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# Vegetation changes from the late Pleistocene through the Holocene from three areas of archaeological significance in Thailand

Joyce C. White[a,*], Daniel Penny[b], Lisa Kealhofer[c], Bernard Maloney[d,✠]

[a] *University of Pennsylvania Museum, 3260 South Street, Philadelphia, PA 19104-6324, USA*
[b] *School of Geosciences, Department of Archaeology and the Australian Key Centre for Microscopy and Microanalysis, University of Sydney, Madsen Building FO9, 2006 NSW, Australia*
[c] *Department of Anthropology and Sociology/Environmental Studies Program, Santa Clara University, Santa Clara, CA 95053, USA*
[d] *School of Archaeology and Palaeoecology, The Queen's University, Belfast BT7 1NN, Northern Ireland, UK*

**Abstract**

Reconstruction of the environmental history of mainland Southeast Asia from the late Pleistocene is a relatively recent endeavor. Beginning in the mid-1990s, lacustrine sediments in Thailand with deposits dating from the late Pleistocene have been cored and analyzed for palaeoenvironmental indicators. The three cores reported here were extracted by the Thailand Palaeoenvironment Project, whose objective was to retrieve empirical data on vegetation and sedimentary sequences that can in turn be related to the growing archaeological record from this part of monsoonal Asia. This evidence, along with data from other recently analyzed cores, is beginning to develop a picture of regionally diverse environmental/cultural trajectories. Possible relationships between the environmental changes and cultural and/or climatic impacts are discussed.


## 1. Introduction

For research on the evolution of Asia's monsoonal system, Thailand holds a key geographic position. The country's latitudinal range (5°27′–20°27′N) spans the transition from subequatorial to fully subtropical environments. Its peninsular exposure to the southwest monsoon traversing the Indian Ocean and northeast monsoon traversing the Pacific, as well as its inland and coastal environs, argue that palaeoenvironmental sequences from the region should have great potential to contribute important insights into the climate history for Asia. Understanding the development of Asia's monsoon climate, moreover, is fundamental to understanding its role as one controlling factor for the natural resource base and agriculture for half the world's population (Maxwell and Liu, 2002, p. 189).

Until recently, however, no sediment records from mainland Southeast Asia dating from the late Pleistocene had been extracted and analyzed for palaeovegetation and other environmental changes. Those records that had been published were only a few millennia in time-depth and derived primarily from coastal environments (Hastings, 1983; Pramojanee and Hastings, 1983; Stargardt, 1983; Sangsuwan et al., 1987; Maloney, 1991). The environmental changes described in these studies reflected the localized impact of middle to late Holocene sea level changes and revealed nothing of the nature of the Pleistocene/Holocene climate change, little on details of regional Holocene climatic change, or the general regional development of monsoon forests.

Moreover, the environmental context for human habitation in mainland Southeast Asia and the nature and magnitude of human impact on the region's environments are poorly understood, despite having long been the subject of interest and debate among prehistorians of the region. Only recently have archaeological data from mainland Southeast Asia, and Thailand specifically, become sufficiently robust that the relationship between cultural and environmental change can begin to be addressed from empirical bases.

The Thailand Palaeoenvironment Project (TPP), codirected by White and Kealhofer, was initiated in 1993 with the goal of obtaining data on environmental

*Corresponding author. Tel.: +1-215-898-4028; fax: +1-215-898-0657.
*E-mail address:* banchang@sas.upenn.edu (J.C. White).
✠The late Bernard Maloney co-authored portions of this paper in an earlier version presented at the Society for American Archaeology meetings in Philadelphia in 1999.

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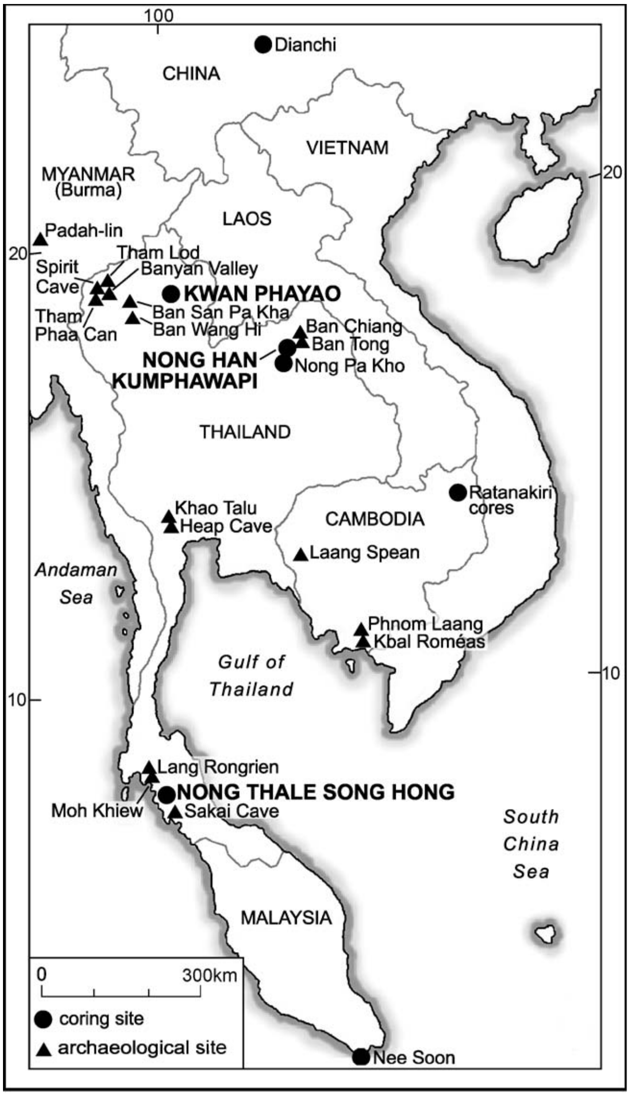

Fig. 1. Locations of the three lake cores extracted and analyzed by the TPP, Kwan Phayao, Nong Han Kumphawapi, and NTSH, as well as other lake/swamp sediment cores and archaeological sites mentioned in the text.

change, primarily from lake sediment cores, in three areas of Thailand with important prehistoric cultural sequences (Fig. 1). These areas also represent environments that contrast in latitude, altitude, rainfall, and other variables. In each area, a primary criterion for choosing a lake for coring was its potential to yield a sequence of significant, hopefully late Pleistocene-aged, time-depth.

## 2. Methods

Sediment cores were extracted from three lakes in the south, north, and northeast of the country (Fig. 1) using a modified Livingston corer. Coring was conducted by Kealhofer and White, and cores were analyzed for pollen by Penny and Maloney and for phytoliths by Kealhofer. In northeast Thailand, ethnoecological research by White added data for land use, and landscape and vegetation variation and modification in the region of the Ban Chiang cultural tradition.

The preparation of sediments for microfossil analysis followed standard procedures: Berglund and Ralska-Jasiewiczowa (1986) with respect to pollen preparation; Stockmarr (1971) with respect to microscopic charcoal particle concentrations; Piperno (1998) with respect to phytolith preparation. The "strength" of each microfossil identification, or the confidence the analyst has in that identification, is indicated by the suffixes "sim." (used when a microfossil type is *similar*, but not identical, to known microfossil types), "comp." (the microfossil is *comparable* to known types, but there is a greater degree of uncertainty), or "id." (only used here in binomial classifications where the analyst wishes to indicate that the identification of the genus is certain but the species is not; e.g., *Podocarpus* id. *amanus* comp.).

A chronology for the three sites is provided by a total of 18 radiocarbon dates (Table 1). In all cases excluding one (OZC-319), age determinations were based on undifferentiated organic material. In the case of OZC-319, only the pollen fraction of the sample was dated. Twelve dates were determined with AMS, and the remainder were conventionally determined. Uncalibrated $^{14}C$ ages are expressed here with the suffix "bp uncal." (before present uncalibrated), whereas calibrated ages are designated BP, BC, or AD "cal." (calibrated).

In the text that follows we employ, a priori, the following conventions for the subdivision of the late Quaternary, which are based primarily on the climate phases described by Maxwell and Liu (2002). The last glacial maximum is here taken to occur around 20,000–18,000 bp uncal., while the late glacial period comprises the period 18,000–12,000 bp uncal. The phrase "terminal Pleistocene," here synonymous with the period often called the "Pleistocene/Holocene transition," dates between 12,000 and 9500 bp uncal. It thus incorporates the first of two "surges" in the strength of the southwest monsoon (Maxwell and Lui, 2002, p. 218) and a generally abrupt transition to wetter conditions. The "late Pleistocene" is used as a more general phrase to encompass evidence from roughly the last interstadial through the terminal Pleistocene. The Holocene is subdivided into the early Holocene marked by the second surge in monsoon strength (9500–7000 bp uncal.), middle Holocene (7000–3500 bp uncal.), and late Holocene ($<3500$ bp uncal.) phases. These subdivisions, being largely based on research conducted elsewhere in South and Southeast Asia, are more or less artificial and may require revision as new data come to hand from interior mainland Southeast Asia.

The following overview of the research of the TPP proceeds from the south (Nong Thale Song Hong—

Table 1
Radiocarbon determinations from three lake sediment cores extracted by the Thailand Palaeoenvironment Project

| Lab. no. | Core section no. | Depth in cm[a] | bp determination | Calibrated dates[b] | | | | Material[c]/method[d] | $^{13}C/^{12}C$ ratio |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 sigma BP | 2 sigma BP | 1 sigma BC/AD | 2 sigma BC/AD | | |
| Nong Thale Song Hong | | | | | | | | | |
| Beta-106539 | 2TS1 | 84–90 | 6330±50 | 7320–7160 | 7420–7090 | 5370–5210 BC | 5470–5140 BC | OS/AMS | −26.0 |
| Beta-106537 | 2TS2 | 156–160 | 10820±50 | 12990–12670 | 13110–12630 | 11040–10720 BC | 11160–10680 BC | OS/AMS | −25.4 |
| Beta-106538 | 2TS3 | 222–226 | 21170±90 | 21270–21070 | 21360–20990 | 19320–19120 BC | 19410–19040 BC | OS/AMS | −22.3 |
| Beta-106540 | 2TS4 | 257–263 | 9420±50 | 10730–10560 | 11100–10400 | 8780–8610 BC | 9150–8450 BC | OS/AMS | −27.4 |
| Beta-101966 | 2TS4 | 318 | 16490±120 | 20000–19300 | 20350–18950 | 18050–17350 BC | 18400–17000 BC | OS/AMS | −27.9 |
| Kwan Phayao | | | | | | | | | |
| Beta-106541 | 2PY1 | 26–30 | 640±40 | 655–560 | 670–540 | AD 1295–1390 | AD 1280–1410 | OS/AMS | −26.3 |
| Beta-106542 | 2PY7 | 211–216 | 780±40 | 730–670 | 770–650 | AD 1220–1280 | AD 1180–1300 | OS/AMS | NA |
| Beta-106543 | 2PY9 | 395–399 | 1860±50 | 1870–1710 | 1930–1630 | AD 80–240 | AD 20–320 | OS/AMS | −23.2 |
| Beta-106544 | 2PY13 | 527–531 | 9850±50 | 11260–11190 | 11550–11170 | 9310–9240 BC | 9600–9220 BC | OS/AMS | −23.7 |
| Beta-099704 | 2PY13 | 546–548 | 19190±120 | 23150–22350 | 23650–21950 | 21200–20400 BC | 21700–20000 BC | OS/AMS | −22.3 |
| Nong Han Kumphawapi[e] | | | | | | | | | |
| OZC-319 | 3KUM1 | 45–46 | 2690±70 | 2860–2740 | 2970–2710 | 910–790 BC | 1020–760 BC | P/AMS | NA |
| Beta-93027 | 3KUM1 | 80–85 | 5540±70 | 6410–6280 | 6490–6190 | 4460–4330 BC | 4540–4240 BC | OS/stan | −28.5 |
| Beta-93028 | 3KUM2 | 136–141 | 6080±60 | 7010–6800 | 7160–6750 | 5060–4850 BC | 5210–4800 BC | OS/stan | −25.0 |
| Beta-93029 | 3KUM2 | 152–157 | 6270±100 | 7310–7010 | 7450–6900 | 5360–5060 BC | 5500–4950 BC | OS/ext | −23.4 |
| Beta-93030 | 3KUM4 | 255–268 | 8610±100 | 9720–9490 | 9950–9400 | 7770–7540 BC | 8000–7450 BC | OS/ext | −22.4 |
| Beta-93031 | 3KUM5 | 355–363 | 8570±110 | 9700–9430 | 9950–9250 | 7750–7480 BC | 8000–7300 BC | OS/ext | −22.1 |
| Beta-72096 | 3KUM7 | 540–545 | 9170±130 | 10510–10210 | 10700–9900 | 8560–8260 BC | 8750–7950 BC | OS/ext | −25.0 |
| Beta-72097 | 3KUM7 | 580–581 | 12270±70 | 15050–14050 | 15450–13850 | 13100–12100 BC | 13500–11900 BC | OS/AMS | −15.9 |

