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

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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 charnockite-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.

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 bamboo. 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
herbaceous peat, underlain in most cases by weathered kaolinite bedrock. A
clayey, silty 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 situ 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
course roots, and rootlets manually. The samples were then treated with 1%
HCl 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 ±σ and a
normalization of δ¹³ C = -25 per mille against PDB was carried out. The
half-life (T½) is 5570 years. All ages stated refer to uncalibrated ¹⁴C 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-washed weathered bedrock is believed to have been transported only short distances.](image-url)
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 (1cm³), and chemical treatment included 10%HCl, 10% NaOH and 40% HF, acetolysis with 1 part of H₂SO₄ to 9 parts C₄H₆O₃ 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.

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

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.

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

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

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Lab. Nr</th>
<th>Fraction</th>
<th>Age yrs BP</th>
<th>δ¹³C</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Site 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>Ua-16393</td>
<td>INS</td>
<td>1025±70</td>
<td>-24.2</td>
<td>Peat</td>
</tr>
<tr>
<td>160</td>
<td>Ua-16394</td>
<td>SOL</td>
<td>2675±60</td>
<td>-23.0</td>
<td>Sandy peat</td>
</tr>
<tr>
<td>230</td>
<td>Ua-16395</td>
<td>SOL</td>
<td>3120±70</td>
<td>-25.7</td>
<td>Sandy peat</td>
</tr>
<tr>
<td>305</td>
<td>Ua-16396</td>
<td>SOL</td>
<td>7935±80</td>
<td>-18.1</td>
<td>Sandy peat</td>
</tr>
<tr>
<td>420</td>
<td>Ua-16397</td>
<td>SOL</td>
<td>9125±80</td>
<td>-18.6</td>
<td>Peat</td>
</tr>
<tr>
<td>487</td>
<td>Ua-16398</td>
<td>SOL</td>
<td>12.970±115</td>
<td>-25.5</td>
<td>Peaty sand</td>
</tr>
<tr>
<td>540</td>
<td>Ua-16399</td>
<td>SOL</td>
<td>15.045±140</td>
<td>-25.5</td>
<td>Org. clay</td>
</tr>
<tr>
<td><strong>Site 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>170</td>
<td>Ua-11126</td>
<td>SOL</td>
<td>3865±80</td>
<td>-26.2</td>
<td>Peat</td>
</tr>
<tr>
<td>245</td>
<td>Ua-11127</td>
<td>SOL</td>
<td>4550±90</td>
<td>-25.9</td>
<td>Peat</td>
</tr>
<tr>
<td>310</td>
<td>Ua-11128</td>
<td>SOL</td>
<td>6610±45</td>
<td>-21.3</td>
<td>Peat sand</td>
</tr>
<tr>
<td><strong>Road cut</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-43</td>
<td>ST-14039</td>
<td>INS</td>
<td>1320±60</td>
<td>-12.5</td>
<td>Sandy peat</td>
</tr>
<tr>
<td>40-43</td>
<td>ST-13783</td>
<td>SOL</td>
<td>2125±70</td>
<td>13.4</td>
<td>Sandy peat</td>
</tr>
<tr>
<td>53-56</td>
<td>ST-13782</td>
<td>SOL</td>
<td>6970±80</td>
<td>-14.6</td>
<td>Sandy peat</td>
</tr>
</tbody>
</table>
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 were shown as percentages of dry weight.

Mineral magnetic analysis

Sub-sampling for mineral magnetic analysis was performed at 1 cm intervals over the entire length of the core. The measurements were carried out at the Department of Quaternary Geology, Land University. Magnetic susceptibility (χ), 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 on 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-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 *Triticum*-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 constrained 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 14C 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. Elaeocarpaceae, Symlocos spp and Meliosma 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 arboresum, Gaultheria fragrantissima and Vaccinium symplocifolium, 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.
aquatic-hygrophytic 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 montane deciduous tree taxa, e.g. Prunus sp., suggests that the regional vegetation contained a diversity of (evergreen-deciduous) mixed forest elements indicating low precipitation.

