The Excavation of Khok Phanom Di

A Prehistoric Site in Central Thailand

Volume IV: Subsistence and Environment: the Botanical Evidence

The Biological Remains (Part II)

By

G. B. Thompson

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(The Biological Remains, Part II)

By

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PREFACE

KHOK Phanom Di is a large prehistoric site located in Chonburi Province, Central Thailand. This is the fourth of a series of volumes which will report on the excavations we undertook there in 1985 as part of our project on the prehistory and early history of the lower Bang Pakong Valley. We are deeply indebted to many individuals and their institutions for the support which has made this project possible. First, we owe a debt to our respective institutions, the University of Otago and the Fine Arts Department, for allowing us the time and resources to devote to research in the Bang Pakong valley.

Financial support for the programme and subsequent analyses was provided by a number of institutions. The Ford Foundation through Dr Thomas Kessinger, then representative in the South-East Asian Regional Office in Jakarta, provided funds to underwrite excavation costs and for Pirapon Pisnupong, Rachanie Thosarat and Phrapid Choosiri to undertake research on the data in New Zealand. The Shell Company of Thailand Limited assisted by the provision of a vehicle and a computer. To M.R. Sarisdiguna Kitiyakara, Chairman, and Precha Phonpraserth, Public Affairs Manager, we offer our thanks for such support, and for the enthusiasm of their visits to the site.

Major assistance was also provided by Earthwatch and its Research Corps, the Wenner-Gren Foundation, the University of Cambridge through its Evans Fund, New Zealand University Grants Committee and the British Academy. The costs of publishing this volume have been defrayed by grants from the Society of Antiquaries of London and the University of Otago.

The palaeoethnobotanical research reported here was supported by postgraduate grants from the Australian National University and the Commonwealth Scholarship and Fellowship Plan of the Association of Commonwealth Universities. At the Australian National University, Professors Jack Golson and Douglas Yen, Dr Mike Smith and Dr Gurdip Singh together supervised Jill Thompson's doctoral dissertation and she would also like to thank Professor T.-T. Chang, Dr Duncan Vaughan, Eva Loresto and Carina Zuño at the International Rice Research Institute for their hospitality and access to their research collections. In Bangkok, advice on the modern Thai flora was generously provided by Dr Kenji Noda, Prasan Suwannamek and Chanpen Prakongvongs (all at the National Weed Science Research Institute), Professor Tem Smitinand and Dr Chewalit Niyomdham at the Royal Thai Forest Department, and Assistant Professors Kosum Pyramarn and Bussaban Na Songkla at the Botany Department of Chulalongkorn University. Songkran Chitrakon of the Rice Research Centre at Pathum Thani provided specimens of wild rice for SEM analysis, as did Professor Chang.

Ethnobotanical fieldwork was carried out with Anat Bamrungwongswe, and we would like to thank him and his family, members of the monastery and the village at Khok Phanom Di, and Vidya Intakosai and his diving colleagues at Sattahip for their kind support during the 1986-7 field season.

Scanning electron microscopy was carried out in the Research School of Biological Sciences at the Australian National University, under the guidance of Roger Heady, Mike Ciszewski and David Vowles. Professor David Harris and Gordon Hillman are thanked for the use of laboratory facilities for coprolite analysis at the Institute of Archaeology, University College London, and Drs. Venkatachala and Haripal Singh provided access to research and library facilities at the Birbal Sahni Institute of Palaeobotany at Lucknow. Wood identifications were provided by Dr Jugo Ilic of the CSIRO in Melbourne and Yvonne Pittelkow at the Australian National University carried out the statistical analysis of the charcoal assemblages. Dragi Markovic and Ian Faulkner of the Research School of Pacific and Asian Studies at the ANU and Martin Fisher and Leslie O'Neill of the University of Otago prepared the plates and figures for this publication. Dr Peter Bellwood, Associate Professor William Boyd and Drs John Flenley, Jon Hather, Lisa Kealhofer, Deborah Pearsall and Nancy Tayles have all commented on earlier drafts of this volume. All are warmly thanked for their contributions.

We acknowledge the invaluable support of the Society of Antiquaries of London in its support for this series.

Most of all, we acknowledge the contribution made by Dr Jill Thompson in this volume, linked with our colleagues Dr Lisa Kealhofer, Dr Dolores Piperno and Mr Graeme Mason.

I. KHOK PHANOM DI: INTRODUCTORY REMARKS

C.F.W. Higham and R. Thosarat

KHOK Phanom Di is a prehistoric settlement located in Chonburi Province, Central Thailand. It covers approximately 5 ha, and rises to a height of just over 12 m above the surrounding rice fields. Following a series of limited excavations by Suchitta (1984), Noksakul (1981) and Pisnupong (1984), we formulated a programme of research which involved a site survey and excavations in a series of sites. These were designed to illuminate the pattern of prehistoric adaptation to one of the world's richest habitats in terms of primary production, the tropical estuary and coast.

A substantial excavation at Khok Phanom Di was always high on our agenda, because its depth, linked with a series of radiocarbon dates obtained by Noksakul, suggested a long sequence. As was reported in the first volume of the excavation report, the set of radiocarbon dates obtained by us indicated a shorter time span than we had anticipated, with initial occupation at about 2000 BC and abandonment five or six centuries later (Higham and Bannanurag 1990a). Excavations lasted for seven months, and we worked within a single square measuring 10 x 10 m. We encountered eleven major layers, although in truth much of the very deep layer ten comprised numerous lenses, some thick and easily followed, others very thin and of limited extent. Where possible, we followed and mapped these lenses as well as the many pits, postholes and other features encountered. But otherwise, we divided our layers into 10 cm 'spits'. When Jill Thompson refers below to such contexts as layer 7:4, or 10:20, the first figure refers to the layer number, and the second to the spit within.

Shortly after the excavation was finished, we wrote a preliminary report in which we divided these layers into three major zones, A, B and C. These recognized the fact that zone A involved the very fine lensing described above, zone B saw these replaced by more uniform deposits and a relative lack of lenses comprising shellfish, and zone C again differed in colour, texture and content. The relationship between the layers and zones is set out in figure 1.

During the accumulation of zones A and B, we encountered many burials, laid out as a rule with the head orientated to the east, and in discrete clusters which formed a chequerboard pattern. Many of the lenses and pits were probably associated with mortuary rituals (Higham and Bannanurag 1990a). We subdivided the burials into successive mortuary phases from MP1–7, and their stratigraphic placement is included in figure 1.

In volume 2 of the excavation report, our colleagues reported on part of the extensive assemblage of biological remains which we recovered (Higham and Bannanurag 1991). The range of data and taxa was extraordinary, including pollen, mammalian, bird, turtle and fish bone, crustacea, shellfish, forams, ostracodes, beetles and parasites. The consensus was that Khok Phanom Di was initially located near the estuary of a major river, which provided access to the estuarine and coastal resources and water transport. With time, however, coastal progradation and possibly a major relocation of the river channel distanced the inhabitants from the estuary.

Volume 3 of our report covered the material culture with the exception of the ceramics (Higham and Thosarat 1993). The occupants of Khok Phanom Di had access to clay deposits and these sus-

tained a pottery industry which will be fully described by Brian Vincent in volume 6 of this series. They also obtained shell, fish bone and turtle carapace for conversion into jewellery. Freshwater bivalves were converted into knives, which were probably used in rice harvesting (Higham 1993), and stone hoes were also found (Pisnupong 1993). Other major artefact forms included stone adzes, bone fishhooks and awls and sandstone abraders. There is, however, no evidence for copper or bronze.

When planning this excavation, we were particularly conscious of the need to implement a programme to retrieve plant material. This, to our knowledge, had never been undertaken consistently during the course of excavating such a lowland site, and we felt it likely that we would encounter rice remains in one form or another. In 1984, we were contacted by Jill Thompson, with the proposal that she join our team in order to study the palaeoflora. We accepted her offer gratefully, and she spent some days before the excavation commenced in late December 1984 supervising the construction of a flotation facility on site. This was greatly assisted by the willingness of the Abbot of Wat Khok Phanom Di to allow us access to the temple water supply.

For the ensuing months, Jill supervised the flotation programme, a period which saw a change of plan in April to continue excavations into the rainy season. This involved flotation under the most difficult circumstances, and a reduction in the sample size. But the rewards were to be seen daily in the growing sample of charcoal, seeds and rice remains.

Once the excavation was complete, we were faced with the dilemma of an academic environment within which the plant remains could be properly examined. In the event, Professors Jack Golson and Douglas Yen of the Australian National University recognized the importance of the material, and supported the award of a scholarship which enabled Jill to pursue her research in the context of preparing a doctoral dissertation. We all owe a deep debt to Jack Golson for his contribution to the completion of both the dissertation and this volume. The University of Otago provided Jill with a postdoctoral fellowship, which gave her the opportunity to finalise the text below.

The reader will find a meticulously detailed description of the plant remains, which illuminates the changing environment of the site's occupants, and highlights the problems and potentials of life in the coastal tropical habitat. The section on the rice remains explores the central issue of determining whether prehistoric material comes from a domesticated or a wild variety. Despite the relative abundance of rice remains from prehistoric East and South-East Asia, there are few full botanical reports. Jill Thompson has concluded that the inhabitants of Khok Phanom Di cultivated rice.

During the final stages of preparing this text, it became clear that the research undertaken on the phytoliths obtained from deep cores taken in the vicinity of the site by Bernard Maloney was nearing completion. This new avenue of research in South-East Asia, pioneered by Lisa Kealhofer and Dolores Piperno, complements the conclusions reached by Jill Thompson, who willingly agreed that a chapter on phytoliths be included in her monograph. During the flotation procedure, numerous very small gastropods were recovered and, again, Graeme Mason's analysis was completed as this text was being finalised. We acknowledge both Jill's agreement to including his results below, and the contributions made by Mr Mason and Drs Kealhofer and Piperno.

All these conclusion will be incorporated with the results from other studies on the excavated material from Khok Phanom Di when, in the planned seventh and final volume of the series, we attempt to place the site within its wider context.

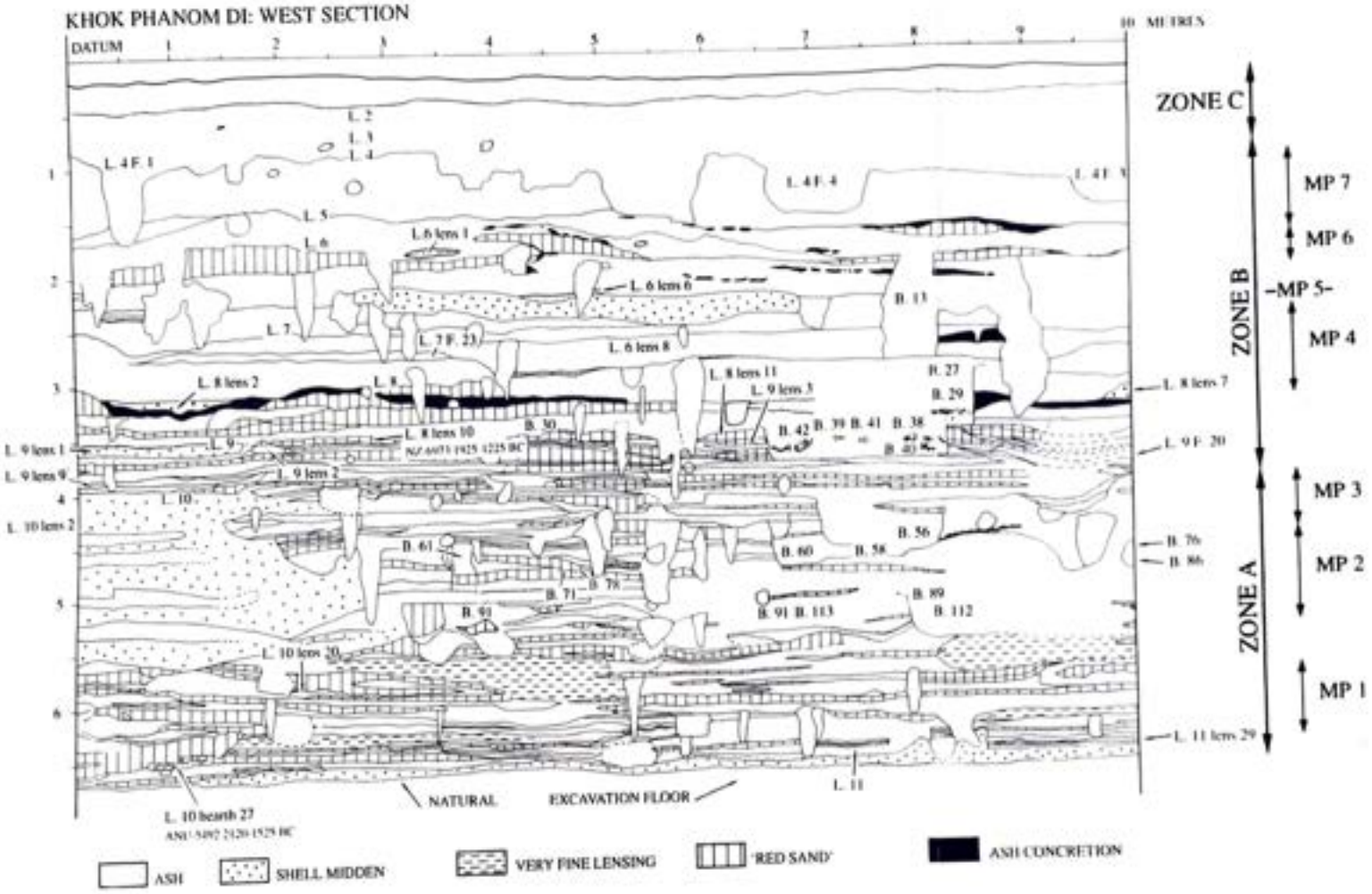


FIG. 1. The west section of Khok Phanom Di, showing the relationship between layers, zones and mortuary phase

II. INTRODUCTION

BACKGROUND TO THE RESEARCH PROBLEM, HYPOTHESIS FORMULATION AND RESEARCH STRATEGIES

THIS volume deals with the recovery, identification and interpretation of plant remains excavated from Khok Phanom Di during 1985 (Fig. 2). It takes as its focus the prehistoric environmental setting and the reconstruction of human-plant relationships, especially the roles of wild and cultivated plant foods in the diet. The area under consideration comprises the mangrove swamps and adjacent plains around the estuary of a major river, perhaps the ancestral Bang Pakong, in Central Thailand and the time is the second millennium BC. Mangrove adaptations were noted as a priority area for research by South-East Asian archaeologists meeting in Phangnga and Bangkok in 1987 (SPAFA 1987:16, 26) and ethnoarchaeological approaches in particular were singled out as appropriate means of addressing the problem. It is hoped that this study will contribute to these areas of archaeological research.

The mound of Khok Phanom Di was first recognized as a human, prehistoric rather than a natural feature during the mid 1970s, when a road was cut through to the summit and to the monastery being built there. Initial investigation of the deposits involved the stratigraphic recording of exposed sections along the roadcutting, followed by two excavations. These produced samples of mangrove/mudflat molluscs *Anadara nodifera*, *Polymesoda erosa* and *Cerithidea obtusa*, many fishbones, and chelae of the crab *Scylla serrata*. Together these suggested that the site had once been located on a higher shoreline (Suchitta 1980, Noksakul 1981, Pisnupong 1984). As has been outlined earlier (Higham and Bannanurag 1990a), five factors pointed to the possibility of finding evidence for early rice cultivation here: the chronology, the ecology, the evolving environment, the concentrated population density and the apparently sedentary nature of the occupation.

First, the site was thought to have been occupied on a higher shoreline, 2–4 m above present, then dated to about 4000 bc (Geyh *et al.* 1979, Tjia 1980, Tjia *et al.* 1983). Dating from the mound supported this. A charcoal sample from 3.8–3.9 m depth in the roadcutting which, from the contours of the mound was roughly the midpoint of the full stratigraphy, provided a MASCA-corrected radiocarbon date (RL-1202) of 1950 +/- 350 BC (Suchitta 1984:10). Samples of human bone from the 1979 excavation by Noksakul provided dates of 6410 +/- 400 bp (uncalibrated) and 6800 +/- 420 bp (Bannanurag 1989:19) from contexts 2 m above the natural deposits under the base of the mound. These, together with the absence of metal from any of the three investigations, led to the inference that the earliest occupation at Khok Phanom Di was in the sixth or seventh millennium BC. The considerable depth of cultural deposits, up to 12 m in some parts of the mound, was also taken to suggest a long sequence of prehistoric occupation (Higham 1984).

Thus, the initial chronological framework was considered to indicate that the occupation at Khok Phanom Di might overlap with the earliest domesticated rice from China. At that point, in 1984, the evidence for this was from Hemudu and Luojiajiao (both in Zhejiang Province on the lower Yangzi Valley) in the fourth to fifth millennium BC (You 1976, Sun *et al.* 1981, Liu 1985, Zhao and Wu 1986-7). Yet the Chinese evidence from the Yangzi valley sites could not be said to



FIG. 2. Air photograph of Khok Phanom Di. The mound is seen as a circular, dark vegetated area in the centre of the figure. Scale, 1 km:55 mm

reflect incipient agriculture because these were established agricultural communities. The critical process of the development of agriculture remained enigmatic in the East and South-East Asian archaeological record.

Second, the postulated ecological situation of the site, with possible access to ephemeral freshwater swamps behind chenier ridges, contributed to a hypothesis that the site might yield not only the remains of domestic rice but also evidence for the transition from the use of gathered wild grasses to cultivated cereals (cf. Higham 1984, 1990). The trigger to adopt new resource exploitation strategies was hypothesized as being environmental instability brought about by fluctuating land-sea relations. Under this scenario, coastal resources including stands of wild rice were thought to have been removed from the site catchment, and rice was gradually brought into cultivation in order to maintain supply. This is in line with the suggestion that the initial isolation of wild plants from their cultivated relatives took place as people moved food plants out of their natural habitats into new environments (Burkill 1952).

In 1985 a team of archaeologists and palaeoecologists from the University of Otago, the Royal Thai Fine Arts Department and the Queen's University, Belfast, set out to examine Higham's hypothesis by marshalling evidence from a number of different directions, from palynological studies of sediment cores taken around the site, to a major excavation at the centre of the mound, where macroscopic plant remains were recovered by flotation. Indications of incipient domestication were therefore sought in much the same way that Yen and Gorman had examined the Ban Chiang plant remains, looking for evidence of the transformation from wild to cultivated *Oryza* during the occupation there (Yen 1982).

In addition to expectations of finding evidence of the prehistoric economy and environment, the archaeobotanical work was viewed as an exploratory case-study in the retrieval of macroremains from a dry, open, low-latitude site. The preservation of plant remains under these conditions, and in the Asian tropics, had long been doubted (cf. Glover 1979:11) and their systematic retrieval by flotation was yet to prove successful in Thailand (pers. comms. A. Clarke and I. Glover, Welch and McNeill 1988-89). Processing the flotation samples was straightforward and the field techniques employed are described in chapter III.

At the outset the plant remains were approached from the perspective that they constituted a set of material from a protracted period, possibly of several millennia, and from a timespan when rice had been brought into domestication, on the basis of evidence elsewhere. Nowhere, however, was there undisputed and published archaeobotanical evidence of rice spanning the foraging to farming transition at a single location, such as that for barley in the Jordan Valley (Kislev *et al.* 1986) and for einkorn wheat and rye at the Middle Euphrates site of Tell Abu Hureyra. Even at Abu Hureyra a stratigraphic hiatus separates the Epipalaeolithic settlement from the possibly intrusive, intensive plant husbandry of the later aceramic Neolithic (Hillman *et al.* 1989). It was considered possible that an equivalent record for rice might be preserved at Khok Phanom Di.

The objectives were reformulated as information became available about the site. Some time after the 1985 excavation, as the radiocarbon chronology began to emerge, the dating of the initial occupation was revised upward, first and tentatively to 4000 BC (Higham *et al.* 1987) on the basis of dates from the central phase of the site. This was again revised to 2000 BC, once the stratigraphically lower samples had been processed (Maloney *et al.* 1989). It became apparent that the site was not only significantly younger than anticipated, with an initial occupation around 2000 BC, but that the deep accumulation of occupation debris was the result of very rapid deposition taking

place over a relatively short, five or six hundred year period. In the light of the revised chronology, and under the long-held conventional view of slow and gradual domestication processes, the plant remains from Khok Phanom Di, and especially those of rice, were eventually examined more in terms of assemblage diversity than of temporal change. New experimental and simulation data (Hillman and Davies 1990a, 1990b) indicating that the period over which phenotypic change may be induced in cereals by reaping and reseeding was radically shorter than was previously believed, has reduced aspirations of detecting *in situ* domestication in the archaeological record in general, though the rapid deposition rate at Khok Phanom Di confers an advantage in this respect.

SOUTH-EAST ASIA AND THE ORIGINS OF TROPICAL AGRICULTURE

Mainland South-East Asia, with its rich biotic diversity and a wide range of plants susceptible to domestication, has long been seen as the home of many cultivated food plants (de Candolle 1884, Haudricourt and Hédin 1943, Pelzer 1948, Vavilov 1951, Sauer 1952, Barrau 1970, Li 1970). Besides rice (*Oryza sativa*)*, these include tubers like taro (*Colocasia esculenta*) and the other aroids *Alocasia macrorhiza* and *Cyrtosperma chamissonis*, as well as the greater and lesser yams (*Dioscorea alata* and *D. esculenta*). The cultivated cereals of the region are Japanese barnyard millet (*Echinochloa frumentacea*) and Job's tears (*Coix lachryma-jobi*), both gradually being replaced by the dominant staple, rice. Tree and shrub crops are also prominent, with these often semi-domesticated plants, for instance breadfruit (*Artocarpus altilis*), contributing carbohydrates. Fruit-bearing treecrops with South-East Asian origins include *Citrus sinensis*, *C. aurantifolia* and *C. aurantium* among others, and protein- and lipid-rich nuts include Indian almond (*Terminalia catappa*) and candlenut (*Aleurites moluccana*) (Harris 1981).

Agricultural antecedents in South-East Asia have attracted the attention of ecologists, geneticists, geographers and archaeologists. Foremost among these has been the American cultural geographer, Carl Sauer (1952), who proposed that the first agricultural experiments were carried out in South-East Asia, and that this was the primary agricultural hearth of the Old World from which the idea of agriculture spread. He envisaged the first agriculturalists as settled fishing communities with access to adequate food supplies, and the time and motivation to experiment with plant cultivation. In some respects, the Khok Phanom Di community resembles Sauer's hypothetical riverine setting. An associated hypothesis that vegetative planting of tubers such as yams, preceded cereal cultivation is one which was then, and remains still, difficult to test. An increasing awareness of archaeobotany in the region, linked with improved methods for identifying tuberous remains (Hather 1991) is, however, improving prospects. Sauer's unsubstantiated but influential theory, based on strong diffusionist concepts, was formulated at a time when archaeological evidence for mainland South-East Asia was very scarce. Mangelsdorf (1954:90), in a review of *Agricultural Origins and Dispersals*, critically concludes:

> A theory almost completely lacking in factual basis may still be stimulating and provocative and may be especially useful if it can be subjected to critical tests which would prove it wrong. I can think of no such tests to apply to Sauer's theory. His two

* Authorities to Latin names are those in the *Flora of Java* except where otherwise stated, and the Thai vernacular names are listed in Smitinand (1980)

> principal hearths occur in regions where few archaeological remains have so far been found and where the climate almost precludes the long-term preservation of herbaceous cultigens. Practically all of his conclusions, although unsupported by evidence, are still virtually impossible to disprove. Indeed if one sought, as an exercise in imagination, to design a completely untestable theory of agricultural origins and dispersals, it would be difficult to improve on this one. In creating such a theory, the author has at least demonstrated that there are still huge gaps in our knowledge of man's history.

Those gaps persist in mainland South-East Asia, where data pertinent to agricultural histories remain patchy. Although the revised age of the Khok Phanom Di plant remains means that they cannot directly address questions of agricultural origins, they may nevertheless contribute to the debate about the processes of rice domestication, especially in the context of associated pollen and phytolith analysis.

ARCHAEOBOTANICAL RESEARCH IN MAINLAND SOUTH-EAST ASIA

The Khok Phanom Di archaeobotanical research needs to be considered against the current palaeoethnobotanical knowledge of the region. The data set is not large. At the time of writing plant remains have been reported (in English) from fewer than twenty five Thai prehistoric sites dating prior to 2000 BP. The overwhelming majority of these reports describe a single taxon, rice, usually simply in terms of its presence or absence from the site. The search for early rice cultivation has been the major motivation for archaeobotanical research in South-East Asia. The second main stimulus for archaeobotanical reports, if not always for systematic research, has been the retrieval of occasional, individual and conspicuous remains from archaeological sites, such as the wooden coffins from Ongbah Cave (Sørenson 1988) and the historic-period shipwrecks from the Gulf of Thailand (Howitz 1977). These wrecks have provided waterlogged wooden artefacts including planks, pegs, bamboo and rattan walling, as well as the boats themselves and their perishable cargoes.

Archaeobotany in Thailand has been strongly integrated with ethnobotanical research. This is partly because the inception of prehistoric archaeology there took place when such themes were being explored worldwide, but also because, in regions such as this where there had been little success in recovering plant remains, what archaeobotanical evidence there was, was better understood in the light of ethnobotanical models of plant exploitation. The plant remains might offer pointers to the wider economy of the site, which could be set in context by reference to current practice.

Examples of this approach are seen in the work of Yen (1977, 1980, 1982), who made plant collections in the north of the country while working on the plant remains from Spirit Cave, Tham Pha Chan, Banyan Valley Cave and Ban Chiang. The ethnoecological approach was particularly well developed at Ban Chiang by White (White 1982a, 1982b, 1984, 1989). Her method was complementary to Yen's assemblage-focused research, as she conducted an in-depth study of a single village community and its plant resources, in order to address questions which are not readily answered by the archaeobotanical record alone.

Archaeobotanical analyses of material from Hoabhinian sites in the Ban Kao district of west-central Thailand (Pookajorn 1984, 1987, Pyramarn 1989) were integrated with the study of contemporary plant use, especially medicinal applications, by the Mlabri, a forager group living in

the north-west of the country (Pookajorn 1990). These studies underscored the conclusions about early- to mid-Holocene broad-based foraging strategies by upland groups, based on the plant remains from Spirit Cave and Banyan Valley Cave, which provided evidence for stimulants, medicinal, poisonous and adhesive plant products, as well as nuts and tree fruits (Gorman 1969, Yen 1977).

Evidence of rice from archaeological sites has primarily been used for tracing the phylogenetic and biogeographical evolution of the cultigen (e.g. Chang 1976a) rather than to consider the place of the crop in the community's economy and diet. The economic and social role of plant remains from archaeological sites has generally been overlooked in favour of the larger story of crop evolution (Dennell 1976). The initial approach to the retrieval of plant remains at Khok Phanom Di followed this traditional path, but the archaeobotanical data which emerged during this analysis have been used here in new and site-focused ways. In the analysis of the rice remains in particular, new methodologies and cryptic identification criteria have been explored, as diagnostic characters have not always been made explicit in the literature, and the strength of future interpretations rests on the credibility of the basic plant identifications. Extensive notes on methods, identification criteria and metric data are set out for the benefit of other specialists. Greater detail than in most archaeobotanical reports is warranted here as we are still at the stage of developing working practices in South-East Asian archaeology, especially in the little-tried field of archaeobotany. It is hoped that this will help stimulate debate on practical methods for working with plant materials from tropical sites in Asia.

The following chapters describe the archaeobotanical fieldwork carried out as part of the Khok Phanom Di project; both the retrieval of the plant remains from the site during the 1985 excavation and the ethnobotanical fieldwork in the region during 1986-7, when a reference collection for identifying the prehistoric material was assembled. A critical approach to sampling methodology and identification criteria is emphasized, so that underlying assumptions are made explicit and the results may be assessed in terms of the techniques and sampling strategies which generated them. The main classes of plant remains from the site (charcoal, seeds and rice) are discussed at length in three succeeding chapters, with the applicability of the archaeobotanical method to a number of research questions demonstrated in each material-related chapter. The issues considered include: which plant taxa are identified from the archaeological deposits and what were their possible uses? What can be inferred about the site's surroundings and what kinds of environmental constraints were imposed on the people living at Khok Phanon Di? Is there evidence for change in plant taxa during the site's occupation and could these reflect changing local ecology that is human-induced or natural? Was this an agrarian community? If so, what kind of food production systems might have been in place, and how did plants gathered from the wild contribute to the food supply?

Chapter IV deals with the charcoals and woods as a basis for reconstructing the arboreal vegetation around the site and explores the evolution of its environment in the context of changing land-sea relations. Chapter V examines the charred seeds extracted from the flotation samples, and the contribution they make to the interpretation of local ecology. Taphonomic factors affecting the mode of arrival of rice into a settlement, its processing and the disposal of specific plant parts are investigated in chapter VI through observation of agricultural practice from lowland Thai farming communities. These provide the foundation of an ethnographic model for interpretating rice remains from archaeological sites. The processing sequence for rice is compared with post-harvest technologies for wheat and barley and suggestions are made to account for the poorer preservation

of rice in the archaeological record. Chapter VII then moves on to a consideration of food plants, with a dual focus, substantively on the rice remains from the excavation, and methodologically with a critical exploration of identification criteria for fragmentary *Oryza* husks. Finally, a synthesis of the archaeobotanical results is presented, with a discussion of the likely human behavioural responses to the reconstructed environmental setting. The resource potential and environmental constraints of the habitats indicated by the plant remains are discussed with some taphonomic consideration of the plant component to the tropical coastal diet.

The cultural and temporal sequences against which the botanical evidence will be examined have been set out in the first and third volumes of this series (Higham and Bannanurag 1990, Higham and Thosarat 1993) and other classes of biological data have been described in volume 2 (Higham and Bannanurag 1991).

III. THAI PLANTS, PAST AND PRESENT

ON-SITE METHODS. THE RECOVERY OF PLANT MACROFOSSILS

AN integral part of the excavation was the retrieval of botanical evidence. Plant parts are preserved in the archaeological record in a number of ways and our sampling strategy was designed to accommodate each category of material and means of preservation, primarily and systematically by flotation, but also by collecting material *in situ* during excavation and by retrieving whatever macroremains were occasionally found in the screens through which all the excavated material was sieved. Flotation produced a great number of charred seeds which have contributed to our understanding of the herbaceous vegetation growing around the site (see chapter V), as well as a diverse range of micromolluscs which are proving equally useful for palaeoenvironmental reconstruction (Mason 1991 and below). These were in addition to vast quantities of very small animal bones, especially the remains of fish and birds, retrieved from the heavy fraction of the flot.

Flotation

Before the development of flotation techniques, the archaeobotanical record was typically confined to waterlogged sites or contexts, or occasional desiccated remains, but more often to plant impressions in pottery, mudbrick and daub, or chance finds of charred grain, often from storage contexts. This was true of areas such as South-West Asia until the 1960s, Northern Europe until the 1970s and it is still largely the case in South and South-East Asia. The archaeobotanical record of rice is therefore skewed towards those sites with massive quantities of very obvious plant remains, such as the waterlogged deposits at Hemudu (Natural History Section, Chekiang Provincial Museum 1978, You 1979, Liu 1985, Zhao and Wu 1986-7). There are also sites with small quantities of visible rice preserved through proximity to metal, such as at Ban Don Ta Phet (Thailand) where spikelets were associated with a bronze bowl (Glover 1990) and Hallur (India) where rice was found encrusted around iron arrow points (Vishnu-Mittre 1971). Elsewhere rice husk and sometimes straw were used as a temper in pottery production or brick manufacture, as in North India (e.g. Vishnu-Mittre and Gupta 1968, Vishnu-Mittre 1969), Burma (Watanabe and Tanaka 1981), Thailand (Watabe and Akihama 1968, Watabe *et al.* 1970, Yen 1982) and the Philippines (Snow *et al.* 1986). These, together with sporadic finds of caches of charred caryopses, are the major forms of preservation which have contributed to our knowledge of archaeological rice and have provided evidence for the history of rice agriculture.

The various parts of cereal plants respond to burning in different ways, so that some elements are destroyed more easily than others. This has been demonstrated experimentally (Boardman and Jones 1990) and by observation of household fires (Hillman 1981) in the case of wheats and barleys. The archaeological record for rice suggests too, that while caryopses may survive combustion in charred form, the lighter chaff and straw components are burnt to ash, as the dominance of charred caryopses, which greatly outnumber other plant parts in Vishnu-Mittre's (1974) summary of rice finds in India, illustrates. Where burnt leaves and husks are found, these are often reduced to ash, such as the hearth material at Ulu Leang in Sulawesi, Indonesia (Glover 1979). In such cases, the

silica skeletons may be examined for macroscopic features or using the spodographic techniques of Watanabe (1968). At other sites, rice husks or grains may be found not as temper, but as impressions on the external surfaces of pottery, for example at prehistoric sites around Udaipur in Rajasthan, north-western India (Vishnu-Mittre 1969), at Non Nok Tha in north-eastern Thailand (Vishnu-Mittre and Gudzer 1983) and at Kenting in Taiwan (Li 1982). These are some of the most difficult macroremains to work with, as the original may have been completely burnt away leaving imprints which are indistinct replicas of the spikelet. Very occasionally, there have been finds of rice remains from sites preserved under anaerobic conditions created by peat formation, such as the late Yayoi period site of Toro in Japan (Watanabe 1968) and the Korean Iron Age site of Shinchang-dong (Thompson ms), but such situations are rare in the Asian archaeological record.

The systematic recovery of plant remains from prehistoric sites by flotation is relatively new to South-East Asia though it had been tried, with varying degrees of success, at other Thai sites before our work at Khok Phanom Di, for example at Ban Don Ta Phet (pers. comms. I. Glover and A. Clarke), at Ban Chiang (White 1982c), Phimai (Welch and McNeill 1988-89) and at Lang Rongrien (Anderson 1990). Prior to these efforts, soil samples were often sieved. Charred rice caryopses were found in the course of wet screening sediments at Ban Na Di (Chang and Loresto 1984, Higham and Kijngam 1984) and fine screening for plant remains was carried out at Spirit Cave (Higham 1989).

The Khok Phanom Di excavation was the first time that large-scale processing of soil samples by flotation was undertaken in South-East Asia and, for this reason, full details of field sampling and flot processing are presented. We set out to process soil from all types of archaeological contexts, not just potentially productive storage areas or hearths. Soil samples were processed through a flotation tank. This works on the principle that materials of differing densities segregate if added to a medium whose density is between that of the materials (Pearsall 1989:24). If carried out consistently, flotation can produce archaeobotanical assemblages free from human bias and suited to analysis where the aims are to reconstruct aspects of past environments and the economic use of plants.

Flotation technique

The flotation system used at Khok Phanom Di (Fig. 3) was a mechanical one, based on French's (1971) Ankara flotation system, as modified by G. Hillman (pers. comm.). This design has been widely used, adapted and tried under many different field conditions (Williams 1973, 1976, Limp 1974, Diamant 1979). It uses a continuous flow of water from beneath to flush a floatable fraction including botanical remains and micromollusca from bulk excavation soil and at the same time cleans heavier items such as artefacts, shell and bone. One of the advantages of this type of machine is that it processes larger quantities of soil more efficiently than, for example, the Cambridge froth flotation tank. This was considered to be important at a site where we were uncertain at the outset of the quantities of soil which would need to be processed in order to obtain a statistically valid archaeobotanical assemblage.

This particular system is simple and relatively inexpensive to construct and, we hoped, easy and reliable to operate at a speed which would keep pace with excavation. We commissioned a local metal worker in Chachoengsao, more accustomed to making funnels, soup tureens and gardening equipment, to make it for us. Chemically aided flotation was not applied at Khok Phanom Di due to the expense of the chemicals, given the large quantities of soil to be processed.

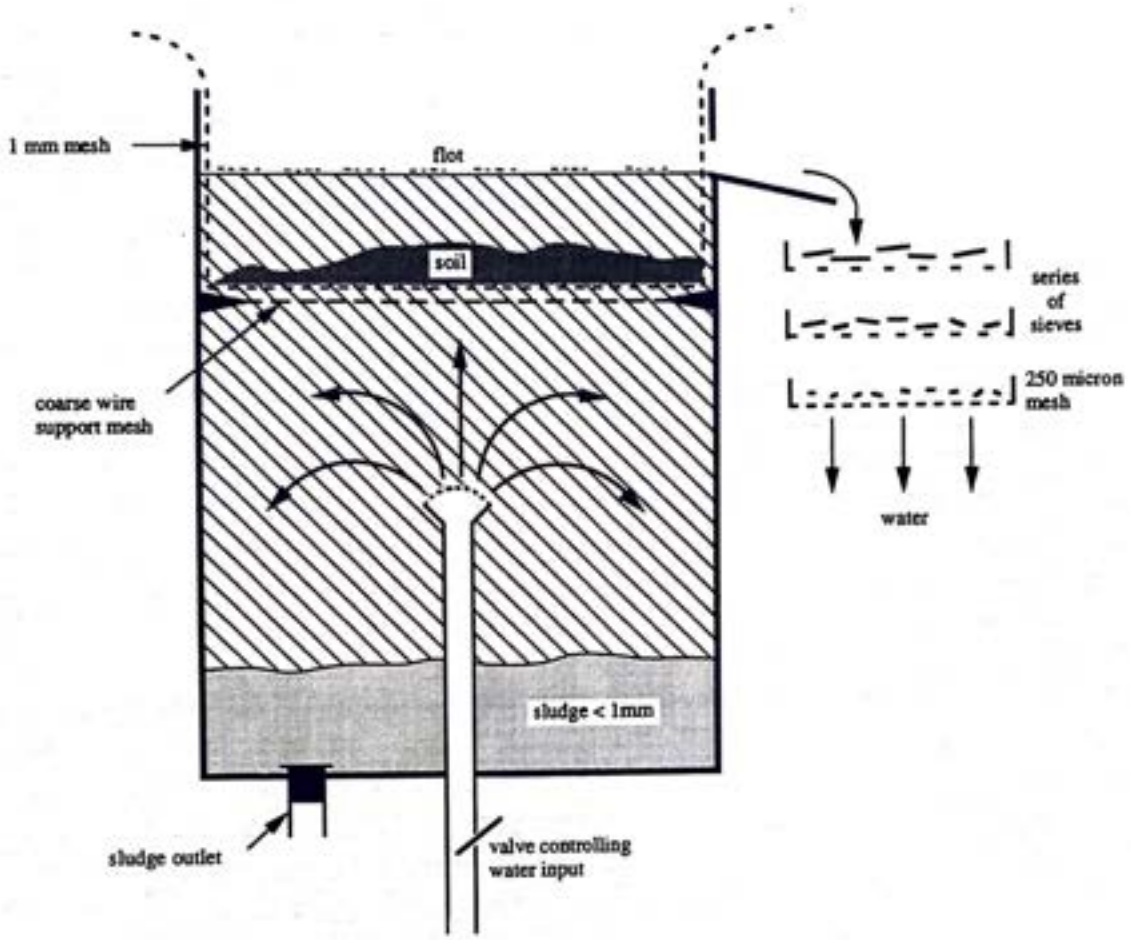


FIG. 3. The flotation tank used in the 1985 excavation at Khok Phanom Di

The flotation system consisted of a large, circular tank, with a water inlet at the base and a spillway at the top. A circular mesh-based rack fitted inside the tank at a level beneath the spillway and rested on metal cross-struts, and a stack of geological sieves was positioned so that the water flowing from the main tank via the weir passed through them. The smallest mesh was 0.25 mm.

Flotation is a labour-intensive operation and three people worked at the task. It is also repetitive and liable to errors, so crews were changed daily, with most people involved having one day a week with the flotation tank. The importance of standardized procedures in order to achieve consistent results was explained to these workers, and this was helped by continuous supervision. Cleanliness in all stages of the flotation procedure was emphasized, in order to minimize contamination from modern plants and between archaeological samples. The equipment was scrupulously washed, scrubbed and checked for damage between samples.

Flotation gives best results with dry soil, so the bulk soil samples were spread on large platters in the sun for one to three hours before being processed. Air-borne contamination by modern charred material was not considered a problem since there was no burning in the vicinity. Slowly, one platter at a time, the soil was poured into the water in the tank and the plant remains were

'floated' out of the soil matrix by their inherent buoyancy and the pressure of water rising from below. The floating material was washed out of the tank through the spillway and caught in the series of screens. After the initial flot had come to the surface and been washed into the sieves, the remaining soil was manually agitated to break up any remaining clumps and release other botanical remains. Samples from layers 5–8 contained some highly compacted lenses where soil needed to be broken down by hand with more agitation than usual, while other layers were noticeably silty. One advantage of the flushing system is that it is possible to change the water pressure to flush different types of remains through the weir, thereby minimising silt in the fine fraction.

This flotation technique splits the soil sample into three fractions (a) the flot, which is caught in the stacked sieves, (b) the heavy fraction of non-buoyant material which remains in the screen tray within the main tank and (c) fine silt which falls through the 1.0 mm mesh within the tank and accumulates at the bottom of the box. This silt fraction was removed through the sludge drain after processing each sample and was discarded. The second product, or heavy fraction, which accumulates in the mesh within the tank, was dried in the shade on tables with mesh tops. These allowed air to reach the damp samples from above and below. Once dry, the samples were sorted by naked eye, with small bones and shells being removed for analysis. This fraction was also checked for visible, non-buoyant plant remains, but these consisted only of small quantities of comminuted charcoal, which were not removed for analysis.

Two sets of sieves were used alternately for wet work with the flotation tank and for drying flot. Whenever possible, the material was dried in the sieve and removed later, as this was thought to reduce damage to the sometimes fragile plant remains. To avoid excessively rapid drying of flot, which can damage the plant remains, samples were dried inside a building. Once dry, the materials were placed in plastic or glass vials and packed in labelled plastic bags ready for shipment overseas.

Sampling strategy for flotation

The main aim of the archaeobotanical analysis was to examine temporal change in the plant assemblage, especially the occurrence of rice and weed seeds. It would have been interesting to sample across as well as down the site and to examine the material in terms of context-related variation in the botanical assemblages. In the event, this proved to be over-ambitious. At the beginning, flot samples were taken from spits, from pits, burials and other features, but time constraints prevented us from continuing with such a comprehensive sampling strategy involving such large quantities of soil. In the latter half of the excavation, emphasis was given to processing only the general occupation debris from spits.

Given the size of the excavated area it was not possible to float all material. It was decided to sample each 100 mm spit from the four quadrants (Higham and Bannanurag 1990:14). Thus, sampling for flotation became a routine aspect of excavation. Composite or 'pinch' sampling was used (Pearsall 1989:96). Small amounts of soil were taken from across a context, then combined as a single sample. The soil samples were double-bagged, with labels outside and between the two bags.

Wherever possible, a standard volume of soil was processed from each context (each 100 mm spit from one quadrant) and initially this was set at ten buckets (100 l). This is notably larger than the sample sizes often chosen by palaeoethnobotanists, but as the density and quality of plant remains from lowland sites in Thailand was unknown in advance, it was considered prudent to oversample at the outset until the density of plant macroremains had been estimated. At this volume, and at the

earlier speed of excavation, we processed three samples per day, when the flotation tank was staffed by three people. During April, at which stage layer 9 was being excavated, it was decided that we should continue to work through the monsoon season. As rain would sometimes hamper flotation, and we would have less time each day to operate the flotation tank, the volume of soil for each sample was halved to five buckets (50 l), in order to maintain the number of samples processed.

Records

Each context sampled for flotation was allocated a unique flotation number, used as a shorthand means of identifying samples at all stages of the flotation and laboratory processing. In the Flotation Logbook, the following information was recorded against each flot number: context information (quadrant, level and spit), date of sampling, the type of context (spit, burial, pit fill, etc.) and the number of buckets of soil taken for the sample. Where the number of buckets was less than the prescribed ten or five (equivalent to 100 or 50 l), for example from small pits, the type of feature and sample size were noted.

THE COLLECTION OF MACROREMAINS

Simply to gather plant macroremains when they are clearly visible to the naked eye is not recommended as the sole method of recovery, because this introduces a number of biases to the data. The recovery tends to be poor, spatially uneven and unreliable for areas which are excavated quickly and depends on the interest and skills of the excavators (Pearsall 1989). Nevertheless, at Khok Phanom Di *in situ* collection provided us with classes of material which were not made available through flotation. While excavating the lower spits of layer 8, we began to notice brownish, fragile pieces of what we took to be rice husk, typically preserved along some of the bedding planes within the soil. Soil blocks were broken open along their natural lines of cleavage and patches of such organic remains found preserved on the surface. These were bagged as found and retained for analysis. Further rice remains were later detected in the flot, once the samples were sorted in the laboratory. These took the form of impressions in and husk fragments adhering to soil particles.

The second class of material to be collected *in situ* was wood charcoal and again this method was found to be more effective than flotation. Lumps of charcoal were commonly seen in layers 4–11. The densest areas of charcoal were removed for radiocarbon dating and other fragments were set aside for identification. Fragments of charcoal were lifted using a trowel point and placed in a communal container for each context. Individual pieces were wrapped in foil, with several fragments packed together in a labelled vial. This care proved worthwhile, since some material fragmented in transit. As each fragment had been packaged individually, it was necessary to identify only one sliver per foil wrapping and this considerably speeded up the identification stage of the work.

Occasionally there were rare finds of large seeds, white fibres in burials (to be described in chapter V), clay-coated ceramics containing rice husks (chapter VII) and pieces of mineralized wood *in situ* in postholes (chapter IV). These were also plotted, recorded, bagged and retained for identification.

Archaeobotanical remains retrieved by screening

All the excavated soil, except that which was floated, was sieved through a 5 mm mesh. This was primarily to recover faunal and artefactual materials, but items such as coprolites were sometimes found in the sieves. Their provenance was recorded and they were bagged and kept for analysis. Descriptions of the rice remains from coprolites are incorporated in chapter VII.

LABORATORY METHODS

Sorting flot

Flot produced by floating soil samples at Khok Phanom Di was a concentration of plant remains from excavated soil (comminuted wood charcoal fragments, charred seeds and fragments of rice husk), but included other buoyant items such as fine twigs and rootlets, micromolluscs, disaggregated soil particles, small bones and coral fragments. The material was not refloated in the laboratory because the repeated wetting and drying of flot has been shown to damage archaeological seeds and charcoal (Jarman *et al.* 1972) and a cursory inspection of the flot showed that the Khok Phanom Di charred plant remains were not robust. The large number of fractured and partial specimens found later confirmed this. Rather, the first stage in laboratory analysis was the time-consuming manual removal of unwanted materials and the separation of items of archaeological interest.

Sampling strategy for sorting flot samples

Given the impracticality of sorting all the material from each of the 474 flot samples from the 1985 excavation, it was decided to concentrate effort on material from a single quadrant. The aim was to sort samples covering the entire length of the stratigraphic sequence. Materials from 46 samples taken from alternate spits in quadrant A were processed. A simple column sample may not necessarily be typical of a whole site (Gasser 1985), but due to time limitations it was not possible to check the representativeness of the material from these samples by extracting and identifying seeds from adjacent stratigraphic columns.

Flotation Data Record Sheets were completed using a documentation system broadly along the lines of that devised for Salmon Ruin, New Mexico (Bohrer and Adams 1977:185). The total volume of the flot was measured and the sample split into three subsamples using 1.0, 0.5 and 0.25 mm sieves. Sorting flot from a single size class is generally recognized to be easier and more efficient than working with material from a mixture of sizes. Material from the largest grade of mesh was sorted first, since this sometimes included whole seeds which were later encountered as fragments in the smaller size categories. This improves the recovery rate in the last and smallest sieve (Bohrer and Adams 1977) but there were very few seeds in the 0.25 mm fraction.

A low power, binocular dissecting microscope was used for sorting, working at magnifications of x10 or x20. At this stage, charcoal was not removed, but items of interest which were segregated from the flot included charred seeds, grains of soil with rice husk attached, bones and microgastropods. The faunal remains were sent to Dunedin for identification (see Mason, below), while the seeds and other plant macroremains from the flot were retained for identification in Canberra. These identifications are taken up in chapter V.

All records from the archaeological samples and the reference collection were entered on a computer database using PC FILE:dB. This allows information to be sorted on any field or a combination of fields, so that, for the archaeobotanical data, an overall impression of the variety and distribution of plant remains through the site was attained, and for the ethnobotanical data, accessions and associated information could be managed.

Identification procedures

In the following chapters, the identification techniques for each class of archaeobotanical material are outlined. Identification criteria suggested by the general botanical literature are summarized before focusing on those characters which have potential for application to archaeological plant remains. This work was carried out at the Department of Archaeology and Natural History (Research School of Pacific and Asian Studies) and the Electron Microscope Unit (Research School of Biological Sciences) at the Australian National University in Canberra, and a total of two and a half years was spent sorting, cataloguing and identifying the materials, both modern and prehistoric.

CREATING A REFERENCE COLLECTION

The identification of archaeobotanical remains proceeds by making comparisons between the morphology of the unknown archaeological specimens and modern, securely identified plant parts. Voucher specimens of wood and seeds collected for reference purposes were charred. One set of herbarium specimens was retained and duplicate sets were deposited with the Royal Forest Department and at the Botany Department of Chulalongkorn University, both in Bangkok. A set of charcoal reference material was left with the Archaeology Division of the Fine Arts Department in Bangkok and a second set is held at the Department of Archaeology and Natural History, in the Research School of Pacific and Asian Studies at the Australian National University. Approximately 550 herbarium specimens were collected and a total of 74 wood types were accessioned.

These voucher specimens were assembled during a second field season (November 1986 to July 1987) dedicated to collecting botanical specimens and gathering ethnobotanical and ecological data.

During this fieldwork frequent reference was made to Watson (1928), Merrill (1946), Corner (1952), Santisuk (1983) and Chayamarit (1984) as guides to taxa existing in South-East Asian mangroves. Thai Military Survey maps at 1:250,000 (1965) and 1:50,000 (1982) were used during fieldwork in conjunction with air photographs of the Khok Phanom Di area and the Welu estuary supplied by the Thai Military Survey Department (1980).

Plant specimens were collected using standard plant presses according to procedures set out by the USDA (1971). Where possible, four complete flowering or fruiting specimens were collected. Where a particular plant part such as the fruit, wood or seeds was likely to be of specific archaeobotanical use, additional quantities were collected. Notes were made on the location of the collection, the vernacular name of the plant, the topography, aspect, soil and associated vegetation. Supplementary information was recorded on the plant's habit and the colour and morphology of the flowers, together with a description of the fruit and seeds. Enquiries were made about uses of the plant known to local people as well as on seasonality of plant resources, their distribution and associated taxa. Each collection was given a serial number and the notes were kept in duplicate

field notebooks. Specimens were pressed in the field, at the time of collection, which is preferable to pressing wilted material after a day of collecting. The presses were dried, often on the roof, exposed to strong sunlight. During the rainy season, an artificial heat source was substituted. Damp blotters which had absorbed moisture from the specimens were exchanged for dry ones daily. Once dry, the specimens were bundled together and taken to Bangkok for identification.

Many initial identifications at generic level were made with reference to material at the herbaria of the Royal Thai Forest Department and the Botany Department at Chulalongkorn University, aided by the books mentioned earlier together with Smitinand (1980), Boonkerd *et al.* (1982) and the *Flora of Java* (Backer and Bakhuisen van der Brink 1963). Further identifications were made by Kuhn Chamlong Phengklai and Professor Tem Smitinand, at the Royal Thai Forest Department's herbarium, and by staff of the Botany Department, Chulalongkorn University (Acharn Kosum Pyramarn, Acharn Bussaban Na Songhkla and Acharn Obchan Thaithong). These plants constituted the working reference collection for the identification of plant macroremains from Khok Phanom Di. They were augmented by other materials donated by the National Weed Science Research Institute, the Royal Thai Forest Department, the Pathum Thani Rice Research Institute (Thailand), the International Rice Research Institute (IRRI) (Philippines) and the Gauba and National Herbaria (Australia).

Other texts which proved to be of use in the later laboratory phases of the work included volumes which were published after the original plant-collecting field-season, such as Aksornkoae and Panichsuko (n.d.) and McMakin (1988), as well as others which were unavailable at the time of fieldwork, Lear and Turner (1977) and Stemmermann (1981).

A comprehensive collection was beyond the scope of this work, but the main economic plants and the major woody and herbaceous taxa from each of the major vegetational zones were collected. The principal aim was to characterize the environmental zones and collect specimens and information about the major economic plants in those areas. Both wild and cultivated plants were included.

Information about temporal variability was gathered through interviews rather than by direct observation. The ethnobotanical component of this field season lasted only seven months, during which collecting was spread through a number of areas, from the rice paddies, house-gardens and estuarine forest in the lower reaches of the Bang Pakong Valley, through the degraded mangroves and salt flats on the coast at Chonburi, to the sandy strand vegetation and dryland cultivation north of Sattahip and the extensive mangroves of the Welu estuary near Chantaburi (Fig. 4). Logistical constraints prevented plant collections from being made throughout the seasons and in all areas, although a conscious effort was made to revisit localities to collect mature or fruiting specimens as they came into season.

Field collections of plant specimens were influenced by the biogeography of the plant communities, by a concern for collecting information on economic plants, especially those gathered for food, and thirdly the need to collect traditional landraces of rice cultivars and to document agrarian practices for cultivating and harvesting rice.

Areas for plant collecting

Collections were made firstly on a biogeographical basis, in close analogues to each of the habitats suggested by the faunal evidence from the 1985 and previous excavations (Noksakul 1981, Suchitta 1980, 1984, Pisnupong 1984), and by the then incomplete palynological and phytolith

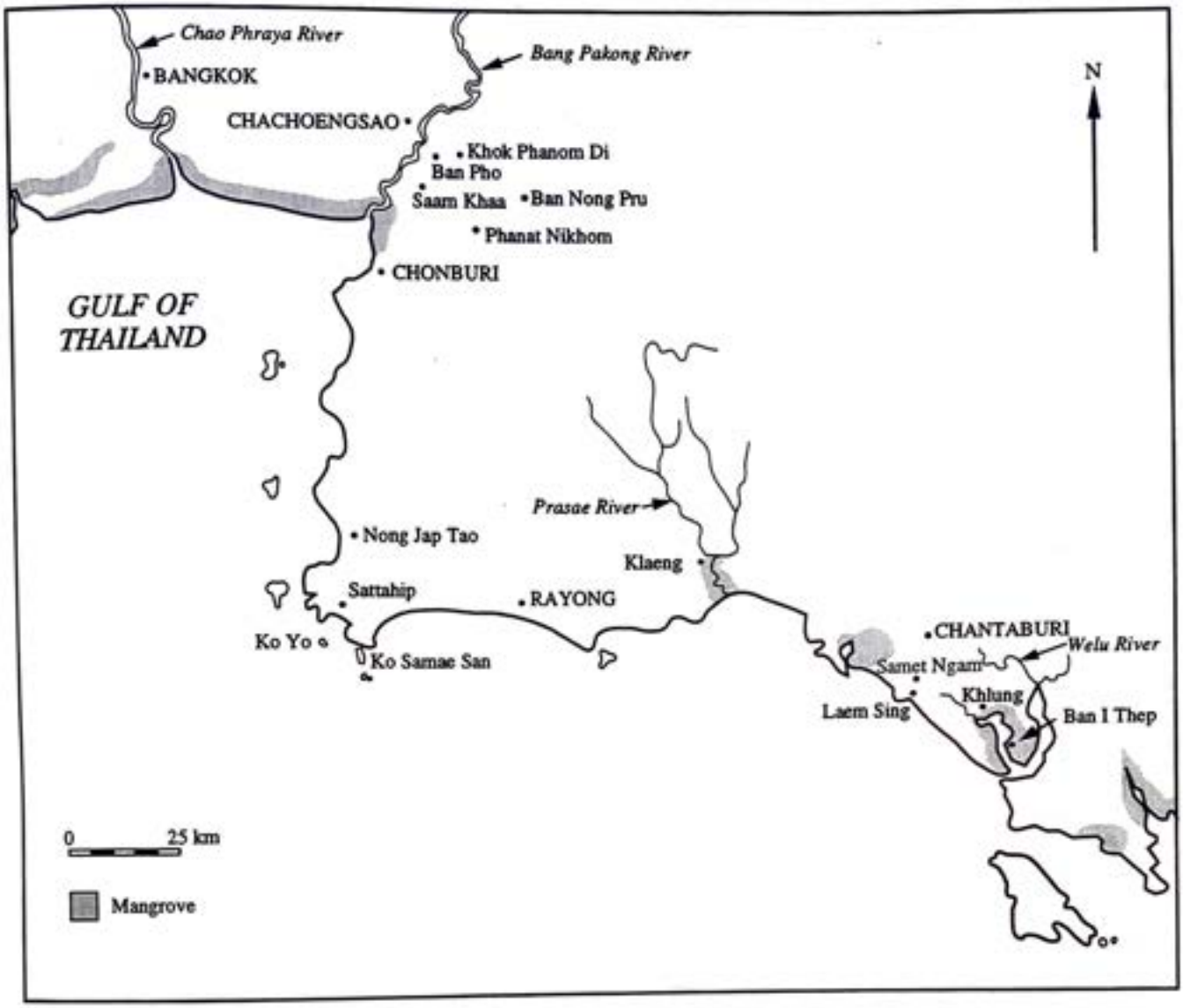


FIG. 4. Localities for plant collection and ethnobotanical fieldwork

data, as present in the region of prehistoric Khok Phanom Di (Higham *et al.* 1987, pers. comm. B. Maloney, cf. Maloney 1986, 1987). Although the most important palynological studies were still underway, interim results suggested that the site had been located close to, or perhaps within, mangrove forest and that grasses had been present, either as a herbaceous swamp behind the mangroves, on cultivated land or growing on the mound itself (Maloney 1987). Interpretation of the pollen evidence at that stage was equivocal as to whether the mangroves were replaced by brackish or freshwater forest with *Carallia* sp. (Maloney 1986, Maloney and Brown 1990). Subsequent pollen and phytolith analyses have extended, refined and revised interpretations to provide a more comprehensive view of the regional vegetation around Khok Phanom Di during its prehistoric

occupation. The final interpretations are discussed in conjunction with the charcoal and seed identifications in chapters IV and V respectively (cf. Maloney 1988, 1991, Maloney and Brown 1990, Maloney and McAlister 1990, Maloney *et al.* 1989, Kealhofer and Piperno below).

Herbarium specimens were collected to represent the dominant plants in a number of distinct vegetational communities so that voucher specimens of timber, seeds, leaves, flowers and fruit would be available for identifying archaeological specimens. The habitats involved were (i) mangrove forest, (ii) herbaceous backswamp to mangrove, (iii) sandy strand floras, (iv) the weed flora from rice paddies, (v) arboreal taxa growing at Khok Phanom Di and (vi) herbaceous ruderals from dryland areas around the mound.

The main priority was to assemble a working reference collection for identifying the archaeological remains and ethnobotanical and ecological enquiries were an adjunct to this. As the palaeoenvironmental data from the 500+ year occupation at Khok Phanom Di revealed an evolving rather than a static situation, the plant collections were spread over a wide area. It was not feasible, then, to establish a permanent base with access to all the habitats of interest or to conduct year-round ethnoecological investigations such as Joyce White had accomplished during her residence at Ban Chiang (White 1982a, 1982b, 1984, 1989).

Working with Anat Bamrungwongse and based at the village of Saam Khaa only 6 km to the north-west of Khok Phanom Di, the first set of collections was made from November to January, at the end of the rains and the beginning of the cool/dry season, when ephemeral swamps and canals were drying out. Herbaceous plants were collected from paddyfields and canal banks, roadsides and small patches of freshwater swamp.

In the Ban Pho area, collecting trips were made inland across the lowlying paddy landscape and also, by small boat, through the network of narrow, nipa-lined, brackish canals connecting hamlets like Saam Khaa with the Bang Pakong River. Plant specimens were collected in progressively larger concentric circles around the village. Plants commonly found in backswamp associations, such as *Ficus* spp. and *Hibiscus tiliaceus*, were seen as occasional individuals along the waterways between Nong Bua and the Bang Pakong River. The banks of the Bang Pakong are also vegetated, around the temple at Bang Khuud, and along inner meander bends, with nipa and its associates *Acanthus ilicifolius*, *Thespesia populnea* and *Pandanus odoratissimus*, within which the climbing palm *Caryota mitis* and the stinging climbers *Columella trifolia* and *Mucuna gigantea* were growing. In the damp areas in the orchards just behind the band of nipa were the herbs *Coccinea grandis*, *Corchorus capsularis*, *Vernonia* sp. and *Wedelia* sp. and in standing water, *Cyperus* sp. For more mature stands of mangrove, we searched the hinterland north and west of the town of Chonburi, but found that much of the forest in that area had been cut prior to industrial development and replaced by shrimp farms and saltpans. We therefore moved progressively down the south-eastern seaboard, searching for areas which might still have mature stands of mangrove.

In February 1986, we joined the Underwater Archaeology team at Sattahip, where the focus for plant collection turned to open sandy coastlines backed by sand dunes and to marshy areas a little further inland. Here, the beachside herbaceous vegetation comprised the creepers *Ipomoea pes-caprae* and *Merremia hederacea* on exposed sand. Behind the dunes were the herbs *Micromelum* cf. *minutum* and *Triumfetta grandidens* and the scrubby xerophytes *Kalanchoe pinnata*, *Connarus* cf. *paniculatus* and the introduced *Opuntia* sp. This vegetation community also included the evergreen *Casuarina* sp., *Calophyllum inophyllum* and *Terminalia catappa*, all typical of the South-East Asian strand flora (Foxworthy 1927). This last tree commonly occurs in monotypic stands

behind the beach. Two trips were made to the exposed and rocky, steep-sided offshore islands, Ko Samaesan and Ko Yo, where the restricted flora included *Hibiscus tiliaceus* trees, the shrubs *Maerua siamensis*, *Flacourtia indica*, *Bridelia* cf. *ovata* and *Bonamia* sp. and, in the understorey, the climbing legume *Mucuna gigantea* with its irritant seed pods.

On the mainland, at higher elevations, dryland cultivation of cassava is the dominant land use, with orchards of durian, coconuts and mangoes, but occasional tall Dipterocarps and shrubby *Combretum punctatum* around villages attest to the former forest cover in this area. Many of the trees here are fruit trees like *Averrhoa bilimbi* and *Syzygium cucuminii*, growing en masse in orchards or planted individually in house gardens. The weedy roadside flora includes *Ageratum conyzoides*, *Boerhavia diffusa*, *Clitorea ternatea*, *Hibiscus sabdariffa*, *Merremia hederacea*, *Mimosa invisa*, *Sida* sp. and *Spilanthes acmella*, together with climbers *Ipomoea pes-caprae*, *Lablab purpureus* and the distinctive *Thunbergia grandiflora* which has showy mauve flowers.

From Nong Jap Tao, Sattahip, a number of collecting trips were made further south, along the coast, to the cleared mangroves of the Maenam Prasae Estuary near Klaeng, approximately midway between the major towns of Rayong and Chantaburi. The mangroves marked on the map for this area had been greatly modified by clearance leaving behind relict vegetation including the climbers *Derris trifoliata* and *Crotalaria striata* growing along salty creeks. Moving still further away from Bangkok, an exploratory trip was made in search of extensive and relatively undisturbed mangrove forest. We were finally able to make the first of a large number of collections from mangroves and backswamps in the Welu Estuary, seaward of *amphoe* Khlung. The Welu Estuary lies between the towns of Chantaburi and Trat at the southern extremity of the eastern seaboard. Although some of the vegetation along the landward margins of this estuary had been subject to clearance for prawn farms, along the seaward, relatively inaccessible reaches, less disturbed plant communities were found.

On subsequent, more extended visits to the area, staying at Ban Hua Ang, literally at the head of the estuary, it was possible to visit the estuarine village of Ban I Thep to discuss local ecology and plant use with fishing families and to collect specimens from plants they described. The trees sampled around the Welu Estuary were the most common mangrove taxa: *Avicennia alba*, *A. officinalis*, *Bruguiera* spp., *Ceriops tagal*, *Excoecaria agallocha*, *Ficus microcarpa*, *Intsia bijuga*, *Lumnitzera* spp., *Melaleuca leucadendra*, *Rhizophora apiculata* and *R. mucronata*, *Scyphiphora hydrophyllacea*, *Sonneratia ovata* and *Xylocarpus moluccensis*. In the drier, cleared and disturbed areas, the fern *Acrostichum aureum* was prominent in monospecific stands. An understorey is poorly developed in mangroves (Christensen 1983), but it proved possible to collect the climbers *Flagellaria indica*, *Sarcolobus globosus*, the low shrub *Clerodendrum inerme* and the woody herbs *Acanthus* spp., *Pluchea indica* and *Wedelia biflora*. Sedges and grasses including *Coix lachryma-jobi* were collected from backswamp areas. In the herbaceous swamps just behind the mangrove belt were sedge and grass communities dominated by *Eleocharis* sp. and *Scirpus* sp., sometimes with the exotic *Zizania latifolia*.

Situated at the ecotone between nipa and rice paddies, the village of Ban Khlong Takhian was the site of additional plant collections and discussions with villagers about their garden plots and possible uses of gathered wild plant resources. Here we collected samples of wild but edible plants. For example, the tubers of *Dioscorea hispida* which need to be peeled and sliced, immersed in salt, then placed in running water for four days before being steamed and eaten. The same overgrown plot also had examples of *Lasia spinosa*, *Amorphophallus* sp. and *Typhonium trilobatum* which

have edible young petioles, *Diplazium esculentum* and *Melientha suavis* with edible leaves and *Tacca leontopetaloides*, the root of which may be ground into flour.

