Relationship of environmental changes in central Sri Lanka to possible prehistoric land-use and climate changes

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Abstract

A radiocarbon-dated pollen-analysed peat sequence from the Horton Plains (>2000 m a.s.l.), in central Sri Lanka, together with physical and chemical parameters (organic carbon, mineral magnetics, carbon isotopes and phytoliths), indicates major environmental changes during the last 24,000 years. The results suggest that a mobile life form, i.e. a hunter–forage culture, predominated in an open landscape, associated with xerophytic vegetation, e.g. Chenopodium spp. at ∼17.5 ka BP. Incipient management of cereal plants and slash-and-burn techniques seem to have prevailed between 17.5 and 13 ka BP, which was indigenous and associated with grazing. Evidence of systematic cereal cultivation in the form of oat and barley pollen grains is found from the late Pleistocene (∼13 ka BP). This is the earliest evidence of farming activities noted in Sri Lanka as well as in south Asia. After 13 ka BP, cereal cultivation was associated with an increase in humidity. With a later abrupt increase in aridity, agricultural land-use decreased from ∼8 to ∼3.6 ka BP, when the area appears to have been almost deserted. After a severe middle Holocene arid phase (i.e. 5.4–3.6 ka BP), the agricultural activity with a limited extension was again initiated by ∼2.9 ka BP. During the next ∼900 years, cultivation ceased allowing the upper montane rain forest to dominate. Between 0.2 and 0.15 ka BP, new phases of agricultural activities were undertaken and potato cultivation took place lately, between 1950 and 1969 AD.

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Keywords: Sri Lanka; Horton Plains; Pollen; Land-use; Climate; Vegetation

1. Introduction

Sri Lanka is a tropical island in the Indian Ocean, hosting prehistoric human settlements from ∼0.2 million years ago to the beginning of the historical period at ∼2.5 ka BP (Deraniyagala, 1992; Kennedy, 1999). The stratified archaeological data on prehistoric subsistence strategy in Sri Lanka indicate a hunting and gathering economy based on resources from existing flora and fauna. Evidence of Mesolithic settlements on the island has been recorded in the form of stone artefacts, together with osteological and archaeo-botanical remains collected from several sequences in cultural layers in cave sites, radiocarbon dated to 37 ka BP (Deraniyagala, 1992; Kennedy, 1993; Kennedy and Zahorsky, 1995; Kennedy, 1999). Possible indications of domestic dogs have been found from several Mesolithic camp sites (Deraniyagala, 1992). Tentative evidence of domesticated cereals is available from a cave at ∼7 ka BP (Deraniyagala, 2001). In the Indian sub-continent, this domestication is supported by finds of microlithic
industries associated with Mesolithic cultures of hunting people, fishermen and pastoralists or people practising some form of early agriculture (Allchin and Allchin, 1989).

Despite numerous attempts in the past, conclusive evidence of the origins of agriculture in Sri Lanka has not yet been found (e.g. Deraniyagala, 1992; Kennedy and Zahorsky, 1995). Therefore, our knowledge regarding the early farming culture in Sri Lanka is incomplete, mainly because of a lack of systematic and interdisciplinary investigations. However, the location of Sri Lanka can be considered as critical for testing the origins of agriculture due to a diverse landscape and resource availability (Abeywickrama, 1955; Harris, 1972; Hather, 1994; Manatunga, 1996; Yasuda, 2002). It is obvious that several of the basic premises for the origin of agriculture are available in Sri Lanka. These comprise diversified natural habitats: i.e., the location where these plants and animals occur in the wild, floristic richness, woodlands, diversified terrains and special skills e.g. a very old tool making tradition. A mild climate with reversed monsoons giving abundant rains and dry periods also occur.

Evidence of Neolithic settlements has been recorded in the form of stone axes and associated domestic plant and animal remains, collected from cultural layers at many archaeological sites in South Asia, but not in Sri Lanka. The origins of farming practices appear to have a considerable antiquity in the Indian sub-continent, starting from ∼10 ka BP (Allchin and Allchin, 1989; Gupta, 2004; Sharma et al., 2004; Singh, 2005). During the first three millennia thereafter, mud–brick architecture was developed and domestic wheat, barley, cattle and goat have also been exploited in an aceramic Neolithic context. Evidence from Indo-Iranian borderlands suggested that domestic sheep, cattle and goat were already husbanded by humans 10–7 ka ago. The data on the origin of crop cultivation in the Indian sub-continent, however, are still too inadequate to lead to a coherent agricultural history (Chakrabarti, 2000).

In south-eastern Asia the earliest known evidences show that nuts and tubers were domesticated ∼11 ka BP (Sundara, 1985). In other parts of the world the changes in subsistence patterns from foraging to farming have been described from several palaeoecological investigations (Normile, 1997; Shen and Crawford, 1998; Hillman et al., 2001; Toyama, 2001). Hillman et al. (2001) report that the earliest farming activities in south-western Asia date to 13 ka BP and in south-eastern Asia to 14 ka BP (Toyama, 2001).

A palynological study of a peat sequence obtained from the elevated Horton Plains indicated that agricultural land-use with barley (Hordeum sp.) cultivation dates back to the middle Holocene (Premathilake, 1997). A 6 m long peat sequence, covering the last 24 ka years, provided evidence for a climatic amelioration around 18.5 ka BP, favouring a gradual expansion of tropical/equatorial forests and subsequently agriculture (Premathilake and Risberg, 2003).

The horizons at Doravaka-lena shelter incorporate geometric microlithic tools and crude red pottery in association with finger millet (Eleusine coracana) grains radiocarbon dated to ∼7 ka BP (Wijeyapala pers. comm.). Black and Red Ware pottery from overlying strata, dated to ∼5 ka BP, is possibly evidence for a Neolithic culture in Sri Lanka (Deraniyagala, 2001). The agricultural history has been interpreted from stratified archaeological data obtained from the main site at Anuradapura, as representing a clear change in land-use between 3 and 2.5 ka BP. During this period, the intensification of agricultural land-use had already occurred in the lowland area. Evidence for the earliest farming activities in Sri Lanka date to the prehistoric early iron using communities (i.e. 3–2.5 ka BP) engaged in horse breeding, iron production and rice cultivation. This contradicts the traditional opinion that according to the 6th century AD chronicles (i.e. Mahavamsa, 1950), Indian migrants have introduced the farming tradition to the island ∼3 ka BP (Gunawardana, 1984).

It is suggested that a more comprehensive study is necessary to test the origin of agriculture in Sri Lanka, as well as in south Asia. The present paper addresses how new interdisciplinary research on prehistoric land-use patterns from the Horton Plains, central Sri Lanka, can be interpreted and integrated in the current discussion about the history of agriculture. The following topics are considered: (1) when did agriculture start, (2) what crops were cultivated, (3) how has climate affected agriculture and (4) what other human activities can be traced. Methods applied are high-resolution analyses of pollen, charcoal, organic carbon, carbon and nitrogen isotopes, and mineral magnetic properties.

2. The environment of the study area

The Horton Plains are characterised by a rolling landscape with mires, plains, forested hilltops, grassy slopes, precipices, brooks and waterfalls. It is located between 6°47′–6°50′ N and 80°46′–80°51′ E in the Central Highlands, 20 km to the south from the well known town “Nuwara Eliya” of Sri Lanka and was designated as a National Park in 1969 in order to preserve the natural montane ecosystem and habitat (Fig. 1). The area covers ∼3160 ha at 2100–2300 m a.s.
l. altitude. The bedrock mainly consists of highly metamorphic rocks, e.g. garnetiferous gneisses, quartz and granulites (Cooray, 1984). The present day climate of the Horton Plains is wet (Balasubramaniam et al., 1993). The average rainfall is about 2200 mm/yr. The precipitation is to a great extent determined by the Southwest Monsoon (SWM), which reaches peaks in June and August. The lower amount of precipitation in December is determined by the Northeast Monsoon (NEM). During the driest period, in February, the mean temperature is 12 °C and the night temperature drops to 5 °C. Upper montane rain forest (UMRF) and grasslands dominate the recent vegetation of which ∼50% is endemic to Sri Lanka. Stratigraphical studies and sampling were performed in one of the major valley systems of Belihul Oya extending in north–south direction. The valley bottom is occupied by mire, mainly covered by dwarf bamboo (Arundinaria densifolia) and grass vegetation.

3. Materials and methods

Two parallel 6 m long cores were taken with a Russian sampler (diameter 5 cm). The lowermost part consists of kaolinite, i.e. weathered bedrock (Risberg pers. comm.). This weathering product is overlain by sediments consisting of clastic particles i.e. sandy clay and silt mixed with organic matter (Table 1). Herbaceous peat constitutes the main part of the core. The peat is dominated by partially decomposed plant remains (e.g. grasses) and humus, occasionally mixed with fine to coarse-grained sediments. Pollen and spore analyses, mineral magnetic, organic carbon and phytolith measurements were obtained from one of the cores, while chemical parameters were measured on the complementary core.

3.1. Pollen and spores

The conventional acetolysis method was used for concentration of pollen grains (Berglund and Ralska-Jasiewiczowa, 1986). Analyses were carried out in intervals varying between 4 and 1 cm. Counting took place under a magnification of X500 (standard), with X1250 and phase contrast for critical identifications (microscopes used were Leitz, Laborlux-S and Zeiss, Axiosplan 2). On average, 750 pollen grains were counted in each sample. Identifications were based on relevant literature in tropical/subtropical pollen flora (e.g. Huang, 1972; Zheng, 1982; Reille, 1998), together with two reference slide collections, one made at the Palynological Laboratory, Museum of Natural History, Stockholm, Sweden, and the other at the Postgraduate Fig. 1. Location map of the Horton Plains national park in central Sri Lanka (park boundary is marked by the dashed line). Thin lines mark the major drainage patterns. Thick lines indicate major roads. FI = Farr’s Inn bungalow. Mountain peaks: To = Totupola, Ki = Kirigalpotta. Insert map of southern India and Sri Lanka. Archaeological locations mentioned in the text are included. 1 = Mannar, 2 = Anuradhapura, 3 = Sigiriya and 4 = Doravaka-lena.