[a] Depth from top of total core. Depths for the Nong Thale Song Hong samples Beta-106537 and Beta-106538 have been revised from Kealhofer (2003).
[b] Calibrated with OxCAL 3.5 with InterCal98 calibration curve.
[c] OS = organic sediment; P = pollen.
[d] Stan = standard radiometric; ext = extended counting; AMS = accelerator mass spectrometry.
[e] Calibrated dates previously published using OxCAL 2.18, 1993 calibration curve (Kealhofer and Penny, 1998; Penny, 1999; White, 1997).

NTSH), to the north (Kwan Phayao), and to the northeast (Nong Han Kumphawapi).

## 3. Results

### 3.1. Nong Thale Song Hong

A 3.18 m core was extracted from NTSH in Trang province, southern Thailand (7°52′N; 99°28′E; ca. 100 m ASL). The area averages 2380 mm of annual rainfall (Ministry of Communications, Thailand, 1977, p. 49). There is a short dry season of 3 months with 1 month (February) with less than 50 mm of rainfall. Regional forests are classified as lowland tropical rainforest dominated by genera of the Dipterocarpaceae.

NTSH is a closed basin lake, some 0.48 $km^2$ in extent, and was selected for coring due to its proximity to late Pleistocene and early and middle Holocene aged archaeological sites, and its position on the western side of the north to south mountainous divide of peninsular Thailand. As a non-karstic lake with no current settlements on its shores (the lake is located in a nature reserve), NTSH was the only lake suitable for coring identified in the vicinity of the prehistoric cave sites. The size of the lake and the lack of fluvial throughput mean that pollen deposition is likely to reflect local rather than regional vegetation, in contrast to larger lakes to the north and northwest (see below). Rockshelter sites within 75 km to the northwest and southeast of the lake reveal a cultural sequence with: (1) an upper Palaeolithic habitation characterized by a flake and core industry dating from ca. 43,000 bp uncal. to younger than ca. 26,000 bp uncal.; followed by (2) a terminal Pleistocene/early Holocene Hoabinhian occupation characterized by flaked core tools; (3) an early to middle Holocene stone age occupation here termed "late lithic" characterized by flaked stone tools, polished stone adzes, and pottery fragments; followed by (4) pottery-using and presumably agricultural groups by at least 4000 years ago (Anderson, 1990, 1997; Pookajorn, 1996; Bellwood, 1997, pp. 258–259).

The NTSH core, which comprises four core sections, has a date of 21,170 ± 90 bp uncal. at 222–226 cm depth (Beta-106538, see Table 1) preceding the beginning of the last glacial maximum. Two lower dates from the stratigraphically lowest core section (2TS4, see Table 1) provide a radiocarbon chronology that is inconsistent with the overlying deposits and these dates are assumed to be unreliable (Maloney, 1999a). Only one pre-Holocene sample contained sufficient concentrations of pollen to permit analysis (206.5 cm depth from core section three, an interpolated age of 17,500 bp uncal.). The pollen record published by Maloney (1999a, b) begins at 155 cm during the Pleistocene/Holocene transition (from approximately 10,600 bp uncal.). Phytoliths are present from 285 cm. NTSH phytolith data and analyses are published in Kealhofer (2002, 2003).

The NTSH phytolith data reveal that the lowest values of arboreal indicators and the highest values of burnt phytoliths (here taken to be an indication of fire activity within the NTSH catchment) occurred during the late glacial period (Fig. 2), possibly a result of a climate considerably dryer and more seasonal than today. Kealhofer (2003) notes that the burnt phytoliths (identified by the presence of black (charred) organic material encased in the phytoliths) predominantly derive from grasses, suggesting the presence of a woodland savannah that was burned regularly. The terminal Pleistocene to early Holocene part of the sequence indicates forest expansion, which is coincident with archaeological evidence for the occurrence of Hoabinhian habitation in the region. Archaeological evidence for late lithic societies appears during the early to middle Holocene when forest indicators are at their height and peaks in both burned wood and phytoliths occur. The period of unambiguous agricultural occupation in the region coincides with a decrease in arboreal indicators in the phytolith record and an increase in burned wood (see Kealhofer, 2003).

The NTSH pollen data (Fig. 3) provide evidence of vegetation change primarily from the terminal Pleistocene (155 cm depth, approximately 10600 bp uncal.). The single late glacial-aged sample at 206.5 cm depth (ca. 17,500 bp uncal.) is difficult to interpret with confidence, but indicates the presence of open forest (dominated by *Castanopsis* comp.), with sufficient standing water to permit relatively high values of the aquatic plant *Nymphoides* and, presumably, the establishment of a reducing a reducing environment at the core site. The diversity of pollen types from forest plants is slightly lower than the average for the entire record, but not markedly so.

The very strong representation of *Lawsonia inermis* pollen (originally identified by Maloney (1999a, b) as *Castanopsis indica* comp.) during the early Holocene may reflect the occurrence of a swamp forest community at the lake margin, probably with a fringe of emergent and floating aquatic plants (notably Poaceae, the sedge genus *Scirpus* comp., and the macrophyte *Nymphoides*) dominating the water front. While some form of swamp forest was probably present throughout the Holocene at this site (variously characterized by taxa such as *Castanopsis*, *Quercus*, *Elaeocarpus*, *Calophyllum*, *Carallia brachiata*, *Eugenia,* and *Ilex*), it appears to have been most strongly developed below 110 cm depth (prior to 6330 ± 50 bp uncal., from an approximate interpolated age of 7900 bp uncal.). The very strong representation of *Nymphoides* pollen at this time is suggestive of high or rising lake levels, presumed to be related to a rising groundwater table as sea levels transgressed the

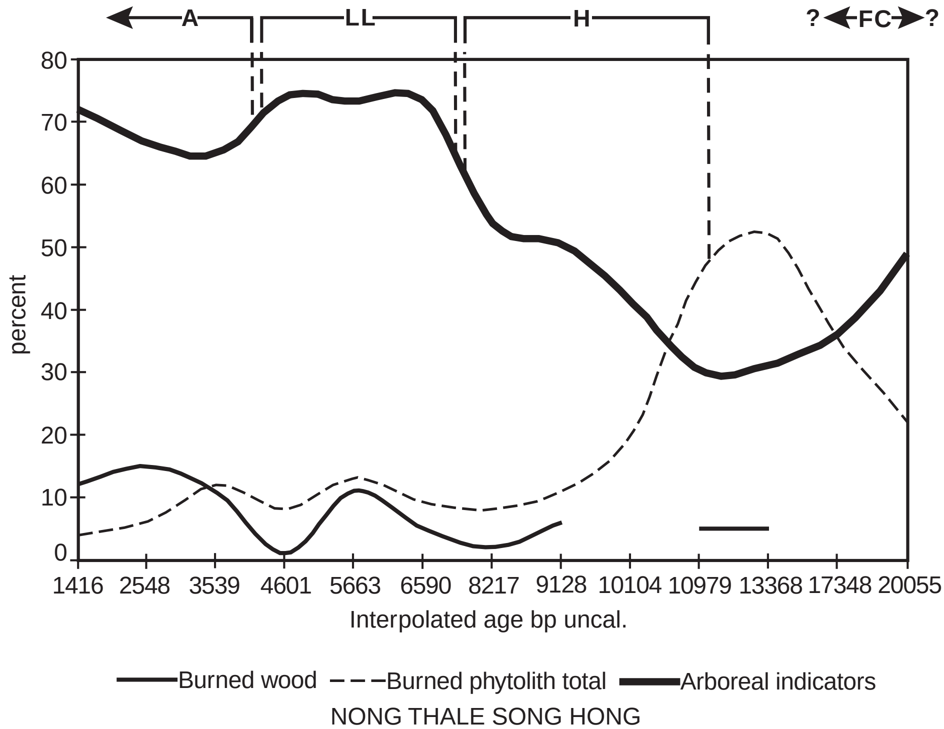


Fig. 2. Summary phytolith chart for NTSH (2TS) prepared by Kealhofer. For more detailed information see Kealhofer (2003). Dating is interpolated from sedimentation rates estimated from $^{14}C$ determinations. "Burned wood" indicates charcoal fragments that are remnants, often silicified, of largish charcoal particles that remain after nitric acid pretreatment. Burned phytoliths are those that encase black (charred) organic material and are sometimes slightly "melted." White added information on the cultural zones: FC = "flake and core" upper Palaeolithic industries; H = terminal Pleistocene to early Holocene Hoabinhian flaked core tool industry; LL = "late lithic" assemblages with flaked stone tools, and polished stone tools and/or pottery fragments; and A = pottery-using, presumably agricultural societies.

continental shelf and as annual rainfall increased as the southwest monsoon flow strengthened. Maloney (1999b, pp. 210–213) notes that disturbance indicators are present in this time frame, including a peak in regrowth taxa *Macaranga* and *Mallotus* ca. 10000 bp uncal., and peaks in charcoal ca. 10000 bp uncal. and ca. 8600 bp uncal.