Finally, the monsoon months of June and July 1987 were spent back at Khok Phanom Di, mapping local landuse and the trees growing on the mound itself, as well as collecting specimens from plants flowering and fruiting in the wet season.

Khok Phanom Di stands out above the flat surrounding plain because it is not only relatively high land but also one of the few areas on the lowlying plains with mature trees other than house gardens (Fig. 2). The house gardens are much smaller in area than the mound and are usually planted with fruit and shade trees. Most of the trees on the mound are self-propagated but many are tended and protected by the monks who live at the temple, or by members of the village community. A few have also been planted. Khok Phanom Di is distinctive in the social as well as the physical landscape, as people visit from surrounding villages and towns to discuss matters of spiritual and physical health with the monks. There is a garden of medicinal plants at the meditation centre and monks prescribe and administer healing plants from here. Certain trees which grow on the mound are rare and not found within many kilometres radius. The mound is also well known for supplying good bamboo, which grows in abundance, especially along the western flank. It is used for the production of fishtraps and basketry, some made for personal use and some sold locally. The two main taxa in the bamboo thickets are *Dendrocalamus asper* and *Thyrostachys* cf. *siamensis*.

Trees on the summit at Khok Phanom Di which were collected as herbarium and wood specimens include *Adenanthera pavonina*, *Aegle marmelos*, *Acacia rugata*, *Albizia lebbeck*, *Annona reticulata*, *Azadirachta indica* var. *siamensis*, *Bridelia* sp., *Capparis microcantha*, *Cassia siamea*, *Crataeva religiosa*, *Delonix regia*, *Dimocarpus longan*, *Diospyros montana*, *Flacourtia indica*, *Hydocarpus calvipetalus*, *Leucaena leucocephala*, *Millingtona hortensis*, *Pithecelobium dulce*, *Randia* sp., *Samanea saman*, *Sindora siamensis*, *Sterculia foetida*, *Tamarindus indica*, *Tectona grandis*, *Zolleringeria* sp. and, around the pond on the south-eastern flank of the mound, *Anacardium occidentale*.

Amongst the tall trees and undergrowth are climbers *Abrus precatorius*, *Azima sarmentosa*, *Caryota urens*, *Cissus hastata*, *Tiliacora triandra* and the wild yam *Dioscorea* cf. *bulbifera*, with understorey plants *Lepisanthes fruticosa*, *Cassia tora*, *Zingiber* sp., *Z. casumanar*, *Z.* cf. *zerumbet*, *Curcuma* sp. and *C. domestica*. In more open areas are the herbs *Abutilon indicum*, *Amaranthus gracilis*, *Asparagus racemosus*, *Boerhavia diffusa*, *Boesenbergia pandurata*, *Cleome viscosa*, *Cynodon dactylon*, *Melochia corchorifolia*, *Ocimum gratissimum*, *Ricinus communis*, *Sida acuta*, *Synedrella nodiflora* and *Stachytarpheta indica*. All these were collected.

In addition to the meditation centre at Khok Phanom Di, there are seven houses where the householders have planted in their gardens the fruit trees *Annona reticulata*, *Carica papaya*, *Cynometra cauliflora*, *Durio zibethinus*, *Eugenia jambos*, *Flacourtia* sp., *Garcinia dulcis*, *Lansium domesticum*, *Mangifer indica*, *Phyllanthus acidus*, *Psidium guajava* and *Sandoricum koetjape*.

It will be evident from the long length of coastline covered that it was not possible to make comprehensive herbarium collections, but the major woody and herbaceous taxa were sampled, and collections were made in the markets, noting cultivated and gathered foodplants for sale.

The flora of the mound and surrounds was also studied by Judith Brown and Bernard Maloney during 1985 (Maloney 1986, 1991).

Plants of traditional economic value

The first criterion for plant collection was biogeography, and the need to sample particular habitats. The second criterion was to collect plants with economic value, for fuelwood, fibre, construction and medicine, although the study was biased towards foodplants. These uses were determined partly by reference to ethnobotanical records highlighting potentially useful plants (cf. Smitinand and Scheible 1966, Pongpangan and Poobrasert 1971, Phengklai and Khamsai 1985), but also from extensive informal interviews with villagers and with women selling plants in the local markets at Chachoengsao, Sattahip and Khlung. Hunting and gathering are today economically insignificant for most people living at Khok Phanom Di, but the knowledge of potentially useful plants, especially those for medicinal use, is retained, and gathering to supplement the normal diet is actively practiced by one family in particular.

The availability and seasonality of these plants were noted, and examples of the gathered plants which were for sale were purchased and added to the reference collection. These were mainly mushrooms like *het samet* (currently unidentified) and *Boletus edulis*, and the shoots of ferns such as *Ceratopteris thalictroides*, *Pteridium aquilinum* and *Diplazium esculentum*. Edible young leaves and flowers of shrubs and herbs include the legumes *Acacia rugata*, *Caesalpinia mimosoides*, *Cassia siamea* and *Leucaena leucocephala* together with *Litsea umbellata*, *Momordia subangulata* and *Spondias pinnata*. The most common freshwater plants for sale were *Ipomoea aquatica*, *Nelumbo nucifera* and *Neptunia oleracea*. Some of the edible flowers gathered for home use and for sale in the market were from the trees *Caesalpinia mimosoides* and *Sesbania grandiflora*, the climber *Antigonon leptopus* and the banana flower *Musa* sp. This list is far from exhaustive and does not do justice to the immense variety of food for sale in a Thai marketplace. A more thorough and wonderfully illustrated account is provided by Jacquat and Bertossa (1990) in their *Plants from the Markets of Thailand*.

Observations of rice harvesting and post-harvest technology

In addition to the collections of ruderal and segetal plants, a concerted effort was also made to document and collect examples of the established landraces of rice and specimens from the various stages of rice harvesting and post-harvest processing which might help interpret the archaeological assemblages, including the remains of rice. This part of the research was carried out around Saam Khaa and Khok Phanom Di, and in the drier areas north-east of Phanat Nikhom. The results are considered in detail in chapters VI and VII. Twenty varieties of rice were collected, from a range of conditions from saline soil close to the coast, to dry, marginal, upland situations. For each type almost 30 attributes were recorded regarding phenotypic characters, cultural practices, the topographic and hydrologic conditions of the fields and notes on pests and diseases, using the International Rice Research Institute's Field Collection Form. These inquiries initiated further discussions with the farmers on non-mechanised means of rice production and post-harvest processing.

Having assembled identified herbarium specimens and the seed and wood collections, work could then proceed on the identification of archaeobotanical materials from Khok Phanom Di. The charcoal analysis is set out in chapter IV, the seed remains and the few miscellaneous botanical finds (white fibres from graves, leaf impressions and nuts) are described in chapter V. A detailed consideration of the remains of rice is presented in chapter VII.

TABLE 1: *List of recorded tree and shrub species in the mangrove formations in Thailand*

Scientific name	Vernacular name	Family	Habit	Distribution		
				C & SE	E	W
Acanthus ebracteatus[1]	*ngueak plaamo*	Acanthaceae	S	+	+	+
Acanthus ilicifolius[1]	*ee kreng*	Acanthaceae	S	+	+	+
Acrostichum aureum[1]	*prong thale*	Pteridaceae	S	+	+	+
Acrostichum speciosum[2]	*prong nuu*	Pteridaceae	S	+	-	+
Aegialites rotundifolia[1]	-	Plumbaginaceae	S	-	-	+
Aegiceras carinuclatum[1]	*lep mue naang*	Myrsinaceae	S	+	+	+
Allophyllus cobbe[2]	*to sai*	Sapindaceae	S	+	+	+
Amoora cucullata[2]	*daeng nam*	Meliaceae	T	+	+	+
Ardisia littoralis[2]	*raamyai*	Myrsinaceae	S/ST	+	+	+
Avicennia alba[1]	*samae khao*	Verbenaceae	T	+	+	+
Avicennia marina[1]	*samae thale*	Verbenaceae	T	+	+	+
Avicennia officinalis[1]	*samae dam*	Verbenaceae	T	+	+	+
Barringtonia asiatica[2]	*chik le*	Barringtoniaceae	T	+	+	+
Barringtonia racemosa[2]	*chik suan*	Barringtoniaceae	T	+	+	+
Brownlowia tersa[2]	*nam nong*	Tiliaceae	S/ST	+	-	+
Bruguiera cylindrica[1]	*thua khao*	Rhizophoraceae	T	+	+	+
Bruguiera gymnorrhiza[1]	*kongkaang hua sum*	Rhizophoraceae	T	+	+	+
Bruguiera hainesii[1]	-	Rhizophoraceae	T	+	+	+
Bruguiera parviflora[1]	*thua dam*	Rhizophoraceae	T	+	+	+
Bruguiera sexangula[1]	*prasak dok khao*	Rhizophoraceae	T	+	+	+
Cassine viburnifolia[2]	-	Celastraceae	ST/S	-	-	+
Cerbera manghas[2]	*teenpet saai*	Apocynaceae	T	+	+	+
Cerbera odollam[2]	*teenpet thale*	Apocynaceae	T	+	+	+
Ceriops decandra[1]	*prong khao*	Rhizophoraceae	S/ST	+	+	+
Ceriops tagal[1]	*prong daeng*	Rhizophoraceae	T	+	+	+
Clerodendrum inerme[2]	*sam ma ngaa*	Verbenaceae	S	+	+	+
Cynometra iripa[2]	*taet ling*	Leguminosae	S/ST	-	-	+
Cynometra ramiflora[2]	*ma kha*	Leguminosae	T	+	+	+
Cycas rumphii[2]	*prong thale*	Cycadaceae	ST	+	+	+
Dendrolobium umbellatum[2]	*chamaep*	Leguminosae	S	+	+	+
Derris indica[2]	*yee nam*	Leguminosae	T	+	+	+
Diospyros ferrea[2]	*lambit thale*	Ebenaceae	ST/T	+	+	+
Dolichandrone spathacea[2]	*khae thale*	Bignoniaceae	T	+	+	+
Excoecaria agallocha[1]	*taatum thale*	Euphorbiaceae	ST/T	+	+	+
Ficus microcarpa[2]	*sai yoi bai thuu*	Moraceae	T	+	+	+

(Source: Thawatchai Santisuk 1983)

[1] Trees and shrubs absolutely bound to salt or brackish water (true mangrove species)

[2] Trees and shrubs belonging to the littoral vegetations and/or inland vegetation which regularly make their appearance in the back-mangroves (mangrove associates)

T = tree, S = shrub, ST = shrubby tree, US = undershrub, C = central, SE = south-eastern or Chanthaburi region, E = east coast of peninsula, W = west coast of peninsula

Scientific name	Vernacular name	Family	Habit	Distribution		
				C & SE	E	W
Glochidion littorale[2]	-	Euphorbiaceae	ST	+	+	+
Guettarda speciosa[2]	*kong kaang huuchang*	Rubiaceae	ST	+	+	+
Heritiera fomes[1]	*duhuun bailek*	Sterculiaceae	T	-	-	+
Heritiera littoralis[2]	*ngonkai thale*	Sterculiaceae	T	+	+	+
Hibiscus tiliaceus[2]	*po thale*	Malvaceae	T	+	+	+
Horsfieldia irya[2]	*kruai*	Myristicaceae	T	+	+	+
Intsia bijuga[2]	*lumpho thale*	Leguminosae	T	+	+	+
Kandelia candel[2]	*rang ka thae*	Rhizophoraceae	T	+	+	+
Lumnitzera littorea[1]	*faat daeng*	Combretaceae	ST/T	+	+	+
Lumnitzera racemosa[1]	*faat khao*	Combretaceae	S/ST	+	+	+
Melaleuca leucadendra[2]	*samet*	Myrtaceae	T	+	+	+
Melastoma villosum[2]	*khlonghleng khon*	Melastomaceae	S	+	+	+
Merope angulata[2]	*manao pee*	Rutaceae	S	-	-	+
Nypa fruticans[1]	*chaak*	Palmae	ST	+	+	+
Oncosperma tigillaria[2]	*laao cha on*	Palmae	T	-	+	+
Pandanus odoratissimus[2]	*toei thale*	Pandanaceae	ST	+	+	+
Peltophorum pterocarpum[2]	*non see*	Leguminosae	T	+	+	+
Pemphis acidula[2]	*thian le*	Lythraceae	S	+	+	+
Phoenix paludosa[1]	*peng thale*	Palmae	T	+	+	+
Planchonella obovata[2]	*ngaa saai*	Sapotaceae	T	+	+	+
Pluchea indica[2]	*khluu*	Compositae	S	+	+	+
Premna obtusifolia[2]	*chaa lueat*	Verbenaceae	S	+	+	+
Rapanea porteriana[2]	*phrong nok*	Myrsinaceae	T	+	+	+
Rapanea umbellulata[2]	-	Myrsinaceae	ST/T	-	-	+
Rhizophora apiculata[1]	*kongkaang bailek*	Rhizophoraceae	T	+	+	+
Rhizophora mucronata[1]	*kongkaang baiyai*	Rhizophoraceae	T	+	+	+
Sapium indicum[2]	*samo thale*	Euphorbiaceae	ST/T	+	+	+
Scaevola taccada[2]	*rak thale*	Goodeniaceae	S	+	+	+
Scolopia macrophylla[2]	*nam taeng*	Flacourtiaceae	ST	-	+	+
Scyphiphora hydrophyllacea[1]	*chee ngam*	Rubiaceae	ST	+	+	+
Sonneratia alba[1]	*paat*	Sonneratiaceae	T	+	+	+
Sonneratia caseolaris[1]	*lam phu*	Sonneratiaceae	T	+	+	+
Sonneratia griffithii[1]	*lam phaen hin*	Sonneratiaceae	T	+	-	+
Sonneratia ovata[1]	*lam phaen*	Sonneratiaceae	T	+	+	+
Suaeda maritima[1]	*cha khraam*	Chenopodiaceae	US	+	+	+
Thespesia populnea[2]	*pho thale*	Malvaceae	T	+	+	+
Xylocarpus gangeticus[2]	*ta bun*	Meliaceae	T	+	-	+
Xylocarpus granatum[1]	*ta buun khao*	Meliaceae	T	+	+	+
Xylocarpus moluccensis[1]	*ta buun dam*	Meliaceae	T	+	+	+

[1] Trees and shrubs absolutely bound to salt or brackish water (true mangrove species)
[2] Trees and shrubs belonging to the littoral vegetations and/or inland vegetation which regularly make their appearance in the back-mangroves (mangrove associates)
T = tree, S = shrub, ST = shrubby tree, US = undershrub, C = central, SE = south-eastern or Chanthaburi region, E = east coast of peninsula, W = west coast of peninsula

TABLE 2: *Additional mangrove plants of Thailand*

Scientific name	Vernacular name	Family
Atalantia monophylla	*manao phi*	Rutaceae
Caesalpinia crista	*thephi*	Leguminosae
Calycopteris floribunda	*thao trut*	Combretaceae
Combretum tetralophum	*thao man daeng*	Combretaceae
Cordia cochinchinensis	*man*	Ehretiaceae
Triumfetta rhomboidea	*seng*	Tiliaceae
Avicennia balanophora		Verbenaceae
Terminalia sertocarpa		Combretaceae
Oncosperma filamentosa		Palmae
Caesalpinia digyna		Leguminosae
Litosanthes biflora	*kamphaeng chetchan*	Rubiaceae
Cassytha filiformis	*rang kasaa*	Santalaceae

(Sources: Aksornkoae and Panichsuko n.d., Aksornkoae *et al.* 1986, Sangdee 1986 and Chapman 1988)

TRADITIONAL USES OF MANGROVE PLANTS

This section has been compiled from ethnohistorical and ethnobotanical accounts of mangrove plant use. The taxa considered are restricted to those of the Thai flora, but the uses are drawn more widely, from South and South-East Asian, Pacific and Australian sources. Many plant uses are similar over a wide geographical area. The broad scope is in part a reflection of the relatively limited ethnobotanical literature regarding mainland South-East Asia written in western languages (some in English, mostly in French) and the need to look further afield, and partly a reflection of historical records and their access. Greater emphasis has been placed on early documentation which might include traditional uses which have lapsed. Many of these are summarised in Burkill's *Dictionary of the Economic Products of the Malay Peninsula.*

The scope is not confined to Thailand, as some previous plant uses have undoubtedly discontinued in that area and remained in practice elsewhere. Barrau (1959, 1970) has argued that the use of economic plants in the Pacific, with their tuber and tree exploitation, reflects an earlier adaptation from mainland South-East Asia where grain crops have become dominant, but occupied a more major part in a more diverse subsistence found in former times.

Some of the more detailed ethnobotanical accounts come from mangrove areas furthest from Thailand, particularly the Andaman Islands, northern Australia and parts of the Pacific. For some areas of mainland South-East Asia, however, there is sometimes information on long-established but outmoded use of wild plants in times of emergency, famine or drought. In this region there are few ethnobotanically-oriented accounts of "traditional" societies living along the coast. Most such studies have focused on upland groups. Boat-dwelling nomads such as the *Orang Laut*, or sea gypsies, have been described though (e.g. Sopher 1977, Sandbukt 1983, Sather 1985, Engelhardt 1989), and the terrestrial aspects of their lives, especially prior to settling down in estuaries and

their stronger incorporation into the local trading network, may provide some insight into the use of littoral and swamp resources.

The medical applications of mangrove plants are numerous (see Burkill 1966 for many references), with the use of healing plants being particularly well integrated into traditional Thai value systems. As medicinal products were used in small quantities, are probably undetectable in the archaeological record by current analytical techniques, and very numerous, they are excluded from further review.

The principal difficulty in using this database for archaeobotanical purposes is that the sources are insufficiently detailed to provide guidance on how useful parts of a plant are prepared and consumed, as food for example, and to indicate, therefore, the degree and manner of their archaeological visibility. Many records place greater emphasis on the end use of a particular plant resource than the associated processing techniques or the waste fractions generated. Such information is equally important for developing an understanding of the taphonomic processes transforming archaeobotanical assemblages. Methodologies for interpreting plant remains from non-agrarian parts of the prehistoric economy are yet to be firmly established. The information set out below cannot remedy this, but aims to provide a starting point for examining the wide variety of reasons for plant use in a mangrove-based community.

1. *Acrostichum aureum*: The fiddleheads and young leaves are eaten, especially the young red leaf-tips (Thailand) (Aksornkoae and Panichsuko n.d.:55, Burkill 1966:41, Dy Phon 1982:158, FAO 1985:36). The dried fronds of this fern are also used for roof thatching, and as kindling which burns rapidly producing little ash (Annam) (Burkill 1966:41).

2. *Aegialites* spp.: This timber produces a little tannin (Burkill 1966:54) and salt can be extracted from the burnt wood (Chapman 1976:379). Honey from the *A. rotundifolia* tree is highly valued, and collected at the end of the dry season (Andamans) (Blasco 1975:161).

3. *Aegiceras* sp.: The leaves were formerly eaten, either raw or cooked (Moluccas) (Burkill 1966:54-5). The timber is used for firewood, but is inferior to other mangroves. It is used in charcoal production in Indonesia, especially when firewood is in short supply (FAO 1985:36).

   The bark is used as a fish poison and the seeds contain saponin (Burkill 1966:54-5). Honey is collected from trees of *A. corniculatum* (Hamilton and Snedaker 1984:6).

4. *Allophyllus* sp.: The Veddas of Sri Lanka use this wood for making bows (Burkill 1966:105).

5. *Amoora cucullata*: The wood is used for posts and firewood, and there is reported to be some tannin in the trunk bark (Burkill 1966:139).

6. *Ardisia littoralis*: The young shoots are eaten (Burkill 1966:221).

7. *Avicennia* spp.: The fruits or seeds and seedlings are edible and are reported as still consumed as famine food, requiring detoxification prior to eating. For example, in Sulawesi the fruits are soaked in water for two weeks to remove the acridity before being eaten (Percival and Womersley 1975:29, Lear and Turner 1977, Hamilton and Snedaker 1984:6).

   In northern Australia (Cape York) the fruits are soaked in water for three nights, then either wrapped in bark and baked, roasted on an open fire, or baked in an earth oven (Specht 1958:499, Golson 1971:203 citing Roth 1901). Roasting the propagules on hot ashes is also reported but apparently only when other foods were in short supply (Smith 1991:11). An edible green gum is extracted by

cutting into the bark, and the flowers (especially *A. germinans*) are important as a source of sweet-smelling honey (Rollet 1975a:207, Chapman 1976:379, Gunn and Dennis 1976:78).

The young leaves of *A. marina* are sometimes used as a vegetable (FAO 1985:36) and also used to flavour mussel meat when this is cooked in an earth oven (Groote Eylandt, northern Australia) (Levitt 1981:84). The flowers of *A. officinalis* are sometimes chewed (India) (Blasco 1975:162).

Timber from *Avicennia* is hard and moderately heavy, brittle and difficult to split. It is an indifferent firewood which burns smoulderingly so is sometimes selected for smoking fish, and in India it is used as firewood only in the absence of *Rhizophora* (Blasco 1975:161). It is valued for its strength and hardness and reported as being used for rice mortars (Asia) and for making shields (Australia) (Dick 1915). Ash from the wood is used as soap (India) (Burkill 1966:275-7) and salt can be extracted from the timber (Chapman 1976:379, FAO 1985:36).

8. *Barringtonia* spp. The cooked pods of *B. asiatica* are edible if cooked long enough to remove the poisonous saponin (Indo-China) and the pulped seeds and bark which both contain saponins are thrown into rivers for fish poison (Burkill 1966:306-7). There are also reported food uses for *B. racemosa*. The Sakai people pound the fruits which are washed with water, the starch is allowed to settle and this is then made into cakes (peninsular Malaysia) (Burkill 1966:308 citing Craddock 1903). Similar uses are recorded for *B. edulis* seeds (Tomlinson 1986:167).

9. *Bruguiera* spp.: The young radicles are eaten, peeled and prepared as a purée or after being preserved (coastal areas of mainland and island South-East Asia, Solomon Islands, Papua New Guinea and northern Australia) (Hale and Tindale 1933:115, Flecker *et al.* 1948:12, Specht 1958:495, Burkill 1966:378, Golson 1971:203, Jardin and Crosnier 1975, Percival and Womersley 1975:29, Harris 1977, 1979, Laderman 1983:223, David 1985:52, Lemmens and Wulijarni-Soetjipto 1992:54). They are used as a staple food in the Torres Strait Islands and coastal Papua New Guinea (Hale and Tindale 1933:94) though elsewhere it is sometimes remarked that they are a famine food eaten only when nothing else is available (Seeman 1865-73). They may be consumed as a dessert (Thailand) (Phengklai 1985:206), sometimes double-boiled, and as a condiment prepared from the bark (Chapman 1976:379).

   The fruits are sometimes used an astringent in betel-quid or as a betel substitute (FAO 1985:36) and the leaves served raw as a flavouring. The bark is sometimes used to flavour a preparation of raw fish, but eating much of this is said to be dangerous (Indonesia) (Burkill 1966:377). The radicles of *B. eriopetala* are peeled, sliced, soaked in water for several days, then steamed, boiled and eaten with coconut cream (Papua New Guinea, New Caledonia and other areas throughout the Pacific) (Barrau 1959:162). In New Caledonia, the leaves of *B. rumphii* are eaten (Rollet 1975a:205).

   The wood from *Bruguiera* spp., being very hard, is used for the interior ribs in boats (Ellen 1985:580), for fishing stakes and for piling, house-posts and rafters although some Malaysian fishermen say that this wood has a peculiar odour which frightens away the fish, so is unsuitable for making fish-traps. The woods of *B. eriopetala* and *B. parviflora* are particularly favoured in northern Australia for making spear tips (Bird 1986:73, Smith 1991:13) and canoe paddles (Specht 1958:495) while that from the aerial roots of *B. rheedii* is used for making bows (Fiji) (Burkill 1966:378).

   The timber is also used in temporary construction as well as being especially good for firewood and charcoal (Burkill 1966:376-7, Hou 1970:8-10, Parkinson n.d.[1972]). An adhesive is made from *Bruguiera* bark (Chapman 1976:379, FAO 1985:36). Tannin from the wood, especially the old wood, is regarded as good for preserving fishing nets and tanning leather, and an extract is employed as a dye (black, orange-reds, brown and violet) (Burkill 1966:376-7, Lemmens and Wulijarni-Soetjipto

1992:54). The bark has adhesive properties and is used in medicinal preparations against diarrhoea, malaria and eye complaints.

10. *Camptostemon* spp.: This soft, light wood is used for making floats for harpoons (northern Australia) (Bird 1986:73).

11. *Carallia brachiata*: The small fruits are reported as edible (Specht 1958:495, Singh and Arora 1978:53, Levitt 1981:111, 133).

12. *Ceratopteris thalictroides*: The young fronds of this aquatic fern are blanched and eaten with a spicy sauce (Thailand) (Jacquat and Bertossa 1990:17).

13. *Cerbera manghas*: The wood provides a fine charcoal and was used in eighteenth century Thailand for making gunpowder (Koenig 1894a:166). Oil is pressed from the sun-dried seeds and used for illumination although the smoke is said to be intolerable and the oil dangerous because of the poisons extracted at the same time. The seeds are used in the Philippines for stupefying fish in small streams (Burkill 1966:520-1).

14. *Ceriops* spp.: The fruit or hypocotyls of *C. tagal* are sometimes eaten (Andaman Islands) (Burkill 1966:524), (Cape York) (Golson 1971:203, citing Roth 1901) and the leaves used to prepare a hot drink (Hamilton and Snedaker 1984:6). Honey is collected from trees of *C. decandra* (Hamilton and Snedaker 1984:6).

    This is one of the most durable of mangrove woods, with many uses. Bent branches are used as knees for boats and trunkwood is used for house-building. The fuelwood has a high calorific value, and the wood burns with a flame too hot for domestic uses as it cracks cooking pots (Lemmens and Wulijarni-Soetjipto 1992:66).

    The timber produces excellent tannin and extracts from the bark are used to toughen fishing lines (Watson 1928:187). Dyes are produced from the bark (black, purple, brown and yellowish-red) which are used for colouring and strengthening clothes and fishing nets (Foxworthy 1909:425, Burkill 1966:523, Hou 1970:11-2, Sin 1990:61).

15. *Cordia cochinchinensis*: The sap around the seeds can be used as a glue (Thailand) (Aksornkoae and Panichsuko n.d.:101).

16. *Cycas rumphii*: The large seeds of this palm are poisonous when fresh but processed flour made from the seeds may be eaten (Thailand) (Thieret 1958, Smitinand 1972:189). The processing involves pounding and soaking the product, repeatedly changing the water until all toxic compounds are extracted. The flour may then be dried for later use. The very young, uncurled leaves are eaten as a vegetable (peninsular Malaysia) (Foxworthy 1922:205) and starch may be obtained from the trunk of the tree (Burkill 1966:730).

17. *Cynometra ramiflora*: These trees are a good source of honey (Hamilton and Snedaker 1984:6).

18. *Derris* spp.: A fish poison is made from the roots and a similar preparation is used as an abortifacient (Burkill 1966:795-804).

19. *Diospyros* spp.: Some species have poisonous properties and extracts from the fruits and roots are used for stupefying fish. Dyes are also made from the immature fruits (Burkill 1966:839).

20. *Dolichandrone spathacea*: This wood is very light so used for making floats for fishing nets (Java). A blackish fibre is prepared from the bark (Burkill 1966:863).

21. *Enhalus acoroides*: This sublittoral seagrass leaves behind a durable fibre once it has become rotten and this is used for making fishing nets (peninsular Malaysia) (Burkill 1966:937).

22. *Excoecaria agallocha*: Condiments are said to be made from the bark (Hamilton and Snedaker 1984:6).

    The sap from the wood of *E. agallocha* is renowned for its irritant effect on skin and for blinding, if it splashes in the eye. Careful removal of the bark before cutting the tree can prevent this though and the wood can then be used for firewood or charcoal (Burkill 1966:1006). The latex is used as a fish poison or a dart poison (India and Indonesia) (Prakash *et al.* 1983, FAO 1985:37) and the timber is used for firewood, for making boxes and as matchwood (FAO 1985:37).

23. *Flagellaria indica*: The stems and the fruit are eaten by the Shompen of Great Nicobar Island (Rao 1984:89). The stems of this plant are also used for basketwork (Foxworthy 1922:179, Henderson 1954:206) and the split stems used to bind roofing panels made from nipa leaves (Thailand) (Larsen 1972:163). The stems are split into four, softened by soaking in water and used to sew bark bowls, to join bark fabric and to seal bark canoes (Groote Eylandt) (Specht 1958:485, Levitt 1981:138).

24. *Ficus* spp.: Fibres from the bark of *Ficus microcarpa* trees are used to make fishing nets and cordage (Sather 1985:173) and some species were formerly used for making clothing (for example among the Pangan of Malaysia) (Skeat and Blagden 1906:143, Burkill 1966:1018).

25. *Glochidion littorale*: There is generally too little wood in the stem of this tree to produce timber (Burkill 1966:1094).

26. *Guettarda speciosa*: Large leaves from this tree are used as plates or around damper before baking the dough in hot sand. The wood may also be used for fire-making (northern Australia) (Specht 1958:500).

27. *Heritiera littoralis*: The seeds are eaten with fish, when the seeds of *Parinarium glaberrimum*, which are preferred, cannot be obtained (Papua New Guinea) (Burkill 1966:1159, Percival and Womersley 1975:29).

    This tree produces a tough and durable timber recommended for boat-building (Chapman 1976:376, Ellen 1985:580) and piling, especially for the corner posts of houses, because it is teredo-resistant (Philippines) (Foxworthy 1909:418). Its twigs are also used for toothbrushes (Burkill 1966:1159).

28. *Hibiscus tiliaceus*: Very rarely, in some parts of Malaysia and New Caledonia, the youngest leaves are eaten (Barrau 1965:290, Burkill 1966:1193). This is one of the most important fibre-making plants in Malaysia and is used for cordage, for caulking boats and making nets, fishing lines and coarse bags. The inner bark was also used in Australia to make rope (Tindale 1925-6:115). Its timber is relatively lightweight and sometimes used for floats (Burkill 1966:1193). Resistant to water, the wood is used for house supports (Malaysia), in spearthrowers and sometimes for the shafts of fish spears and other spears requiring light shafts (Australia) (Tindale 1925-6).

29. *Intsia* spp.: The fruits of *I. retusa* are poisonous, but when heated, shelled and soaked in water for three to four days they serve as famine food (eastern Malaysia) (Burkill 1966:1265).

    The wood contains tannin and the bark from these trees produces a durable yellow-brown dye used for colouring mats and fabric (Foxworthy 1909:425, 1927:158,189, Burkill 1966:1265). The wood is a good timber, used for corner posts of houses (Philippines) (Foxworthy 1909:422), for boat keels and frames (Kinnimonth 1982:32) and especially for the rudders and superstructure (Maluku) (Ellen 1985:580).

30. *Lumnitzera* spp.: The leaves are eaten as a vegetable in India, Melanesia and other Pacific islands (Rollet 1975a).

    The timber from *Lumnitzera* trees is hard and durable, and used for piles as it is teredo-resistant (Malaysia, Philippines and Borneo) (Foxworthy 1909:418, Burkill 1966:1395). It is generally a poor firewood (Chapman 1976:379) although *L. coccinea* is better than wood from *L. racemosa*. This is said to be particularly useful during wet weather such as during cyclones, as the flames are difficult to extinguish (Groote Eylandt) (Levitt 1981:88).

31. *Lygodium* spp. The young leaves of this climbing fern are boiled or steamed and eaten, and the stems are also used in basketry (Thailand) (Phengklai 1985:207).

32. *Melaleuca leucadendra*: The young leaves are consumed cooked, and this is an everyday rather than a famine food (Cambodia) (Dy Phon 1982:162).

    The timber is durable in contact with sea water and teredo-resistant so is useful for house posts, for piles and for boat-building (Foxworthy 1909:418, Burkill 1966:1455). Its bark is used to seal the seams in boats and is put, with dammar, into torches (Ellen 1988:580). The wood is also used as floats for fishing nets and cajeput oil is made from the leaves (Foxworthy 1922:172). In northern Australia sheets of bark are chosen to make waterproof shelters while thinner pieces of bark are used to wrap items to be carried (Groote Eylandt) (Levitt 1981:109).

33. *Nypa fruticans*: This versatile palm produces a number of food products. The young inner part of the stem is boiled with a syrup made from the fruit (Phengklai 1985:206) and the gelatinous endosperm of the young seeds are also edible (Koenig 1894a, Foxworthy 1922:159, Davis 1988, Hamilton and Murphy 1988). Sap is tapped from the inflorescence stalk and converted to sugar, alcohol and vinegar (Tuck and Nor 1987:16, Hamilton and Murphy 1988, Fong 1992:46).

    Nypa fronds are put to widespread use in South-East Asia as thatching material for roofs of houses or boats, and are made into baskets, bags, mats, wrappers for dammar torches and cigarette papers (Foxworthy 1922:159, Burkill 1966:1584-8, Fong 1992:46). Lightweight arrows are made from the petioles which are also burnt as fuel and used as rafters supporting *Nypa* roofs. The leaves are converted into brooms, palm-leaf raincoats and matting (Davis 1988:109). Salt is sometimes extracted from the ashes of the roots and leaves (Foxworthy 1922:206, Rollet 1975a:208).

34. *Oncosperma tigillaria*: Several parts of this palm are used as food throughout mainland and island South-East Asia. The flower is used to flavour rice and the fleshy fruit and the terminal buds are used as vegetables and in salads (Foxworthy 1922:160, Chapman 1976:379, Dy Phon 1982:160, Laderman 1983:222, FAO 1985:37). The small, flat, pulpy fruits are also made into a preserve or chewed as a betel nut substitute.

    The wood is very hard and durable but with great elasticity (Foxworthy 1922:160, Burkill 1966:1608) so can be used for deeply planted fishing stakes and as piles to support riverside housing (FAO 1985:37, Chan 1986:50). The spines studding the stem are used as blowpipe darts and as the head of javelins when spearing fish. The sheaths of the flowers commonly serve as buckets and as containers for boiling water and baskets are made from the leaves (Burkill 1966:1608).

35. *Pandanus odoratissimus*: The leaves are cooked with rice to impart the smell of new rice (Lugod and de Padua 1979:62).

36. *Peltophorum pterocarpum*: This timber is useful for boat-building and the bark is used to produce a yellow-brown dye (Java). It is also commented that cattle will eat the leaves of this tree (Burkill 1966:1716).

37. *Pemphis acidula*: The acid leaves from this tree are eaten raw (Malaysia) (Burkill 1966:1716).

    This timber is notably hard, so used for items such as anchors, treenails and pestles, as well as for fuel (Malaysia) (Burkill 1966:1716) and digging sticks for uprooting yams and spearing mud crabs (Australia) (Specht 1958:498, Levitt 1981:98).

38. *Phoenix paludosa*: The young inner parts of the upper stem from this palm are boiled or steamed and eaten as a vegetable in soup and the fruits added to curries (Thailand) (Burkill 1966:1743, Phengklai 1985:206). The terminal shoots or the cabbage are eaten on a daily basis in Cambodia (Dy Phon 1982:160) and the fruits consumed in India (Blasco 1975:163).

39. *Pluchea indica*: Young shoots and leaves are eaten and used for flavourings (Cambodia, Thailand and Java) (Dy Phon 1982:160).

40. *Premna integrifolia*: The leaves are sometimes cooked with fish having objectionable flavour in order to mask the taste (Burkill 1966:1838).

41. *Rhizophora* spp.: The hypocotyls or fruits are sometimes eaten, although they contain toxic principles which need to be removed first. Boiling with wood ashes is said to make the preparation less unpalatable (Burkill 1966:1935, Singh and Arora 1978:69, Hamilton and Snedaker 1984:6). Alcoholic drinks are also prepared from the juice of these hypocotyls (Morton 1975:117, Chapman 1976:379, FAO 1985:37).

    The timber from *Rhizophora* is exceptionally heavy and resistant to sea-water. Its prime use in boat-building is for anchors (Indonesia) (Ellen 1985:580) and it is good for poles and house-frames in the swamps although it is reported that the building timber is only durable if the piles are completely buried and cannot be attacked by sea worms (Macnae 1968:234). It is also the preferred wood for making fish-traps, while the aerial roots are elastic and used for making bows (Seeman 1918:65-73). As with other timber of the Rhizophoraceae, this wood makes excellent firewood as it is easily split and high in calorific value. It is one of the preferred timbers for charcoal production.

    The bark and leaves make a good dark brown to black dye, sometimes used as a hair dye (Fiji) and the bark contains high proportions of tannin (Burkill 1966:1931-5). These tannins are employed to strengthen fishing nets and lines. West Indian fisherman rub their fishing lines with the cut end of a hypocotyl and soak their nets in the red liquid from boiled hypocotyls in order to strengthen them (Morton 1965:115). Sap from the timber is mixed with sap from *Hibiscus moschatus* and used by potters as an external application to pottery immediately after firing (Seeman 1918:65-73).

42. *Sarcolobus globosus*: The seeds of this climber are very poisonous, but their mesocarp may be eaten once cooked (Thailand) (pers. comm. Chewalit Niyomdham).

43. *Sapium indicum*: The seeds may be eaten when quite ripe, but care should be taken to put no more than one seed into the mouth as the latex in the fruit wall is caustic (Burkill 1966:1996).

    The chief use is as a dye (yellow-green and black) but the pounded fruits are also used as a fish poison (Burkill 1966:1995).

44. *Scaevola taccada*: The leaves may be eaten (India) (Singh and Arora 1978:37).

45. *Scyphiphora hydrophyllacea*: This is a very hard, dark brown wood which is used to make fence posts and tool handles, and is also a good firewood (Chapman 1976:379).

46. *Sonneratia* spp.: The ripe fruits are edible although acidic, and reported as having been gathered for food in eighteenth century Thailand and currently in India, Malaysia and Java where they are used

to flavour fish or for making vinegar (Koenig 1894a:127, Foxworthy 1922:213, Burkill 1966:2088, Percival and Womersley 1975:29, Singh and Arora 1978:72). The young fruits of *S. caseolaris* are sour and used for flavouring chutneys and curries, and the ripe fruits which have a cheese-like taste are eaten raw or cooked (Burkill 1966:2089). Fruits of *S. acida* are used for making vinegar (Brown 1958:43). Those from *S. ovata* are reported as being eaten as a raw vegetable (Indonesia and Thailand) (FAO 1985:37, Phengklai 1985:206). The leaves from *Sonneratia* may be eaten raw or cooked, sometimes in a fish stew (Vietnam, Cambodia and Laos) (Vu Van Cuong 1965:210)

The wood has a high ash content and a high calorific value, but is inferior to other mangrove woods like *Rhizophora* and *Ceriops* and is not chosen when alternatives are available (Vu Van Cuong 1965:201, Burkill 1966:2089) although it is used as tinder during the conversion of *Rhizophora* to charcoal (Vu Van Cuong 1965:199). The teredo-resistant timber is favoured for piling (Philippines and Indonesia) (Foxworthy 1909:418, Burkill 1966:2090, Ellen 1985:581). The wood from *S. griffithii* is cut into large posts for supporting quays, but iron spikes, nails and bolts are soon rusted by the wood's high salt content (Macnae 1968:234). The pneumatophores are converted into corks by shaping them and boiling them in water (Sri Lanka, Thailand, Philippines and Borneo) and they are also used as fishing floats (Foxworthy 1909:427, Chapman 1976:379).

47. *Suaeda maritima*: The leaves are eaten as a green vegetable in Java (Heyne 1927:604, Backer 1954:106) and India (Singh and Arora 1978:38).

48. *Thespesia populnea*: The leaves are eaten by the Shompen of Great Nicobar Island (Rao 1984:89) The fibrous bark is used for caulking boats and making cordage and fishing lines (Burkill 1966:2192). Tannin may also be extracted from the bark and the wood (Foxworthy 1922:198). The timber is hard and almost indestructible underwater, the wood being better than that from *Hibiscus tiliaceus* but the fibre inferior (peninsular Malaysia) (Seeman 1918:65-73). This wood is also used for spears which require light shafts such as those used for fishing, but as this wood is heavier than that from *Hibiscus tiliaceus*, it is used only when well dried (Groote Eylandt) (Levitt 1981:100).

49. *Trianthema portulacastrum*: The green leaves of this herb are eaten (India) (Christensen 1983:8).

50. *Tupis grandis*: This is an edible, succulent herb, found in fresh and saltwater swamps (Thailand) (Phengklai 1985:206-7).

51. *Xylocarpus* spp.: The dense, even-grained and teredo-resistant wood from *Xylocarpus* trees is preferred for house-posts and boat building, especially for treenails, and is valued for furniture making (Foxworthy 1909:418, Burkill 1966:458-61, FAO 1985:37). The wood of *X. moluccensis* has high calorific value. Tannin from the timber is used for tanning heavy hides and for toughening fishing nets. A dark brown dye is extracted from the wood of *X. granatum* and the seeds and the astringent bark have some uses for medicine and for fish poison (FAO 1985:37, Lemmens and Wulijarni-Soetjipto 1992:128). Oil produced from the seeds of *X. moluccensis* is used as an illuminant and as hair oil (peninsular Malaysia) (Foxworthy 1922:171, Chapman 1976:379) and a bright red dye is made from the wood.

IV. THE CHARRED AND MINERALIZED WOOD REMAINS

CHARRED WOOD

AMONG the plant macroremains from Khok Phanom Di was abundant wood charcoal, the examination of which had two main aims: to estimate the relative density of charcoals through the profile, and to examine temporal changes in taxonomic composition. The former has implications for the nature and intensity of site use, deposition processes and subsequent reworking of the matrix. The latter may inform us about the types of timber brought onto the site, and by inference, the local environment (Smart and Hoffman 1988).

In most cases, charred plant remains such as seeds, fibres and crop residues are the products of accidental burning, whereas wood charcoal is, in some contexts, far more likely to result from intentional burning. Thus, making allowance for taphonomic factors, 'the archaeological patterning directly translates to a pattern of human behaviour' (Pearsall 1983:122). The charcoals at Khok Phanom Di may represent residues from a number of former activities involving deliberate burning: domestic cooking, smoking fish, producing smoke to ward off mosquitoes and other insects (Aksornkoae *et al.* 1986, Bird 1986), industrial activity or even use in rituals when burying the dead (White 1986, 1988).

Accidental or secondary sources of charcoal could have been associated with a further range of wood uses at the site, such as the preparation of medicines, manufacture of tools, weapons, utensils, furniture, boats, houses, fibres, fishing equipment, accoutrements for decorating pottery and so on. Broken or discarded objects may also have been tossed into a fire or the finished products accidentally set alight. Offcuts and wood chips from building construction are particularly likely here, given the number of postholes excavated which suggest stilt-supported buildings. Each of these activities might be associated with particular timber selections. Some of the traditional South-East Asian uses recorded for mangrove and mangrove-associate woods are set out above, and point to the range of possible wood-working and wood-using activities which, if carried out at Khok Phanom Di, might have contributed directly or indirectly, to charcoals in the archaeological record.

At Khok Phanom Di, ash deposits associated with graves have been interpreted as the debris from some form of burial ritual, either 'cleansing the ground' before grave-digging, or graveside food preparation for 'mortuary feasting in commemoration of the dead ancestors' (Bannanurag 1989), with the latter interpretation being favoured (Higham and Bannanurag 1990b). A number of methods are used for cooking shellfish. Meehan (1982) describes *Anadara granosa*, the most common species at Khok Phanom Di, being cooked directly in hot ashes by members of the Anbarra community in Arnhem Land, northern Australia. Other techniques involve steaming or roasting the shellfish in a pit or earth oven or in, around, over or under an open fire (Waselkov 1987).

Other reasons for lighting fires at the site include firing pottery, but wood charcoal is likely to be a minor by-product of this, since pots are thought to have been fired in the open air, probably using grass-fuelled timber or bamboo rafts. Ceramic objects interpreted as firing platform supports

have been found (Vincent 1987). These are similar in form, and most probably in function, to the clay supports for the timber framework on which pots are currently fired in north-eastern Thailand, as reported by Bayard (1977b) and White (1982c). The preferred fuels for present-day potters working with this technique tend to be dried grasses, especially rice straw or husks (Solheim 1964, 1967, Bayard 1977a, 1977b, McGovern *et al.* 1985, White 1982c, 1988), in combination with palm leaves (Arafin 1991). Bark, dried manure (Lefferts 1988) or split bamboo (Bayard 1977b, Longacre *et al.* 1991) are alternatives. All are chosen for producing instantaneous high heat (Rye 1981). They are used even when hardwood sources are in abundant supply. Such light grassy fuels condense to a fine ash rather than charcoal, but charred wood fragments from the raft may persist if combustion has been incomplete. The lowest ash lenses of zone A prior to the use of the area as a cemetery are consistent with interpretations of ceramic production (Vincent 1987).

In addition to deliberately chosen firewood and burnt woody refuse, further sources of charcoal might have been the accidental or deliberate burning of trees growing around, if not actually on top of the mound in antiquity. There may even be charcoal from the accidental destruction of wooden buildings. This can sometimes be traced in the archaeological record by large burnt timbers or lines of ash representing rafters and beams, as demonstrated by experimental destruction of timber buildings followed by excavation of the remains (Coles 1973, 1979). However, if the building was well ventilated, as South-East Asian stilt buildings are, a large destructive fire may equally have resulted in complete combustion and very few charcoals. This kind of destruction would be hard to discern in the archaeological record.

Hearths were largely confined to layers 10-8 (Higham and Bannanurag 1990a) and were less common than the extensive charcoal spreads which were sampled for charcoal identification. As White (1988) points out from her interviews and observations of village life in north-east Thailand, ground-level fires are relatively few and ephemeral in a settlement where most occupation is above ground level. The diffuse nature of the charcoal spreads would be compatible with domestic cooking in a stove, high up above the ground in raised stilt-buildings, with ash and charcoals intermittently being dropped to the ground below. Here they might be dispersed across a wide area by natural and human agency. Open fires at ground level are lit to dispose of garden and domestic waste. At Khok Phanom Di, Saam Khaa and Nong Jap Tao refuse was repeatedly burnt at one place in the household compound on approximately a weekly basis.

In modern Thai villages, cooking food is undoubtedly the most common fire-generating activity and it seems highly likely that most of the charcoal described here is debris from intentional burning of fuelwood, quite possibly in the context of funerary feasting. The charcoal can thus be considered to come from functionally equivalent contexts throughout the site, irrespective of whether they are primary burning features or contexts of secondary deposition such as middens and charcoal spreads. This assumption underpins the discussion of temporal change in sample composition below.

Contributions of charcoal analysis to understanding archaeological sites

Archaeological charcoals have been used primarily as radiocarbon samples for establishing site chronologies but more recently their identifications have contributed to environmental interpretation and have generated data on timber selection for specific purposes. Charcoal identifications contribute to the reconstruction of past vegetation, especially the *local* arboreal environment, which is generally better represented as wood remains than as pollen, where local woodland details may merge with the regional picture. There are two reasons, though, why the pollen analyses linked

with this study (Maloney 1987, 1988, 1991, Maloney and Brown 1990, Maloney and McAlister 1990, Maloney *et al.* 1989) may be unusual in providing a local perspective on the vegetation within the regional picture. Firstly, some mangrove pollens are known to be deposited very close to source. Grindrod's (1985) studies of modern pollen traps in northern Queensland have demonstrated that certain mangrove pollen types, namely *Bruguiera/Ceriops* and *Avicennia*, tend to be deposited close to source. Their presence in the fossil record therefore suggests that the site was very close to the trees in question, within the landward mangrove zone. Second, the sediment cores were drilled very close to Khok Phanom Di so that the palynological record could be tied in with the archaeological evidence. Overall, the pollen cores document vegetational history from *c.* 5500 BC onwards and overlap with the occupation deposits of zone A and up to approximately layer 6:6 in zone B, in the second millennium BC (Maloney and McAlister 1990). The charcoal data continue, albeit weakly, through to zone C, thereby extending the vegetation record into the latest occupation phase.

In other situations, using taxa with known physiological requirements, preferably in marginal environments, from a wide range of archaeological sites and over a long timespan, data from archaeological charcoal have been employed for palaeoclimatic reconstruction (Neumann 1989, Prior 1983, Tusenius 1989). This would, however, be an inappropriate aim with respect to a single site with a short chronology, especially a site in a mangrove environment where the vegetation is edaphically and hydrologically rather than climatically controlled at low latitudes (Blasco 1984).

Further inference from charcoal analysis concerns wood use, notably patterns of timber selection for a variety of purposes, as detected in studies of context-related variation in wood assemblage composition (Shay and Shay 1978, van Zeist *et al.* 1984), and studies of firewood choice and fuel resource management (Pearsall 1983, Miller 1985, Smart and Hoffman 1988, Johannessen and Hastorf 1990). The samples from Khok Phanom Di are not well suited to this approach as they do not derive from a variety of well-defined context types at the site. They can, though, provide information about domestic cooking fires and may still indicate something about fuelwood selection, resource management and the local ecology.

Integrating cultural and ecological explanations for the archaeobotanical record is profoundly difficult and both are relevant in the interpretation of the Khok Phanom Di charcoal data. Although ecological conditions initially govern the range of taxa available for selection, people match specific wood types with particular purposes, so that a cultural filter operates in tandem with ecological factors, charring conditions, anatomical differences and other post-depositional taphonomic factors to produce an archaeological charcoal assemblage.

MINERALIZED WOOD

A few samples of mineralized timber, whose original purpose may be specified unequivocally, were also recovered. From two zone A graves the remains of wooden linings, coffins, biers or even pillows (cf. Radcliffe-Brown 1932 on Andaman mortuary practices) are described from beneath the skeletons in burials 100 and 107 (Bannanurag 1989, Higham and Bannanurag 1990a). A third sample was found with B. 43 in zone B (pers. comm. C.F.W. Higham). In six rare instances mineralized stumps or slivers of wood were discovered *in situ* within postholes and have been examined:

Layer 10:2, quadrant D, feature 12

Layer 10:8-9, quadrant D

Layer 10:19, quadrant A, feature 10

Layer 10:20, quadrant D, feature 5

Layer 10:21, quadrant A, feature 4

Layer 10:22, quadrant C, feature 5

Additional samples of mineralized wood were taken from contexts where the wood use was not self-evident. These were:

Layer 8:7, quadrant D, lens 12 (a shell lens)

Layer 10:5, quadrant D, feature 19 (a small irregular area of disturbance)

Layer 10:14, quadrant C, feature 28

Layer 10:20, quadrant B

Layer 10:25, quadrant A

These highly mineralized materials are likely to be the product of very swift replacement of the timber's cellulose by soluble minerals percolating through the soil profile. Chemical analysis using EDAX on carbon-coated specimens, examined by scanning electron microscope, indicated a single strong peak of calcium. This suggests that the wood had been replaced by calcium carbonate in solution, derived from later shell middens.

These specimens retain the outward appearance of wood, but their internal anatomy is obscured by mineral replacement. They are very dense and hard, making them difficult to fracture. Examination by incident light microscopy was unsuccessful due to the high reflectivity of the mineralized surfaces, while SEM revealed that much of the anatomy had been obscured by crystallization. The fact that the wood may have become rotten and degraded during partial waterlogging *in situ* may also have reduced the recognizable anatomical characters (pers. comm. W.E. Boyd).

Splinters or thin plates of the mineralized wood from each sample were immersed in distilled water and cleaned in an ultrasonic bath before being slowly air-dried and mounted on stubs for SEM examination. The general structure was consistent with the fragments being a hardwood, but detailed diagnostic features were not visible. In a couple of specimens, there were small areas where the mineralized infill of the vessels was recognizable in an undifferentiated groundmass. In another case the surface gave the overall impression of being a radial longitudinal section. Although it was possible to confirm that these are petrified woods, diagnostic features are not adequately preserved to allow identification (Fig.11).

The single exception, where preservation was adequate for a range of diagnostic features to be discerned using SEM, was the remains of a wooden coffin or bier from B. 107. Slivers of mineralized wood were attached to the bones. They were especially well preserved around the right tibia and the grain was noted to run parallel to the body (Bannanurag 1989). This particular burial was cut about 5.4 m below datum (Mortuary Phase 2) in layer 10:15. The individual interred

here was an adult female, around 40 years old at death, who was buried covered with red ochre, possibly wrapped in *tapa* cloth (barkcloth, the examination of which will be discussed in chapter V). She was placed in a grave with a burnishing stone, the jaw of a sambar deer and a macaque femur (Bannanurag 1989). The only aspect in which this grave was remarkable was in the discovery of the wooden bier. It is quite possible that burial on a wooden bier was commonplace at Khok Phanom Di, but that the evidence rarely survives.

The sample comprised nearly 20 small slivers of mineralized wood which had been replaced and infilled by calcium carbonate. The wood is most probably diffuse porous, having solitary and radially paired vessels, but due to its preservation in long thin fragments, it was not possible to have a broad view of the transverse section. The rays are triseriate and biseriate, with large cells at the tails. The inter-vessel pits were observed to have classic diagonal alignment and their diameters were less than 3 microns, which places them in the category of 'alternate minute' pitting (Barefoot and Hankins 1982, Ilic 1987) (Fig. 11). This was, then, not a Rhizophoraceae-type wood, but one of the mangrove associates, possibly *Xylocarpus* sp.

METHODS OF CHARCOAL ANALYSIS

Quantifying the charcoal assemblage

The meaningful quantification of charcoal and fossil wood assemblages has long been overlooked, but is now receiving more attention in the archaeobotanical literature (Miller 1985, Boyd 1988a, 1988b, Thompson 1994), although a consensus is yet to be reached on the ideal means of tackling the problem. Quantitative methods, such as numbers of fragments (e.g. Western 1971, Johannessen and Hastorf 1990), weights (e.g. Spratling 1979) and even volumetric measurements (e.g. van Zeist and Heeres 1973, van Zeist *et al.* 1984) have superseded the simple listing of taxa found at a site (e.g. Hyde 1932, Mabey and Hyde 1940, Salisbury and Jane 1940, Chowdury and Ghosh 1954-5). The relative advantages of using fragment counts or weights vary between sites, according to preservation conditions and the taxonomic composition of the assemblage. Where wood taxa known to produce particularly fragile charcoal are found in the archaeological record, even as small fragments, their interpretive importance may be disproportionate to their size. Some authors prefer to use a single means of quantification, while others employ a combination of the two (e.g. Miller 1985). A similar debate over absolute numbers and relative frequencies is yet to be conclusively resolved and the choice of the best approach may depend entirely upon the questions posed and the uniformity of preservation and sampling throughout the materials analysed.

Patterns of charcoal fragmentation at Khok Phanom Di could not be predicted from accounts of mangrove charcoal identifications in the archaeobotanical literature, so both weight and fragment counts were adopted. In the event, the two measures provided similar results. The number of fragments may be a good method for assessing the proportion of a charcoal type within a sample, and drawing comparisons between samples when there is an even distribution of charcoal fragments by weight and size. This is less appropriate though, where distributions are skewed. Where there is differential fragmentation between taxa and material is examined across all size classes, the importance of small fragments is overemphasized if quantification is by count. In such instances, measurements by weight will provide a better estimate of relative contributions to the assemblage.

Where there is a wide variation in charcoal density between types, though, heavy fragments will be overestimated by weight measurements. Both these possibilities are explored below.

Sample collection and selection

Charcoal was found throughout the site and was collected from all four quadrants of the excavation. However, since the primary aim was to examine temporal changes in the charred wood assemblage and there were time constraints limiting the amount of material to be examined, samples for analysis were restricted to selected contexts from a single quadrant spanning the depth of the profile. Quadrant C was excluded on stratigraphic grounds. This was the part of the site where a raised rectangular mortuary structure was found (Higham *et al.* 1987, Higham and Bannanurag 1990a). This meant that this quadrant had an atypical depositional history. After initial assessment of the number and volume of archaeobotanical samples from the other three quadrants, charcoal from the south-western area, quadrant A, was selected, as with the flot analysis.

Sampling the charcoal assemblage

The basic on-site sampling of charcoal has been outlined in a preceding section. However, the means of sampling, and the different, sometimes conflicting aims of charcoal collection, need to be reiterated, since the field sampling strategy has implications for the charcoal analysis and interpretations.

The samples for analysis were not the full complement of charcoal from the site. The assemblage had been biased in both systematic and non-systematic ways. During the excavation, some charcoal had been retained for radiocarbon dating and some was included in the soil processed by flotation, while the remaining conspicuous pieces were set aside as separate charcoal samples. It is this last fraction which is described in this section. A fourth component is likely to have been selection in favour of large fragments and incomplete retrieval (Pals and Voorrips 1979), and these types of sampling error are particularly hard to quantify. During excavation, careful attention was given to establishing the chronological framework for the site, and highest priority was accorded to retrieval of well-provenanced charcoal for dating purposes. Separate samples were put aside for submission to radiocarbon laboratories and were not identified before they were dated. Records were kept of the total sample weights and have been included here (pers. comm. C.F.W. Higham). Four of the radiocarbon samples dated came from quadrant A. Two were from layer 8:7 lens 10 and layer 10:6 lens 3. The weights of these samples have been incorporated in table 3 along with data for the hand-picked samples. The other two were from hearths in layer 10, pits 22 and 25, and are excluded here as their charcoal weights refer to very localized concentrations. As mentioned in the previous section, a sample of soil from each excavated spit was used for flotation. The standard sample size was 100 l for layers 1-9:3 and 50 l for layers 9:4 to the bottom of the cultural deposit at 11:2. The charcoal included in these provenanced samples was not included in the analysis. In principle, it should be possible to estimate the weight of charcoal in these samples, because they constituted a known proportion, 100 or 50 l from spits of known volume (5 m^2 x 0.1 m). In practice this is not so, because clearly defined features intruding into a spit were removed separately and the extent to which this reduced the volume of spits was not recorded. Thus the volumes of the spits which provided the hand-picked samples available for archaeobotanical analysis varied from one level to another according to the intricacies of the stratigraphy.

TABLE 3: *Total weights of charcoal samples from successive contexts in quadrant A*

Context	Total weight of charcoal sample (g)	Context	Total weight of charcoal sample (g)
2:1	27.27	9:2 lens 4	11.04
2:2	1.99	9:2	14.05
2:3	0.50	9:3	20.62
3:1	1.21	9:4	19.68
3:2	2.47	9:5	18.59
3:3	0.12	9:6 lens 9	6.25
3:4	0.32	9:7	31.23
4:1	0.04	10:1	7.79
4:2	-	10:2	41.57
4:3	-	10:3 lens 2	299.03
5:1	-	10:3	24.23
5:2	0.08	10:4	35.25
5:3	-	10:5	24.97
5:4	1.49	10:6	47.27
5:5	0.38	10:6 lens 3*	4.60
6 lens 1	0.35	10:7	52.17
6:2	0.13	10:8	36.27
6:3	-	10:9	47.08
6:4	0.43	10:10	76.38
6:5	-	10:11	24.39
6:6	-	10:12	34.04
6:7	-	10:13	16.63
7:1	4.16	10:14	30.62
7:2	-	10:15	44.46
7:3	-	10:16	50.19
7:4	-	10:17	176.72
7:5	0.70	10:18	54.32
7:6	0.14	10:19	57.21
7:7	-	10:20	24.07
8:1	6.00	10:21	42.33
8:2	5.47	10:22	22.74
8:3	7.04	10:23	49.97
8:4	-	10:24	103.54
8:5	0.12	10:25	19.72
8:6	5.31	10:26	44.33
8:7 lens 10	6.37	11:1	18.81
9:1	25.82	11:2	5.16

* charcoal sample used for radiocarbon dating

- no charcoal sample

It is obvious, then, that the charcoal density data presented here are subject to a number of qualifications: hand-picking is not a precise method of recovery; charcoal was not recorded from cultural material subjected to flotation; more earth was removed for such samples in the upper part of the site (where charcoal was less common) than in the (more charcoal rich) lower part; and the volume of the spits from which the analysed charcoal samples were recovered was not constant.

The most heavily disrupted spits had the highest charcoal concentrations suggesting minimal effect on the final interpretation, with the volume of charcoal samples providing some general indication of the amount of charcoal through the archaeological profile.

Identifying charred woods

A total of 775 charcoal fragments were examined from 24 of the 61 quadrant A charcoal samples. Where possible, fifty specimens per sample were weighed and examined microscopically. In samples from layers 1-8 (zones C and much of B), preservation was poor, the mean weight of fragment smaller and the density of charcoal in the matrix less, so the number of fragments both available for analysis and falling in the identifiable size range (>0.01 g and roughly equivalent to the 2 mm fraction) was fewer than in the lower strata. The sample size was, therefore, sometimes restricted to fewer than twenty fragments. A cut-off point of 0.01 g was chosen for both technical and anatomical reasons. Smaller specimens were excluded because they were generally too small to handle, making it difficult to produce good clear fractures in all three planes. Certain identification criteria require a general view so that the distribution of anatomical elements may be observed. With very small pieces, features such as the alignment of parenchyma and storeyed rays are not always seen.

The fact that the pieces selected for identification were the largest from each sample potentially introduces an element of bias. If certain charcoal types inherently rupture more readily than others, those which typically occur as small slivers will be overlooked or underestimated. Fragments of the Rhizophoraceae-type tend to fracture easily. They tend to split parallel to the grain due to weakness along their broad and long rays. However, despite their relative fragility, Rhizophoraceae-type charcoals are well represented in the assemblage. The possibility that a combination of this tendency for Rhizophoraceae-type charcoal to splinter, and the preferential choice of large fragments for identification has detrimentally skewed the data is explored further below.

The decision to identify fifty specimens from each sample reflected the abundance of materials available and the taxonomic diversity of tropical forests. Sample sizes of twenty fragments have been acceptable elsewhere (Miller 1985, Smart and Hoffman 1988, Johannessen and Hastorf 1990), but optimal sample size should increase with floristic complexity (Smart and Hoffman 1988). It was therefore thought appropriate to examine a greater number of pieces than convention suggests. The larger sample size also reduced the need for strictly random sampling across all fragment sizes, since a greater proportion of the total material could be examined. The ratio of examined material to the total sample is given as a percentage in terms of weight in table 4. This ranged from only 12 per cent of a very large sample in layer 10:3 lens 2 to 100 per cent for a number of small samples from the upper part of the site.

Preparation of reference material

Voucher specimens of twig and mature timber were taken from trees and shrubs growing in the mangroves, backswamp, sandy coastal and other lowland areas of south-eastern Thailand. Addi-

TABLE 4: *Sample composition of charcoal identifications (raw data). First column: weight (g). Second column: number of fragments*

Context	Rhizophoraceae -type		Non-Rhizo-phoraceae		Indet-erminate		Total		% weight examined
3:1	-	-	1.06	14	0.15	3	1.21	17	100
3:2	0.91	3	1.30	14	-	-	2.21	17	89
3:4	-	-	0.32	4	-	-	0.32	4	100
5:2	0.08	2	-	-	-	-	0.08	2	100
5:4	0.14	2	1.27	9	0.05	3	1.46	14	98
5:5	0.18	2	-	-	0.20	7	0.38	9	100
6:lens 1	0.09	2	0.20	4	0.06	2	0.35	8	100
6:2	-	-	0.08	3	0.05	4	0.13	7	100
7:1	1.55	20	1.57	23	1.04	7	4.16	50	100
7:5	0.20	4	0.05	4	0.45	2	0.70	10	100
8:1	0.98	24	-	-	0.04	1	1.02	25	17
8:2	1.71	29	0.05	1	-	-	1.76	30	32
8:3	2.17	37	0.35	11	0.07	2	2.59	50	36
9:1	6.43	39	1.54	6	0.85	5	8.82	50	34
9:6 lens 9	2.52	30	3.30	16	0.43	4	6.25	50	100
10:3 lens 2	34.56	50	-	-	-	-	34.56	50	12
10:7	16.88	49	0.19	1	-	-	17.07	50	33
10:11	12.70	44	1.25	4	0.44	2	14.39	50	59
10:16	18.99	46	1.42	4	-	-	20.41	50	41
10:20	16.38	47	0.91	1	0.72	2	18.01	50	75
10:23	11.32	38	4.91	12	-	-	16.23	50	32
10:26	38.22	50	-	-	-	-	38.22	50	86
11:1	10.48	48	0.81	1	0.44	1	11.73	50	62
11:2	5.15	30	-	-	-	-	5.15	30	100

tional plant parts, such as *Bruguiera* hypocotyls (embryonic roots), which ethnographic evidence suggests may have been brought into a settlement as food (see chapters III and VIII), were also charred and included in the reference collection. The comparative material was supplemented by wood thin sections from the Forestry Department of the Australian National University.

Each type of reference charcoal was initially fractured, then examined and photographed using SEM, so that photomicrographs, descriptions and actual comparative material were all to hand when the archaeological materials were identified. Within the wood/charcoal reference material, the common seaward taxa were better represented, because backswamp and freshwater swamp areas have nearly all been destroyed in the clearance of land for agriculture along the south-eastern seaboard of Thailand. It was not possible to find a close analogue to the forest which might have grown inland behind Khok Phanom Di during prehistory, if indeed those areas were forested rather

than under herbaceous freshwater swamp as the pollen seed and phytolith evidence suggests. Freshwater lowland forest is restricted to low-altitude depressions in peninsular Thailand (Smitinand and Pheng Khlai 1973). Occasional relict mangrove associates grow alongside canals and roads as shade trees in *changwat* Chonburi, their growth permitted by the saltwater wedge which extends many kilometres inland (Whitten *et al.* 1987). Specimens of their leaves, fruits and timber were added to the reference collection whenever feasible.