Table 1

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Lithology</th>
<th>Colour</th>
<th>Macrofossils</th>
</tr>
</thead>
<tbody>
<tr>
<td>000–139</td>
<td>Peat</td>
<td>BL/VDB (10YR 2/1, 2/2)</td>
<td>1,2,3,4</td>
</tr>
<tr>
<td>139–165</td>
<td>Sandy peat</td>
<td>BL/VDB (10YR 2/1, 2/2)</td>
<td>1,2,3,4</td>
</tr>
<tr>
<td>165–172</td>
<td>Peat</td>
<td>BL (10YR 2/1)</td>
<td>1,2,3,4</td>
</tr>
<tr>
<td>172–200</td>
<td>Sandy peat</td>
<td>BL (10YR 2/1)</td>
<td>1,2,3,4</td>
</tr>
<tr>
<td>200–216</td>
<td>Peat</td>
<td>BL (10YR 2/1)</td>
<td>1,2,4</td>
</tr>
<tr>
<td>216–228</td>
<td>Sandy peat</td>
<td>BL (10YR 2/1)</td>
<td>1,4</td>
</tr>
<tr>
<td>228–353</td>
<td>Peaty sand</td>
<td>BL/VDB (10YR 2/1, 2/2)</td>
<td>1,2,3,4</td>
</tr>
<tr>
<td>353–367</td>
<td>Peat</td>
<td>BL (10YR 2/1)</td>
<td>1,3,4</td>
</tr>
<tr>
<td>367–373</td>
<td>Sandy peat</td>
<td>BL (10YR 2/1)</td>
<td>1,4</td>
</tr>
<tr>
<td>373–405</td>
<td>Peat</td>
<td>GA/BL (10YR 5/1,2/1)</td>
<td>1,2,4</td>
</tr>
<tr>
<td>405–432</td>
<td>Sandy peat</td>
<td>GB (10YR 5/2)</td>
<td>1,2</td>
</tr>
<tr>
<td>432–525</td>
<td>Peaty sand</td>
<td>BL/VDB (10YR 2/1, 2/2)</td>
<td>–</td>
</tr>
<tr>
<td>525–529</td>
<td>Silt + organic</td>
<td>GB (10YR 5/2)</td>
<td>1,3,4</td>
</tr>
<tr>
<td>529–585</td>
<td>Silt + organic</td>
<td>BL/YE/WH/OYE</td>
<td>3,4</td>
</tr>
<tr>
<td>585–600</td>
<td>Sand + clay,</td>
<td>WH/OYE/YE</td>
<td>1,3,4</td>
</tr>
</tbody>
</table>

Colours are determined according to the Munsell Soil Colour Chart (1988).
Colours: black (BL); very dark brown (VDB); dark brown (DB); greyish brown (GB); yellow (YE); olive yellow (OYL); white (WH); greyish (GA). Macrofossils: 1 = grass; 2 = wood; 3 = charcoal; 4 = non-identified.
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The number of microscopic charcoal particles with a diameter > 25 μm was also counted on the same slides as used for pollen analyses. Percentages were calculated as charcoal particles/charcoal particles + pollen sum. The abundance of each taxon was calculated as a percentage of the total pollen sum excluding aquatic pollen taxa. Pollen concentration values were calculated as an additional parameter. These, together with microscopic charcoal and organic carbon curves, are also shown in the pollen diagrams. The local pollen assemblage zones (LPAZ) were differentiated on the basis of fluctuations in tree pollen frequencies, by subjective boundary definitions. CONISS constrained cluster analysis was used as complementary method (Grimm, 1987).

In the human impact diagram, the identified herb pollen taxa were categorized in 16 groups following the ecological descriptions given by Bond (1953), Pemadasa (1984) and Dassanayake et al. (1980–2000). These groups were summarized into five land-use categories (Table 2) following Holmes (1951), Bond (1953), Perera (1969), Muller-Dombois and Perera (1971), Behre (1981), Fernando (1984), Berglund and Ralska-Jasiczczowa (1986), Manatunga (1996), Saarse et al. (1999) and Poska (2001). Palynological richness, i.e. the total number of taxa, was calculated as an additional indicator of human impact. Especially, the number of herb taxa is expected to increase in connection with human activity. Since the basic sum is varying, this technique gives only a rough estimate.

3.2. Identification of cereal pollen types

The identification of pollen types from cultivated Hordeum, Avena and Triticum was based on measurements of size, annulus diameter (anl-D) and surface structures referring to Beug (1961), Andersen and Bertelsen (1972), Andersen (1979) and Kohler and Lange (1979). According to these references, cultivated cereal pollen types should be > 37 μm in size and have an anl-D > 8 μm. This literature refers to a temperate environment making a direct comparison with tropical conditions difficult. Measurement on pollen grains from recent material collected from the Horton Plains during the 1970′s, deposited at the herbarium in Peradeniya,

<table>
<thead>
<tr>
<th>Groups</th>
<th>Ecological groups</th>
<th>Indicator taxa</th>
<th>Land-use categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Cultivated plants</td>
<td>Hordeum sp., Avena sp., Triticum sp.</td>
<td>Cultivated fields</td>
</tr>
<tr>
<td>B</td>
<td>Pastures</td>
<td>Indigofera sp., Cerastium sp., Desmodium spp., Achyranthes spp.</td>
<td>Pastures</td>
</tr>
<tr>
<td>C</td>
<td>Field and disturbed grounds</td>
<td>Polygonum lapathifolium, Plantago spp., Humulas sp.</td>
<td>Ruderal communities (major)</td>
</tr>
<tr>
<td>D</td>
<td>Waste grounds</td>
<td>Chenopodiaceae, Chenopodium spp., Gomphrena sp., Hewittia sp., Cruciferae, Cassia sp., Spermacoce sp., Malva sp.</td>
<td>Ruderal communities (major)</td>
</tr>
<tr>
<td>E</td>
<td>Open ground/patanas</td>
<td>Bupleurum sp.</td>
<td>Ruderal communities (major)</td>
</tr>
<tr>
<td>F</td>
<td>Weed</td>
<td>Centella sp., Coriandrum sp., Aster sp., Crepis sp., Cleome sp., Stellaria sp., Evolvula sp., Caryophyllaceae, Salvia sp., Ocimum sp., Labiatae, Polygonum caespitosum, Veronica sp.</td>
<td>Ruderal communities (minor)</td>
</tr>
<tr>
<td>H</td>
<td>Disturbed/damp grounds</td>
<td>Hydrocotyle sp., Cardamine african, Dipsacus sp., Exacum sp., Juncus sp., Liliaceae, Limnophila sp.</td>
<td>Ruderal communities (minor)</td>
</tr>
<tr>
<td>I</td>
<td>Open grounds</td>
<td>Peucedanum sp., Sanicula sp., Galium sp.</td>
<td>Ruderal communities (minor)</td>
</tr>
<tr>
<td>J</td>
<td>Shady grounds</td>
<td>Arisaema leschenaulti, Rhyynchotecum sp., Balanophora sp.</td>
<td>Ruderal communities (minor)</td>
</tr>
<tr>
<td>K</td>
<td>Shady/damp/waste grounds</td>
<td>Asteraceae (echinolphate), Patrinia sp.</td>
<td>Ruderal communities (minor)</td>
</tr>
<tr>
<td>L</td>
<td>Damp/shady grounds</td>
<td>Impatiens spp., Commelinaeaceae, Neanotis spp., Ranunculus spp.</td>
<td>Ruderal communities (minor)</td>
</tr>
<tr>
<td>M</td>
<td>Waste/patanas</td>
<td>Hypericum japonicum, Euphorbia sp.</td>
<td>Ruderal communities (minor)</td>
</tr>
<tr>
<td>N</td>
<td>Secondary forest/grasslands</td>
<td>Euphorbia sp.</td>
<td>Ruderal communities (minor)</td>
</tr>
<tr>
<td>O</td>
<td>Secondary forest/shady grounds</td>
<td>Coleus sp., Rubia sp.</td>
<td>Ruderal communities (minor)</td>
</tr>
<tr>
<td>P</td>
<td>Disturbed grounds</td>
<td>Oenothera sp., Plumbago sp., Verbascum sp., Verbena sp.</td>
<td>Ruderal communities (minor)</td>
</tr>
</tbody>
</table>
revealed that cultivated *Hordeum* sp. \((n=25)\) had a mean pollen size of 46.8±2.3 μm, a mean anl-D of 10.1±0.5 μm and a scabrate pattern. *Avena–Triticum* spp. \((n=25)\) had a mean pollen size of 50.9±2.3 μm, a mean anl-D of 12.8±0.7 μm and a verrucate pattern. The differentiation between *Avena* sp. and *Triticum* sp. is based on the surface ornamentation and the shape of the grains (Beug, 1961; Andersen, 1979). These measurements can be compared with data from the eight most common wild Poaceae species growing on the Horton Plains \((n=80)\), where mean pollen size ranges between 40.1±1.5 and 26.8±4.4 μm and mean anl-D range is 8.5±1.0 and 6.3±0.4 μm. In this work, the positive identification of cereal pollen types is based mainly on comparison with the recent material. Highest emphasis is put on anl-D followed by the surface pattern and grain size. In order to describe the size and anl-D variations in the fossil sequence, pollen grains >37.5 μm with an anl-D >8.6 μm were measured and grouped into eleven (11) and five (5) classes, respectively (Figs. 2 and 3). Total Poaceae pollen counted at each level constitutes the base for percentage calculations.

The accuracy of the measurements within the 11 size classes in Fig. 2 is in the order of ±1 μm being influenced mainly by the degree of physical preservation. The accuracy of the measurements within the five anl-D classes in Fig. 3 is in the order of ±0.5 μm. The zones in Figs. 2 and 3 follow the LPAZ.

