pre-farming culture (LPAZ 2 and at Site 1) and unit 2b to the cultivation phase (LPAZ 4 at Site 1).

## Site 2

The pollen diagram for Site 2 may be divided into 6 local pollen assemblage zones (Fig. 6). Pollen concentration values in LPAZ 1 (>5000 BP, 330-256 cm) are low, and the significant occurrences of Poaceae and *Michelia nilagirica* pollen indicate dry, cool climatic conditions. This matches with a decline in humid forest species, *e.g. Syzygium* spp, and the appearance of xerophytic taxa, e.g. *Chelianthes* sp., suggesting an open forested landscape with scattered occurrences of *Michelia nilagirica*. Asteraceae and *Peucedanum* spp predominate as a result of the cool, dry climate, while the organic carbon content has decreased to around 2%. There are no indications of human activities that affected the vegetation. The 310cm level yielded a date of 6610 ± 45 $^{14}$C yr BP.

The increment in rain forest pollen, e.g. Syzygium spp and Psychotria zeylanica, in the lowermost part of LPAZ 2 (5000 - 4000 BP, 256-190 cm) indicates a change towards a climatic situtio n with high precipitation. The increase in peteridophytes and theappearance of *Piper* sp. support this. The organic carbon content increases slightly as a result of the wet conditions. The aquatic pollen taxa *Laurembergia* spp and Cyperaceae decrease in the middle part of zone 2, indiating a short event with dry conditions, tentatively dated to around 4000 BP. The local vegetation is marked by a relative increase in meadow species. The 245cm level has been dated to 4550±90 $^{14}$C yr BP.

A minor occurrence of cultivated *Hordeum* sp. pollen around 4200 BP together with high percentages of microscopic charcoal particles clearly indicate cereal cultivation some distance away from the coring site. Small-scale forest clearance is indicated by the minor presence of *Osbeckia* spp pollen, but the chain fern, *Woodwarkia* sp. (Pteridaceae), evidently survived in the gorges or barrancos when the ferset was cleared. *Dicranopteris* sp. (Pteridaceae) spores indicate the presence of man-made clearings, trails and roadsides (Camus *et al.* 1991).

The significant increase in pollen of *Syzygium* spp, *Glochidion coreaceum* and *Rhododendron arboreum*, representing humid forest, in LPAZ 3 (4000 - 3000 BP, 190-135cm), indicates an abrupt rist in precipitation, culminating around 3000 BP. It appears that a warm, temperate climate prevailed. At this time, and the zone is characterized by a high abundance of pollen of the aquatic taxa Cyperaceae and *Laurembergia* spp, supporting the notion that.the hydrology in the mire altered towards wetter conditions. Spore of *Sphagnum* sp. indicate a lowering of the pH, *i.e.* a change from a meadow towering a mire (*cf.* Schimper 1964). The 170 cm level was dated to 3865±80 $^{14}$C yr BP and has an organic carbon content of 9%.

The forest composition changes dramatically at the zone 3/4 boundary. A number of pollen taxa disappear, probably because human activity in the area decreased. Most of these three taxa re-appaer in the upper part of zone

3, but with low perceentages, possibly in response to a short re-visit by man. Anthropogenic pollen representation is relatively low, but minor occurrences of cultivated *Hordeum*-type pollen may indicate scattered, occasional cereal cultivation around 3000 BP.

As far as <u>LPAZ 4</u> (3000-2000 BP, 153-78 cm) is concerned, precipitation around 2500 BP may be considered relatively low by comparsion with the zone 3, as indicated by pollen of *Prunus* sp. and *Rubus leucocarpus*, which perfer open, sunny places and cleared areas with an annual rainfall of around 2000mm/yr (Dassanayake and Fosberg 1981; Werner and Balasubramaiam 1992; Balasubramaniam *et al.* 1993). The decrease in *Glochidion* sp. and *Rhododendron arboreum* pollen also supports this assumption. The decline in aquatic and hygrophyte pollen indicates a dry climatic event.