Preparation and examination of archaeological specimens

Individual fragment weights were recorded and each piece of charcoal was stored in a numbered glass vial. The grain of each piece was identified under low power stereomicroscope or by eye, so that the fractures through the specimen could be accurately aligned. Each fragment was broken manually after being superficially scored with a thumbnail or razor blade, following Leney and Casteel (1975). The small fragments were then mounted on glass slides using a mounting medium strong enough to hold the charcoal in place under the microscope, but also permitting the fragment to be removed and reoriented or split again. Extraneous powder was removed from the surface with a quick jet of air. Transverse, radial longitudinal and tangential longitudinal planes (TrS, RLS and TLS) were examined. Specimens were viewed using an epi-illuminating petrographic microscope (Olympus BH2) at magnifications of x100–x1,000. The lowest magnification was appropriate for viewing the overall pattern of vessels in TrS, while most diagnostic characters important for separating the woods in question here were clearly visible in TLS and RLS at x500. Magnification of x1,000 was reserved for checking supplementary details, such as the type of fine pitting in the ray-vessel walls.

Examples of each archaeological 'type' were examined using SEM to provide supplementary diagnostic features and a photographic record of the material. Fragments were mounted on SEM stubs using nail polish, and sputter-coated with gold in an atmosphere of argon. The elemental carbon in charcoal is conductive, and although it is not obligatory to coat such specimens, this does improve conductivity and resolution, which in turn provides better images (McGinnes *et al.* 1974). This is particularly true for charred archaeological plant remains, containing impurities which charge under the electron beam (pers. comm. J. Hather).

With careful fracturing it was possible to expose the structural details of all three planes in a single fragment. An adjustable stage allowed the specimen stubs to be tilted and rotated to view all orientations. Specimens were examined using a Cambridge Stereoscan microscope operating at 20kv and photographed using Kodak FP4 or Plus-X pan film.

The charred woods from Khok Phanom Di were generally well preserved and although some variation in hardness was observed, none were so friable that they required artificial hardening before being split (cf. Prior 1988). Exceptionally poor preservation was seen in a minority of Rhizophoraceae-type charcoals from layers 10 and 11, where diagnostic features were sometimes slightly obscured by ferrous and calcium carbonate minerals which had crystallized within fissures and/or cell lumina.

Identification criteria

Diagnostic characters as defined in general anatomical texts (Butterfield and Meylan 1980, Barefoot and Hankins 1982, Metcalfe and Chalk 1983, Wilson and White 1986, Ilic 1987) were compared with published descriptions of South-East Asian and Pacific woods (Gamble 1902

[1972], Foxworthy 1909, Janssonius 1952, Coode 1969, Hayashi *et al.* 1973, Keating and Bolza 1982), although these tend to focus on economically valuable timbers and many offer only cursory descriptions of microscopic anatomy. Wood anatomy literature dealing with mangrove taxa include Panshin (1932), Patanaprasith (1966), Mukherjee (1969), van Vliet (1976) and Rao *et al.* (1989). These were consulted in conjunction with modern reference material. Features from the unknown charcoals were used also to generate lists of woods from the Computer-Aided Wood Identification (GUESS) program in association with the Oxford/PRL/CTFT/NCSU databases (LaPasha 1986).

The features considered to be most informative were: the type of vessel perforation plate (scalariform or simple), the number of bars in the case of scalariform perforation plates, the type of vessel to vessel (intervascular) pitting (scalariform or alternate) and the width and type of rays. In mangrove woods, transverse sections contribute fewer diagnostic features than the other two planes, as there are broad similarities between these woods in this respect. They are all diffuse porous, predominantly with solitary pores and a tendency towards radial files of two to six vessels (mainly in radial pairs). Differences between them are subtle and certain ancillary features such as the distribution of parenchyma, useful for separating fresh specimens, do not always survive charring well (Rossen and Olson 1985). An exception, however, is the genus *Avicennia*, where the transverse view is indeed helpful (Ilic 1987). This wood has 'concentric, branching bands of interxylary phloëm' (Panshin 1932) which may be seen in cross section, but in small archaeological fragments it is not always possible to have a large enough transverse view to see the gross distribution of phloëm. In general, the tangential and radial longitudinal sections expose more informative characters, including the type, width and distribution of rays, intervessel pitting and the perforation plates.

Mangrove forest is a distinctive and relatively species-poor habitat compared with adjacent lowland regions (Banijbatana 1957). The identification of woods from this zone should be more straightforward than for other tropical forests, though it is undoubtedly more complex than working with, for example, the limited temperate European or semi-arid West Asia floras. Dichotomous keys for the identification of mangrove woods are provided by Panshin (1932) and Patanaprasith (1966), but it is difficult to apply them to charred archaeological remains because they often employ quantitative features and their validity is limited when examining tiny fragments. Pyrolysis does not preclude wood identification, but it does distort and eliminate certain features, making charcoal identification rather more challenging than that of non-charred timber (McGinnes *et al.* 1974, Rossen and Olson 1985). An example of one conventional identification criterion not reliably recognized in charred specimens of a mangrove timber is the presence of lysigenous break-down areas in the rays of *Aegiceras corniculatum* (Ilic 1987). These could well be confused with distorted or fused cells in charred specimens. Situations such as this necessitate a change in the ranking of diagnostic features and the application of keys specifically designed for use with charcoal rather than fresh timber.

The problems of identifying charred archaeological wood have been addressed in certain temperate regions (e.g. Schweingrüber 1976, Prior 1983, 1988, Rossen and Olson 1985, Minnis 1987). Although these accounts provide methodological insights applicable to Thai material, none directly addresses South-East Asian taxa. A summary of the characters found useful for examining common burnt mangrove timbers has been compiled after consulting the literature and checking the features against modern, identified, charred woods (Table 5). There are no other published reports on mangrove charcoal identification in the archaeological literature with which to compare this

work. Charcoals have sometimes been recovered, but remain to be identified, from other prehistoric sites located within, or with access to, mangroves. Examples include sites in Arnhem Land in northern Australia (Clarke 1985, Allen 1987, Meehan 1988), at Shark Bay, Western Australia (Bowdler 1990) and various middens excavated in the Andaman Islands (Cooper 1985), the Niger Delta of West Africa (Nzewunwa 1980) and in north-eastern Venezuela (Sanoja 1989).

TABLE 5: *A preliminary key for identifying common charred archaeological wood from mangrove and mangrove associates in Thailand, using microscopic criteria*

Ray width	Intervessel pitting	Ray type	Genus	Key characteristics
WOOD WITH SCALARIFORM PERFORATION PLATES				
multiseriate	scalariform	heterogeneous	*Rhizophora**	scalariform perforation plates, 5-11 bars; septate fibres present
			*Bruguiera**	scalariform perforation plates, 6-11 bars; septate fibres present
			*Ceriops**	scalariform perforation plates, 5-8 bars; no septate fibres
WOOD WITH SIMPLE PERFORATION PLATES				
uniquely uniseriate	alternate bordered	homogeneous	*Lumnitzera**	radial files of vessels in groups of 2-4
		heterogeneous	*Allophyllus***	
			*Excoecaria**	rays homogeneous/heterogeneous
			*Melaleuca***	rays short (<10 cells tall)
mainly uniseriate (with some biseriate)	alternate bordered	homogeneous	*Dolichandrone***	some perforation plates reticulate; ray-vessel pits in 3-4 horizontal rows
			*Amoora***	septate fibres
		homogenous-heterogenous	*Sonneratia**	25% perforations scalariform or reticulate, parenchyma lacking, fibres septate, vestured pits
			*Scyphiphora**	
		heterogeneous	*Cerbera***	rays 12+ cells tall, 4-8 rows of pits in vessel-ray walls
mainly biseriate (with some uniseriate)	alternate bordered	homogeneous	*Intsia***	aliform parenchyma

TABLE 5 (cont.)

Ray width	Intervessel pitting	Ray type	Genus	Key characteristics
			*Amoora***	septate fibres
		heterogeneous	*Avicennia**	concentric branching bands of interxylary phloem; rays uni-, bi- and triseriate, but sometimes up to 6 cells wide
mainly biseriate (with 3-4 seriate)	alternate, bordered	homogeneous-heterogeneous	*Aegiceras**	fibres and vessels storied, ray-vessel pits in 4-5 horizontal rows, cell rays mostly 2-3 seriate rays, but some uniseriate; rays storied
		heterogeneous III	*Xylocarpus*/***	
mainly triseriate (with some biseriate)	alternate bordered	heterogeneous III	*Hibiscus***	occasional 4-seriate rays; large tails to rays tri- and biseriate rays; rays 50+ cells high
			*Barringtonia***	
multiseriate (4-10 seriate)	alternate bordered	homogeneous (or heterogeneous III)	*Heritiera*/***	rays rarely heterogeneous, mostly 3-4 seriate, plus many uniseriate rays
		?	*Brownlowia***	rays storied
		heterogeneous III	*Thespesia***	rays 2-4 cells wide (mostly triseriate)
			*Clerodendron***	? scalariform perforation plates

* Trees and shrubs absolutely bound to salt or brackish water (true mangrove species)
** Trees and shrubs belonging to littoral vegetation and/or inland vegetation which regularly appear in the back-mangroves (mangrove associates) (Santisuk 1983)

Based on data from Panshin (1932), Patanaprasith (1966), Coode (1969) and van Vliet (1976) following the organization of Schweingrüber (1978)

Categories of charcoal and levels of confidence

The charcoals were divided into three general types on the basis of their internal anatomy.

i. Rhizophoraceae-type: Mangrove members of the Rhizophoraceae (*Rhizophora*, *Bruguiera* and *Ceriops*) are readily separated from other kinds of mangrove woods by their scalariform perforation plates and conspicuous scalariform intervascular pits running the entire length of the vessels. These are seen most clearly in tangential longitudinal section. These features are clearly visible in both the reference material and the archaeological specimens.

Separation of charcoals in the Rhizophoraceae can be difficult at the generic level. Within the Rhizophoreae sub-division of the family, mangrove genera are partially distinguished from one another by the number of bars in their scalariform perforation plates, but the range of bars per perforation plate overlaps between genera (van Vliet 1976) (Table 5). It is therefore necessary to survey across a wide range of vessels to obtain a representative sample of perforation plates.

There is a double problem with reliably applying this criterion to archaeological charcoal. Firstly, incomplete preservation in archaeological charcoals often prevents an estimation of the numbers of bars in a perforation plate. Secondly, it is difficult, with small pieces of archaeological charcoal, repeatedly to fracture the specimen so that a number of well-preserved scalariform perforation plates are visible. Two potential diagnostic features for *Ceriops* are the shape of the vessel-ray pitting, which is vertically unilaterally compound ... with +/- oval ray pit[s]' (also illustrated by Ilic 1987:127), and the fact that this genus is the only one lacking septate fibres (Van Vliet 1976:57). These features were not reliably observed in the experimentally charred woods, as adjoining cell walls sometimes appear to fuse, obscuring the presence of septa and the form of vessel-ray pits. Such characters are not reliable then, for separating *Ceriops* amongst charred archaeological woods. The three genera, *Rhizophora*, *Bruguiera* and *Ceriops* have therefore been aggregated and the confidence with which they can be distinguished from other mangrove woods is high. Figure 5 illustrates the similarities in intervessel pitting and scalariform perforation plates between modern voucher and archaeological specimens.

Rhizophora, *Bruguiera* and *Ceriops* occupy precise and predictable ecological niches and are therefore particularly effective indicator taxa for reconstructing past habitats. They have a global distribution, but are always confined to mangrove ecosystems. Moreover, their positions in the mangal community, their distributions and associated taxa in each region are well understood in both general ecological terms through an extensive ecological literature, and for the Thai situation in particular (Aksornkoae 1976, Santisuk 1983, Miyawaki and Suzuki 1985, Miyawaki, Fujiwara *et al.* 1985, Miyawaki, Okuda *et al.* 1985). *Rhizophora* tends to occur in tall monospecific stands, forming the coastal fringe of the mangrove belt, while *Bruguiera* and *Ceriops* occupy a relatively drier zone to the landward side.

ii. Non-Rhizophoraceae: Wood from Non-Rhizophoraceae mangrove and mangrove-associated trees and shrubs lack scalariform perforation plates and scalariform pitting. Here the intervessel pitting is of the alternate bordered variety. The width and form of the rays are useful diagnostic features in longitudinal sections. The details of these are summarized in table 5. Archaeological specimens have been classified according to this provisional key and seven types are described below, but as published descriptions and reference materials are lacking for many of the possible contributing taxa, the charcoal could only tentatively be identified to genus in the most favourable circumstances.

Santisuk (1983:79-81) lists a total of 52 arboreal mangrove and mangrove-associate genera from Thailand, augmented by a further five (mainly climbers) by Aksornkoae and Panichsuko (n.d.) (Table 1). This compares with only 15 genera covered in the wood anatomy literature (Panshin 1932, Patanaprasith 1966, van Vliet 1976). In view of the incomplete database, and the strong possibility of making a wrong identification, the Non-Rhizophoraceae group has not been subdivided. Features such as the width and form of rays were recorded for individual specimens, but all charcoals lacking scalariform perforation plates and having alternate pits were provisionally assembled in a single category for the purpose of analysis.

This class of timbers with alternate bordered pits is not exclusive to mangrove and associated habitats. Trees with this character grow in inland tropical forest too, but it was impossible to make allowance for this given the lack of published studies on wood anatomy from the relevant environments and the limited reference collections. While, strictly speaking, the charcoals in this class may have come from other ecologically distinct environments, and there is certain faunal

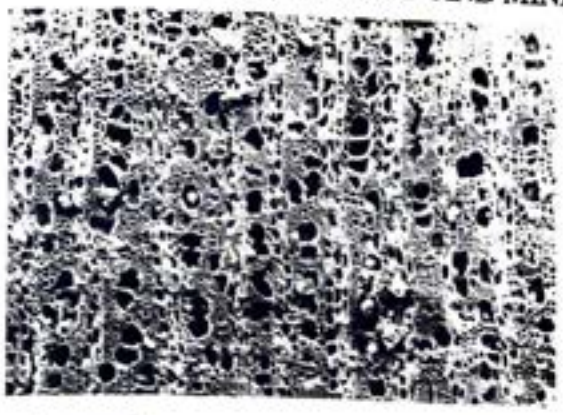












FIG. 5. Rhizophoraceae-type charcoals
1. Layer 10:26, transverse section, scale 200 microns **2.** Layer 10:26, tangential longitudinal section illustrating broken scalariform perforation plates, scale 100 microns **3.** Layer 10:26 radial longitudinal section, illustrating scalariform intervessel pitting, scale 50 microns **4.** Modern charred *Ceriops tagal* (an example of Rhizophoraceae-type wood) in transverse section, scale 200 microns **5.** Modern charred *Ceriops tagal* wood in tangential longitudinal section, illustrating scalariform intervessel pitting and a fragmented scalariform perforation plate, scale 50 microns **6.** Modern charred *Bruguiera* sp. hypocotyl in longitudinal section, scale 50 microns

evidence for the occupants of Khok Phanom Di hunting animals far afield (West 1991), inter-regional trade in anything as bulky as firewood is highly unlikely, as is the common use of driftwood from upstream by people living in such a well-timbered area. Timbers exotic to the local region may have been used at Khok Phanom Di, but only in small quantities, for specialized purposes, and are unlikely to be represented in large quantities among the charcoal. People living in the mangrove area close to Khlung, near Chantaburi, use the special vines *tawan khieow* and *tau mongkut* which grow in the upland forest for making fish traps. This is an example of a highly specialized and lightweight import of plant products from an adjacent ecological zone for use in a mangrove community, though with low archaeological visibility.

Given the low-lying topography of the region, and the high proportion of undoubtedly mangrove remains in the form of Rhizophoraceae-type charcoals, the likelihood is that the remaining charcoals are from other mangrove and mangrove-associate taxa.

iii. Indeterminate: A small proportion of the Khok Phanom Di charcoals could not be assigned to the first two classes. The possibility that these may be parenchyma from tubers was ruled out (pers. comm. J. Hather). Many examples may have been rotten, distorted or degraded prior to burning, while others may be from roots, bark, twigs, juvenile wood, compression or tension wood. Identification of root-wood, for example, is problematic, though not impossible with the aid of authenticated specimens (Cutler *et al.* 1987). The presence of root-wood in the charcoal assemblage at Khok Phanom Di is a distinct possibility, since a number of mangrove taxa have aerial roots which would have been accessible for firewood. Other woody plant parts, such as the spike pneumatophores of *Sonneratia*, have specific traditional uses for making fishing floats and corks (Burkill 1966, Chapman 1976) and might therefore be present in the charcoal record. These would have been classified as Indeterminate because of their atypical anatomy. Preparation of the reference collection anticipated such finds but none were made. In the sample from layer 7:1 there were small fragments of what seemed to be two kinds of possible nutshell which have been scored as Indeterminate charcoal. Their anatomy has been examined using SEM, but identifications could not be made due to lack of reference material.

Given the multiple constraints to identifying the Khok Phanom Di charcoals, data have been bulked into three broad classes: Rhizophoraceae-type, Non-Rhizophoraceae (with alternate bordered pits) and Indeterminate. Within these categories, identifications have a high degree of certainty at the broad level, but lack taxonomic and ecological resolution.

Discussion

Conventional incident-light microscopy permits large numbers of specimens to be examined as sample preparation is quick and simple, but the full range of diagnostic criteria is not always visible. Extensive use of SEM allows identification with greater taxonomic precision, since additional diagnostic features are observed with improved clarity at higher magnifications and greater resolution. This was an instance of striking a compromise between archaeologically appropriate categories and levels of identification, as well as combining the analysis of adequate sample sizes with the economic use of expensive and time-consuming equipment such as SEM. Although specimen preparation for the SEM is relatively easy, and viewing and photographing the charcoal is simple, the number of specimens which could be examined per session was restricted by the time taken to produce a vacuum in the chamber with porous specimens such as wood, whenever specimens were switched. Thus, while it would probably have been feasible to separate the genera in the

Rhizophoraceae using SEM, this refinement would not have greatly extended our archaeological interpretations. *Rhizophora*, *Bruguiera* and *Ceriops* occupy adjacent areas of the mangrove forest and have similar traditional uses. SEM examination of Non-Rhizophoraceae charcoals may well have permitted fuller anatomical descriptions, but these could not have been used due to lack of voucher specimens and incomplete documentation. Priority was given in this instance to assessing a larger assemblage at low taxonomic resolution but high confidence of determination, rather than identifying fewer specimens to a more precise level.

Intensity of occupation

The second major aspect of the charcoal analysis concerned an assessment of charcoal concentration and fragmentation through the stratigraphic column.

Charcoal density

Density ratios, relating the weight of charcoal to a known volume of archaeological matrix, may be useful as a broad indicator of 'intensity' of site use (Pearsall 1983). Each charcoal sample from quadrant A was weighed (Table 3, Fig. 6) in order to provide a general indication of the density of charcoal within the matrix, subject to the provisos mentioned earlier. Various taphonomic factors which may affect these data and their subsequent interpretation are outlined below.

Charcoal fragmentation

The degree of comminution of charcoal fragments may broadly indicate the extent of attrition, dispersion and disturbance of the sediment, assuming similar sizes of incoming fragments. Taphonomic factors contributing to the size of charcoal fragments in an archaeological assemblage are numerous and their interactions complex and difficult to assess. These include the actual size and weight of charcoal fragments at source, which is in turn related to cultural preference for fuelwoods, variation in fragmentation rates between taxa, conditions of combustion and the dimensions of the original timbers (Smart and Hoffman 1988). These combine with post-depositional factors influencing subsequent disintegration. It is quite likely, however, that charcoal samples taken from sites of *in situ* burning have larger fragments than redeposited charcoal spreads. Similarly, sediments deposited and sealed quickly contain larger charcoal fragments than those deposited on open occupation surfaces exposed to rain and wind and subject to repeated trampling. General observations in Thai villages indicate that the charcoal fragments seen on ground surfaces are quickly broken down through attrition and then widely dispersed.

In this analysis, weight was used as an alternative to fragment size, with the justification for this demonstrated by the high correlation between proportions of the assemblage calculated either by percentage weight or percentage numbers, and by the sample splitting exercise (below). In order to acquire some quasi-quantitative data on the degree of charcoal fragmentation through the profile, fifty of the largest fragments from each of 38 contexts were weighed. The specimens used were those from the 24 samples where identifications were made, and 14 supplementary samples. In the upper layers, where fewer than fifty fragments constituted the sample, all pieces larger than 0.01 g were included. The mean fragment weight and standard deviation for each sub-sample were calculated. As the data differed from a normal distribution, minimum and maximum values for

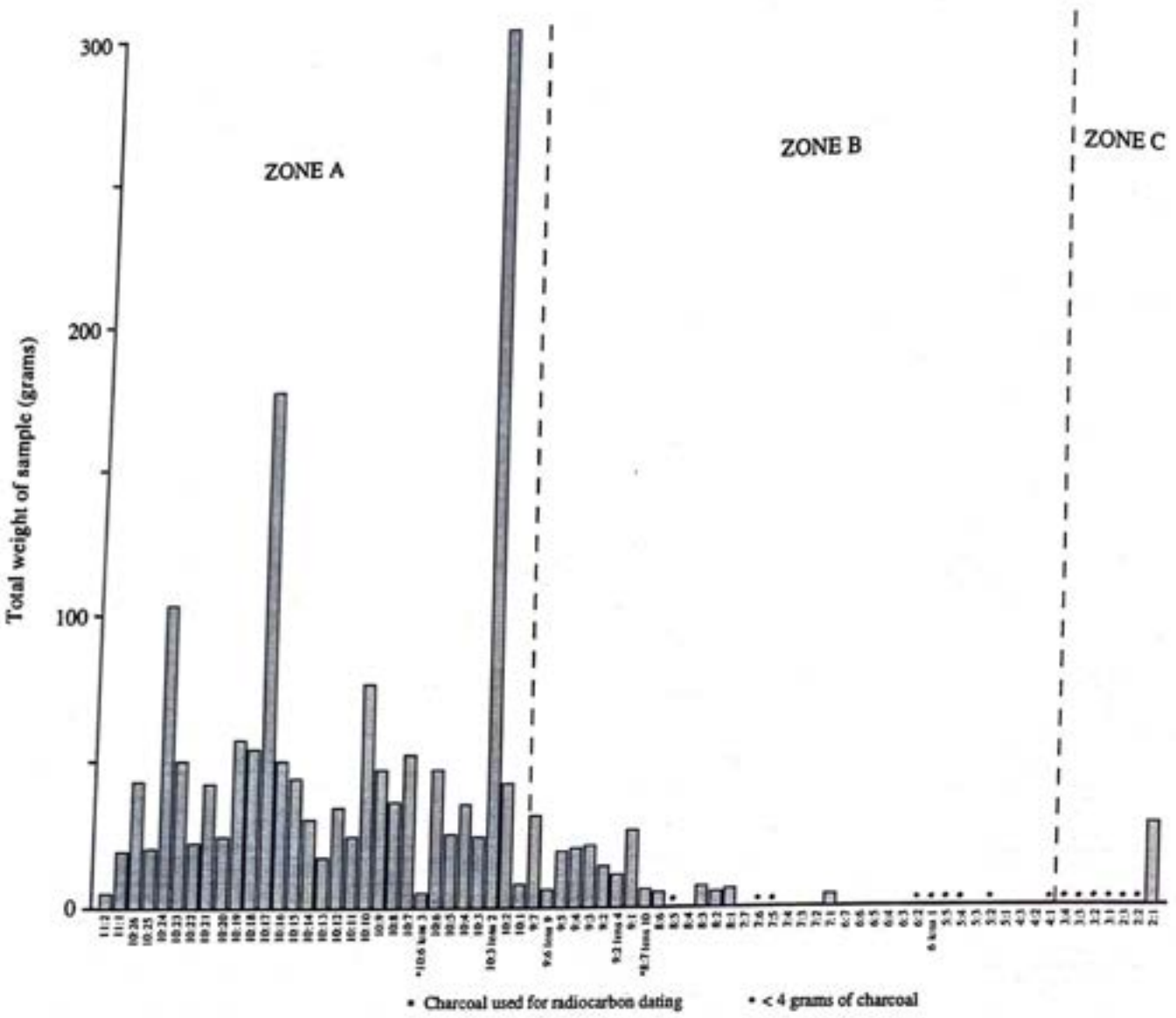


FIG. 6. Total weights of charcoal samples from successive contexts in quadrant A

each sample are given rather than the standard deviation (Table 6, Fig. 7). The relationship between mean fragment weight and depth below datum is illustrated in figure 7. Once identifications had been made, it was also possible to take differential fragmentation between taxa into consideration (Fig. 9).

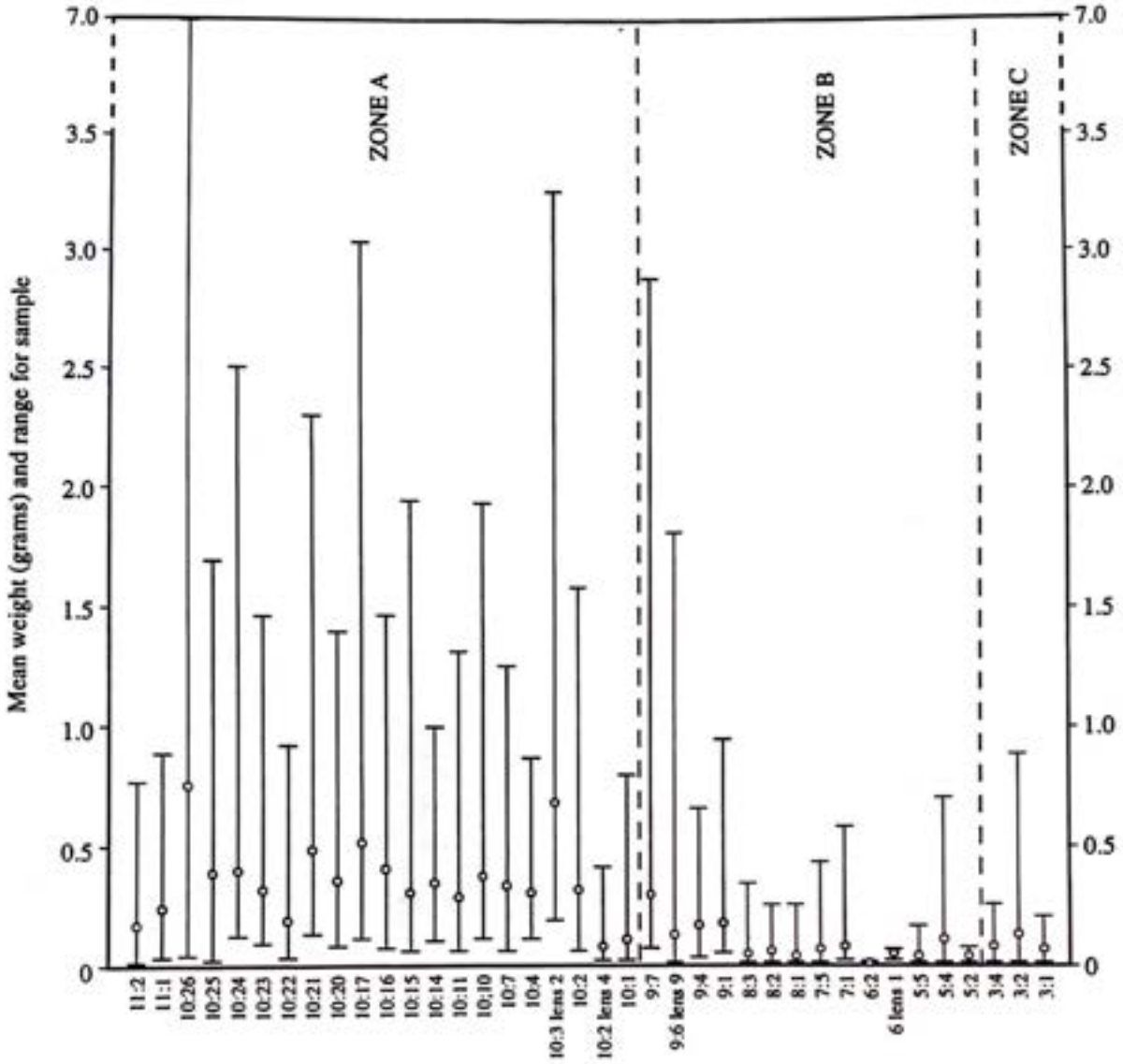


FIG. 7. Mean weights and ranges for 38 charcoal samples from quadrant A

Further discussions on methodology and quantification

Density differences between charcoal types

One assumption in quantifying a charcoal assemblage by means of fragment weight, especially where this is thought to be related to fragment size, is that there is little or no variation in charcoal density between taxa. This is probably not valid for charcoals from mangroves and associated habitats, where certain woods are renowned for their high density and others for their lightness (Table 7). The Rhizophoraceae-type woods are valued for their heaviness and high heat output on combustion. *Rhizophora* is especially hard and dense, at 1.09 g/ml (Taylor 1982:3) or 60-70lbs/ft^3 (Morton 1965:115). At the other end of the spectrum are the woods of *Excoecaria agallocha* and

TABLE 6: *Mean weight of charcoal fragments (g) for each of 38 charcoal samples from quadrant A*

Context	Mean fr weight (g)	Range	n frs	Context	Mean fr weight (g)	Range	n frs
3:1	0.071	0.01 - 0.21	17	3:2	0.130	0.01 - 0.89	17
3:4	0.080	0.01 - 0.26	4	5:2	0.040	0.01 - 0.07	2
5:4	0.106	0.01 - 0.70	14	5:5	0.042	0.01 - 0.17	9
6 lens 1	0.044	0.02 - 0.06	8	6:2	0.013	0.01 - 0.02	7
7:1	0.083	0.02 - 0.59	50	7:5	0.070	0.01 - 0.44	10
8:1	0.041	0.01 - 0.26	25	8:2	0.059	0.01 - 0.26	30
8:3	0.052	0.01 - 0.35	50	9:1	0.176	0.05 - 0.96	50
9:4	0.165	0.03 - 0.67	50	9:6 lens 9	0.125	0.01 - 1.83	50
9:7	0.303	0.70 - 2.88	50	10:1	0.111	0.02 - 0.80	50
10:2	0.321	0.06 - 1.93	50	10:2 lens 4	0.078	0.02 - 0.41	50
10:3 lens 2	0.691	0.20 - 3.26	50	10:4	0.314	0.11 - 0.88	50
10:7	0.341	0.06 - 1.27	50	10:10	0.380	0.11 - 1.95	50
10:11	0.288	0.06 - 1.33	50	10:14	0.351	0.10 - 1.01	50
10:15	0.306	0.06 - 1.96	50	10:16	0.408	0.07 - 1.48	50
10:17	0.519	0.11 - 3.04	50	10:20	0.360	0.08 - 1.40	50
10:21	0.493	0.12 - 2.31	50	10:22	0.192	0.03 - 0.93	50
10:23	0.325	0.09 - 1.47	50	10:24	0.401	0.12 - 2.53	50
10:25	0.394	0.02 - 1.71	50	10:26	0.764	0.04 - 7.00	50
11:1	0.235	0.03 - 0.89	50	11:2	0.172	0.01 - 0.76	30

fr fragment

Melaleuca leucadendra, which are so light that they are used as fishing floats (Burkill 1966, Blasco 1975).

It is not known how this range in wood densities converts to charcoal densities. This could be investigated in additional experimental work, along with tests to assess whether charcoal density is related to robustness and preservation in the archaeological record. The degree to which this has affected the current analysis is uncertain. The relatively dense Rhizophoraceae-types are abundant, but it is not known whether any of the woods from the light end of the spectrum are present in the charcoal assemblage.

Exploring the relationship between charcoal weight and fragment size

In order to be able to compare the results from this analysis with others where occurrences are reported in terms of fragments falling into defined size categories, a subsidiary experiment explored the relationship between fragment weight and size. A large charcoal sample from 10:23 was split through a stack of sieves with mesh 6, 4 and 2 mm. Thirty randomly selected fragments from each

TABLE 7: *Specific gravity of mangrove woods (adapted from Walsh 1977:350 who uses the data of Cox 1911 and Becking* et al. *1922)*

Specific gravity	Taxa
> 0.90	*Rhizophora* spp., *Bruguiera* spp., *Ceriops* spp., *Heritiera littoralis*, *Cynometra ramiflora*
0.75-0.90	*Lumnitzera* spp., *Sonneratia alba*
0.60-0.75	*Xylocarpus* spp., *Aegiceras corniculatum*
0.45-0.60	*Dolichandrone longissima*
0.30-0.45	*Avicennia* spp., *Sonneratia acida*, *Excoecaria agallocha*, *Cerbera manghas*

FIG. 8. Charcoal identifications derived from three size fractions

sieve were individually weighed. The weight threshold between the three different size fractions was established by selecting the smallest fragments in the 6 mm sieve and the largest in the 2 mm fraction (Table 8, Fig. 8). The results from this test show that the fragments of charcoal in the 6 mm category tend to weigh at least 0.9 g, while those in the 2 mm fraction tend to weigh less than 0.015 g. As the minimum fragment weight in the analysis was 0.01 g, the material examined was roughly equivalent to a >2 mm size fraction.

Testing the validity of the sampling strategy: exploring differential fragmentation between charcoal types

Manual collection of charcoal samples during excavation favours larger fragments, thereby over-representing taxa with relatively robust structure or the least tendency to shrink in charring (Pals and Voorrips 1979). Thus, in our attempts to retrieve and curate charcoal fragments large enough for identification the samples were inadvertently biased at the outset. A policy of extracting and examining only fifty large pieces of charcoal from each sample was adopted in order to sub-sample

TABLE 8: *Mean fragment weight for three size fractions of charcoal*

Size fraction	Mean weight (g)	Std. deviation	Range
6 mm	0.087	0.033	0.5–0.34
4 mm	0.039	0.024	0.1–0.11
2 mm	0.015	0.007	<0.01–0.4

from the sometimes very large quantity of charcoal available for investigation. Standardized counts are commonly applied for analysing archaeobotanical assemblages, though they are most applicable where preservation conditions are homogeneous throughout the range of contexts. This was not the case at Khok Phanom Di, where the number of fragments and the size/weight of individual pieces varied within the site. There was the possibility, therefore, that a particularly fragile charcoal type which only occurred as comparatively small pieces might not have been detected in the charcoal record at all.

The mean fragment weight for the three main classes of charcoal identified are presented for each sample in table 9 and graphed in figure 9 so that comparisons can be made between and within contexts. Standard deviations are inappropriate for these data as the distributions differ from normal. The distributions of charcoal weights around the mean are skewed by the presence of a few exceptionally large pieces in most samples. The bars extending from the mean points in figures 7 and 9 indicate the minimum and maximum values for each sample and illustrate the extent of the skew.

In the lower part of the site, where Rhizophoraceae-type remains are dominant in terms of both numbers of fragments and bulked weight of charcoal, they typically occur as smaller pieces than the Non-Rhizophoraceae class. This means that, although sampling for identification has focused on the largest fragments, the less frequent type, namely the Non-Rhizophoraceae charcoals, have still been detected, at least in terms of their presence in the assemblage.

The data illustrate too, that there has indeed been a bias toward the larger and heavier fragments of the Non-Rhizophoraceae charcoals. Given that we are interested in examining temporal change in assemblage composition from a situation where the earliest samples are dominated by Rhizophoraceae-type woods, the combined sampling and preservation bias is therefore *towards* detecting any change in assemblage composition and not regarded as a fundamental problem.

A further point arising from table 9 is that fragments in the Indeterminate class did not have a notably smaller fragment weight than the other types. Small fragment size sometimes hinders identification (Smart and Hoffman 1988), but was not a problem here.

The greater likelihood of fracturing by the Rhizophoraceae-type charcoals, and hence the probable bias in favour of larger, Non-Rhizophoraceae charcoals, was examined further by identifying a nominal sub-set of ten fragments selected from each of the sieved fractions from 10:23 in order to see how sample composition varied between size classes. Identifications and scores are given in table 10. Despite the small sample sizes used in this subsidiary experiment, the greater fragmentation of Rhizophoraceae-types is confirmed by the lack of Non-Rhizophoraceae fragments in the smallest size fraction.

TABLE 9: *Mean fragment weights and the range of the data for the three main categories of charcoal within each context*

Context	Mean fragment weight (g) and range for sample					
	Rhizophoraceae -type		Non-Rhizo-phoraceae		Indeterminate	
3:1	-	-	0.076	(0.01-0.21)	0.050	(0.01-0.12)
3:2	0.303	(0.03-0.69)	0.093	(0.01-0.89)	-	-
3:4	-	-	0.080	(0.01-0.26)	-	-
5:2	0.04	(0.01-0.07)	-	-	-	-
5:4	0.07	(0.01-0.13)	0.141	(0.02-0.70)	0.027	(0.03-0.04)
5:5	0.09	(0.01-0.17)	-	-	0.029	(0.01-0.07)
6 lens 1	0.045	(0.04-0.05)	0.050	(0.04-0.06)	0.030	(0.02-0.04)
6:2	-	-	0.013	(0.01-0.02)	0.013	(0.01-0.02)
7:1	0.078	(0.03-0.19)	0.068	(0.02-0.22)	0.149	(0.03-0.59)
7:5	0.05	(0.03-0.08)	0.013	(0.01-0.02)	0.225	(0.01-0.44)
8:1	0.041	(0.01-0.26)	-	-	0.040	-
8:2	0.059	(0.01-0.26)	0.050	-	-	-
8:3	0.059	(0.01-0.35)	0.032	(0.01-0.09)	0.030	(0.07-0.04)
9:1	0.165	(0.05-0.96)	0.257	(0.08-0.64)	0.170	(0.05-0.44)
9:6 lens 9	0.084	(0.01-0.31)	0.206	(0.01-1.83)	0.108	(0.03-0.26)
10:3 lens 2	0.691	(0.20-3.26)	-	-	-	-
10:7	0.344	(0.06-1.27)	0.19	-	-	-
10:11	0.289	(0.06-1.33)	0.312	(0.15-0.46)	0.220	(0.17-0.27)
10:16	0.413	(0.07-1.48)	0.355	(0.17-0.59)	-	-
10:20	0.349	(0.08-1.40)	0.91	-	0.360	(0.25-0.47)
10:23	0.298	(0.09-1.26)	0.409	(0.12-1.47)	-	-
10:26	0.764	(0.04-7.00)	-	-	-	-
11:1	0.218	(0.03-0.89)	0.81	-	0.440	-
11:2	0.172	(0.01-0.76)	-	-	-	-

TABLE 10: *A comparison between charcoal identifications from three size fractions*

Sieve size	Rhizophoraceae-type				Non-Rhizophoraceae			
	Weight (g)	Count	% Weight	% Count	Weight (g)	Count	% Weight	% Count
6 mm	0.98	7	73	67	0.36	3	27	33
4 mm	0.43	7	68	67	0.43	3	32	33
2 mm	0.19	10	100	100	-	-	-	-

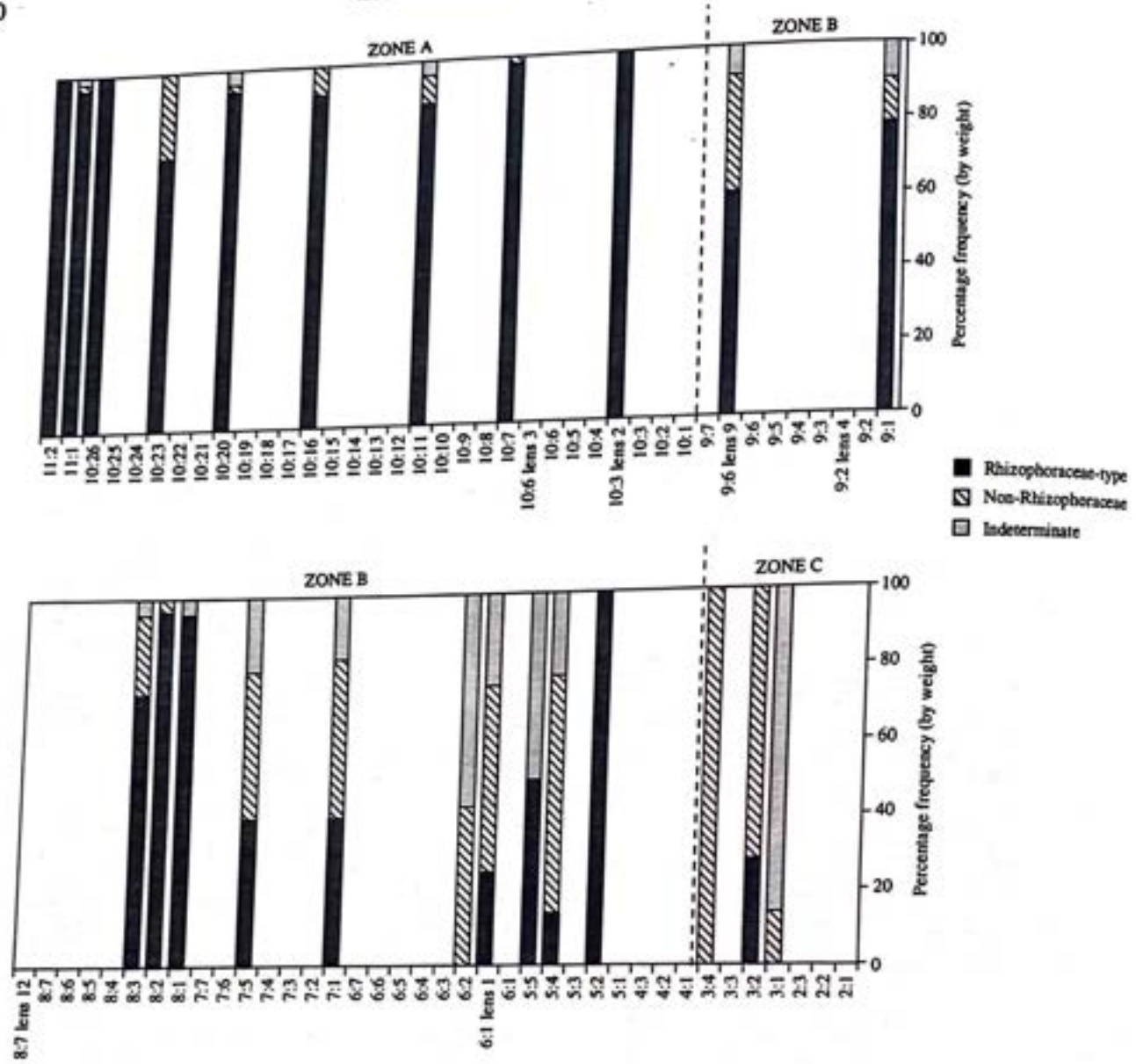


FIG. 9. A comparison between the percentage frequency by weight for the three types of charcoal

RESULTS

Data on the taxonomic composition of charcoal samples are presented in terms of proportions in table 11, with the value for each charcoal type calculated as a proportion of the total weight and total number of fragments examined in each sample. The ratio of Rhizophoraceae-type to Non-Rhizophoraceae charcoals offers an equally valid means of assessment and has been employed in statistical modelling (pers. comm. Y. Pittelkow). Standardized figures in the form of percentage frequencies are employed for the interpretation of sample composition through time, as they are more readily comparable through the sequence than raw measures (either weights or counts) in analyses where sample size varies.

TABLE 11: *Relative frequencies of the three charcoal categories. First column: percentages by weight. Second column: fragment count*

Context	Rhizophoraceae -type		Non-Rhizo-phoraceae		Indeterminate	
3:1	-	-	88	82	12	18
3:2	41	18	59	71	-	-
3:4	-	-	100	100	-	-
5:2	100	100	-	-	-	-
5:4	9	14	85	64	6	21
5:5	47	22	-	-	53	78
6 lens 1	26	25	57	50	17	25
6:2	-	-	44	43	56	57
7:1	37	40	38	46	25	14
7:5	29	40	7	40	64	20
8:1	96	96	-	-	4	4
8:2	97	97	3	3	-	-
8:3	84	74	13	22	3	4
9:1	73	78	18	12	10	10
9:6 lens 9	40	60	53	32	7	8
10:3 lens 2	100	100	-	-	-	-
10:7	99	98	1	2	-	-
10:11	88	88	9	8	3	4
10:16	93	92	7	8	-	-
10:20	91	94	5	2	4	4
10:23	70	76	30	24	-	-
10:26	100	100	-	-	-	-
11:1	89	96	7	2	4	2
11:2	100	100	-	-	-	-

Sample composition has been assessed in terms of both weight and fragment count, with a high degree of correlation between them being noted. Pearson's correlation coefficient, a non-parametric statistic, has been used to examine the link between weights and fragment counts for each charcoal type and the results are as follows: Rhizophoraceae-type .958, Non-Rhizophoraceae .924 and Indeterminate .831. These point to a very strong association between the two means of measurement, similar to that observed by Miller (1985). One implication of this is that in future analyses of charcoals from similar sites with equivalent woody taxa, it would probably be adequate to limit the analysis to fragment counts as a means of assessing abundance within a sample. A standard number of fragments could be selected randomly from the 2mm fraction.

Another and perhaps more justifiable means of summarising the data is to use presence analysis or ubiquity. The presence of a category or taxon is expressed as a percentage of the total number

of samples analysed (Table 12). For example, Rhizophoraceae charcoals were identified from one third of the zone C samples, 92 per cent of those from zone B and all the samples examined from zone A. Presence analysis is applicable here as a moderate, if not large number of samples has been examined, although the uppermost phase is not well represented in this respect. Interpretations drawn from table 12 are masked somewhat, though, by the fact that the A, B, C zonation for the site does not fit particularly well with the charcoal data, as will be discussed below.

TABLE 12: *Presence analysis of charcoal types in samples: comparisons between zones*

Zone	Rhizophoraceae	Non-Rhizophoraceae	Indeterminate
C	33%	100%	33%
B	92%	75%	83%
A	100%	75%	33%

DISCUSSION

One of the primary aims of the charcoal analysis was to contribute to the reconstruction of past vegetation around the site, by reference to modern phytoecological models. The data are interpreted in terms of the local arboreal flora. Additional comments on their implications for resource availability will be reserved until chapter VIII.

The interpretation of charcoal assemblage composition in terms of the plant communities around a site is complex, given the variety of factors influencing wood selection, combustion and fragmentation patterns. Nevertheless, it is quite likely that in a situation of abundant supply, firewood was gathered from the immediate environs of the site. The very fact that fuelwood is a heavy, bulky commodity, usually required on a daily basis, and that it is not conveniently portable means that people generally minimize the distance they haul fuel. Thus, in areas where there is no shortage of wood, firewood is likely to be derived from the immediate vicinity of the site. Alternatives may be substituted once the first choice has been depleted.

The fact that the same types of wood are represented in abundance through a range of archaeological contexts indicates that the trees which produced them were probably growing in the vicinity over some hundreds of years. Moreover, as the material analysed was derived from as many as 24 contexts through the stratigraphic sequence and the fires which generated them were probably of similar nature, a temporal pattern in charcoal sample composition can be discerned.

Modern mangrove ecology

Ecological interpretations about the trees and shrubs from which the archaeological charcoals are derived are based on extensive studies of mangrove ecology in Thailand (Schmidt 1902, Banijbatana 1957, Smitinand and Pheng Khlai 1973, Aksornkoae 1976, Santisuk 1983) and elsewhere in South-East Asia (Watson 1928, Brown 1958, Chapman 1976, 1988, Whitten *et al.* 1987), as well

as Papua New Guinea (Percival and Womersley 1975), India (Blasco 1975, 1977), Burma (Kurz 1974), Australia (Hutchings and Saenger 1987) and North/Central America (Chapman 1964).

Mangrove forests have distinctly-zoned habitats with bands of plant communities running parallel to the coastline. In Thailand, as elsewhere, this has been the subject of ecological studies (Aksornkoae 1976) and phytosociological work emphasising the changes in natural forest brought about by human disturbance or destruction (Miyawaki and Suzuki 1985, Miyawaki, Fujiwara *et al.* 1985, Miyawaki, Okuda *et al.* 1985). Watson (1928) recognized five zones within the mangrove forests of peninsular Malaysia based on a salinity gradient perpendicular to the shore, although more recent studies have demonstrated that mangroves have broadly overlapping salt tolerances and that environmental physiology, exposure, geomorphology, substrate and soil conditions are additional contributing factors (Fig. 10; Carter 1988).

The zonation of undisturbed mangal communities in Thailand is schematically summarized in figure 10. In the outermost coastal zone and along the mudflats of the lower reaches of rivers, exposed to wind, waves, saltwater and an unstable muddy substrate, are the pioneer taxa *Avicennia officinalis*, *A. alba*, *Sonneratia alba* and *S. caseolaris* (Santisuk 1983, Miyawaki, Fujiwara *et al.* 1985, Miyawaki, Okuda *et al.* 1985). Behind this community may lie a belt of *Bruguiera cylindrica*. Along the shores of estuaries *Rhizophora* tends to grow in pure stands, with *R. mucronata* growing in the muddier, wetter, shoreward positions and the smaller *R. apiculata* on slightly drier ground. Aksornkoae (1976) reports the results of vegetation mapping and ecological fieldwork around the Welu River downstream of Chantaburi, having worked in the same area where most of the mangrove specimens of the reference material for this study were collected. He comments that taxonomic diversity of the seaward zone is lower, but stand density higher, than in other parts of the mangroves. An intermittent associate along the water's edge is the salt-tolerant, trunkless palm, *Nypa fruticans*, but this is usually confined to the banks of smaller fresher streams running through the mangrove and extending along brackish watercourses for kilometres inland.

Behind the *Rhizophora* zone, the next band is slightly elevated, inundated only by high tides, and its floral community has greater taxonomic diversity (Aksornkoae 1976). The plants here require slightly fresher water and comprise members of the Rhizophoraceae, primarily *Bruguiera gymnorrhiza*, *B. sexangula*, *B. cylindrica* and *Ceriops tagal*, and individual *Rhizophora apiculata*, *Xylocarpus obovatus* (= *granatum*) and *X. moluccensis*. Associated taxa are *Heritiera littoralis*, and two members of the Malvaceae, *Thespesia populnea* and *Hibiscus tiliaceus*. Moving landward, *Lumnitzera* spp., *Excoecaria agallocha* and *Sonneratia* spp. also feature in this inner zone. Flatter areas and *Thalassina* mounds (created by mantis shrimps) are typically occupied by monotypic stands of *Ceriops* and the occasional individual *Lumnitzera* tree (Aksornkoae 1976, Miyawaki, Fujiwara *et al.* 1985). After forest clearance, the fern *Acrostichum aureum* is a swift coloniser in open areas, often associated with *Xylocarpus moluccensis* (Miyawaki, Fujiwara *et al.* 1985).

Further inland still, in even drier soils, beyond the reach of the highest tides, is the transitional zone to inland forest, where the dominant trees in swampforest are *Melaleuca leucadendra* with *Cassytha filiformis*, and on drier ground, *Intsia bijuga*, the climber *Flagellaria indica*, *Oncosperma tigillaria* palms, *Hibiscus tiliaceus* and the low shrub *Clerodendrum inerme*. Localities experiencing intermittent inundation by seawater are usually vegetated by a combination of (a) *Lumnitzera* spp. and *Scyphiphora hydrophyllacea* or (b) *Pandanus* sp., *Hibiscus tiliaceus*, *Ardisia littoralis* and *Cerbera manghas* (Miyawaki, Fujiwara *et al.* 1985).

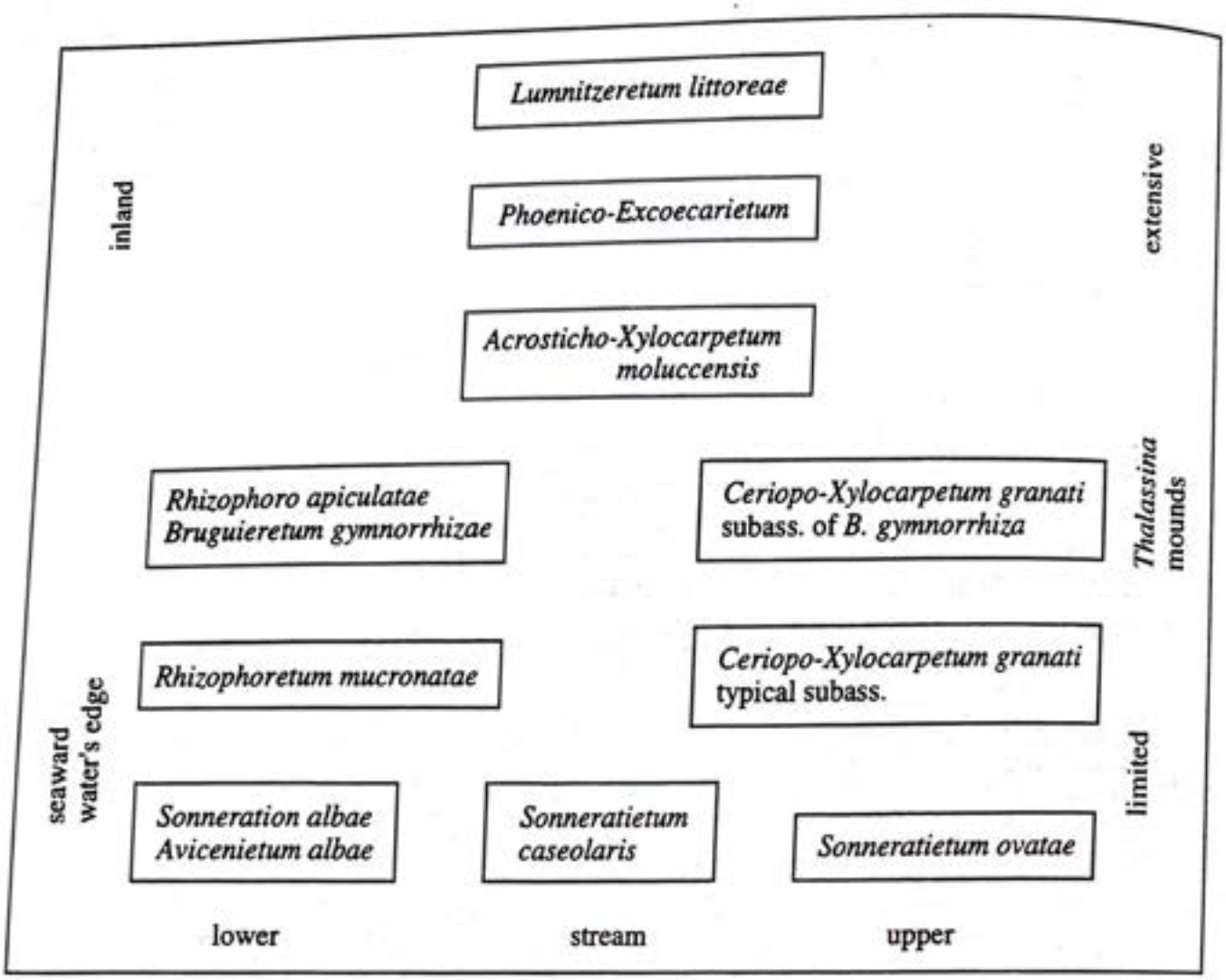


FIG. 10. Schematic distribution of floral associations within Thai mangroves (source: Miyawaki, Fujiwara *et al.* 1985:18)

Members of the mangal and associated communities differ in their utility for palaeoenvironmental reconstruction. Some backswamp trees have precise physiological requirements as they occupy a narrow and predictable zone. Others are components of a number of allied communities and consequently make less reliable ecological indicators. *Thespesia populnea* and *Barringtonia asiatica*, for example, have wide distributions as they grow in sandy littoral areas along the coast, on the islands around Sattahip, and in the drier parts of the mangrove backswamp (Santisuk 1983, van Steenis and Veldkamp 1987). *Avicennia* is another example of an adaptable genus, tolerant of a range of salinities. The three species of *Avicennia* with Thai distributions occupy different niches, ranging from water's edge to dry land. As the charcoal cannot be identified below the generic level, *Avicennia* is a poor palaeoecological indicator.

The classic view of an accreting, low-energy, tropical coastline is that mangrove communities gradually replace one another through succession over a period of time, with the plants responding to gradual sediment deposition and changing hydrologic conditions. Where human intervention occurs, the secondary vegetation may differ from the original community in its zonation, architectural structure and taxonomic composition. Disturbed or degraded vegetation at the terrestrial margin is typically dominated by the fern *Acrostichum aureum* with shrubby *Acanthus ilicifolius* and *A. ebracteatus*, and the climbers *Derris trifoliata* and *Finlaysonia maritima*. In the littoral zone *Rhizophora* and *Bruguiera* are replaced by *Nypa*, *Ceriops* or *Avicennia* (Sukardjo and Akhmad 1982, Miyawaki, Fujiwara *et al.* 1985, Singh *et al.* 1986). Where dense fern cover establishes itself quickly, it becomes difficult for the light-demanding mangrove seedlings to regenerate. The natural vegetation is usually replaced by secondary forest, then if felling is repeated, a scrubby grassland is created. The seaward zone, originally occupied by *Sonneratia* and *Avicennia* spp., converts to scrubby *Aegiceras corniculatum*. The *Rhizophora/Bruguiera* forest is replaced by *Acanthus* and *Finlaysonia maritima*, with shrubby *Clerodendrum inerme* and *Premna obtusifolia*. Moving further inland still, the secondary grassland/scrub of *Lumnitzera racemosa* and *Scyphiphora hydrophyllacea* takes the place of the natural *Ceriops/Xylocarpus* community. In the final landward association, a combination of *Phoenix paludosa*, *Derris indica* and *Hibiscus tiliaceus* replaces *Lumnitzera* and *Excoecaria*. Eventually, with repeated logging, all that remains is bare mud, devoid of vegetation (Miyawaki, Fujiwara *et al.* 1985).

The final ecological issue to be touched on here, as it has implications for the availability of different fuelwoods in terms of distance carried, is the scale of habitat zonation. Mangal may stretch along an estuary for tens of kilometres inland, but each plant community may occupy a band only a few hundred metres wide. The pollen evidence suggests just this for the prehistoric surrounds of Khok Phanom Di during its earliest occupation. The sediments from cores JB 2 and BMR 2, only 500 m apart, are thought to reflect contemporary adjacent *Rhizophora* and *Bruguiera/Ceriops* communities. This fine-grained floral mosaic means that the occupants of an estuarine/riverine settlement like Khok Phanom Di could well have had access to a range of arboreal taxa within, say, a kilometre radius. The possible use of *Xylocarpus* sp. timber for a coffin or bier in B. 107 is noteworthy, as it coincides with a phase of the site when Rhizophoraceae-type woods were the dominant fuel choice and the site is thought to have been surrounded by *Bruguiera* and/or *Ceriops*. *Xylocarpus* trees would most probably have been growing in the zone immediately inland, on slightly elevated and slightly drier ground.

Firewood use by modern mangrove dwellers

South-East Asian mangrove forests have been subjected to extensive felling and management in recent years, having been called upon to make a significant contribution to fuelwood supplies in the expanding cities of the region. Charcoal from mangrove wood is so highly prized for its high heat production that trade in this commodity has even reached international levels (Samapuddhi 1955). The woods of the Rhizophoraceae, *Rhizophora* and *Ceriops* in particular, are sought for conversion into charcoal, and are also the preferred fuelwoods for people living in the mangrove swamps today. The integration of these once marginal and isolated communities into the regional economy is such that the prime woods are now sold and the occupants of the estuarine stilt-villages, living within the mangrove belt itself, must resort to second-rate timber for their own domestic needs. The Rhizophoraceae timbers are dense and hard, producing a steady reliable heat and little

smoke. The heartwood and proproots have higher calorific values than the bark (Rollet 1975b, Aksornkoae 1982) and they may even be set alight when still green (Cobban 1968, Rollet 1975b). One advantage of *Rhizophora* wood is that it is easy to split, but the timber of *Ceriops* is said to produce a flame so hot that it sometimes damages cooking pots (Lemmens and Wulijarni-Soetjipto 1992). Another good charcoal producer is *Cerbera manghas* (Burkill 1966), while poorer alternatives include *Pemphis acidula*, *Heritiera littoralis* and *Xylocarpus* spp., according to Percival and Womersley (1975), writing about Papua New Guinea. They add that the indifferent woods of *Aegiceras corniculatum*, *Avicennia* spp. and *Sonneratia* spp. are the very last resort for lighting fires.

Certain timbers are avoided and others chosen for specific purposes. *Excoecaria agallocha*, for example, is avoided as a fuelwood due to its unpleasant, poisonous smoke. In Malaysia its timber is nevertheless cut for commercial charcoal production, where removal of the bark prior to felling reduces the danger from the irritant sap (Burkill 1966). In the Philippines (Rollet 1975a) and Malaysia (Burkill 1966) the wood of *Avicennia* is the preferred choice for smoking fish, but this is said to be pungent and to smoulder excessively for general use (Crisp *et al.* 1990). By contrast, in tropical northern Australia, it is the wood of *Rhizophora mucronata* which is selected for smoking *bèches de mer* (Rollet 1975a) and the bark of *Melaleuca leucadendra* is regarded as good tinder. Bundles of *Melaleuca* bark mixed with dipterocarp latex are sold in Thai markets as firelighters.

Observations of the current fuelwood situation and interviews with people living within and close to mangrove areas during the 1986–7 field season, in conjunction with ethnobotanical literature, all indicate that *Rhizophora* and *Ceriops* are regarded more highly than other timbers, but that people minimize the distance they move bulky firewood. The interplay between preference and proximity is probably obscured in the archaeological record. The preponderance of Rhizophoraceae-type charcoals in the first half of the occupation at the site could be accounted for both in terms of local abundance and firewood preferences, while its occurrence in zone C samples, at a time when other lines of evidence point to a different local ecology, could reflect curation of timber and/or continuing preference for an increasingly scarce resource.

Charcoal assemblage composition

There were dense deposits of charcoal within layer 11 at the base of the cultural sequence. These presumably represent the debris from the initial clearance of the site, as does microscopic charcoal from natural at the base of the archaeological deposit (Maloney and Brown 1990). The microscopic charcoal particles may, however, have been washed into the fluvial deposit and could be interpreted as earlier clearance in the vicinity. In layer 11, the charcoal assemblage is made up entirely of Rhizophoraceae-type woods, indicating that the site had been vegetated with *Rhizophora*, *Bruguiera* or *Ceriops* trees prior to occupation. It seems unlikely that live *Rhizophora*, standing in water, would burn easily. Furthermore, these fragments are neither abraded nor highly fragmented, as would be the case if they had been derived from water's-edge vegetation, with the incoming tide washing around the stilt-roots. Perhaps these were dessicated stands of mangrove, stranded above the high water mark after a change in the local hydrology. Alternatively, the trees at the site prior to human occupation may have been *Ceriops* or *Bruguiera*, which prefer to grow in slightly drier parts of the mangrove beyond highwater mark. Indeed, *Bruguiera* comp. pollen, comprising both these genera, is represented in the pollen spectrum for this period in the sediment

cores BMR 2 and KL 2, taken only 200 m north-west of the mound (Maloney 1991). *Bruguiera* and *Ceriops* pollen are not dispersed very far from their source. Although this pollen type is only a small part of the pollen spectrum in those sections of the BMR 2 and KL 2 cores which correlate with the lowest phase of the 1985 excavation, its very presence suggests that these trees were growing close to the site. It has been suggested that the latest, but undated core, JB 2, also coincides with prehistoric occupation at Khok Phanom Di (Maloney 1991). This part of the pollen record is dominated by *Rhizophora*, another locally distributed pollen type. This suggests that *Rhizophora* was most probably growing around the coring site only 250 m from the southern edge of the mound, so all mangrove members of the Rhizophoraceae may have been close at hand, with the river lying to the south of the settlement. The cache of ten ground stone adzes in the basal spit of layer 11 point to the felling of trees, but they may have been used for trimming and ringbarking in conjunction with clearance by fire.

There has been a suggestion that some of the lenses in layer 10 are overwash deposits (Higham *et al.* 1987) and 'fine loess derived from mud-flats' (Maloney 1988), implying that the area occupied was not beyond the reach of storm surges. The ostracode and sedimentological data conversely suggest that the site was never inundated (McKenzie 1991, Aitken 1993). The charcoal evidence does not support the early idea that the cultural deposits were laid down on a spit or barrier beside a lagoon (Higham *et al.* 1987), because such a geomorphological feature is unlikely to have been covered with mature trees. Equally, the charcoal record does not support an alternative hypothesis that the founding population of Khok Phanom Di settled a chenier ridge (Maloney and Brown 1990, Maloney 1991), although such a drier raised area would indeed have been a relatively attractive place for occupation within the swamp. Cheniers, together with the landward margins of the mangroves, are the favoured camping ground of Yolgnu Aboriginal people in northern Australia when they move into mangroves (Bird 1986) and are similarly favoured for settlement in the Malaysian peninsula (Allen 1988/89).

These ridges are typically associated with estuaries and adjacent mudflats. They may form at the landward side of the intertidal zone, within or behind the mangrove belt, and are considered to result from the reworking of shelly material by storm action (Chappell 1987, Short 1989). Ecological reports for Thailand are silent on present-day chenier ridge flora, but in northern Australia this stands out from the adjacent mudflats and mangroves and includes *Celtis paniculata*, *Trema aspera*, *Manilkara kauki*, *Mimusops elengia* and *Cochlospermum gillivraeia*, *Osbornia* sp. and *Ipomoea pes-caprae* (Macnae 1968, Grindrod 1985). In the landscape of Princess Charlotte Bay, the cheniers are set at least a kilometre landward of mangal *per se* and may not provide an appropriate analogue for the flora of cheniers within the mangrove forest itself. By contrast, cheniers along the east coast of peninsular Malaysia and, to a lesser degree along other stretches of South-East Asian coasts, are vegetated by stands of *Casuarina equisetifolia* (Macnae 1968). If the occupants of Khok Phanom Di did indeed colonize a chenier ridge with a distinct flora, this has not been indicated by the charcoal record. The high proportion of Rhizophoraceae-type charcoals are more compatible with an estuarine or river bank. This fits well with the results of sedimentological analyses which indicate that the natural substrate underlying the cultural stratigraphy was a river floodbank deposit (Aitken 1993).