### 3.3. Comments on the identification of cereal-type pollen grains

In LPAZ 1, a number of the observed Poaceae pollen grains fulfilled the size requirement \((i.e. >46.8 \mu m)\) to be classified as domesticated cereal types. These grains, however, did not have large enough anl-D, i.e. >10.1 μm, and no clear surface patterns, and so they were not considered as belonging to a cereal type. The data resemble Group II, which comprises wild and cultivated species of the *Hordeum* group (Andersen, 1979). It is likely that the pollen grains identified in LPAZ 1 are close to the following wild species: *Hordeum jubatum* (anl-D=9.6 μm), *Hordeum nodosum* (anl-D=9.3 μm), *Hordeum murinum* (anl-D=9.3 μm), *Glyceria fluitans* (anl-D=9.6 μm), and *Glyceria plicata* (anl-D=9.7 μm).

In LPAZ 2–6, the size of the Poaceae pollen is 46.6–67.5 μm and the anl-D values are 8.6–16 μm, which resemble Group II (*Hordeum* group) and Group III (*Avena–Triticum* group) as suggested by Andersen (1979). In the sequence analysed, the predominant mode class for pollen size and anl-D size is 46.6–49.5 μm and 8.6–10.5 μm, respectively, and indicates that cultivated *Hordeum* sp. common for Group II dominates. Larger grains with bigger anl-D belong to Group III, which mostly comprises cultivated species e.g. *Avena* sp. and *Triticum* sp. A cereal type pollen grain from *Avena* sp. is shown in Fig. 4. The identification of fossil cereal type pollen in a montane tropical environment is ambiguous, due to the representation of a large number of species and their uniformity. Since the identification of cereal pollen grains from temperate areas (Andersen, 1979) is based on the morphological features, i.e. size, anl-D and surface pattern, the comparison with cereal pollen found in LPAZ 3–6 might involve errors. It is likely that Poaceae pollen from tropical areas display both a larger size and a bigger anl-D. The surface pattern, however, should not be different. These errors might have been reduced in LPAZ 1–2, because temperate climatic condition prevailed in the Horton Plains during the late Pleistocene and early Holocene.

### 3.4. Mineral magnetic parameters

Mineral magnetic parameters were analysed in order to describe concentrations and grain size variations of the magnetic minerogenic component in the sequence. These variations are believed to depend on erosion of the valley sides close to the sampling site. Since the pollen diagram indicates the presence of humans in the near vicinity, the degree of erosion can be interpreted in term of anthropogenic activities (Lagerås and Sandgren, 1994; Eriksson and Sandgren, 1998).

Sub-sampling for mineral magnetic analysis was performed at 1 cm intervals over the entire 6 m length of the core. Magnetic susceptibility (χ) can be related to the concentration and presence of ferrimagnetic minerals in a sample. Anhysteretic remanent magnetization (ARM) reflects the concentration and presence of finer magnetic grains. Saturation isothermal remanent magnetization (SIRM) is mainly a measure of ferrimagnetic minerals, generally magnetite (Fe₃O₄). This parameter depends on magnetic grain size. The S-ratio was calculated as IRM₀.₁ T/SIRM (Thompson and Oldfield, 1986). This ratio reflects the magnetic mineralogy in a sample. The measurements were carried out at the Department of Quaternary Geology, Lund University, Sweden. The magnetic susceptibility (χ) was measured using an air-coiled susceptibility bridge in a peak alternating field of 0.1 mT. ARM was induced in an AC demagnetizer with a peak alternating field of 100 mT and the remanence was measured on a Molspin spinner magnetometer. SIRM was achieved in a high magnetic field of 1 T.
Fig. 2. The distribution of the grass pollen (Poaceae) size classes in percentages from the sequence analysed. Less than 37.5 μm size class includes wild grass species. The zones are referring to the local pollen assemblages. + = occurrences.
produced by a Redcliff pulse magnetic charger and induced remanence was measured on the spinner magnetometer. ARM and SIRM were determined using the Molspin anhysteric remanent magnetizer and Molspin Minispin fluxgate magnetometer. After the saturation procedure, the samples were placed in a weak field.

![Figure 3](image1)

**Fig. 3.** The distribution of the grass pollen annulus diameter (anl-D) size classes in percentages from the sequence analysed. Less than 8.5 μm anl-D size class includes wild grass species. + = occurrences.

![Figure 4](image2)

**Fig. 4.** Fossil pollen grain of *Avena* sp. i.e. oat (A) natural grass type (B and C). Scale bar: 10 μm.
negative field of 0.1 T (isothermal remanent magnetization; IRM$_{-0.1\ T}$) using a Molspin pulse magnetic charger and the remanence was measured on the spinner magnetometer. After completion of the magnetic analyses, the samples were dried and weighed to allow calculation of the mass specific concentration parameters (Thompson and Oldfield, 1986). Correlations between the master core (MS) and complementary core (MS1) collected for chemical parameters were carried out by means of lithostratigraphy and magnetic susceptibility and the depths were transferred to the MS (Fig. 5).

Note: In general, lithological compositions of both cores are similar. However, the correlation of the susceptibility ($\chi$) determinations of the lowermost part of the cores remains still somewhat questionable. It might be related to very local lithological changes of the core positions. Relatively high concentration of clastic particles (e.g. sand) due to bedrock erosion or soil-forming processes at local vicinity of the lowermost part of the MS1 core positions may indicate somewhat high $\chi$ values. Locally increased erosion also causes much higher concentrations of clastic particles which relate to an abrupt increase in $\chi$ determinations throughout of the MS1 core.

3.5. Chemical parameters ($\delta^{13}\text{C}$, TOC, TN and C/N ratio)

There are two principal carbon fixation pathways ($\text{C}_3$ and $\text{C}_4$) during the process of photosynthesis in plant communities (Sage, 1999). $\text{C}_3$ and $\text{C}_4$ plants have widely different $^{13}\text{C}/^{12}\text{C}$ ratios ($\delta^{13}\text{C}$). Notably, $\text{C}_4$ plants are mainly tropical arid-climate grasses while $\text{C}_3$ plant community includes trees, shrubs and cool-climate grasses. Therefore, $\delta^{13}\text{C}$ can be used as a palaeoecological indicator. Fifty seven (57) samples were analysed at 10 cm intervals from the complementary core. The sample material was put in an Ag-container and 2 M HCl was added to remove carbonates. Sample weights varied between 2.1 and 91.6 mg. The samples were allowed to dry in 60 °C overnight and then compressed to small spheres. For stable isotope analysis, the samples were combusted at 1020 °C with a Carlo Erba NC2500 analyser connected, via a split interface to reduce the gas volume, to a Finnigan MAT Delta plus mass spectrometer. From these measurements the reproducibility of $\delta^{13}\text{C}$ (vs PDB) was calculated to be better than 0.15‰. Total organic carbon (TOC) and total nitrogen (TN) values were determined simultaneously when measuring the isotope ratios. TOC was also determined as an additional indicator to understand changes in, for example, the productivity of source plants, hydrology and agricultural practices when measuring the mineral magnetic parameters using an ELTRA CS 500 simultaneous carbon sulphur analyser. The relative errors were <1% for both measurements. Because of the heterogeneous character of the samples, the actual values may be somewhat uncertain. The general trends, however, are considered reliable.

3.6. Phytoliths analysis

Phytoliths were separated from the materials by standard methods (Battarbee, 1986). Organic material
was oxidised in 40% H₂O₂ in room temperature and on a water bath. Clay particles were removed after 2 h of sedimentation in 100 ml beakers. Sand and coarser particles were removed after 5 s of sedimentation. The residue was mounted in Nephrax.

3.7. Radiocarbon dating

Fourteen (14) bulk samples were collected from the core and dated (Table 3) at the Ångström Laboratory, Uppsala University, Sweden, by the AMS technique (Possnert, 1990). In all measurements except the uppermost sample the soluble fraction was dated. Coarse plant remains e.g. rootlets were removed manually. Ages are stated with ±σ and a normalization of δ¹³C = −25‰ against PDB was carried out. The half-life (T½) is 5570 years. In order to facilitate comparison with previous publications, the ages stated in the text refer to calibrated years BP (ka BP). The ages are calibrated according to Stuiver et al. (1998) (<18,000 ¹⁴C yrs BP) and Kitagawa and van der Plicht (1998) (>18,000 ¹⁴C yrs BP).

4. Results and interpretation

4.1. Chronology

In order to calculate accumulation rates, linear interpolations were performed between adjacent calibrated radiocarbon dates (Fig. 6). The uppermost date (Ua-16393 at 80 cm) was extrapolated to the ground surface at the 0 point. This age–depth model was chosen within the 1-sigma uncertainty ranges of the 14 dates. In general, accumulation rate was low throughout the late Pleistocene and Holocene. According to the age–depth relationship, high accumulation rates appear between 10.5–9 and 3.1–2.6 ka BP. In general, the rates vary between 0.05 and 1.60 mm/yr and may be explained by fluctuation of the ground water table and/or the input of sand in various proportions. Another possibility is an input of nutrients from human activities within the drainage area of the valley.

Peat started to accumulate on the valley bottom ~17.1 ka BP. The accumulation rate was low, resulting in only about one metre to be formed until 10.2 ka BP.