A rise in dry forest, probably with a mix of deciduous and evergreen elements (Dipterocarpaceae, *Acacia*, Combretaceae and *Lagerstroemia*) on the slopes around the lake, particularly between ca. 7600 and 3300 bp uncal., is interpreted by Maloney (1999a, b) as an indication of edaphic dryness. The increasing importance of the regrowth tree *Macaranga* from approximately 7000 bp uncal., supported by slightly higher values of grass pollen and the fern *Lygodium*, may also reflect increasing dryness in the forests surrounding the lake. The development of this drying trend within the period of the early Holocene monsoon maximum, a period when soil moisture conditions should have been relatively high and unlikely to have impeded plant growth, is curious. The disappearance from the pollen record of the palm *Borassodendron machadonis* from ca. 4000 bp uncal., an indicator of everwet rainforest (Hodel, 1998), is strongly suggestive of locally dry conditions. Clear signs of disturbance are evident after 4000 bp uncal., with a dramatic and sustained rise in microscopic charcoal particle concentrations, indicating a rise in burning in the catchment, and increases in a number of disturbance indicators (including *Macaranga, Mallotus*, *Trema*, Urticaceae/Moraceae, and possibly *Schima wallichii*). Curiously, these developments are coincident with increases in possible swamp forest elements (*Elaeocarpus rugosus* comp., *Carallia brachiata*), the aquatic plant *Nymphoides*, and the fern *Lycopodium cernuum*, all of which are suggestive of locally wetter conditions. A number of useful plants such as *Palaquium*, *Piper*, *Areca*, and others (e.g., *Caryota*, *Corypha*, and *Mangifera*, recorded in only trace amounts and not shown in Fig. 3) are apparent, particularly above 15 cm depth (ca. 1500 bp uncal.), which Maloney interprets as direct conservation of specific forest resources by people. Charcoal particle values decrease above 15 cm depth, indicating a further change in fire activity in the catchment to, presumably, less intense/more frequent burns, which is consistent with the interpretation of an actively managed landscape.

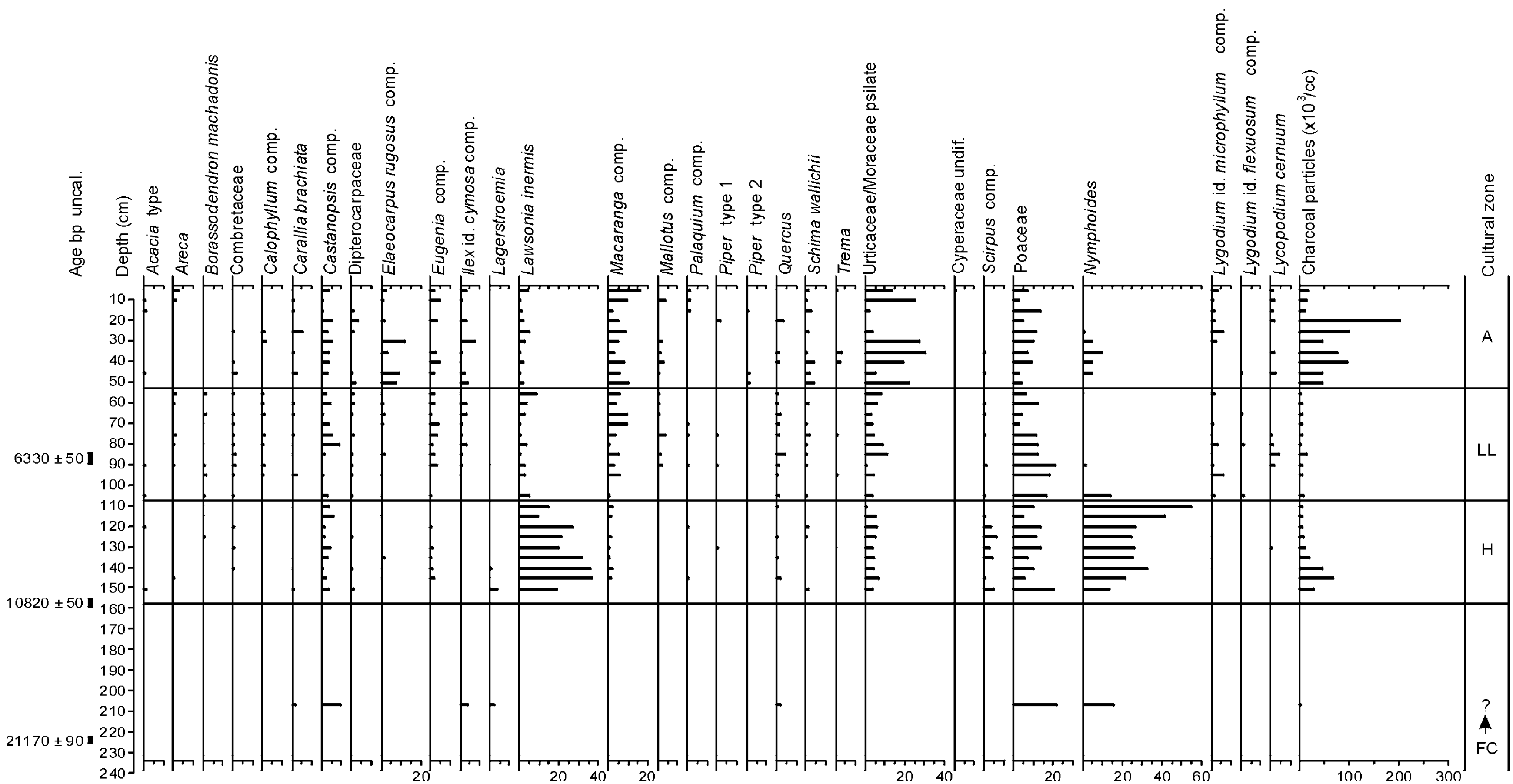


Fig. 3. Pollen diagram of selected taxa for NTSH (2TS) prepared by Penny from Maloney's data. White added information on the cultural sequence: FC = "flake and core" upper Palaeolithic industries; H = terminal Pleistocene to early Holocene Hoabinhian flaked core tool industries; LL = "late lithic" assemblages with flaked stone tools, and polished stone tools and/or pottery fragments; and A = pottery using, presumably agricultural societies.

The NTSH pollen and phytolith data indicate a very dynamic vegetation history that appears to have been influenced by a number of factors. Conditions are thought to have been generally too dry to permit the preservation of pollen (indicating permanently or seasonally dry sediments) prior to the terminal Pleistocene. The phytolith evidence dating from the last glacial maximum reinforces the interpretation of a dry late glacial period in the area. Late Pleistocene human groups in south Thailand using flake and core technologies, or at least the youngest example (Moh Khiew Cultural Level 2, Pookajorn, 1996) which falls somewhere between 26,000 and 11,000 bp uncal., likely had access to environments dryer than today.

Rising sea levels during the terminal Pleistocene/early Holocene appear to have exerted a strong influence on lake levels via a rising groundwater table, reflected by the strong development of marginal swamp forest and the coincidental association between the representation of aquatic plant pollen (*Nymphoides*) in the NTSH core and published sea-level curves for the Malay peninsula (Tjia, 1996). Increased rainfall associated with a strengthening southwest monsoon flow in association with the transgressive shore line is here assumed to have been an important influence on local hydrology also. Hoabinhian occupation of the area coincides with this dynamic period of increasing moisture and resultant forest development. Kealhofer (2003) suggests on the basis of the phytolith record that local hunter-gatherers responded to the expanding early Holocene forests by creating gaps and disturbance and thus maintaining weedy species.

Evidence of forest disturbance and possibly drier conditions on the slopes around the lake is apparent from the end of the early Holocene and roughly coincides with late lithic occupations in the area. It is not until ca. 4000 bp uncal. (ca. 2600 BC cal.), however, that pronounced changes in forest composition and fire regime occur. These pronounced changes are of probable natural and human origin, and they appear roughly 600 years before the time when archaeologists are confident of the presence of agricultural settlements (ca. 2000 BC cal., Bellwood, 1997, p. 259). There is clear evidence that useful plants were being either conserved or planted in the catchment from at least ca. 1500 bp uncal., (ca. AD 540 cal.). There is more equivocal evidence in the pollen record for forest clearance and horticulture earlier in the record (particularly the appearance of *Artocarpus* pollen from ca. 4400 bp uncal. (ca. 3115 BC cal.); Maloney, 1999a, b) during late lithic occupation in the region (e.g., contemporary with Moh Khiew Cultural Levels 5 and possibly 4; Pookajorn, 1996, pp. 206–207). Kealhofer (2003) argues from the phytolith record that by the end of the early Holocene changes in the forest structure suggest that local inhabitants were cultivating/managing forest species.

### 3.2. Kwan Phayao

In north Thailand, a 5.88 m core was extracted from the 20 km$^2$ lake, Kwan Phayao (19°10′N; 99°52′E; ca. 380 m ASL). The lake sits within an intermontane valley with surrounding terrain rising to 1500 m ASL. The lake is fed primarily from the north by the Mae Nam Ing, and is drained by the same river to the southeast. Today, this area averages around 1162 mm annual precipitation with a 6–7 month dry season with 5 months averaging less than 50 mm. Eighty-nine percent of the precipitation falls between May and October when the southwest monsoon is active. Mean annual temperature is 25°C with November–February being the coolest months and March–August the hottest. The region supports, on the lower slopes and valleys, mixed deciduous forests formerly dominated by teak (*Tectona grandis*) and Dipterocarpaceae, but now characterized by "weedy" secondary deciduous forest (Maxwell et al., 1995). Ecotonal forests with a strong evergreen component (particularly *Pinus merkusii*) occur on higher slopes (850–1000 m ASL), and evergreen pine forest (dominated by *P. kesiya*) occurs above 1000 m ASL.

Late Pleistocene hunter-gatherer occupation in north Thailand from just before the last glacial maximum (ca. 22,200 bp uncal.) has been recently documented at Tham Lod in the karstic environment 200 km to the west of Kwan Phayao in Maehongson province (Shoocongdej, 2002, pp. 17–18). Terminal Pleistocene/early Holocene sites with Hoabinhian stone tool industries (dated at Spirit Cave to ca. 11,350 bp–8505 bp uncal., ca. 11,450 BC–7550 BC cal.) have also been excavated in or near limestone rockshelters or caves in Maehongson province (e.g., Gorman, 1969, 1972; Shoocongdej, 2002). Late lithic deposits with pottery fragments and polished tools in predominantly flaked tool assemblages appear by the middle Holocene, based on a date of 5360 ± 120 bp uncal., (ca. 4205 BC cal.; GaK-4341) from GL2 at Banyan Valley Cave (Reynolds, 1992). Late lithic deposits may be as early as the seventh millennium BC cal. at Spirit Cave (Gorman, 1972), which would overlap dates for the late lithic in south Thailand. These Maehongson sites, generally found between 500 and 1000 m ASL, provide the most thoroughly published portion of the prehistoric sequence in northern Thailand. Reconnaissance surveys have identified flaked core tools and polished stone tools typologically attributable to Hoabinhian and late lithic settlement 80–100 km north and southwest of Kwan Phayao in Chiang Rai and Nan provinces, respectively (Sharp and Sharp, 1964; Koch and Siebenhüner, 1969; Pautreau et al., 1990). Iron age settlements are being uncovered 100–120 km west and southwest of Kwan Phayao. This late iron age occupation probably dates to the first half of the first millennium AD based on ceramic typology at Ban Wang Hi in Lamphun province

(Pautreau et al., 1997), and a date in the first millennium AD from Ban San Pa Kha, a similar iron age site in Chiang Mai province (Srisuchat, 1989).