The observations of "uncertain" cereal pollen types around 14,000 BP do not necessarily point to cereal cultivation, 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 grasses. The sharp fluctuations in the curve for woody forest taxa indicate a succession in the vegetation, which might be the result of a close relationship between prehistoric humans and the prevailing climate. The appearance of secondary 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, Ocimum 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 anthropogenous signal (Dassanayake and Clayton 1997). The high percentage of microscopic charcoal particles may have originated from domestic fires. The 487 cm level is dated to 12,970 ± 115 ¹⁴C yr BP.

**LPAZ 3** (12,500 - 9000 BP, 478-41cm) features relatively low pollen concentration values 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 agreement with the high values for aquatic hygrophytic plants (30%).

During the period 11,750 - 10,500 BP the woody forest plants decrease, indicating a cooling phase 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 walker*, *Ericoculun 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 forest 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%), together 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 ¹⁴C yrs BP.

**LPAZ 4** (9000 - 3000 BP, 412-200cm) is characterized by an almost continuous curve for *Poaceae* pollen of the cultivated type. There are several significant variations in the composition of the natural 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 cinnamonoea*, 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 forest. The organic carbon content increased, displaying a peak of about 10%.
Major forest elements, e.g. Syzygium spp, decrease in this sub-zone, indicating forest clearance, while the cultivated 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 forest clearance, an interpretation supported by the occurrence of secondary forest 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 Amenotaxus 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 precipitation. The increased precipitation can be correlated with the inwash of sand to the sampling site. In the uppermost part of the zone, aquatic and hygrophytic plants show an abrupt decrease, suggesting a dry climatic event.

The occurrence 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 microscopic charcoal particles probably originated from forest clearance, or alternatively from domestic fires situated far away from the coring site. This interpretation is supported by the secondary forest. The minor occurrences of Osbeckia walkeri, Labiatae (Leuca spp), Cardamine african and Polygonum chinese indicate that forest clearance had taken place, while Ocimum spp, Urena sp. and meadow plants are evidence of grazing.

The increases in Syzygium spp, Eugenia mabaeoides, Symlocos spp, Elaeocarpus spp, Glachidion coreaeusem and Psychotria spp, Glochidion coreaeusem and Psychotria spp in LPAZ 4C (8000 - 7000 BP, 340-296cm) indicate a rise in precipitation, an interpretation supported by the significant occurrence of mallotus walkeri, Strobilanthes spp and Rapanea robustata. Aquatic and hygrophytic pollen values increase, confiming 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 interpreted as resulting from cultivation. Likewise the occurrence of Indigofera sp., Rubs spp, Sarcococca zeeylanica 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 dry climate. The gradual decreases in Syzygium spp, Eugenia nabeoideas, Psychoria spp, Symlocos spp and Adinandra lasiopetala suggest a reduction in precipitation, which 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 indicates cool, dry conditions. Hordeum-type pollen and high values for microscopic charcoal particles suggest that the land has been used for 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 Strobilanthes spp, Phylanthus spp, Poaceae, Asteraceae and Cyperaceae are observed. The surface 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 aridity, 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 4E (4500 - 3000 BP, 253-200 cm), indicating an increase in precipitation. The first appearances of Canarium spp, Ixora sp. and Turpinia sp. conditions, and the significant representation of shrubs, e.g. Rapanoea 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 occurrence of Hordeum-type pollen and the high percentage 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 forest clearances, while grazing is evidenced by the presence of Crotalaria spp and Ocimum spp. One possible reason for the decrease 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, 200-125 cm), 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±60¹⁴C 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 occurrence 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 coreaceum, supported by a reappearance of Amoanthaceae/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±70¹⁴C yr BP.

In PPAZ 7 (800 - 200 Bp, 60-14cm), the vegetation composition (e.g. Syzygium spp, Calophyllum walkerii, 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 evidence of forest clearance and grazing.
Mineral magnetic analyses

The low ARM/SIRM rations, remaining at 0.05 for the entire core 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/χ 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 magnetic concentration (as reflected by χ, 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 ascribed to various degrees of dissolution of hard 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 form under dry/arid condition, 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 χ ARM and SIRM is probably the result of major forest clearance, resulting in an increase in the inwash of mineralogenic particles. Unit 2b corresponds to the cultivation phase, when the variations in SIRM in horticulture 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 source, 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).