Table 3
Radiocarbon dates of bulk peat obtained from the sampled core

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Lab. nr</th>
<th>Fraction</th>
<th>¹⁴C age ± 1σ (yr BP)</th>
<th>δ¹³C (%)(PDB)</th>
<th>Bulk samples</th>
<th>Calibrated age ± 1σ (yrs BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>Ua-16393</td>
<td>INS</td>
<td>1025 ± 70</td>
<td>−24.2</td>
<td>Peat</td>
<td>1060–1020 (8.1%); 1000–900 (43.8%); 870–790 (16.3%);</td>
</tr>
<tr>
<td>125</td>
<td>Ua-17188</td>
<td>SOL</td>
<td>3235 ± 60</td>
<td>−23.2</td>
<td>Peat</td>
<td>3560–3510 (13.6%); 3.480–3380 (54.6%); 2850–2820 (16.3%); 2815–2745 (51.9%);</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>
<td>3450–3420 (3.9%); 3120–3010 (62.0%);</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>
<td>3230–3210 (2.3%);</td>
</tr>
<tr>
<td>250</td>
<td>Ua-17189</td>
<td>SOL</td>
<td>3060 ± 50</td>
<td>−22.6</td>
<td>Sandy peat</td>
<td>3350–3210 (68.2%);</td>
</tr>
<tr>
<td>290</td>
<td>Ua-17190</td>
<td>SOL</td>
<td>5080 ± 65</td>
<td>−24.1</td>
<td>Sandy peat</td>
<td>5910–5740 (68.2%);</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>
<td>8990–8880 (21.4%); 8870–8820 (9.7%); 8810–8800 (1.5%); 8790–8640 (35.6%);</td>
</tr>
<tr>
<td>350</td>
<td>Ua-17191</td>
<td>SOL</td>
<td>8805 ± 70</td>
<td>−19.2</td>
<td>Sandy peat</td>
<td>10,150–10,130 (1.2%); 10,120–10,080 (6.9%); 10,070–10,060 (1.6%); 10,040–10,020 (1.9%); 10,010–9990 (2.3%); 9930–9690 (54.6%);</td>
</tr>
<tr>
<td>420</td>
<td>Ua-16397</td>
<td>SOL</td>
<td>9125 ± 80</td>
<td>−18.6</td>
<td>Peat</td>
<td>10,400–10,210 (68.2%);</td>
</tr>
<tr>
<td>460</td>
<td>Ua-17192</td>
<td>SOL</td>
<td>9195 ± 75</td>
<td>−18.9</td>
<td>Peat</td>
<td>10,480–10,460 (3.1%); 10,430–10,240 (65.1%);</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>
<td>16,000–15,200 (68.2%);</td>
</tr>
<tr>
<td>499</td>
<td>Ua-17193</td>
<td>SOL</td>
<td>12,950 ± 100</td>
<td>−25.6</td>
<td>Peaty sand</td>
<td>15,950–15,150 (68.2%);</td>
</tr>
<tr>
<td>540</td>
<td>Ua-16399</td>
<td>SOL</td>
<td>15,045 ± 140</td>
<td>−25.5</td>
<td>Silt + org.</td>
<td>18,350–17,650 (68.2%);</td>
</tr>
<tr>
<td>580</td>
<td>Ua-17194</td>
<td>SOL</td>
<td>18,410 ± 185</td>
<td>−22.3</td>
<td>Silt + org.</td>
<td>22,300–21,450 (68.2%);</td>
</tr>
</tbody>
</table>

Date intervals in the sequence analysed represent ±0.5 cm. Calibrated ages are according to Stuiver et al. (1998). Probability percentages are shown in brackets.
Fig. 6. Age/depth relationship according to calibrated radiocarbon dates for the core studied. Sedimentation rates are calculated by linear interpolation between calibrated ages. Zone boundaries for pollen and spores, mineral magnetic and chemical parameters are included. The detailed lithology can be found in Fig. 2 and Table 1.

The period 9–3.6 ka BP exhibits the lowest accumulation rate throughout the sequence, including a palynological hiatus between 5.4 and 3.6 ka BP i.e. a total lack of pollen and spore concentration associated with the sequence, but no indication for a lithological hiatus (cf. Sukumar et al., 1993 and Gasse, 2000). These can be explained by a deterioration in climate, i.e. an aridification causing oxidization of the organic material. The hiatus inferred from palynological changes between 284 and 256 cm prohibited a single linear regression through all 14 dates. Therefore, the dates above and below the hiatus were treated separately. Between 10.6 and 15 ka BP another hiatus might be present; however, this is very difficult to explain due to lack of data. During periods with high accumulation rates several dates yield similar ages, despite a stratigraphic difference of up to one metre. Around 3 ka BP, some of the dates are inverted (i.e. 2675±60 and 3235±60). The AMS date 2675±60 yr BP has been regarded while the date 3235±60 yr BP has been disregarded only after considering possible options when the construction of age–depth model was adopted (Fig. 6). The AMS date 12,970±115 yr BP at 487 cm depth is considered to fit within the age–depth model than the younger date, 12,950±100 yr BP at 499 cm depth. This can be explained by the contamination of younger organic materials, such as remaining root fragments. Note that some gaps may be present in developing a chronological control for this particular site due to insufficient number of radiocarbon dates.

4.2. Reliability of the chronology

Several problems are associated with the radiocarbon dates. Developing a more accurate chronological model for a particular site can be limited by an insufficient number of radiocarbon dates, plateau positions in the calibration curve, location of the cores collected, sub-sampling procedures and nature of the sample. Radiocarbon bulk dates of peat are problematic, yielding in some case ages that are too young (cf. Olsson, 1974; Possnert, 1990) or too old (cf. Nilsson et al., 2001). In the present study, the source of the dated carbon is not known; therefore, it has to be taken into consideration that the quality of the AMS dating on bulk samples in some cases might be regarded as less reliable. The absence of carbonate in the bedrock of the Horton Plains implies that one of the major sources (e.g. older carbon contamination) of error can be neglected. But, in one case, the date appears to be too old (i.e. 3235±60) and this may contain somewhat older detrital organic material derived from a lower stratigraphic level. Thus, the bulk dates obtained from the Horton Plains sequence may show somewhat younger ages due to the following possible sources of error: (1) downward penetrating humic acids, (2) ground water fluctuations,
(3) remaining rootlets/roots i.e. bioturbation (cf. Olsson, 1974; Possnert, 1990). The effect of the first two error sources (i.e. 1 and 2), however, is considered diminished to a much lower level in most cases, partly due to the high degree of compactions throughout the sequence. Thus, it is obvious that bioturbation (i.e. 3) may have been the most likely source of contamination. Therefore, it is believed that possible contamination was mainly in the remaining rootlets. Because the rootlets were manually removed and the fact that vegetation is dominated by Poaceae and Cyperaceae with short root systems in the vicinity of the coring points it is assumed that this contamination is also negligible. The radiocarbon dates were calibrated without correction (Table 3).

4.3. Zonation of pollen data and interpretation

More than 200 pollen taxa have been identified most of them occurring at low frequencies (Figs. 7A and B). Unknown pollen types make up 1–15% of the count at any given level analysed. Pollen preservation is generally good throughout the sequence except between 284 and 256 cm depth at which a hiatus is suspected. The key features of the local pollen assemblage zones (LPAZ) are discussed in detail below. Their age intervals are deduced from the age–depth model (Fig. 6). An interpretation of possible climatic conditions for each LPAZ can be found in Premathilake and Risberg (2003).

4.3.1. LPAZ 1 (600–546 cm; >24–18.5 ka BP)

This zone is characterised by high values of Chenopodium spp. and Gomphrena sp. (Fig. 8A) indicating a xerophytic vegetation community. Pollen values in the following groups: “pastures” (G), e.g. Achyranthes aspera and Cerastium sp., “field and disturbed ground” (C), e.g. Plantago spp., together with “weeds (F)”, e.g. Caryophyllaceae and Labiatae, provide possible evidence of a disturbance that maintained some pioneer vegetation (Fig. 8A).

4.3.2. LPAZ 2 (546–364 cm; 18.5–9.9 ka BP)

The pollen concentration values of this zone are fairly high in relation to LPAZ 1. UMRF arboreal taxa, e.g. Syzygium sp. Elaeocarpus spp., Symplocos spp., Ilex spp., Adinandra lasiopetala and Meliosma simplificolia, Semicarpus sp., Rhododendron arboareum (Fig. 7A), start to increase and appearance of shrubs e.g., Juniperus sp. and Cypressus sp. and the herb taxa Chenopodium sp. and Gomphrena sp. (Fig. 7B) values decrease upwards suggesting an expansion of tropical/equatorial forest as a result of climatic amelioration.

At 527 cm depth (corresponding to ~17.5 ka BP) domesticated Avena sp. (oat) pollen appears (Fig. 8A). This continues sporadically upwards within LPAZ 2. Pollen grains of Hordeum sp. (barley) also appear later in the LPAZ 2. The sharp fluctuations (Fig. 7A) in the curves of UMRF taxa indicate a succession in the vegetation. The taxa included in the ecological groups (Figs. 8A and B) “G”, “C”, “F”, “secondary forest/shady (O)” and “disturbed ground (P)” may indicate the continuing disturbance as do the occurrences of open land shrub taxa, e.g. Juniperus sp. and Rubus spp., Sarcococca zeylanica, and Rhamnus arnottianus. In the middle part of the zone, minor occurrences of pollen grains from Buchanania (axillaris?), an edible plant, and the cultivated shrub Spiraea sp. occur. The high percentages of microscopic charcoal particles may originate from forest burning.

4.3.3. LPAZ 3 (364–284 cm; 9.9–5.4 ka BP)

There is a high representation of rain forest and aquatic taxa (Premathilake and Risberg, 2003). A domesticated pollen type of Poaceae appears sporadically while minor sporadic re-occurrences of S. zeylanica, Spiraea sp., Rubus spp. and Indigofera sp. are noted (Figs. 7A and 8A). Sporadic occurrences of “O” and “disturbed ground/damp” (H) taxa, e.g. Rubus spp., Rubia cordifolia and Cardamine african can be identified. The few pollen finds of plant species representing the “cultivated” groups and/or “waste ground” (A/D), e.g. Malva parviflora, occur. Relatively high values of microscopic charcoal particles (e.g. average 50%) occur. Indications of human disturbances decrease upwards in the zone corresponding to an increase in pollen from upper montane rain forest trees up to 300 cm (Fig. 7A), indicating a recovery of the vegetation and a rapid regeneration of the rain forest. Uppermost part of the zone, UMRF pollen values and the organic carbon content rapidly decrease. Appearance of cereal pollen grains also gradually declined upward in the zone.