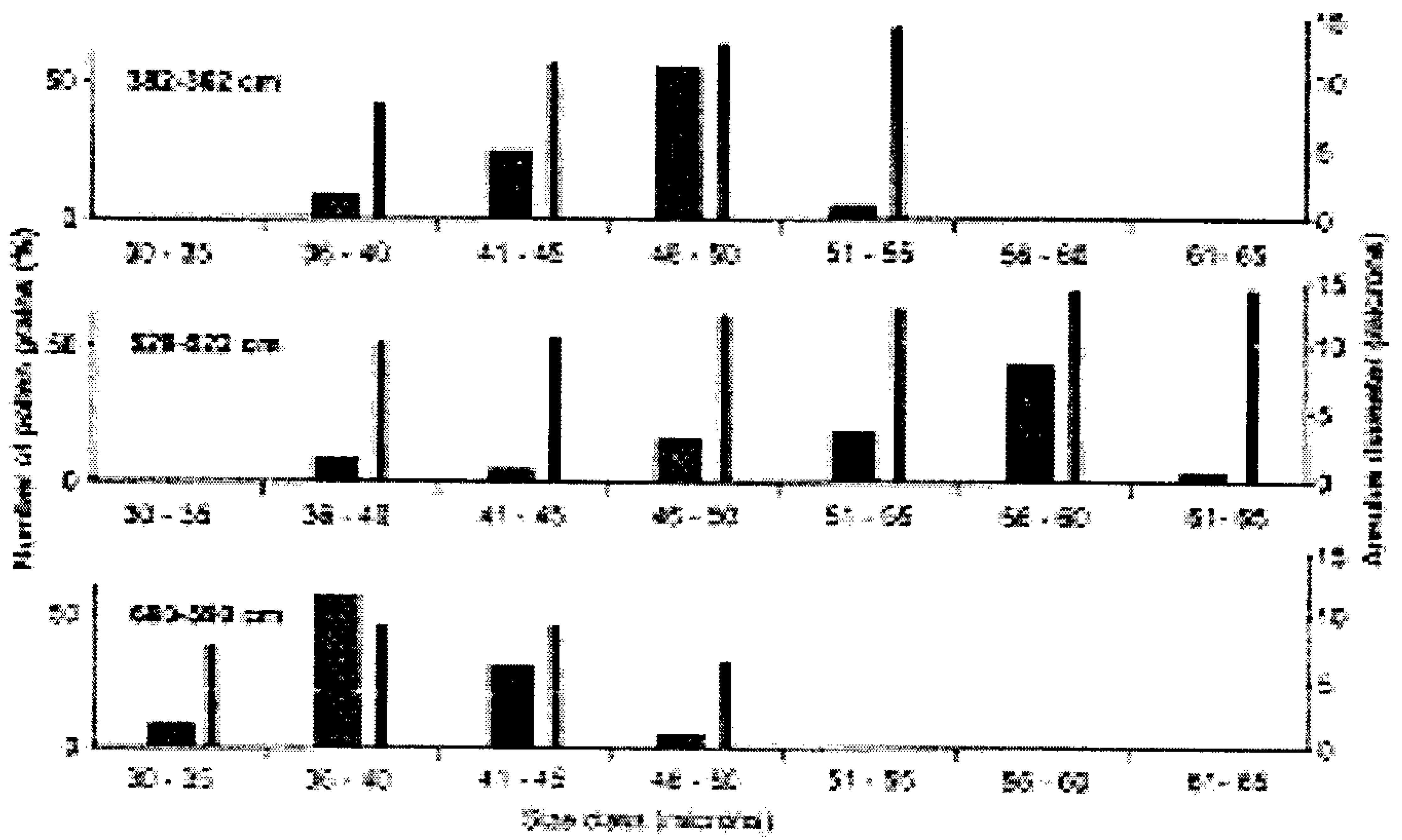

FIGURE 10:Statistical analyses of cereal-type pollen grains in three intervals betwee 600 and 362cm at Site 1. Stippled columns refer to size classes and solid columns to annulus diameter (in microns). n=150 for the lower and upper intervals (three slides each). n=100 for the middle interval (two slides).

The pollen composition of <u>LPAZ 5</u> (2000 - 1000 BP, 78-48cm) reflects a mixed deciduous and evergreen forest consisting of species such as *Micchelia nilagirica, Glochidion coreaceum, Prunus* sp., *Symplocos* sp. and *Psycchotria zeylanica* and indicaing a fairly humid, cool climate. The gradual increase in aquatic and hygrophyte pollen and Asteraceae (*Cerpis* spp) and *Peucedanum* sp. is also indicative of a humid, cool climate.