Proportions of Rhizophoraceae-type charcoals are consistently high throughout layers 11 to 8 (zone A and the beginning of zone B), after which they rapidly decline. They move from figures in excess of 90 per cent at the top of layer 8 to less than 10 per cent of the assemblage in layer

5 (Fig. 9). An exception is layer 9:6 lens 9, where the Rhizophoraceae-type is in a minority in terms of percentage weight if not by fragment count. The fire which contributed charcoal to this particular lens may well have had a singular purpose, or the lower than expected proportion of Rhizophoraceae here could be accounted for by a few disproportionately heavy Non-Rhizophoraceae fragments in the sample.

From layer 7 Rhizophoraceae charcoal decline, associated with a rise in the proportion of Non-Rhizophoraceae and Indeterminate types. The frequencies of Non-Rhizophoraceae and Indeterminate charcoals are correlated, as in most bioarchaeological analyses, where the proportion of unidentifiable material is often related to taxonomic diversity. In this particular analysis it is also more likely for a Non-Rhizophoraceae fragment than for a member of the Rhizophoraceae group to be classed as Indeterminate. This is because it is easier to classify distorted Rhizophoraceae-type remains than equally degraded Non-Rhizophoraceae fragments, as characteristic scalariform intervascular pitting is recognizable even in poor specimens.

The changing ratio of Rhizophoraceae-type to Non-Rhizophoraceae charcoals in relation to depth has been modelled statistically (using GLIM version 3.77), with the boundary between a hypothetical mangrove-dominated zone and a Non-Rhizophoraceae-dominated zone located at different depths. The modelling confirms the view that the A,B,C zonation which had originally been derived on stratigraphic and artefactual grounds is inappropriate for summarising the charcoal data. Furthermore, it shows that there is little evidence from the charcoal assemblage for the exact location of a boundary or, in graphic terms, a distinct break-point in the curve of declining Rhizophoraceae proportions. The modelling exercise was equivocal on whether a zone boundary could be detected or whether the change was gradual, but one model which detected a zone effect placed the boundary between 2.9 and 3.6 m depth below datum, that is within layer 8 (pers. comm. Y. Pittelkow).

There was no evidence for burnt bamboo among the charcoal samples from Khok Phanom Di. Elsewhere the charred remains of bamboos with diameters up to 14 cm, found at Spirit Cave, were interpreted as having been used as cooking vessels (Gorman 1971). The occupants of Khok Phanom Di evidently had no lack of ceramic vessels for cooking and while it is not surprising that bamboos are absent from the pollen record contemporaneous with the earliest occupation of the site, bamboo may possibly have been growing in the vicinity during the latest phase of occupation.

Charcoal density

The decreasing proportions of Rhizophoraceae-type fragments coincide with a gradual decline in charcoal concentration through the profile. The interface of layers 8 and 9, postdating the boundary between zones A and B, would be a possible break-point if one has to be drawn. The A/B divide is a major stratigraphic break between layers 10 and 9, interpreted archaeologically in terms of a hiatus in burials coupled with a change from complex lensing in zone A to more even deposition with fewer intercutting features in zone B (Higham *et al.* 1987). Bannanurag (1989) emphasizes continuity of material culture and inferred subsistence activity through zone A to layers 8 and 7 of zone B. Faunal remains indicate that a high proportion of food came from marine and estuarine sources throughout zones A and B. Intricate intercutting of features and lenses in zone A means that the volume of soil contributing to the undifferentiated spit samples must have been less than in other parts of the site. Despite the smaller sampling units in zone A, charcoal density is signifi-

cantly greater than elsewhere, suggesting that the variation in sample size has not seriously affected these general inferences.

Despite the limitations of the data outlined above, charcoal concentration through the stratigraphic sequence may be assessed in general terms because a large number of samples has been weighed and a broad trend is apparent. Table 3 and figure 6 detail the total weight of each charcoal sample, while table 6 presents the mean fragment weight for selected samples, with the minimum and maximum values. The charcoal density and fragmentation data (Tables 3 and 6, and figures 6 and 7) point to heavy and concentrated charcoal deposits consisting of coarse pieces in layers 11-9 (zone A and basal zone B). From layer 8 upwards (in zones B and C) the weight of individual pieces and their abundance decline together (Fig. 6). The zone A samples derive from charcoal spreads associated with complex ash lenses (Higham and Bannanurag 1990b). Throughout this period, charcoal was deposited in large amounts, with a number of lenses such as 10:3 lens 2 having outstandingly high concentrations of very large fragments. This could be the product of multiple fires and/or rapid deposition achieving speedy protection of the deposit, or even avoidance of the area so that the charcoals were not broken down by human or animal trampling.

The burial/midden complex which characterizes zones A and B is absent from the latest phase, zone C. This contrast is associated with a change in activities from a mix of possible pottery firing, inhumation, burial feasting and domestic activity in the two lower zones to a ceramic workshop in zone C (Higham *et al.* 1987). Layers 1-6, which make up zone C and the top of zone B, contained virtually no charcoal, so there are no radiocarbon dates for the upper contexts and little charcoal for identification. Even where charcoal does occur, it is usually as highly comminuted fragments sparsely distributed through secondary deposits.

There is a clear correlation between the total weight of the charcoal samples and the mean weight of the largest fragments. Together these decline from a maximum in layer 10 through layers 9 and 8 to a minimum in layers 5-4, rising slightly again in the upper layers, 3 and 2. One remarkable charcoal sample which does not fit the overall pattern is from layer 10:26, where an unexceptional sample in terms of total weight comprises the heaviest/largest mean fragment weight. This could conceivably be due to inconsistent sampling in the field, but is more likely to indicate an unusual burning event, where debris from the fire was especially well covered and/or swiftly protected leaving particularly heavy/large chunks of charcoal in the deposit. Radical differences between the pottery traditions of layers 11 and 10 have been interpreted as separate unconnected occupations at the site (pers. comm. B. Vincent). There is a possibility then that the high charcoal concentrations in 10:26 could represent a second burn-off of vegetation prior to the layer 10 occupation.

Charcoal density and composition considered together

The change in the relative frequencies of charcoal types occurs near the layer 8/7 boundary, dated to around 1800 BC (Bannanurag 1989), notably after the decline in charcoal abundance and after the A/B zone boundary. This is suggestive of a continued burning of the preferred Rhizophoraceae woods in progressively smaller volumes after they are replaced in the neighbourhood first by backswamp members of the mangroves, then, conjecturally, by open plains.

The exact degree to which archaeological charcoals reflect the species composition of woodland surrounding a settlement cannot be known and precise reasons for the change in charcoal types observed here are difficult to assess. A number of alternative interpretations could be placed on the data. Was the transition from a Rhizophoraceae-dominated charcoal assemblage to a preponder-

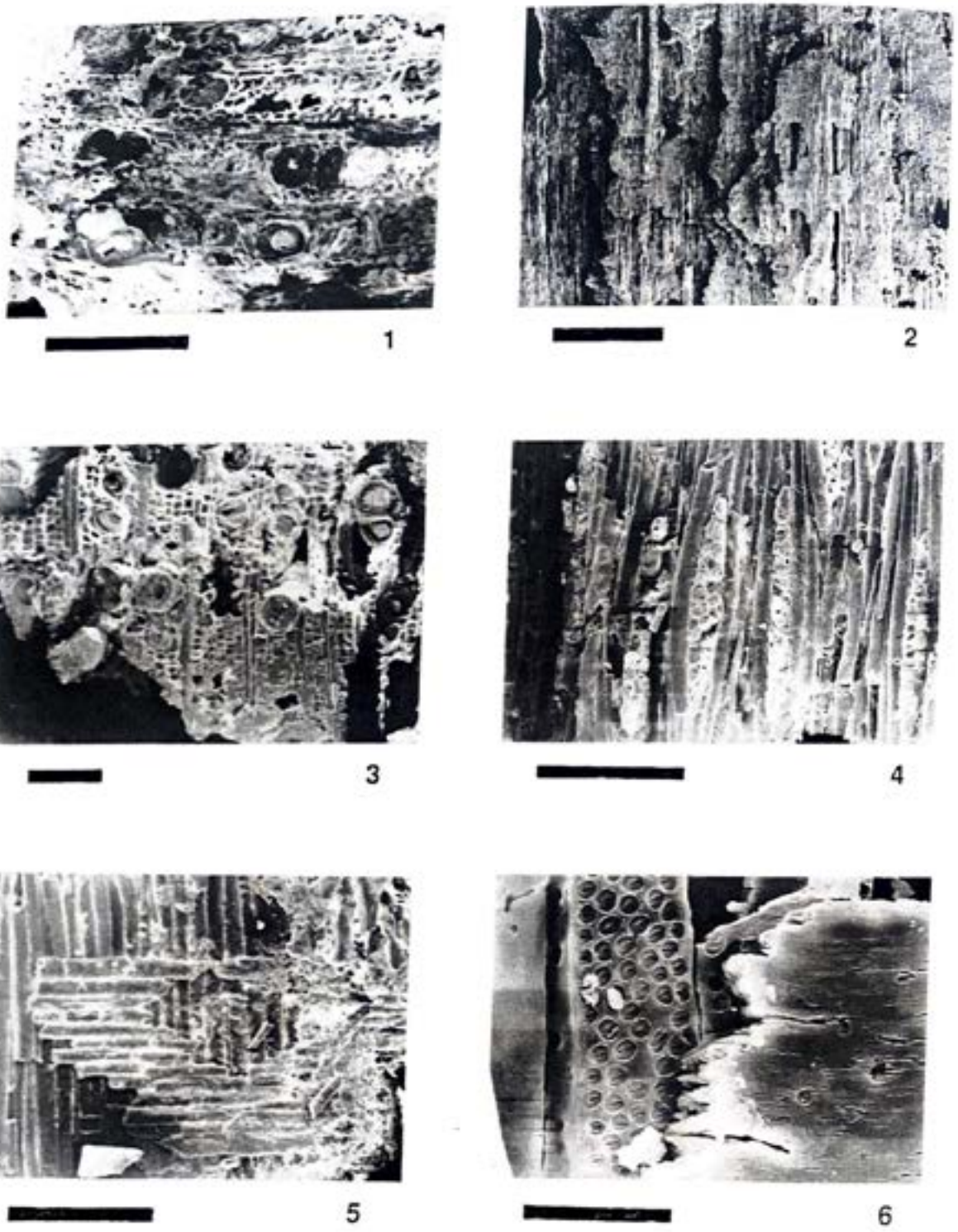


FIG. 11. Mineralized wood
1. Layer 10:2 quadrant D feature 12; transverse section, radial file of 2-3 vessels, rays 2-3 cells wide, scale 200 microns **2.** Layer 10:15, quadrant A feature 10; radial longitudinal section, scale 1 mm **3.** Burial 107, transverse section, scale 200 microns **4.** Burial 107, tangential longitudinal section, rays bi- and tri-seriate, scale 200 microns **5.** Burial 107, radial longitudinal section, scale 200 microns **6.** Burial 107, alternate bordered intervascular pitting, scale 200 microns

ance of Non-Rhizophoraceae woods a reflection of habitat change and hence changing availability of timber resources around the site, a function of new activities, or evolving opinions on acceptable timbers for established and continuing activities? The last option seems least likely as the records of timber preferences indicate that these are repetitive and well integrated into local tradition across a wide geographical area. One could also hypothesize that the radial depletion of preferred fuelwoods in the immediate environs of the site may have been followed by a substitution with alternative fuelwoods available close by, and the Non-Rhizophoraceae charcoals may be *Avicennia* and *Sonneratia*, the pioneers most likely to occur in the regrowth after Rhizophoraceae have been cleared. This possibility has been checked by re-examining the Non-Rhizophoraceae charcoals from the lower samples but none closely match the reference specimens or published descriptions for these genera. Changes in relative frequencies could relate more to new uses for certain woods or shifting patterns of activity across the site, but the high representation of essentially mangrove taxa, evidenced by the Rhizophoraceae-type woods in samples from layers 11-8, and their decline in subsequent stratigraphic units are most consistent with changing habitats around the site, particularly since there is no correlation with cultural change. All strands of ecological data point to a change from a forested situation to open swamp-grasslands which could well have brought about a change in the consumption of increasingly scarce timber and fuelwood resources by the occupants of the site. The combination of increasingly limited firewood supplies and different activities in this part of the site could therefore explain the paucity of charcoal in the upper part of the stratigraphy.

The wider picture

The filter effects of human selection on the charcoal record limit palaeoenvironmental inferences drawn from the data at this point, so we turn to comparisons with other lines of inquiry, preferably those with a strong ecological signature. The pollen evidence from six cores taken in close proximity to the site has provided the groundwork for three-dimensional reconstruction of vegetation around Khok Phanom Di. In brief, their combined evidence points to early burning in the region (*c.* 6000 BC), prior to earliest human occupation detected by the 1985 excavation (*c.* 2000 BC), and to mangrove forest gradually giving way to a marshy grassland as sea level declined relative to the site's location. The same theme is repeated by the phytoliths (Maloney and Rovner 1991, Kealhofer and Piperno this volume) and the ostracodes and forams (McKenzie 1991), all of which provide reliable baseline data for environmental reconstruction as their remains have been deposited by natural rather than cultural means. The geoarchaeological data suggest that the site originally occupied a stream-side location in a floodplain setting (Aitken 1993) while the biological sources place the site within access of mangroves, and with a marshy hinterland of brackish and freshwater swamps. With falling sea levels the local hydrology became more brackish. Prograding alluvial deposits allowed fresher water taxa to colonize the area through time, so that the mangrove shore receded, to be replaced by brackish marshland habitats. The presence of freshwater ostracodes in a soil sample from layer 8 in the east section of the excavation, also indicates some freshwater ponds or even rice paddies close to the site (McKenzie 1991).

Even greater precision regarding the evolving environmental situation is found with the molluscan data as the taxonomic diversity is high (up to 43 taxa in a single spit) and taxa can be assigned to as many as ten distinct habitats, ranging through subtidal mud, intertidal sand, rocky ground, landward mangal and upland limestone (Mason 1991). Moreover, these remains are from the ar-

chaeological contexts rather than the associated sediment cores so meet fewer correlation problems. From this it is concluded (Mason 1991) that 'the earliest inhabitants of Khok Phanom Di settled on a slightly elevated river levée close to an open coast bearing patches of clean, sandy and coralline sediment. There was also a substantial estuary not far from the site. With the passage of time, the diminution of seaward mangal species and those from clean water habitats suggests a prograding, muddy coastline and increasingly freshwater environment..... There are strong indications that the inhabitants of the site encountered the advent of non-estuarine, even non-riverine, conditions certainly by the beginning of layer 6'.

The remains of fish, crabs and turtles, found dominantly in zones A and B (Kijngam 1991) contribute to our knowledge of the environment and diet of the Khok Phanom Di people during the major occupation phases. The mammalian and avian remains on the other hand, inform us about the ecology of zone C, where the pollen data are absent, plant macroremains are not well represented and the molluscan and fish remains less abundant. The faunal assemblages show a rapid change from water-dominated resources in zones A and B to a land-based fauna in zone C (Higham *et al.* 1987), with a marked increase in abundance and diversity of mammals in the uppermost phase (Grant and Higham 1991). The zone C remains of woodland and grassland species include pig (*Sus scrofa*), macaque (*Macaca* sp.), the swamp cervids, Eld's deer (*Cervus eldi*) and Schomburgk's deer (*C. schomburgki*) and the forest-dwelling sambar (*C. unicolor*) (Grant and Higham 1991). Environmental indicators restricted to this period are the bones and teeth of tiger (*Panthera tigris*), porcupine (*Hystrix* sp.), crow (*Corvus* sp.) and the dusky broadbill (*Corydon sumatranus*) (West 1991), which are all typical of drier inland rather than coastal conditions. The general situation, according to the combined faunal remains, is one of forest, though not the swamp forest once considered likely from the pollen record (Maloney 1987, 1991), together with open herbaceous swampy grassland and access to freshwater in a nearby river and local ponds.

Changes in the charcoal assemblage fit well with this composite schema and are, therefore, probably reflections of changing local ecology rather than in consumer selection or taphonomic factors. The macroremains extend inferences about the vegetation from the pollen, which cease before this period but, given the current state of reference materials, the charcoals cannot shed much light on the kind of inland forest which succeeded the mangrove system. The exact nature of the inland forest is yet to be defined, but Takaya (1987) suggests that the stands of *Combretum quadrangulare* commonly seen across the young delta areas today and the rarer but previously more extensive *Melaleuca leucadendra*, could be survivors from former swamp forest. Other possible components are *Mitragyna javanica* var. *microphylla*, currently growing in the swampier areas of the old delta (Murata and Matsumoto 1974). None of these genera feature in the latter phases of the pollen record but the presence of *Combretum* could be obscured by identification problems among the Combretaceae/Melastomataceae, which are scored in the pollen analyses as a combined category (Maloney 1991).

The universally detected change from mangal to brackish then freshwater swamplands with dryland forest could be linked to fluvial progradation raising the landsurface above the tidal range, or mangroves eliminating themselves through succession, similar to the situation described for mid-Holocene northern Australia (Grindrod 1985, Clark and Guppy 1988). An alternative explanation, applied to an analogous pollen record in the Straits of Malacca, is that a sharp drop in *Rhizophora* is due to falling sea levels (Hillen 1983/4). The former conclusion seems more plausible and is

allied with the possible lateral movement of the river (the ancestral Bang Pakong) away from the mound.

UNKNOWN CHARCOAL TYPES

Amongst the Non-Rhizophoraceae charcoals, seven individual types were recognized but could not be confidently ascribed to a named genus. They are described below, so that determinations can be made when improved reference materials are to hand.

Type i: possibly Ulmaceae or Oleaceae, *Olea* sp. (pers. comm. J. Ilic) (Fig. 12:1-3). This distinctive charcoal type is the commonest amongst the Non-Rhizophoraceae fragments and is recorded from all three zones, from layer 9:1 up to 3:1. In transverse view, it is diffuse porous, with solitary vessels as well as many radial pairs. The rays are exclusively uniseriate, from 3-12 cells high. Intervessel pitting is alternate and the perforation plates simple.

Type ii: Meliaceae, *Agalia* sp. or *Amoora* sp. (pers. comm. J. Ilic) (Fig. 12:4-6). Occurrence: a single fragment in layer 3:2. This individual fragment is diffuse porous, with few, large dispersed vessels occurring singly or, more frequently, in radial pairs or files of three. Slight aliform or vasicentric parenchyma tending to diffuse were observed. Intervascular pitting is alternate. Rays are large-celled, homogeneous and uniseriate, 6-12 cells in height. Sometimes the rays split to biseriate for a single cell in the middle of the ray, with the biseriate section no wider than the uniseriate part.

Type iii: Ulmaceae (pers. comm. J. Ilic) (Fig. 13:1-3). Occurrence: layer 3:7. This charcoal type has exclusively solitary pores and is diffuse porous. The rays are exclusively uniseriate and heterogeneous, 5-8 cells tall. Preservation of this fragment was poor and it was difficult to discern the inter-vessel pitting.

Type iv: Ulmaceae (pers. comm. J. Ilic) (Fig. 13:4-6). One context only, layer 3:2, in zone C, where it is clearly the most important variety. It is semi-ring porous, with alternating rings of solitary pores and bands of radial clusters of 2-5 vessels. Intervascular pitting is alternate and perforation plates are simple. The rays are multiseriate, predominantly three cells wide but occasionally biseriate, with a tendency to be storied.

Type v: Ulmaceae (possibly *Celtis* sp. or *Holoptelea* sp.) (pers. comm. J. Ilic) (Fig. 14:1-3). The fragment illustrated is from 9:1, but this variety was also found in other zone A samples. It is diffuse porous with some solitary, radial pairs and clusters of three vessels. The perforation plates are simple and the inter-vessel pitting is alternate. Its rays are homogeneous and largely biseriate with a few triseriate examples. They are distinctive in transverse view.

Type vi: Bombacaceae, Malvaceae or Sterculiaceae (pers. comm. J. Ilic) (Fig. 14:4). This was the only example of this charcoal type from 10:23, and also occurred as single fragments in 7:1, but is found at a higher frequency in 10:26. Type vi is diffuse porous with sparse solitary pores. Its rays are heterogeneous, 8-10 cells tall and dominantly biseriate, with a few uniseriate and triseriate. In each case the tail cell to the ray is large and wide.

Type vii: Melastomataceae (possibly *Memecylon* sp.) (Fig. 14:5-6). Occurrence: a single fragment in 3:2 . This type of charcoal is diffuse porous, with vessels of two different sizes. The large vessels occur singly and are sparsely distributed. Intervascular pitting is irregularly alternate. The rays are heterogeneous, multiseriate and short, 2-3 cells wide. The fibres are septate.

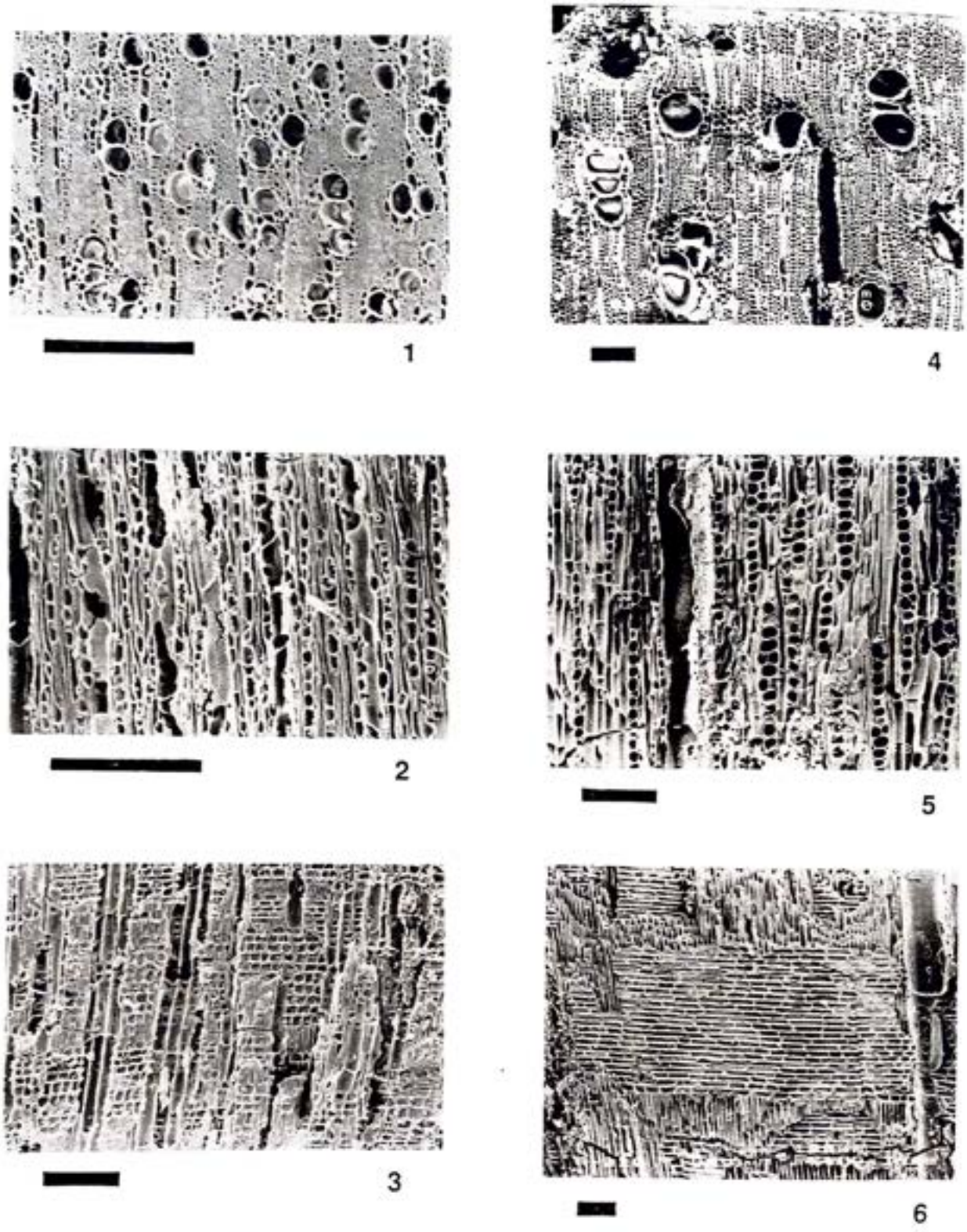


FIG. 12. Indeterminate charcoal types
1. type i, possibly Ulmaceae or Oleaceae, transverse section, scale 200 microns **2.** type i, tangential longitudinal section, scale 200 microns **3.** type i, radial longitudinal section, scale 200 microns **4.** type ii, Meliaceae, *Agalia* sp. or *Amoora* sp., transverse section, scale 100 microns **5.** type ii, tangential longitudinal section, scale 100 microns **6.** type ii, radial longitudinal section, scale 100 microns

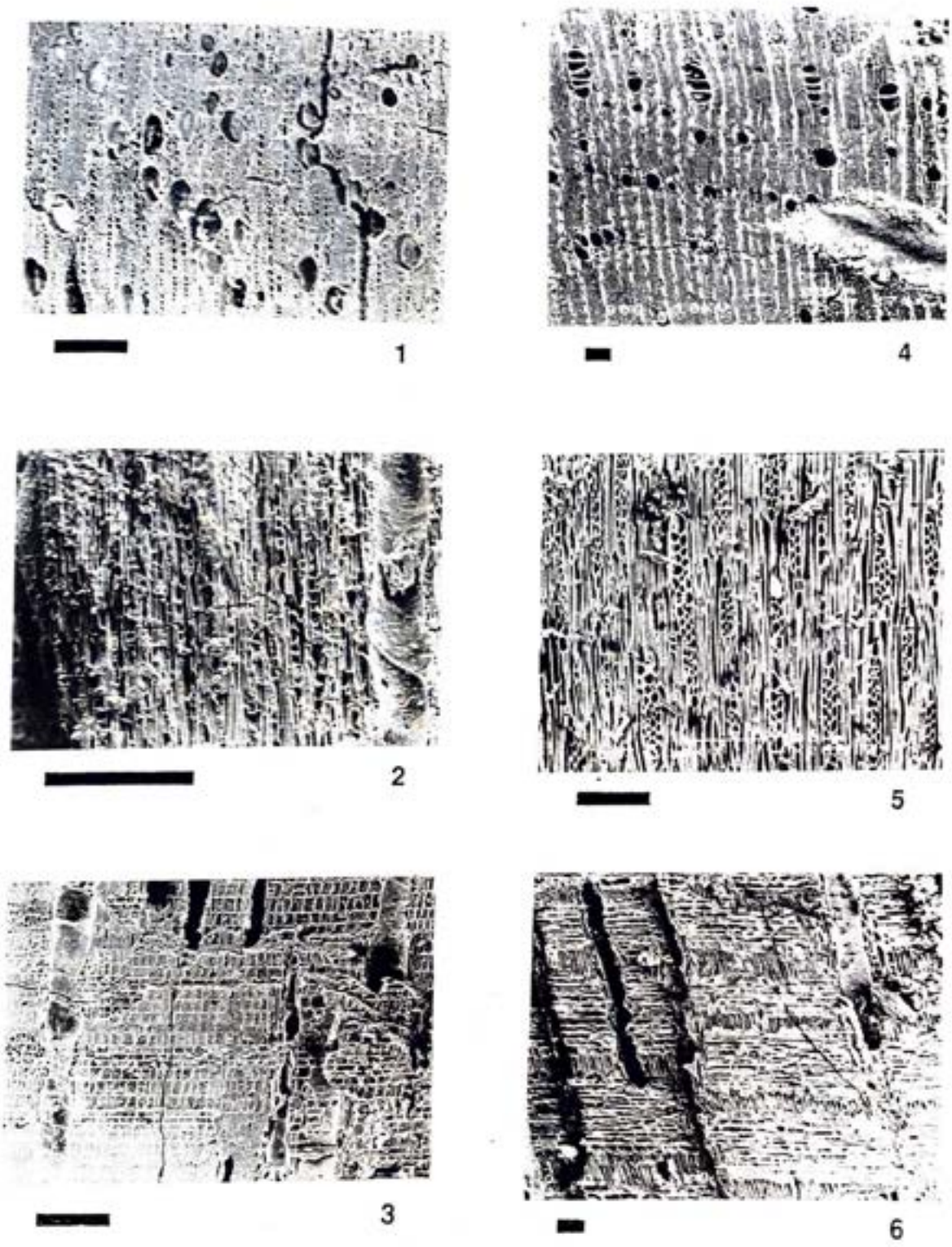


FIG. 13. Further indeterminate charcoal types
1. type iii, Ulmaceae, transverse section, scale 200 microns **2.** type iii, tangential longitudinal section, scale 200 microns **3.** type iii, radial longitudinal section, scale 200 microns **4.** type iv, Ulmaceae, transverse section, scale 100 microns **5.** type iv, tangential longitudinal section, scale 100 microns **6.** type iv, radial longitudinal section, scale 100 microns

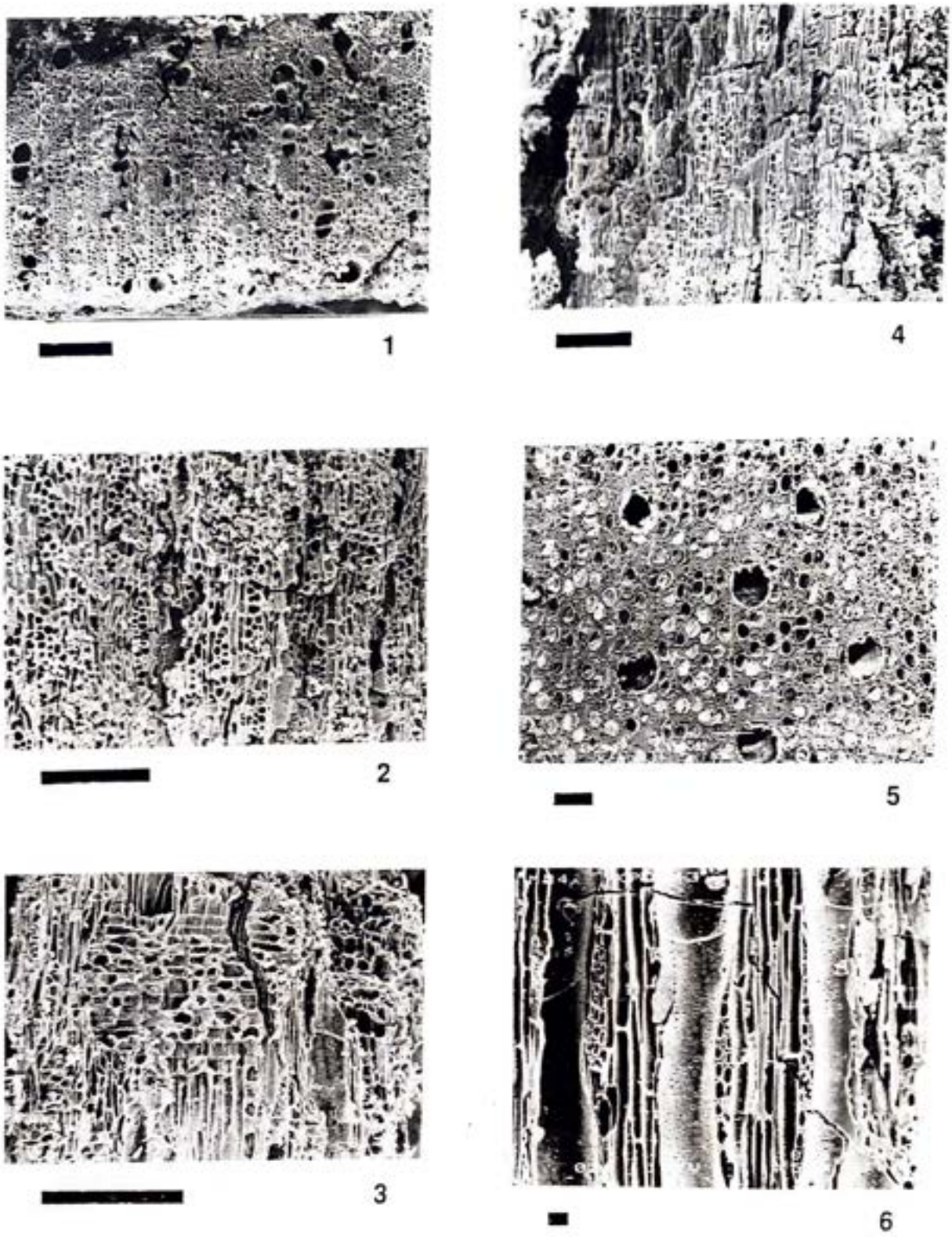


FIG. 14. Further indeterminate charcoal types
1. type v, Ulmaceae, transverse section, scale 200 microns **2.** type v, tangential longitudinal section, scale 200 microns **3.** type v, radial longitudinal section, scale 200 microns **4.** type vi, Bombacaceae, Malvaceae or Sterculiaceae, tangential longitudinal section, scale 100 microns **5.** type vii, Melastomataceae, transverse section, scale 100 microns **6.** type vii, tangential longitudinal section, scale 100 microns

V. SEEDS AND MISCELLANEOUS PLANT REMAINS

INTRODUCTION

THIS chapter concerns the description and identification of charred seeds with particular reference to plant use, especially for food, and seeds as indicators of habitats which may have surrounded the prehistoric settlement. Conclusions will complement those from the charcoal record by providing information on the herbaceous as distinct from the arboreal flora. The seed evidence is important because other lines of biological evidence, particularly the pollen, phytolith and molluscan data, all indicate the presence of herbaceous swamps in the vicinity of the site, especially in the later occupation phases.

The term 'seed' is applied in a broad, conventional, rather than a strictly botanical sense, to disseminules or fruiting bodies of all kinds, including caryopses (of Poaceae or Gramineae) and achenes or nuts (of Cyperaceae), and parts of those fruits. The non-charred seeds are assumed to be modern contaminants and have been excluded, although one type which was not carbonized but equally does not look modern (cf. *Amaranthus* sp.) will be described with the archaeological material. Charred seeds were found throughout the excavated contexts, although their concentration varied. Seed densities were generally low in comparison with some other archaeological sites (e.g. Crawford 1983, Miksicek 1987). Quantitative aspects of the data will be discussed at greater length later in the chapter.

Seeds from 46 samples of flot from contexts in quadrant A were classified according to their gross morphology. These samples span the full stratigraphic sequence, and were extracted from a total of 3190 litres of soil, which was only *c.* 10 per cent of the soil samples floated at the site.

The majority of the seeds were from the Cyperaceae (sedges) and Gramineae (grasses), but few could be securely identified to the generic level (Tables 13 and 28). A further group of seed types was often represented by a single item and could not be named. This is only to be expected from a region where reference collections are poorly developed, organic preservation is poor and the seed remains are unfamiliar. Basic descriptions of these indeterminate seeds are given on page 96 ff. These unknown seeds were found at very low frequencies and are not considered further.

METHODS OF SEED IDENTIFICATION

Initial progress towards identification was made by reference to seed atlases and taxonomic literature such as Noda *et al.* (1985, 1986) and Sastroutomo (n.d.), which cover South-East Asian seeds, and Tadulingam and Venkatanarayana (1985) for southern India. These were supplemented by general seed identification manuals for other regions (e.g. Winton and Winton 1932, Martin and Barkley 1961, Musil 1963, Berggren 1969, 1981, Montgomery 1977) and the family-level descriptions given by Gunn (1972), along with discussions of seed morphology and taxonomy for particular groups (e.g. Martin 1954, Schuyler 1971, Haines and Lye 1983, Sharpe 1986, Bruhl 1990) and archaeobotanical publications which consider diagnostic criteria (e.g. van Zeist and Bakker-Heeres 1982, 1984, 1985, Crawford 1983).

TABLE 13: *Frequency of seed types, weighted for the volume of soil processed in each context*

Context	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2:1	-	-	-	1	-	1	7	-	-	-	3	6	-	1	-	11
2:3	-	-	-	-	-	-	1	1	-	-	3	3	-	-	-	15
3:1	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	9
4:1	-	1	1	1	-	3	-	1	-	-	-	5	-	-	-	16
5:1	-	-	-	8	-	8	-	-	1	-	1	1	-	-	-	9
5:4	-	-	-	-	2	2	-	-	-	-	-	-	-	-	-	1
5:5	-	3	-	5	-	8	-	-	-	-	-	-	-	-	-	15
6:1	-	-	1	16	6	23	-	-	3	-	-	3	-	-	-	18
6:3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
6:4	-	-	-	2	2	4	-	-	-	-	-	-	-	-	-	4
6:5	-	-	-	8	-	8	-	-	1	-	-	-	-	-	-	2
6:7	-	4	-	11	1	16	1	-	3	-	-	-	-	-	-	15
7:7	-	3	1	21	3	28	-	-	-	-	-	-	-	-	-	5
8:1	-	1	-	23	4	28	-	1	1	-	-	-	-	-	-	8
8:3	-	1	-	-	-	1	-	-	-	-	-	1	-	-	-	-
8:5	-	6	1	29	1	37	-	-	1	-	-	2	-	-	-	8
8:6	-	1	-	2	-	3	-	-	-	-	-	1	-	-	-	5
8:7 1 12	1	8	1	65	21	96	-	-	-	-	-	-	-	-	-	4
9:1	-	1	-	33	-	34	-	-	11	-	-	-	-	-	-	1
9:2	-	-	-	24	-	24	-	-	1	-	-	-	-	-	-	1
9:3	-	7	-	36	-	43	1	-	-	-	-	1	-	-	-	1
9:3 1 6	-	-	-	33	-	33	-	-	-	-	-	-	-	-	-	-
9:5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
9:6	-	10	-	26	-	36	-	-	-	-	-	-	-	-	-	18
10:3 1 2	-	2	-	10	-	12	-	-	-	-	-	-	-	-	-	2
10:5	-	4	-	4	-	8	-	-	-	-	-	-	-	-	-	2
10:7	-	2	2	16	-	20	-	-	-	-	-	-	-	-	-	2
10:8	-	-	-	2	-	2	-	-	-	2	-	-	-	-	-	2
10:9	-	-	-	58	-	58	6	-	2	-	-	6	-	-	-	4
10:11	-	6	-	2	-	8	2	-	-	-	-	-	-	-	-	4
10:13	-	-	-	10	-	10	2	-	-	-	-	-	-	-	-	-
10:15	-	4	-	16	-	20	4	4	4	-	-	-	-	-	-	-
10:16	-	-	4	4	-	8	-	-	4	-	-	-	-	-	-	2
10:17	-	-	2	2	-	4	10	-	6	-	-	-	-	-	-	-
10:18	-	2	2	10	-	14	-	-	28	2	-	-	-	-	-	4
10:19	-	-	24	10	-	34	-	-	538	-	-	-	-	-	-	8
10:20	-	4	2	6	-	12	-	-	616	-	-	-	18	-	-	8
10:21	-	4	-	-	2	6	8	6	88	-	-	2	-	-	-	6
10:22	-	-	2	2	-	4	-	2	38	-	-	-	-	-	-	2
10:23	-	4	-	-	-	4	-	-	10	-	-	-	-	-	-	6
10:24	-	-	-	4	-	4	-	-	32	-	-	-	-	-	2	2
10:25	-	-	2	-	106	108	-	2	54	-	-	-	-	-	24	-
10:26	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	2
11:1	-	-	4	-	-	4	-	-	12	-	-	2	-	-	-	2
11:2	-	-	-	-	-	-	-	2	12	-	-	-	-	-	2	4

1. *Fimbristylis* sp. (Cyperaceae). 2. *Eleocharis*-type (Cyperaceae). 3. cf. *Schoenoplectus*-type (Cyperaceae). 4. cf. Cyperaceae endosperm (A). 5. cf. Cyperaceae endosperm (B). 6. Combined Cyperaceae. 7. cf. Paniceae (Gramineae). 8. Indeterminate Gramineae. 9. *Suaeda maritima* Dum. 10. *Trianthema portulacastrum* L. 11. *Portulaca* cf. *oleracea*. 12. *Amaranthus* sp. 13. cf. *Amaranthus* sp. 14. cf. *Sida* sp. 15. Unknown, type 1. 16. All Indeterminates.

Conventional keys for seed identification often rely on features such as colour and enclosing structures which are not usually preserved in the archaeological record, especially in charred material. It is sometimes more appropriate to use interactive computer databases of taxonomic information which can be sorted on a range of features from fruit alone (e.g. Watson and Dallwitz 1988 and Bruhl 1990). The application of keys narrows the range of possible determinations and preliminary identifications may be verified or possible identities narrowed with fully identified reference material. The primary resources were herbarium specimens collected during fieldwork and seed accessions at the National Weed Science Research Institute (Bangkok), supplemented by collections in Canberra at the Australian National Herbarium, the Gauba Herbarium and the Commonwealth Scientific and Industrial Research Organization. These extended the source of reference materials from South-East Asia to Australia and Papua New Guinea. Although geographic variation in seed morphology has only occasionally been demonstrated, it should not be totally discounted (Brisson and Peterson 1976). The fact that some of the reference material had an Australian source may have been a minor limiting factor.

The current biogeographical distributions of native plants were also considered, exotic taxa being eliminated and highest priority given to herbaceous taxa associated with mangrove backswamps and freshwater wetlands, the communities known from the faunal and pollen records to have existed around the site. While climatic change is not thought to be have been responsible for significant shifts in vegetation zones in mainland South-East Asia in the last 4,000 years, anthropogenic factors have had major effects on plant distributions and components of plant associations, especially in intensively farmed lowland areas.

The range of possible comparative taxa was extended to plants recorded throughout lowland central and peninsular Thailand as some pollen types with a present-day southerly distribution were identified in the cores. The identification of Thai plants is not always straightforward. The flora is relatively undercollected and not yet fully documented (Larsen 1979). The *Flora of Thailand* (Smitinand and Larsen 1970-84) is being published in instalments by family, and other relevant publications are dispersed through the taxonomic literature (see Walker 1952 and Hansen 1973 for summaries). More extensive botanical research over a longer timespan in other parts of mainland South-East Asia provides additional information relevant to Thailand (cf. Ridley 1922-25, van Steenis 1950–in progress, Henderson 1954, Aubréville and Tardieu-Blot 1960-in progress) and Smitinand (1980) provides a list of most taxa in the country although it is not comprehensive.

Measurements were taken from the archaeological specimens and from a range of closely related seed types, in fresh and charred form. Metric data (in mm) were recorded using a micrometer in the eyepiece of a binocular microsope, in a standardized way following Helbaek (1970:191):

L = length; in cereal grains from the embryo point (radicle) to the apex; in round seeds (e.g. pea) the greatest dimension parallel to the cotyledons.

B = breadth, width; in cereal grains maximum dimension between the flanks; in discoid seeds (e.g. lentil) the greatest diameter.

T = thickness; in cereal grains the maximum dimension from the dorsal to the ventral side, the latter being the surface dissected by the ventral furrow; in leguminous seeds (e.g. pea and lentil) the maximum dimension at right angles to the cotyledon plane.

Means are presented only where the archaeological seeds may have derived from a single population. Modern seeds from the reference collection were charred in a form as close as possible to the archaeological specimen. For example, where an archaeological seed was found naked, its likely equivalent was charred without lemmas and paleas in the case of Gramineae, or without the pericarp for *Chenopodium* spp.

Experimental charring of weed seeds and cereal grains has shown variable distortion with different temperatures and oxidising conditions (Helbaek 1970, D.G. Wilson 1984, Smith and Jones 1990), moisture (Stewart and Robertson 1971) and the morphology and chemistry of the seed (Wasylikowa 1986). Generally, seeds become shorter in length and broader in width after charring, although the response varies between taxa charred under identical conditions (D.G. Wilson 1984). In preparation for identifying each type of archaeological seed from Khok Phanom Di, charring experiments were undertaken on groups of ten seeds from a range of taxa. Dry modern specimens were first measured for length, width and thickness, wrapped in aluminium foil then heated in a muffle furnace at 250° C for 30 minutes. The seed packet was allowed to cool slowly to room temperature before the contents were removed and remeasured. Some specimens were then dissected to investigate the condition and shape of the endosperm. The archaeological seeds had undergone less distortion than the experimentally charred reference material so may have been burnt at a lower temperature for a longer period or under different oxidising conditions.

The seed coat (testa) (*sensu* Fahn 1974:534) is one source of diagnostic criteria which can aid identification even to species level. Surface texture and the presence/absence and type of reticulation may provide clues to a precise identification but require the high resolution and magnification provided by scanning electron microscopy. SEM complemented conventional light microscopy in the investigation of potential diagnostic features for identification of unknown archaeobotanical material. Although there is much information on testa topography (Brisson and Peterson 1976), many features conventionally recorded are modified by charring, making charred reference material indispensable for archaeobotanical purposes. Extensive use of SEM allowed very fine surface detail on the testa of both archaeological specimens and modern reference material to be considered.

Clean dry mature seeds were photographed at x40–100 and seed surface topography was viewed at magnifications up to x3,000. Testa topography varied with the quality of preservation in the archaeological specimens. Seeds were mounted on circular SEM specimen holders using nail polish. Small amounts of colloidal silver were applied to the undersurfaces to prevent charging. Specimens were coated with 250Å of gold using a Dynavac 12/14C evaporative coater and examined using a Cambridge Stereoscan 360 Scanning Electron Microsope with the accelerating voltage set at 15kV. Photographs were taken using Ilford FP4 or Kodak PXP film.

RESULTS

Descriptions and photographs of each class of material are presented below, along with data on preservation and distortion. The identifiable seeds are listed first, followed by one unknown type. As with many archaeobotanical assemblages, some seeds remain 'indeterminate' or 'unknown'. These may be anonymous because of a lack of appropriate comparative collections or their poor preservation. Basic descriptions of unidentified specimens are listed on page 110ff.

Diagnostic criteria as well as reasons for eliminating similar and/or closely related taxa are discussed so that identifications may be assessed by others (cf. Wasylikowa 1986). This is followed by a summary of occurrences and a consideration of alternative methods of quantifying seed data. The chapter concludes with a discussion of the plants and habitats represented by the seed assemblage.

Seed shapes were assessed in terms of the chart of symmetric plane figures developed by the Systematics Association Committee of the International Association for Plant Taxonomy (Montgomery 1977, Berggren 1981). Assessments of preservation were made according to the schema of Hubbard and al Azm (1990:104) (1 = perfect, 6 = poor). The level of confidence of each identification follows the terminology of Crawford (1983), which is in principle similar to the five-point scheme used by Yen (Bodner 1986). The level of confidence is qualified by the terms questionable, possible and probable. A seed type is only named to species where the genus is monospecific in the region. Morphological and taxonomic descriptions of the seeds follow below, with Monocotyledons before Dicotyledons. Within these the commonest families are treated first and in each family the most secure identifications take precedence. Palaeoethnobotanical reconstruction drawing on economic and ecological information about the plant taxa from the seed assemblage is discussed in a later section.

MONOCOTYLEDONS

(a) Cyperaceae: *Fimbristylis*-type (possibly *F. dichotoma*) (Fig. 17:1)

A single *Fimbristylis*-type achene has been identified from 8:7 lens 12. This is a broadly ovoid seed, biconvex, and with a very broadly ovate cross section. It is prominently reticulate over the entire surface, with longitudinal striae which are slightly more conspicuous than the transverse ridges. It is 1.15 mm long, 0.85 mm wide and 0.6 mm thick. It is very probably a member of the genus *Fimbristylis*. It resembles the example of *Fimbristylis* sp. illustrated by Noda *et al.* (1986) and conforms with the generic description supplied by Haines and Lye (1983). The species of *Fimbristylis* listed by Smitinand (1980) in his dictionary of Thai plant taxa are:

F. acuminata Vahl	*F. globulosa* Kunth	*F. quinquangularis* Kunth
F. aestivalis Vahl	*F. hookeriana* Boeck.	*F. rigidula* Nees
F. dichotoma Vahl	*F. junciflorus* Kunth	*F. savannicola* Kern
F. dipsacea Clarke	*F. miliacea* Vahl	*F. smitinandii* T. Koya
F. eragrostis Hance	*F. monostachyos* Has	*F. thomssonii* Boeck.
F. fusca Benth.	*F. pauciflora* R. Br.	*F. tristachya* R. Br.

Additional taxa are recorded by Kern (1955, 1962a 1962b, 1965, 1967a, 1967b, 1967c) and Harada *et al.* (1987). The variation in surface topography and gross morphology between species in this genus would allow identification to proceed further, given a well-preserved archaeological specimen, but this was not possible in this instance due to the lack of a complete range of reference material.

The following comparative material was examined at the National Weed Science Research Institute or the Australian National Herbarium: *F. acuminata*, *F. aestivalis*, *F. dichotoma*, *F. eragrostis*, *F. fusca*, *F. miliacea*, *F. monostachyos*, *F. pauciflora* and *F. quinquangularis*. The remaining species are described in Ridley (1925). *Fimbristylis acuminata*, *F. globulosa* and *F. pau-*

ciflora can be eliminated on the grounds of gross morphology as they are trigonous (Sastroutomo n.d., Henderson 1954). The following are also inappropriate because of their surface patterning: *F. acuminata* has five transverse ridges (Ridley 1925:153); *F. fusca* is obscurely warty; and *F. globulosa* is "very finely warty" (Henderson 1954:263). Of the two species of *Fimbristylis* in the collection at the National Weed Science Research Institute, *F. miliacea* is too small to be the archaeological *Fimbristylis*-type achene and has a surface morphology which differs from that of the archaeological specimen, while *F. dichotoma* is nearly the appropriate size and has the gross morphology to fit the archaeological seed. This also conforms broadly with the published dimensions of seeds from this species, given as length = 1.004 mm (0.95–1.11 mm) and mean of width and thickness = 0.668 mm (0.62–0.72 mm) by Noda *et al.* (1986:126).

The surface topography, with well-defined, broadly hexagonal reticulation across the entire surface of the seed, was closer to the pattern observed in charred specimens of *F. dichotoma* than to that of fresh seeds of this taxon. The surface patterning was suppressed in the central areas of the uncharred seeds and more pronounced in charred specimens. The *Fimbristylis*-type seed could be the species *dichotoma*, but this remains only a possibility as the full range of taxa within the genus was unavailable for comparison with the archaeological specimen.

(b) Cyperaceae: *Eleocharis*-type (Fig. 17:3)

A total of 57 charred achenes similar to the sedge *Eleocharis* sp. were recorded from layers 10 to 4. These ranged in shape from broadly elliptic to ovate in outline and have a biconvex, very broadly ovate to depressedly ovate cross section. Their longitudinal section is obovate, the margin is keeled and the style-base swollen. The remains of perianth segments (hypogynous bristles) are occasionally preserved, but the barbs are absent or damaged. Testa surfaces show finely reticulate transverse cell patterning, especially beneath the perianth bristles, around the margins and near the base and apex. The internal surface of the testa is transversely finely striated. Some specimens have split open along marginal cracks to reveal a charred endosperm. The endosperm is firm and the embryo at the acuminate apex appears to be more fragile than the cotyledon. The cross section of the endosperm is very broadly to depressedly ovate. The flatter side of the endosperm is sometimes slightly concave.

Perianth bristles are restricted to the tribes of Rhyncosporeae and Scirpeae within the family Cyperaceae (Haines and Lye 1983) and suggest the genera *Rhyncospora*, *Schoenoplectus* (=*Scirpus*) and *Eleocharis*. All are reported in the pollen samples taken adjacent to the site (Maloney 1991). However, the distinctive swollen style-base is only found in *Eleocharis* and *Rhyncospora* (Martin and Barkley 1961). The members of these taxa reported for Thailand are *E. spiralis* (Noda *et al.* 1985:36) and, according to Smitinand (1980): *E. acutangula* Schult., *R. corymbosa* Britt., *E. dulcis* Trin., *R. rubra* Makino, *E. fistulosa* Schult., *R. wallichii* Kunth (= *R. rubra* Makino), *E. geniculata* Roem. and Schult., *E. ochrostachys* Steud. and *E. tuberosa* Schult.

The *Eleocharis*-type seeds from Khok Phanom Di are smaller than fresh and charred specimens of *Eleocharis* from the reference collection, but their overall proportions, characteristic swollen style-base and perianth bristles indicate that they are probably members of this genus, though the possibility of their belonging to *Rhyncospora* cannot be ruled out.

TABLE 14: *Dimensions of* Eleocharis*-type achenes and endosperm (mm)*

Context	Length	Width	T	P	Context	Length	Width	T	P
Achenes									
8:1	1.10	0.80	0.55	3	8:3	0.75	0.65	0.45	3
8:5	1.40	1.00	0.65	4	8:12 l 12	1.10	0.90	0.60	2
8:12 l 12	1.10	0.70	0.50	2	8:12 l 12	0.95	0.75	0.50	2
8:12 l 12	0.95	0.70	0.35	2	9:1	1.00	0.90	0.50	4
9:3	1.20	0.80	0.65	3	9:3	1.20	0.80	0.50	2
9:3	1.40	0.70	0.50	2	9:6	1.20	0.80	0.50	2
10:9	1.25	0.80	0.60	3	10:15	1.50	0.95	0.70	4
10:15	1.50	0.90	0.70	3	10:20	1.25	0.90	0.55	3
10:20	1.20	0.70	0.50	3	10:21	1.20	0.75	0.50	2
10:21	1.00	0.70	0.50	2	10:21	0.80	0.70	0.50	2
10:23	0.85	0.55	0.45	2					
Endosperm									
5:5	0.70	0.60	0.40	2	5:5	0.70	0.50	0.35	2
5:5	0.60	0.45	0.35	2	6:7	0.55	0.50	0.35	2
6:7	0.60	0.50	0.45	2	6:7	0.80	0.60	0.45	2
6:7	0.70	0.60	0.45	3	7:7	0.80	0.70	0.45	2
7:7	0.90	0.70	0.40	3	7:7	1.20	0.80	0.45	1
8:5	1.20	0.80	0.50	1	8:5	0.80	0.65	0.40	2
8:5	0.60	0.55	0.30	2	8:5	0.80	0.50	0.40	2
8:5	0.70	0.60	0.30	1	8:5	0.60	0.50	0.40	2
8:6	0.65	0.50	0.35	2	8:7 l 12	0.70	0.60	0.40	2
8:7 l 12	0.75	0.55	0.40	2	8:7 l 12	0.80	0.55	0.35	2
9:3	0.70	0.70	0.40	2	9:3	0.75	0.65	0.40	2
9:3	0.85	0.70	0.45	1	9:3	0.70	0.70	0.40	1
9:6	0.75	0.60	0.40	2	9:6	0.80	0.65	0.45	2
10:3 l 2	0.90	0.65	0.45	2	10:5	0.80	0.75	0.45	2
10:5	0.75	0.75	0.45	2	10:7	0.75	0.65	0.45	2
10:9	0.90	0.70	0.45	2	10:9	0.85	0.70	0.40	2
10:18	0.80	0.75	0.50	2					

Distortion for all specimens = 1, l: lens, T: thickness, P: preservation

(c) Cyperaceae: *Schoenoplectus*-type (=*Scirpus*-type) (Fig. 17:5)

Twenty-seven complete *Schoenoplectus*-type achenes were recovered from samples spanning almost the entire depth of the site. These are broadly obovate in longitudinal section, tapering to an acuminate stylebase; their cross section is transversely elliptic. Their surfaces are slightly

striated parallel to the long axis, with the cell pattern most distinct at the apices. Some specimens have broken along fractured margins, releasing the endosperm. Entire specimens were dissected to examine the internal structure of the endosperm and embryo, and some specimens were found simply in the form of endosperm, without their testa. The endosperm generally has an elliptic cross section, with one side more plano-convex than the other and the distal area is often broken or missing. There are transverse striations across the endosperm. Fine striations on the inner face of the testa (as described by Martin 1954:514) indicate that these belong to Cyperaceae.

Amongst the Cyperaceae, this class of seeds resembles descriptions of both *Schoenoplectus* (=*Scirpus*) and *Carex* achenes in their obovate, biconvex shape (Kern 1974, Kern and Nooteboom 1974) and it is often difficult to distinguish between these in archaeobotanical specimens (Bohrer 1970). While the archaeological seeds closely conform to descriptions of these genera, and a tentative nomination of *Schoenoplectus* was supported by Bruhl's automated database, it has been impossible to match exactly the archaeological specimens with any of the herbarium collections for these genera.

Members of these taxa listed by Smitinand (1980) are: *S. articulatus*, *S. erectus* Poir., *C. cruciata* Vahl, *S. grossus* L.f., *C. cryptostachys* Brogn., *S. grossus* var. *kysoor* Clarke, *C. indica* Linn. = *juncoides* Roxb., *C. stramentita* Boott Boeck., *S. mucronatus* L., *C. thailandica* T. Koyama and *C. tricephala* Boeck.

S. articulatus, *S. grossus* and *S. juncoides* are illustrated by Noda *et al.* (1985, 1986). Unlike the archaeological material, these species are trigonal and have very different testa surfaces. Again, the prominent transverse ridges, especially along the margins of *S. erectus* eliminate this species (Gauba 23029), as these features were not observed in the archaeological specimens. *S. juncoides*, on the other hand, is biconvex, which is a point of similarity. Although Henderson (1954) describes *S. mucronatus* as trigonal, other accounts note some intraspecific phenotypic diversity. Kern (1974) for instance, states that the nuts may be strongly dorsiventrally compressed, planoconvex, or trigonous but the dorsal angle indistinct, broadly obovate, shortly apiculate, scarcely rugulose to smooth and ranging in size from 1.75–2.25 by 1.5–1.75 mm. It is possible that the archaeological material lies within this broad range of variability, but is closer to part of the spectrum which is not represented in the reference material.

Fresh specimens of *Schoenoplectus mucronatus* were charred and the data comparing sizes of achenes before and after charring are presented in table 15. These achenes are much larger than the archaeological specimens, but have similar proportions. The length:width ratio for the archaeological *Schoenoplectus*-type seeds is 1.20, compared with 1.25 and 1.30 for the modern specimens of *Schoenoplectus mucronatus* before and after charring. The *Schoenoplectus*-type is confidently ascribed to the Cyperaceae, but the generic determination should be regarded as questionable.

(d) cf. Cyperaceae endosperm (type A) (Fig. 18:1)

This is the second most frequent 'seed' type in the analysis, totalling 387 items. These subcircular 'seeds' which are actually endosperm because most specimens appear to be incomplete, a few having a fragment of testa attached, have a sub-rectangular cross section. There is a small circular scar (diameter approximately 1 mm) at the proximal end and a large elliptical scar at the distal end which is possibly where the embryo has broken away. The specimens with testa attached were examined using SEM, but diagnostic cellular details were not preserved. Very occasionally,

TABLE 15: *Mean dimensions (mm) of modern achenes and seeds before and after charring at 250° C for 30 minutes*

	Before charring			After charring		
	Length	Width	Thickness	Length	Width	Thickness
*Eleocharis spiralis**						
Mean	1.39	1.00	0.67	1.31	0.92	0.66
S.D.	0.110	0.082	0.067	0.117	0.123	0.053
*Eleocharis dulcis**						
Mean	1.48	1.04	0.74	1.45	1.02	0.72
S.D.	0.079	0.061	0.047	0.112	0.063	0.041
*Fibristylis dichotoma**						
Mean	1.31	0.84	0.49	1.26	0.82	0.47
S.D.	0.072	0.053	0.052	0.070	0.048	0.054
*Schoenoplectus mucronatus (= Scirpus mucronatus)***						
Mean	1.94	1.55	0.83	1.96	1.51	0.88
S.D.	0.094	0.160	0.103	0.050	0.148	0.101
*Portulaca oleracea**						
Mean	0.59	0.56	0.30	0.64	0.55	0.28
S.D.	0.097	0.080	0.041	0.039	0.037	0.029
*Amaranthus spinosus**						
Mean	0.83	0.75	0.41	0.72	0.65	0.45
S.D.	0.049	0.064	0.039	0.048	0.072	0.123
*Amaranthus viridis**						
Mean	1.03	1.00	0.70	0.98	0.93	0.66
S.D.	0.063	0.072	0.033	0.059	0.059	0.032
*Trianthema portulacastrum***						
Mean	1.64	1.48	0.83	1.59	1.46	0.78
S.D.	0.078	0.103	0.054	0.097	0.128	0.035

* from the National Weed Science Research Institute, Bangkok
** from the Australian National Herbarium, sheet Paijmans 2067

one of these specimens was seen with a mottled surface. These were examined using SEM, but it remained unclear whether the pitting was an artefact of charring or a genuine anatomical feature. Dimensions for specimens from four selected contexts are presented below (Table 18).

The identification of archaeological seeds which have lost their seed coats is highly problematic (Pearsall 1989), as the comparative internal anatomy of seeds has not been well documented (but see Martin 1946). Even where the 'fruit contents' or endosperm have been found in archaeological

TABLE 16: *Dimensions of whole* Schoenoplectus*-type achenes (mm)*

Context	Length	Width	T	P	D	Context	Length	Width	T	P	D
4:1	1.40	1.00	0.70	1	1	6:1	0.75	0.95	0.45	2	1
8:7 1 12	1.20	broken	broken	2	1	10:7	1.10	0.90	0.40	3	1
10:17	1.40	1.30	0.65	1	1	10:18	1.40	1.25	split	2	2
10:19	1.20	1.00	0.50	1	1	10:19	1.40	1.20	0.65	1	1
10:19	1.50	1.25	0.55	1	1	10:19	1.40	1.30	0.65	1	1
10:19	1.50	1.15	0.60	1	1	10:19	1.40	1.20	0.50	2	1
10:19	1.60	1.15	0.55	1	1	10:19	1.20	1.00	0.50	1	1
10:19	1.25	1.05	0.55	1	1	10:19	1.60	1.15	0.50	2	1
10:19	1.40	1.00	0.50	2	1	10:20	1.10	1.10	0.65	1	1
10:22	0.75	0.90	0.45	2	1	11:1	1.70	1.10	0.55	1	1
11:1	1.40	1.10	0.60	1	1						

D: distortion, I: lens, T: thickness, P: preservation

TABLE 17: *Dimensions of* Schoenoplectus*-type endosperm (mm)*

Context	Length	Width	T	P	Context	Length	Width	T	P
6:1	0.70	0.95	0.40	1	6:1	0.75	0.95	0.45	2
7:7	0.75	0.80	0.35	1	8:5	0.90	0.95	0.50	1
8:7 1 12	0.70	0.90	0.35	1	8:7 1 12	0.85	1.00	0.40	1
10:16	1.00	0.95	0.50	1	10:16	0.80	0.85	0.40	1
10:19	1.10	0.90	0.30	1	10:22	0.75	0.90	0.45	1
10:25	0.85	0.80	0.45	2	11:1	0.90	0.85	0.30	1

I: lens, T: thickness, P: preservation. Distortion for all specimens = 1

contexts, such as the remains of *Carex* and *Scirpus maritimus* in Syrian sites, they have not been fully described or illustrated (cf. van Zeist and Bakker-Heeres 1982). Among the Khok Phanom Di assemblage, a clue to possible identity was provided by other whole charred achenes which were dissected (or fell apart) to release their endosperm. Some variation in the length:width:thickness ratios amongst the endosperm was noted, and it is quite possible that some of these incomplete specimens were derived from types not represented as entire disseminules in this assemblage. This class of 'seed' also bears some resemblance to others which were initially classified as cf. Cyperaceae endosperm (type B). Dimensions for the two types are set out in table 19.

Producing reference material for comparison with these charred endosperm was not straightforward as, after considerable trial and error, working with different combinations of temperatures, oxidization conditions and charring times, it was not possible to reproduce experimentally the ex-

act conditions which charred the archaeological seeds. Each time a batch of modern material was charred and measured, some of the least distorted seeds were dissected, but it often proved impossible to separate the testa from the endosperm. The experimentally charred seeds were more fragile and fused than the archaeological specimens, suggesting that the conditions which led to preservation perhaps involved lower temperatures and longer exposure than in the experimental situation.

TABLE 18: *Dimensions for cf. Cyperaceae endosperm, type A (in mm)*

	Length	Width	Thickness	W/T	L/W
layer 8:1, n=21					
Range	0.40-0.70	0.45-0.70	0.30-0.50	1.20-1.71	0.80-1.30
Mean	0.57	0.57	0.40	1.46	1.01
S.D.	0.075	0.071	0.063	0.223	0.130
layer 8:5, n=25					
Range	0.35-0.75	0.45-0.75	0.20-0.50	1.10-2.75	0.73-1.22
Mean	0.57	0.61	0.40	1.58	0.94
S.D.	0.099	0.087	0.083	0.338	0.114
layer 8:7 lens 12, n=43					
Range	0.50-0.75	0.55-0.75	0.35-0.50	1.22-2.00	0.71-1.09
Mean	0.60	0.66	0.42	1.60	0.91
S.D.	0.067	0.054	0.043	0.195	0.108
layer 9:3 lens 6, n=10					
Range	0.35-0.70	0.40-0.70	0.30-0.50	1.33-1.86	0.86-1.11
Mean	0.56	0.60	0.40	1.50	0.93
S.D.	0.114	0.114	0.078	0.178	0.093

Preservation for all specimens = 1 Distortion for all specimens = 1

(e) cf. Cyperaceae endosperm (type B) (Fig. 18:2)

This group of charred endosperm probably derives from Cyperaceae achenes. They lack their testa and are broadly ovate endosperm with an acuminate apex. The cross section is depressed ovate. These endosperm have a small circular scar on the base similar to the *Eleocharis*-type achenes and the cf. Cyperaceae endosperm (type A) described above. The apex (?embryo) of the cotyledon appears relatively fragile, as if it might break off and leave a form similar to the type A specimens.