4.3.4. LPAZ 4 (284–256 cm; 5.4–3.6 ka BP)

This zone is characterised by extremely low pollen concentration values. Only a few (1–5) pollen grains of tree taxa, e.g. Ilex spp., Elaeocarpus spp., and A. lasiopetala, together with pollen from shrubs, e.g. Strobilanthes spp., Phylanthus spp. and herbs, Poaceae, Asteraceae and Cyperaceae, were observed (Figs. 7A, B and 8B). The surface characters of the exine on most of the pollen grains were not distinct (e.g. very faint colour), and also ruptured and bent. The lack of pollen grains in this zone possibly be ascribed to aridity,
Fig. 7. A. Simplified percentage pollen diagram displaying selected upper montane rain forest (UMRF) tree and shrub pollen taxa. + = occurrences. B. Simplified percentage pollen diagram displaying selected upper montane rain forest (UMRF) herbs and aquatics/semi-aquatics pollen taxa. Spore flora (Pteridophytes and Moss), algal cysts, total concentration and curve for organic carbon are included. + = occurrences.
Fig. 7 (continued).
Fig. 8. A. Human impact diagram for the sequence analysed. Individual curves for ecological groups (i.e. A = Cultivated lands, B = Pastures, C = Field and disturbed grounds, D = Waste ground, E = Open ground/patanas, F = Weeds). Palynological richness (PL. richness) is shown. + = occurrences. B. Human impact diagram (continue). Individual curves for G = Patanas, H = Disturbed/damp ground, I = Shady ground, J = Shady/damp/waste ground, L = Damp/shady ground, M = Waste/patans, N = Secondary forest/montane grasslands, O = Secondary forest/shady ground, P = Disturbed ground and indifferent taxa. Microscopic charcoal particles are shown. Total sum of the ecological groups C, D, E, N, O and P are considered as representative of major ruderal communities, while sum of the other groups F, G, H, I, J, K, L, M and P are considered as representing minor ruderal communities. + = occurrences.
causing unfavourable edaphic conditions for preservation. The organic carbon content is low due to more arid conditions. There is no conclusive pollen evidence for human activity; however, microscopic charcoal particles and grass phytoliths appear.

4.3.5. LPAZ 5 (256–108 cm; 3.6–2 ka BP)

The pollen values UMRF, e.g. Syzygium spp., Elaeocarpus spp., and Symplocos spp., gradually increase upwards suggesting a climatic amelioration. In the lowermost part of the zone, cultivated pollen types and taxa representative of the ecological group “C” occur. Similarly, pollen taxa included in the ecological groups, e.g. “O” and “P” are also indicative of human induced environment. The sharp fluctuations in the curve of UMRF trees indicate changes in the vegetation.

4.3.6. LPAZ 6 (108–14 cm, 2–0 ka BP)

The pollen values for UMRF trees in the lower part of the zone are fairly low in relation to LPAZ 5. This relative reduction of the UMRF (mainly Syzygium spp., Elaeocarpus spp., and Euonymus revolutus) can be interpreted as a result of forest destruction. Agricultural activity is indicated by high occurrences of pollen from Triticum sp. (6%) and microscopic charcoal particles (around 35%). Observations of pollen from Berberis sp. and Nandina domestica also support this interpretation. Sarcococca zellanica, Rubus spp., and Indigofera sp. give evidence of forest clearance and grazing.

4.4. Mineral magnetic analyses

According to the variation in magnetic concentrations and mineralogy reflected by $\chi$, ARM and SIRM and S-ratio, the core can be divided into three main magnetic units (Fig. 9). The origin of the clastic component is mainly detrital, indicated by low ARM/SIRM ratios, i.e. 0.025, for the entire core, except the uppermost 40 cm and some samples around 550 cm in depth. In general, magnetic susceptibility is extremely low in the peat and sediment sequence due to organic and sandy composition. The low SIRM/$\chi$ ratios throughout the core imply that coarse multidomain magnetic grains dominate in the magnetic stratigraphy.

4.4.1. Unit 1 (600–529 cm; 24–17.5 ka BP)

The lowermost unit, which consists of sandy clay and silt with organic material is characterised by low magnetic concentrations. The lowest S-ratios, $-0.8$ around 585 cm in depth, are indicative of magnetically soft minerals, e.g. magnetite. The detrital origin of

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Fig. 9. Mineral magnetic concentrations and ratios for the sequence analysed. In magnetic unit 2, the periods with low magnetic concentrations are marked with a light grey shade, whereas periods with high values are white. Magnetic unit 2a corresponds to the incipient cereal plant management (LPAZ 2 in Fig. 8A) and unit 2b to the cultivation phase (LPAZ 3 in Fig. 8A).
magnetite may have derived from bedrock erosion or soil-forming processes (Snowball, 1996; Walden et al., 1999). Sand and clay accumulated during LGM are characterised by low S-ratios. The S-ratios increase to 0 at the boundary between magnetic unit 1 and 2a, suggesting an increase in magnetically hard minerals (e.g. hematite). The magnetic unit 1 corresponds to LPAZ 1, defined as representing xerophytic vegetation associated with a semi-arid climate.

4.4.2. Unit 2 (529–87 cm; 17.5–1.1 ka BP)
This unit consists of a mixture of peat and sand, and has overall higher magnetic concentrations than unit 1. High S-ratios indicate the presence of magnetically hard minerals in the sequence. The unit is divided into three sub-units (2a–2c, from older to younger) according to the variations in magnetic concentrations. Periods with low, or relatively low, magnetic concentrations are marked with a grey shade in the diagram, whereas periods with high values, or relatively high values, are white.

Higher and lower magnetic concentrations alternate over relatively long periods in sub-unit 2a compared to sub-unit 2b. In sub-unit 2b, several prominent high peaks can be identified, sandwiched in between periods with lower concentrations. In general, magnetic concentrations are stable in sub-unit 2c, except between 175 and 162 cm.

In sub-unit 2a, the initial increase in \( \chi \), ARM and SIRM is probably the result of an input of magnetic particles into the valley, possibly caused by erosion due to reduced vegetation cover. This input was favoured by the presence of an open landscape as indicated by the pollen data, which records major forest clearance. In the upper part of the zone, magnetic concentrations decrease, probably as a result of more dense vegetation cover binding the soil. In sub-unit 2b, the variations in SIRM in particular, may be attributed to the shifting pattern of cereal cultivation interpreted from the pollen data. The uniform pattern of concentration values in sub-unit 2c may be due to the lack of cereal cultivation activities (cf. LPAZ 5).

4.4.3. Unit 3 (87–0 cm; 1.1–0 ka BP)
The magnetic concentrations are again higher than in sub-unit 2c. The values in S-ratios decrease from 0 to −0.6, reflecting a change in magnetic mineralogy. \( \chi \), ARM and SIRM increase gradually indicating higher concentrations of magnetic minerals.

The rise in ARM/SIRM ratios indicates an increase in the portion of fine-grained, secondary, soil-derived magnetic minerals (Walden et al., 1999). Secondary minerals (e.g. bacterial magnetite) might be produced from bacterial activity in the very uppermost portion. The increase in ARM may have been caused by sub-recent cereal cultivation (cf. LPAZ 6).

4.5. Chemical parameters (\( \delta^{13}C \), TOC, TN and C/N ratio) and phytoliths

The sequence can be divided into three zones according to the variations in \( \delta^{13}C \), TOC, TN% and C/N ratios (Fig. 10). Phytolith assemblage zones follow the zones in Fig. 10.

4.5.1. Zone 1 (600–475 cm; >24–13.6 ka BP)
The \( \delta^{13}C \) values become lighter throughout the zone, averaging around −26‰ PDB, which indicates the domination of C_{3} plants (e.g. grasses). Low TOC values (average 2%) reflect vegetation consisting of plants producing low biomass and amount of detrital matter (e.g. silt and sand) or low preservation (cf. LPAZ 1). In the very uppermost part of the zone (<15 ka BP), few fan-shaped grass opal phytoliths occur, consisting of *Oryza* sp. (i.e. swamp grass). Consistently low values in TN may reflect poor nutrient conditions in the environment. Increased C/N ratios from 10 to 22 indicate that the local environment around the sampling site was subject to slope processes, bringing reworked terrestrial material into the site (cf. Aucour et al., 1999; Lücke et al., 2003).

4.5.2. Zone 2 (475–300 cm; 13.6–8 ka BP)
The \( \delta^{13}C \) values range between −15‰ and −26‰ PDB, which indicates the presence of a mixed C_{3}/C_{4} plant community in the vicinity of the sampling site. However, \( \delta^{13}C \) values become heavier at the middle part of the zone (i.e. −15‰ PDB), which indicates that C_{4} grasses dominated as the major carbon source (e.g. swamp grasses) and aquatics were dominated e.g. *Limnophyton* sp., *Rhynchoglossum* sp. (cf. LPAZ 2). This interpretation is supported by the frequent occurrence of fan-shaped grass opals phytolith from *Oryza* sp. around 10 ka BP. The combined fan-shaped and papillae phytoliths evidence are indicative of cereals. TOC values increase to about 15% then drop to 5% and rise again to 20% maximum around 9 ka BP. They very abruptly drop again to less than 1% around 8 ka BP. The increasing trend in TN implies relatively nutrient rich environment. The almost identical patterns of TOC and TN are indicative of climatic amelioration as indicated by pollen records. C/N ratios increase ranging from 22 to 30, and gradually decrease to 20%.
4.5.3. Zone 3 (300–0 cm; 8–0 ka BP)

The $\delta^{13}C$ values reach c. $-25\%$ PDB suggesting a dominance of C$_3$ plants. There is a gradual increase in TOC and TN, reaching to 20% and 1.5% respectively, with the climatic amelioration. Stable C/N ratios remain constant at 21 for the entire zone, apart from the uppermost 80 cm. Very few papillae and fan-shaped phytoliths of cereals occur only in the uppermost part of the zone.