In LPAZ 6 (1000 BP - present, 48-0 cm), the composition of the pollen spectra is marked by an increase in humid forset species, e.g. Syszygium spp, *Glochidion coreaceum* and *Casearia* sp., suggesting a significant rise in precipitation towards the top of the diagram. The expansion of Strobilanthes spp, chloranthaceae and Cordia sp. reflected in the aquatic-hygrophytes, provides support for this.

The increase in the pollen of tree taxa in the uppermost part of LPAZ 6, i.e. since about 3000 BP, indicates more pronounced human activity and corresponds to "British Colonial Times", when humans indulged in hunting and subsequent increase in biotic pressure also contributed to the changes. The increasing proportions of Asteraçeae pollen (*Anaphalis* sp.) together with Peucedanum sp. support these interpretations.

**Comments on the appearancce of cereal type pollen**

As is evident from Fig. 10, the first appearance of cereal-type pollen is "uncertain" on the basis of the main criteria for judging the relationship between domestic or cultivated types and their wild ancestors, because of similarities in size and structure. The disteribution of the size measurements below 478 cm shows a continuty of two well separated groups (Fig. 10). Morphologically, the first cereal-type pollen at 529 cm in the diagram is close to the *Hordeum* and *Avena* types, with the pollen size of the *Hordeum* type being 40-50 $\mu$m and anil-D approximately 10 $\mu$m together with a sharp annulus margin and a single grain structure, and that of the Avena type 55-65 $\mu$m and anl-D approximately 15 $\mu$m, together with a double grains strucrture. Critical identification was an uncertain matter because the surface structures on mst of the grains had deteriorated greatly on account of corrosion, degradation, mechanical damage and thepresence of detritus. Nevertheless, the grain sizes and anl-D seem to show some relationship between the domestic and wild ancestors of these types. These pollen grains were identified as cultivated types (*Hordeum* sp., *Avena* sp. and *Triticum* sp.), since cultivated pollen grains are 45-65$\mu$m in diameter, with an annulus diameter of 10-14$\mu$m, in spite of the fact that they showed both single grain and double grain structures (*cf.* Beug 1961, Kohler and Lange 1979).

## DISCUSSION

**Stratigraphy and chronology**

The bedrock of the Horton Plains is granitic, making it likely that no carbon of infinite age has been incorporated in the peat. If affeceted, the bulk dates obtained from the sequences may show somewhat too young ages, as a result of downards penetrating humic acids and rootlets (*cf.* Olsson 1974, Possnert 1990, Risberg 1991). In order to calulate accumulation rates, linear interpolations were performed between adjacent radiocarbon dates. The uppermost date for Site 1 (Ua16398 and Ua-16399) were used for a linear extrapolation downwards. Even though only three dates were available for Site 2, the same procedure was adopted (Figs. 7 and 8).

The Site 1 sequence containd three distince sedimentary units: a lower sandy-silty clay (600-460cm), n intermediate unit with alternating sequences of sandy peat and peaty sand (460-139cm) and an upper one consisting of peat (139-0ccm). The uppermost part of the lower unit consosts of minerogenic particles mixed with organic material. The two radiocarbon dates obtained for this unit from in-washed weathered bedrock (sandy-silty clay) and bare soil, is of Late Pleistocene age. The bottom of the sequence is estimum (LGM) at 18,000 BP (*cf.* Overpecck *et al.* 1996). The two radiocarbon dates for the lower part of the intermediate straigraphical unit indicate rapid acumulation in the early Holocene (10,000 - 8000 BP), but it is obvious that the accumulation rate decreases abruptly in the middle part. The three uppermost radiocarbon dates again indicate rapid accumulation in the late Holocene (3000-0 BP).

The estimated variation in the accumulation rate at Site 1 between 0.2 and 1.6 mm/year (Fig. 7) can be explained by the input of sand in various proportions at times of high erosion and/or a fluctuating groundwater table. Peat started to accumulate, indicating mire development, at an age of approximately 11,000 BP, but the average accumulation rate is extermely low between 7500 and 3500 Bp (0.2 mm/yr), so that it is likely that one or more hiatuses are present somewhere within this interval. The low accumulation rate can be explained by climatic factors, i.e dry, cool conditions prevailed, oxidizing the organic material. An alternative possibility is that the meandering brooklet passed through the coring site, so that little or no accumulate, in fact stream-bed erosion would have been more probable. The accumulation rate for the Site 2 sequence is estimated to have varied between 0.3 and 1.1 mm/year (Fig. 8). The bottom of the sequence is dated to around 6500 BP, with no organic material to be oxidized. Another possible reason is that the valley inclination in relation to the lower threshold in the south did not allow enough water to be retained to permit the accumulation of organic matter, i.e. the ground-water table was too low.