In order to compare the two varieties of endosperm, measurements were taken from type B specimens from the base (the proximal end with the small circular scar) to the change in texture between the embryo and the cotyledon, where a fracture might occur to produce a type A specimen (see Fig. 18:2). These 'length' measurements are incorporated in the length:width ratio of table 19.

From this it appears that, despite general morphological similarities, the metric data do not support the notion that the two varieties were derived from a single type of achene or seed. However, the resemblances are probably close enough that they are from members of the Cyperaceae. Both may fall within the range of variability of the modern population. More experimental work with comparative material is required to investigate this.

TABLE 19: *Summary of metric data for selected samples of cf. Cyperaceae endosperm, types A and B*

	Context	Mean W/T	Mean L/W
Type A	9:3 lens 6	1.50	0.93
	8:5	1.58	0.94
	8:7 lens 12	1.60	0.91
	8:1	1.46	1.01
Type B	8:7 lens 12	1.39	0.79

(f) Gramineae, type A, cf. Paniceae (Fig. 18:3)

A number of small charred naked grass caryopses were recovered from the flot. Their lemmas, paleas and embryos are missing. They are all distinctly elliptic in longitudinal section, with an embryo on the ventral surface, extending two-thirds of the grain's length. Each grain is widest around the midpoint of its length and thickest towards the distal end. The distal end is usually rounded and sometimes slightly pointed. The proximal end is split by the embryo on the ventral surface. The dorsal surface is flat or concave, sometimes with a slight groove running parallel to the margin. One specimen has a small, protruding, oval area at the proximal end of the dorsal surface, with a groove parallel to the margin running from the proximal end to about half way around the margin. The dorsal surface is flat or slightly concave and the ventral surface markedly convex. The dimensions of these specimens are listed in table 20.

Considerable variation is observed. The relatively large size of the embryo in proportion to the seed indicates a Panicoid grass (Kozlowski 1972). The plano-convex distal surface seen in the archaeological specimens is common in members of the Paniceae. The general shape resembles illustrations of the *Setaria* caryopses (Martin 1946, Martin and Barkley 1961) and also that of *Echinochloa* spp. and *Setaria* spp. depicted by Hubbard (1992). In fresh material, Panicoid caryopses are typically tightly enclosed by lemmas and paleas in contrast to these archaeological specimens, which are naked. It is particularly difficult to separate the lemmas and paleas from the caryopses, so charring experiments with modern grains were carried out with the lemmas and paleas attached. Thirty minutes in a muffle furnace at 250°C produced well-preserved lemmas and paleas, but the endosperm in the grains had liquefied and extruded through the covering structures. It was not possible to produce charred grains of *Setaria* for comparison with the archaeological specimens.

TABLE 20: *Dimensions for Gramineae, type A caryopses (cf. Paniceae) (mm)*

Context	Length	Width	Thickness length	Embryo width	Embryo	Preservation	Distortion
2:1	1.00	0.70	missing	missing	missing	3	1
2:1	1.10	0.85	0.50	0.60	0.50	1	1
2:1	1.10	0.80	0.50	0.80	0.45	2	1
2:1	0.90	0.70	0.50	0.60	0.40	3	1
2:1	0.80	0.65	0.30	0.30	missing	3	1
2:1	0.65	0.60	0.35	0.35	0.25	1	1
2:3	0.80	0.60	0.45	0.60	0.25	2	1
6:7	1.20	1.00	0.60	0.75	0.55	1	1
9:3	1.00	0.75	0.35	0.30	0.30	2	1
10:9	1.05	0.80	0.55	0.75	0.40	2	1
10:9	0.70	0.70	0.50	0.40	0.30	3	1
10:9	0.95*	0.90	0.50*	0.50	0.40	2	1
10:11	1.00	0.85	0.60	missing	missing	3	1
10:13	1.00	0.75	0.50	0.60	0.30	2	1
10:17	0.85	0.60	0.45	0.55	0.25	3	1
10:17	0.85	0.95	0.55	0.50	0.20	3	1
10:17	0.80	0.75	0.50	missing	missing	3	1
10:17	0.90*	0.70	0.50	missing	missing	3	1
10:17	1.25	1.00	0.60	0.80	0.50	1	1
10:17	1.30	1.00	0.50	0.85	0.55	1	1
10:21	1.20	1.00	0.70	0.70	0.50	2	2
10:21	1.30	1.00	0.75	0.90	0.40	4	1
10:21	1.10	0.80	0.50	0.65	0.50	3	2
10:21	1.00	0.90	0.55	0.65	0.50	2	1

* Measurement incomplete because specimen broken or abraded

The caryopses in question bear a strong morphological resemblance to the photographs of seeds identified as *Echinochloa*-type (barnyard grass) by Crawford (1983) but are significantly smaller than the Japanese specimens. However, they are quite different from the experimentally charred *Echinochloa crus-galli* caryopses from the reference collection. The Gramineae identified in the pollen record are *Coix*, *Paspalum*, *Oryza* and *Eragrostis* (Maloney and Brown 1990), but none of these is comparable to the charred caryopses. The level of identification therefore remains at the tribe Paniceae.

(g) Indeterminate Gramineae (Fig. 18:3-4)

This class includes the remaining nine assorted Gramineae caryopses in the charred seed assemblage. These do not constitute a homogeneous group. At least five different types are brought together here and most appear to be unique. They are described individually in table 21.

TABLE 21: *Dimensions and descriptions for indeterminate Gramineae caryopses (mm)*

Context	Length	Width	Thickness	Embryo length	Embryo width	Preservation	Distortion
2:3	0.50	0.70	0.25	0.30	0.20	1	1
Elliptic caryopsis with very broadly ovate cross section. Dorsal end rounded and proximal end less so. Well-defined and shallow embryo on ventral surface.							
4:1	1.50	1.00	0.80	0.70	0.40	2	1
A unique large oblong caryopsis, ends truncate, sides parallel, dorsal surface flat. Cross section hexagonal and with longitudinal surface striae.							
8:1	0.75	0.45	0.25	0.25	0.30	3	1
Elliptic caryopsis, sides parallel, distal end rounded, proximal end less rounded. Cross section broadly ovate, dorsal surface almost flat, ventral surface convex. Distinct embryo on the ventral surface. Condition poor, highly abraded.							
9:2	1.00	0.45	0.25	0.40	0.25	3	1
Long and narrow caryopsis, sides parallel, distal end rounded, proximal end arcuate. Cross section depressed ovate. Dorsal surface flat to slightly concave. Ventral surface has shallow indistinct embryo. Surface topography not preserved.							
10:15	0.75	0.50	0.45	0.30	0.20	3	2
Small, narrow and elliptic seed with longitudinal striations on the surface. Sides parallel, with maximum width at midpoint of length. Distal and proximal ends rounded. Maximum thickness in central area of seed. Dorsal surface slightly concave. The embryo is one third to half the length of the seed. Possibly a member of the Andropogoneae.							
10:15	0.75	0.45	0.25	0.30	0.20	3	2
Description as above.							
10:22	1.20	0.90	0.60	0.85	0.45	1	1
Elliptic caryopsis with parallel sides, distal end rounded, proximal end rounded and tapering; dorsal and ventral surfaces parallel to each other, but dorsal surface flatter than ventral surface. Poorly defined embryo on ventral surface, greater than half the length of the seed.							
10:25	1.25	1.10	0.75	1.00	0.35	2	2
Broadly elliptic caryopsis, widest at midpoint to length; cross section transversely elliptic. Well-defined embryo on ventral surface, perhaps with some embryo still preserved. Dorsal surface has a broad and shallow crack, with additional charred material adhering to this surface.							
11:2	1.05	1.00	0.75	missing	missing	3	4
Broadly elliptic caryopsis. Proximal end blunt; distal end rounded. Ventral surface largely abraded, embryo not visible. Dorsal surface flat to concave.							

DICOTYLEDONS

(a) Chenopodiaceae: *Suaeda maritima* Dum. (Fig. 18:5-6)

The most abundant seed type is *Suaeda maritima* Dum., a herbaceous plant, sometimes taking the form of a low shrubby herb, commonly found growing in swampy salty clayey soils in open areas behind mangrove. It is the red and purple leaves of this plant which give the impression of a reddish hue across the saline plains during the dry season (Larsen 1963). Most of the specimens were recovered from two samples in layer 10. The seeds are horizontal and ovoid with a slight notch between the tip of the radicle and the cotyledons. The radicle tip projects from the seed, the margin is rounded, the cross section lenticular and the sides biconvex. Slight furrows run parallel to the margin along the radicle. A few specimens have a distinctly mottled surface. SEM studies of the testa suggest that the mottling is perhaps more an artefact of charring than due to cell patterning.

These seeds were usually hollow and about ten per cent were broken along the margin. Fragments of testa were sometimes found and were counted in a systematic way: for instance, two halves (the commonest size of fragment) or four smaller pieces were scored as one specimen (after Wasylikowa 1986).

The gross morphology in outline suggests that this type of seed is probably in the Chenopodiaceae. Possible taxa include *Atriplex*, *Chenopodium* and *Suaeda*. *Atriplex* is not recorded by Smitinand (1980) or by Larsen (1963) as occurring in Thailand. The only taxon in this family to be found in mangrove swamps or adjacent areas is *Suaeda maritima*, a small herbaceous plant which grows on open saline plains near the coast (Larsen 1963), but *Chenopodium* should not be eliminated on biogeographical grounds alone. While *Chenopodium* spp. are listed in neither Smitinand's dictionary (1980) nor IRRI's summary of weeds of rice in Thailand (Moody 1989), *C. ficifolium* Smith ssp. *blomianum* (Aellen) Aellen is mentioned as a ruderal in north and north-east Thailand (Harada *et al.* 1987) and *C. album* is reported as having a 'cosmopolitan' distribution (Larsen 1963). The *Flora of Thailand* does not yet cover these taxa, but the following are known to grow today in adjacent parts of mainland South-East Asia: *C. botrys*, *C. ambrosioides*, *C. hybridum*, *C. polyspermum*, *C. ficifolium* and *C. acuminatum* subsp. *virgatum* (Larsen 1989), although *C. ambrosioides* is an introduction from tropical America (P.G. Wilson 1984). The archaeological specimens under discussion were compared with each of the above taxa, as fresh material from the seed collections at CSIRO and the Australian National Herbarium and with charred material where available, as well as with published photographs and accounts. Data for *C. hybridum* and *C. acuminatum* subsp. *virgatum* are not presented due to lack of reference material.

Metric data were recorded for charred and fresh examples of the modern taxa which could possibly be equivalent to the Chenopodiaceae seeds from Khok Phanom Di, and these are set out in table 22, alongside published figures for dimensions of seeds from other members of the Chenopodiaceae. While dimensions of the seeds found at Khok Phanom Di are closest to figures for *Suaeda maritima* and *Chenopodium album*, none of the archaeological material exhibited the radial cell pattern typical of *Chenopodium* and all lacked the membranous exocarp seen there.

One criterion for distinguishing between these genera in fresh material is the form of the embryo. In *Suaeda* this is a flat spiral and in *Chenopodium* it is ringshaped (Martin 1946, Berggren 1981). It was impossible to use this to verify the identification of the archaeological specimens from this site because most were hollow. The internal surfaces of some broken testa were exam-

TABLE 22: *Dimensions of* Suaeda maritima *and* Chenopodium *spp. seeds (mm)*

Type	Length	Width	L/W	Thickness	Source
KPD *Suaeda maritima*	0.99	0.84	1.18	0.52	Khok Phanom Di excavations
S. maritima	1.18	0.98	1.20	0.62	Thai fieldwork collection
S. maritima *	1.07	0.88	1.22	0.51	Thai fieldwork collection
S. maritima	1.20-1.70	1.40-2.00		0.70-0.90	Berggren (1981:46)
S. maritima	1.10-1.20	1.10-1.40		0.60-0.70	Berggren (1981:46)
S. maritima	1.60	1.80	0.89	0.90	Montgomery (1977:71)
S. maritima	1.00	1.00	1.00	0.50	Martin and Barkley (1961:152)
Chenopodium album	1.45	1.36	1.07	0.70	Australian National Herbarium, sheet Albrech 520
C. album *	1.32	1.24	1.06	0.84	Australian National Herbarium, sheet Albrech 520
C. album	1.10-1.60			0.60-0.80	Berggren (1981:46)
C. album	1.20	1.00	1.20	0.50	Montgomery (1977:69)
C. album	0.80-1.40				Engstrand and Gustafsson (1974)
C. ambrosioides	0.74	0.67	1.10	0.45	Australian National Herbarium, sheet Pullen 3642
C. ambrosioides *	0.69	0.61	1.13	0.59	Australian National Herbarium, sheet Pullen 3642
C. ficifolium	0.80-1.20			0.50-0.80	Berggren (1981:46)
C. ficifolium	1.03	0.98	1.05	0.53	Australian National Herbarium, sheet Blom. C.sn.Canb.123089
C. ficifolium *	1.02	0.92	1.11	0.61	Australian National Herbarium, sheet Blom.C.sn.Canb.123089
C. polyspermum	1.01	0.96	1.05	0.54	Australian National Herbarium, sheet Leenhouts 2856
C. polyspermum *	0.96	0.91	1.05	0.64	Australian National Herbarium, sheet Leenhouts 2856
C. polyspermum	0.80-1.20			0.50-0.60	Berggren (1981:46)
C. botryodes	0.60-1.00			0.30-0.40	Berggren (1981:46)
C. botrys	0.70	0.70	1.00	0.50	Montgomery (1977:6)

* Denotes charred specimens after 30 minutes at 250° C (mean from N=10)
Data from Berggren (1981) refer to diameters, and to the capsule rather than the seed

ined using SEM to see whether the impression of the cotyledons and embryo was preserved, but none was visible.

The gross morphology and particularly the prominent radicle of the archaeological specimens were closer to *Suaeda maritima* than to *Chenopodium* spp.; indeed, the small but distinct protruberance in the incurvation between the radicle tip and the median part of the fruit is diagnostic for

TABLE 23: *Dimensions for* Suaeda maritima *seeds from layer 10:19 (mm), (a subsample of 20 seeds from a total of 268)*

	Length	Width	Thickness
Range	0.85-1.20	0.75-1.05	0.45-0.60
Mean	0.99	0.84	0.52
S.D.	0.085	0.086	0.033

Preservation in all specimens = 1
Distortion in all specimens = 1

this genus (van Zeist and Heeres 1982). The lenticular cross section was closer to *Suaeda* than *Chenopodium*, as the latter tends to have a more rounded margin. Although the archaeological seeds conformed fairly well with photographs and illustrations of *Suaeda maritima* (cf. Montgomery 1977, Berggren 1981, van Zeist and Bakker-Heeres 1984, 1985) and examples from the reference collections from Thailand, the testa surfaces differed. The testa of modern charred and uncharred examples of *Suaeda maritima* seeds have a rectangular patterning, not observed in the archaeological material. The latter have grooves and ridges, especially around the margin of the radicle. The differences may be due to the high degree of polymorphism in this taxon (cf. Backer 1954) or to charring conditions, but more reference material would be necessary to investigate these possibilities. Certain atypical archaeological specimens did have a mottled appearance, due to surface cracking. This was usually hexagonal and compatible with formation by shrinkage on cooling and splitting along the cell walls of the testa.

(b) Amaranthaceae: *Amaranthus* sp. (Fig. 19:1-2)

Thirty five seeds belonging to the genus *Amaranthus* were recovered in the flot. These are circular/lenticular seeds with a distinct narrow marginal rim and a notched margin. The testa is black and shiny. Many of this group are hollow, squashed, split or distorted in other ways. Amaranth seeds were found at low frequency, usually just one seed per sample, in soil from most levels of the excavation, from 11:1 up to layer 2:1. The narrow rim distinguishes this group from members of *Chenopodium* which have a rounded margin (Martin and Barkley 1961). SEM studies of seed coat topography indicate that the archaeological specimens are closer to *A. viridis* than *A. spinosus*. The testa of *A. viridis* has a well-defined reticulation visible at magnifications around x200, whereas that of *A. spinosus* is smoother and the fine cell patterns are not visible unless viewed at higher magnifications, from x700–1,000. Members of this genus recorded for Thailand (from upland areas) are *A. gracilis* Desf. and *A. tricolor* L. (Harada *et al.* 1987), but these were not available for comparison and charring.

(c) Amaranthaceae: *Amaranthus*-type

A total of 18 seeds resembling *Amaranthus* sp. were found among the flot from 10:20. These flat discoid seeds have a lenticular cross section with a slightly grooved, rounded margin and a small notch on the margin, though without a pronounced radicle. All the specimens were hol-

TABLE 24: *Dimensions for* Amaranthus *sp. seeds (mm)*

Context	Length	Width	T	P	D	Context	Length	Width	T	P	D
2:1	0.95	0.85	*	2	3	2:1	0.85	0.80	*	2	3
2:1	0.80	0.75	0.50	3	3	2:1	0.75	0.75	0.55	2	3
2:1	0.70	0.70	0.45	2	3	2:3	0.70	0.60	*	2	3
2:3	0.75	0.70	*	2	3	2:3	0.90	0.80	*	2	3
3:1	0.90	0.80	*	2	3	3:1	0.90	*	*	4	3
4:1	1.00	0.95	0.65	1	1	4:1	0.95	0.95	0.75	3	1
4:1	0.90	0.85	0.60	2	3	4:1	1.05	*	*	3	3
4:1	0.75	0.75	*	3	3	4:1	1.00	0.95	0.60	2	2
5:1	1.25	*	0.50	3	2	6:1	0.80	0.75	*	3	3
6:1	1.00	0.90	0.70	3	3	6:1	1.00	0.95	0.50	3	3
8:3	0.90	0.75	0.40	1	1	8:5	0.75	0.75	0.35	2	2
8:5	0.90	0.90	0.50	1	1	8:5	0.90	0.90	0.55	1	1
9:3	0.90	0.80	0.60	1	1	9:3	0.95	0.95	0.60	3	2
10:9	0.85	0.80	0.55	2	1	10:9	0.70	0.70	0.20	2	1
10:19	0.80	0.75	0.50	2	2	10:20	1.05	1.20	0.75	3	2
11:1	1.00	1.00	0.75	2	2						
Mean	0.94	0.88	0.57								
S.D.	0.13	0.14	0.13								

* Measurement not taken due to excess distortion, T: thickness, P: preservation, D: distortion

low, and some were cracked and missing a large portion of the testa. They were neither charred nor appeared modern. They are possibly degraded modern contaminants or possibly mineralized archaeological specimens. Their black outer coat has rubbed away to reveal a cream/white/grey, possibly mineralized surface. The testa topography around the margins, fading into the central area of the seed, has rectangular grooves with the slightly raised rectangular reticulate cell pattern seen in modern *Suaeda maritima*.

These seeds are smaller than those identified above as *Amaranthus* sp. but they have a similarly rounded form. The cross sections differ as this type does not have the markedly compressed rim typical of the genus *Amaranthus*. In lateral view their rounded profile is closer to *Chenopodium*, but they do not exhibit the characteristic radial cell pattern associated with that taxon. This particular conflicting combination of characters, and poor preservation, make it difficult to offer a confident identification for this seed type, which has tentatively been ascribed to *Amaranthus*-type.

(d) Portulacaceae: *Portulaca* cf. *oleracea* (Fig. 19:3-4)

Seven seeds have been identified as *Portulaca* cf. *oleracea*. Obovate in outline, these small seeds are compressed with convex faces and an elliptic cross section. Their entire surface is covered with short rounded warty papillae in parallel lines. The papillae at the margin are slightly smaller than those on the sides but the surfaces were partly obscured by soil adhering between tubercules.

TABLE 25: *Dimensions of* Amaranthus*-type seeds from layer 10:20 (mm) (a sample of 9 of the 19 seeds)*

	Length	Width	Thickness	Preservation	Distortion
Range	0.70-0.80	0.65-0.80	0.40-0.55	2,3,4	1,2
Mean	0.75	0.72	0.47		
S.D.	0.035	0.050	0.051		

These seeds are charred and hollow. They are a good match for modern specimens of *Portulaca oleracea* L. in terms of gross morphology, surface ornamentation and dimensions (as seen in collections at the National Weed Science Research Institute and descriptions published by Montgomery 1977, Noda *et al.* 1985 and Noda *et al.* 1986). They can be confidently ascribed to the genus *Portulaca* and they closely resemble the species *oleracea*. Other members of this genus are *P. grandiflora* Hook.f., *P. pilosa* L. and *P. quadrifida* L. (Smitinand 1980:273), but these differ from *oleracea* in size and ornamentation (Geesink 1976).

TABLE 26: *Dimensions for* Portulaca *cf.* oleracea *and* Trianthema portulacastrum *seeds (mm)*

Context	Length	Width	T	P	Context	Length	Width	T	P
Portulaca cf. *oleracea*									
2:1	0.70	0.60	0.30	1	2:1	0.70	0.60	0.25	2
2:3	0.60	0.45	0.15	2	2:3	0.60	0.50	0.15	2
5:1	0.90	0.80	0.30	2					
Trianthema portulacastrum									
10:8	1.75	1.55	0.85	2	10:18	1.50	1.25	0.75	2

* Distortion for all specimens = 1, T: thickness, P: preservation

(e) Aizoaceae: *Trianthema* (=*Sesuvium*) *portulacastrum* L. (Fig. 19:5-6)

The identification of two charred reniform seeds confidently named as *Trianthema portulacastrum* L. is important because these are from plants which grow on dry open saltflats, a habitat not indicated by other biological indicators at the site. The seeds were found in layers 10:8 and 10:18. These seeds have marked ridges running perpendicular to the margin, and each seed tapers from a thick cross section to a narrow one close to the radicle. They are both hollow and missing the area near the radicle.

The gross morphology, dimensions and, most notably, the ridged margin of these archaeological seeds are clearly comparable to those of the *T. portulacastrum* sheet at the Australian National

Herbarium, where seeds were noted to have a length and width of 1.5 mm. They are also similar to descriptions and illustrations of seeds from the same taxon in the *Flora of Australia* (*c.* 1.5–2 mm wide) (Prescott and Venning 1984). This prehistoric seed type does not have the 'round reticulum' noted by Noda *et al.* (1985) but is similar in shape to the published photograph.

Trianthema portulacastrum L. is a procumbent, rather succulent herb, having thick fleshy linear leaves with reddish stems. It is common in the saline soils around the Gulf of Thailand today, especially along riversides (Larsen 1963). It has also been noted as a weed of cultivation or associated with disturbed ground in areas of the world where it is not native (Friend 1983, Prescott and Venning 1984).

(f) Malvaceae: cf. *Sida* sp.

A single, well-preserved, charred seed resembling those of the genus *Sida* was recovered from 2:1. This is obovate in longitudinal section and triangular in cross section, with a broad, upstanding ridge along the ventral surface. The dimensions are 1.30 x 1.00 x 1.10 mm. According to Smitinand (1980), species with a Thai distribution are *S. acuta*, *S. cordifolia*, *S. coryfolia*, *S. glutinosa* and *S. rhombifolia*, but the archaeological specimen in question most closely resembles seeds from *S. spinosa*, the prickly mallow. These perennial weedy herbs usually grow in disturbed waste areas and along roadsides in dry sandy conditions (Noda *et al.* 1986). They have numerous medicinal properties as well as producing useful fibres (Burkill 1966).

INDETERMINATE SEEDS

(a) Unknown: Type 1 (Fig. 20:1-2)

Ten indeterminate seeds of a single type were found in 10:25. These seeds have been termed 'unknown' rather than fully 'indeterminate' because they appear to be sufficiently distinctive to be identifiable if a wider selection of reference material were available. Their occurrence in the earliest phase of the stratigraphy alongside seeds like *Suaeda maritima* suggests that they might be the fruiting bodies of another saline mudflat plant.

This type comprises symmetrical, 'pear-shaped' seeds, with a pointed, slightly curved beak (*c.* 0.3 mm long) at the distal end. A slight ridge runs the length of each seed along the margins. The cross section is transversely broadly elliptic at the proximal end, becoming flatter (transversely elliptic) towards the distal end and the longitudinal section is ovate. The proximal end has a circular scar. All specimens are split along one margin and the seeds have flared open, which means that the width measurements overestimate the breadth of the seeds. The split reveals the endosperm inside. These are the same general shape as the testa and sometimes occur with fragments of testa attached, though more commonly without. Neither the testa nor the endosperm surfaces show any distinctive features of potential diagnostic value. Where this type of endosperm occurs without a testa, they are in a particularly poor condition. The preservation of the endosperm is generally poor, 5 or 6 on the Hubbard and al Azm scale (1990), but they do not appear to be significantly distorted. There is some resemblance to seeds of *Ruppia* sp. (Potamogetonaceae) as illustrated by Martin and Barkley (1961:131) but this has not been confirmed with comparative material.

TABLE 27: *Dimensions for whole unknown: Type 1 seeds (mm)*

	Length	Width	Thickness	Preservation	Distortion
Range	0.85-1.70	0.65-1.10	0.60-1.80	2,3	1,2,3
Mean	1.29	0.89	0.84		
S.D.	0.290	0.190	0.369		

(b) Other indeterminate seeds

The remaining categories are indeterminate dicotyledonous seeds. They are only represented by a small number of items, usually just one seed in a class. Brief descriptions are presented on page 110ff.

DISCUSSION AND INTERPRETATION

Charred seeds found in an archaeological matrix may derive from cultural and noncultural sources and be biased by a number of factors. Seed production rates are known to vary widely between taxa and between seasons. Preservation conditions (notably charring regimes) vary, and a broad range of site-formation processes affects seed survival and the movement of seeds through the soil profile. Furthermore, sampling and flotation procedures vary in their efficiency to recover plant remains. While ethnobotanical and ecological models may help to resolve certain biases in the archaeobotanical record, it is difficult to control for them all.

Sample contamination is a recurrent problem. This may be caused by redeposition of disturbed older material, intrusion of younger material from further up the profile or poor sampling and flotation methods. Every effort was made during both field flotation and post-excavation processing to prevent cross contamination of samples by using clean equipment at all times. The possibility remains, however, especially in intricately complex stratigraphy such as the zone A sediments at Khok Phanom Di, that the seed assemblages have been evened out by post-depositional factors. It was not possible, due to time constraints, to examine the extent of this smoothing or disturbance by analysing flot from a range of context types across one phase. Had the seed density been a factor higher, there would have been the opportunity to increase the number of samples sorted.

A further source of difficulty can be contamination by modern seeds (Keepax 1977). Recent materials may be identified by their viable embryos (Wasylikowa 1986), but this was not an option with the hollow, but possibly modern seeds at Khok Phanom Di, such as those described above as cf. *Amaranthus* sp. Following Keepax (1977) and Minnis (1981), the uncharred seeds found in the flot were treated as if they were modern contaminants and excluded from the analyses. This affected, for example, six non-charred seeds of *Acalypha indica* L., found in layer 10:21. Given the depth below datum of the soil sample with which they were found, it seems unlikely that they were *in situ* contaminants which had moved down through the soil profile, but were perhaps part of the modern seed rain at the site during excavation and flotation.

Seed frequencies

Interpretations based on the raw frequency of seeds in a sample are known to overlook complexities inherent in the data (Popper 1988) and counts are usually, at the very least, standardized for the volume of soil processed. In this analysis, the amount of soil sampled for flotation was, for pragmatic reasons, varied at different stages during the excavation, but sample volumes were recorded (see chapter III) and have been used to provide an indication of the number of seeds recovered per 10 l of earth from each context (Table 29, Fig. 15), as well as to standardize the seed identification frequencies (Table 13).

Seed concentrations at Khok Phanom Di range from to 0.2 to 65 seeds per 10 l of soil, with most contexts yielding less than one item. These figures are similar to other sites in tropical regions (cf. Miksicek 1987, Allen 1988) although there are no directly comparable data from South-East Asia. The notion of sample splitting in order to minimize labour-intensive flot sorting and seed identification, while retaining statistically significant sub-samples, has little application here on account of the low seed densities in the cultural matrix. Even where 100 l of soil were processed by flotation, the numbers of archaeological seeds were still smaller than would constitute a statistically valid sample according to Hansen (1980) or van der Veen and Fieller (1982). A macrofossil concentration diagram for the numbers of seeds from samples of equivalent size is presented with the total weights for charcoal samples as figure 15. This illustrates the relative quantities of charcoal deposited through the stratigraphic profile and, if we are correct in assuming a standard deposition rate throughout the occupation, the amount of charcoal in each deposit may approximately correspond to the number of fires lit. This might be considered an index of preservation for charred seeds because where burning has been extensive or frequent, the likelihood of other plant products being preserved by charring is higher than in charcoal-free deposits (Miller 1988).

Seed frequencies vary markedly between contexts at Khok Phanom Di. The generally higher concentrations in samples from zone A could be due to the greater frequency of burning during that phase as described in chapter IV, but that does not account for the unusually large seed concentrations in layer 10:19–20. At this point in the stratigraphy the peaks in charcoal density do not correspond to the most seed-rich samples, suggesting that the higher numbers of seeds found in contexts 10:19 and 10:20 cannot be accounted for simply by superior preservation conditions. Rather, this could possibly be linked with the dominance of *Suaeda maritima* seeds in these contexts. *S. maritima* is a variable rather than a prolific seed producer, but perhaps its growth in colonies, coupled with delayed germination and low seed viability (Chapman 1947, Ungar 1974, 1982), have led to its prominence in the seed bank. Its presence at much lower levels in other samples suggests that this is not always the case though, so the large number of *Suaeda* seeds in 10:19 and 10:20 is more likely an indication of relative abundance in the area, or possibly indicates that it was being used by the community. The documented uses of this plant are few (see page 35). It warrants only an occasional note about the edibility of its leaves, so if there are few cultural reasons for its arrival at the site, a more likely explanation for the high densities of its seeds in two samples from layer 10 could be overrepresentation due to the plant's proximity, coupled with natural deposition.

The low numbers and poor preservation of plant remains are partly attributed to the open, exposed nature of the site, where charred seeds would be disturbed and broken down by heavy tropical rainfall and perhaps monsoon flooding. Additional possible reasons, especially regarding

TABLE 28: *Presence of seed types at Khok Phanom Di*

Context	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2:1	-	-	-	x	-	x	x	-	-	-	x	x	-	x	-	x
2:3	-	-	-	-	-	-	x	x	-	-	x	x	-	-	-	x
3:1	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	x
4:1	-	x	x	x	-	x	-	x	-	-	-	x	-	-	-	x
5:1	-	-	-	x	-	x	-	-	x	-	x	x	-	-	-	x
5:4	-	-	-	x	x	-	-	-	-	-	-	-	-	-	-	x
5:5	-	x	-	x	-	x	-	-	-	-	-	-	-	-	-	x
6:1	-	-	x	x	x	x	-	-	x	-	-	x	-	-	-	x
6:3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x
6:4	-	-	-	x	x	x	-	-	-	-	-	-	-	-	-	x
6:5	-	-	-	x	-	x	-	-	x	-	-	-	-	-	-	x
6:7	-	x	-	x	x	x	x	-	x	-	-	-	-	-	-	x
7:7	-	x	x	x	x	x	-	-	-	-	-	-	-	-	-	x
8:1	-	x	-	x	x	x	-	x	x	-	-	-	-	-	-	x
8:3	-	x	-	-	-	x	-	-	-	-	-	x	-	-	-	-
8:5	-	x	x	x	x	x	-	-	x	-	-	x	-	-	-	x
8:6	-	x	-	x	-	x	-	-	-	-	-	x	-	-	-	x
8:7 1 12	x	x	x	x	x	x	-	-	-	-	-	-	-	-	-	x
9:1	-	x	-	x	-	x	-	-	x	-	-	-	-	-	-	x
9:2	-	-	-	x	-	x	-	-	x	-	-	-	-	-	-	x
9:3	-	x	-	x	-	x	x	-	-	-	-	x	-	-	-	x
9:3 1 6	-	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-
9:5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x
9:6	-	x	-	x	-	x	-	-	-	-	-	-	-	-	-	x
10:3 1 2	-	x	-	x	-	x	-	-	-	-	-	-	-	-	-	x
10:5	-	x	-	x	-	x	-	-	-	-	-	-	-	-	-	x
10:7	-	x	x	x	-	x	-	-	-	-	-	-	-	-	-	x
10:8	-	-	-	x	-	x	-	-	-	x	-	-	-	-	-	x
10:9	-	-	-	x	-	x	x	-	x	-	-	x	-	-	-	x
10:11	-	x	-	x	-	x	x	-	-	-	-	-	-	-	-	x
10:13	-	-	-	x	-	x	x	-	-	-	-	-	-	-	-	-
10:15	x	-	x	-	x	x	x	x	-	-	-	-	-	-	-	-
10:16	-	-	x	x	-	x	-	-	x	-	-	-	-	-	-	x
10:17	-	-	x	x	-	x	x	-	x	-	-	-	-	-	-	-
10:18	-	x	x	x	-	x	-	-	x	x	-	-	-	-	-	x
10:19	-	-	x	x	-	x	-	-	x	-	-	-	-	-	-	x
10:20	-	x	x	x	-	x	-	-	x	-	-	-	x	-	-	x
10:21	-	x	-	-	x	x	x	x	x	-	-	x	-	-	-	x
10:22	-	-	x	x	-	x	-	x	x	-	-	-	-	-	-	x
10:23	-	x	-	-	-	x	-	-	x	-	-	-	-	-	-	x
10:24	-	-	-	x	-	x	-	-	x	-	-	-	-	-	x	x
10:25	-	-	x	-	x	x	-	x	x	-	-	-	-	-	x	-
10:26	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	x
11:1	-	-	x	-	-	x	-	-	x	-	-	x	-	-	-	x
11:2	-	-	-	-	-	-	-	x	x	-	-	-	-	-	x	x
Total	1	57	27	386	93	564	25	11	746	2	7	29	9	2	14	187

1. *Fimbristylis* sp. (Cyperaceae). 2. *Eleocharis*-type (Cyperaceae). 3. cf. *Schoenoplectus*-type (Cyp.). 4. cf. Cyperaceae endosperm (A). 5. cf. Cyperaceae endosperm (B). 6. Combined Cyperaceae. 7. cf. Paniceae (Gramineae). 8. Indeterminate Gramineae. 9. *Suaeda maritima* Dum. 10. *Trianthema portulacastrum* L. 11. *Portulaca* cf. *oleracea*. 12. *Amaranthus* sp. 13. cf. *Amaranthus* sp. 14. cf. *Sida* sp. 15. Unknown, type 1. 16. All Indeterminates.

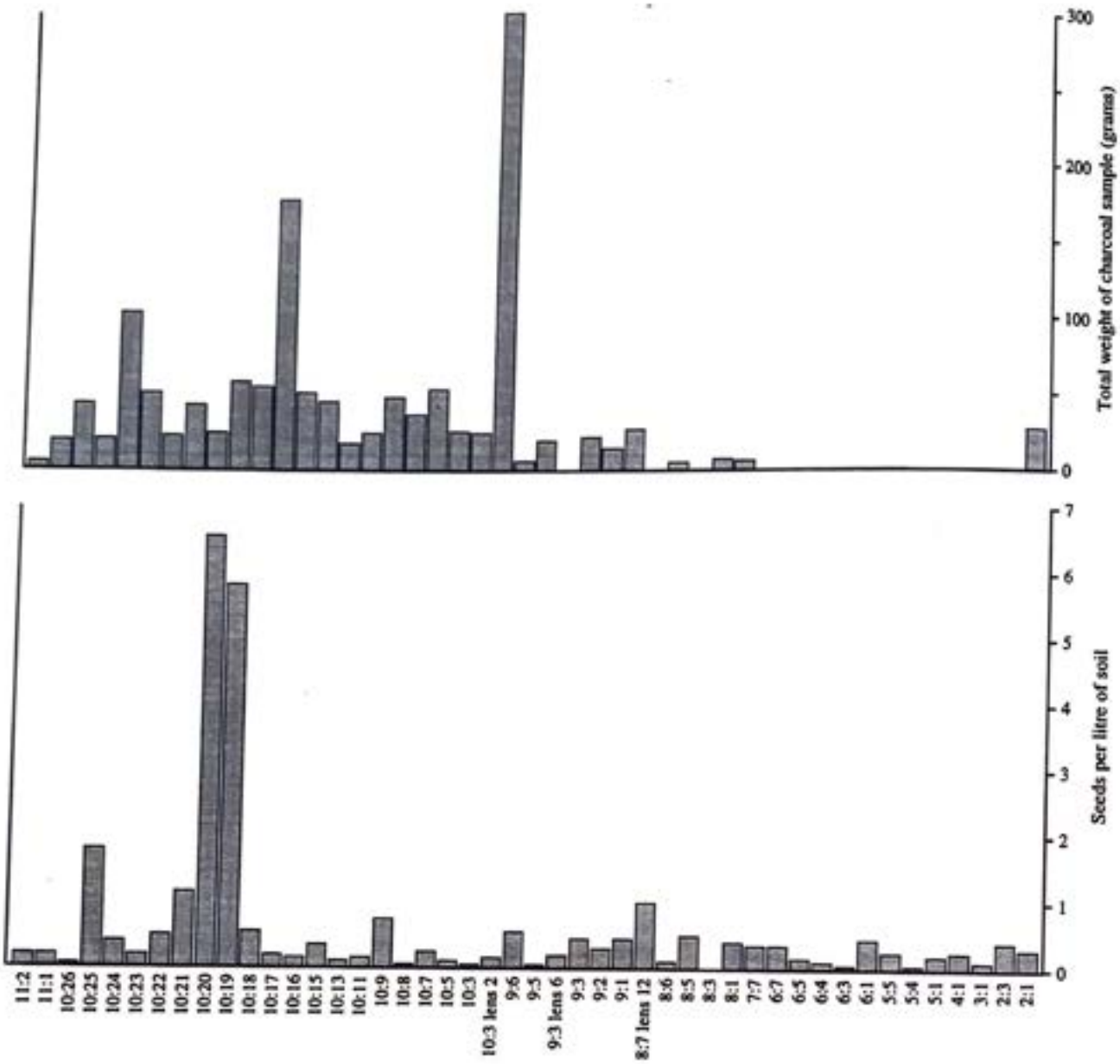


FIG. 15. A comparison between charred seed and charcoal densities through time

cultivated plants, will be discussed later in the light of traditional South-East Asian food processing practices.

The low density of charred seed remains in general supports the inference that all the archaeological seeds may be the products of burning waste or firing of the vegetation growing at or around the site during its prehistoric occupation. The small and heterogeneous charred seed assemblages are consistent with a model of deposition by plants without economic use (cf. Dennell 1976). If natural rather than cultural reasons are more likely to be responsible for the seed rain, their remains

may not inform us directly about plant use at the site but are indicative of the local character of the vegetation.

TABLE 29: *Density of seeds in the cultural matrix*

Context	seeds per sample	Buckets of soil	Seeds per 10 l	Context	seeds per sample	Buckets of soil	Seeds per 10 l
2:1	24	8	3.0	2:3	20	8	4.2
3:1	11	10	1.1	4:1	25	10	2.5
5:1	20	10	2.0	5:4	3	10	0.3
5:5	23	10	2.3	6:1	47	10	4.7
6:3	5	10	0.5	6:4	4	5	0.8
6:5	10	8	1.3	6:7	35	10	3.5
7:7	33	10	3.3	8:1	38	10	3.8
8:3	2	10	0.2	8:5	48	10	4.8
8:6	9	10	0.9	8:7 lens 12	100	10	10.0
9:1	46	10	4.6	9:2	26	10	2.6
9:3	46	10	4.6	9:3 lens 6	10	3	3.3
9:5	1	4	0.3	9:6	27	5	5.4
10:3 lens 2	7	5	1.4	10:3 lens 2	2	3	0.7
10:5	5	5	1.0	10:7	11	5	2.2
10:8	3	5	0.6	10:9	38	5	7.6
10:11	7	5	1.4	10:13	6	5	1.2
10:15	16	5	3.2	10:16	7	5	1.4
10:17	10	5	2.0	10:18	24	5	4.8
10:19	290	5	58.0	10:20	327	5	65.4
10:21	58	5	11.6	10:22	23	5	4.6
10:23	10	5	2.0	10:24	20	5	4.0
10:25	94	5	18.8	10:26	3	5	0.6
11:1	10	5	2.0	11:2	10	5	2.0

The seed remains: qualitative and quantitative results

Standardized frequencies are presented in table 13, along with presence/absence data in table 28, and together they form the baseline for an interpretation of the charred seed assemblages. Absolute counts are usually considered to be too strongly affected by taphonomy and are notorious for introducing a spurious sense of accuracy to the data, while presence analysis disregards the actual frequency of a taxon. Instead, it provides an indication of ubiquity, the number of samples in which the taxon occurs within a group of samples (Popper 1988). One critical feature of this statistic is that it is only valid for comparing the presence of a particular taxon between zones or sites and not for drawing comparisons between classes of seeds found at a site. Ubiquity in-

dices are provided here to examine the changing presence of particular seed types within the three stratigraphic zones at Khok Phanom Di, and to provide comparisons with future analyses.

Alternative methods of data presentation such as ranking are inappropriate for analysing these assemblages as the samples do not meet the prerequisites of good preservation and high seed frequency (Popper 1988). Furthermore, there is inadequate information on seed productivity for the taxa examined here.

TABLE 30: *Ubiquity indices for seed classes found in the charred seed assemblage and the three major stratigraphic divisions (per cent of contexts in which the seed type occurs)*

	All contexts n=46	Zones A n=22	B n=21	C n=3
Fimbristylis-type	2	-	5	-
Eleocharis-type	46	41	57	-
Schoenoplectus-type	30	41	24	-
cf. Cyperaceae endosperm, type A	74	72	81	33
cf. Cyperaceae endosperm, type B	22	9	40	-
Combined Cyperaceae	87	91	90	33
Gramineae-type A (cf. Paniceae)	22	27	10	66
Indeterminate Gramineae	17	23	5	33
Suaeda maritima Dum.	50	68	40	-
Trianthema portulacastrum L.	4	9	-	-
Portulaca cf. *oleracea*	7	-	5	66
Amaranthus sp.	28	14	33	100
cf. *Amaranthus*-type	2	5	-	-
cf. *Sida* sp.	2	2	-	-
Unknown, Type 1	2	14	-	-
Combined Indeterminate	85	77	90	100

Pollen and seed data

In some instances the seed identifications extend the information available from the pollen data. While it is virtually impossible to distinguish between pollen types in Chenopodiaceae at the generic level using conventional light microscopy (Caratini *et al.* 1973) and many palynologists prefer to group Chenopodiaceae and Amaranthaceae together, their seeds can be identified with greater taxonomic precision and confidence. Little potential economic information is lost by amalgamating the two families, as the herbs have similar uses (Cummings 1989), but the ability to distinguish between the seeds is useful in ecological interpretation, especially in a tropical lowland/coastal environment where *Suaeda*, *Chenopodium* and *Amaranthus* grow in different habitats.

With the Cyperaceae, pollen can be identified to a more refined level than the charred achenes described here. This is due in part to the careful taxonomic work on sedge pollen by Maloney (1991), who has taken the determinations further than usual during his investigations at Khok Phanom Di, and also due to the generally poor and incomplete state of preservation among the charred macroremains. In the analysis of pollen from cores taken around the site, six genera in the Cyperaceae have been noted: *Carex* comp., *Cyperus* comp., *Eleocharis*, *Fimbristylis* comp., *Scirpus* comp., *Rhynchospora* sim., and a further group of undifferentiated Cyperaceae (Maloney 1991). With the achenes, moderately confident determinations are made for *Eleocharis*-type and *Schoenoplectus*-type (= *Scirpus*-type) and the single example of a charred *Fimbristylis* nutlet. Most of the Cyperaceae-type remains are incomplete specimens where the endosperm has been stripped of the diagnostic outer testa. These have been identified through comparison with the contents of whole but broken *Eleocharis*-type and *Schoenoplectus*-type specimens and their identifications are regarded as questionable.

Modern pollen traps have shown that the Cyperaceae as a whole are less well represented in the pollen record than in the actual vegetation of back mangroves (Caratini *et al.* 1973, Somboon 1990). Thus, while the Khok Phanom Di pollen record has relatively few Cyperaceae types at low frequencies, sedges are prominent in the charred seed assemblage from the archaeological site. The seeds and pollen together indicate the presence of herbaceous wetlands in the region around the site during and prior to the prehistoric occupation of the mound.

Habitats indicated by the identified seeds

Mangrove forest is dominated by arboreal plants, with very little shrubby undergrowth and virtually no herb layer. The taxa which might have contributed to the seed rain at Khok Phanom Di are restricted to secondary communities or disturbed, degraded mangrove areas, to herbaceous swamps and to the saltflats at the landward edge of the mangal. The charred seed samples are dominated, in terms of ubiquity, by members of the Cyperaceae and, in terms of absolute frequency, by *Suaeda maritima*, the former being glycophytes and the latter a halophyte. Together they indicate the past presence of two distinct herbaceous communities close to the mound: brackish to freshwater swamps and flat, open, saline plains behind the mangrove. Across these lowlying coastal plains the distribution of vegetation types is under strong hydrologic control, which is in turn linked to topography (Murata and Matsumoto 1974). Thus the presence of seeds from a group of plants with similar ecological requirements not only indicates particular floral communities but, by association, also provides indications of landforms and hydrology. The specimens which have survived for examination are probably only the most robust types from, and only a small proportion of, the original seed rain in the area, so are considered here as indicators of wider plant communities.

The seeds of *Suaeda maritima* and *Trianthema portulacastrum* (= *Sesuvium portulacastrum*) were produced by members of saltmarsh communities. These plants grow today on the open, hypersaline plains in the upper intertidal zone, landward of the mangrove and on the beach ridges interdigitating with mudflats around the Gulf of Thailand (Fig. 16). Both halophytes, these taxa are limited to saline conditions and will not grow in non-saline soil (Chapman 1947), so are effective indicators for palaeoenvironmental reconstruction. At the landward fringe to the mangrove, *T. portulacastrum* is found as an understorey beneath *Avicennia marina* in open parkland (Macnae 1968), but *Suaeda maritima* is not shade-tolerant (Chapman 1947), and is restricted to open plains. The presence of these taxa points to salt in the soil rather than to saline groundwater, which is

better represented by the distribution of the fern *Acrostichum* spp. (Takaya 1987). Floristically sparse and with patchy plant cover, the saltflat flora is usually restricted to salt-tolerant members of the Aizoaceae, Chenopodiaceae and Poaceae (Hutchings and Saenger 1987). In Thailand, these comprise the succulent halophytes *Trianthema portulacastrum* (Aizoaceae), *Suaeda maritima* (Chenopodiaceae) mentioned above and salt-tolerant grasses like *Diplachne fusca*, *Sporolobus virginicus* and *Paspalum vaginatum* (Bor 1962, Macnae 1968, Lazarides 1980).

These areas then, are relatively bare fringes at the highwater-mark, intermittently inundated by extreme tides, and other areas lying behind the mangrove proper. The vegetation of the salt flats is uniformly low and the topography flat. Halophytic herbs are the sole lifeform across most of this open, shadeless country, which is so desiccated in the dry season that much of the area is devoid of vegetation (Macnae 1968, Grindrod 1985). As soil salinity declines inland with slightly higher altitudes and close to watercourses, the depauperate saltflat flora grades into more diverse plant communities. In the drier conditions at the margins of saline flats and along the banks of brackish swamps, the modern herbaceous flora includes *Wedelia biflora* and *Pluchea indica* (Compositae), *Synostemon bacciformis* (Euphorbiaceae), *Amaranthus* spp. (Amaranthaceae), with some *Indigofera hirsuta* (Leguminosae) and the grasses *Aeluropus lagopoides*, *Spinifex littoreus* and *Zoysia matrella* (Bor 1962, Lazarides 1980, McMakin 1988). One of the sedges with a wide distribution through Thai mangroves, backswamps and less saline soils is *Bulbostylis barbata* (Henderson 1954, Caratini *et al.*1973, Smitinand 1980).

The second major group of 'seed' remains comprises the achenes or nutlets of Cyperaceae, produced by perennial or annual grass-like herbaceous plants usually growing in shallow fresh to brackish swamps and at the margins of seasonal pools or streams. Here, hydrological conditions are radically different from those of the salt flats, especially during and after the monsoon, when precipitation and increased stream discharge combine to flood much of the lowlying area just inland of the saltflats. This freshwater flushes out salts which have been lifted through the soil profile by dry season evaporation.

These low-lying areas provide temporary bodies of shallow water where annual sedges flourish along with the halophytic grasses *Paspalum distichum* and *Panicum repens* (Lazarides 1980). Some annuals have specific physiological requirements or tolerances. For example, in the area of annual herbs to the east of the Chao Phraya River, the sedge *Scleria poaformis* marks the zone of acid sulphate soils (Takaya 1987), while closer to the coast clear freshwater pools on acid soils are marked by the acidophilous *Utricularia*, *Blyxa*, *Najas*, *Hydrilla*, *Eleocharis* and *Eriocaulon* (Murata and Matsumoto 1974).

The macrofossil remains from Khok Phanom Di include examples of *Eleocharis* and *Schoenoplectus* (= *Scirpus*), two of the most common wetland plants from the shallow perennial swamps (Takaya and Thiramongkol 1982). The present distribution of *Scirpus grossus* in particular, coincides with permanently swampy conditions. These sedges are often accompanied by *Xyris*, *Nymphaea*, *Nelumbo*, *Ottelia*, *Trapa*, *Hydrilla* and occasionally, the paperbark trees *Melaleuca leucadendra* (Vidal 1979). This tree marks freshwater swamplands and is known to have been more extensive in the recent past (Takaya 1987). Other hydrophytic perennials in this permanently flooded area are *Monochoria*, *Aneilema*, *Typha*, *Juncus*, *Cyperus*, *Cladium*, *Scleria*, *Fimbristylis*, *Hydrocera*, *Aeschynomene*, *Sesbania*, *Ammannia*, *Rotala*, *Gratiola*, *Lindernia* and *Torenia* (Murata and Matsumoto 1974). The effects of seasonal flooding are weak in this area as the soil is permanently wet. In addition to the rooted aquatic herbaceous vegetation mentioned above, are

floating plants (pleustophytes). Examples include *Azolla*, *Salvinia*, *Eichhornia* and *Utricularia* (Vidal 1979). The remaining identified seed types in the Khok Phanom Di flot samples are *Amaranthus* sp., cf. *Sida* sp. and *Portulaca* cf. *oleracea*, all widespread in places disturbed by human activity. These and other weedy annuals may have been growing within the settlement or quickly colonized parts of the site during times of temporary abandonment.

Plants as resources

Some of the taxa in the archaeological assemblage grow in the vicinity of the site today as arable weeds. *Fimbristylis* sp., for example, has a wide tolerance of flooding, being found in deepwater- as well as shallow-flooded rice (Moody 1989), but it is not an obligate segetal. Indeed, it is equally likely to be found growing in natural ephemeral freshwater conditions or, rarely, along sandy coasts and on cheniers (Grindrod 1985, van Steenis and Veldkamp 1987).

The charred seed assemblage as a whole is ambivalent about the prehistoric practice of agriculture in the area. The seeds identified are possibly but not necessarily from arable land and could equally have been produced by plants growing at the edge of natural freshwater wetlands. Their existence nevertheless affirms the kind of hydrological and topographic situations where lowland swamp riziculture could have been undertaken. Charred rice husks and silica skeletons were found in abundance in the prehistoric deposits at Khok Phanom Di, but this important economic plant is not represented among the charred plant remains as charred grain. Fragments of charcoal and other burnt plant materials in the size range of charred rice caryopses were retrieved by the flotation system, so their absence is not likely to be due to biased recovery techniques. The remains of rice and taphonomic factors influencing its preservation are described in chapters VI and VII.

There are no charred macroscopic remains capable of supporting the supposition of Maloney and Brown (1990) that 'millets' were being grown in the neighbourhood of Khok Phanom Di in later prehistory. Some of the charred grass caryopses are probably in the Paniceae, but none of these is within the size range of cultivated millets like *Echinochloa crus-galli* (cf. Crawford 1983).

Although no cultivars were found except rice, and none of the seeds recovered are considered likely to be food debris, it is conceivable that some may represent gathered wild resouces where plant parts other than the seed, the tender leaves or seedlings perhaps, were consumed. The consumption of palatable young leaves from annual herbs (quelites) may make a significant, albeit seasonal, contribution to the diet (Bye 1981). For example, *Suaeda maritima* leaves are reported as being eaten as a vegetable in Indonesia and India (Backer 1954, Burkill 1966, Singh and Arora 1978). Parallel uses are cited for *Portulaca oleracea* (Geesink 1975, 1976) and *Trianthema portulacastrum* (Weber 1991), and the leaves and sometimes the stems of several species of *Amaranthus* are also rainy-season foods throughout the lowlands of South and South-East Asia (Smitinand and Scheible 1966, Lugod and de Padua 1979, Westphal and Jansen 1989, Jacquat and Bertossa 1990). *Amaranthus* leaves are reputed to be good sources of iron (Singh and Arora 1978) and protein (National Academy of Sciences 1975) and their derivatives also have a variety of medical applications (Burkill 1966, Dastur 1985). It is the youngest, non-lignified leaves and stem tips which may be eaten, raw or lightly steamed. In Thailand, where they are greatly relished, they are often accompanied by the spicy sauce *naam prik*. Uncultivated edible greens are widely traded in Thai markets and gathered for home-consumption, but despite their current culinary popularity, their use would probably have low archaeological visibility.

Cyperaceae achenes are possible by-products of foodplants, though here, it is the carbohydrate-rich corm, of *Eleocharis* and *Cyperus* for example, which is eaten raw, boiled or after being roasted on hot coals (Smitinand and Scheible 1966, Phengkhlai and Khamsai 1985, Russell-Smith 1985, Jacquat and Bertossa 1990, Smith 1991). The evidence for plant use is tenuous. The presence of plants which may in some instances provide food or some other useful raw material is no proof that they were actually used in that way by the prehistoric people at Khok Phanom Di. However, the occurrence of the plant remains at the site allows hypotheses to be formulated which may be tested by cross comparison with other data, such as the analysis of coprolites or the chemical composition of human bone.

Comparisons between phases

If the seed remains are combined into three groups representing saltflats, freshwater marshes and dryland habitats, it is apparent that their occurrence follows the general change from a mangrove/saltflat environment to an inland situation with temporary freshwater pools, which has already been demonstrated by the charcoal and other lines of evidence. The halophytic taxa are more prominent, in terms of frequency as well as ubiquity, during zone A, although the seeds of *Suaeda maritima* occur in very small numbers as late in the stratigraphy as layer 4. This is at a time when the site was considered to have become removed from the coast, suggesting that the seeds arrived by cultural rather than by natural means, the plants having been brought to the site for some specific purpose. The presence of Cyperaceae achenes throughout the flot samples attests to the presence of swamps in proximity to the site throughout the time of occupation. The resource potential of such areas will be explored in chapter VIII.

TABLE 31: *Dimensions for unidentified Type xi seeds*

Context	Length	Width	Thickness	Preservation
9:2	0.60	0.45	0.45	2
9:6	0.60	0.50	0.50	1
9:6	0.50	0.50	0.50	1
9:6	0.60	0.50	0.50	4
9:6	0.55	0.50	0.50	4

Distortion for all specimens = 1

MISCELLANEOUS BOTANICAL FINDS

White fibres found in close association with the skeletons in a number of graves at Khok Phanom Di are considered to be the remains of *tapa* or beaten barkcloth (Higham *et al.* 1987:152, Bannanurag 1989:39). The burials in which these fibres occurred spanned the entire mortuary sequence, comprising graves numbered 151, 144, 142, 140, 139, 136, 130-4, 125-6, 117, 114, 112, 110, 107, 102, 90, 64, 57, 54, 40, 38, 33 and 19. For illustrations of these burials see Higham and Bannanurag

(1990a). A further suggestion that the bodies were bound in perishable materials prior to interment is that the bones of the upper arms were sometimes found unnaturally close to the upper torso, for example in burial 129 (Higham and Bannanurag 1990a). In some but not all cases, the *tapa* was accompanied by red ochre, and comprised part of an elaborate yet variable burial ritual with shell and stone jewellery, turtle carapace, ceramic vessels and pottery-making tools also being placed in the grave (Bannanurag 1990). The fibres sometimes ran over the ceramic grave goods, as in burial 130, suggesting to Higham and Bannanurag (1990a) that the body and its accompaniments were bound together before being placed in the grave. Remnants of similar material were also found attached to one of the human skeletons (burial 11) from the 1979 excavation. No such evidence was recorded during the 1982 investigations (Bannanurag 1989).

Tapa: production and product

Tapa is a non-woven felted material prepared from bast fibres of the inner bark of certain trees. These are the longest and strongest of all plant fibres. The tradition of producing beaten fabrics persists throughout the Pacific and especially in Polynesia, where the raw materials are derived mainly from trees in the Moraceae. *Antiaris toxicaria*, *Artocarpus blumei*, *A. communis* and *Ficus* spp. are commonly used, and especially fine and pliable products are made from the bark of *Broussonetia papyrifera*. The cloth may be decorated with brown, black and red dyes derived from various plant products, including the bark of *Aleurites moluccana*, *Bischofia javanica*, *Casuarina equisetifolia*, *Ficus* sp. and *Rhizophora mangle*, the roots of *Curcuma viridiflora*, the seeds of *Aleurites moluccana* and the fruit of *Piper* sp. (Bell 1988, Kooijman 1988, Aragon 1990). Alternative sources of bast fibres for *tapa* manufacture in the Pacific are *Entada phaseoloides*, *Morus alba*, *Pipturus* sp., *Neaudia melastomaefolia*, *Rubus* spp., *Pisonia* sp. and the strand or mangrove associates *Hibiscus tiliaceus* and *Thespesia populnea* (Hotta 1962, Kooijman 1972). These last two grow in the Bang Pakong estuary today, are well represented in the backswamps to Thai mangrove and were most probably present in the prehistoric neighbourhood to Khok Phanom Di, although their remains have not been positively identified at the generic level in either the charcoal or pollen assemblages (see chapter IV on the charcoal data and Maloney 1991).

Tapa is produced by peeling bark from the plant, scraping the inner and outer layers apart using a knife or shell, followed by extended soaking of the inner bast fibres to improve their workability and remove impurities. Protracted pounding between special beaters and a board or anvil spreads and laminates the bark into fine sheets which may be sewn or beaten together and decorated at a later stage.

The trees currently in use for barkcloth production in the Pacific are indigenous to East Asia, which some consider to be the origin of its manufacture and the source of the skills, the raw products and the migrants bringing *tapa* from mainland and island South-East Asia to the Pacific islands in the second millennium BC (e.g. Kooijman 1972). Archaeological evidence is patchy and undoubtedly under-represents the fabric's history. *Tapa* is made both from and with plant products. The raw materials and most of the main tools used in production are derived from ephemeral organic items. The use of grooved wooden beaters and beating boards fashioned from dense timbers like *Casuarina*, and stencils cut from the leaves of banana or *Barringtonia asiatica* (Kooijman 1979) means that the manufacture of beaten barkcloth would, under most circumstances, have low archaeological visibility, but stone beaters were sometimes employed, and stone or shell knives could potentially point to the extraction of bast fibres. In stone-poor and timber-rich areas the

process might remain elusive while the use of *tapa* beyond the production site would be virtually impossible to detect.

None of the lithics from Khok Phanom Di have been interpreted as having an association with *tapa* production (Pisnupong 1993). The worked shell collection from the site was examined for use-wear, with the cutting of finished barkcloth rather than its production in mind (Higham 1993). The gloss and striations on the archaeological tools are definitely not similar to those created by experimental cutting of *tapa* and as they closely match those produced by reaping rice, their hypothetical use for scraping bark is no longer an issue. There is a further possibility, that a distinct chemical signature might be revealed in ceramic vessels used for retting and fermenting fibres or for preparing dyes, although there are no investigations of this to date (pers. comm. B. Fankhauser). The presence of stone bark beaters in a number of South-East Asian prehistoric sites suggests the antiquity of barkcloth in the region, but the remains of *tapa* itself from archaeological contexts are, not surprisingly, extremely rare. A fragment is reported from 2000 BC contexts at Huaca Prieta in north coastal Peru (Bell 1988), presumably preserved through desiccation. Stone beaters with grooved surfaces, thought to be implements for *tapa* manufacture, date to the third millennium BC in Taiwan (Chang 1970 citing Chang 1954a), the second millennium BC in the Philippines (Tolstoy 1963) and to the same timeframe in peninsular Malaysia (Sieveking 1956, Dunn 1971), where the finds at Jendaram Hilir (Leong 1990) are in a chronological and cultural context (cord-marked pottery and tripod pots) not dissimilar to those of Khok Phanom Di.

Prehistoric sites in the lower Bang Pakong valley fall, then, within the geographical area and time period when beaten barkcloth could most certainly have been produced, or received through trade. As noted on page 32, a number of plants from the mangrove and associated plant communities are used for fabric or cord production, with *Hibiscus tiliaceus* the prime source of bast fibres in the region, being exploited wherever it grows, including the coastal regions of Thailand (Burkill 1966, Phengklai and Khamsai 1985). A similar but inferior cordage is made from *Thespesia populnea*. In peninsular Malaysia the bark of *Hibiscus tiliaceus* is stripped, spread out on the ground for a day or two to dry, then the fibre is separated from the useless outer layer and twisted, or plaited into a rope (Burkill 1966:1192, paraphrasing Watson 1913). It is said that steeping improves the quality of the end-product, which is more often cordage than fabric, and commonly used in fishing lines, nets and traps. Other members of the coastal flora with documented fibre-making uses are *Dolichandrone spathacea*, *Ficus* spp., the seagrass *Enhalus acoroides* (Burkill 1966) and species of the climber *Derris* (Foxworthy 1922).

Records of barkcloth production in mainland South-East Asia include brief references to the use of *tapa* for clothing by highland agricultural people in central Vietnam (Colani 1936) and the use of barkcloth by the indigenous groups of peninsular Malaysia, the Sakai, Semang and the Jakun (Skeat and Blagden 1906). The trees exploited are the wild breadfruit, *Artocarpus* spp., *Antiaris toxicaria* and various *Ficus* species. In peninsular Malaysia the bark is made supple by minimum preparation, either by pounding between stones or by the combination of a wooden mallet, preferably heavy palm wood, and a tree trunk. Barkcloth production from *Antiaris toxicaria* in particular, is a protracted process as the raw material is leached to remove toxins by immersion in running water for as long as a month, prior to being beaten. There are also ethnohistorical records among the Semang people of Kedah, where unbeaten strips of leached and dried bark are worn as loincloths (Skeat and Blagden 1906).

Given Khok Phanom Di's access to herbaceous swampland and inland forest as well as to mangroves, further possibilities should be considered. Fibre plants from Thailand are outlined by Phengkhlai and Khamsai (1985), with an assortment of uses ranging from string, cordage, ropes, sacks, hats and fish traps to paper pulp. These products might, in modified form, have been used to furnish a shroud or winding cloth. Their list includes the following native trees, shrubs, woody herbs and climbers with central and lowland Thai distributions, many of which were collected in the vicinity of the site today: *Abelmoschus moschatus*, *Abroma augustifolia*, *Abutilon indicum*, *Alchornea rugosa*, *Antiara toxicaria*, *Aquilaria crassna*, *Artocarpus elastica* (peninsular distribution), *A. lakoocha*, *Bauhinia bracteata*, *B. integrifolia*, *B. racemosa*, *Bombax ceiba*, *Broussonetia papyrifera*, *Careya sphaerica*, *Corchorus capsularis*, *Cordia dichotoma*, *Crotalaria juncea*, *Cyperus* spp., *Derris scandens*, *Ficus auriculata*, *F. bengalensis*, *F. benjamina*, *F. hispida*, *Flagellaria indica*, *Hibiscus macrophyllus*, *Holoptelea integrifolia*, *Lannea coromandelica*, *Litsea glutinosa*, *Lygodium* spp., *Melia azedarach* (= *Azadirachta indica*), *Morinda umbellata* (peninsular distribution), *Musa* spp., *Nepenthes* spp., *Pentapetes phoenicea*, *Pterocymbium javanicum*, *Schumannianthus dichotomus* and *Sterculia coccinea* (peninsular distribution).

The fibre plants with peninsular distributions are listed as they include taxa like *Artocarpus* sp. which has been identified in the Khok Phanom Di pollen record (Maloney 1991). Given the fact that the unknown fibres were found from the lowest phase of the site onwards, up to and including burial 19 which was interred in the mortuary platform in late zone B, and that local conditions were demonstrably estuarine and mangal during the first centuries of occupation at Khok Phanom Di, it seems most likely that if the fibres were part of a locally-produced plant-based commodity, they would have come from one of the mangrove or mangrove-associate trees. The lists of taxa set out above, provide an indication of the broad range of reference materials with which archaeological plant remains from possible beaten barkcloth could be compared, but in the context, *Hibiscus tiliaceus*, *Thespesia populnea* and other plants with coastal distributions would seem to be the most likely contenders.

The archaeological fibres

Samples of the white fibres were examined by a number of specialists, but the results are inconclusive and conflicting. Maloney analysed soil from immediately beneath some of the fibres from burial 149 and found large numbers of phytoliths, some of which were tentatively identified as the grass *Echinochloa*, with others possibly from the Compositae, Cyperaceae and Commelinaceae, as well as amorphous grass pollen (Maloney 1986, 1988, Maloney and Brown 1990, Maloney and Rovner 1991).