5. Discussion

5.1. Catchments of pollen and charcoal

The relationship between the spatial distribution of modern pollen and its representative vegetation (i.e. pollen influx values) is very critical in palaeoecological research. Pollen influx values should be established in various environments, from a closed forest to an open valley system of the Horton Plains, in order to evaluate the fossil pollen spectra. On this line, however, no studies have been undertaken. Therefore, a general introduction to modern pollen–vegetation relationships can be determined from the analysis of the very uppermost fossil pollen assemblages and distinct contemporary vegetation communities of the Horton Plains. A total of 54 woody species belonging to 31 families have been encountered, of which 50% are endemic to Sri Lanka. Lauraceae, Symplocaceae, Myrtaceae, Clusiaceae are the most dominant families and Syzygium spp., Symplocos spp., Calophyllum spp. and Cinnamomum sp. the most dominant genera. Small and large tree trunks and branches carry a thick coast of mosses, such as Frullania sp., Bazzania sp. and Sphagnum spp. Large tree Cyathea cinuata is one example of a large fern species and Lycopodium spp. and Psilotum sp are also present. Rhododendron arboretum spp. zeylanicum is one of the most characteristic species within the upper montane rain forest. Undergrowth of the forest often consists of dense masses of Strobilanthes spp. In addition, Coleus spp., Osbeckia spp. and Impatiens spp. are common. The
grasslands are dominated by *Chrysopogon zeylanicum*, *Andropogon lividus* *Arundinella villosa* and *Garnotia tectorum*. Pollen taxa distinguished in the arboreal fossil pollen spectra were probably from the species growing in upper montane rain forest and low montane forest in Sri Lanka. However, very few pollen taxa from the low montane arboreal forest (<900 m) were distinguished. It seems that fossil pollen spectra represent much more regional view of the composite vegetation of the Horton Plains. Burning and cutting have been the most important disturbances maintaining the successional cycles in the upper montane rain forest and grasslands (Amarasinghe and Pemadasa, 1983; Deraniyagala, 1992). Climate change has also drawn attention to the importance of those two types of vegetation communities. By burning of the communities, charcoal particles preserved in the peat and sediment sequence may permit evaluation of past fire activity.

### 5.2. Comments on swamp history (mire history)

Pollen and spore spectra constructed from the sequence were used to reconstruct effective changes in moisture, precipitation and to trace human activities. It is suggested that the main causes behind the vegetation changes and human activities should be highlighted separately. For this purpose, ecological groups including pollen indicator species approach were used. However, some ecological grouping contains species, which are growing on swamps (i.e. mire). Therefore, it is necessary to take account of the site environment, i.e. local swamp history, from the pollen and spore analysis. Pollen and spore spectra and siliceous microfossil analysis suggested eight periods of distinctive on-site vegetation changes during the 24 ka years. 24–18.5 ka: aerial condition and grasses and herb-rich environment, 18.5–12 ka: semi-dry mire, 12–10.2 ka: shallow water body, 10.2–5.4 ka: mire, 5.4–3.6 ka dry mire, 3.6–2 ka: wet mire, 2–0.5 ka: mire and 0.5–0 ka: semi-dry mire (Premathilake and Risberg, 2003).

### 5.3. Climate and palaeoenvironmental setting for human activity

High-resolution palaeoclimatic records from different archive (e.g. peat, lake sediment and deep-sea) show variations in total annual rainfall over South Asia during the late Pleistocene/Holocene (Sirocko et al., 1993; Gupta et al., 2003; Staubwasser et al., 2003). It is obvious that impact of annual rainfall changes described by investigations in cave deposits, archaeological deposits and organic accumulations in the interior of the island of Sri Lanka and in sand dune areas along the coast is coherent with twists and turns of early human settlements and civilization (cf. Deraniyagala, 1992; Premathilake, 2003). However, this section shows the converging evidence for climate change during the late Quaternary and briefly outlines the environmental history of the Horton Plains, Central Sri Lanka. The rainfall characteristics in different parts of Sri Lanka are fairly different (Suppiah, 1987). The author showed a bimodal pattern in the annual principal rainfall cycle. Except for the east coast region, all other parts of Sri Lanka are coincident with the northward and southward migration of the Intertropical Convergence Zone (ITCZ). During the South West Monsoon, the ITCZ-induced rainfall prevails from April to June and from September to November and westerly winds lead to the heavy rainfall on the western hill slopes of the Island from June and September i.e. more than 2500 mm/yr (Zubair, 1999). The winter monsoon rainfall of the island is from October to the December i.e. less than 1750 mm/yr. It is estimated that the western hill slopes of the island (i.e. 2500 m a.s.l.) have the highest rainfall reaching 6000 mm/yr from May to December (cf. Zubair, 2003, 2004). South west monsoon rains (SWMR) have very high impact upon the Horton Plains, Central Sri Lanka. The connection between the SWMR and the environmental setting (e.g. local and regional vegetations types) has been recorded in Table 4. The changes in vegetation types are, partly, the results of large variations in the SWMR in response to seasonal shifts in the position of the ITCZ and its associated belt of convective activity (cf. Premathilake and Risberg, 2003). In contrast, the maximum Upper Montane Rain Forest (UMRF) condition (i.e. under the hyper humid; Table 4) is reported during the heavy regional rains (strong SWMR), when the ITCZ migrates to its most northerly position, almost directly over the Horton Plains, central Sri Lanka, which is supported by comparison of the several Holocene records (cf. Neff et al., 2001; Gupta et al., 2003). The

**Notes to Table 4:**

- Vertical arrows indicate gradual changes, while solid horizontal lines denote more abrupt changes. Dotted lines indicate gradual transitions. UMRF = Upper Montane rain Forest. G/PG = Glacial/Postglacial. Capital letters A–G refer to marked peaks in the precipitation (i.e. high rainfall).
- Data in the column showing regional climate events are compiled from references mentioned in the text covering mainly the Arabian Sea and the Indian sub-continent. In the same column arrow heads indicate short-term intensified monsoonal climatic regime i.e. SWM (South West Monsoon), while the bars indicate more consistent patterns.
Table 4
Compilation of the data obtained from the different parameters and interpretations of palaeoenvironment and climate

<table>
<thead>
<tr>
<th>Assemblage zones</th>
<th>Calendar yrs BP</th>
<th>Lithology</th>
<th>Pollen and spores</th>
<th>Diatoms</th>
<th>Phytofths</th>
<th>Chemical parameters</th>
<th>Site environment</th>
<th>Dominant vegetation</th>
<th>Relative precipitation</th>
<th>Local climatic events</th>
<th>Regional climatic events</th>
<th>Epochs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-dry mire</td>
<td>Peat</td>
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<td></td>
<td>Mire</td>
<td>5</td>
<td>Scattered UMRF</td>
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<td></td>
<td></td>
<td>Humid (G)</td>
<td>Decreasing</td>
<td></td>
<td>Medieval warm period</td>
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<td>Wet mire</td>
<td>4</td>
<td>UMRF</td>
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<td>Humid (E)</td>
<td>Increasing</td>
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<td>Increase in aridity</td>
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<td></td>
<td>Dry mire</td>
<td>3</td>
<td>UMRF minimum</td>
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<td>Semi-arid</td>
<td>Decreasing</td>
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<td></td>
<td>Mire</td>
<td>3</td>
<td>Grasslands</td>
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<td></td>
<td>Hyper-humid (D)</td>
<td>Increasing aridity</td>
<td></td>
<td>Climatic optimum</td>
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<td>Shallow water body</td>
<td>2</td>
<td>UMRF maximum</td>
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<td></td>
<td></td>
<td>Per-humid (C)</td>
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<td>SWM</td>
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<td>2</td>
<td>Semi-deciduous seasonal forest</td>
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<td>Relatively dry</td>
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<td>SWM peak</td>
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<td>Silt</td>
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<td>Xerophytic (dry forest)</td>
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<td>Weak SWM</td>
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<td>Organic matter</td>
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Legend:
- UMRF: Unidentified Myriophyllum sp.
- SWM: Summer monsoon
- G: Glacial
- PG: Post-glacial

Note: The table and diagram depict changes in various environmental parameters over time, with arrows indicating trends such as increasing or decreasing humidity, aridity, and other climatic indicators.
South West Monsoon downturn, particularly mid-Holocene aridity (i.e. severe decrease in mean annual rainfall) when the ITCZ seems to have gradually reduced its presence in the region, could be special time periods in the continental tropic that have been previously underestimated. In addition, El Nino-southern oscillation (ENSO) phenomenon is now recognized as a primary mode of seasonal climatic variability, particularly in the tropics (Ropelewski and Halpert, 1987, 1989; Kane, 1998; Zubair, 2002, 2003). Rasmussen and Carpenter (1983) and Kane (1998) have studied the relationship between the ENSO and rainfall over India and Sri Lanka. The authors have shown that the ENSO warm conditions are often associated with decreased of annual SWMR (i.e. increased droughts conditions) in Sri Lanka, but intermonsoon season rainfall shows a strong opposite tendency (e.g. floods). Thus, interpretations of the proxy data found from this study reveal that the mean annual rainfall of Sri Lanka is diminished by variations of the mean ITCZ position, with time and the ENSO phenomenon.

5.4. Late Pleistocene hunting and gathering

Long-term land-use history can be reconstructed using radiocarbon-dated pollen diagrams, interpreted in terms of vegetation changes (e.g. Vuorela, 1986; Delcourt et al., 1986; Kealhofer and Penny, 1998; Poska, 2001). The approach of using indicator species in the pollen stratigraphy conduces to the understanding of past human economy and life styles. Therefore, the main features of human life style in the Horton Plains are discussed here. Before 17.5 ka BP, the landscape of the area was probably open with a prevailing semi-arid climate as indicated by pollen (cf. LPAZ 1), δ13C and TOC (cf. Zone 1) records during the Last Glacial Maximum (LGM). The occurrences of the wild plant families, Plantaginaceae, Chenopodiaceae, Polygonaceae, Amaranthaceae and Caryophyllaceae indicate dwelling patterns of hunters and foragers (Kajale, 1996a). The pollen taxa of Cerastium sp., Desmodium sp. and Achyrantes sp. appear, probably being favoured by grazing animals. Pollen from Plantago sp. indicates human induced environment. Stands of wild relatives of Hordeum sp. and Avena sp. were also present in the grasslands. The vegetation compositions deduced from the pollen data and soil forming processes detected from S-ratios suggest that the population consisted of mobile groups of hunter–foragers. It is possible that this life form could have dominated due to the low carrying capacity (i.e. lack of rain forest) in the Horton Plains as well as in most parts of the island during the LGM (Deraniyagala, 1992). It is thought that they settled in small camps in different environments, ranging from the damp and cold high plains (e.g. Horton Plains) to the lowlands (e.g. Mannar). Human bone material found from several prehistoric cave sites of the island, dated between 37 and 6.5 ka BP, has been subject to detailed physical anthropological studies (Kennedy et al., 1987; Kennedy, 2000; Hawkey, 2000). These studies show that the prehistoric population constitutes close genetic affinities to the recent Veddha aboriginal population in Sri Lanka. The modern life styles between Veddha and hunter–forage populations could not have been too different in Sri Lanka and among indigenous populations in India, Andaman Island and Malaysia (Deraniyagala, 1992; Kennedy, 1993; Deraniyagala, 2001). Osteological analyses indicate that the prehistoric human diet comprised of a mixture of wide range of food-plant and animals (Deraniyagala, 2001).