## Palaeoclimate

The sequences analyzed provide a framework for describing the Late Quaternary palaeovegetation of the elevated in it (Fig. 11). The most significant changes are: (1) the initially low proportion of forest, which declines until 15,000 BP, (2) a general increase in the forset, culminating around 7000 BP, (3) a forest decline ending around 5000 BP and (4) fluctuations in forest growth from that time onwards.

The dry, cool (arid) climate prevailing between 17,500 and 15,000 BP (LPAZ 1, Site 1) suggests a weakening of the south-west (summer) monsoon (SWM) in Asia and a strengthening of the north-east monsoon (NEM), resulting in a net reduction in presipitation. This period was accompanied by cool global temperatures (Sukumar *et al.* 1993). The evidence of aridity during the LGM and the Late Pleistocene in the Horton Plains has many parallels in other parts of the Indian subcontinent (*cf.* Vasanthy 1988; Singh *et al.* 1990; Sukumar *et al.* 1993; Sukhija 1998, Andrews *et al.* 1998), and the weakening of the monsoon circulation during the LGM is also amply supported by pollen Sea (Van Campo 1986, Overpeck *et al.* 1996). Similar records of comparable age in the Sumatra and Java highlands, Indonesia, indicate arid climatic conditions (Stuijts *et al.* 1988, Hope and Tulip 1994, Kaars *et al.* 2000), and comparable climatic variations have been observed in pollen records from southern, eastern and central Africa convering the same time span (Maitima 1991; Scott 1989; Bakker and Coetzee 1988)

The vegetational cmposition at about 15000 BP (LPAZ 1/2 boundary, Site 1), suggests that precipitation and the mean temperature both increased slightly. This event, ending 13,500 BP, could have been caused by a sttrengthening of the monsoons. Overpeack *et al.* (1996) suggest that the SWM was weak unitil around 13,00 - 12,500 BP, while Sukumar *et al.* (1993) and Van Campo (1986) report that it reached a peak close to 11,000 BP. My results indicate that the monsoon reached a sligh peak at 13,500 BP, possibly as a result of the strengthening of the NEM. As the values for Amaranthaceae/*Achyranthes aspera* and Asteraceae (a winter rain taxon) are much higher in LPAZ 2 (Site 1) than at present, it appears that the aridity was probably caused by a decline in SWM precipitation and that NEM precipitation (in winter) was probably higher then at present

The establishment of xerophytic woodlands during the preiod 13,500 - 12,200 BP (uppermost part of LPAZ 2, Site 1) indicates a decrease in precipitation. This matches with the weakening of the SWM at this period,