Another sample was submitted to the Royal Botanic Gardens, Kew (London) and the material described as 'groups of fibres with short chains of thinner-walled cells adhering to them in places' which could not be matched to any reference material (pers. comm. T. Lawrence). The possibility of the material being from a monocotyledon could not be excluded, however. The representativeness of this particular sample is unknown, as it was submitted shortly after the excavation and before other examples were examined, when the variability in materials from different contexts was unknown.

As part of this study, examples of the white fibres from four burials and two pits were examined by SEM (x70-x1,000) and compared with samples of *Artocarpus* sp. *tapa* from Fatu Hiva, Marquesas Islands, (courtesy of P. Bellwood) and other fabrics from Fiji and Tikopia considered

most probably to have been made from *Broussonetia* sp. (pers. comm. D. Roe) (Fig. 20:5). The archaeological specimens in question were from burials 117, 125, 136 and 151, and 10:7 feature 29 and 10:15 feature 23, both in quadrant C.

The archaeological samples fell into two categories. First, the material from burials 125, 151 and 136 and from 10:7 feature 29 all comprised numerous, long, fine fibres of even diameter (Fig. 20:3). None of these matched the modern examples in any respect. Their fibre diameters, at 5 microns, were consistently smaller and far less variable than those of the modern *tapas*, with a range of 10–23 microns. Moreover, their straight parallel form was far more regular than the curves and twists in the modern specimens (Fig. 20:5-6). Results from EDAX of carbon-coated specimens indicated a prominent peak of silicon for these filament-like fibres, suggesting that they might include phytoliths, whereas those from the modern *tapa* specimens had more diverse chemical profiles, perhaps because they had absorbed pigments and oils (Erhardt and Firnhaber 1987).

The second type of archaeological fibre was from burial 117 where the fibres were not finely filiform and had notch-like projections along their length. The diameter of these fibres lies within the range of the modern *tapa* specimens. Another example was from the pit, feature 23 in 10:15 (Fig. 20:4). This sample resembled plant fibres, but further investigation with an extended reference collection would be needed to pursue this.

The preliminary observations noted here are unable to confirm or reject the hypothesis that a beaten barkcloth was used to wrap the bodies interred at Khok Phanom Di. The majority of the small number of specimens examined were clearly not *tapa*. This is probably the type which has subsequently been identified as asbestos fibres, on morphological grounds and the fact that they did not burn (Aranyanak 1991), but a contradictory report stating that fibres from burial 151 were definitely not asbestos was received from an authority in New Zealand (pers. comm. K. Wellington). The second group mentioned, with closer resemblance to modern *tapas*, points to the need in any further work to examine a larger number of examples to establish the range of variation in the archaeological material and to have access to a more extensive reference collection including plant products indicated by the ethnobotanical data reviewed above. Strictly speaking, the identification of fabrics and bast fibres should be straightforward using polarized light (Körber-Grohne 1991a, and 1991b), if preservation of the archaeological specimens is good. However, the combination of freeze fracture with SEM examination including backscattered imaging has recently been shown to provide more information on the interior of archaeological fibres (Angel and Jakes 1990) and such techniques might aid future investigation of the Khok Phanom Di remains.

UNIDENTIFIED SEED TYPES

Type i. Two transversely broadly elliptic seeds from 10:20. Rounded margin. Preservation poor: approximately 20 per cent of the margin has been broken away. Cross section transversely narrowly elliptic. Dimensions 0.75 x 0.90 x 0.50 and 0.60 x 0.75 x 0.20 mm.

Type ii. A single broadly elliptic (barrel-shaped) seed found in 6:6 lens 9. Cross section circular. Dimensions: 1.30 x 0.60 x 0.60 mm.

Type iii. Occurrence, 2:1. A single, well preserved seed with a broad, upstanding ridge along the ?ventral surface. Obovate in longitudinal section and triangular in cross section. Dimensions: 1.30 x 1.00 x 1.10 mm.

Type iv. Also found in 2:1, this single, well-preserved seed is ovate in outline, having one pointed and one rounded end. A fine ridge runs from the pointed end along approximately one third of the ?ventral surface, where there is a small elliptic depression. Cross section is transversely broadly ovate at the rounded end and tapers toward the pointed end because of the ventral ridge. Dimensions: 1.30 x 0.70 x 0.70 mm.

Type v. Narrowly elongate ?seed, tapering to the distal end. Cross section sub-circular. Slightly reticulate surface, but the pattern is not regular. Some of the striations run parallel to the long axis. Dimensions: 1.5 x 0.40 x 0.40 mm. Found in the flot sample from 2:3. This is morphologically similar to but larger than the seeds of *Typha angustifolia*, which also differ from this specimen by having a clearly longitudinally reticulate surface.

Type vi. A singular seed found in 2:3, triangular in shape, curved in profile, having an elliptic cross section towards the base of the triangle and tapering in thickness to the apex. Dimensions: 0.80 x 0.60 x 0.25 mm.

Type vii. A single flat endosperm with mottled surface, possibly a distorted or fragmented example of a cf. Cyperaceae endosperm. Occurrence in 10:20. Dimensions: 0.94 x 0.90 x 0.30 mm.

Type viii. Two circular ?seeds, one more globular than the other, having a rough surface. Dimensions: (10:5) 0.55 x 0.55 x 0.40 mm and (10:18) 0.55 x 0.55 x 0.55 mm.

Type ix. A single broadly ovate seed found in 7:7, having convex depressions on both surfaces. Elliptic cross section at broadest end, tapering to the other end. Dimensions: 0.75 x 0.70 x 0.40 mm. The general morphology resembles *Eleusine coracana* illustrated by Musil (1963: Pl.XXVI.138), but this is a native of India.

Type x. A single tiny flat disc, found in 10:7, diameter 0.45 mm and thickness less than 0.05 mm.

Type xi. Barrel shaped seeds, broadly elliptic with truncate ends, one of which has a clear circular scar; cross section circular; some slight longitudinal surface patterning.

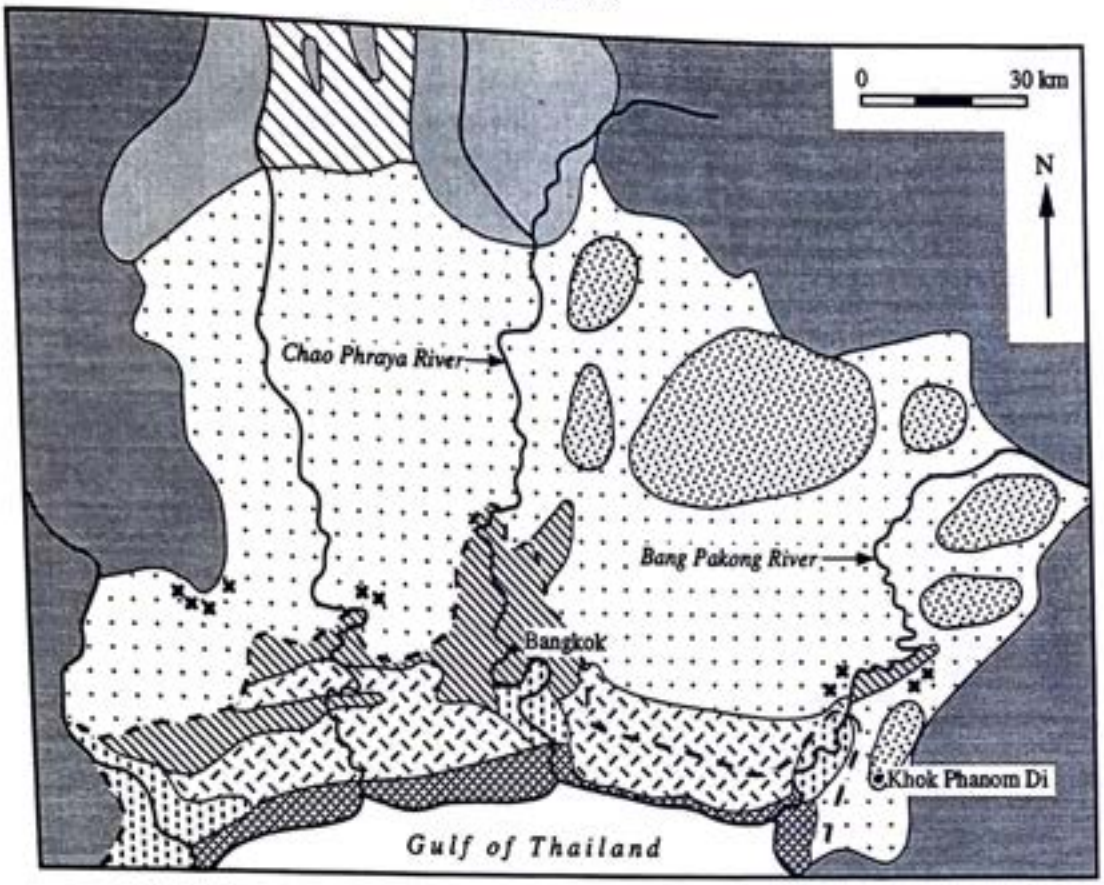
Type xii. A singular, ovate seed with circular cross section and longitudinal section ovate. Some longitudinal striae on the surface at the proximal end. Provenance: 4:1. Dimensions: 0.75 x 0.50 x 0.50 mm.

Type xiii. A single, rectangular seed from 3:1, the longitudinal section is a rounded rectangle and cross section is elliptic. Dimensions: 0.95 x 0.60 x 0.40 mm.

Type xiv. Transversely broadly elliptic cotyledons with asymmetrical, very broadly ovate cross section. Proximal end has small circular scar (diameter 0.2 mm); dorsal surface convex; ventral surface more strongly curved. Provenance 10:20. Dimensions: 0.75 x 0.75 x 0.60 mm.

Type xv. A single, large, rounded ?seed, broadly elliptic in longitudinal section and transversely broadly elliptic cross section. Parallel-sided with truncate ends. Preservation fair, with some pitting on the dorsal surface and possibly some bulging. Part of one end is missing. Found in 10:5. Dimensions: 1.25 x 1.05 x 0.90 mm. Similar to this, but larger, more

rounded and with an ovate rather than a plano-convex cross section, is a specimen from 2:3 measuring 1.0 x 0.95 x 0.65 mm. This could possibly be a member of the Carophyllaceae, but is neither *Agrostemma githago*, which is too large at 3.0 x 2.5 x 1.7 mm according to Martin and Barkley (1961:155), nor *Silene* sp., which has disc-like seeds (0.5 x 1.5 mm) (Martin and Barkley 1961:156), as illustrated in Winton and Winton (1932:332). Other possibilities are *Silene burmanica*, which is confined to northern Thailand, and *Stellaria media*, which has a cosmopolitan distribution through the region today but is probably not native (Larsen 1963:61). *S. paniculata* is an upland plant (Larsen 1963:62), so is also unlikely on biogeographical grounds.



Nipa and mangrove

Eleocharis sp. *(phong kratium)*.....Perennially wet

Fruit and vegetable growing area

Coconut plantation

Limit of *Acrostichum aureum (piyo)*.....Limit of saltwater incursion

Pluchea indica (nat).....Saline soil

Predominantly annual herbs with *Scleria poaeformis (ton pru)*.....Sulphate acidity

Predominantly annual herbs

Floating rice with occasional *Mitragyne* sp. *(krathom)*

Paddy fields with termite mounds and house compounds with fruit trees

Rice fields and *Dipterocarpus* open forest

FIG. 16. Vegetation zones in the Chao Phraya Delta (redrawn from Takaya 1987:154)

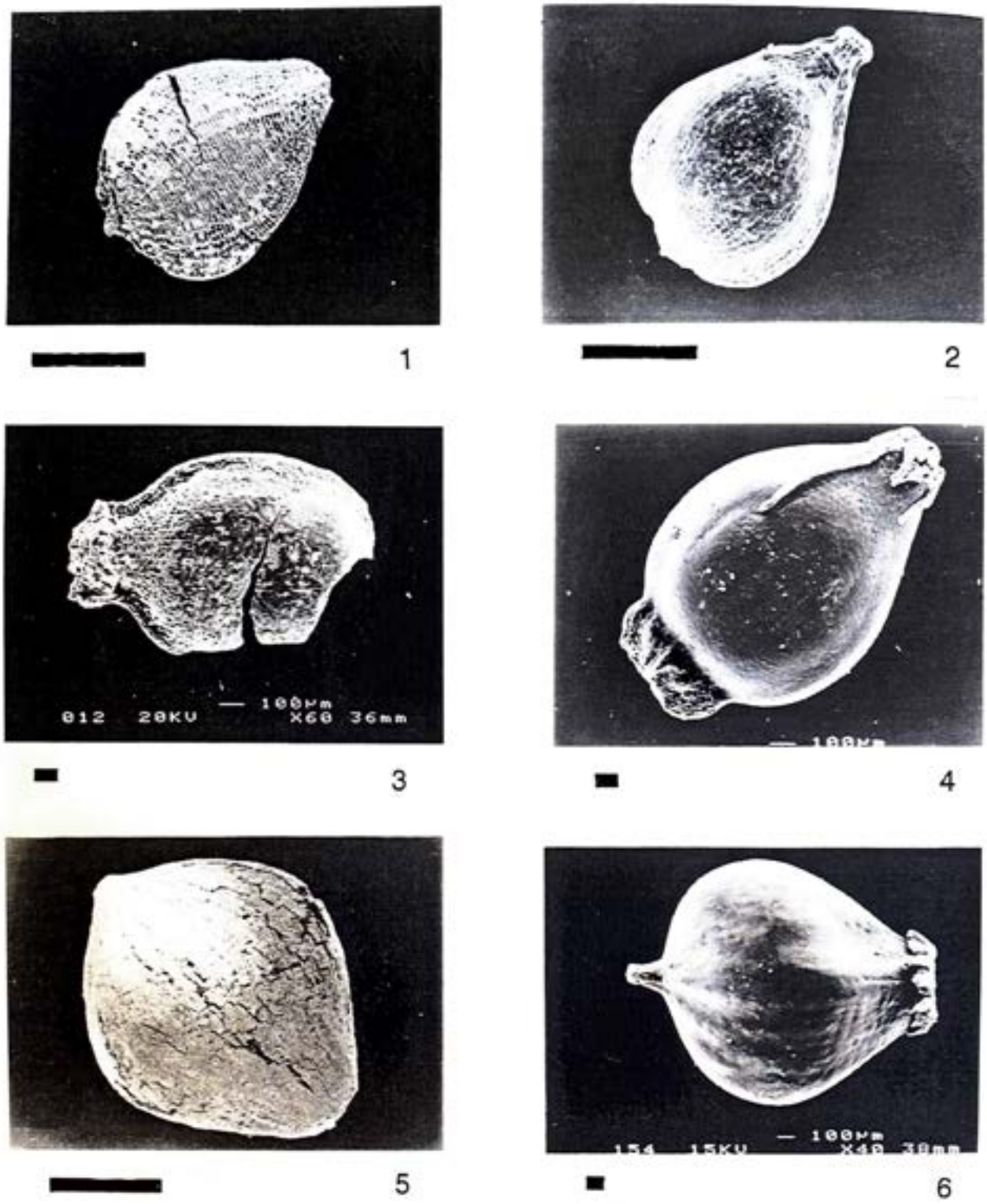


FIG. 17. Archaeological seeds and examples from the reference collection
1. *Fimbristylis*-type achene from 8:7 lens 12, scale 500 microns **2.** Modern charred achene of *Fimbristylis dichotoma*, scale 500 microns **3.** *Eleocharis*-type testa from context 8:5, scale 100 microns **4.** Modern charred achene of *Eleocharis dulcis*, scale 100 microns **5.** *Schoenoplectus*-type achene from 10:19, scale 500 microns **6.** Modern charred achene of *Schoenoplectus mucronatus*, scale 100 microns

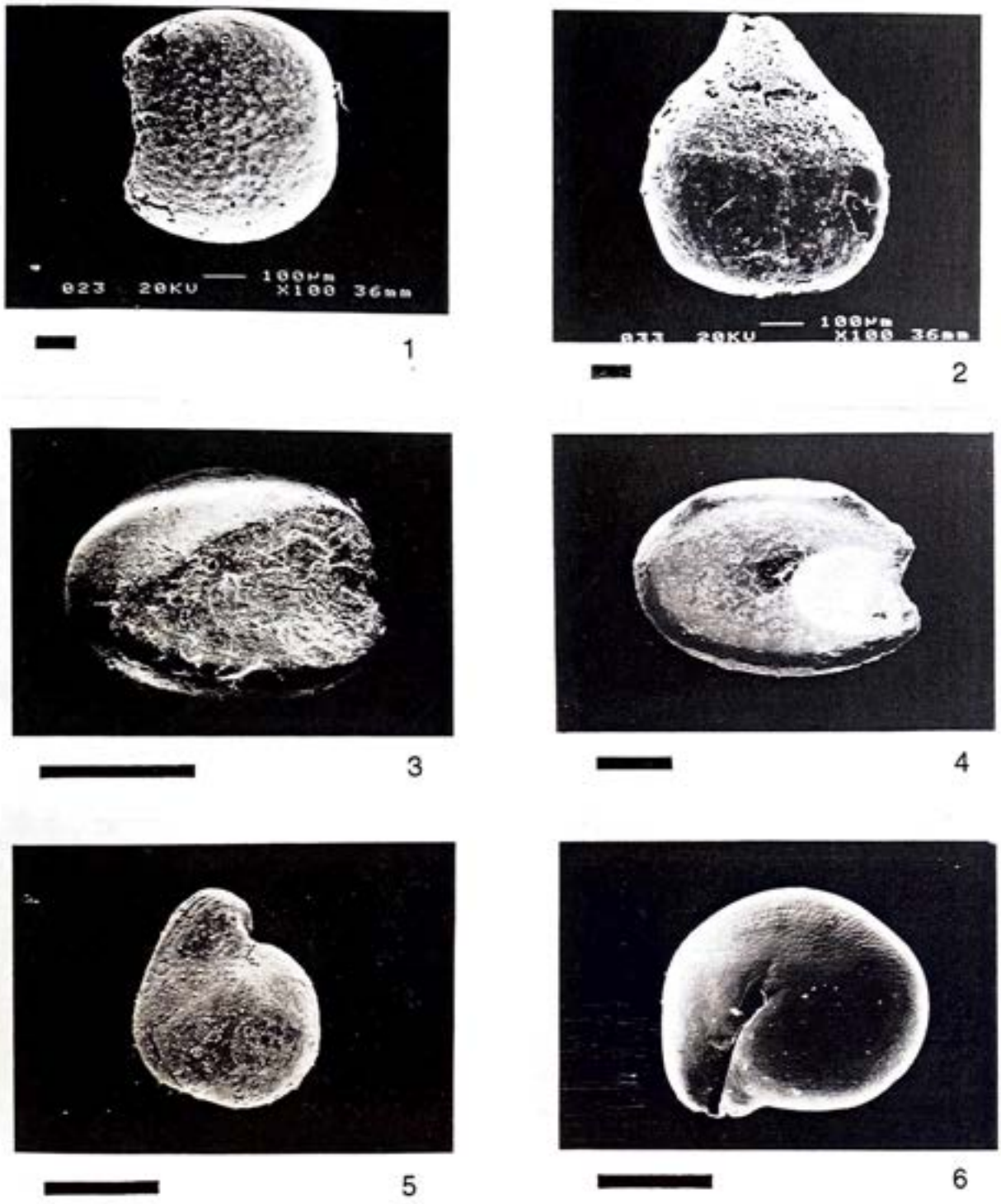


FIG. 18. Endosperm of Cyperaceae, Indeterminate Gramineae and *Suaeda maritima* seeds
1. cf. Cyperaceae endosperm type A, 8:7 lens 12, scale 100 microns **2.** cf. Cyperaceae endosperm type B, 8:7 lens 12, scale 100 microns **3.** Indeterminate Gramineae caryopsis, type A (cf. Paniceae), layer 2:1, scale 500 microns **4.** Indeterminate Gramineae caryopsis, layer 2:1, scale 200 microns **5.** *Suaeda maritima* seed from layer 10:19, scale 500 microns **6.** Modern, charred *Suaeda maritima* seed, scale 500 microns

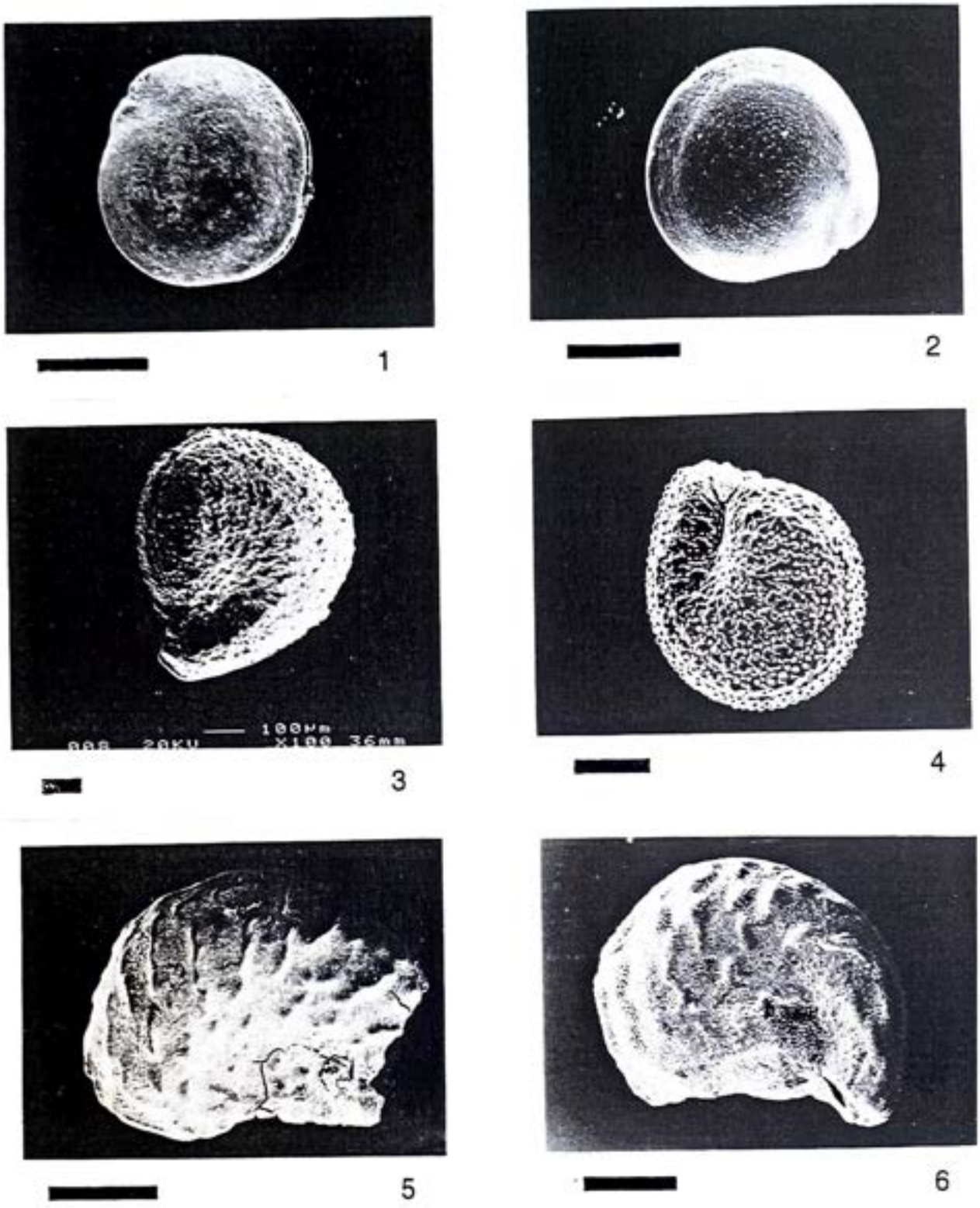


FIG. 19. Seeds of *Amaranthus*, *Portulaca oleracea* and *Trianthema portulacastrum*
1. *Amaranthus* sp. seed from layer 10:19, scale 500 microns **2.** A modern charred *Amaranthus viridis* seed, scale 500 microns **3.** *Portulaca oleracea* seed from layer 2:1, scale 100 microns **4.** Modern charred *Portulaca oleracea* seed, scale 200 microns **5.** *Trianthema portulacastrum* seed from 10:18, scale 500 microns **6.** Modern *Trianthema portulacastrum* seed, scale 500 microns

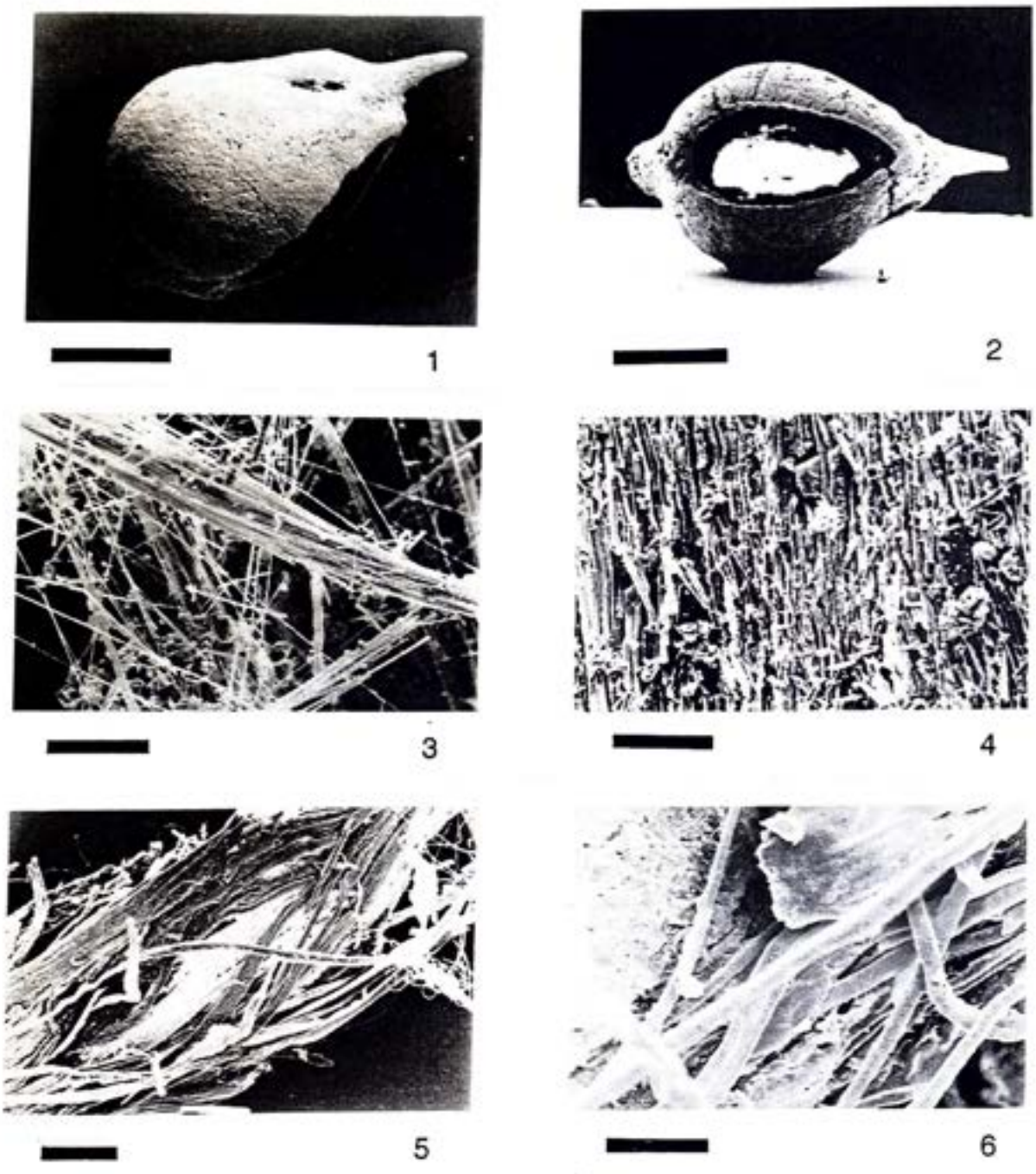


FIG. 20. Unidentified seeds, white fibres from graves and modern *tapa* cloth
1. Unknown type 1 seed from 10:25, scale 500 microns **2.** The same unknown type 1 seed from 10:25, lateral view, scale 500 microns **3.** Unidentified white fibres from burial 136, scale 100 microns **4.** Unidentified white fibres from 10:15 feature 23, scale 100 microns **5.** Fibres from Fijian *tapa*, probably made from *Broussonetia* sp. bark, scale 200 microns **6.** Further example of Fijian *tapa*, scale 100 microns

VI. ETHNOGRAPHIC MODELS FOR INTERPRETING RICE REMAINS

INTRODUCTION

MOST of the macroscopic remains of rice found at Khok Phanom Di were fragmentary husks. In order to understand how this came about it is useful to consider the crop husbandry and grain processing sequences for rice as each stage in processing a grain crop has a discernable and measurable effect on the composition of its product and by-products. Models of post-harvest processing have been developed for a range of crops such as glume wheats in Turkey (Hillman 1973, 1981, 1984a), free-threshing wheats and pulses in Turkey (Hillman 1984a, 1985) and Greece (Jones 1984a, 1984b, 1988), barley and rye in Fennoscandia (Engelmark 1989) and for quinoa and other crops in the Peruvian Andes (Sikkink 1988). These involve the detailed study of present-day pre-mechanized crop husbandry practices and their effects on the composition of crop (by-) products. They have subsequently been applied to pre- and proto-historic cereal remains across a broad geographical area, from Greece (Jones 1981, 1987), to the Netherlands (van Vilsteren 1984), England (Hillman 1982), Wales (Hillman 1984a) and Scotland (Milles 1985).

The kinds of questions which can be addressed by archaeological plant remains, when interpreted via ethnographic models, include whether a site was a primary producer or consumer settlement, the identification of specific agrarian practices such as the method of tilling, time of sowing, the means of weeding, the use of irrigation and the harvesting techniques, as well as the identification of functions of structures within the site.

The basic underlying principle in the formulation of ethnographic models for interpreting archaeobotanical assemblages is that:

> ... if, in the present-day cultivation of prehistoric crop types, a particular feature of the composition of crop products (or by-products) can be demonstrated to result exclusively from the use of a defined operation or sequence of operations then, given a closely similar archaeological sample of plant remains, it can be suggested that these remains were the product of essentially similar operations or sequences of operations that may have been used in the prehistoric context (Hillman 1981:126-7).

Ethnographic crop-processing studies with the specific goal of describing data useful to archaeobotanists interested in rice have yet to be carried out in the same detail as for crops traditional in South-West Asia and the Mediterranean, but the investigations described here make an initial contribution.

RICE AND THE ARCHAEOLOGICAL RECORD: TAPHONOMY

This section will describe aspects of paddy production technology which influence the way in which the rice plant is broken up during the long and complicated series of post-harvest procedures

which are undertaken to extract, clean and prepare grain for consumption. This account is based on evidence regarding the ways in which agriculturalists treat their rice harvest.

Non-agrarian use of rice

Examination of contemporary foragers and ethnohistorical descriptions may usefully suggest a range of non-, but not necessarily pre-agrarian approaches to food gathering which aid our understanding of past wild-plant exploitation. This is based on the assumption that traditional agricultural techniques were modifications of closely similar (in some respects perhaps identical) practices used by non-agricultural peoples to procure food from the seeds of wild grasses (Harris 1984). Current methods for gathering wild rice point to possible incipient domestication processes, but none of these strategies for plant exploitation necessarily represents the exact applications by prehistoric populations.

Seed collection from wild rices continues in some parts of India (Oka and Morishima 1971), West Africa (Morishima 1984, Harlan 1989), and South America (le Cointe, 1947, cited by Oka and Morishima 1971). Little has been written about the ways in which non-agrarian communities or agriculturalists who gather wild rice process their harvest, as most writers focus on the harvest itself rather than post-harvest practices and patterns of refuse disposal. Harvesting methods are reported to range from beating the spikelets of long-stemmed floating rice into boats (Coyaud 1950, Delvert 1961), to sweeping ripening stands with fishing nets or baskets made tacky with latex (Vaughan 1989) or simply gathering the naturally dehiscing grains by beating them into a basket or bowl (Morishima 1984, Harlan 1989). In brief, the sequence of processing techniques and the composition of the crop products and by-products are probably broadly similar to those for the agrarian situation described below, but in those areas for which we have most detailed data, among the Aboriginal people of Arnhem Land in northern Australia, gathered seeds of wild rice are soaked in water before their husks are rubbed apart by hand (Cribb and Cribb 1974, Isaacs 1987). There are also records of bundles of ripe grasses, including rice, being dried in the sun, then burnt to separate the grains from the straw. The seeds were then winnowed from the ash (Specht 1958). An additional phase of grinding the grain into flour was practiced by the Anbarra Gidjingali people (Fujiwara *et al.* 1985). The paste from rice flour was occasionally baked and eaten, but this grain played an insignificant role in the diet and was only rarely gathered (Jones and Meehan 1989). It is difficult to predict precisely the kinds of waste which would result from these processes, given the general level of descriptions, but an important and recurrent observation limiting the archaeological detection of non-agrarian rice use is that, on the basis of ethnographic and ethnohistorical accounts, most plant processing and consumption probably occurred close to the foodsource, at ephemeral camps beside swamps rather than back at large base-camps which might leave a trace in the archaeological record.

Introducing crop processing and its archaeobotanical applications

Returning to the agricultural use of rice and its archaeobotanical signature, the analysis of dehusking techniques and their associated by-products is important because crop remains from prehistoric sites in South-East Asia often appear as secondary products rather than as prime grain. The abundance of by-products (such as charred husks, stem fragments and culm nodes) in the archaeological record is likely to increase with the greater use of flotation in Asian excavations. This

approach of modelling current agrarian practice also extends the analysis of archaeological rice remains beyond the important, and not so simple, distinction between wild and domesticated types. The focus is moved, then, from a phyto-evolutionary perspective, to one emphasising cultural and ecological interpretations about a specific site from the botanical evidence.

The green revolution of the 1960s and '70s transformed the social and agronomic landscape of lowland Thailand. It brought not only new and improved seed stocks to farmers, but more mechanized techniques, higher yields and integration into a wider market economy. The pre-60s 'traditional' techniques varied between regions according to rice varieties, landforms, edaphic and climatic conditions (Fukui 1978). Variation was, however, more in terms of land- and water-management and cropping systems rather than harvest and post-harvest technology. Despite the apparent diversity of techniques outlined below, there is a broad congruence between the stages of production in each cropping and post-harvest system, with the overall goal being the production of clean dry prime grain for consumption. In the traditional system, harvesting and processing of rice can be subdivided into five main stages.

1. The crop is harvested from the field.
2. It is threshed and winnowed, to separate the spikelets from the stems.
3. Whole spikelets are stored.
4. Immediately prior to cooking and consumption, the spikelets are milled or pounded, dehusked and winnowed again, to separate the prime grain from the waste fractions.
5. The grain is cooked and consumed.

These operations eliminate, separate or discard specific plant parts at particular stages in the sequence. This means that the potential exists for distinguishing between producer and consumer sites on the basis of certain plant parts surviving archaeologically. In a self-sufficient community, evidence for all stages of the process might be seen in the archaeological record if the crop is initially threshed and winnowed in the settlement rather than the field. By contrast, in a consumer community, where the grain supply has been traded in from elsewhere, presumably as whole spikelets, there would only be indications of stages 3 to 5. Such a distinction is critical at a coastal site like Khok Phanom Di, where one question is whether the rice was cultivated and processed locally or produced elsewhere and imported as a trade commodity.

Post-harvest techniques for rice processing in the lower Bang Pakong Valley and adjacent areas

The following account of the rice harvest and post-harvest methods, witnessed in the villages of Nong Bua and Ban Nong Prü, as well as at Khok Phanom Di (*tambon* Thakham) (see Fig. 4) in December 1986 and January 1987, is given specifically from the perspective of tracing the physical breakdown of the rice plant into components which may, or may not, be found within an archaeobotanical assemblage (Figs. 32 and 33). Samples of the prime products and the waste fractions were taken at each stage in the process and were subsequently examined in the laboratory. Field observations were augmented by extensive discussions with farmers about their past and present crop husbandry practices. The major stages in the sequence, the most important tools and the (by-) products are discussed and a later section will place the agrarian practices from the Bang

Pakong Valley in wider spatial and historical perspective by drawing on descriptions by nineteenth century travellers through South-East Asia, accounts of contemporary anthropologists and geographers who have documented agricultural practice, and the recollections of elderly Thais and their descendants. All these sources will contribute to a taphonomic model of agrarian practices relevant to the interpretation of plant macrofossil assemblages from archaeological sites in Asia.

Crop processing and other agrarian practices have been inherently conservative. There has been a lack of technological innovation in agricultural techniques, so that the basic traditional methods used for producing Thai rice have not altered radically over many generations, until the last thirty or so years. The late 1960s formed a watershed to the north-west of Khok Phanom Di (Fukui 1978), with the expansion of more intensive techniques such as irrigation, drainage and fertilizer use together with the introduction of High-Yielding Varieties (HYVs). These new varieties replaced native rices throughout the country, above all in the Central Plain, and there seems to have been a particularly rapid uptake of the more productive strains in the Chachoengsao area (Fukui 1978). The use of HYVs now allows a second, dry-season crop to be cultivated in some parts of the study area. Despite all these changes, elderly people living in villages around Khok Phanom Di are able to describe the traditional agricultural techniques which have generally been superseded, while in certain villages the older methods of milling rice are still practised on a small scale. Even in the village at Khok Phanom Di a range of methods is employed for harvest and post-harvest technology. The smaller farmers without access to mechanized technology and HYVs continue to grow traditional landraces and to hand-thresh their crops.

This is an area of rainfed lowland rice, with transplanting rather than broadcasting, where a single rice crop is produced per annum. Broadcasting is largely confined to deep-water rice production in the central areas of the Chao Phraya delta. In the Bang Pakong area, rice is sown in June, transplanted in July to August and harvested during the coolest part of the year, from December into most of January. The higher areas with better drainage are the first to be harvested, as are the early season rices. Late-season rices are harvested in January. Such scheduling disperses the harvesting effort during a time of labour shortage and also allows a range of varieties, suited to many ecological niches, to be planted. Certain traditional varieties such as *khao haa loi* (500 rice), *khao luang* (yellow rice), *khao met lek* (small-seeded rice) and *khao bao tha haeng* (early-season dry-eyed rice), are maintained, but farmers comment on the reduction in the range of types available, compared with even 20 years ago. These are non-glutinous, strongly photoperiod-sensitive varieties.

Transplanting is the conventional means of planting rice in the lower Bang Pakong area, but in 1987 the monsoon was later than ever before in the memory of elderly people at Nong Bua, so some of the new crop was broadcast as late as August when the rains finally arrived. Traditional short-season rices were substituted that year, as they would come to maturity during the abbreviated growing season.

In the late 1980s a number of techniques for threshing rice could be observed in the Bang Pakong Valley. They ranged from the most mechanized hired threshing machines, which operate out in the fields, to variations on more traditional methods, with small tractors now commonly taking the place of the buffaloes, which used to dislodge the rice spikelets from the stems by treading. Livestock numbers are dwindling in the villages of the south-east today (Tsuijii 1978), but foot-treading by people continues in a minority of communities in the north-east of the country. The sequence of harvest and post-harvest techniques described here emphasizes the most tradi-

tional methods of crop husbandry used in the area. Some of the tools employed are illustrated in figure 35.

1. Laying the rice. Ten days prior to cutting, a farmer moves through the paddy field, carrying a long bamboo pole which is swept horizontally across the top of the standing plants, to push them down towards the ground. This is, in effect, a kind of artificial lodging. It is undertaken to help the reapers later, and if not carried out, the rice will probably lodge naturally, falling in a tangle which is much more difficult to harvest (Rajadhon 1961).

2. Preparing the threshing floor. The threshing floor is a wide flat area, around 15 m in diameter, in the farm compound and immediately next to the house. It has usually become overgrown during the past year, so the first task is to remove all the weeds using a long-handled knife and a coarse rake. The area is then swept clear, and a new clean smooth surface is created by coating the ground with a mixture of water and buffalo dung, which is allowed to dry for a couple of days before the threshing. This surface will keep the grain clean, protect it from the soil during threshing and prevent grains being lost down cracks in the soil. It is also said to be water-resistant, should there be an unseasonal shower.

3. Reaping/harvesting. The harvesters often sleep overnight in shelters in the fields to protect their crop and to be ready to start work well before dawn. Reaping begins around daybreak and continues into the middle of the day. Everyone is covered from head to toe, swathed in extra sarongs and cloths, so that the sun cannot burn and the silica-rich stems scratch them. In the Bang Pakong area harvesting is carried out using a metal sickle with a finely serrated edge, but in other parts of the country, particularly the south, the tool is a small semi-circular knife (Boeles1966). Some implications of the choice of reaping tool will be discussed in a later section.

   Great care is taken in reaping so that grains are not dislodged from the plant. Most of the rice is cut with 60-70 cm of stalk attached, leaving long stubble in the field, but a small proportion is cut close to the ground so that it has long stalks which can be threshed by hand. The hand threshing is carried out to provide a special batch of grain for a Merit Making ceremony just before the grain is put into storage. In lowland Thailand, as in Kalimantan, the 'use of more traditional tools or techniques is a characteristic of all the ritually important stages of the ... [agricultural] cycle' (Dove 1985:266).

   Bundles of cut rice may be laid over the stubble and left to dry in the fields for up to four days, then sheaved. Alternatively, it is immediately bundled into sheaves with strips of bamboo (Rajadhon 1961), or ties made using long straws twisted and tied into a rough cord. These and other ancillary operations tend to be carried out at night. The sheaves, which will produce about 10 kg of paddy once threshed, are propped into groups of three or four and left in the field for a couple of days before being moved to the threshing ground. This period allows some of the moisture in the grains to evaporate before threshing. The moisture content of rice at harvest is around 20 per cent and the preferable level at threshing is 13-14 per cent (Krishnashreni 1981).

   At present, the harvested rice may be moved to the home compound for threshing for security reasons (Fig. 21), but in the past more of this work was carried out in the fields to minimize



FIG. 21. Rice sheaves are carried from the field to the farm for threshing

grain losses during transport and handling (Chung and Lee 1978, Kaga n.d.). Such losses were probably more apparent to people in the past, growing crops with a greater propensity for shattering.

The sheaves are carried to the farm by boat, cart, wagon or bicycle, then moved into the yard in pairs, strung over each end of a pointed bamboo pole which is hoisted over the shoulder. They are stacked in a wall along the length of the threshing floor, with the heads of the sheaves to the middle of the stack, for protection from birds and rain. Farmers prefer to move their sheaves at night or in the cool of the early morning, when the air is still and more humid, since this reduces grain loss by shattering.

In the past it was common to burn the stubble to fertilize the fields, as Koenig (1894b) describes for his visit to Thailand in 1779, but now the straw is often cut to feed the livestock during the dry season. A less important use of straw is as a fuel, especially in the braziers which keep the harvesters warm at night. Straw is regarded as a useful commodity and may be cut and kept by the workers in a second round of reaping in which case the straw is taken as part-payment for their labour (Sharp *et al.* 1953).

4. Gleaning. Further reaping may be carried out by children, the elderly or people from the poorest households. They take the few panicles accidentally missed by the main reapers or those ignored the first time because the grains were immature.

5. Laying out the sheaves to be threshed (Fig. 22). Threshing is carried out with the blessing of the Rice Goddess, MæPhosop, who is worshipped with ceremonial food and other offerings. This, and the Merit Making ceremony carried out after threshing, are described by Rajadhon (1961:359-362, 368-73). Other accounts emphasising the rituals associated with rice harvest

in Thailand include: Lewis (1982) for Akha swidden agriculturalists in Burma and northern Thailand and Hanks (1972:78-80) for communities in the Chao Phraya delta.



FIG. 22. Rice sheaves being laid out in a circle for threshing

When the time is ready for threshing to begin, again around dawn, about 15 large short-stemmed sheaves are carried from the large stack to the middle of the threshing floor, where they are laid flat in a circle with the grain pointing outwards. A sickle is used to split them open, and they are then surrounded in an ever-expanding spiral by smaller sheaves with heads pointing towards into the centre. A total of 80–100 sheaves is processed per session.

6. Threshing. The main objective in threshing is to separate the spikelets from the straw and to produce spikelets for storage. In the past this separation was done by treading, either by people or by teams of muzzled buffaloes tethered to a central pole and driven in circles over the straw pile. It was said that the buffalo were made to wear straw shoes to protect the grain from being crushed. Trampling may be enhanced by crushing the crop with a stone roller (Hillman 1984b:123, describing the rice harvest in the Kizilcahamam area of Turkey). This apparently softens the stalks, making them better buffalo fodder (Hickey 1964). Threshing and trampling are now more commonly accomplished by driving a small tractor pulling a sledge over the pile of sheaves.

   The carpet of rice straw is turned over to redistribute the unfragmented panicles; new sheaves are added and threshing resumes. The tool used is a long-handled, widely-tined rake. Once the spikelets have been separated from the rachis bases, long stems of straw are cleared away using a long-handled tool with a single prong, while the *kenoon* (finer straw fragments, leaves, many panicle branches and unthreshed spikelets) is removed with a coarse rake and brushes. Those rice spikelets which had fallen through to the bottom layer of the straw pile,



FIG. 23. Rice sheaves being threshed by tractor

are scraped together with a bar-bladed scraper (Fig. 35, item 18) and stray spikelets brushed to the centre of the threshing floor, scooped into large storage baskets and put to one side until the threshing operation is completed (Fig. 24).

Grain loss during threshing occurs where there is failure to separate all the grains from the stalks because certain spikelets refuse to shatter. This loss is negligible though, in comparison with the number of spikelets which shatter and drop during transport to the threshing floor. That both losses take place in the harvest of a single variety indicates a range of shattering types within the single population and would probably have been more pronounced in early cultivars.

The long-stemmed rice sheaves mentioned earlier were destined for manual threshing or lashing, which sometimes involves a tool illustrated by Colani (1936:215) and best described by Rajadhon (1961:362) as 'two pieces of wood about a meter long, tied together at the head with a rope. The rope is long enough to form a loop to go around a sheaf of rice and be caught up at the far end of the piece of wood'. A simpler, straw version of this was in operation at *tambon* Nong Bua during the 1986/7 harvest. A single small sheaf was encircled with a straw loop, held tightly in a two-handed grip, raised above the head and repeatedly slammed down on the edge of a large wooden threshing tub (Fig. 25). The shock of the straw hitting the tub caused the spikelets to drop. Bamboo mats screening three sides of the tub prevented the rice from spilling and scattering. Similar threshing techniques seen in north-east Thailand involve beating the rice against a slotted bamboo frame or giant circular baskets 'eight to ten feet in diameter and ... about four feet deep' (Kingshill 1960:35). These methods are also used in parts of Cambodia, where it has been calculated that one person can produce 150-



FIG. 24. Rice straw is raked from the loose spikelets and retained for animal feed

200 kg of rice per day, compared with a pair of buffaloes trampling out 300–500 kg (Tichit 1981).

7. Primary winnowing. The next stage is the winnowing of the crop. The rice is sometimes given the opportunity to dry before the winnowing stage. This increases the weight differential between the filled and unfilled spikelets, which improves the efficiency of winnowing. Long-handled wooden shovels are used to toss the rice into the air. The late afternoon is the preferred time of day for this, once the breeze has risen. The spikelets and other heavy



FIG. 25. Rice sheaves being theshed by hand

fragments such as culm nodes fall at the feet of the winnowers, while the lighter fragments including dust, unfilled spikelets and broken husks are blown further, falling in a diffuse spread across the threshing floor. A second round of primary winnowing may be carried out on the heap of heavy spikelets and dense nodes together with the fraction which has settled a little downwind. The latter consists largely of empty spikelets and straw fragments, but also contains small grains which are separated by being skilfully shaken back and forth on a shallow winnowing tray. The heavy filled spikelets are worked to the back of the tray, while the lighter materials are edged to the front and drop to the ground or blow away. This 'waste' fraction is set aside for storage as chicken feed.

The straw is then loosely bundled so that it can be carried away on a bamboo raft and stored for use as buffalo feed. The rice spikelets are swept up into a single pile on the threshing floor, measured in standard-sized baskets and bagged into hessian or jute sacks for transport to the storehouse.

8. Drying. The moisture content of the paddy may need to be further reduced before the spikelets are stored. This prevents rotting, germination or pest attack during storage. The drying period varies between one and three days, according to the moisture content of the

grain and the weather conditions. The crop is spread out to dry on mats, in the threshing compound or sometimes in the road, and is intermittently raked to turn the grain. At night it is raked together and the pile protected from dew and rain with mats. An additional factor, as Dove (1985) points out, is that dry grain is lighter, so requires less labour when being transported from the threshing floor to the storehouse. Thorough drying of seed rice is said to be critical for good germination rates in next year's crop.

9. Storage is as semi-clean spikelets or 'rough' rice, that is, grains enclosed in their husks (lemmas and paleas), a few of which are still attached to broken panicle branches by the pedicel.

   The storehouse is a separate rat- and moisture-proof thatched granary constructed on stilts. It is built from woven bamboo slats, lined with a layer of buffalo dung and mud to prevent infestation by pests or leakage of the valuable grain.

   In steps 1-9, the rice is treated in bulk. Harvest, threshing and winnowing are labour-intensive activities demanding coordinated effort by a team of workers and are often field-based operations. After the crop has been placed in storage, it is treated in much smaller batches, on a daily basis. The subsequent work is carried out by women of an individual household, within their home compound.

   Industrial-scale powered mills have been in operation in and around Bangkok since 1858 (Johnston 1976a). Today the vast majority of the farmers in the south-eastern lowlands sell their harvest to the mills. They also send the rice for domestic consumption to be milled mechanically, paying for the service with a proportion of their crop. A few farms still have old mortars hidden away in the storage area under the house, but it is rare to find anyone actually using them. In the village of Ban Nong Prü, away from the intensively farmed coastal lowlands and in a marginal dryland area on one of the alluvial terraces 7 km north-east of Phanat Nikhom, the traditional pestle and mortar were still used for milling some of the rice for home consumption at the time of fieldwork. One of the families kindly agreed to demonstrate the processes so that the techniques could be recorded and samples taken from each stage in the sequence (Figs. 26 and 28).

   The preferred practice is to mill rice on a daily basis, as freshly milled grain is generally considered tastier. The required amount is taken from the store and laid out to dry in the sun for a few hours, which improves subsequent milling.

10. Milling: separating grains from husk. A small mill is used to fragment the dried spikelets, with friction splitting the husks, releasing the grain and dislodging some of the bran. This type of mill (Fig. 35 item 29, 27), which is usually kept under the house, was described by an American travelling through Siam in the late nineteenth century:

> The mill consisted of two parts ... but, instead of the usual two coarse stones, they were made of thin slabs of hard wood embedded in mud and surrounded by wicker-work. The motive power was a man and a woman, who worked this primitive machine by means of a long pole and a cross-piece of bamboo at one end, with the upper mill-stone (or rather mud and wood basket), it being the same principle as that applied to our grindstone. (Vincent 1873:180).



FIG. 26. Rice spikelets being pounded by pestle and mortar to release the grain from the husks

Similar equipment was noted as the most popular means of milling rice in lowland Burma during the early years of this century (Anon. 1913). The operation of such a machine was also described by Halliday (1917, citing from the *British Burma Gazetteer*):

> The mill consists of a solid cylinder of wood about two feet in diameter, the upper surface roughened with radiating lines, a quarter of an inch deep being cut into it; on this works another cylinder, the lower surface similarly roughened, with an opening through it in the shape of an inverted truncated cone: to one side of this upper piece is loosely fastened the end of a long pole, and by working this backwards and forwards the upper cylinder is made to revolve and to husk the grain which is passed in at the top and comes out between the two portions of the mill.



FIG. 27. A rotary rice mill of the kind described by Halliday (1917)

Horizontally pushing and pulling the long lever makes the upper cylinder rotate around a vertical axis, so that the husks of the rice in the grooves between the two cylinders are cracked by the movement. The milled product falls from a spout in the mill into a basket below. The rice mixture at this stage consists of whole dehusked grain which is still covered with bran (pericarp), entire split lemmas and paleas, many paired and others singly, smaller longitudinal husk fragments and small stem fragments. The same combination results from an alternative means of splitting open the spikelets by means of a long-handled wooden mallet in a large round wooden mortar (*krok*, Fig. 35 26-8). Both techniques were observed in use by members of a single household at Ban Nong Prü.

11. Secondary winnowing. The milled rice mixture is extracted and winnowed in a large flat circular basket by tossing it into the air with a flick of the wrists and catching it again. This separates the lightest husk fragments, some of which remain attached to the rachilla, glumes and pedicels. The mixture is repeatedly tossed into the air and caught again, so that the lighter fraction of broken husks (*klæb*) blows away. Once the remaining combination consists of grains and husks with the same general density, the basket is shaken from side to side at an angle so that the husked paddy is separated from the dehusked rice. The winnowing process separates three fractions: the prime grain (*khao nak*), which is retained in the basket, the broken grains (*khao khrung met*), which fall to the ground and will be gathered together,

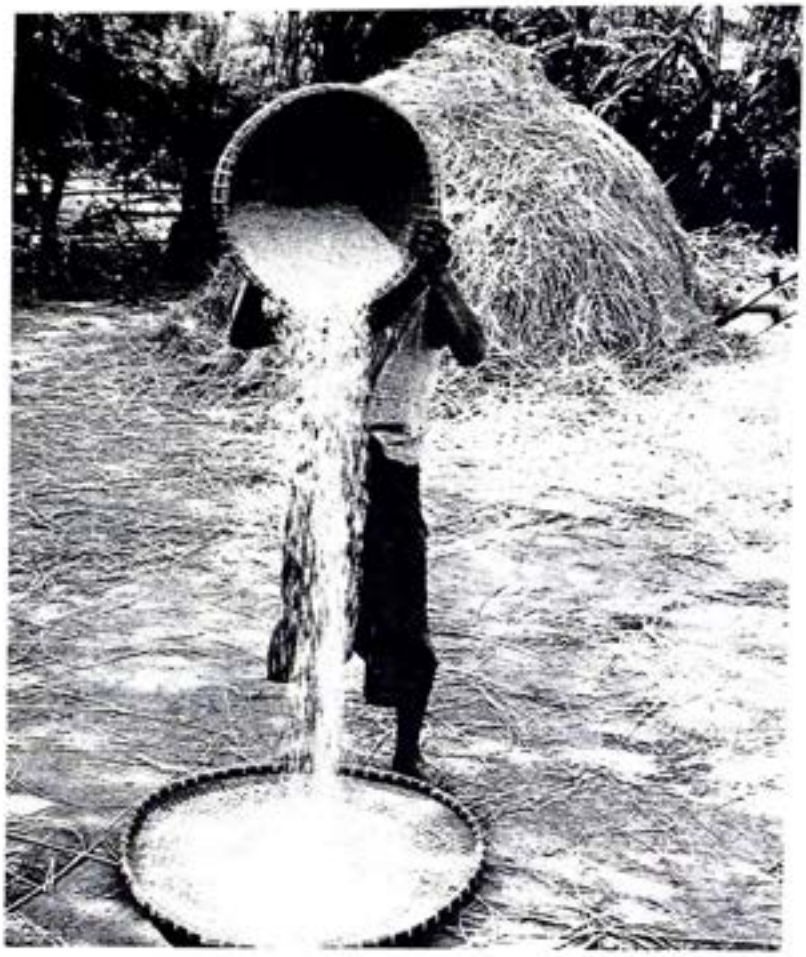


FIG. 28. Winnowing rice husks away in the wind, to leave the prime grain in the basket on the ground

stored and subsequently used for feeding ducks, hens and pigs, and the waste fine fraction (*klæb*) comprising whole split husks (lemmas and paleas), unfilled spikelets and a few pieces of stem (*faang*), together with the secondary branches from the panicle and panicle branch fragments (*kanun*). This waste fraction is commonly used as kindling and fuel for domestic fires or for smouldering fires beneath the house, to ward away mosquitoes (Tichit 1981).

Samples were taken of the *klæb* (the waste fine fraction) before and after being burnt in a kitchen fire. The degree of combustion varied through the burnt sample. The majority of husks had been charred black, a few were apparently unaffected and remained pale brown while others had been ashed white. The fragments had curled inwards; they remained whole but had become fragile, especially the ashed items. Some *klæb* is used as kindling and fuel but it also provides a good packing medium for breakable objects and is still commonly

used in Thai markets as insulation or packing for eggs or pots. More importantly, from an archaeological perspective, it is a source of temper in pottery, mud-bricks and daub.

The small number of clean (bran-free) grains may be removed by hand at this stage in order to prevent them from being damaged by further pounding. The remaining paddy is then returned to the mortar for a second round of pounding.

12. Pounding. At this point the grain mixture mainly comprises polished grain, mostly whole but some broken, with about 5 per cent of the sample covered with bran. There are also some broken husks along with whole filled spikelets which were not split open by the milling or initial pounding. This combination is pounded to remove the bran and polish the grain. A heavy long-handled mallet is used with a large wooden mortar made from tough dipterocarp timber (Fig. 29). If stage 9 of the process is carried out by manual pounding, the mixture may be transferred to a second, smaller mortar for this second round of pounding, where it may be processed by two women pounding alternately. If only one large mortar is available and a long pole rather than a mallet has been used to pound the rice, the finer end will be used for the second pounding.

13. Coarse sieving. The grain is still contaminated with small pieces of straw and some long husk fragments of comparable size grade, so it is sieved through a basket with 2 mm mesh. This divides the rice into a coarse fraction retained in the sieve (*c.* 90 per cent of the total) and finer-grade material which passes through (see stage 16 below for further treatment of this material). The coarse fraction comprises grain (polished rice), husks and straw fragments larger than the grain.



FIG. 29. A mixture of spikelets, broken straw and splintered husks in the mortar

14. Repeated winnowing. The coarse fraction is then separated further by being slowly poured from a basket onto a round flat woven tray (Fig. 30). Fine fragments of chaff blow away and settle on the farmyard floor, perhaps to be gathered up and stored for later use as chicken feed or simply left for the birds to scavenge. The heavier fraction (grain and a few large fragments of husk) is deftly shaken back and forwards in the tray to separate items of similar density further and the chaff is discarded.



FIG. 30. Cleaning rice grain to remove husk fragments

15. Hand cleaning of this semi-clean grain removes any final contaminants of approximately the same size range and density as the prime grain, such as small stones and dense chaff fragments (*khao pluuk*, Fig. 31). The clean rice, some of which is broken, is washed to remove dust, then cooked, usually by steaming or boiling in water. Cooking accidents occasionally occur which might char some grain, but generally any burnt rice from the bottom of the cooking pot is fed to the ducks and the dogs.

16. Fine sieving. The fine fraction from stage 12 is sieved to separate the *rum*, fine bran and very fine fragments of husk, from the coarser *khao plaay*, broken grain fragments and very small fragments of husk. The latter is stored for feeding to pigs, chickens or ducks or may even be fermented into rice wine. In times of shortage, these broken grains may be picked out by hand and used to augment the prime grain as human food, but normally they are regarded as animal food.

The sequence of these processes, their effect on the composition of the crop and the final distribution of the by-products are summarised in figures 32 and 33.



FIG. 31. Further cleaning of the rice grain to remove the finest husk fragments

TRADITIONAL AGRICULTURAL PRACTICE IN LOWLAND THAILAND

One problem with documenting the most basic traditional *lowland* rice-production technology is that the south-east and the central plains of Thailand which are the regions of archaeological interest here, are the very areas where the greatest technological changes have recently taken place, especially in the lowlying irrigated lands where two crops per year can be sown. Within Thailand, and throughout mainland South-East Asia in general, the most traditional farming systems, involving shifting agriculture, are currently restricted to highland areas, where dry cropping is prevalent. Historically, shifting cultivation has been carried out in all parts of the region, presumably including the coastal zone. There were shifting cultivators in the lower central Thai plain prior to the canal-building campaigns and the extension of the agricultural frontier during the late fifteenth- to early sixteenth-centuries (Hubbard 1977) preceding the more concerted efforts of reclamation in the late-nineteenth century (Johnston 1976b, Hanks 1972). By the end of this period the lower Bang Pakong and adjacent areas in the Chao Phraya delta were known as 'uninhabited wasteland of jungle grass' (Johnston 1976:41). The Prawetburirom Canal, built in 1877, cut through an open grassland to connect the lower Chao Phraya with the Bang Pakong. When Warington Smyth visited, seven years later, the land was a 'lonesome waste of swamps and grasses .... unclaimed except by the buffalo and the heron' (Warington Smyth 1898:53). To the eighteenth and nineteenth century traveller, sailing along the coast of the Gulf, the land was fringed by largely uninhabited mangrove swamps, with only the occasional fishing village. Inland, the mangrove merged to nipa palms and salt flats, followed further from the coast by coconut and areca groves, citrus orchards and finally rice paddies (Koenig 1894a, Warington Smyth 1898). The Danish botanist, Koenig, who visited Thailand in 1779, documented numerous plant collections during his journey up the Chao Phraya

to Bangkok and then along the south-eastern seaboard to Chantaburi (Koenig 1894a). His descriptions of the mangrove and swamp flora, and the villages of the estuary and along the coast offer a picture of houses raised on stilts, mainly made from bamboo and thatched with *Nypa* leaves, set amongst *Rhizophora* and *Avicennia.*

There are a few references to nineteenth century shifting cultivation in the lowland zone of Thailand (Hanks 1972), and the Irrawaddy delta of Burma, where we are told that swamp rice could be grown for two years before the plot was abandoned (Huke 1970, Adas 1974). In general, though, we have little information about the cropping systems other than their existence. According to Takaya (1980), prior to the Bowring Treaty (1855) there were probably three groups of people living in the Chao Phraya and Bang Pakong deltas: first, the sedentary rice growers located along the major watercourses, practising broadcast agriculture; second 'shifting rice growers who planted along the coast' using transplanting techniques, who were 'mainly engaged in fishing and wood cutting'; and third, the people of Bangkok and adjoining towns. Johnston (1976a) surmises that shifting cultivation was probably not widely practiced in the historic period, although we may note that Hanks (1972), writing about the history of Bang Chan, east of Bangkok, offers an example of this minority form of land management when he mentions that in the early days of that settlement, in the late nineteenth century, some plots were shifted on a yearly basis.

Nevertheless, these extensive systems seem to have been rapidly replaced by more intensive methods by the turn of the century. Most of delta area was colonized by wet rice cultivators. Vast new areas were brought under cultivation, rather than seeing the intensification of a pre-existing system. Such shifting agricultural communities as existed, were replaced by sedentary settlers and by the mid 1940s, when Pelzer surveyed shifting agriculture throughout South-East Asia, it was estimated that only in the Outer Islands of Indonesia were there shifting cultivators on level lowlands (Pelzer 1948).

Present-day shifting swampland rice agriculture in Sarawak (Padoch 1982), Kalimantan (Dove 1985, Watson 1985, 1987) and peninsular Malaysia (Lambert 1985) perhaps offer the closest ecological analogues to the prehistoric conditions at and around Khok Phanom Di. In these areas, naturally damp pockets of soil are cultivated, artificial water-control and land-levelling are kept to a minimum and a wide range of rice varieties is sown in a mosaic of microenvironments. Methods of land preparation, planting and weeding in these areas differ from those applied to the pond field paddies of the Bang Pakong area today (to be described later) and harvesting is carried out with finger knives, but the post-harvest techniques are very similar in outline to those described here.

Regional variations in harvesting and post-harvest operations

The harvest and post-harvest techniques described above were in common operation throughout the rice-growing areas of south-eastern Thailand prior to 1960, but variations are noted for other parts of the country and the wider rice-growing region, and one has to draw from the similarities between these numerous systems, past and present, across a broad geographical area, in order to create a model of rice post-harvest processing methods which may be applied to the archaeobotanical record.

The sources

Western-language historical sources providing ethnographic data have been written by travellers and government officials and often involve casual observations of agricultural practices.

Theirs is a comparative perspective and details of agricultural life may only be provided when radically different from their home country. Commentary is also more likely to be on the progressive and sophisticated than on mundane means of production. These accounts may not be the work of professional ethnographers but sometimes provide a useful window on ecology, agriculture or crop processing techniques (e.g. Bowring 1857, Bock 1884, Halliday 1917). The similarity of present-day techniques with those operating at the turn of the twentieth century is illustrated by accounts about and photographs of Thai agriculture as recorded by Graham (1904).

Professional investigations by historians, geographers, ecologists and anthropologists, generally later than the writing of travellers, provide additional information about Thailand and other parts of South-East Asia (e.g Hanks 1972, Kaufman 1960). Together, these sources indicate the range of techniques applied to a single task, the harvesting and preparation of a staple grain, rice, for food.

Upland harvest and post-harvest procedures are broadly similar to those of the lowlands, with various adaptations for altitude, steep slopes, dryland farming techniques and inclement weather during the harvesting season. The majority of these differences do not affect the processing of the crop *per se*. The contrasts are largely in terms of land management, above all dry-cropping rather than pond-field cultivation, and differences in the timing rather than the type of operation. Reaping, for example, takes place earlier in the uplands than at lower altitudes, because of the shorter growing season and the use of appropriately short-season rice varieties, but the techniques employed and the composition of the crop-products are broadly similar to the lowland harvest.

Turning in detail now to variations in crop-processing technology, each stage in the sequence will be described as before, to set the operations described for the Bang Pakong area in broader perspective.

Harvesting: the use of finger knives

The implement used to reap the crop in Central Thailand is a curved sickle with a metal blade, but the shape of the tool varies from region to region, from a more hooked blade in the north-east to an almost straight one in the north (Kanokpongchai 1985). The method of reaping is broadly similar though, with a handful of panicles being harvested in each cutting motion.