It has been postulated that the hunter–foragers fed themselves using food-plants and animals from the island as well as from the Indian sub-continent (e.g. Deraniyagala, 1992). This includes canarium nuts, wild breadfruit, bananas, grasses and fruits in the hilly areas and hunting animals on the open slopes and plains near watering points. This interpretation is based on stratigraphic cultural material studied from southern Asia, i.e. India, Pakistan and Sri Lanka (Jarrige, 1985; Kajale, 1990a; Kajale, 1996a,b).

Current results from the Horton Plains support this interpretation since herding (Bos indicus?) and the incipient management of cereals (i.e. oat and barley) occur to some extent from 17,500 cal yrs BP onwards. This also coincides with a semi-humid event (17.6–16 ka BP), suggesting favourable climatic conditions (i.e. warmer/humid), influencing the plant management system (cf. Singh, 1990; Premathilake and Risberg, 2003). From 17.5 ka BP through the late glacial, the cereal management was periodic in character. Relatively cool and dry conditions followed in the early Holocene (Premathilake and Risberg, 2003). Several other indications support this emergence of the plant management system, which includes pronounced fluctuations in the arboreal and non-arboreal taxa (cf. LPAZ 2), pastures, different types of disturbed fields, e.g. patanas and increase in mineral magnetic concentration (e.g. χ, and SIRM). Frequent burning and forest clearances (i.e. slash-and-burn) by the prehistoric people may have contributed to the expansion of patanas (Perera, 1967; Muller-Dombois and Perera,
The high representation of pollen taxa within the group "patanas (G)") might be the result of a close relationship between prehistoric humans and the prevailing vegetation.

In the middle part of LPAZ 2, the presence of an edible plant (Buchanania axillaris) and a cultivated shrub (Spiraea sp.), are further pieces of evidence of the management system. The high percentages of microscopic charcoal particles may originate from domestic fires in swamp (mire) burning, i.e. slash-and-burn activity. This scenario was probable during the early stages of the mobile life style. Therefore, it is logical to assume that the hunter–foragers had acquired the techniques and practices to convert the wild plants into domestic ones from ∼17.5 ka BP onwards. However, it does not indicate the start of agricultural activities but, the beginning of plant management.

The process of domestication has played a central role in the development of prehistoric social environment and the material culture. Archaeological and historical data obtained from the Horton Plains suggest that the area was subject to fire, forest clearance and grazing (Deraniyagala, 1992). Periodic fires seem to have occurred since at least 28 ka BP in the surrounding upland and montane grasslands, and in all likelihood, there was burning of the forests on the Horton Plains (Deraniyagala, 1992). These may have been caused by humans during small-scale seasonal movements into the montane region. Close to the site studied, there is evidence of prehistoric humans in the form of undated microlithic stone artefacts, which were assigned to the Mesolithic culture in Sri Lanka (Deraniyagala, 1992). The domestic cereal types may have derived from wild progenitors of the potentially domesticable Hordeum sp. and Avena sp. plants. These wild progenitors were growing already before the LGM within the vegetation of the Horton Plains. At this early stage, such plants may have been growing as weeds among other grasses. This is supported by the presence of wild grass species belonging to Aveneae (e.g. A. sterilis, A. fatua, A. barata and Helictotrichon sp.) and Triticaceae tribes (e.g. Brachypodium sp.) that are represented in the present vegetation of the Horton Plains and its surroundings (Clayton et al., 1994). It is implied that the area could have served as a primary source of genetic variability (wild species) for the domesticated Hordeum and Avena–Triticum-types, pollen of which appear later in the core sequence. Several of the basic requirements for the origin of the domestication processes were available in the Horton Plains. These comprise e.g. a mild, dry climate, burning of forest, presence of humans with a shifting of setting mode, wild progenitors, rolling plains, headwaters of streams, forested hills and grassy vegetation (cf. Redman, 1988; Singh, 1991). The Horton Plains, and the surrounding area, display all these basic factors implying a particularly diverse landscape with a wide range of resources. These highland areas are also suitable for summer grazing and the streams could have been dammed with soil barriers in order to regulate the flow of water permitting incipient cereal plant management (Deraniyagala, 1992).

It is believed that the hunter–foragers had some experience with plant management since 17.5 ka BP, while they were still mainly engaged with hunting and foraging. The appearance of pollen from cereal type plants indicates that the mobile life style lost importance in the Horton Plains. This interpretation is supported by arguments that the grasslands of the Horton Plains are a result of major forest clearing during prehistoric time (de Rosayro, 1946a,b,c; Senaratne, 1956; Perera, 1967; Muller-Dombois and Perera, 1971; Deraniyagala, 1972; Amarasinghe and Pemadasa, 1983; Deraniyagala, 1992). The forest clearance can be related to patch production for hunting or incipient cereal management and subsequent cultivation. Some areas of the grasslands were selected for campsites, contributing to the anthropogenic landscape of the Horton Plains (Deraniyagala, 1992). Kennedy and Zahorsky (1995) have claimed, based on the analysis of human bone material from several prehistoric sites located in lowlands that a relatively isolated population lived in restricted areas from the late Pleistocene to the modern time (Deraniyagala, 2001). Palaeoecological evidence for the origin of agriculture has been found from the Indian sub-continent as well as in Southeast Asia (i.e. Pakistan, India, Papua New Guinea, Indonesia, Thailand and Taiwan, at a somewhat later stage as compared to this study (Allchin and Allchin, 1989; Hather, 1994; Chakrabarti, 2000). It is also proposed, but not established, that the mountain region of Sri Lanka could have constituted another “hearth” for the domestication of plants as suggested by Deraniyagala (1992). This would be the case if prehistoric humans in the Horton Plains cultivated wild grains first, and subsequently, fully domesticated them during the end of late Pleistocene and beginning of the early Holocene. The combined pollen, opal phytoliths, mineral magnetic composition, and palaeoclimate evidence (shown by TOC, TN and δ13C) strongly implicates very abrupt climate change as a key factor leading to the agricultural community between 13.6 and 9 ka BP (zone 2 in Fig. 10). In general, the palynological richness also increased during this period. This includes the occurrences of several
pollen taxa representative of “B”, “G” and “F” (e.g. *Achyranthes* sp., *Indigofera* sp., *Heracleum* sp. and *Veronica* sp.). The crop cultivation probably took place close to the sampling site. These activities seem to have caused an abrupt decrease in *Chenopodium* spp. and increase in Pteridaceae (*Pteridophytes*). The initiation of systematic cereal cultivation took place in the middle part of the climatically humid phase between 13.6 and 12 ka BP, i.e. the end of the late Pleistocene. To some extent, this also marks a change from mobile to sedentary life style.

The results indicate that the incipient management of oat and barley continued for a period of 4.5 ka BP (17.5–13 ka BP). During this period, prehistoric humans developed advanced techniques and practices for plant domestication. In the Horton Plains, environmental factors such as climate and soil forming processes coincide with the incipient and succeeding land-use. It is also suggested that the time lag (i.e. 4.5 ka BP) is reasonably long to consider that the agriculture origins followed a macro-evolutionary experiment as suggested by Richerson and Boyd (2000).

5.5. Farming activity

5.5.1. Early Holocene farming

The origin of farming in different parts of the world is complex (Normile, 1997; Toyama, 2001; Hillman et al., 2001). In the Jiangxi Province of China, South-Eastern Asia, rice plant (*Oryza sativa*) phytoliths have been recovered from pottery at an excavation covering the period 14–9 ka BP (Toyama, 2001). Palaeobotanical data from China suggest that rice cultivation was the main subsistence for human culture. At the Abu Hureyra site on the Euphrates in south-western Asia, the yielded remains of cultivated rye (e.g. *Secale cereale*) indicate systematic cereal cultivation, 13 ka BP (Hillman et al., 2001), which is synchronous with the new data achieved from the Horton Plains. It is suggested that the prehistoric cereal cultivation, which occurred in the south Asian region, confirms the diversity of the agriculture at the same time.

During the early Holocene, the main cultivated crops in the Horton Plains were *Hordeum* sp. and *Avena* sp. The cultivation occurred continuously between 10 and 9.5 ka BP, associated with more humid conditions around 8.7 ka BP. After this age, towards the end of the early Holocene, the state of the cultivation was sporadic in the vicinity of the sampling site, which reveals human influence occurred in limited extent. This may indicate temporary habitations and/or shifting patterns of cultivation, as shown by variation in SIRM (cf. sub-unit 2b, Fig. 9). This is supported by several other lines of evidence, e.g. the reduction in pollen values of livestock farming, cultivated and/or waste ground group, field and disturbed ground, regeneration of rain forest. The decrease in cultivation can be explained by a gradual increase in aridity, which started ∼8.6 ka BP and lasted until the end of middle Holocene i.e. 3.6 ka BP.