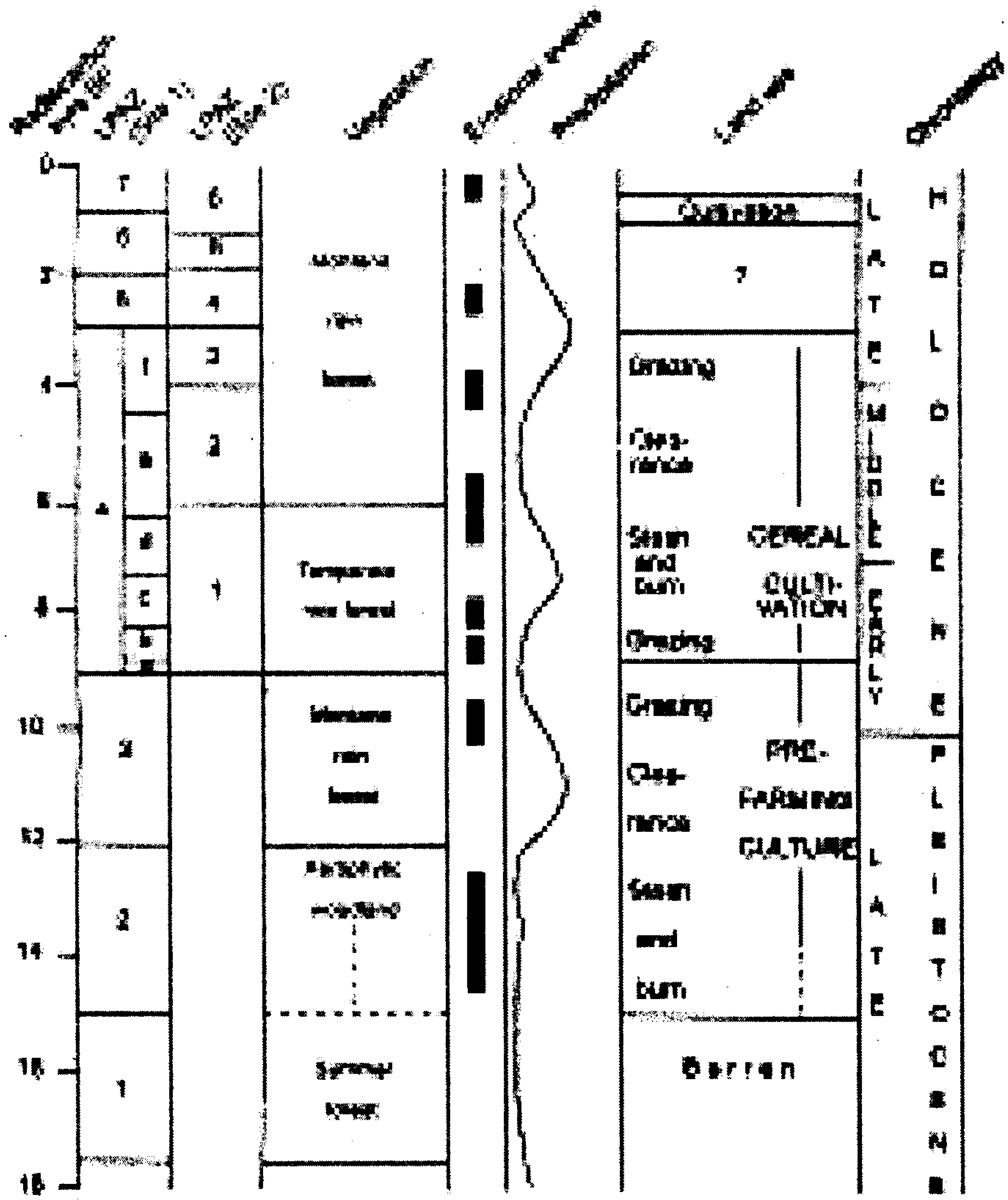


**Figure 11: Compilation of data from Sites 1 and 2**

as described by Singh *et al.* (1990), Sukumar *et al.* (1993) and Overpeack *et al.* (1996). Kealhofer and Penny (1998) reached the same conclusion when desccribing a diversification of the dry land forest, as identified by pollen and phytolitths, in a lake in north-eastern Thailand. The spread of humid forest, e.g. *Syzygium* spp, after this period indicates an increase in SWM rainfall and high mean temperatures around 11.800 BP. These results agree quite well with the palaeoclimatic data presented by Overpeck *et al.* (1996), Van Campo (1986) and Sukumar *et al.* (1993) concerning the simultaneity of the maximum monsoon iintensity.

The decline in the rain forest around 10,000 BP (LPAZ 3 Site 1) points to a cooler climate and a reduction in precipitation. Van Campo (1986) mentions the expansion of mangrove forests in southwest India as indicating a decrese in monsoonal rainfall after 11,000 BP, and this has also been wivwly recognized elsewhere. A similar effect on early Holocene climatic events has been observed in reconstructions of the monsoon climate (Sukumar *et al.* 1993, Sukhija 1998)

The significant exoansion of the temperate montane rain forest during the period 10,000 - 7300 BP suggests a general increase in presipitation (LPAZ 4 A-C, Site 1), but this period is followed by minor fluctuations in woody, aquatic and hygophytic vegetation types, pointing to several dry, cool episodes (Fig. 5). This observation is consistent with a strengthening of the SWM and higher mean temperatures for this periodd, suggesting cool, arid to semi-arid conditions in the central and westers parts of the Indo-Gangetic Plains (Sukumar *et al.* 1993, Srivastava *et al.* 1998, 1998). The transition from an arid period to a humid one around 12,000 - 8000 BP has been discussed by Sukhija (1998). Dry climatic conditions were observed in eastern Nepal around 11,000 BP by Yonebayashi and Minaki (1997), and our observations concerning a trens towards increased precipitation are in good agreement with these results.