![Mineral magnetic concentrations and ratios for Site 1](image)

**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, \textit{e.g.} \textit{Syzygium} spp, and the appearance of xerophytic taxa, \textit{e.g.} \textit{Chelianthes} sp., suggesting an open forested landscape with scattered occurrences of \textit{Michelia nilagirica}. Asteraceae and \textit{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 310\text{cm} level yielded a date of 6610 ± 45 \textsuperscript{14}C yr BP.

The increment in rain forest pollen, \textit{e.g.} \textit{Syzygium} spp and \textit{Psychotria zeylanica}, in the lowermost part of \textit{LPAZ 2} (5000 - 4000 BP, 256-190 cm) indicates a change towards a climatic situation with high precipitation. The increase in pteridophytes and the appearance of \textit{Piper} sp. support this. The organic carbon content increases slightly as a result of the wet conditions. The aquatic pollen taxa \textit{Laurembertia} spp and \textit{Cyperaceae} decrease in the middle part of zone 2, indicating 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 245\text{cm} level has been dated to 4550±90 \textsuperscript{14}C yr BP.

A minor occurrence of cultivated \textit{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 \textit{Osbeckia} spp pollen, but the chain fern, \textit{Woodwarkia} sp. (Pteridaceae), evidently survived in the gorges or barrancos when the ferret was cleared. \textit{Dicranopteris} sp. (Pteridaceae) spores indicate the presence of man-made clearings, trails and roadsides (Camus \textit{et al.} 1991).

The significant increase in pollen of \textit{Syzygium} spp, \textit{Glochidion coreaceum} and \textit{Rhododendron arboreum}, representing humid forest, in \textit{LPAZ 3} (4000 - 3000 BP, 190-135cm), indicates an abrupt rise 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 \textit{Cyperaceae} and \textit{Laurembertia} spp, supporting the notion that the hydrology in the mire altered towards wetter conditions. Spore of \textit{Sphagnnum} sp. indicate a lowering of the pH, \textit{i.e.} a change from a meadow towering a mire (\textit{cf.} Schimper 1964). The 170 cm level was dated to 3865±80 \textsuperscript{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 percentages, 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 LPAZ 4 (3000-2000 BP, 153-78 cm) is concerned, precipitation around 2500 BP may be considered relatively low by comparison with the zone 3, as indicated by pollen of *Prunus* sp. and *Rubus leucocarpus*, which prefer open, sunny places and cleared areas with an annual rainfall of around 2000mm/yr (Dassanayake and Fosberg 1981; Werner and Balasubramaniam 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.

![Graph](image)

**FIGURE 10:** Statistical analyses of cereal-type pollen grains in three intervals between 600 and 362 cm 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 LPAZ 5 (2000 - 1000 BP, 78-48 cm) reflects a mixed deciduous and evergreen forest consisting of species such as *Michelia nilagirica, Glochidion coreceum, Prunus* sp., *Symplocos* sp. and *Psychedoria zeylanica* and indicating a fairly humid, cool climate. The gradual increase in aquatic and hygrophyte pollen and Asteraceae (*Ceppis* 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 forest species, e.g. Syzygium 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 Asteraceae pollen (Anaphalis sp.) together with Peucedanum sp. support these interpretations.

Comments on the appearance 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 distribution of the size measurements below 478 cm shows a continuity 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 µm and anil-D approximately 10 µm together with a sharp annulus margin and a single grain structure, and that of the Avena type 55-65 µm and anil-D approximately 15 µm, together with a double grains structure. Critical identification was an uncertain matter because the surface structures on most of the grains had deteriorated greatly on account of corrosion, degradation, mechanical damage and the presence of detritus. Nevertheless, the grain sizes and anil-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 45-65µm in diameter, with an annulus diameter of 10-14µm, 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 affected, the
bulk dates obtained from the sequences may show somewhat too young ages, as a result of downwards penetrating humic acids and rootlets (cf. Olsson 1974, Possnert 1990, Risberg 1991). In order to calculate 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 contain three distinct sedimentary units: a lower sandy-silty clay (600-460 cm), an intermediate unit with alternating sequences of sandy peat and peaty sand (460-139 cm) and an upper one consisting of peat (139-0 cm). The uppermost part of the lower unit consists 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 estum (LGM) at 18,000 BP (cf. Overbeck et al. 1996). The two radiocarbon dates for the lower part of the intermediate structural unit indicate rapid accumulation 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 extremely 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 forest, 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 (LPAL 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 precipitation. 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 (Stuivts 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 covering the same time span (Maitima 1991; Scott 1989; Bakker and Coetzee 1988)