An alternative to the sickle is the rice- or finger knife, an implement comprising a small flat horizontal blade, made of iron, tin, copper or even the sharpened edge of a sardine can (Dove 1985), set in a vertical handle of bamboo, bone or metal (Miles 1979). This is held in the palm of one hand and used to cut individual panicles of rice by pulling a single stem against the blade. Excellent illustrations of such knives from Laos, Annam, northern Thailand, Borneo and Java are to be found in the publications of Colani (1936), Fischer (1938) and Miles (1979), along with Indonesian examples which even include implements made from shell (Fischer-Utrecht 1937, 1939). This last example is not dissimilar to the worked shell artefacts found during the Khok Phanom Di excavations, which have, by means of replication experiments and examining use wear, been interpreted as rice-cutting tools (Higham 1993).

The finger knife is currently used throughout island South-East Asia, Malaysia and peninsular Thailand, whereas the sickle is the traditional tool amongst lowland communities of the mainland, through Burma, westwards into India and Pakistan and north-eastwards into China. In peninsular Thailand, the current border between the two technological provinces lies just south of the Isthmus

of Kra (Boeles 1966). The hill tribes of mainland South-East Asia also use the finger knife for harvesting (Kingshill 1960, Judd 1964, Barney 1970, Kunstadter 1970).

Finger knives, being used to cut individual panicles, are especially effective for traditional varieties of swamp rice, where the crop matures unevenly. A second reaping follows after a few days, once more panicles have ripened and turned colour (Watson 1987). The practice also allows the harvesters to pay attention to the quality of individual panicles. Those unripe are left to mature and unfilled or unsound ones are avoided or discarded. Selection may even be taken to the level of individual grains, with only half a panicle being taken if only the upper grains are sound (Dove 1985). This ability to cut individual panicles may have originated from the necessity to select only the good grains from a heterogeneous crop.

Use of the finger knife generally involves cutting the stem relatively short, just below the panicle. About 20 cm of stem may be left attached, but as this is too short to be tied as sheaves, the panicles are placed in large circular baskets for transport to the threshing floor. This means that spikelet loss in transit is less than with long-stemmed sheaved rice. Rice cut by finger knife may sometimes be stored on the panicle, without being threshed first (Ja'far 1897, Jenks 1905, Conklin 1980, Bodner 1986, Prill-Brett 1986), and is more often threshed by foot-treading than by manual beating as the stalks are too short to be grasped. The sickle is the quicker of the two harvesting techniques, but with the small hand-held knife stems are cut individually, and with even length, making the harvest easier to thresh or store.

Yet another, minor technique for harvesting is 'milking' the grain, the removal of the rice spikelets by hand. This is the main harvesting technique used by the Lamet swidden cultivators of northern Laos (Burling 1963, Izikowitz 1979) and for over-ripe fragile panicles as an adjunct to finger knives by the Kantu' of Kalimantan (Dove 1985). This a rare form of 'gathering' which actually selects for the shattering type of rice, within an agricultural system.

Threshing

The current methods of threshing rice in south-east Thailand have already been described, namely tractor threshing and its antecedent, buffalo treading. There are historic records of buffalo treading from Thailand and elsewhere. For example, Young (1907) describes night-time threshing using buffaloes in late nineteenth century Thailand, while Knox, visiting Sri Lanka two hundred years earlier, in 1681, describes and illustrates cattle threshing rice by trampling (de Silva and Beumer 1988). Alternative methods for threshing are as follows:

1. Flailing the crop to dislodge the spikelets, using sticks, bamboo, coconut leaves (Kaga n.d.) (Indonesia) or a hinged wooden device (Philippines) (Saunders *et al.* 1980).

2. Stamping or treading the panicles barefoot. Rubbing the rice between the feet is widespread throughout island and mainland South-East Asia and has been documented in parts of northern Thailand (Judd 1964), Malaysia (Gianno 1990), in Assam (Barney 1970) and amongst the Lamet of northern Laos (Izikowitz 1979). Working on a woven pandanus mat, the treaders grip a horizontal bamboo structure and work the rice between their feet to release the spikelets. Sherman and Sherman (1990) describe this practice in rural Sumatra, where the sheaves are shuffled along a line of 'stampers', finally being passed to women and girls who shake free any remaining grains. An elaboration on this is to use a bamboo-slatted threshing

table or low platform upon which unthreshed rice is placed, ready to be threshed by foot. Beneath the platform are mats which catch the threshed rice. The loose spikelets fall between the slats, while the pedicels and straw remain above (Copeland 1924, Dove 1985). This technique can thresh rice twice as fast as the simpler foot-threshing method (Watson 1987). Foot-threshing in general has been shown to be faster than flailing for comparable material and has the added advantage of incurring less grain loss or damage (Kaga n.d., citing *Rice Post Harvest Technology* 1976). The rate of production has been calculated as 100 kg/hr (Tichit 1981) or 300 kg in a six-hour day (Watson 1987).

3. Stripping, by pulling the straw or panicle through a large wooden comb (Japan and Korea) or a V cut in a piece of wood (Philippines) (Saunders *et al.* 1980).

Winnowing

The natural wind may be augmented by hand-wafted bamboo mats or, nowadays, by a mechanical wind-generator. In Burma, bamboo platforms are sometimes constructed in the threshing area and baskets of threshed paddy passed up to a person who gently pours the contents down onto the floor. The chaff is blown away and a pile of moderately clean paddy builds up on the threshing floor (Grant 1932).

A little-used alternative to wind winnowing is the water-separation method for removing the minority of unfilled husks from the majority of filled grain. This is described by Watson (1987) for Kalimantan, where it is usually reserved for cleaning seed.

> Rice is placed inside a dugout canoe that is then filled with water. With stirring, empty husks float to the top and are discarded. Depending on the size of the canoe, 100 kg or more can be winnowed in an hour. The disadvantage of this method is that winnowed rice must be immediately and completely sun dried to prevent deterioration.

Irrespective of the techniques chosen, the combined effects of the threshing and winnowing are to release the spikelets from the pedicels and to separate the heavy (grain) fraction from the lighter straw, which is stored separately, mainly for feeding buffaloes, while finer winnowing products may be saved for chicken feed.

Storage

Storage facilities for rice vary in construction and scale, from individual baskets or bins to capacious buildings (see Clément 1985 for extensive descriptions). Baskets are regarded by the farmers as best, because they provide good aeration, and are cheap and durable, but wood or bark containers generally offer better protection against rats. The woven mud-plastered baskets may be placed high on a raised platform and protected by a roof of leaves (Young 1907). Additional measures may be taken to protect the crop from insect and pest infestation during storage. These include the placement with the grain of particular plants or plant extracts, such as the wood of *Azadirachta indica*, insect repellent oils or minerals (Golob and Webley 1980).

De Young (1966) lists three types of granary seen in northern Thailand. They range in capacity from a 'small beehive cone' made from woven bamboo, either kept under the house or as a separate building, to large rectangular timber-built structures, raised on pillars. Irrespective of style and size, all have anti-pest features such as stilts, sometimes with projecting water-filled plates half way up

the pillars. These prevent insects and rats from climbing up to the grainstore. A regular feature in monsoon Asia is projecting eaves to protect the building and its contents from the rain. At a much smaller scale, large baskets or bins kept inside or under the house may be sufficient for families who have relatively little grain to store.

Spikelets may be stored in times of plenty for up to ten years, but some may spoil, in which case the damp, sprouted, weevil-infested, mouldy or rotten grain is generally disposed of by burning. This offers one possible avenue for rice to enter the archaeological record as whole charred spikelets.

The storage of crop-processing by-products is equally important from an archaeobotanical perspective and the main by-product of harvesting and threshing is straw. The diet of the Thai buffalo is mainly native grasses, supplemented by green weeds from rice fields (Suwatabandhu 1950, Kittipong 1983), tree leaves and rice straw (Gillogly 1988), although the high silica content of straw limits its palatability and digestibility (van Soest and Jones 1968, Rovner 1987). A prominent feature of lowland farmyards is a tall pole around which a straw stack is built, but alternatively feed is stored in a covered enclosure, or even in the branches of a tree (Niezen 1986). Additional uses for rice straw are as a fuel for firing pottery, for kindling and for making minor products like straw rope, paper, woven shoes and medicines (Elvin 1982).

Secondary by-products, at this point, are the winnowings (*kanoon*), comprising mainly straw fragments and broken panicle branches, with unfilled or very light spikelets. These are stored in a third set of baskets or buildings. The winnowings used as chicken feed are broken down, but the waste used as kindling or coarse temper for pottery or mud-bricks may well be preserved and could be found in an archaeological context.

Milling

Rice is commonly milled within the household compound in quantities adequate for daily use. The precise technique varies from region to region within Thailand, employing either a pair of horizontal grindstones (described earlier), or a pestle and mortar, which may be a levered pedal or a manual device.

Foot-powered mortars and pestles are still in use in the uplands of Thailand, in Burma (Anon. 1913) and eastern India (Raychaudhuri 1961). It was described by Young (1907:209) as:

> ... simply a short, broad stump of a tree with a conical hollow inside, the apex of the cone being near the ground. A long lever carries at one end a heavy wooden hammer-head, which falls into the hollow of the stem. It is raised by placing the foot on the other end of the lever, and then jumping up so as to press upon the lever with the whole weight of the body. The women are generally employed in this work, and in any small village you can hear the steady thump, thump of the hammers from morning to night, and see the girls and young women jumping on and off the short end of the lever, with an almost painful regularity and precision.

The replacement of the simple mortar and pestle by foot-operated rice pounders has been attributed to the advent of wet rice in the traditionally dry-rice area of northern Thailand, together with tougher-husked varieties with less propensity to shatter (Burling 1963). Foot-powered mortars in dry upland areas have a water-powered equivalent elsewhere, for example amongst the Man of Vietnam (Dement'eva-Leskinen 1969).

Simpler wooden pestles with hand-held poles, fundamentally similar to the technique described for Ban Nong Prü in the research area, have been described amongst the Mnong Gar or *Phii Bree* and the Brou, upland swiddeners respectively in Vietnam (Condominas 1957) and Cambodia (Matras-Troubetzkoy 1978). This is the simplest milling technique in operation in South-East Asia today and for that reason, probably the oldest, along with the use of stone mortars and rollers which are not reported for the present-day but have been found in archaeological sites and interpreted as such. The activities associated with the sandstone grindstones and pounders from Khok Phanom Di have not been firmly established, but it is surmised that their use was possibly the sharpening of stone or bone tools, or even the grinding and powdering of grain (Pisnupong 1993). The shape of the smooth worked surfaces suggests grinding in a backwards-forwards rocking motion rather than a rotary movement.

Milling experiments have been carried out to compare the fracture patterns produced by grinding and milling rice spikelets using the main techniques described here, circular grinding and vertical pounding (Yen 1977). The results indicate that the breakage patterns found in prehistoric spikelets from Banyan Valley Cave in north-western Thailand are better replicated by stone pounding implements used with a rocking motion than the pestle-and-mortar or mill used by subsistence farmers living in the area today.

Storage and use of milling by-products

The range of by-products and their varied uses within an agricultural community, means that certain parts of the rice plant are modified and incorporated into durable materials which may become preserved in the archaeological record, while others are employed or discarded in such a way that they are likely to decay soon after use. Rice bran, for example, is one of the final products of milling which is fed to pigs, while *khao plaay*, broken rice with small fragments of husk, is fed to chickens (Gillogly 1988). These uses are unlikely to preserve the plant products in a form which might eventually figure in the archaeological record, except in the rare instance where coprolites are found. Burning, on the other hand, may char or ash the materials, favouring preservation. Husks have been used to power industrial-scale rice mills since the early years of this century (Graham 1904, Johnston 1976a), but also have a long tradition of use as kindling in domestic fires and for firing pottery. Straw is also used as fuel in kitchen fires and braziers and for pot firing. These then are the components of the rice plant which are most likely to be found by excavators with a keen eye for plant remains or the policy of sampling and floating soil samples to extract plant remains.

The most common form in which rice remains were encountered at Khok Phanom Di are as husk fragments which have been used to temper pottery, so the issue of pottery making technology becomes germane and will be examined further.

CROP PROCESSING AND ARCHAEOLOGICAL REMAINS

The crop products and by-products have been described in terms of their progressive breakdown, and the presence or absence of the various plant components at each stage of the crop-processing sequence, as well as the means and distribution of their disposal. From this it can be seen that there are differences between plant parts which might be discarded and appear in the archaeological record at a producing site (Fig. 32) compared with a consumer site (Fig. 33), where rice is

brought in as spikelets and milled close to consumption. Archaeobotanical assemblages could be distinguished by the presence of long straw fragments and abundant panicle branches at the locus of threshing, invariably close to production, and conversely an archaeobotanical assemblage dominated by split and fragmented husks (lemmas and paleas) at places where rice had been milled for consumption.

This qualitative assessment is all that the poor preservation of the Khok Phanom Di archaeobotanical remains warrants. The remains of rice here are mainly husks, both fragmentary pieces and fewer whole spikelets (from the soil, the coprolite samples and as temper in potsherds) along with monocotyledon stems (most probably rice) preserved within the soil. The occurrence of these stem fragments, if confirmed as rice by phytolith analysis, would point to Khok Phanom Di being a rice producer site.

The data presented here are a first step in producing a model for application to an archaeological situation and would be improved by more extensive systematic surveys of traditional agricultural practice. Quantification of sample composition awaits replicate materials, ideally from harvests across a wide environmental gradient and from communities using finger knives which are closer to the reconstructed prehistoric technology, in conjunction with more plant remains from archaeological sites with which to compare the results. The plant remains from Khok Phanom Di are clearly not preserved in a manner which would indicate the probability of particular plant parts being preserved in the archaeological record by charring. Further development of the work has extended to charring experiments and the examination of assemblages of archaeological specimens to assess which plant parts are most likely to survive (Thompson in prep.). The ethnographic samples could then be assessed in terms of the most persistent plant parts and diagnostic ratios between specified components of the plant could be used to characterize them, and to classify archaeological material.

THE ARCHAEOBOTANY OF WHEAT AND BARLEY PROCESSING

The basic sequence of operations for threshing, winnowing and milling rice is akin to that for the glume wheats, einkorn (*Triticum monococcum*), emmer (*T. dicoccum*) and spelt (*T. spelta*), rather than the free-threshing wheats *T. durum* and *T. sphaerococcum*, bread wheat (*T. aestivum*) or barley (*Hordeum vulgare*), rye (*Secale cereale*) and oats (*Avena sativa*), where the grains separate from the chaff when threshed. The sequence is similar up to and including the stage of primary winnowing. After this the wheats are sieved to remove loose heavy straw nodes, seed heads and weed seeds (Hillman 1984b), whereas rice is put directly into storage at this point. A main difference, archaeobotanically, is that processing of wheats and barley breaks down the ear and stem into many more discrete parts. There are, however, two other archaeobotanically important features of the wheat/barley system which have less importance in the case of rice. They are crop contamination by weed seeds and the role of heat during processing.

Crop processing techniques are known to differ in terms of scale, and to a lesser degree in type, between wet and dry areas of the wheat-growing world, but the post-harvest treatment of rice varies less between the various climatic regions of Asia. In wet parts of Europe, crop storage is conventionally as semi-clean spikelets and dehusking occurs, as with rice, on a daily basis, often indoors. In more arid areas, on the other hand, the whole crop is processed at harvest time and stored

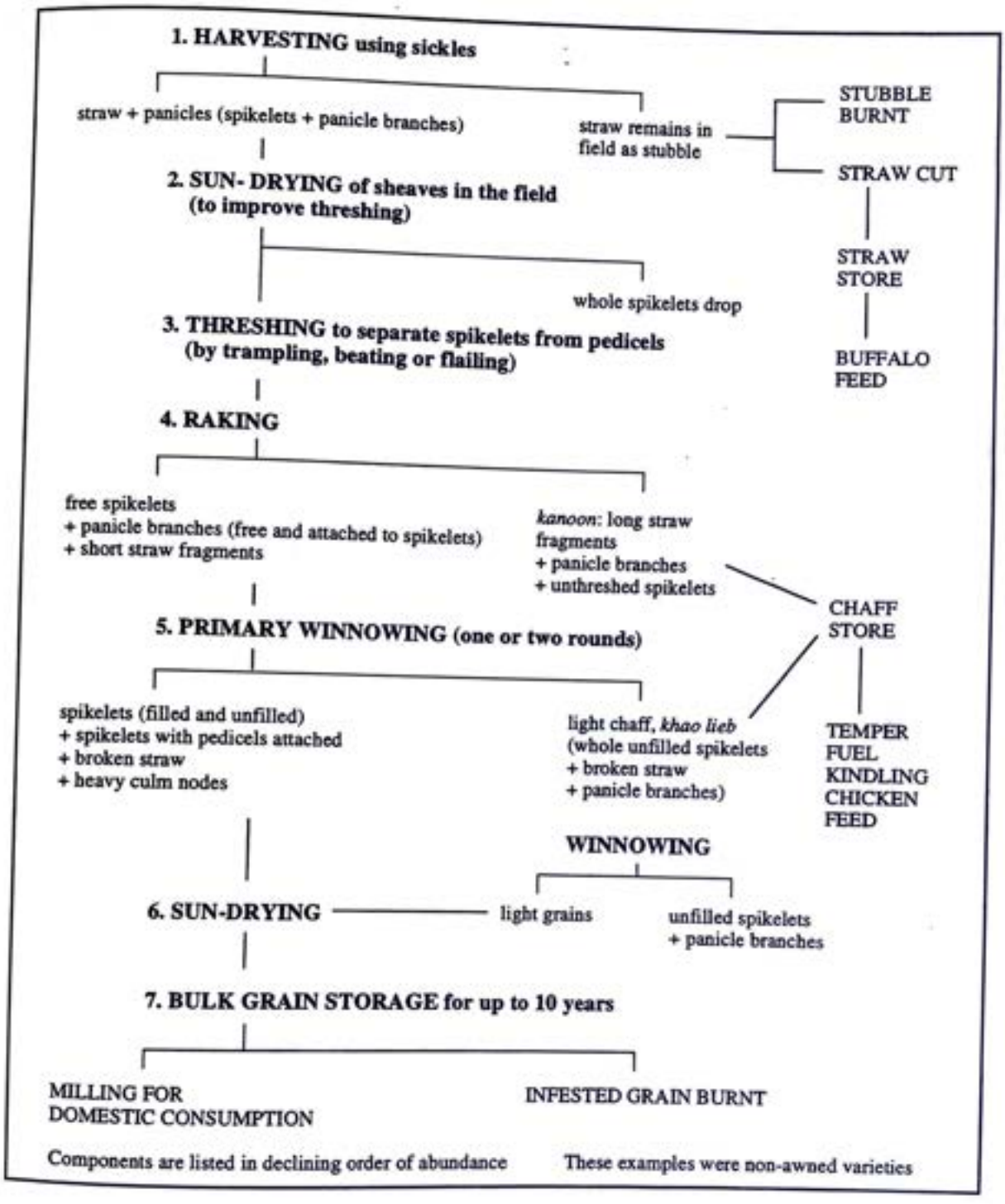


FIG. 32. Schematic diagram of the traditional harvest and post-harvest procedures for processing lowland rice: the major operations, composition of prime products and by-products, and their uses

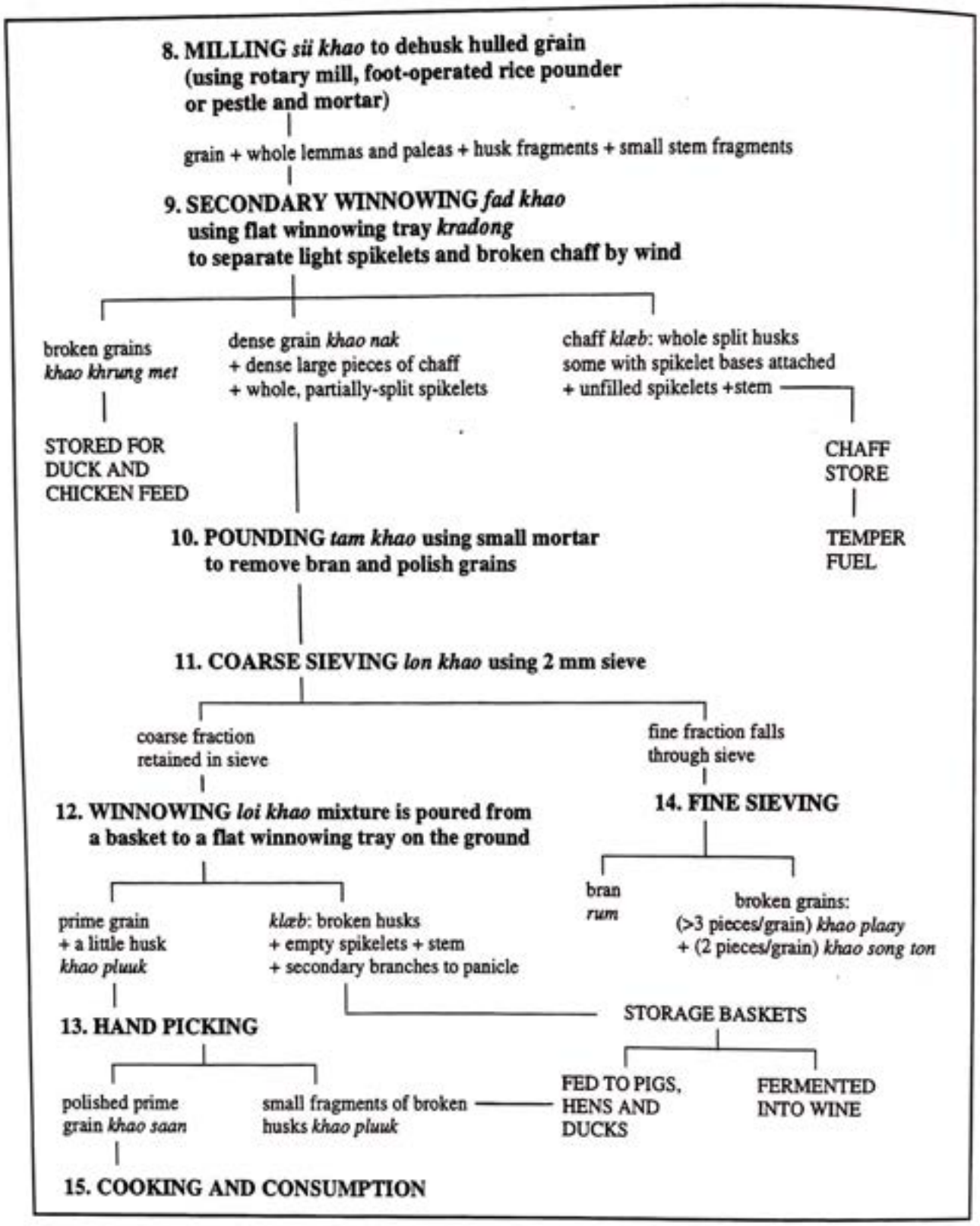


FIG. 33. Schematic diagram of the traditional milling and pounding of rice, the composition of prime products and by-products and their uses

as grain (Hillman 1984b). In the case of rice, storage is, almost without exception, as spikelets, apart from situations where the crop is reaped with a finger knife with so little stem or panicle attached that bulk storage sometimes occurs prior to threshing.

Crop contamination by weed seeds

European archaeobotanists have emphasized the potential of weed seeds for characterising and statistically differentiating between the various crop-processing by-products, and have demonstrated that the composition of archaeological assemblages of charred seeds provide information for elucidating past agrarian practice (e.g. Jones 1984a, 1987, Englemark 1989). The utility of this approach to rice, and especially to the pond-field agriculture of South-East Asia, is limited by the fact that the rice harvest is usually rather weed-free in comparison with that for wheat, barley and oats. Weeds certainly exist in rice fields, above all in dry upland conditions and in the early pre-flooding stages of deepwater rices where seedlings are trying to establish themselves in dry ground (De Datta and Zahidul Hoque 1982), but weed infestation is troublesome to the farmer more because of competition than on account of contamination of the harvest.

None of the samples of rice-processing by-products collected from the lowland rainfed systems in Thailand contained any weed seeds, and the same cleanliness was noted by Yen (1982) for samples from an upland harvest. The absence of weed seeds is probably due to a combination of ecological and cultural factors. Floristic diversity of weeds in rice is related to a combination of physical and agronomic factors, namely the landform and the soil moisture regime, together with cropping methods such as land preparation techniques, seeding methods and the frequency of weeding, as well as the cleanliness of the seed source. In pre-mechanized, non-chemical agriculture the prime reason for the paucity of weeds is that non-aquatic segetals cannot tolerate the inundation conditions of wet rice and are drowned out by rising water levels (Fukui 1978). Most troublesome weeds of lowland rice are semi-aquatic grasses and sedges which can co-exist with wet rice in flooded conditions, causing substantial crop losses due to competition (Table 32).

Upland and deepwater rices tend to suffer from weed competition more than swamp rice or irrigated crops. Noxious weed infestation is worst, and floristic diversity greatest, where rice is broadcast into dry soil, and of all the cropping systems for rice, this most closely resembles that for arid-land cultivation of wheats and barleys. By contrast, swamp rice cultivation, a variant of which is most likely to have been found around prehistoric Khok Phanom Di, seems to have less serious weed infestation than other types of land management. Weeding is regarded as unnecessary, for instance, in the swamp swiddens worked by the Kantu'. This is in part attributed to a lack of weed regrowth because of thorough clearance of the plots. Weeds are slashed and left to rot in standing water and the soil surface is chopped and turned (Syarifuddin *et al.* 1983). The fact that the rice is transplanted so that it has a competitive advantage over weeds at an early stage in its growth is equally critical, while standing water prevents most subsequent weed growth (Dove 1985).

Agronomic practices most likely to affect the degree of weed infestation are the planting methods, with broadcast rices having more weeds than transplanted ones where the young seedlings have a competitive advantage. The reaping method may also play a role in the cleanliness of the rice crop, especially when the finger knife is employed. As mentioned earlier, the use of this small blade permits selection of only the healthy ripe panicles, weeds being left behind in the field, along with unsound and unripe grain.

TABLE 32: *Thai weed floras associated with rainfed, deepwater and upland rice production*

Weeds of rainfed rice[a]	Weeds of deepwater rice[a]	Weeds of upland rice[b]
Chara zeylanica	*Pentapetes phoenicea*	*Dactyloctenium aegyptium*
Cyperus difformis	*Aeschynomene indica*	*Digitaria adscendens*
Cyperus pulcherrimus	*Alternathera philoxeroides*	*Eleusine indica*
Echinochloa crus-galli	*Cyanotis axillaris*	*Eragrostis tenella*
Fimbristylis littoralis	*Ipomoea aquatica*	*Panicum repens*
Leptochloa chinensis	*Melochia concatenata*	*Cynodon dactylon*
Ludwigia hyssopifolia	*Commelina diffusa*	*Chloris barbata*
Marsilea minuta	*Echinochloa colona*	*Brachiaria reptans*
Mimulus orbicularis	*Panicum cambogiense*	*Ageratum conyzoides*
Monochoria vaginalis	*Leptochloa chinensis*	*Amaranthus viridis*
Scirpus juncoides	*Echinochloa crus-galli*	*Commelina bengalensis*
Sphenoclea zelanica	*Paspalum scrobiculatum*	*Euphorbia hirta*
Utricularia aurea	*Ischaemum barbatum*	*Gomphrena celosioides*
	Cyperus pulcherrimus	*Heliotropium indicum*
	Fimbristylis littoralis	*Mollugo pentaphylla*
	Cyperus rotundus	*Phyllanthus nururai*
		Cyperus rotundus

(Sources: [a] Kittipong 1983 [b] Vongsaroj n.d.)

The potential for tracing past agricultural techniques by examining weed-seeds in the archaeological record is more promising then, in regions of dryland farming and where the sickle is used, than in areas of low-lying swamplands or with a finger knife technology.

The role of heat in cereal processing

Glume wheats are gently parched in ovens and kilns in order to make their husks brittle prior to dehusking. Rice, like bread wheat, may be under-represented in the archaeological record because parching is not required for separating the grains from the husk and there are fewer points of contact between the crop and fire where charring accidents could occur. Other South-East Asian food plants such as Job's tears (*Coix lachryma-jobi*) are, however, roasted as part of their preparation (Bodner 1986), providing more chances for cooking accidents. Thus, *Coix* would theoretically be more likely to occur in the charred archaeobotanical record than would rice.

The heat rice does require during processing is usually supplied by the sun. Insolation reduces the moisture content of rice spikelets so they can be efficiently winnowed and safely stored, and renders the husks more brittle before milling or pounding. However, in some damp upland areas artificial heat may be needed. During the rainy season in the northern mountains around Mae Hongson, for example, rice spikelets are gently heated on a metal plate prior to pounding (personal observation), and in the mountains of Vietnam we are told that

> Every morning the woman takes the needed amount of rice, places it in a basket, *and suspends it over a hearth.* She then puts the ears on the floor, which has been carefully swept beforehand, and threshes it with her feet, while holding on to a rope. Then she winnows it and pours it into a foot-powered mortar to hull it (Dement'eva- Leskinen 1969:6) [emphasis added].

Situations such as these increase the possibility for accidental charring and mean that charred rice remains are more likely to be found in cooler upland areas than in the lowland plains where the natural sunlight provides all the heat necessary for parching the grain.

A variation on rice processing: *khao mao*

An alternative dehusking and cooking technique for rice, which brings the grain and husk into closer contact with fire, opening up the possibility of charring accidents and thereby increasing archaeological visibility, is the preparation of *khao mao* (*mpin* in Kalimantan, Dove 1985, *emping* in Malaysia, Kato 1988). In Thailand this is a sweetmeat delicacy made from toasted pounded rice grains mixed with coconut. In preparing this dish, young grains of glutinous rice (*Oryza sativa* L. var. *glutinosa*) are roasted in the husk. This was seen at Samet Ngaam, near Chantaburi (see Fig. 4), in December 1986, and samples were collected of the prime products and each of the by-products at each stage of the processing. Storage and use of by-products were said to be identical to the main sequence outlined above.

Glutinous rice is a staple crop in the highlands of mainland South-East Asia, but restricted to specialized uses in the lowlands (Golomb 1976). *Khao mao* may be prepared at harvest time in the lowlands, because the short-season glutinous rice matures earlier than *khao saan* (regular rice) and is ready to be consumed at a point when the previous year's stored grain is almost depleted. It is also considered a festive dish, for celebrating the harvest season. The sequence of operations in preparing *khao mao* is as follows (see also Fig. 34):

1. Reaping. This was a small-scale operation to prepare a single dish for four adults, so only a single sheaf of immature sticky rice was cut. The implement used was a curved sickle and the stems were cut at their midpoint.
2. Threshing. The bundle was placed in a hessian sack and trodden to dislodge the spikelets from the stems. With the bundle still tied, the spikelets were shaken out onto a finely woven bamboo mat. The stems and leaves, with a few immature rice spikelets remaining attached to the panicle, were discarded. The prime product at this stage comprised both filled and unfilled spikelets, with 2 per cent of these still attached to broken pedicels and panicle branches. Breaks in the panicle were typically at the secondary branch.
3. Winnowing. The main product was transferred from the mat to a basket and winnowed by pouring the grain from head height to the ground. The by-product at this stage was made up of whole but immature, unfilled spikelets and small, light but grain-filled spikelets, at a ratio of 3:1. About 2 per cent of the sample was of spikelets attached to pedicels and panicle branches.
4. Second winnowing. The main product was retained and shaken in a large flat circular winnowing basket. The fine fraction was skilfully worked to the edge away from the operator,

who tossed the waste to the floor. This light winnowing by-product comprised smaller and lighter whole husks along with pedicel, straw and leaf fragments.

5. Parching. A small wood-fueled brazier was lit and the whole spikelets were parched in a metal container for ten minutes.

6. Pounding. Once cool, the toasted spikelets were pounded in a large wooden mortar using a wooden pestle and paddle. The pestle was applied in a repetitive vertical pounding motion, while the paddle was intermittently used to redistribute the mixture of grains and husks. This pounding broke open the lemmas and paleas to release the bran-covered grain.

7. Third winnowing. Further winnowing produced a by-product dominated by broken husk fragments, some of which had glumes and spikelet bases attached. These husks had split into long rectilinear pieces, some of which were the full length of the spikelet. This fraction also included broken or sometimes complete caryopses, many of which had been blown away because they were still partially encased by their husks. Less than 1 per cent of the sample comprised paired lemmas and paleas.

8. Secondary pounding. The prime product was returned to the mortar for further pounding. This removed the bran from the outer surface of the grains and squashed the polished caryopses. Subsequent winnowing for a fourth time produced waste of a much finer size grade, mostly small longitudinal fragments of husk, bran and the occasional misplaced piece of prime grain.

9. Hand sorting. The prime grain was finally sorted by hand to remove any stray grains that had not been successfully dehusked. The final product was a toasted, battered grain to be eaten with coconut milk and sugar. The majority of the rice remained as intact, if flattened grains, but others were smaller broken fragments. About 10 per cent of the final product retained the reddish coating of the pericarp. The finest by-product of all was the residue left inside the mortar. This mainly comprised bran and fine husk particles, together with some of the flattened prime grain.

This description of *khao mao* production indicates one of the methods of preparing rice which could offer more possibilities for cooking accidents than possible with the conventional sun-dried techniques. Food prepared in this way would have a greater chance of being accidentally charred and thereby being preserved for incorporation in the archaeological record.

This overview of agrarian and crop-processing activities and their role in the taphonomy of rice demonstrates some of the mechanisms by which rice may be incorporated in the archaeological record. A subsequent stage in the taphonomic pathway is the inclusion of comminuted husks as temper in pottery. This was one of the most conspicuous forms of rice preservation at Khok Phanom Di and will be discussed further in the following chapter.

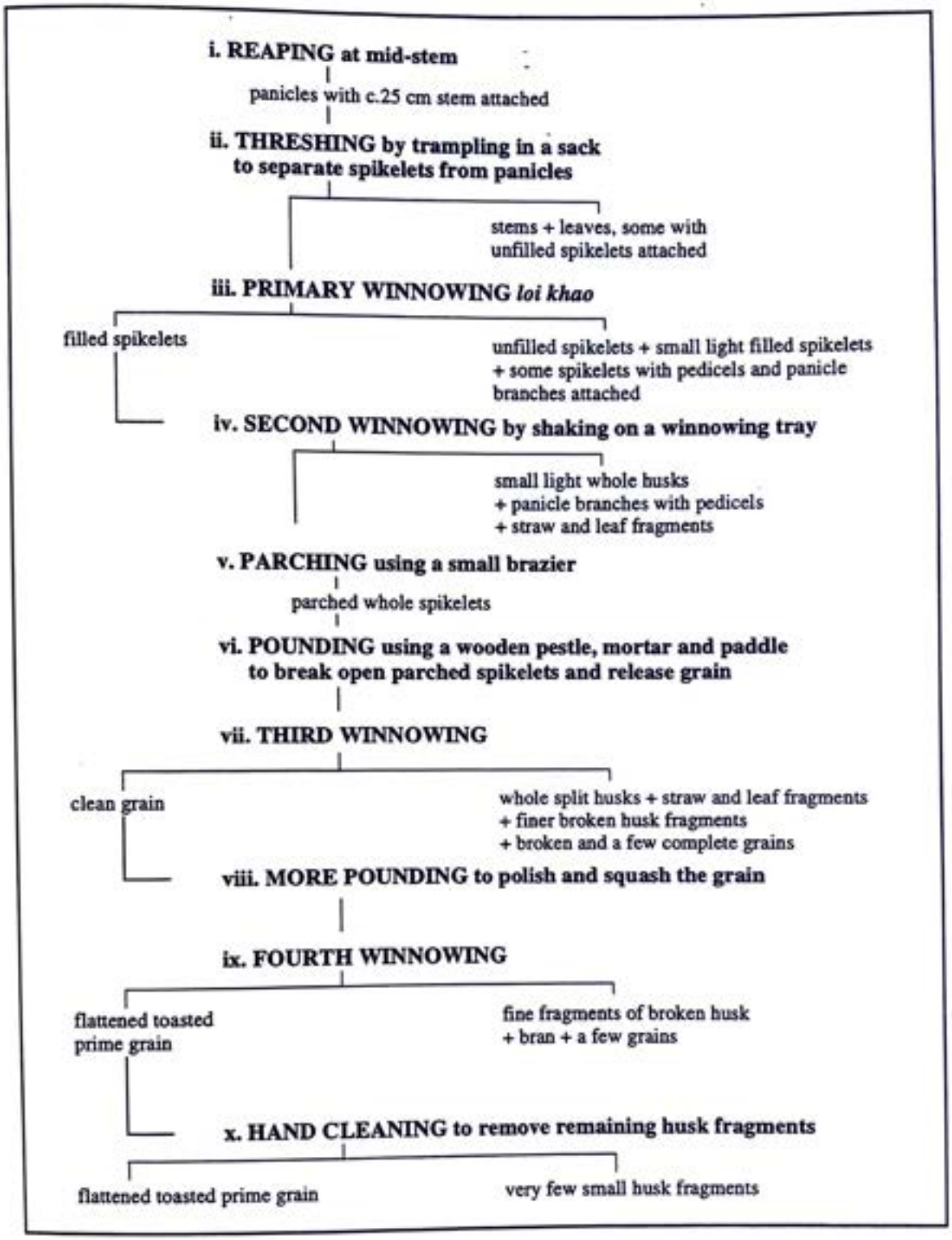


FIG. 34. Schematic diagram of the preparation of *khao mao*

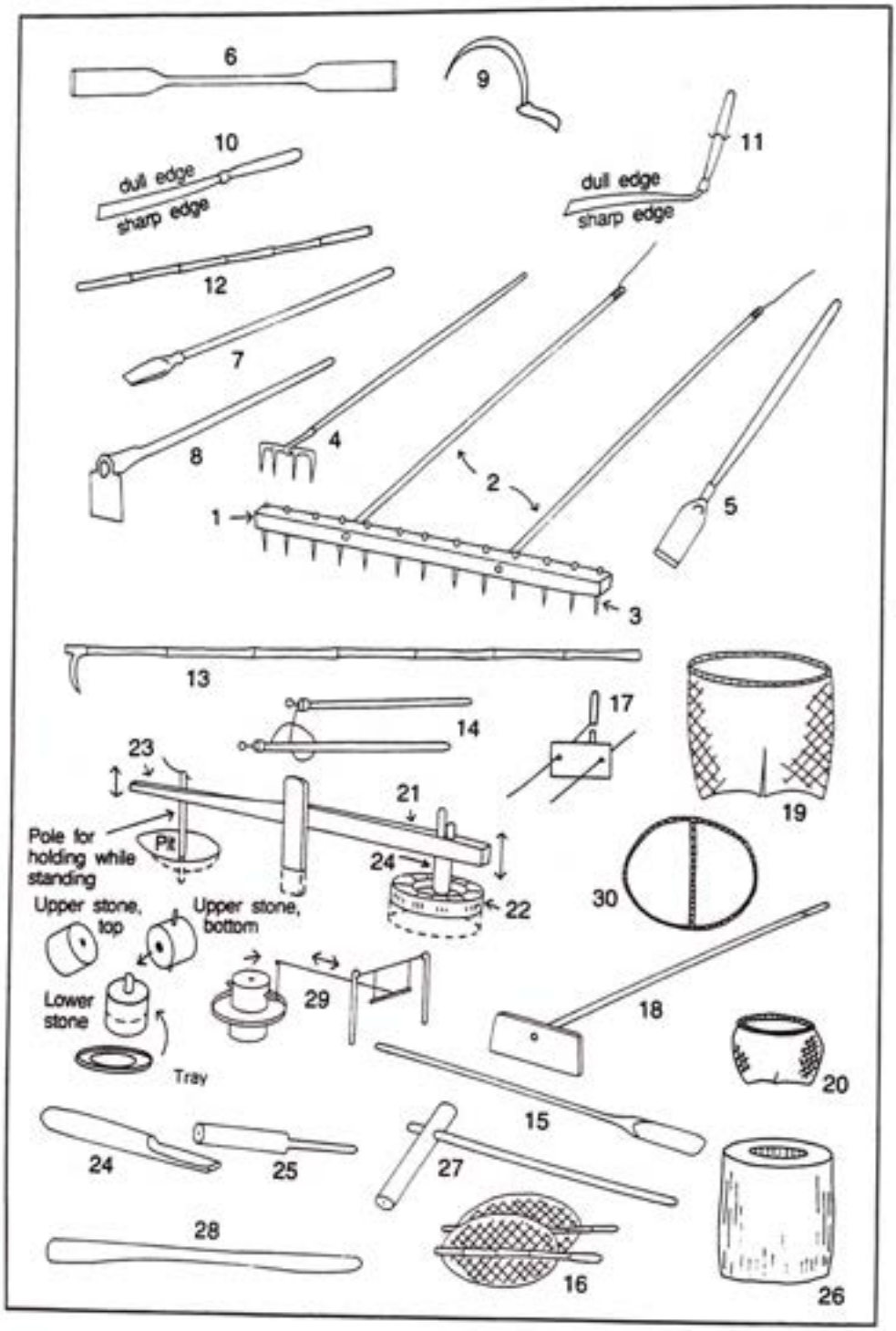


FIG. 35. Traditional implements for harvest and postharvest processing of rice. **1.** harrow, **2.** *khan* of the harrow, **3.** harrow teeth, **4.** iron rake, Chinese style, **5.** iron shovel, **6.** wooden shovel, old style, **7.** spade, **8.** hoe, **9.** sickle, **10.** chick-head shovel, **11.** *liam*, a kind of big curved knife with long or short handle, **12.** bamboo pole for carrying rice seedlings over the shoulder, **13.** straw hook, made of bamboo, used in threshing and picking out straw, **14.** threshing "chopsticks" of hardwood and bamboo for holding rice sheaves and beating them, **15.** shovel with groove, made of lightweight hardwood, for tossing rice, **16.** mats for shaking out rice dust, woven entirely of bamboo including the border, **17.** board for pushing rice, of the kind having ropes which they vie in pulling ceremonially, **18.** *thadthaa*, **19.** *kachee* or *sàd* for measuring rice, woven, **20.** *kàbung* or *lûng sàd*, **21.** lever pestle, for pounding, **22.** lever-pestle mortar of wood, buried in the ground, **23.** tail of the lever, **24.** pestle for pounding, **25.** pestle for *soom*, **26.** hand mortar, of wood, **27.** big hammer-shaped pestle, for hand mortar, **28.** pestle for hand mortar, **29.** rice mill, woven, **30.** winnowing basket woven of bamboo bark with wooden cross-piece, for winnowing rice. (Source: Rajadhon 1961:379–80)

VII. THE RICE REMAINS

INTRODUCTION

TWO of the main aims of the 1985 excavation were to seek evidence for the plant part of the human diet, particularly the use of rice as a carbohydrate source, and to consider the environmental context for rice domestication. At the outset, one of the hypotheses had been that the prehistoric occupants of the site may have begun to domesticate rice in the course of cultivating wild rice. A possible stimulus was thought to be that land-sea relations changed leaving the Khok Phanom Di people progressively more isolated from their established swampland food resources, which may have included wild grasses such as rice (Higham 1984). In the event, rice remains, from domestic crops rather than wild grasses, were found throughout the stratigraphic sequence, and in a wide variety of forms. The evidence for rice comprises fragments of husk preserved as ash within the soil, in pottery and coprolites and other gut/faecal deposits.

This chapter will describe the rice remains in terms of their retrieval, preservation and occurrence through the stratigraphic profile. Criteria for distinguishing between the remains of domestic and wild rices in the archaeological record will then be discussed, with application to the macroremains in question here.

Conceptual approaches to the domestication of rice

The history of archaeobotanical research in South-East Asia, while neither long nor extensive, has been intimately linked with the quest for evidence of agricultural origins, especially the domestication of rice. Theories of plant domestication based on biogeographical and genetic data have provided a context for archaeobotanical finds (Gorman 1969, 1970), with controversial claims for early agriculture in the region (cf. Solheim 1970, 1972).

The fundamental distinction between cultivation and domestication is that cultivation involves human manipulation of ecosystems while domestication entails human manipulation of a plant's means of reproduction and its genetics. Domestication may occur in the course of cultivation, a concept introduced by Helbaek (1970:195) when he wrote:

> ... a cultivated plant need not necessarily be domesticated – indeed, cannot by any means so be from the outset - whereas on the other hand, a domesticated plant can only exist as a cultivated plant. Cultivation is a matter of governing ecology, while domestication depends on some physiological inefficacy in a plant, of which man takes advantage.

Non-domesticated plants may be cultivated, and in the case of cereal crops there was a period of pre-domestication cultivation before phenotypic changes were induced by the unconsciously selective agronomic practices of the cultivators. The issue of incipient rice domestication has a long history in South-East Asian archaeology (Hutterer 1983), yet there remains a gap between the conceptual models regarding the evolutionary pathways of domestication and archaeobotanical evidence demonstrating that process.

Genetic and biogeographical data indicate that the two species of domestic rice, *Oryza sativa* L. in Asia and *O. glaberrima* Steud. in Africa, evolved separately from perennial grasses, but the precise pathways and the intermediate ancestors continue to be disputed. In West Africa, the cultigen *O. glaberrima* is thought to have been produced from the annual *O. barthii*, preceded by the perennial *O. longistaminata* (Portères 1956, Harlan 1973), although this has been rejected by Second (1985). The Asian cultivar, *O. sativa* L., is considered to have evolved from either the annual *O. nivara* Sharma et Shastry (= *O. fatua*, *O. sativa* var. *fatua*, *O. sativa* forma *spontanea*) (Sharma and Shastry 1965b) which in turn derived from the perennial *O. rufipogon* Griff. (Whyte 1972, Harlan *et al.* 1973, Shastry and Sharma 1974, Chang 1976a and 1976b, Second 1985), or directly from the perennial *O. perennis* Moench. without an intermediate annual stage (Morishima *et al.* 1963, Chandraratna 1964, Sampath 1964, Oka 1975, 1988; see Fig. 36). A third proposed progenitor for the cultivar is an intermediate perennial-annual type of rice, considered to have given rise not only to the crop plant but also to wild annuals (Oka 1974, Sano *et al.* 1981, Sano and Morishima 1982, Morishima 1986). It is doubtful whether archaeobotany will be able to contribute substantially to this debate without great refinement in identification criteria, or the discovery of plant remains which are significantly better preserved than those customarily found. The cultivar is thought to have differentiated in the course of domestication into three varieties, with subsp. *indica* probably having its origin in South-East Asia, *japonica* (or *sinica*) at higher altitudes in southern China (Oka 1974, 1975, Oka and Morishima 1982), and *javanica* in tropical island South-East Asia (Chang 1976a), although the timing and location of these changes remain to be resolved. It has been argued that electrophoretic data (Second 1982, 1984, 1985) and restriction fragment length polymorphism data (Wang *et al.* 1992) are consistent with two independent domestications of rice in Asia, creating *O. sativa* var. *indica* and *O. sativa* var. *japonica*, again in monsoonal South-East Asia and southern China respectively.

Introgressive hybridization between wild and cultivated rices has produced weedy or spontaneous intergrades adapted to disturbed environments, found growing in or alongside rice fields. These mimic the cultivars but retain the wild-type shattering habit. They are collectively called *O. sativa* forma *spontanea* Roschev. The genetic flexibility within the genus, especially the infusion of genes from the cultigen to the wild types, has been documented by Harlan *et al.* (1973:320):

> In eastern India, weed rice is a serious pest of paddy fields. Indian plant breeders once developed some distinctive purple-leaved cultivars so that farmers could distinguish weeds from cultivated rice at an early stage and could clean their fields by pulling up the weeds. Within a few years, however, the weed race had picked up the purple-leaved character.

Cytogenetically, all these taxa share the genome A, (n=12). They are all members of the primary gene pool, which means that the cultivar, the weedy or spontaneous races and their wild relatives are all part of the same biological species as they are inter-fertile, but they have nevertheless been named as if they were three distinguishable taxa (Harlan and de Wet 1971). They may be differentiated by their habitats and to some degree by morphology. With due acknowledgment of the continuum between the perennial and annual types of wild rices and their single species in biological terms, the terms *O. rufipogon* and *O. nivara* will be applied here to the perennial and annual forms of wild rice, in a conceptual sense.

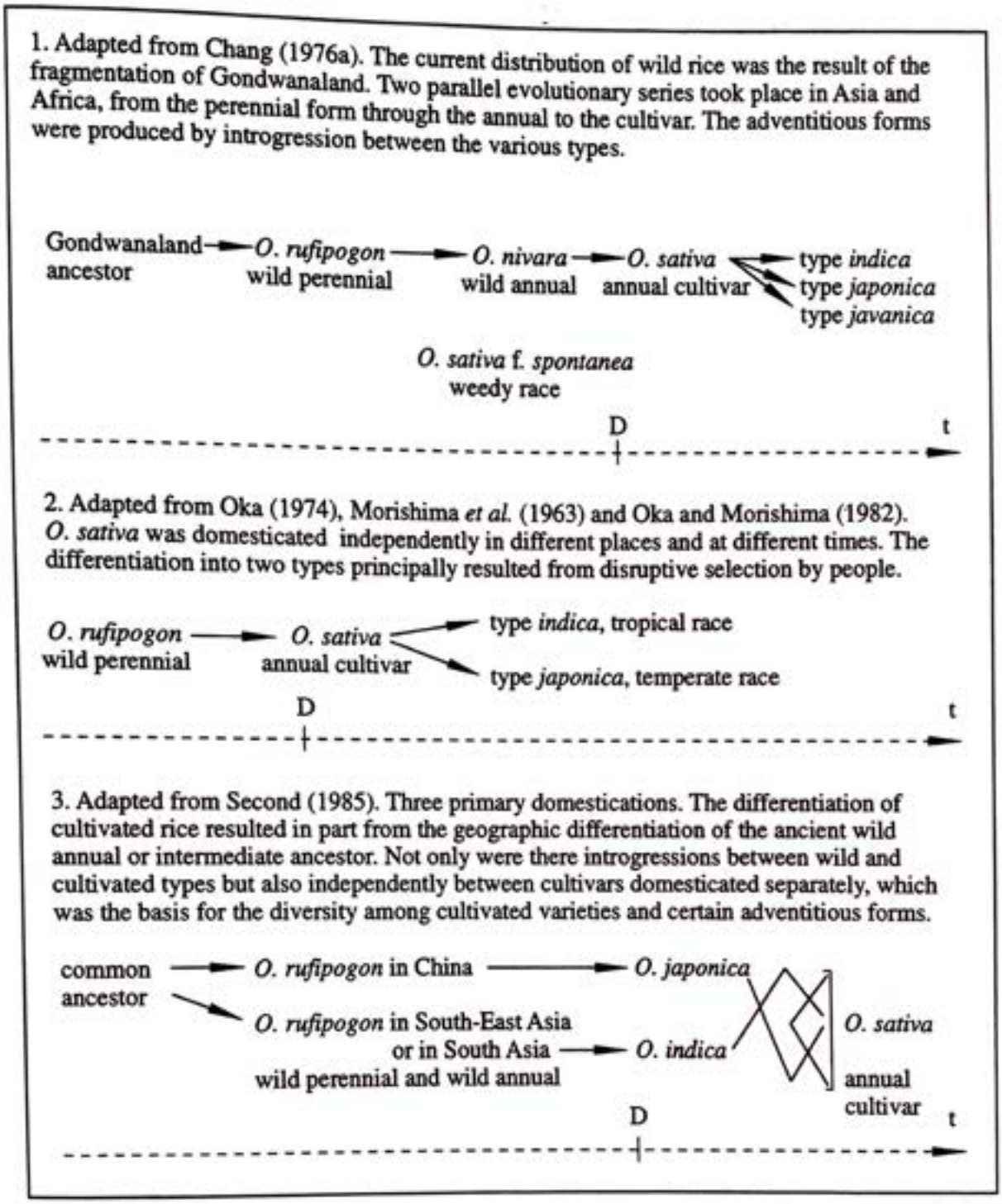


FIG. 36. Schematic representation of three hypothetical phylogenetic pathways for Asian rices. Time (t) is indicated along the horizontal axis, with the point of domestication marked as D. (Adapted from Second 1985:28)

Domestication in cereals almost never produces a new species in biological terms (Harlan and de Wet 1971, Harlan *et al.* 1973, de Wet 1981), and the differentiation within *Oryza* is particularly troublesome. According to Harlan (1977:370) '[t]he situation is genetically messy and the interactions are so extensive that the nature of the original wild race is difficult to untangle'. Furthermore, Duistermaat (1987:157) opens her recent revision of *Oryza* with the salutary warning that '*Oryza* L. (Gramineae) is taxonomically a difficult genus'. This she attributes to polymorphism in the cultivar *O. sativa* L., due to selection and introgressive hybridization. Given the difficulty, widely acknowledged by taxonomists, in distinguishing these taxa even in perfect herbarium specimens, it is not surprising that archaeobotanists find the identification of fragmentary, distorted archaeological material highly problematic and this has been a matter of some concern in this research.

The ecological and geographical origin of Asian cultivated rice

The typical habitats of perennial wild rices are permanently wet localities, such as river flats, deltas and open parts of inundated tropical forest, whereas their annual relatives are adapted to temporarily flooded areas, shallow ponds, drainage channels and irrigation ditches which support lush herbaceous growth during the monsoon and become progressively more parched during the dry season (Morishima *et al.* 1961, Tateoka 1963, Sharma and Shastry 1965b). The perennial *O. rufipogon* is procumbent, produces tillers at its higher nodes, is photoperiod-sensitive and self-pollinating, producing few seeds, while annual populations of *O. nivara* are erect, self-pollinating, strongly awned and high seed producers. Their seeding coincides with the end of the wet season. The low-lying ephemeral swamps which are the home of annual wild rices are now considered as the locus of incipient rice agriculture in the form of wetland cultivation, with broadcast sowing on naturally flooded land (Harris 1974, Chang 1976b, Harlan 1977). This represents a change in opinion from the idea that dry-rice shifting cultivation in the uplands preceded swamp paddy and pond-field cultivation (cf. Whyte 1972, An 1989), based on the distribution of the 'simplest' agricultural techniques practiced among the hill tribe communities of South-East Asia. The semi-aquatic habit of wild rices argues against dryland cultivation in the hills being the earliest riziculture, as does the advanced and highly selected nature of dryland rice varieties (Chang 1989). Wetland cultivation would fit more closely with the physiological requirements of wild rice and presumably those of early cultivated varieties. Swamp cultivation would be most practical in the lowlands and on the alluvial soils of the lower reaches of river systems.

In wider geographical terms, annual grasses including wild rices are thought to have developed from perennial forms in the southern foothills of the Himalayas through physiological stress during the fluctuations of temperature and precipitation of the late Pleistocene (15-10,000 bp) (Whyte 1972, 1985). The region of incipient rice domestication and agricultural origins has been demarcated variously as China (de Candolle 1884), India (Vavilov 1926, 1951, Ramiah and Ghose 1951), mainland South-East Asia (Spencer 1963, Li 1970, Sampath 1973), a broad belt along the lower slopes of the Himalayas from upper Burma to southern China (Chang 1976a) and recently, on linguistic grounds, central and south-eastern China and adjacent areas of South-East Asia (Bellwood 1990, Higham and Thosarat 1994). The most widely respected and quoted view is that of T.-T. Chang (1976a), whose analysis was based on the current distribution of wild rice, which may have differed under early Holocene climatic conditions, and may have spread alongside the cultivars. The putative area for early rice domestication is thus diffuse and imprecisely defined. It also diverges from the archaeological data. Currently, the earliest evidence for domestic rice is at Hemudu

on the lower reaches of the Yangzi River and possibly at Pengtoushan further inland, although here the botanical evidence for domestic rice has not yet been published (Yan 1991).

Models depicting the emergence of rice agriculture cannot yet be validated on the basis of archaeological evidence. The repeated reformulation of hypotheses regarding forager-farmer transitions, rice domestication and the origins of agriculture far outpace the rate of excavation, and the empirical data for testing these conceptual models remain wanting in South-East Asia. Reliably identified botanical specimens from well-dated, carefully excavated and documented sites are lamentably few and secondary evidence is still sometimes used instead of plant remains for defining a site's subsistence base. In Vietnam, for example, 'Neolithic' sites, implicitly agricultural, are defined as such simply on the grounds that they contain ceramics, ground stone tools and 'hoes', but without reference to faunal or floral evidence (Higham 1989). The archaeobotanical research undertaken at Khok Phanom Di was designed to provide a more rigorous approach to the subject.

THE RICE REMAINS FROM KHOK PHANOM DI

The most useful and best preserved macroscopic plant remains found on dry open archaeological sites are usually those preserved by charring. At Khok Phanom Di, more than four hundred soil samples were systematically floated to extract plant remains and other classes of biological material. The resulting light fraction, or flot, included wood charcoals, seeds and quantities of finely fragmented, ashed rice chaff. No caryopses were recovered by flotation but a small cache of charred caryopses or spikelets is known to have been recovered by Noksakul during earlier investigations at the site. Three 'grains' were found with skeleton 3, according to Bannanurag (1989:21), but descriptions have not been published and the plant remains themselves were not available for examination as part of this study. The paucity of charred remains in general and caryopses in particular at Khok Phanom Di was surprising given that experience elsewhere has indicated that most habitation sites produce charred remains of food plants if flotation is carried out (Hillman 1981). The dearth of charred rice remains is related to a number of taphonomic factors including the filtering effect of crop processing operations, and the narrow range of charring conditions which produce recognisable rice remains as discussed in chapter VI.

On-site sampling for rice

Plant remains were extracted through the systematic flotation of sediment, as well as the manual retrieval of husks during excavation. Ashed husks were recovered by flotation of bulk soil samples and from soil blocks which were subsequently disaggregated in the laboratory under low power binocular microscopes. These soil blocks provided fewer but better preserved examples of ashed rice husk and silica skeletons.

Rice was present through virtually the entire stratigraphic sequence of flot samples. Soil samples for rice were taken from a depth of 1.5 m onwards, when the excavators began to notice husks on the bedding planes of the soil. These samples comprised soil blocks, with dimensions varying from *c.* 100 mm^3 to 150 x 200 x 100 mm. A solitary sample was removed from layer 6:1, but from layer 8:7 down to layer 10:22 soil blocks were retained more frequently, because rice was more conspicuous.

We turn now to the pottery with rice husk inclusions, of which there were three kinds: inclusions in clay externally coating some cord-marked pottery, temper in the fabric of the vessel, and spicules of rice husk within bleb-tempered grog. A small number of sherds had both a rice-tempered fabric and an external coating of clay.

The ceramic sequence

There is a wealth of evidence for a long-established, local potting tradition at Khok Phanom Di. Raw materials are present as sand and clay caches; potting implements (anvils and burnishing pebbles), ash debris and platform supports from firing pottery have all been recovered, and above all, vast quantities of ceramic sherds and whole vessels interred in burials. Vincent (1989) has summarised the ceramic sequence within a four-phase framework. This is based on vessel morphology and information regarding production methods, ceramic technology and clay sourcing inferred from thin sections. Locally-prepared and imported ceramics are both considered.

The Khok Phanom Di ceramics are described at length elsewhere (Vincent in prep.) but the critical points here, in terms of pottery providing evidence for the use of rice, are that the local production methods switched to tempering with rice husk only during the final phase of the occupation, and that exotic rice-tempered wares were found throughout the five hundred year sequence, but that they made up only a very small proportion of ceramic assemblage. These include exotic bleb-tempered grog fabrics throughout the sequence, but although spicules of rice are visible in thin section, they are too small to contribute to an analysis of rice husk topography.

The ceramic data suggest an initial brief occupation at the site represented by the basal 30 cm of cultural deposit, a short hiatus in occupation and a second major reoccupation, with the area under excavation used as a burial ground and subsequently as a ceramic workshop. During the earliest phase, locally-prepared pottery was sand-tempered, but ceramic phases 2 and 3 are characterised by a different and distinctive potting technique which employed grog temper. The final ceramic period, coinciding with the potting workshop, is marked by fabrics heavily tempered with rice chaff. Potters are regarded as technologically conservative, especially in their choice of tempering agents. The use of rice husk within a potting tradition therefore suggests easy access to supplies of husk and other crop processing waste, and most probably the local cultivation of rice.

The Khok Phanom Di people were evidently involved in a wide trade network, exchanging pottery and other commodities across a wide region. Imported sherds, representing a number of mineralogically distinct sources across the south-eastern uplands, are recorded throughout the stratigraphic sequence. A very small percentage of these exotic wares was tempered with rice husk. This is indicative of agriculture across the region, but as these chaff-tempered wares were limited to single sherds per excavated context, it is difficult to draw any firm conclusions about variability in the cultigen.

Rice remains examined by SEM

Two classes of pottery were rice-tempered: locally-made pottery in layer 3, which is Ceramic Period 4, when the excavated area is interpreted as a potting workshop, now more removed from the coast, and secondly, exotic pottery in the lower two zones (Vincent 1987, 1989). Nine rimsherds of local ware from layer 2:3 were broken up to extract rice remains. These contributed well-preserved material, and more than 600 small fragments of husk were examined. Exotic wares were analysed

from layers 5:1, 6:4, 6:7, 7:1, 7:7, 8:2, 8:5, 9:2, 9:6, 10:4, 10:8 and 10:26. Most of these were very small sherds, some measuring less than 1 cm^2.

The classes of material are described below in ascending order of quality of preservation. Specimens from the flot were preserved in the worst condition, while some of the husks in the coprolite from burial 67 were found as virtually entire husks (lemmas and paleas), preserved with a high degree of detail. The occurrence of each type is summarized in table 33. The flot samples were all from quadrant A, while the soil blocks and the ceramic materials were taken from all four quadrants of the excavation.

TABLE 33: *Summary table of the occurrence and condition of rice husk remains*

Layer	Flot	Soil	Clay coating	Temper	Coprolite
1	-	-	-	-	-
2	F	-	-	good	-
3	F	-	-	-	-
4	F	-	-	medium	poor
5	F	S	-	poor	poor
6	F	S	-	poor	poor
7	F	-	-	medium	-
8	F	S	medium	medium	-
9	F	S	medium	poor	-
10	F	S	good	medium	good
11	-	S	-	-	-

F and S indicate the presence of rice husks in some of the samples from the layer
poor/medium/good indicate the presence of rice husks and their general state of preservation

In addition to these fragments from spikelets, there were a few instances where the remains of monocotyledon leaves and/or stems were found adhering to bedding planes within the soil samples. The possibility that these represent rice straw could be confirmed by means of phytolith analysis. The presence of straw could indicate the harvesting method used (whether the culms were cut at the base or near the panicle), and could even provide evidence supporting the notion that Khok Phanom Di was a rice producer site (see also the section on crop processing above).

Rice remains from the soil matrix

Rice remains occur in the soil throughout the stratigraphic sequence at Khok Phanom Di, apart from layer 1. Evidence takes the form of fragmentary, ashed and charred husks as well as impressions of husk on soil particles in the flot samples from quadrant A. These occurred from layer 2:1 through to layer 11. Silica skeletons were found in soil sampled as blocks and later excavated under low power binocular microscope in the laboratory. In the flot, both impressions and husk fragments themselves were found, with impressions being the more numerous. This material was very poorly preserved, with impressions similar to, but considerably more degraded than, the impressions of

husk from the pottery. Most of these specimens were less than a millimetre in their longest dimension and typically took the form of impressions in a silty matrix or as highly abraded fragments of husk attached to a soil particle, probably preserved because of their high silica content. Most of these husks were not charred and were not discrete items. Sometimes, where the surface layer had been removed, the inner cell structure was exposed (Fig. 42:2). Occasionally, where small pieces of husk occurred in the flot samples, as in flot from layer 6:1, the surface was obscured and although tubercules were visible, their gross morphology was unclear (Fig. 42:1). The poor preservation of rice remains recovered by flotation is probably related to their immersion in water. This caused some silica skeletons to separate from the soil matrix, led to the disintegration of siliceous husk fragments and disaggregated the soil particles which had, *in situ*, been part of an impression.

The chequerboard arrangement of tubercules on these husk epidermal fragments and impressions, and the broken trichomes embedded in the impressions, indicate that the remains belong to the genus *Oryza*. Specimens from the flot were neither sufficiently complete to provide macroscopic features for identification, nor adequately preserved to offer micromorphological characters. Nevertheless, they were recorded in systematically collected samples and therefore provide a controlled indication of the deposition of rice throughout the occupation of the site. Specimens from the flot samples from eight quadrant A contexts were examined using SEM (Table 34, Fig. 42).

TABLE 34: *Rice husk from the flot examined by SEM*

Context	Condition and type of rice remains
6:1	poorly preserved husk fragments
9:1	poorly preserved husk fragments, some showing sub-surface anatomy
10:5	poorly preserved husk fragments, tubercules and a single trichome visible
10:21	poor impressions, some husk fragments showing sub-surface anatomy
10:22	husk fragments, with tubercules obscured by soil accretions
10:23	impressions and husk fragments showing sub-surface anatomy
10:25	poorly preserved husk fragments, some with sub-surface features visible
10:26	poorly preserved impressions
11:1	poorly preserved impressions
11:2	poorly preserved impressions, some fragmentary husks with sub-surface features visible

The rice husks that were visible on the bedding planes of soil blocks were apparently deposited as entire lemmas and paleas. Examination by light microscopy revealed the chequerboard arrangement of tubercules typical of *Oryza*, but it is difficult to confirm this through the fine anatomical details seen by SEM, since blocks of soil are not sufficiently coherent to resist being placed under vacuum without first being stabilized by chemical impregnation.