There has been no systematic archaeological investigation close to Kwan Phayao. Although located at a greater distance from a known prehistoric cultural sequence than the other TPP coring locations, Kwan Phayao was selected for study because its geographic position and large size seemed likely to produce a regionally integrative and lengthy palaeoenvironmental sequence at a latitude and in terrain comparable to other parts of north Thailand known to have had prehistoric occupation.

The stratigraphically lowest dated horizon has a date of 19,190 ± 120 bp uncal. (Beta-099704; 546–548 cm depth), which indicates that the sequence dates from at least the last glacial maximum. The large age difference between Beta-106544 (527–531 cm depth) and Beta-099704 (546–548 cm depth) may indicate extremely slow or negative sedimentation rates at the core site, suggesting that the record is discontinuous preceding and/or during the terminal Pleistocene portion of the sequence. There are four ‘‘spikes’’ in pollen concentration values in the Phayao record (15, 144, 293, and 433 cm depth), which may reflect slow sedimentation rates if pollen influx to the core site is assumed to be near constant over time. The fact that none of these spikes occur in the Pleistocene section of the core, which has relatively low and stable pollen concentration values, may indicate that pollen influx to the site was low at that time (an interpretation not obviously supported by the pollen data) or, more probably, that drying and deflation of exposed sediments has destroyed evidence of higher pollen concentrations along with much of the late Pleistocene record.

Despite the fragmentary nature of the record, the Kwan Phayao pollen data, analyzed by Penny, imply greater stability during the late Pleistocene than other areas in Thailand (Fig. 4). The pollen data indicate dominance of pine and oak woodland throughout the late Pleistocene possibly indicating the occurrence of these presently highland plants at lower altitudes under a cooler-than-present temperature regime. The ground flora was dominated by the fern genus *Lygodium*, implying open-canopied woodland on relatively dry slopes. Values of sedimentary charcoal particles are low throughout the late and terminal Pleistocene and through much of the Holocene, suggesting that fires may have been relatively infrequent, in strong contrast to the NTSH charcoal record.

The presence of a definable Pleistocene/Holocene ‘‘boundary’’ is uncertain at Phayao given the apparently discontinuous nature of the sediment record during that time. Sedimentation rates appear to remain very low or negative throughout the early to middle Holocene and, consequently, interpretation of the palaeovegetation data during the early and middle Holocene is difficult. There are, however, very subtle shifts in the composition of the regional forests between 433 and 383 cm depth (an interpolated age range of 4500–1700 bp uncal.), with taxa such as Dipterocarpaceae (*Hopea/Shorea* type, *Dipterocarpus* type), *Macaranga* and Fagaceae (*Lithocarpus/Castanopsis* type and, arguably, *Quercus*) either not apparent or poorly represented during this period relative to the rest of the record. The significance of this is uncertain, but may reflect the development of drier conditions from the end of the middle Holocene related to a regional weakening of the southwest monsoon flow over Indochina (Maxwell and Lui, 2002).

The broad character of the regional vegetation appears to have changed very little by the time more rapid and (presumably) continuous sedimentation occurs in the late Holocene (centered around 1860 ± 50 bp uncal; ca. AD 170 cal.). The pine/oak woodland dominates the pollen influx to the site up to recent time, although the previously codominant *Quercus* is less abundant above 240 cm depth (earlier than 780 ± 40 bp uncal., at an approximate interpolated age of 900 bp uncal.). The dominance of pine throughout the Phayao record, even under a recent climate regime where pine communities grow on slopes around 470 m above the lake, reflects the extreme over-representation of this genus in the total pollen influx to the site. This over-representation of pine confounds an understanding of the spatial relationship between source and sink, and it is only below 560 cm depth (an interpolated age of roughly ca. 33,000 bp uncal.), where the average representation of *Pinus* pollen exceeds 90% of the pollen sum, that it can be said with some confidence that pine woodland occurred close to the lake. The dominance of pine pollen gives a strong impression of stability in the regional vegetation, possibly more apparent than real, but which is nonetheless in stark contrast to the evidence from south and northeast Thailand, where increasing temperature and precipitation at the end of the Pleistocene triggered substantial vegetation changes.

There are, however, clear changes in the Kwan Phayao catchment during the late Holocene. A decrease in the dominant dryland pollen types above 370 cm depth (after 1860 ± 50 bp uncal.; ca. AD 170 cal.; Beta-106543) is coincident with high values of sedimentary charcoal and the increased occurrence of regrowth taxa (particularly *Macaranga* and *Trema*) suggesting an increase in forest disturbance probably through burning. The calculation of simple linear sedimentation rates based on the radiocarbon chronology indicates an increase in the rate of sediment supply to the lake from this time. Increased productivity in the lake, caused by the increased influx of nutrients from the catchment, triggered ‘‘blooms’’ in green and blue-green algae and changes in the abundance of aquatic plants (Penny,

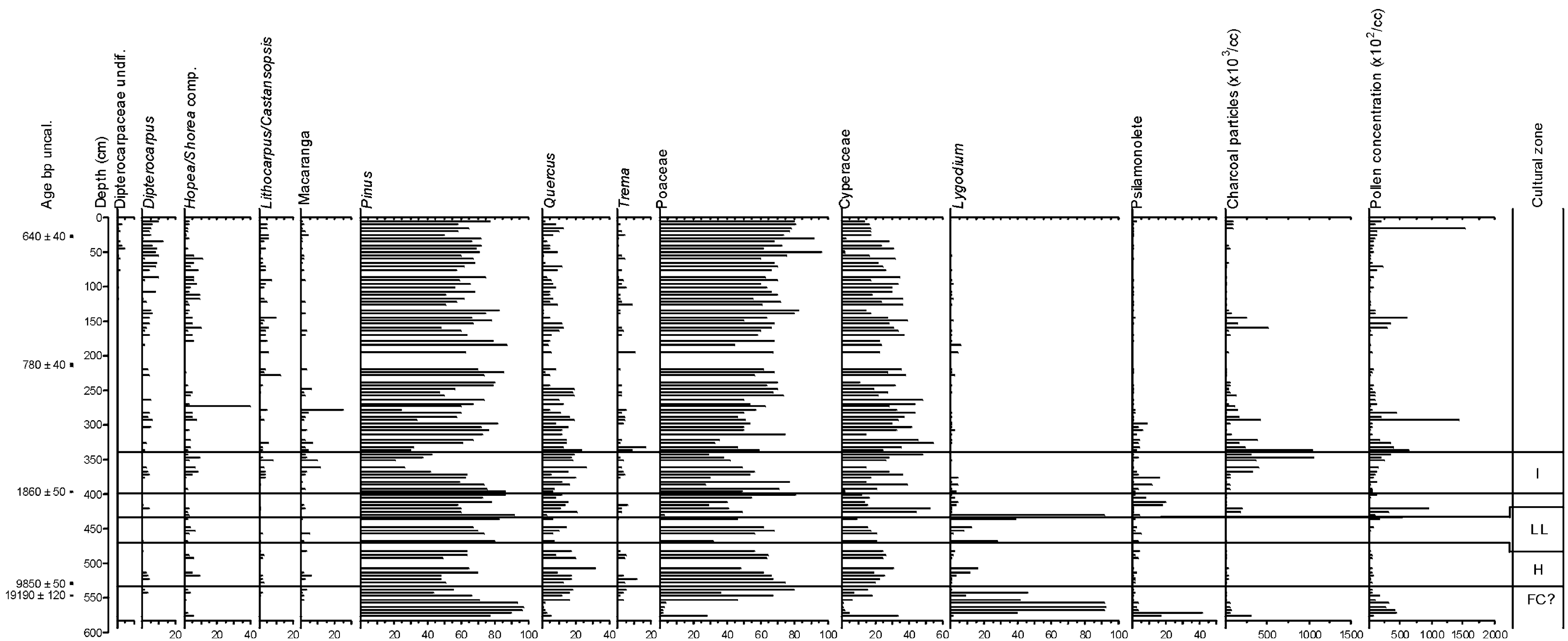


Fig. 4. Pollen diagram of selected taxa for Kwan Phayao (2PY) prepared by Penny. White added information on the cultural zones: FC? = late Pleistocene hunter-gatherers probably with a flake and core toolkit; H = terminal Pleistocene to early Holocene Hoabinhian flaked core tool industry; LL = "late lithic" assemblages with flaked stone tools, and polished stone tools and/or pottery fragments; and I = iron age (late), presumably agricultural societies.

unpublished data). In concert, these data are suggestive of slope mobilization following forest disturbance, possibly associated with the establishment or intensification of human land use in the high-relief catchment.

Relating the Phayao sequence to the known cultural record of north Thailand leads to several observations, although the distance from excavated archaeological sites and the problematic chronology of the Phayao record make any such observations necessarily tentative. The apparent continuity of a pine/oak dominated flora across the Pleistocene/Holocene boundary at Phayao suggests that the Hoabinhian and possibly preceding late Pleistocene hunter-gatherer occupations at higher elevations to the northwest of Phayao likely occurred in forests broadly comparable with those described by Smitinand (1989) as a subcategory of coniferous forest and classified by Stott (1976) as Dipterocarpus Pinetum-merkusii, both of which have a strong coniferous/Fagaceous component with many deciduous broadleaf species (notably genera of the Dipterocarpaceae). The strong representation of grasses and the fern genus *Lygodium* through much of the late Pleistocene and early Holocene implies an open canopied woodland and relatively dry slopes, perhaps indicative of a generally drier environment until the middle Holocene.

Middle Holocene late lithic occupation of northwest Thailand (by the fifth millennium BC cal. and possibly as old as the seventh millennium BC cal.) took place while only subtle vegetation changes are apparent in the Phayao record, such as reduced diversity and abundance of subdominant plant taxa, while pine and oak remain dominant. These changes are too subtle to interpret with confidence, but are perhaps consistent with the development of slightly drier conditions. *Lygodium* is markedly reduced above 450 cm depth, which has an approximate interpolated age of 6000 bp uncal., implying the development of a more "closed" forest relative to the early Holocene. There is no middle Holocene evidence for increased fire activity in the Phayao catchment.

The beginning of the marked changes in the Phayao pollen record for the last 2000 years (from about 370 cm depth) coincides with late iron age settlement in north Thailand which, although not yet identified in the immediate vicinity of Kwan Phayao, is documented 100–120 km to the west and southwest (Srisuchat, 1989; Pautreau et al., 1997). The initial acceleration in the rate of sediment supply to the lake, in concert with evidence for burning and forest disturbance, suggests strongly that an intensification of land use occurred from at least the 2nd century AD cal. Interestingly, the absence of obvious changes in the core suggestive of agriculture from earlier sediments, and the fact that no discrete late Holocene bronze age occupation has yet been clearly identified in northern Thailand, suggest that substantial environmental impact of agricultural societies in the greater northern region may have been later than in some other parts of Thailand.

### 3.3. Nong Han Kumphawapi

A 6.18 m core was extracted from Nong Han Kumphawapi, a 32 km$^2$ lake in the Udon Thani province of northeast Thailand (17°11′N; 103°2′E; ca. 170 m ASL). The main inflow to the lake is via the Huai Phai Chan Yai, which rises on the northwestern slopes of the Phu Phan range to the northeast of the lake. To the south Lam Pao drains the lake, although the diapiric salt mound of Ban Don Kheo impedes its drainage. The area averages 1521 mm annual rainfall (Ministry of Communications, Thailand, 1977, p. 15) and has a pronounced 6–7 months dry season with 5 months (November–March) averaging less than 50 mm precipitation.