The farming activity recorded from the Horton Plains and its age can be compared with corresponding results obtained in South and Southeast Asia. Neolithic farming practices, including cultivation and cattle breeding, appear to have had considerable antiquity in Pakistan at Mehrgarh and in India at Rajasthan, Vindhyan Hills, Chopani-Mando, Lahuradewa and Koldihwa between 10 and 7 ka BP (Meadow, 1981; Jarrige, 1981; Costantini, 1981; Alchlin and Alchlin, 1989; Chakrabarti, 2000; Gupta, 2004; Singh, 2005). Sharma et al. (2004) and Singh (2005) have described an early stage of farming at around 15 ka BP based on the occurrence of *Cerealea* and other cultural pollen and microcharcoal records found in Northern India. The fossil pollen evidence from the Papua New Guinea highlands indicates that complex agricultural systems were developed since 9 ka BP (Denham et al., 2003). In addition, pollen and charcoal records achieved from a sedimentary sequence in the highlands of Indonesia indicates anthropogenic disturbances ∼13 ka BP, which may correlate with the spread of agricultural innovation in lowland Papua New Guinea (Golson, 1989; Hope and Tulip, 1994).

5.5.2. Middle Holocene farming

During the middle Holocene (8–3.6 ka BP), the overall percent decrease in cereal-type pollen (LPAZ 4), indicates a significant reduction of cultivation, which is also in good agreement with the very abrupt decrease in the UMRF components implying unfavourable environmental conditions, e.g. persistent multi-century aridity. Palynological hiatus appears to be coherent with the most prominent climatic change (i.e. severely increased aridity) between 5.4 and 3.6 ka BP. Thus, these data indicate a very significant reduction in South West Monsoonal rains (cf. Staubwasser et al., 2003). It is suggested that repeated severe drought cycles may have initiated depletion of habitats of agrarian community of the Horton Plains, probably re-locating to the lowland areas in Sri Lanka. This severe drought period is probably the result of climatic conditions that prevented the ITCZ and its associated rainfall from penetrating far north. In South and West Asia, intensified aridity around 4 ka BP badly affected the
Old World societies e.g. Mesopotamia and India (Dalfès et al., 1997; Enzel et al., 1999). It is very obvious that the drought event at 4.2 ka BP traced from planktonic oxygen isotope ratios, off the Indian delta is coherent with the termination of urban Harappan civilization in the Indus valley (Staubwasser et al., 2003).

Archaeological evidence of geometric microlithic industry in association with cereals and Black and Red Ware from the Doruvaka-lena shelter in Sri Lanka, were dated to 7.25 and 5 ka BP, respectively (Wijayapala pers. comm.). Furthermore, a geometric microlithic horizon dated to ∼3.75 ka BP revealing the knowledge of copper industry, was found at Mantai in the North-Western part of the island (cf. Seneviratne, 1995). Jarrige (1985) has suggested that a more diversified agricultural system for the Indus region and Peninsular India developed after 6 ka BP. This farming system included cultivation of naked wheat as the most important crop within a diverse economic system (Chakrabarti, 2000). Also, finds of domesticated sheep, goat and wild boar attest to more diversified animal husbandry within this economic system. Well-developed farming practices, using a multi-cropping system, existed in the Indian sub-continent between 4.55 and 3.65 ka BP. This system included e.g. sorghum, millet, finger millet, wheat, barley and an animal husbandry e.g. cattle, sheep and goat (Possehl, 1995; Weber, 1995; Kajale, 1996b; Weber, 1999).

In addition to western India and Pakistan, rice cultivation amongst the cereal crops has been reported from several sites in Rajasthan, Uttar Pradesh, Maharashtra, Bihar, Kashmir, Swat Valley and at Pirak in the Kachi Plains dating from 4.5 to 4 ka BP (Stacul, 1981; Allchin and Allchin, 1989; Chakrabarti, 2000). The micro-botanical data (pollen, spores, charcoal and phytoliths) recorded by Kealhofer and Piperno (1994) and Kealhofer and Penny (1998) suggest intensification of agricultural activities in Thailand as early as 7–6 ka BP.

5.5.3. Late Holocene farming

There are only a few traces recorded of arable farming in LPAZ 5 suggesting that the area was subjected to very limited human activities at the beginning of the late Holocene (i.e. 3.6–2.9 ka BP). This is indicated by the few sporadic finds of cultivated cereal type pollen together with the pollen taxa included in the group “C”. Minor re-occurrence of the pollen taxa included in the group “N/O” indicates small-scale deforestation. The significant increase in the UMRF components implies a prevailing humid climate and a lower grazing pressure on the forest due to a decrease of livestock farming. Thereafter, the farming activity was completely abandoned for ∼800 years as indicated by the lack of cereal type pollen. Uniform patterns in χ, ARM and SIRM (Fig. 9), in age corresponding to LPAZ 5, are probably the result of an absence of disturbances around the site.

The last stage of farming culture in the Horton Plains has been postulated for the period between 2 and 0.15 ka BP. The findings of cereal type pollen (Triticum—Avena sp., Hordeum sp.) and the decrease in pollen values of UMRF provide evidence of human impact. Pollen grains from Berberis sp. and N. domestica in LPAZ 6 indicate that the land area was mainly used for Triticum sp. cultivation, which possibly started close to the sampling site. These activities increased slightly during the latter part of the period. It is believed that the small-scale cultivation of Hordeum vulgare, Avena sativa and Triticum aestivum occurred during the last century within the upper montane region of Sri Lanka (Senaratne, 1956). The increase in the values of mineral magnetic parameters in unit 3 (Fig. 9), corresponding to LPAZ 6, is probably the result from erosion caused by cereal cultivation. The rise in ARM at the very top of the core is probably a result of potato cultivation between AD 1950 and 1969. Traces of these activities can be seen in the form of terraces in some places along the valley slopes.

Most of the areas in the Indian sub-continent have been subjected to a settled farming system as a basic subsistence strategy during the late Holocene. Palaeobotanical evidence for these systems includes finds of cereals and other crop cultivation from 3.2 ka BP to modern time (Kajale, 1988, 1990b, 1994, 1996b, 1997). The earliest manifestation of the early iron using communities in Sri Lanka is radiocarbon dated from ∼3000 ka BP onward at sites located in lowland areas (<900 m a.s.l.) e.g. Anuradhapura and Sigiriya (Seneviratne, 1984, 1988; Deraniyagala, 1992; Myrdal-Runebjer, 1996; Mogren, 1999). The early iron using communities of Sri Lanka, 3–2.5 ka BP, are referred to as the transition from prehistoric to historic time. This transition is characterised by breeding of horses, practising of iron production and rice cultivation. This period is obvious in the lowland areas of the island and in much of the Indian sub-continent, suggesting an expansion of agricultural activities with advanced pottery, mortuary practices and irrigation techniques (Siriwewa, 1983; Allchin and Allchin, 1989; Deraniyagala, 1992; Myrdal-Runebjer, 1996). These data imply that the prehistoric farming settlements in the Horton Plains (i.e. highland) were gradually re-located at ∼2.9 ka BP in the lowland areas, following the
monsoon regime. It is reasonable to assume that the South West Monsoon (SWM) became stronger between 3.6 and 2 ka BP (Premathilake and Risberg, 2003). According to the geomorphology of the island, the increased water budget received from the SWM could have been properly managed with the large-scale irrigation works which started around 2.4 ka BP at Anuradhapura (Myrdal-Runebjer, 1996). This intensified the rain-fed agriculture (e.g. rice) on the lowland areas of the island. This surplus of water, however, could not be utilised in the highland areas due to physiographic and technological barriers. Thousands of tanks and canals were built all over the lowlands during the rules of several kings of the Anuradhapura and Polonnaruva kingdoms. Between 1.6 and 0.8 ka BP, a most sophisticated hydraulic civilization existed, which served as a great economic foundation for a diversified agriculture (Nicholas, 1960; Gunawardana, 1978; Brohier, 1979; Fernando, 1982; Siriweera, 1990).

This subsistence strategy includes several cereal crops, e.g. rice, millet and finger millet, but not barley, oat and wheat, mainly due to a lack of temperate climatic conditions in the lowlands. The last stage of cultivation, mainly of wheat, started in the Horton Plains nearly synchronous with the time of the start of irrigation techniques in Sri Lanka.

These data indicate a complex subsistence strategy, which was furthermore diversified by the introduction of wheat cultivation in the Horton Plains. Archaeobotanical evidences, i.e. seeds from cultivated wheat dated to ∼2.3 ka BP, were found in an excavation at the ancient international port site in Mantai. It is likely that migrants introduced wheat to the Island from the Indian sub-continent as suggested by Kajale (1990c). Due to the favourable climatic condition that prevailed in the highlands, wheat was adapted at a later stage in the Horton Plains.

6. Conclusion

Pollen records, plantopal phytoliths, TN, TOC, δ13C, C/N ratios, and mineral magnetic measurements, together with radiocarbon dates on a peat sequence obtained from the Horton Plains, central Sri Lanka, provide a framework to study land-use changes during the last 24,000 years. The different proxies show that the hunter–foragers in central Sri Lanka had a mobile lifestyle until ∼17.5 ka BP in an open landscape associated with xerophytic vegetation. From this age onwards, the lifestyle diversifies with the achievement of incipient cereal plant management together with slash-and-burn techniques. Grazing and forest clearances were also involved. This diversification coincides with a climatic amelioration, i.e. an increase in humidity, during the late glacial. Several wild grass species, growing in semi-arid climatic conditions during the LGM, served as primary sources of genetic variability for the domesticated cereal types. Thereafter, a certain degree of systematic cultivation started ∼13 ka BP probably within an indigenous context, e.g. Vedda aboriginal population. The cultivation might have started to decline ∼8 ka BP, and came to an end 3.6 ka BP possibly due to intensified aridity as indicated by the lack of UMRF pollen. Then, the agricultural activity was limited until 2.9 ka BP. From that age until 2 ka BP, no cultivation activities are recorded, instead UMRF dominated. Soon after 2 ka BP a new phase of agricultural activities was re-established, terminating by 0.15 ka BP. Potato cultivation took place between 1950 and 1969.

In short it is concluded that:

- incipient cereal plant management started ∼17.5 ka BP,
- slash-and-burn activity, forest clearances and grazing have been applied,
- cultivation of oat (Avena sp.) and barley (Hordeum sp.) started ∼13,000 ka BP. Wheat (Triticum sp.) was introduced ∼2 ka BP,
- post-LGM and late glacial climatic ameliorations favoured the early development of cultivation while middle Holocene aridity caused a decrease.

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