The period between 7300 and 6000 BP is marked by a gradual decrease in the montane rain forest, indicating a progressively arid climate. This trens is clearly taken up by the decline in humid forest between 6000 and 4500 BP on account of a significant reduction in precipitation (LPAZ 4D-E, Site 1, and LPAZ 1, Site 2). The composition of the vegetation in precipitation was limited until around 5000 BP, although arid climatic conditions were recorded on the Indian subcontinent around 6500 BP and during the period 5000 - 3000 BP (Sukumar *et al.* 1993; Srivastava *et al.* 1998). Our observations concerning the weakening of SWM over the central part of

Sri Lanka are in quite good agreement with the lake level decline and/or glacial advance in eastern Nepal between 11,000 and 1600 BP reported by Yonebayashi and Minaki (1997).

The gradual increase in rain forest indicates a progressive trend in monsoonal rains cluminating around 3000 BP (LPAZ 4F, Site 1, and LPAZ 3, Site 2), the subsequent fluctuations in the rain forest (LPAZ 5/6, Site 1, and LPAZ 4/5, Site 2) indicating alternate periods of weakening and strengthening of the monsoon rains until about 800 BP. This was followed by alternating cool and dry climatic episodes. Bonnefille and mohammed (1994) have reported cooler climatic conditions in the mountains in southeastern Ethiopia during the period 3000 - 2000 BP, and most of the palaeoclimatic records from Nilgiris suggest cool or dry episodes in the same period (Vasanthy 1988). The general increase in humid forests nebertheless indicates a trend towards higher precipitation after this, and the relatively high abundance of rain forests between 800 and 500 BP likewise suggests a slight increase in monsoon rainfall (LPAZ 7, Site 1, and LPAZ 6, Site 2).

**Land-use history**

The first indications of human impact in the pollen diagram, dated to around 14,000 BP, consist of pronounced fluctuations in arboreal and non-arboreal taxa and imply severe deforestation, forest clearance and grazing. The occurrence of pollen of *Plumbago zeylanica* (LPAZ 2), which is a very characteristic species in anthropogenic localities, also indicates the presence of humans. Yhis species could have been introduced by humans migrating from the lowlands to the highland ares, as it occurs today in the vegetation of the lowland area.

The occurrence of an "uncertain" ceral-type pollen taxon can be discussed in the context of the process of domestication of cereal plants. The identification of such grains as cultivated types is uncertain and must be based on a number of criteria, as the process of domestication has played a very central role in the development of pre-historic social environment and the material culture of prehistoric man. Archaeological and historical data obtained from the Horton Plains suggest that the area was subjected to fires and grazing (Pearson 1899; de Rosayro 1946; Chapman 1947; Holmes 1951; Szechowycz 1954; Koelmeyer 1957; Manathunga 1994), and there is evidence of the presence of pre-historic man in the form of microlithic stone artefacts close to the sites studied here (Deraniyagala 1971, 1992). The pollen records of the sequesces analzed provide valuable information for the understanding of the diversity of the human culture that prevailed around 14,000 BP (cf. LPAZ 2 at Site 1). According to the size measurements and their statistical analysis (Fig. 10), the uncertain cereal-type pollen grains seem to be close to *Avena* and *Hordeum* sp. (Beug 1961), but the arrangement of collumellae on the pollen grains from the two lower sequenses analyzed are indistinet relative to typical cultivated *Hordeum* and *Avena* sp. This means that they may be derived from wild progenitors of potentially domesticable *Hodeum*-sp and *Avena*-sp plants growing within the vegetation of the Horton Plains. At this early stage such plants may have been growing as weeds among other grasses. This argument is not contradictory, because grass taxa belonging to the tribe of *Aveneae* and *Hordeae* are represented in the present vegetation of Horton Plains. These could have sered as "primary sources" of genetic variability (wild types) for the domesticated *Hordeum* and *Avena* sp. which appear later in the sequence. This idea is furthermore supported by Trimen and Hooker (1890) and Senewiratna nad Appadorai (1989). who discovered wild grasses in the mountainous area of Sri Lanka, notably *Oryza* sp. and some other types. The basic requirements for the domestication process, e.g. a mild, dry climate, burning of the forest, the presence of human beings and a diverse landscape, as maintained by Redman (1988), were available in the Horton Plains aroundd 14,000 BP.