Although Thai Forestry Department maps indicate that this region is virtually undifferentiated dry deciduous dipterocarp forest (Royal Forest Department, Thailand, 1962), ethnoecological research (White, 1995) supplemented by interpretation of aerial photographs dating from the 1950s indicates that a mosaic of natural vegetation types existed recently in this region (Fig. 5). Forests are mostly deciduous, but with edaphically influenced zones and pockets of semi-evergreen and riparian/inundated forests. The vegetation mosaic is reflected in a patchy distribution of a wide range of subtropical natural resources including wild rices, yams, and other useful and edible plants, as well as wild animals. Modern day agricultural societies take advantage of the landscape mosaic to maintain a broadly based cropping system, although dependent on inundated rice, including both swidden and horticultural techniques. Local residents also consume many non-cultivated foodstuffs (White, 1995). Nong Han Kumphawapi is located in the midst of a region noted for the prehistoric Ban Chiang cultural tradition, a series of settled societies with premetal, bronze age, and iron age phases (White, 1986).

Cores from Nong Han Kumphawapi, including the core 3KUM (termed KUM.3 in Penny, 1999) discussed here, have been the subject of several publications (Kealhofer, 1996; Penny et al., 1996; Kealhofer and Penny, 1998; Penny, 1999). The TPP core 3KUM, which has the oldest sequence from the lake, has a basal date of 12,270 ± 70 bp uncal. (ca. 12,700 BC cal.; Beta-72097; Table 1). Like NTSH and Kwan Phayao, the terminal Pleistocene data from Kumphawapi indicate a dry climate with a low representation of trees and low total species diversity. Phytolith evidence suggests that frequent burning of ground cover occurred during that period (Kealhofer, 1996, 2002).

The Holocene ushers in marked vegetation changes consistent with increased precipitation and conditions

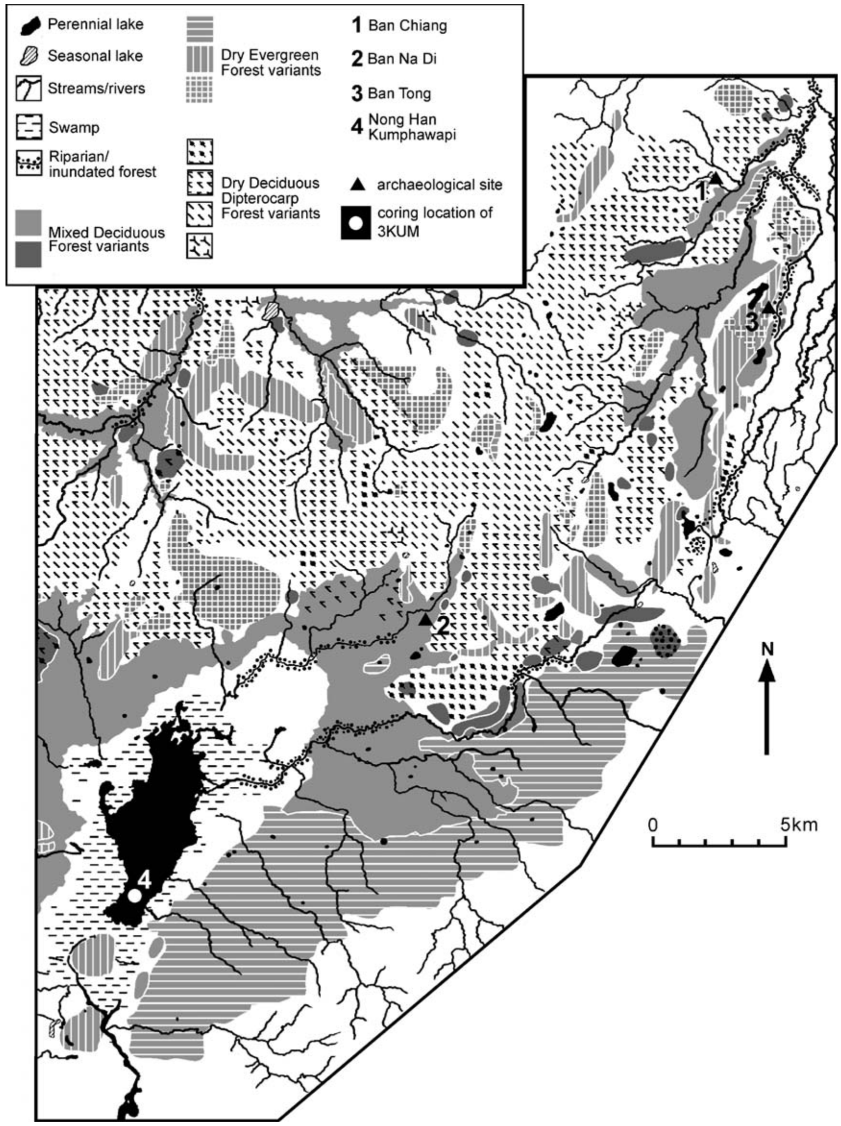


Fig. 5. Vegetation map of the Ban Chiang/Nong Han Kumphawapi region, prepared by White based on interpretation of aerial photographs from the 1950s in conjunction with the ethnoecological field research undertaken in 1979–1981 and 1994.

more humid than present. There is a gradual increase in the abundance and diversity of forest pollen types above 250 cm depth (ca. $8610 \pm 100$ bp uncal.; Beta-93030), and by the middle Holocene (170 cm depth) pollen taxon diversity is more than double that recorded during the terminal Pleistocene. Species composition at that time suggests vegetation comparable to modern day mixed deciduous/dry evergreen forests (Penny, 1998). The phytolith evidence (Kealhofer, 1996, 2002) shows a parallel shift in the grasses that are burnt from Panicoid (savannah-adapted) to Bambusoid (likely a ground cover of dry dipterocarp forests) during the Pleistocene/Holocene transition.

There is no undisputed Palaeolithic or early to middle Holocene habitation of the Kumphawapi catchment yet identified archaeologically, although Kealhofer (1996, 2002; see also Kealhofer and Penny, 1998) argues that the phytolith evidence from the early to middle Holocene suggests anthropogenic disturbance. The pollen evidence (Fig. 6) reveals several shifts during the Holocene (Penny, 1999) that have a number of possible explanations related to regional climate, changing local lake hydrology, and anthropogenic impact.

The existing archaeological sequence from the Kumphawapi catchment correlates roughly with the top meter of the 3KUM core in which there is pollen but no phytolith evidence. A peak in microscopic charcoal concentrations beginning at 90 cm depth appears to coincide with dramatic decreases in many dryland tree taxa (*Celtis*, Combretaceae/Melastomataceae, *Dipterocarpus*, *Lagerstroemia*, *Lithocarpus*/*Castanopsis*, *Macaranga*, *Trema*, and others) and an overall decline in diversity to levels comparable with the late Pleistocene flora. The high charcoal zone ends around 60 cm.

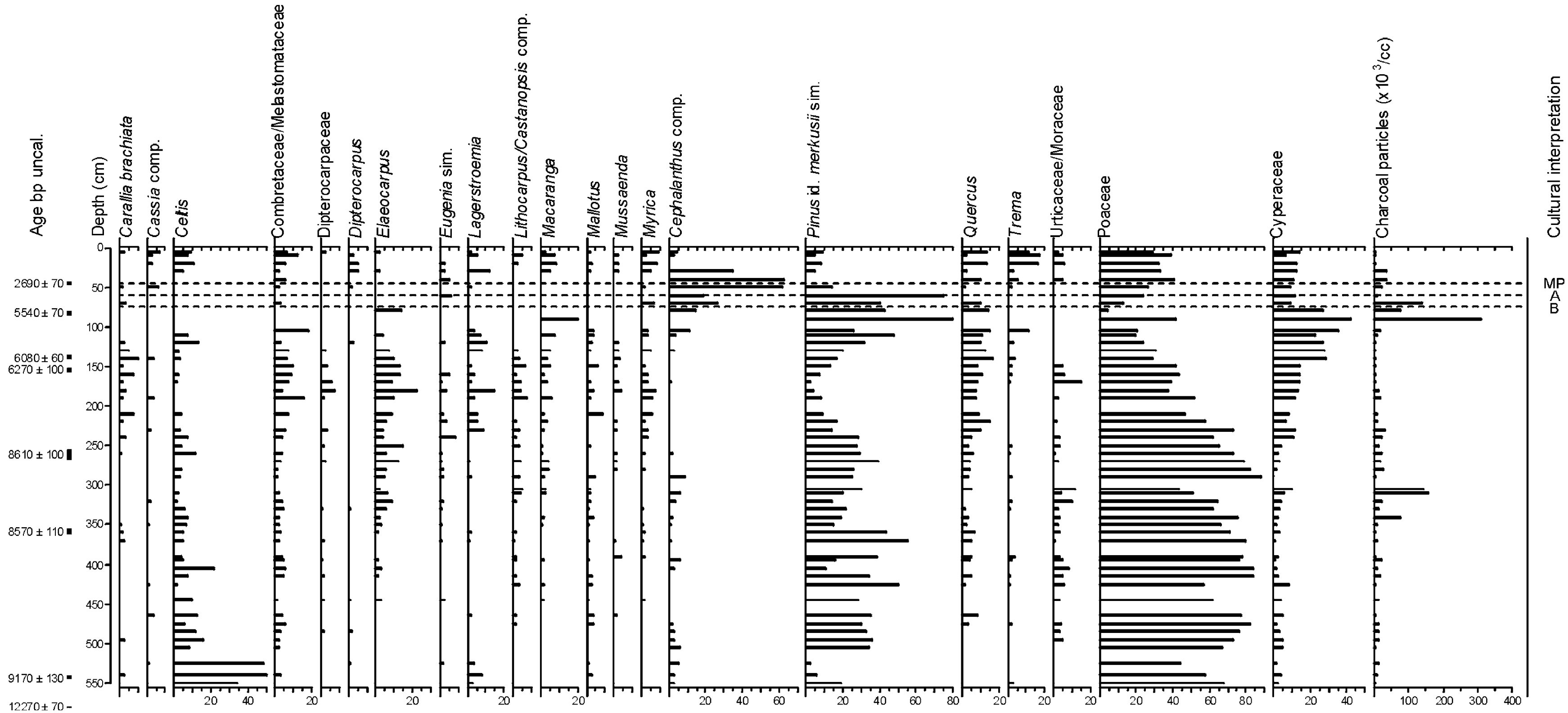


Fig. 6. Pollen diagram of selected taxa for Nong Han Kumphawapi (3KUM) prepared by Penny. White added information on the cultural interpretations discussed in the text: A = "interpretation A" for timing of appearance of agricultural societies in the Kumphawapi catchment based on archaeological evidence; B = "interpretation B" for timing by which agricultural societies appear in the Kumphawapi catchment based on archaeological evidence; and MP = beginning of Middle Period at Ban Chiang during which iron and water buffalo appear probably indicating the beginning of intensification of wet rice agriculture.