The vegetation composition at about 15000 BP (LPAL 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 strengthening of the monsoons. Overpeck et al. (1996) suggest that the SWM was weak until around 13,000 - 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 slight 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 LPAL 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 period 13,500 - 12,200 BP (uppermost part of LPAL 2, Site 1) indicates a decrease in precipitation. This matches with the weakening of the SWM at this period,
as described by Singh et al. (1990), Sukumar et al. (1993) and Overpeck et al. (1996). Kealhofer and Penny (1998) reached the same conclusion when describing a diversification of the dry land forest, as identified by pollen and phytoliths, 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 intensity.

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 decrease in monsoonal rainfall after 11,000 BP, and this has also been vividly 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 expanse of the temperate montane rain forest during the period 10,000 - 7300 BP suggests a general increase in precipitation (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 period, suggesting cool, arid to semi-arid conditions in the central and western 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 trend 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 trend 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 culminating 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 nevertheless 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. This species could have been introduced by humans migrating from the lowlands to the highland areas, as it occurs today in the vegetation of the lowland area.

The occurrence of an "uncertain" cereal-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 sequences analyzed 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 sequences analyzed are indistinct 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 served 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 around 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. According to the theory of domestication and the origin of plant agriculture, Michaels (1999) suggests that the first "agriculture" took place in Taiwan around 12,000 BC. The minrobotanical data (pollen and phytoliths) of Kealhofer and Penny (1998) suggest human/environment interaction in Thailand during the early Holocene. The burned phytoliths at the Late Pleistocene/Early Holocene boundary indicate 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, do not necessarily indicate that "cereal cultivation" took place at 14,000 BP (LPAZ 2), although possible to trace a certain relationship in connection 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 prehistorical stage of farming/pastoral culture. It is in any case valuable to discuss 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-scale 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. The 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 human interference continued until around 3000 BP (LPAZ 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 together 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 front of terraces in some places along the valley slopes.

**CONCLUSION**

The broad trends in the evolution 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 present. The pollen records suggest an arid and relatively species-poor environment during the Late Pleistocene, with dry land forest (xerophytic woodlands) predominating. A at the end of that period an increase in precipitation is recorded. Two significant phases of rain forest expansion (8000 - 7000 and 4000 - 3000 BP) suggest an increase in precipitation. In addition, an arid climatic phase is observed from 6000 to 5000 BP, and a short wet phase around 600 BP.

The first indications of human impact are dated to around 14,000 BP, when extensive forest 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 pre-farming/pastored from 14,000 to 10,000 BP, and the start of agricultural land-use is dated to around 9000 BP. Little 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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References


Chapman, V. J., 1947: The application of aerial photography to ecology as exemplified by the Natural vegetation of Ceylon. Indian Forest Research 73, 287-314.


De Rosayro, R. A., 1946: The montane grassland (patanas) of Ceylon. Tropical Agriculture 102, 4-16.


Gupta, P. L. and Prasad, K., 1985: The vegetational development during 30,000 ears B. P. at colgrain, ootacamud, Nilgiris, South India.


Kohler, E. and Lange, E. 1979: A contribution to distinguishing cereal from wild grass pollen grains by LM and SEM. Grana 18, 133-140.


Singh, G., 1971: The Indus Valley culture seen in the context of post-glacial climatic and ecological studies in northwest India. Archaeology and physical anthropology in Oceania 6, 177-189.


Szechowycz, R. W., 1954: Some observations on climate, soil and forest climax. Ceylon Forester 1, 131-141.