Singh (1971, 1990) has argued that the palaeoenvironmental changes between 14,000 and 13,000 BP were especially suitable for the above process. Acording to the theory of domestication and the origin of plant agriculture, Michaels (1999) suggests that the first "agriculture" took place in Taiwan around 12,00 BC. The minrobotanical data (pollen and phytoliths) of Kealhofer and Penny (1998) suggest human/environment interraction in Thailand during the early Holocene. The burned phytoliths at the Late Pleistocence/Early Holocene boundary inddicate that people were involved in the burning of the forest. Pollen and microscopic records contained in a sequence from the highlands of Indonesia suggest that human activity started around 11,000 BP in the African mountains. The uncertain cereal-type pollen grains in our material, however, o not necessarily indicate that "cereal ccultivation" took place at 14.000 BP (LPAZ 2), although possible to treace a certain relationship in connecction with the process of heredity reorganization in wild and domestic plants that might represent the beginning of the process of domestication of *Hordeum* and *Avena,* possibly reflecting a preomitive stage of farming/pastoral cculture. It is in any case valuable to discss these "observations" regarding the transformation from wild plants to domestic ones. There is obviously a need not only for more extensive archaeological studies but also for further cytogenetic investigations, particularly comparisons of chromosomes and chromosome sets between the wild and domesticated strains of *Hordeum* sp. and *Avena* sp. Evaluation of the pollen data available in LPAZ 3 (Site 1) reveals that small-sccale human activities took place until about 10,000 BP. Grazing indicates that the pastoral activities were spread over the region, whereas arable activities were negligible. Gupta and Prasad (1985) have described an early stage of farming at around 10,000 BP based on the occurrence of Cerelea pollen in the southern Indian hills (Nilgiris).

The *Hordeum*-type pollen in LPAZ 4 A-F and the Avena-type pollen in LPAZ 4 A-B together indicate the first true cereal cultivation the was occurring around 9000 BP, accompanied by deforestation caused by human activities. Likewise the indicators of grazing suggest that pastoral activities continued together with corresponding results obtained in India. Swiddening in Rajasthan has been dated to 9500 BP and Neolithic agriculture at Koldihava, near Allahabad, to 8000 BP. Thr cultivation of rice at Koldihava and Babor has been dated to 7000 and 6400 BP, respectively (Singh 1971, Agrawal *et al.* 1975, Dhavalikar *et al.* 1988). During the period 6500-3000 BP the overall representation of cereal-type pollen is low, but stray finds together with indicators of forest clearance and grazing reveal that huaman interference continued until around 3000 BP (LAZ 4 D-F, site 1, and LPAZ 2/3, Site 2). These activities may have been carried out on a small scale and/or at an extraregional level.

The area seems to have been completely abandoned between 3000 and 800 BP, there are no records of arable farming in LPAZ 5/6 (Site 1) or LPAZ 4/5 (Site 2), but the occurrence of *Triticum* type pollen togher with small-scale deforestation, grazing and soil erosion during the period 800-200 BP provides evidence of a human impact on the environment. *Berberid* sp. and *Nandina domestica* (LPAZ 6/7, Site 1) indicate that the land area was used for *Triticum* cultivation, and it is possible that this started at a regional or extra-regional level and increased slightly at a later stage close to the sampling point. The increase in ARM at the very top of the core is probably the result of potato cultivation between 1950 and 1969. Traces of these activities can be seen in the from of terraces in some places along the valley slopes.

## CONCLUSION

The broad trens in the evoluton of the palaeoenvironmental seems to be captured in the peat sequences analyzed from the Horton Plains, which record the key climatic shifts and human activities from the LGM (18,000 BP) until the presents. The pollen records suggest an arid and relatively species-poor environment during the Late Pleistocene, with dry land forst (xerophytic woodlands) predominating. A at the end of that period anincrease in precipitation is recorded. Two significant phases of rain forest expansion (8000 - 7000 and 4000 - 3000 BP) suggest an increase in presipitation. In addition, an arid climatin phase is observed from 6000 to 5000 BP, and a short wet phase arouns 600 BP.

The frist indications of human impact are dated to around 14,000 BP, whwn extesive orest clearance and grazing can be traced in the pollen spectra. It is possible that the Horton Plains area may have acted as one of the ancestral homelands for cereal plants (*Hordeum* sp. and *Avena* sp.). A prefarming/pastorded from 14,000 to 10,000 BP, and the start of agricultural land-use is dated to around 9000 BP. Litle agricultural activity can be identified after 6500 BP until around 3000 BP. The area was then abandoned for some time, until it was used for small-scale *Triticum* cultivation between 800 and 200 BP. Potato cultivation took place between 1950 and 1969.

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