According to interpolated ages, the zone of disturbance lasts over 2000 years, from before approximately 5500 bp uncal. (based on Beta-93027 at 80–85 cm) to 3500 bp uncal. (i.e., the disturbance lasts roughly 4400–1800 BC cal.). Penny (1999) notes that this disturbance begins toward the end of a period that in other parts of Southeast Asia is documented as relatively humid (Maxwell and Liu, 2002).

With the beginning of the late Holocene—around 60 cm interpolated date of ca. 1800 BC cal.—microscopic charcoal concentrations have fallen relative to the very high values observed between 90 and 60 cm depth. *Cephalanthus* comp., likely a swamp forest tree (referred to as Naucleaceae in Penny et al., 1996), is the dominant contributor to the pollen influx. Several forest taxa reappear (*Dipterocarpus*, *Cassia*, *Eugenia*, and *Trema*) although the representation of these taxa is very low relative to their representation during the early and early middle Holocene. The main phase of "recovery" in forest cover, or perhaps a period of acceleration in forest recovery, dates from $2690 \pm 70$ bp uncal. (ca. 890 BC cal., at 45 cm depth; OZC-319). This main phase of recovery is characterized by a marked increase in the concentration and diversity of pollen taxa (including *Celtis*, *Dipterocarpus*, *Lagerstroemia*, *Macaranga*, *Mallotus*, *Mussaenda*, *Myrica*, *Trema*, Urticaceae/Moraceae, and possibly Combretaceae/Melastomataceae and *Quercus* also).

The relationship between these events and the climatic and cultural history of the region is a topic of discussion among scholars. Archaeologists disagree on when there is *archaeological* evidence for societies practicing plant cultivation in the Sakon Nakhon Basin. There are two main interpretations.

Interpretation "A" (e.g., Higham, 1996, p. 241; see also Bellwood, 1997, p. 255) argues, based primarily on dates in Thailand and elsewhere in Southeast Asia associated with a particular widespread ceramic decoration, that agriculture appears during the latter part of the third millennium BC cal. This would fall just below 60 cm in the 3KUM sequence. The implication of the 3KUM evidence for interpretation A is that agriculture appeared *after* a long period of forest disturbance and at a position in the core when the charcoal concentrations are declining sharply and the pollen evidence indicates that the forest began to recover.

Interpretation "B" (White, 1986, pp. 222–223, 1997) argues, based primarily on dates from basal deposits from Ban Chiang and Ban Tong, two long-term settlements in the Kumphawapi catchment, that societies cultivating plants appeared in the region *by* the mid-fourth millennium BC cal. This point falls roughly at 75 cm in the core—i.e., in the middle of the zone of disturbance.

Although no definitive conclusion can be drawn based on present data as to when plant cultivation appeared in the region and what impact it had on the environment, the existing data raise new issues to take into consideration. For example, the marked forest disturbance dating to the fifth and fourth millennia BC cal. evidenced in 3KUM occurs among taxa attributable to modern dryland dry- to mixed-deciduous forest (such as genera of the Dipterocarpaceae, with *Carallia*, *Elaeocarpus*, *Lagerstroemia*, *Myrica*, *Quercus*, and others). If the disturbance was due to plant cultivation, a targeted disturbance of this sector of the ecosystem argues for cultivation of upland species, perhaps with a horticultural or slash and burn cropping system, not the cultivation of wet rice as the primary initial cropping system used in this area.

Yet archaeological rice is present by the late third millennium BC cal. at Ban Chiang, and by the second millennium BC cal., settlement patterns appear to show a preference for locations where wet rice cultivation is possible (Kijngam et al., 1980). The cultivation of wet rice, which favors low-lying landscapes, tends to be much less invasive of dryland forest than slash and burn cultivation (White, 1995). Thus the changes in the palaeoenvironmental evidence in 3KUM beginning at 60 cm (the early second millennium BC cal.) for a decline in burning and the incipient recovery of dryland forest species, described above, might indicate a shift in emphasis in land use and cropping technology, away from upland and toward wetland niches, rather than the initial introduction of systematic plant cultivation to the region. The main phase of forest recovery beginning in the early 1st millennium BC correlates well with archaeological evidence from the site of Ban Chiang of possible archaeological indicators of agricultural intensification, including the appearance of iron and domesticated water buffalo during the site's Middle Period. (Cf. Kealhofer (1997) for discussion of phytolith evidence for changing cultivation strategies in central Thailand.)

However, without the identification of sites of plant cultivating societies dating to the fifth millennium BC cal., and with the sparse archaeological evidence for fourth millennium BC settlement, forest disturbance preceding the late third millennium BC cal. cannot be attributed unequivocally to plant cultivation and thus might be due to other causes such as natural forest fires or hunter-gatherer activities (e.g., Higham and Lu, 1998, p. 873). It is, on the other hand, unlikely that hunter-gatherer groups could be responsible for forest disturbance of the magnitude and duration apparent in the middle Holocene Kumphawapi pollen data, and the initiation of forest disturbance under a climatic regime probably wetter than today argues against a simple climatic interpretation (Penny, 1999). These attributes are more consistent with sustained and intentional anthropogenic activities usually associated with systematic plant cultivation. Moreover, archaeological evidence for hunter-gatherer occupation of the region has not been identified, and analogues for hunter-gatherers causing comparably profound destruction of vegetation come from significantly drier environments (e.g., Pyne, 1991). What is needed to resolve the issues raised by these data is additional archaeological and palaeoenvironmental research.

## 4. Discussion and interim conclusions

Although there are significant gaps and unresolved issues in both the palaeoenvironmental and archaeological data in the three areas of Thailand investigated by TPP, nevertheless, discussion and interim synthesis of the data to hand can serve to highlight areas of progress in our knowledge as well as outline topics for future research.

### *4.1. Last glacial maximum to late glacial period*

Evidence of Pleistocene-aged environments from the three TPP cores, although sparse and circumscribed by chronological uncertainties, points to a relatively dry and cool late Pleistocene in south, north, and northeast Thailand. The evidence from northeast Thailand is supplemented by the pollen record from Nong Pa Kho, close to Nong Han Kumphawapi (Penny, 2001), that indicates the presence of a glacial-aged flora comparable to the pine/oak vegetation observed at Phayao, but with a stronger Fagaceous component (*Quercus* and *Lithocarpus/Castanopsis*). Prominence of pine and oak have also been noted at a comparable period in cores from higher latitudes and altitudes in Yunnan (Lin et al., 1986; Sun et al., 1986). This evidence raises the possibility that much of northern Southeast Asia to southwest China may have supported a widespread pine/oak dominated vegetation under a cooler and probably drier-than-present climate. Although discontinuities in lake sediment sequences can have many local causes, that discontinuities in the pollen sequences during the late glacial period may exist in the Kwan Phayao, Nong Han Kumphawapi, Nong Pa Kho, and NTSH cores (likely caused by drying of the lakes) suggest a markedly drier climate at least seasonally for all three subregions during this time range. This relatively arid climate is consistent with the formation of a loess "mantle" across many areas of Southeast Asia (Šibrava et al., 1996), which has been tentatively dated to the late Pleistocene (Sanderson et al., 2001). It is noteworthy that, despite a growing number of palaeoenvironmental studies in mainland Southeast Asia, the vegetation of the last glacial maximum is yet to be fully described.

In the south of Thailand, NTSH lacks continuous pollen evidence for the late glacial period, although Kealhofer (2002, 2003) argues that the phytolith evidence (also noted above in Fig. 2) suggests a dry climate with grasses and sparse tree cover in the vicinity of the lake. There is no indication in the terminal Pleistocene/initial Holocene pollen assemblages from NTSH, however, to suggest that the pine/oak association noted for more northerly latitudes might have extended this far south. Moreover, conditions on the west coast of the Malay peninsula may have been relatively wetter than the northern interior of mainland Southeast Asia during the last glacial maximum and late glacial period, given the relatively narrow continental shelf off the west coast (Voris, 2000) that may have provided a more maritime influence on regional climate. Closer to the equator, at Nee Soon swamp in Singapore (Taylor et al., 2001), taxa found today in tropical montane contexts were found at lower elevations during the late glacial period, indicating cooler-though not necessarily drier-than-present climates during the late glacial period. Nee Soon, like many studies in the Indonesian archipelago (Flenley, 1985; cf. Flenley, 1996), provides evidence for cooler temperatures and the lowering of temperature-controlled vegetation belts in the equatorial tropics prior to the Holocene, and possibly more seasonal although not necessarily lower total rainfall at this latitude (Taylor et al., 2001, p. 284).

Burning is in evidence in all three parts of Thailand during the late Pleistocene, but apparently to different degrees. The phytolith evidence in south Thailand (Fig. 2) suggests that fire was common, and high levels of charcoal are also noted further south at Nee Soon for this period (Taylor et al., 2001). Phayao has evidence for relatively infrequent burning during this period, but burning may have been more common in northeast Thailand (Penny, 2001, p. 123), despite similar vegetation cover. This difference may reflect the development of a more pronounced dry season in northeast Thailand during the late Pleistocene, in addition to strong pre-existing edaphic and topographic differences between the two regions.

The implications of these contrasting vegetation and fire histories for late Pleistocene human occupation of the region can only be addressed superficially at this point. Future archaeological research may yet document human habitation in northeast Thailand dating to the late Pleistocene; late Pleistocene archaeological faunal assemblages recently excavated in northern Thailand are not yet published in sufficient detail to permit examination of the evidence for human exploitation of specific environmental contexts. Only in south Thailand can we begin to examine a relationship between the environment and archaeological evidence for human occupation for this time.

Faunal remains from archaeological sites provide dated evidence, independent of sediment records, for habitats, human exploitation strategies, and their changes over time. Although Kealhofer (2002, p. 183) argues on the basis of NTSH phytolith evidence that woodland savannah supporting large grazing animals would have been present in southern peninsula Thailand during the late Pleistocene southern peninsular Thailand, late Pleistocene archaeological fauna from this region indicate the presence of a vegetation mosaic and clear human interest in forest-dwelling species. The fauna listed by Pookajorn (1996) for Moh Khiew cave Cultural Levels 1 and 2 (the only Pleistocene-aged archaeological deposit with published fauna in south Thailand) show no overt focus on fauna specializing in grazing savannahs. Cultural Level 2, itself undated but which falls between ca. 26,000 and 11,000 bp uncal. based on dates from Cultural Levels 1 and 3, is the archaeological deposit closest in time to the NTSH Pleistocene phytolith sequence.

The fauna listed for Moh Khiew Cultural Level 2 demonstrate a focus on resources from a variety of forest habitats. Although many faunal taxa are not identified to species and thus are of limited use for environmental inferences, several that are, include browsers preferring forest-to-forest edge habitats (e.g., *Muntiacus muntjak*, *Tragulus javanicus*); large mammals living in denser arboreal habitats (*Helarctos malayanus*); and small mammals ranging from upper canopy to ground level dwellers such as *Arctogalidia trivirgata* and various members of the orders of Primates and Rodentia. A variety of mollusks were also found. Although savannah-preferring grazers are not identified in Cultural Level 2 at Moh Khiew, earlier late Pleistocene deposits do include grazers. *Bubalus bubalus* was identified in Moh Khiew Cultural Level 1 predating ca. 26,000 bp uncal.; and the Lang Rongrien late Pleistocene fauna from stratigraphic units 7–10 dating between ca. 27,000 and 43,000 bp un cal. does include grazers (e.g., *Cervus eldi*), along with forest dwelling browsers, and marsh and streamside dwellers (Karen Mudar, personal communication, 2002).

In summary, the existing archaeological evidence for late Pleistocene southern Thailand shows that people in southern Thailand had access to and exploited habitats ranging from dense forests to more open niches. Archaeologists will point out that the majority of late Pleistocene archaeological sites were likely drowned with the Holocene rise in sea levels and thus lost to archaeological visibility, and that the absence of excavated open air assemblages is another significant bias. Nevertheless, the habitat preferences of late Pleistocene fauna from Moh Khiew and Lang Rongrien imply that a mosaic of vegetation types with variation in openness did exist in peninsular south Thailand during this period. This archaeological evidence demonstrates the role of archaeology in multi-proxy assessment of palaeoenvironments and indicates that the late Pleistocene environment and its relationship to human occupation in south Thailand are more diverse and complex than revealed at NTSH. In this regard, Maloney (1999b, p. 214) cautioned that the NTSH vegetation evidence is better for detecting habitat changes in the immediate vicinity of the lake rather than regional climatic events or regional evidence for human environmental impact.

The causes of the burning that was clearly present in the south during the late glacial period are as yet uncertain, even though it is in all likelihood a preagricultural context. Studies of hunting and gathering strategies employed by living groups show that fire is a convenient and often-used tool for both hunting and plant collecting and hence unlikely to have been ignored in ancient times (Pyne, 1991; White, 1995, pp. 58–59). On the other hand, naturally caused fires are a common feature of many seasonally dry vegetation types, and charcoal can be prominent in core sediments whose deposition is known to precede the appearance of humans (e.g., late Pleistocene/early Holocene Madagascar (Burney, 1987); see also Kershaw et al., 1997). Distinguishing one cause from another, or their relative impact at any given point in time, will require much thoughtful analysis incorporating a wide range of evidence, and will be particularly complex when both natural and cultural causes have a high potential for being present.

### *4.2. Terminal Pleistocene to early Holocene*

TPP cores offer evidence that there may have been variability in the timing, degree, and nature of impact of the Pleistocene/Holocene transition and the early Holocene monsoon maximum in each subregion of Thailand. Pollen and phytolith data from northeastern Thailand (Kealhofer, 1996; Kealhofer and Penny, 1998; Penny, 2001), and phytolith data from southern Thailand (this paper; also Kealhofer, 2002, 2003) show an expansion of arboreal vegetation in response to increased precipitation as the southwest monsoon strengthened over the period 12,000–9500 bp uncal. Pollen data from the south (Maloney, 1999a, b) and north of Thailand (this paper; Penny, unpublished data) do not record this transition in detail. The pine/oak forest so common in pre-Holocene assemblages in the north of the country was rapidly replaced in the northeast by both deciduous and evergreen broadleaf taxa at the outset of the Holocene. However, pine/oak dominated vegetation appears to have persisted in the northwest, suggesting *prima facie* that the impact of changing climates at the Pleistocene/Holocene transition may have been much more muted (or less apparent in pollen records) in the continental highlands than elsewhere in Thailand.

Alternatively, the remarkable difference in early Holocene biogeography between the northeast and the northwest need not reflect subregional climatic differences, but rather simply reflect the differential response to Holocene changes of two areas close in latitude but with marked topographic differences. In the mountainous northwest it was possible for cool-adapted forests to retreat relatively short horizontal distances to higher altitudes in response to rising temperature and precipitation and, by virtue of the pollination strategies of the codominant genera, remain strongly represented in the pollen influx to the intermontane valleys. This is not the case in the northeast, a landscape of low relief, where the cool-adapted coniferous forests must have retreated considerable horizontal distances to occupy very small areas of refugia, such as the plateau of Phu Kradung in Loei province of northeast Thailand (ca. >1200 m ASL). Such an interpretation is consistent with the modern disjunct distribution of conifers in Thailand (Stott, 1976, pp. 53–55; Werner, 1997; Richardson, 1998, pp. 24–25), and may explain the extraordinary divergence of the north and northwest of Thailand in terms of their biogeographic development at the outset of the Holocene.

It is noteworthy that Maxwell (1999, 2001) reported a delayed occurrence of the Pleistocene/Holocene transition at Cambodian lowland lakes, beginning about 8500 bp uncal., or about 1000 years later than southwest China (i.e., at Dianchi, Sun et al., 1986). The TPP cores emphasize this variability in the timing and character of the Pleistocene/Holocene transition in Southeast Asia. This variability may relate, in part, to the variable width, sill depth, and slope of continental shelves and their variable rate of inundation during the most recent deglaciation (Maxwell, 2001, p. 398). That the gulf of Thailand may have been dry until well into the Holocene may account for a delay in the onset of moist conditions in northeast Cambodia. The continentality of northeast Cambodia would have been markedly increased during the late glacial maximum, lasting into the period of deglaciation. At a sea level 100 m below present levels, northeast Cambodia would have been more than 1100 km from the southwest margin of Sunda. Slow penetration of a warm shallow sea into central Sunda during the early Holocene, to form what is now the Gulf of Thailand, may have had significant implications for timing of increased rainfall in northeast Cambodia, which is dependent on the gulf for its summer rainfall today. Kripalani et al. (1995) have demonstrated that parts of Cambodia are significantly out of phase with the southwest monsoon under the present climate regime, whereas northern and northeast Thailand are found to be in phase (Kripalani et al., 1995; Kripalani and Kulkarni, 1997). This subregional variability in the effects of the southwest monsoon may reflect the direct influence of rain-bearing monsoon winds from the Indian Ocean and the Andaman Sea on northern and northeast Thailand, areas that may have been less dependent on the Gulf of Thailand as a source of moisture and thus showed the effects of the Holocene transition earlier than parts of Cambodia.

More or less coterminous with the terminal Pleistocene and early Holocene was the development and probable north to south spread of "Hoabinhian" technologies—a lithic industry characterized by cobble stones flaked on one side. The TPP data indicate that Hoabinhian societies existed and expanded during a period when most of mainland Southeast Asia experienced dynamic forest development and diversification under conditions of increasing annual rainfall, albeit with varying degrees of seasonality. On the other hand, the Phayao record did not reveal environmental changes in the terminal Pleistocene to early Holocene time frame for northern Thailand. Although Kealhofer (2002, p. 185) argues that changes in burnt phytoliths from the early Holocene at Kumphawapi as well as central Thailand indicate "that people were managing the landscape from the beginning of the period," the pollen data from Kumphawapi and Phayao show no evidence for anthropogenic burning or vegetation impact in this time frame. There is modest evidence in the pollen record for some disturbance in the NTSH core during the early Holocene (and unlike northeast and central Thailand there is contemporaneous evidence for early Holocene Hoabinhian occupation in the south), but that disturbance cannot be unequivocally attributed to human activities (Maloney, 1999b, pp. 210–213).

Although the proposal that Hoabinhians were plant manipulators/domesticators (Gorman, 1969) has not gained widespread acceptance among archaeologists (e.g., Higham and Thosarat, 1998, p. 31), food remains found in Hoabinhian sites show that humans at that time exploited a wide range of environmental niches (Gorman, 1971; Higham, 1977). While many Hoabinhian sites reveal what archaeologists call "broad spectrum" hunting and presumably gathering from forested contexts, on the other hand, other Hoabinhian sites show more focused resource exploitation, including shell fish in coastal and riverine contexts, and, at Tham Phaa Can in the northern Thai uplands in the middle Holocene, large ungulates, some of which favored open environments (Higham, 1977, p. 411).

In northern Thailand during the late Pleistocene/early Holocene Hoabinhian period, the relevant published faunal remains suggest only subtle temporal and spatial variation, possibly related to the, at best, muted environmental changes for this period in that region implied by the Phayao evidence. However, faunal remains from early Holocene levels at sites in south Thailand, while together showing an array of habitat exploitation, also show site-to-site and possibly temporal variation in species composition that probably reflects the range of habitats close to each of the sites.

Lang Rongrien (Kijngam, 1990) has the strongest evidence for large mammal hunting reflecting a range of closed canopy and more open environments. The decrease from stratigraphic unit 6 to 5 (dating ca. 9600 bp uncal. to ca. 7500 bp uncal.) among deer species in the proportion of open habitat grazers *Cervus eldi/C. porcinus* relative to forest preferring browsers *Muntiacus muntjack* and *Cervus unicolor* perhaps reflects the post-Pleistocene reduction of open patches and closing in of the forest in south Thailand with increased rainfall during the early Holocene. Eight kilometers away at Moh Khiew in Cultural Level 3 (dates ranging from ca. 11,000 to 8500 bp uncal,) fewer species of large mammals are present (none of which are grazers), and upper canopy primates (absent at Lang Rongrien) and squirrels are important. That grazers were present during the Pleistocene at Lang Rongrien but not identified at Moh Khiew Cultural Level 2 reinforces the impression that despite their proximity, Lang Rongrien and Moh Khiew had somewhat different exposure to open environments, and the reduction of open habitats with the onset of the Holocene affected this component of faunal resources at Lang Rongrien more than at Moh Khiew. Sakai Cave Cultural Level 1, dating ca. 9000 bp uncal. with a Hoabinhian assemblage, has no ungulates, but does show focus on primates, probably reflecting its more interior position, higher elevation, and likely less patchy and more densely forested environment relative to the other two sites (Pookajorn, 1996).

In summary, the environmental context during the terminal Pleistocene and early Holocene of mainland Southeast Asia appears to have been rich and diverse in resources, complex and dynamic in terms of its vegetation. Humans appear to have developed skill sets and tool kits that were generalized enough to employ in a variety of tropical environments and an interest in a variety of forested contexts in the different subregions. Yet they were capable of focused exploitation of narrow niches, thus overall able to take advantage of their rich array of options.

### 4.3. Middle Holocene

The middle Holocene is at once a problematic and critical time-period for understanding the interactions between humans and the landscape. During this period, environmental changes associated with a regional weakening of the southwest monsoon flow over South and Southeast Asia obfuscate the impact of humans on the environment.

In this article, we suggest that the evidence from NTSH reflects both cultural and natural influences on environmental conditions during the Holocene, including the period prior to the unequivocal emergence of agriculture in the area. We also point out above and elsewhere (Penny et al., 1996; Kealhofer and Penny, 1998; Penny, 1999) reasons to favor or at least seriously consider cultural interpretations for the changes in the Kumphawapi core (evidence for burning and coinciding major forest disturbance) beginning by about 5500 bp uncal. (ca. 4400 BC cal.). On the other hand, recent palynological evidence from Ratanakiri province, north-east Cambodia (Maxwell, 1999, 2001), reveals increased burning and vegetation changes dating from ca. 5300 bp uncal. (hence about two centuries after changes appear in Kumphawapi) that are interpreted as evidence of a drier and more seasonal climate from this time.

That these two spatially disparate sites (ca. 600 km apart) should reveal broadly similar vegetation changes with near synchronicity raises important issues. While Maxwell (2001) favored a climatic interpretation of the Ratanakiri data, the archaeological record for the region (Kojo, 1998), though meager, was not considered in the interpretation of the Ratanakiri lake sequences (indeed, the sites were chosen for coring due to their perceived remoteness from nearby recent and ancient human settlement; Maxwell, 1999, p. 129, p. 210, 2001, p. 391; see also Maxwell and Liu, 2002, p. 215.) Although only undated sites are reported from a rapid reconnaissance survey (Kojo, 1998), most of the sites appear to be 30 km or less from the Ratanakiri pollen sites. The remains found at these localities primarily included polished adzes, which are considered likely of neolithic and/or bronze age, thus middle to late Holocene (no bronze artifacts were found, but it is known that polished adzes were used during the Southeast Asian bronze age.) Although favoring a climatic interpretation for middle Holocene changes, in his doctoral dissertation, Maxwell (1999, p. 226) pointed out, as we do here, that it is at present "impossible to say with confidence that the changes… are primarily attributable to climatic change, or… to human control of the fire regime."

Contributing to the uncertainty concerning the role of humans in vegetation change during the middle Holocene is the scarcity of archaeological evidence published in detail for this period, and the inconsistent manner in which archaeologists have interpreted that evidence. Middle Holocene assemblages often have both flaked and polished or edge-polished stone tools, and/or ceramic fragments. These latter two elements have resulted in some difficulty in developing terminology for these assemblages. Should they be considered "Neolithic" (Aung Thaw, 1973; Reynolds, 1990, p. 15; Pookajorn, 1996, p. 206), even though domesticated fauna have not been observed, and arguments for plant cultivation have been largely dismissed? Or a distinct phase of the Hoabinhian such as a "late Hoabinhian" (Pookajorn, 1990, p. 22)? Are ceramics associated with Hoabinhian lithics intrusive (Shoocongdej, 1996, p. 212; Higham and Thosarat, 1998, p. 30)? Terminology thus far developed for these assemblages is unhelpful as it has

Table 2
Late lithic deposits associated with middle Holocene dates in Thailand, Cambodia, and Myanmar (Burma)

| Site | Level | $^{14}$C determination bp uncal. | Lab no. | Material | Associated artifacts | References |
|---|---|---|---|---|---|---|
| Padah-lin | 1B, Tr. I, layer 2 | 6570±125 | R2547/2 | Charcoal | Flaked lithics, pottery, edge ground tools | Aung Thaw (1973) |
| Banyan valley | GL2 | 5360±120 | Gak-4341 | Charcoal | Flaked lithics, pottery, edge ground knife | Reynolds (1992) |
| Khao Talu | Cultural Level II | 4520±430<br>4215±95 | OAEP-107<br>OAEP-054 | NA<br>NA | Flaked lithics, pottery | Pookajorn (1990) |
| Heap Cave | Culural Level II | 4350±400<br>4100±300 | OAEP-154<br>OAEP-153 | NA<br>NA | Flaked lithics, pottery | Pookajorn (1990) |
| Moh Khiew | Cultural Level 4 | 7060±100<br>6090±150<br>5940±140<br>5590±70 | OAEP-1277<br>OAEP-1278<br>OAEP-1289<br>OAEP-1291 | NA<br>NA<br>NA<br>NA | Flaked lithics, pottery, polished adzes | Pookajorn (1996) |
| Moh Khiew | Cultural Level 5 | 4240±150 | OAEP-1290 | NA | Flaked lithics, pottery, polished adzes, bone tools | Pookajorn (1996) |
| Kbal Roméas | Shell midden, 50 cm thick | 5370±140 | Gif-872 | Shell | Pottery, lithics unknown | Carbonnel and Delibrias (1968), Carbonnel (1979), Bronson and White (1992)[a] |
| Phnom Laang | Top level 50 cm thick | 4370±135 | Gif-1167 | Bone Collagen | "Bacsonian", bone tools | Carbonnel and Delibrias (1968), Carbonnel (1979), Bronson and White (1992)[a] |
| Laang Spean | Cultural level II | 6240±70 | MC-273 | Charcoal | Flaked lithics, pottery | Mourer (1977), Carbonnel (1979)[a] |

[a] There are slight discrepancies in reporting these dates among these references.

connotations that confound the issues further (Reynolds, 1990, pp. 12–13), which is why we use the more neutral phrase "late lithic" here for these distinctive middle Holocene cultural assemblages.

Late lithic assemblages are not uncommon in mainland Southeast Asia during the middle Holocene, even if not well understood or fully described. Sites with late lithic deposits associated with dates in the middle Holocene have been found in south, west, and north Thailand, Cambodia, and Myanmar (Burma) (Table 2). They frequently but not exclusively overlie classic Hoabinhian deposits. Even though the dating and stratigraphic integrity of some of the examples listed in Table 2 have been questioned (e.g., Reynolds, 1990), the middle Holocene dating and stratigraphy for the recently summarized remains at Moh Khiew Cultural Level 4 (Pookajorn, 1996, p. 206) are convincing for two reasons. Not only are the four dates internally consistent with each other and dates from higher and lower levels, but the Moh Khiew stratigraphy correlates reasonably well at several points with the sequence at nearby Lang Rongrien. That other deposits probably attributable to the late lithic and datable to the middle Holocene have been found in Phangnga and Surat Thani provinces (Srisuchat, 1989) indicates that Moh Khiew Cultural Levels 4 and 5 reflect a possibly widespread late lithic occupation in south Thailand in that time frame.

Banyan Valley and Laang Spean are also examples whose reports convincingly argue for a stratigraphic relationship between middle Holocene dates and associated ceramic fragments. Although outside of our immediate area of concern (west of the Annamite range), middle Holocene cultures in Vietnam such as the Dabut culture (Bui Vinh, 1991) have been more fully defined and exhibit shifts in settlement locales as well as the addition of ceramics and polished stone tools to the material culture. Viewing the available evidence, it is clear that human technologies in mainland Southeast Asia were changing during the middle Holocene, even if the details in terms of land use remain to be fully investigated and described.

Although archaeologists working in Thailand and Cambodia have yet to focus on the late lithic period, *prima facie* the development of polished stone tools implies working with wood, and the appearance of ceramics implies changes in cuisine and hence subsistence/land use strategies. Whether or not we can identify unambiguous archaeological evidence for plant cultivation during the middle Holocene remains a question for the future. On the palaeoenvironmental side, a more sophisticated approach is required to identify the impact that various possible land use strategies might have on various Southeast Asian vegetation types. More detailed study of the region's ecology of land use with a focused effort to identify impact on the taxa preserving in the pollen and phytolith records will assist in distinguishing changes in cores attributable to climate variations from changes due to human efforts to replace natural with cultivated vegetation. Although a full discussion of the possible land use strategies of early plant cultivating societies in the region is beyond the scope of this article, the importance of upland slash and burn and horticultural techniques in traditional Southeast Asian cropping strategies has long been recognized. Rice grown under inundation, with cropping techniques that range from extensive to intensive, will likely impact natural vegetation differently than the upland cropping techniques. That these land use strategies might also differ in their impact (and thus appearance in lake sediment evidence) depending on preceding vegetation type, soils, population density, how the land use strategies were combined with each other, along with other variables, will likely also need to be considered.

### 4.4. Late Holocene

Changes occur in the palaeoenvironment record from the beginning of the late Holocene that also may have both human and natural components. In the northeast, evidence for sharp decline in burning and incipient stages of forest regeneration during the early second millennium BC cal. roughly coincides with the development of bronze age culture and the documented occurrence of archaeological rice (White, 1997).

The main phase of forest regeneration, centered around the early first millennium BC cal. (OZC-319, Table 1) generally coincides with evidence for presence of iron and water buffalo, hence the presence of technologies that can be useful for intensification of wet rice cultivation. Contemporaneous changes in the Ratanakiri cores suggested to Maxwell (2001, p. 399) a stronger southwest monsoon flow, but he argued elsewhere that these changes could be equally related to a change in anthropogenic fire use—from irregular, intense, and indiscriminate burns to controlled, low-intensity ground-cover burns that have a muted impact on forest trees and produce less aerial charcoal (Maxwell, 1999, pp. 227–228). Almost an identical interpretation was put forward by Penny (1998, p. 195) to explain the forest recovery at Kumphawapi—i.e., a shift from the unmanaged burning of forests to the controlled burning of herbaceous ground cover (e.g., rice stubble and agricultural weeds). (See, however, Kealhofer (1996) for an argument on the basis of phytolith evidence that a shift in the Kumphawapi catchment from unmanaged anthropogenic understory burning to managed burning of field weeds occurred much earlier—by the middle Holocene.)

In the south, beginning some centuries before the late Holocene, changes in tree pollen and increases in sedimentary charcoal demonstrate forest clearance presumably for upland agriculture, with some possibly useful plant species selectively conserved (Maloney, 1999b). These changes somewhat precede the most commonly given date of 2000 BC cal. or just prior for the earliest archaeological evidence from west-central to south Thailand and down to Malaya for more settled and presumably agricultural cultures (Bellwood, 1997, p. 259). This change in land use likely overwhelms any climate change signal for this period.

Interestingly, a recovery of tree pollen is apparent in the Nong Thale Hong Song pollen record dating from approximately 1100 bp uncal. Exactly what this might mean in terms of land use changes is not yet clear. At that time, historic kingdoms and trading states were engaged in constant shifting of power balances in both mainland and island Southeast Asia, and there may have been associated changes in population density and subsistence regimes. Maloney (1999a, p. 136) suggested that the frequency of shifting cultivation may have become less in the last few hundred years at that site, and the emphasis in land use stressed conservation and planting of useful trees in the NTSH catchment.

In the north at Phayao, evidence consistent with forest clearance comes later than south or northeast Thailand—not until the late iron age (ca. AD 170 cal.; Beta-106543). The rapid sedimentation associated with evidence for burning and vegetation disturbance would be consistent with an intensification of upland cultivation (Turkelboom et al., 1997), broadly contemporaneous with late iron age settlements to the west and southwest.

### 4.5. Summary

The TPP research has documented diversity in the palaeoenvironmental picture of late Pleistocene and Holocene Thailand. While much research in both archaeology and palaeoenvironmental reconstruction remains to be done, the asynchronous patterning of charcoal peaks and variable vegetation changes among not only the inland cores from Thailand, but also including those from Cambodia, leaves the impression that anthropogenic environmental impact has an important role in explaining past vegetation changes and was regionally markedly variable, not fitting a single chronological or land use scenario. Moreover, the evidence available suggests that an interaction between subregional climate variability, including the development and regional history of the monsoon system, and subsistence and land use strategies existed that affected subregional vegetation histories. Study of this interaction will likely assist in the interpretation of cores from lake sediments. However, in order to be able to specify sequential relationships more precisely, much more refined subregional chronologies for both archaeological and palaeoenvironmental data will be required than are currently available. Study of the ecological and successional relationships among vegetation types and land use strategies will also assist in core interpretation. Finally, more comprehensive implementation of multiproxy methodologies, including comparing and cross-checking results among data sets, will enrich and increase validity among environmental reconstructions. These conclusions heighten the importance of coordinating archaeological and palaeoenvironmental research in order to achieve the most meaningful interpretations of past environmental evidence.

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