Silica skeletons of rice husks preserved in this way are very fragile indeed. Separating them from the soil using fine paintbrushes, scalpels and dental probes often leads to their immediate disintegration. This class of remains is, however, important, because it provides occasional examples of whole husks. Length and width dimensions expressed as a ratio have previously been

used with both Indian and Thai archaeological material for separating wild from cultivated rice husks (Vishnu-Mittre 1974, Yen 1977) (see p. 178 below). Nevertheless, in the case of the Khok Phanom Di material, it was rare to find specimens where both the length and width were found intact (Fig. 42:4-5). Fracturing the soil to reveal the specimen often led to crumbling or cracking of the husk, and many of the specimens were missing their margins so that measurements were incomplete.

The preservation of these husk fragments in the soil is most probably due to their high silica content which renders plant material, usually dissociated as phytoliths, relatively resistant to decay, even in calcareous soils (Rovner 1983, Powers and Gilbertson 1987). The threshold of alkalinity beyond which phytoliths are lost in solution is pH 9 (Rovner 1983). Soil pH values for the matrix at Khok Phanom Di range between pH 8 and 9 (Aitken 1992).

Silica requirements for rice are high (Barnes 1990) and the absorption and deposition of this mineral within the plant tissues reduces susceptibility to disease and pathogenic fungal and insect attacks, which may predispose silica-accumulating plants to selection as crops (Rovner 1987). One remarkable feature of *Oryza* is that it accumulates silica in abundance – more than other cereals (Yoshida *et al.* 1962b, Brandenburg *et al.* 1985). Silicification of various parts of the plant has been investigated in a number of studies. These have included the lemma and palea (Thomas and Jones 1970, Soni and Wynn Parry 1973, Kaufman *et al.* 1981, Balasta *et al.* 1989), the leaf epidermis (Soni *et al.* 1972, Maeda and Miyake 1973, Terrell and Robinson 1974, Kunoh and Akai 1977, Kaufman *et al.* 1981, Dayanandan *et al.* 1983, Takeoka *et al.* 1983, Kaufman *et al.* 1985), the stem (Kaufman *et al.* 1972, Jones 1975, Kaufman *et al.* 1981) and the scutellum of the caryopsis (Tanaka *et al.* 1976). Comparative studies have demonstrated that the husk has the highest concentration of silica (Yoshida *et al.* 1962a and 1962b, Juliano 1985). This high mineral content, up to 20 per cent of dry matter, with 99 per cent of this being silica (Thomas and Jones 1970), prevents rice straw, ploughed into the soil by farmers, from rotting away for many years (Jones 1975). This may account for the preservation of prehistoric rice, and spikelets in particular, in the soil at Khok Phanom Di. The high proportion of silica may also help to preserve the three-dimensional structure of the husk.

Burnt silica skeletons from the husks of other cereal crops have been reported for archaeological contexts, but the example cited for rice mentions siliceous remains from the megalithic site at Keppa in South India which, like some of those from Khok Phanom Di, were not actually burnt but nevertheless preserved in the soil (pers. comm. M. Kajale cited by Robinson and Straker 1991).

Rice remains from the pottery

Clay coating

Complete or near-complete husks or, more commonly, impressions of rice husk were also observed in a 1-2 mm layer of fired clay found only on the external surfaces of certain cord-marked body sherds. It is uncertain whether the coating was deliberately applied, in which case the husks were intentionally incorporated, or whether the clay layer might have resulted from placing a damp pot on a muddy husk-covered surface whereby clay and spikelet fragments accidentally adhered to the underside of the vessel.

The layer of clay was sometimes as hard as the ceramic matrix, suggesting a single firing, while in other examples it was softer than the main body of the vessel and easily flaked away. This could

be due to a second firing at a lower temperature, possibly over a hot cooking fire (pers. comm. R. Fordham-Edwards). The combination of a high-fired internal surface and a rough, low-fired external one could possibly have been used in pots designed to cool liquids through evaporation.

The material with clay accretions was found in 47 contexts, from layers 8 to 10. Within each context there was a range of preservation conditions. Colours of the clay coating ranged from pale buff, through pale yellow to reddish orange. While plant remains were clearly visible in all these materials, both as husk fragments and as impressions, the darker clays contained the largest and least fragile pieces of husk, preserved as white ash. This may be attributable to higher firing temperatures.

In high-fired examples, the clay layer was prized apart using a scalpel or dental tools, while in the softer sherds, organic inclusions were exposed by flaking or gently brushing. The fragile husks were lifted using a very fine damp paintbrush or the static charge around a filament of plastic. Breaking open the clay matrix frequently resulted in damage to the organic temper, but it was apparent that most fragments came from the central and thickest area of the lemma and palea. Occasionally there were lemma or palea tips (notably without awns) and, very rarely, part of a hollow rachilla. The significance of the lack of awns will be addressed below.

The husk fragments, especially when examined under SEM, were more informative than the impressions, which proved difficult to analyse due to the poor resolution of anatomical details in the coarse sandy matrix. Most skeletons were extremely delicate and many disintegrated during extraction. Scanning electron microscopy revealed that the cellular structure and topography of the silica-rich husks were clearly preserved (Fig. 42:6). Fine details such as microhairs were visible between the rows of tubercules, and macrohairs or trichomes were often intact.

In the case of husks from both the soil and the clay-coated pottery, length and width measurements were recorded using a low-powered binocular microscope with a calibrated graticule inserted in the eyepiece. The results are presented below in tables 35 and 36 respectively. Numbers of observations per context were very small and there were few spikelets where both length and width dimensions could be measured, so length/width ratios could be calculated in only a few cases. Some 15 per cent of the clay-coated sherds examined had spikelet remains or impressions where either a complete length or width dimension was measurable, but fewer than 5 per cent of the husks were intact (Fig. 42:5). Impressions were very dense in the clay coating, but the fragmentary preservation made identification of the rice inclusions far from straightforward.

Ceramic temper

Turning now to the rice husks which had been incorporated within the body of a small proportion of the Khok Phanom Di ceramic assemblage, we found better preservation of the remains. Organic material may be deliberately incorporated in the matrix of a vessel in order to improve the workability of the clay and to reduce the shrinkage on firing (Rye 1981). In rice-growing areas the material chosen for temper is often broken rice husk.

Vishnu-Mittre (1969) tried thin-sectioning potsherds to examine rice husk inclusions but found the technique unsatisfactory because the plant remains were fragile, so this was not attempted with the Khok Phanom Di material. Rather, fired husks were observed on broken surfaces of the pottery or fell out of the matrix when a sherd was broken open. These separate fragments were more amenable to SEM examination than those which remained attached to the pottery. As many as

twenty individual husk fragments were mounted on a single aluminium stub for SEM examination. This provided better results than mounting small sherds, as with the Ban Chiang ceramics (cf. Yen 1982). Small pieces of pottery with exposed husk fragments were initially examined using SEM, but the loose contact between the organic temper and the pottery matrix was associated with charging problems which could not be overcome by heavy gold coating. Individually mounted charred or ashed fragments of temper from ceramics and the silica skeletons from the clay coating provided superior SEM images (Fig. 43:1).

Preliminary attempts to screen sherds for organic inclusions by xeroradiography was unsuccessful and discontinued. Rice husks recovered from the Khok Phanom Di ceramics were found on internal fracture planes running parallel to the body of the sherd. No impressions on the sherd surfaces were seen, unlike the report for Ban Chiang pottery (cf. Yen 1982). Sherds with husk fragments protruding from their broken edges were split open using pliers and the husks removed with a fine paintbrush.

The standard of preservation observed for husks from vessel temper was broadly comparable to specimens from the external clay layer, but there was greater variation among the temper samples, in terms of condition and fragment size. This may reflect the selection of tempers from different stages in the crop-processing sequence and different pre-processing methods for the temper amongst the exotic and local wares, as well as possible differences in firing conditions.

Rice-tempered ceramics from other prehistoric Thai sites

Comparisons between the Khok Phanom Di ceramic assemblage and pottery from other Thai sites are addressed by Vincent (in prep.). At Non Nok Tha, where the pottery classification system was based on vessel morphology and fabric types, five of the eleven categories included rice chaff, often in combination with other tempering agents. These were: sand and chaff; fine chaff and sand; chaff; prepared temper (grog with chaff inclusions); and chaff and laterite (Bayard 1977a). Each pottery type is described as containing not only characteristic proportions of chaff, but husk fragments of a particular size grade. Moderate amounts of rice chaff were recorded for both the 'sand and chaff' and the 'chaff and laterite' categories, although the latter also contained occasional pieces of straw. This contrasts with the material in the 'chaff-tempered' class where 'large amounts of rice chaff in large pieces' were observed. The 'fine chaff and sand' -tempered vessels were noted to contain a smaller grade of chaff fragments. Finally, 'ground fired clay which had previously been tempered with chaff' is considered by Bayard to be difficult to distinguish from the 'chaff-tempered' type.

By contrast, the pottery from Ban Chiang is noted for outstanding uniformity in production techniques, if not in stylistic tradition, over a protracted period of several millennia (White 1982c, McGovern 1989). Rice was employed as a temper for the entire timespan, being a minor component during the Early Period, the dominant tempering agent in the Middle Period, but almost absent in the Late Period assemblage (White 1986, McGovern 1989). Refiring experiments indicated low-firing temperatures (500–700°C), which may well have been the case for the Khok Phanom Di pots. The firing technique was thought to have been 'in the open by piling the fuel up around the vessels, as is still the practice today' (McGovern 1989:75). This is cited as an example of constancy of tradition, where the use of ethnographic analogy is valid in archaeological interpretation. Contemporary accounts of potting techniques therefore provide an indication of one set of taphonomic factors known to influence the way in which rice enters, and is preserved in, the archaeological record.

Rice remains in coprolites

Finally, rice was also found at Khok Phanom Di in coprolites, which are of two kinds: fossilized faeces, probably from dogs, where husks were present as poorly preserved impressions in a hard, mineralized matrix, and a second type, represented by a single coprolite found in burial 67, comprising mainly small fish bones, hair, stone grit and discrete husks. Thirdly food remains were found in the lower abdominal area of burial 56. This was dominated by fine fish bones but comminuted rice husks were also found (Higham *et al.* 1987, Higham and Bannanurag 1990a).

?Dog faeces

Mineralized coprolites are one of the more remarkable classes of material recovered at Khok Phanom Di, with more than one hundred examples occurring in layers 4 to 11 of the excavation. Most were found in layer 4. They are usually sub-cylindrical, with a relatively smooth outer surface, up to 60 mm in length and up to 20 mm in diameter. Such dimensions are much smaller than typical human stools which have a diameter between 25 and 38 mm (Rothman and Katz 1964) and is more compatible with a canine source (pers. comm. A. Jones). The colour of the outer surfaces was usually obscured by soil, but the inner fractured surfaces were pale yellow to cream (Munsell 7.5YR 7/4–10YR 7/4). In cross section, these coprolites had a distinct break in texture between a smooth outer shell (1-1.5 mm thick) and a blocky inner core.

The mineralized faeces are partially composed of calcium carbonate, as indicated by effervescence on immersion in dilute hydrochloric acid. The chemical reaction and the creamy-yellow colour of the matrix suggest that the coprolites are largely calcium phosphate, with a lesser amount of calcium carbonate. The high phosphate content is thought to relate to the considerable amount of bone within the faeces, while the carbonate may well have been derived by leaching of shell remains deposited at higher stratigraphic levels in the site.

Non-destructive X-radiography was applied to four coprolites from layer 4. A range of combinations of exposure time and kV was tried, with 4–5 minutes at 40 kV producing the most reasonable results for detecting bone within the fossilized faeces. Poor resolution in the photographic images was partly related to the thickness of the specimens. It is difficult to detect bone embedded in a phosphatic matrix using X-radiography, so xeroradiography was tried later and found to be more effective, as it is more sensitive to relative densities.

A single coprolite from quadrant D, layer 4:4 feature 2, weighing 12.4 g, was immersed in 30 per cent alcohol and cleaned by ultrasound for 60 minutes then fractured with a scalpel. The specimen crumbled easily. The remains were immersed for 12 hours in Villaneuve's decalcifying solution, washed, centrifuged in distilled water and reweighed at 10.3 g. The *c.* 15 per cent loss in weight is attributed to the removal of calcium. Fragments of the coprolite were mounted on slides in glycerol and scanned by transmitted light microscopy at magnifications of x100–x300. There was a general paucity of botanical material, even recognisable plant cells (pers. comm. G.C. Hillman).

Four further specimens from layer 4 were manually fractured and fragments mounted on aluminium stubs for SEM viewing. The typical fracture pattern differed from that for pottery, where breaks occur along lines of weakness formed by husk. In the mineralized coprolites, cleavage was through rather than parallel to the husk fragments, which meant that the rice husks from the ?dog coprolites were not readily amenable to analysis in terms of surface topography (Fig. 43:4).

Human faecal remains and gut contents

The coprolite from the grave fill of burial 67 has provided, in some respects, the best preserved botanical specimens from the site. The husks supply data on the gross morphology of spikelets (Fig. 44:1-2) and contribute relatively large fragments of lemma and palea with clearly visible surface details, of equivalent standard to the temper. They will be described further in later sections when diagnostic criteria are assessed. This identification of rice in the coprolite is supported by that of the beetle *Oryzaphilus surinamensis*, which commonly infests stored products, including rice (Harris 1991). Further evidence for rice in the diet is the food debris found in the pelvic region of burial 56, which was cut at 4.3 m below datum (Higham and Bannanurag 1990). This included a few comminuted husk fragments amongst hundreds of small fish bones and scales.

The origin of the coprolite from burial 67 is questionable as it may have originated from a human, a dog, or even a pig. While few canid or suid remains were found in the excavation (Higham *et al.* 1987, Higham and Maloney 1989, Grant and Higham 1991), it was initially surmised that it is more likely that dogs or pigs rather than humans would have consumed rice husk, which is not only barbed but also would be unpalatable to people because of its sclerified nature, unless perhaps consumed as a part of a gruel. However, three other studies of faeces or gut contents of undisputed human origin mention large components of chaff in fossilized faeces (Netolitzky 1911, 1912 and Wood Jones 1910, all cited by Cummings 1989). Ninety per cent of Nubian human coprolites included large numbers (up to even 99 per cent of the total volume of individual coprolites) of tiny lemma and palea fragments from sorghum and wheat (Cummings 1989:85–6, 94), while the suite of plant macroremains from Upper Egyptian mummified bodies studied by Netolitzky contained barley chaff, as did the intestinal contents of Predynastic bodies examined by Wood Jones. These examples illustrate that humans may consume comminuted cereal chaff although, as noted earlier, the husks from rice are more silicified and barbed than those of wheat and barley. Additional evidence takes the form of a tentative identification of a parasite egg in the coprolite from burial 67 as *Fasciolopsis buski*, a 'common parasite of man and pigs' (Morseth 1991:242). Small numbers of parasite ova from the human whipworm, *Trichuris* sp., were also found in one of the mineralized coprolites (pers. comm. A. Jones). This is thought to have been passed by a dog as it contains tiny splinters of mammalian bone and charcoal fragments. The possibility remains then, that the coprolite represents canine or suid and human food, since dogs or pigs may have scavenged and consumed human faeces.

DISTINGUISHING BETWEEN ARCHAEOLOGICAL REMAINS OF WILD AND DOMESTICATED RICES

This section discusses methodologies for distinguishing between wild and domestic rices, using micromorphological criteria developed from modern material for application to archaeological specimens. One of the major research areas frequently addressed by archaeologists working in South-East Asia relates to the date, the location and circumstances in which rice was initially brought into cultivation and subsequently domesticated. These were some of the questions considered during data collection at Khok Phanom Di. The feasibility of solving this problem in its narrowest definition, that is, the transition from the wild to domestic phenotype, at *any* site, has recently been brought into question by Hillman and Davies (1990a and 1990b), who doubt the archaeological visibility of what was potentially a quick transition, in the order of only twenty to thirty years. The rapid build-up of cultural material at Khok Phanom Di means that the resolution of the archaeological record need not necessarily be an impediment to discerning the domestication process in this instance. More than 6 m of cultural debris were deposited during no more than five to six-hundred years and sampling units of 10 cm provide fine temporal resolution for the data. The problem remains, however, of whether dependable diagnostic criteria can be established for segregating wild and domestic types of rice in archaeological specimens, and whether the plant remains from this site are adequately preserved to provide reliable information.

Terminology for describing rice anatomy (Figs. 37, 39a-b and 45:5-6)

The inflorescence of rice, the panicle, comprises numerous spikelets attached by stalk-like pedicels to the branching panicle. At each pedicel apex are two rounded rudimentary glumes and a raised abscission surface which fits with the rachilla of the spikelet. Each elliptic-oblong, laterally compressed spikelet includes two small sterile lemmas, a rachilla and a fertile floret made up of the fertile lemma and the palea (together commonly referred to as the husk), and the flower which develops into the caryopsis. This is also termed a 'grain' or 'seed', but is morphologically a fruit (Chang and Bardenas 1965). The rachilla (sometimes referred to as the callus) is the small axis of the spikelet lying between the sterile lemmas and the point of attachment to the pedicel (the abscission surface). It is comma-shaped in *Oryza sativa* and *O. rufipogon*, producing an oblique disarticulation surface when the grain matures and is shed (Sharma and Shastry 1964) (Figs. 45:5-6) and 46:2).

The appropriate term to describe the husk, hull or outermost protective structures covering the grain has long been debated, but recent opinion is that the part of the plant formerly referred to as a fertile lemma, upper flowering glume, outer glume, lower palea, palea inferior, valvule or valve (Chang and Bardenas 1965, Katayama 1969, Clifford and Watson 1977) or as a glume, as in much of the archaeobotanical literature (e.g. Glover 1979, Yen 1982), should rather be termed a lemma (Weatherwax 1929, Santos 1933, Clifford and Watson 1977, Vaughan 1989). This is the term which will be used here.

The lemma is described as 'the larger, indurate (hardened), 5-nerved bract which partly envelops the smaller, 3-nerved palea' (Chang and Bardenas 1965:10). It is 'boat-shaped' and almost a V in cross-section, with inrolled margins where it fits tightly around the palea (Juliano and Aldama 1934). It is thicker in the central area and thinner towards its base and apex. These thicker parts are stronger, a likely reason for their greater representation in the archaeological record. Both

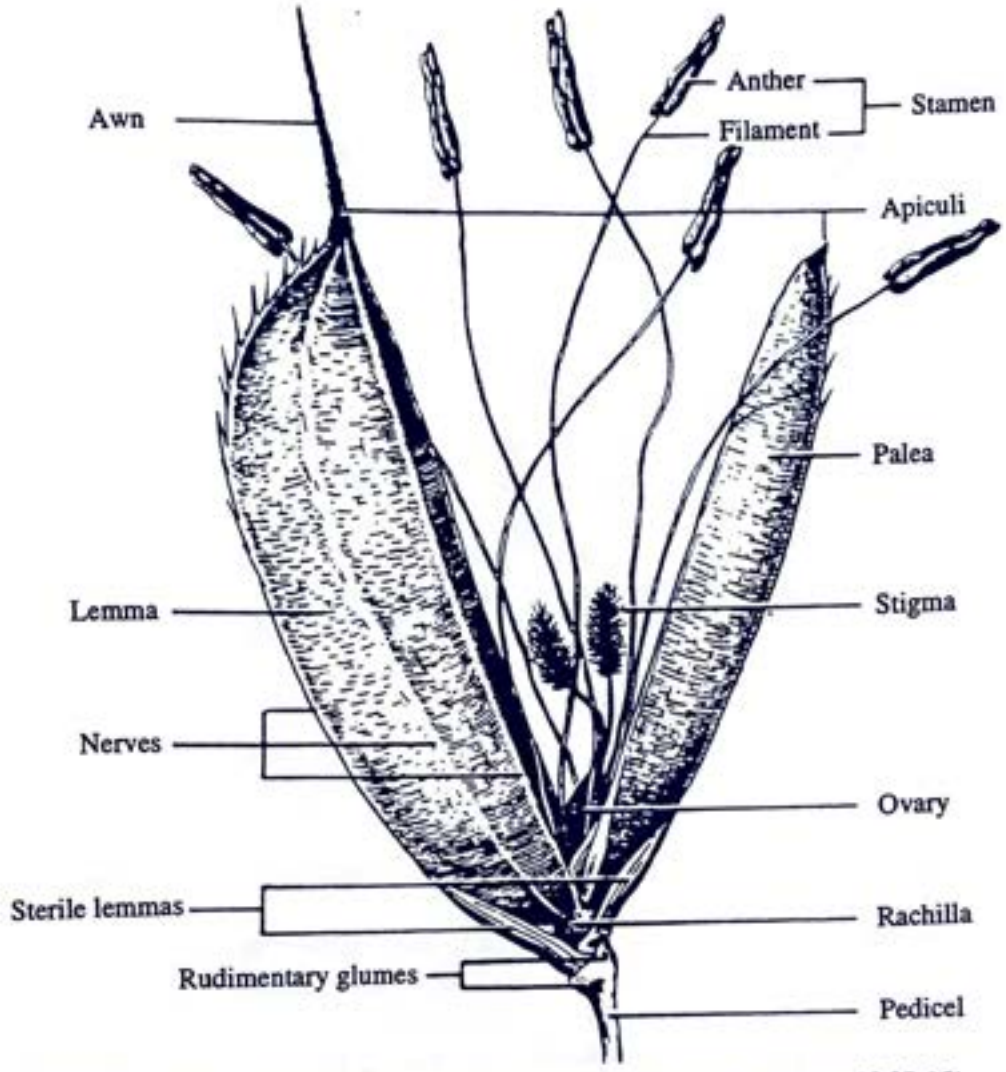


FIG. 37. Parts of the rice spikelet (Source: Chang and Bardenas 1965:10)

lemma and palea are highly silicified at maturity. The lemma has a terminal tuft of trichomes (hairs) and an awn extending from its distal end, in wild as well as in many native cultivars. The awn is covered with many trichomes.

There has also been considerable disagreement on the term for the three-nerved bracteole opposite the lemma in the position of the palea, which is now conventionally referred to as the palea (Clifford and Watson 1977:29, Duistermaat 1987:159). This is usually much smaller than the lemma but has a similar structure and similar epidermal features, though three vascular bundles or nerves, unlike the lemma's five. The marginal nerves are much smaller than the central one. These are useful in orientating fragmentary archaeological specimens. The size of the nerve can indicate whether a particular fragment comes from a lemma or a palea, and sometimes from which part of the spikelet. Lemmas and paleas have similar surface topography, except along the palea margins which are overlapped and concealed by the lemma. Here the papillae are smaller. The inner surface of both lemma and palea is fibrous, longitudinally striated and, unlike the outer sur-

faces, has stomata (Maeda 1972). In addition to these two fertile bracts, there are two small vestigial glumes or sterile lemmas at the base of the spikelet (Fig. 37).

General features distinguishing wild and domestic forms of cereals

Domestication implies human control of a plant's breeding system and is accompanied by various morphological changes, including a change in colour, especially in the economically important parts of the plant, and by the loss of protection from predators, for instance, the loss of spines or toxicity. Concomitant physiological changes affect the speed and synchronicity of seed germination, the plant's reaction to day length and the length of its life cycle. These physiological adaptations are less likely to be detectable in the archaeological record (though see work of Butler 1988, 1989, 1991 exploring the link between *testa* morphology and dormancy in grain legumes).

A wide range of morphological characters may be altered under domestication, including awn robustness, glume rigidity, grain size, numbers of fertile florets, tillering tendency, uniformity of grain ripening, photosynthetic rate, and the abundance of barbs and hairs on the rachis and glumes. However, the most critical adaptive differences involve loss of wild-type seed dormancy and rachis fragility, and, of these, only rachis fragility is readily apparent morphologically (Hillman and Davies 1990a). In wheats, the wild-types also differ from domesticates in the degree to which their spikes disarticulate at maturity and the way in which the lemmas, paleas and glumes tightly wrap the wild grains, making them difficult to thresh (Sharma and Waines 1980).

General features distinguishing wild and domesticated rices

The analysis of intrageneric variation in *Oryza* (e.g. Morishima and Oka 1960) has conventionally used life-forms and macroscopic anatomical characters for species separation (Table 35). These aspects of the plant have little direct value to the archaeobotanist, because they emphasize vegetative plant parts like leaves which are rare in the archaeological record. Distinctions between wild and domesticated plants are also often made in terms of population characteristics, for example wild plants have a high rate of seed shedding, small grain weight and small spikelet numbers per panicle (Oka and Morishima 1971), and the cultivars exhibit synchronous maturity (Second and Ghesquière 1985). Such characters are not easily assessed for archaeobotanical material.

Archaeologically applicable criteria for distinguishing between wild and domesticated rices

Conventional criteria for distinguishing wild from domestic rices are summarised in table 35 and by Duistermaat (1987) among others, but their archaeological applicability is limited by the form in which *Oryza* remains are found in archaeological or other depositional contexts. Rice remains are variously recovered as pollen, phytoliths, starch grains, husks and their impressions, as well as charred and waterlogged grains and spikelets. The taxonomic resolution to which specimens in each of these classes of material may confidently be ascribed varies.

Microscopic remains

Pollen

The identification of Gramineae pollen at the generic level remains to be firmly established and applied to sub-fossil samples. There is understandably, therefore, discussion on the possibility

TABLE 35: *Key to the differentiation of wild rice species* Oryza rufipogon *and* O. nivara *from cultivated* O. sativa

Character	Species		
	O. rufipogon	*O. nivara*	*O. sativa*
Branching	Extravaginal	Intravaginal	Erect
Growth habit	Decumbent to erect	Semidecumbent	Erect
Spikelet shape	Slender	Bold	Variable
Apiculus	Blood red	Purple or green	Green
Pericarp	Red or purplish	Reddish-dirty white	Variable
Anther length	Long	Medium	Medium
Awn	Slender/flexuous and frequently reddish	Stout, long and frequently reddish	Slender/ awnless to awned
Life-span	Perennial	Annual	Annual
Habitat	Stagnant and seasonal swamps	Drainage ditches and shallow ponds	Domesticated culture
Grain shattering	Readily before fully ripe	Before fully ripe	Variable but less shattering than wild
Grain dormancy	High	High	Variable

(Source: Wirjaharja *et al.* 1983:321)

of separating fossil pollen of *O. sativa* from that of its wild relatives, even using SEM or phase-contrast microscopy (Maloney 1990). Unlike other cereals, the pollen of domestic rice does not tend towards gigantism and, as the pollen grains of *Oryza* overlap in size with those of other South-East Asian grasses, size alone cannot be relied upon for separating rice pollen from that of other grasses (Maloney 1991). Nevertheless, there is a size similarity between the Gramineae pollen from the cores taken around Khok Phanom Di and those from present-day cultivars from Sumatra. These, together with identifications of herbaceous plants which may be ruderals, and a rise in charcoal particle frequency, are taken as circumstantial evidence for rice cultivation in the area of the site (Higham and Maloney 1989, Maloney 1991). In the matter of improving identification criteria, however, the examination of the surface patterning on pollen exines offers one possibility for making finer taxonomic distinctions, both at the generic level and within *Oryza*, but this criterion remains to be evaluated using SEM before applications to routine light microscopy can be developed (Maloney 1990).

Phytoliths

The recognition of rice as phytoliths (the biogenic silica which accumulates within the cell lumen) is less problematic than with pollen as when leaves from *Oryza* spp. decay, they leave distinctive bulliform or bilobate cells. These may confidently be named at the generic level, but at the time of writing, the distinction between species remains unresolved. The analysis and description of rice phytoliths has been given most attention in Japan, which lies outside the natural distribution of wild rices ancestral to the cultivar, so the issue of distinguishing between the phytoliths of wild and domestic plants has not been relevant there. Fujiwara and his co-workers claim to be able to distinguish between the *japonica* and *indica* subspecies of *Oryza sativa* (Fujiwara 1976, Fujiwara and Sasaki 1978, Sato *et al.* 1990), but still consider it impossible to distinguish conclusively between the remains of domesticates and wild rices from phytolith morphology (Fujiwara and Sasaki 1978). Research continues on the identification of rice phytoliths, in their separation from other members of the Gramineae as well as the wild/domestic dichotomy (Pearsall 1990, pers. comm. L. Kealhofer).

Starch Grains

As with phytoliths, the common starches can be identified microscopically at a generic level (Schoch and Maywald 1967), but species are not identifiable, above all for rice where taxonomic distinctions are blurred. Rice is an A-starch, separable from tuberous B-starches by their different X-ray diffraction patterns (Badenhuizen 1969). The starch grains of *Oryza* are compound, 2-10 microns in diameter (Fahn 1974, Jackson and Snowdon 1990), and united in aggregates similar to oats (Juliano and Aldama 1934), but prospects for pursuing finer identifications of starch grains preserved within archaeological ceramics are slim.

Chemical properties

Recently, chemical research has set out to finger-print the lipids extracted from cereal grains using infrared spectroscopy. The feasibility of separating closely related taxa has been demonstrated, even at the sub-specific level (McLaren *et al.* 1991). This has been established for modern, experimentally charred caryopses of *Triticum* spp. and subsequently applied to morphologically indistinguishable Mesolithic charred grain from Syria with good results. Such studies foreshadow research yet to be completed for *Oryza* spp. The chemical signature of rice is clearly distinguished from that of other food plants (Hill 1988, Hill and Evans 1989), and the encouraging results from the South-West Asian cereals suggest that this technique may eventually be able to separate not only between cultivars and wild rices, but also between the races *indica*, *japonica* and *javanica*.

Macroscopic remains

As it is currently difficult to distinguish unambiguously between the use of wild and domestic rices using pollen and phytoliths, attention turns to macroscopic materials in order to track the process of domestication. Macroremains may, when specific parts such as the rachilla are fortuitously preserved in the archaeological record, be more informative than other classes of evidence. However, as will be seen in the following discussion, the most valuable parts of the rice plant are

rarely found, while those most common, namely husk fragments, need to be assessed very carefully before even a tentative statement can be proposed regarding the state of domestication of the parent plant.

Caryopses

Charred grains of rice are sometimes retrieved from archaeological deposits, even if systematic attempts are not made to recover botanical material, especially when they are found *en masse* in storage contexts. The overall size and shape of the grains, as summarized by their length/width ratio, has been used to indicate the degree to which their stock has undergone domestication (Vishnu-Mittre 1972), but this is brought into question in the discussion below. The grain surfaces of freshly dehusked caryopses have also been examined by Savithri (1976), who concludes that the degree of twisting in the *hilum* scar (straight in *O. rufipogon* and slightly twisted in *O. sativa*) is rather more consistent than the number of longitudinal ridges and furrows along the grain for separating wild from cultivated rice. She stresses though, that these characters should be used in combination with other features and that more extensive studies of reference material should be made. Surface features of the caryopsis may prove useful as analysis of their transverse cells in modern wild, domesticated and weedy wheats and ryes has shown cellular differences along the domestication gradient (Körber-Grohne and Piening 1980, Körber-Grohne 1981a, Colledge 1988).

Husk

This is the plant part most commonly represented in the archaeobotanical assemblage at Khok Phanom Di, as at other South-East Asian sites. Diagnostic characters for separating wild from domestic rices relate to the fact that while wild plants are well adapted for seed dispersal, domesticates have been selected to retain their seeds for human use and are dependent on people for reproduction. Thus, domesticates can be recognized by the lack of some seed-dispersing characters, such as the ability to shed seed naturally, the absence of self-implantation features like awns, or the reduction of other characters, like the backwards-facing barbs on the sterile lemmas. Other features are not directly linked to the plant's mode of reproduction and hence its degree of domestication, so these are less useful for archaeobotanical identification. Secondary characters, such as grain size and husk topography, are less responsive to changes in human use of the plant and their status is not indicative of the earliest phases of domestication.

Presence or absence of awns on the fertile lemma

One character with potential for distinguishing between wild and domesticated rices is the presence or absence of an awn. This is a single long straight tapering bristle-like projection from the apical end of the spikelet, as we have seen above (Fig. 37). There is some debate as to whether they are 'filiform extension[s] of the keel of the lemma' (Chang and Bardenas 1965:10) or whether all five nerves in the lemma contribute to the awn (Roy 1968). Round in cross-section and with a thick-walled epidermis, awns have a heavy siliceous cuticle with numerous small trichomes on the surface. Awns are associated with seed dispersal and implantation into the soil. The presence of awns is fairly constant within most species of *Oryza* (Sano and Morishima 1982), but in

cultivars very many variations are noted, ranging from complete absence to awns up to 6 cm in length (Hoagland and Paul 1978, Duistermaat 1987). Thus, while the presence of an awn does not necessarily mean that the spikelet came from a wild plant, its absence can only imply that the spikelet was from a domesticate. Although prehistoric rice remains rarely include awns, they are not entirely unknown in the archaeological record, for example, at Hastinapura (Chowdhury and Ghosh 1954-5) and at Hemudu (Second 1985). A broken apiculus at the end of the lemma can still indicate that an awn was once present.

Some of the husks from Khok Phanom Di included the distal end of the lemma. Wherever this was preserved, awns were absent and the apiculus was rounded, indicating that the plant was of a domesticated variety (Fig. 44:1-2).

Shedding habit

One of the primary differences between wild grasses and their domestic counterparts is that wild plants are reproductively self-sufficient whereas domesticates rely on human intervention. In wild rices, reproduction may be by vegetative means, as in the rhizatomous *O. perennis/rufipogon*, or through the dispersal of seeds, as in annual wild rices. The spikelets of annuals are deciduous, automatically and rapidly dehiscing when ripe. By contrast, harvesting with a sickle, followed by reseeding (Harlan *et al.* 1973), preferably in a new plot (Hillman and Davies 1990b), unconsciously selects for the low proportion of mutant, non-shedding plants in a stand of wild grasses (Zohary 1969, Wilke *et al.* 1972, Harris 1976). Thus, domesticates typically retain the spikelet on the pedicel until beaten apart by threshing. In all major cereals the ease of detachment is the character which shows the strongest differences between wild and cultivated or domesticated varieties (Harlan *et al.* 1973). This is seen in rices where *rufipogon* and *sativa* are morphologically so similar that they are not readily distinguishable except in that *rufipogon* has 'spikelets deciduous' (Morishima *et al.* 1961:330). The non-shedding response to human intervention is translated anatomically and morphologically through a change in the abscission scar and this sometimes features, albeit rarely, in archaeobotanical remains. This line of enquiry has been profitably followed in the study of progenitors of barleys and wheats (Kislev 1989, Hillman and Davies 1990a).

Cultivation experiments with wild rices (*Oryza perennis* Moench = *O. rufipogon* Griff) have shown that the shedding character is particularly sensitive to cultivation pressure. After only five generations of experimental cultivation, it was observed that the percentage of grains lost by shedding had fallen significantly (Morishima *et al.* 1961, Oka and Morishima 1971, Oka 1974). Grain shedding (or the lack of it) is, therefore, a potentially sensitive indicator of human-plant interaction with high predictive value in archaeobotanical terms. The reason for the speed of response by the plant is that such a qualitative change is usually controlled by a single or a few major recessive genes operating under relatively simple patterns of inheritance (Pickersgill and Heiser 1976). The genetic control of shattering in rice is not entirely clear. Some geneticists suggest that in rice, as with barley, fragility of spikelets is under the control of a pair of complementary genes (Nayar 1958, cited by Sharma and Waines 1980, Woods and Clarke 1976), while according to others, more than two genes are involved (Chang 1964). In the wild type, shattering is partially dominant or simply dominant over non-shattering types (Richharia and Misro 1962). Although the precise nature of inheritance of non-shattering in rice is not yet completely defined, the important fact is that this gene control is simple so that the establishment of non-shattering traits is genetically straightforward.

Mechanism of shedding

At abscission, the spikelet detaches from the rachilla or pedicel along an oblique line of weakness termed the abscission layer. This is a line of relatively thin-walled cells within the abscission zone, between the lower sterile lemma and the apex of the pedicel, leaving a horizontal or oblique scar (Chang and Bardenas 1965). In longitudinal section, the abscission layer comprises one or two layers of thin-walled parenchymatous cells (Jin 1986), surrounded on both sides by 'layers of heavily lignified sclerenchymatous cells. The abscission layer extends from the epidermis to the central vascular tissues in the pedicel. It does not cut right through the pedicel but leaves the central vascular bundle and several layers of sclerenchyma tissue bordering the vascular tissues of the pedicel intact' (Zee *et al.* 1979:5). In wild annual *O. nivara* the cells of the abscission layer stretch the full width of the pedicel, except for the vascular tissue, and lignified (sclerified) cells around the vascular channel are absent (Srinivas *et al.* 1979).

Comparative studies of pedicel histology have indicated that 'varieties with relatively larger parenchymatous cells in the abscission layer and a thinner sclerenchymatous tissue (fewer cell layers) bordering the abscission layer and the central vascular bundle of the pedicel are essentially more fragile (i.e. mechanically weaker). Consequently their spikelets are more susceptible to shattering' (Zee *et al.* 1979:6). Separation occurs due to changes in the histochemistry of the abscission zone, with dehydration and collapse of these cells.

Variation in the degree of shedding has been linked to (1) the thickness of sclerenchyma between the abscission layer and the central vascular bundle (Inouye *et al.* 1985), (2) the abscission layer and the development of cracks in it (Hu *et al.* 1964), (3) the number of cells in and the length of the abscission layer (Zee *et al.* 1979) and (4) the development of lignified cells in the supporting zone of the pedicel (Srinivas *et al.* 1979). Seed shedding is not, however, completely confined to wild-type rices (Sharma and Shastry 1965b). Weedy types found in rice fields and certain varieties of present-day traditional cultivars retain some of their capacity to shed seed naturally (Ramiah and Rao 1936, Srinivas *et al.* 1978). This is evidenced by up to 30 per cent loss of crops due to grain shedding (Bhalerao 1930, Ramiah and Rao 1936). Indeed, there is a wide spectrum in ease of detachment ranging from cultivars which readily drop their seeds when harvested, to others where the pedicel and spikelet adhere so firmly to one another that threshing becomes problematic. Environmental factors associated with variable shedding rates include insolation, temperature and humidity during ripening (Inouye *et al.* 1985). The process of selection for non-shedding types which presumably occurred with the earliest harvests continues today. Native varieties grown in Japan until the 1920s, which were threshed by beating against a wooden frame, had lesser tensile strength than the improved *japonicas* of today (Jin and Inouye 1981), and non-shedding is a character which continues to be bred intentionally into the improved strains of 'miracle rice'.

There are also differences in grain shedding among the subspecies. Generally, *indicas* are known to have higher shedding rates than *japonicas* and in one study of Indonesian rices, the shedding habit in the *bulu* rices (similar to *indicas*) was attributed not so much to the presence of an abscission layer, as to the *cracking* of that layer (Jin and Inouye 1985).

Given the introgression of wild-type characters into the domestic population and the inherent variability amongst cultivars, the wild-type of abscission scar may be found in wild grasses as well as certain cultivated cereals and, presumably, various grades in between. These could be regarded as cultivated but not fully domesticated crops (Hillman and Davies 1990a). Despite these

limitations, the abscission scar typical of a non-shedding rice is indicative of human intervention in the breeding system of the plant and is potentially capable of indicating even the earliest stages of domestication. This could be seen in the archaeological record through a gradual change in the ratio between predominantly wild (shedding) and predominantly mutant (non-shedding) plants. For many generations, the two types would co-exist in the population and intermediate forms might also occur.

TABLE 36: *Length/(breadth x thickness) ratios for modern wild and cultivated rice grains*

	Vishnu-Mittre (1972:20, 1974:13) (n=100)	Savithri (1976:49) (n=10)
O. perennis Moench	2.20	2.20, 2.41
O. officinalis Wall	2.36	1.33, 1.57
O. rufipogon Griffiths	2.64	1.50
O. sativa var. *spontanea* Koenig	1.77, 1.79	
O. sativa var. *japonica*	1.70	
O. sativa var. *indica*	1.71	

Abscission scars

When the spikelet falls away from the pedicel, an abscission scar is left on the rachilla and the pedicel which can indicate whether the spikelet was threshed or detached naturally. These features have been widely reported in the literature on rice anatomy. The scar on the rachilla is of greater concern to us here, as this has the greater chance of archaeological preservation. Abscission of plant parts in general has been extensively reviewed (Kozlowski 1973) and details of anatomical changes during abscission have been reported for the grasses *Zizania aquatica* (Hanten *et al.* 1980) and *Avena fatua* (Yeung *et al.* 1987) among others. Published illustrations of abscission zones in rice are most often in longitudinal section and, while useful in providing an histological perspective on the development of the abscission zone, they do not show the aspect most readily seen in archaeological specimens without dissection. Surface views of abscission scars do not feature in even the most comprehensive SEM studies of rice anatomy, such as Zee's seminal report (1981), so have been investigated here and are described below for both modern and archaeological specimens (see pages 185-187).

TABLE 37: *Mean length/width ratios for spikelets from 1573 populations of South-East Asian cultivated rice,* Oryza sativa *(see figure 38)*

L/W Ratio	No. of populations			
	Cho & Kuriyama (1965:618)	Morishima *et al.* (1984)	Hamada (1965)	Total
0.90–.99	0	0	1	1
1.00–.09	0	0	0	0
1.10–.19	0	0	0	0
1.20–.29	0	0	0	0
1.30–.39	0	0	0	0
1.40–.49	0	0	0	0
1.50–.59	0	0	0	0
1.60–.69	0	0	0	0
1.70–.79	0	0	0	0
1.80–.89	0	0	1	1
1.90–.99	0	0	0	0
2.00–.09	0	0	15	15
2.10–.19	3	3	13	19
2.20–.29	3	3	41	47
2.30–.39	7	1	62	70
2.40–.49	12	7	55	74
2.50–.59	16	7	65	88
2.60–.69	16	8	59	83
2.70–.79	12	9	58	79
2.80–.89	22	3	54	79
2.90–.99	22	9	67	98
3.00–.09	18	10	71	99
3.10–.19	22	14	64	100
3.20–.29	26	6	69	101
3.30–.39	41	9	66	116
3.40–.49	24	6	65	95
3.50–.59	22	6	67	95
3.60–.69	24	1	62	87
3.70–.79	22	5	57	84
3.80–.89	8	3	45	56
3.90–.99	5	1	34	40
4.00–.09	4	1	16	21
4.10–.19	2	0	6	8
4.20–.29	1	0	6	7
4.30–.39	1	0	3	4
4.40–.49	0	0	1	1
4.50–.59	1	0	2	3
4.60–.69	0	0	0	0
4.70–.79	1	0	1	2
TOTAL	335	112	1126	1573

TABLE 38: *Mean length/width ratios for spikelets of wild rice*

Taxon/Type	Colln. No.	L/W Ratio	Taxon/ Type	Colln. No.	L/W Ratio
Akihama and Watabe (1970)					
Unspecified wild rice	1		Hybrid	31	3.71
	2	3.26		32	3.47
	3	3.22		34	3.51
	4	2.99		35	3.40
	5	3.46		36	4.05
	6	3.23		37	3.27
	7	3.11		38	3.57
	8	3.77		40	3.13
	9	3.76		41	3.86
	10	3.29			
	11	3.73			
	12	4.09	*O. sativa*	33	2.53
	13	3.10			
	14	3.49			
	15	2.90			
	16	3.06			
	17	3.52			
	18	3.27			
	19	3.29			
	20	3.10			
	21	2.96			
	22	3.26			
	23	3.54			
	24	3.77			
	25	3.44			
	26	3.29			
	27	4.93			
	28	3.14			
	29	3.31			
	30	3.27			
Sakai *et al.* (1961c:63)*			*O. perennis*	Ky	3.25
		Nt	2.80		
				Th-(1)	2.51
				Th-(2)	3.30
				Kd	3.71
				Md	3.44

(* n = 50 except Th-(2) where n = 27)

Table 38 (cont.) *Mean length/width ratios for spikelets of wild rice*

Taxon/Type	Collection	Number	L/W Ratio
Sharma and Shastry (1965a:248)			
Balunga: 'B'-type; procumbent perennial plants, swamp habitat			
	Nowgong	SC 159	4.00
	Burdwan	SC 170	3.54
	Cuttack	SC 120	3.75
	Raipur	SC 155	3.50
Balunga-like 'B(S)'-type; similar to 'B'-type, except decumbent, swamp habitat			
	Manipur		2.33
	24-Parganas	SC 125	2.33
	Cuttack	SC 107	2.00
Nivara: 'N'-type; semi-erect or erect, annual plants, found in seasonal ditches			
	Kanpur	SC 81G	2.53
	Dangs	SC 377	2.33
	Bilaspur (M.P.)	SC 85E	2.67
	W. Godavari	SC 31	2.83
	Darwin	SC 57	3.15
Nivara-like: 'N(S)'-type; similar to 'N'-type, but erect rather than semi-erect, found in seasonal ditches			
	Dangs	SC 75	2.33
	Bilaspur (M.P.)	SC 85F	2.68
	Koraput	SC 41	2.67
Sativa-like 'S(B)'-type; 'field *spontaneas*'; similar to *sativa*-type, but shattering, with awns and black husks; resembling balunga-type; found in cultivated fields			
	Sibsagar	SC 30	2.67
	Cuttack	SC 19	3.00
Sativa-like: 'S(N)'-types; 'field *spontaneas*'; similar to *sativa*-type, but shattering, and with awns and black husks; resembling *nivara*-type; found in cultivated fields			
	Aligarh	SC 79C	3.00
	Gaya	SC 63	3.00
	Raigarh	SC 83E	3.00

Hairiness of the sterile lemmas

A pair of sterile lemmas are the 'two flowerless bracts at the base of the spikelet' (Chang and Bardenas 1965). These are triangular to linear-lanceolate and slightly concave, with hairs along their margins, keel and at the apex (Juliano and Aldama 1934). They become lignified, making them tough and brittle by maturity. There is interspecific variation in the size and degree of pubescence of the sterile lemmas through the genus *Oryza*. The cultivated taxa are more glabrous than the wild (Gopalakrishnan and Shastry 1965) and within the cultivars the range extends from extreme glabrousness in *javanicas* to extreme pubescence in *japonicas*, with *indicas* intermediate (Gopalakrishnan and Shastry 1965). This feature could, therefore, be a useful if ancillary character for distinguishing between wild and cultivated types in archaeological specimens, where whole or near-complete spikelets are recovered with microanatomy preserved intact. This particular part of the plant was not found among the fragments of husk from the pottery or soil at Khok Phanom Di. Most of the spikelets from the coprolite in burial 67 which retained their rachilla lacked sterile lemmas because of mechanical breakage or chemical deterioration through digestion. Although two of the more complete specimens did show the feature, preservation was inadequate to indicate the pubescence.

Size of caryopses and spikelets: measurements of length and breadth

This is one of the traditional criteria applied by archaeobotanists to suites of cereal remains (van Zeist and Heeres 1973, cf. Hopf 1978, van Zeist and Bakker-Heeres 1982, Amblard and Pernes 1989) and arises from the fact that in many cereals domestication is accompanied by selection for larger grain size (Harlan *et al.* 1973). The use of this character requires the examination of a large range of specimens, since the size of grains varies within and between biological populations and between crop products at different points in the processing sequence. There is variation between spikelets on the same plant, between plants in a single population and between populations of a given taxon, just as there are differences in size between samples from prime grain and tail grain.

Size and shape are recognized as derivative features and not symptomatic of a particular stage of domestication (Kislev 1989). There are problems inherent in using these characters for describing and categorizing archaeological plant remains because there may have been post-depositional distortion in the form of shrinkage, through charring or desiccation, or even swelling if the grains were waterlogged. It is more reliable to calculate ratios which summarize shape than to use absolute measurements. The effect on rice of charring under various temperature and oxidization regimes has been explored by Garton (1979) and Thompson (in prep.).

The length/width criterion has been applied in previous analyses of archaeological rice to distinguish between wild-type and domestic caryopses, for example at Chirand in Bihar by Vishnu-Mittre (1972), who pointed to the tendency of modern wild grains to be more slender than domestic caryopses. Using modern reference indices (Table 36), the ten charred grains of rice from Neolithic Chirand were considered to be of two types, some from *O. sativa* or *O. sativa* var. *spontanea* and others from the wild species, *O. perennis* and *O. rufipogon*. The indices deduced by Vishnu-Mittre from modern reference material are very general initial guidelines, pointing to gross morphological contrasts between grains from wild and domestic plants. As no indication of standard deviation or the range of values for each sample is provided, it is difficult to assess the overlap between the sam-

pled populations. The reliability of this criterion for separating wild from domestic grains has been brought into question by Savithri (1976), substantiated by Sharma (1983) and is echoed here. The variation in grain dimensions and ratios among native cultivars, as demonstrated by a global survey of more than 2,400 varieties (Nagamatsu 1942), is greater than that for wild types. In the case of rice, people have selected mainly for an increase in grain size, but also for certain small-seeded types, such as *khao met lek* (small-seeded rice), one of the varieties grown in the Bang Pakong area. Thus, although the charred caryopses recovered by Chester Gorman from burials at Ban Chiang, were rather small, initially suggesting that they might be from a wild rice, it was found that they fell within the wide size range of traditional cultivars grown by subsistence cultivators in north-west Thailand, without taking into consideration the shrinkage effects of charring (Yen 1982).

Dimensions and ratios for whole spikelets: studies of modern rice populations and their application to archaeological specimens

The reliability of length/width ratios of whole spikelets (rather than just the grains) for characterizing modern populations of wild and cultivated rices, and hence their capacity for distinguishing between the two types in archaeological material, has been considered with reference to published data. Length, width and thickness dimensions for caryopses and spikelets of modern wild and domestic rices are frequently provided in the course of taxonomic and agronomic papers, but are rarely expressed as ratios, explicitly examined in terms of variability or used to compare wild rices with their domestic counterparts. The aim here is to draw together data from disparate sources to establish whether the length/width ratio of a spikelet is a valid indicator of the taxonomic status of the parent plant.

Lengths and widths for complete spikelets from Laos, Thailand and Cambodia have been recorded for a total of 1573 populations of native cultivars (Cho and Kuriyama 1965:607–18, Hamada 1965:544–83, Morishima *et al.* 1984:52, 73–5). Equivalent data are available for wild *O. perennis* from the west coast of Sri Lanka (Sakai *et al.* 1961:63) and from India (Sharma and Shastry 1965a:248). Wild and cultivated rices from Thailand are together included in studies by Akihama and Watabe (1970:342–3) and Morishima *et al.* (1961:330). These data are combined in figure 38 and tables 41–42 and indicate considerable inter- and intra-specific variability, as well as significant overlap between the distributions of the two types. The length/width criterion is therefore less than satisfactory for making the distinction between wild and cultivated rices in either modern or archaeological specimens.

The discriminating power of length/width ratios for whole spikelets is no stronger, then, than for grains. While it remains important to include basic dimensions as part of the description of an archaeobotanical assemblage, the indices based on them cannot confidently be used as a definitive means of determining the taxonomic status of the parent plant. These criteria were nevertheless applied to the husk remains from Banyan Valley Cave which were said by Chang probably to be wild, partly on the basis of their size. The specimens ranged in length from 7.2 to 8.5 mm, with widths from 2.6 to 3.9 mm (Yen 1977:585, 587).

Surface morphology of lemmas and paleas

Rice husks were recovered from the deposits at Khok Phanom Di, some with surface features clearly retained, particularly in the specimens preserved in faecal material, as temper in pottery

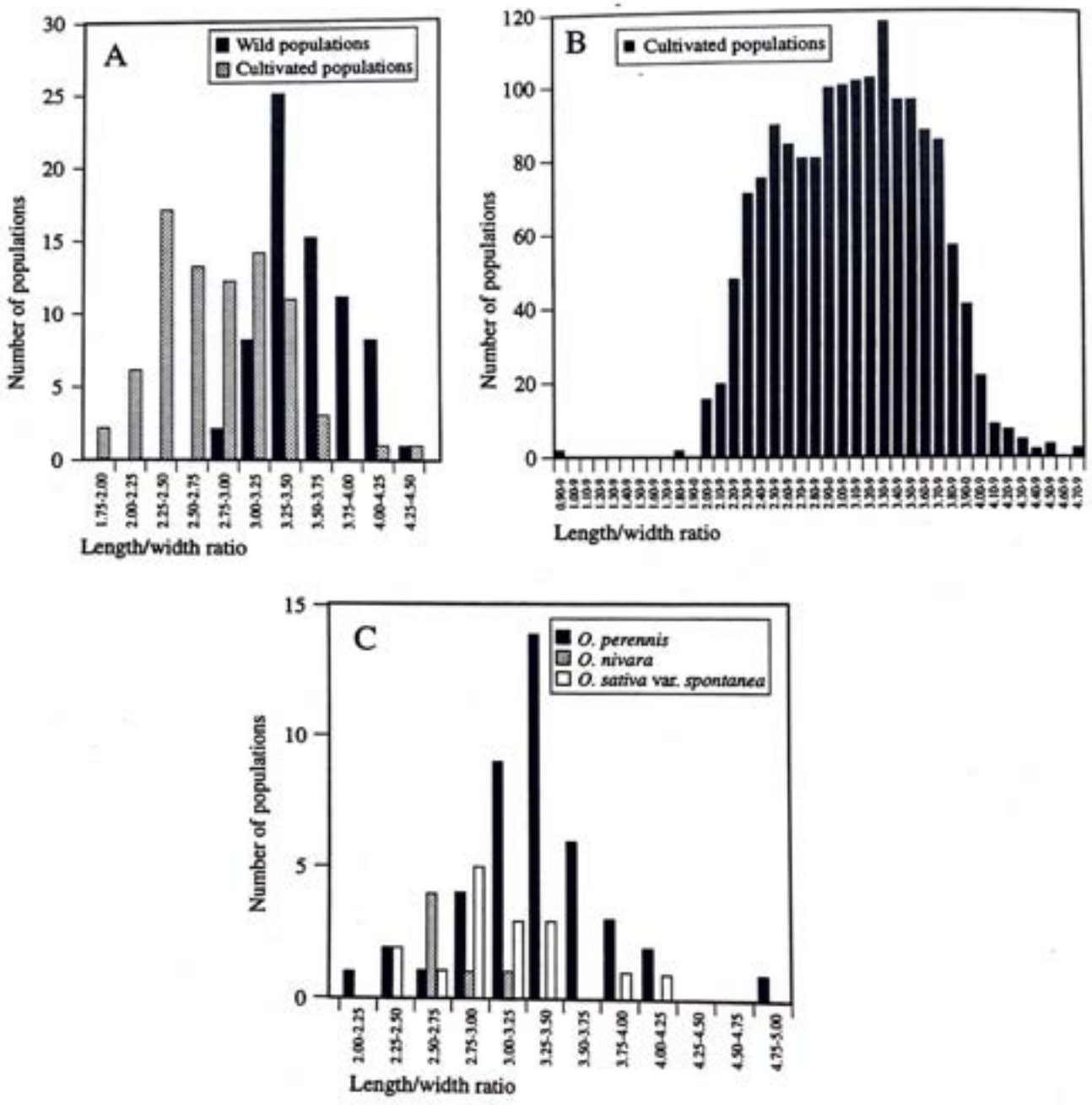


FIG. 38. Mean length/width ratios for spikelets from A: 150 populations of cultivated and wild Thai rice (Source: Morishima *et al.* 1961:330), B: 1573 populations of cultivated rice. Combined data from Cho and Kuriyama (1965:618), Morishima *et al.* (1984:52, 73–5) and Hamada (1965:544–83) and C: 65 populations of wild rice (Sources: Akihama and Watabe 1970:343, Sakai *et al.* 1961:63 and Sharma and Shastry 1965a:248)

and in the clay coating to cord-marked ceramics. The great majority of these husks were fragmented, having been broken down by threshing and milling in the course of food preparation and in preparing crop processing waste for ceramic temper. As a result, instead of focusing on the gross morphology of the spikelet, attention must be redirected to details of the husks' distinctive surface topography.

The taxonomic value of studying epidermal features of lemmas and paleas has been illustrated in various other taxa in the Gramineae (Clark and Gould 1975, Thomasson 1986), used to demonstrate relationships between some fossil and living grasses (Thomasson 1978, 1980) and even applied to the analysis of prehistoric wheats and barleys (Hopf 1954, Körber-Grohne and Piening 1980). The potential of this approach to the archaeobotany of rice has long been recognized by scientists like Chowdhury and Gosh (1954-55), Buth and Saraswat (1972), Savithri (1976) and Sharma (1983), although their results have not been published.

Comparative SEM studies examining fine structural differences in the morphological characteristics of the inflorescence bracts have usually concerned widely separated taxa, with very few studies focused on variation within a single species or comparing cultivars with their wild relatives (Hoagland and Paul 1978). In this section, the anatomy and topography of lemmas and paleas in domestic rice and its close relatives will be outlined from published descriptions and from an examination of reference material. The ways in which these features have previously been applied at a range of taxonomic levels will be outlined, before turning to the possibility of using lemma and palea topography for distinguishing between wild and domestic rices.

Studies of the anatomy and morphology of *Oryza* lemmas and paleas: separating rice from other cereals and wild grasses on the basis of epidermal characteristics of the spikelet

The reliability of lemma and palea topography for discriminating between taxa is greatest at the generic level, declining further down the taxonomic hierarchy. In an archaeological application, subfossil cuticles found in terracotta have been identified as wheat, rather than rice, on the basis of epidermal characteristics, the type of stomata and silica bodies, and the shape of the hairbases (Vishnu-Mittre and Savithri 1973). Sharma (1983) also compared the husk morphology of *Oryza* to 83 species in 13 genera of Asian wild grasses and confirmed that the chequerboard pattern of upstanding tubercules is unique to rice. Micromorphological characters are particularly effective for discriminating between spikelets of *Oryza* and the closely related genus *Leersia* (Terrell *et al.* 1983), as well as within the genus, between the four sections of *Oryza* (Kihara and Katayama 1960, 1962, Sharma and Shastry 1965c, Katayama 1969).

Distinguishing between wild and domestic rices through lemma and palea topography

The surface topography of *Oryza* spp. lemmas and paleas has been described by Katayama (1969), in general terms for *Oryza sativa* by Zee (1981) and with great attention to anatomical and histological detail by Juliano and Aldama (1934:40–6). Published SEM photomicrographs have been provided for the cultivar by Maeda (1972), Watson and Dikeman (1977) and Zee (1981).

Micromorphological surface features of lemmas and paleas include siliceous tubercules, trichomes and microhairs (Fig. 46:1). The abaxial (outer) surfaces of the lemma and palea have similar topography, covered with numerous, closely-spaced tubercules or papillae, which project from the surface. Each of these large compound tubercules is circular to elliptical at its base and

has one to three distinct silica-rich projections on the outer epidermal wall, as well as small protruding granules along its flanks. Tubercules with a double apex are features of wild rices (Katayama 1969) and cultivars (Maeda 1972). Tubercule diameters range from 50 to 150 microns. Silica is deposited throughout the cell walls of the rice husk but is mainly localized in the inner and outer epidermal cells, especially in the papillae (Santos 1933, Yoshida *et al.* 1962b, 1962c, Soni and Wynn Parry 1973, Kaufman *et al.* 1981, Balasta *et al.* 1989). The epidermal cells of lemma and palea are square to rectangular, laterally elongate and dentate along their lateral margins. Each cell corresponds to a single tubercule. The margins of these anastomosing cells can be seen as sub-surface ribbed undulations along the flanks of some tubercules. Papillae are conspicuously arranged in longitudinally parallel lines. Transverse rows are straight, but sometimes wavy, creating the more or less chequerboard arrangement so distinctive of the genus *Oryza*.

TABLE 39: *Density of tubercules in a range of reference specimens of wild and cultivated rices*

Taxon	Number of granules [tubercules] per 0.5 mm^2 of the central lemma [photographed at x20]
O. nivara	42
O. rufipogon	42
O. sativa var. *sativa*	42
O. sativa var. *mutica*	56
O. sativa (medium-sized variety from Roxburgh)	72
O. sativa (large-sized variety from Roxburgh)	42
O. sativa subsp. *brevis*	72–81
O. sativa	49–56
O. sativa (from Philippines)	81
O. sativa (from Siam mountains)	81
O. sativa var. *spontanea*	49
O. sativa (from Afghanistan)	56
O. sativa (medium-sized variety from Sri Lanka)	42
O. sativa (large-sized variety from Sri Lanka)	56–63
O. sativa var. *sativa* (from Kashmir)	56
O. sativa var. *sativa* forma *mutica*	48
O. sativa var. *sativa* (from Jalpaiguri)	36
O. sativa (medium-sized variety from Roxburgh)	56–64

(Source: Savithri 1976:63–7)

In the longitudinal depressions between the tubercules there are two kinds of distally pointing hair: thick-walled unicellular macrohairs or trichomes, sometimes referred to as prickle-hairs (Metcalfe 1960, Terrell and Wergin 1981, Terrell *et al.* 1983), together with much smaller, more fragile two-celled microhairs (Zee 1981, Fig. 46:1). Microhairs were noted on the husks from ce-

ramic temper at Khok Phanom Di, but are generally of little diagnostic value because they occur in both wild and cultivated rices and because their distal cells are easily distorted or destroyed. These smaller hairs are well preserved in fresh comparative material, but even if taxonomically valid differences are observed, these could probably not be employed for characterizing the archaeological material due to inconsistent preservation.

Trichomes, by contrast, are larger, rigid, sharp-pointed and much more robust. Their cell walls thicken, becoming silicified, tough and bristle-like at maturity. Large enough to be visible to the naked eye, they are irregularly distributed across the spikelet, tending to concentrate along the margins, the middle nerve or keel and at the tip of the lemma (the apiculus, Fig. 45:6). They are more common in the wild rices *O. rufipogon* and *O. nivara* (Sharma and Shastry 1965b) and conspecific weedy red rice (Hoagland and Paul 1978) than in the cultivars, as they are features adaptive for self-dispersion. The degree of pubescence in the seed coat varies among the cultivars, with some varieties ciliate and others smooth.

Comparative SEM studies on another cereal crop and its wild relatives, oats (*Avena sativa*, *A. fatua* and their F1 hybrids), have concluded that the shape of the prickles on the lemma and the type of columnar and subular prickles on the awns are useful characters for separating these closely related taxa (Baum 1971). Among the rices, inter-specific differences have been observed in the morphology of the hair bases, particularly in the size of the lumen (Savithri 1976:92, text figs. 28–30). Careful dissection of *Oryza sativa*, *O. perennis* and *O. rufipogon* spikelets demonstrated these to be taxonomically useful features.

Diagnostic features

Differences in the microtopography of lemmas and paleas from wild and domesticated rices are subtle. In respect of Gramineae in general, Metcalfe's (1960:xxxix) authoritative opinion that 'intraspecific differences are very minor when compared with those that are interspecific, many of them being quantitative rather than qualitative' is applicable to members of *Oryza* where the taxa are not genetically isolated, as in the conventional definition of a species.

The means of separating wild from cultivated rices using these features in the archaeobotanical record has been addressed by Yen (1982), and also by Savithri (1976) and Sharma (1983) after their 'exhaustive investigations on ... epidermal studies of lemma and palea ... of a wide range of the wild and cultivated species of *Oryza*' at the Birbal Sahni Institute of Palaeobotany in Lucknow (Saraswat 1986:100).

These studies were based on twenty accessions of wild *Oryza* species, many beyond the geographical range of the putative ancestors of domestic rice, and fourteen varieties of cultivars from the herbarium of the Royal Botanic Gardens, Kew. Savithri (1976) measured the number of tubercules in 1 cm^2 of a x20 photomicrograph of the central part of the spikelet, which is equivalent to an area of 0.5 mm^2 on the specimen. One of her main conclusions is that tubercule density on the central lemma is diagnostic at the species level, although this is not self-evident in her data (Table 39). Furthermore, the density of tubercules varies between different areas of the spikelet (Fig. 40) and accurately using the density index to categorize temper in pottery which is highly comminuted would be problematic. It is often difficult to ascertain with any certainty the region on the spikelet that a small piece of husk was originally from. An examination of the data on tubercule densities

TABLE 40: *Cell shape characters of* Oryza *husk*

Species	Cell Shape	Trichomes-Papillae	Cell Wall Thickenings
O. perennis	square, rectangular	present	double wall, serrated
O. spontanea	square with raised cells (gives a small roundish appearance)	few not distinct	thick, cells walls
O. rufipogon	square	few	thick wall, distinct (gives a roundish appearance to cells)
O. sativa (*indica*)	big squares	none	double wall
O. sativa (*japonica*)	small squares	none	thick double wall

(Source: pers. comm. T.-T. Chang in Yen 1982:56)

compiled from Savithri's thesis (Table 39) repeats the now familiar wide intraspecific variation and overlap between the cultivars and their wild relatives.

Extensive extracts from Savithri's (1976) and Sharma's (1983) accounts are quoted here (with permission from the Director of the Birbal Sahni Institute) because the results of these two detailed studies are unpublished apart from a small portion of Sharma's findings (Vishnu-Mittre 1989, citing Dixit *et al.* 1987) and the theses are not accessible outside India. Savithri (1976:63–5), using light microscopy, describes her reference material (with *O. nivara*, before *O. rufipogon*) as:

> *Oryza rufipogon*: Ornamentation pattern regular and composed of distinct rounded granules [tubercules] close to one another and well raised from the general surface. A squarish dark area seen between every four granules. Number of granules in one cm^2 of the central area of the lemma is 42. Anastomosing layer faintly indicated towards the basal region of lemma as well as palea.
>
> *Oryza nivara*: Ornamentation pattern regular composed of closely arranged granules which are neither completely cubical nor completely rectangular. Slits dark in straight lines between them. Number of granules in one cm^2 of the central area of lemma is 42. Anastomosing layer visible only at the base of the lemma.
>
> *Oryza sativa*: Ornamentation pattern regular. Granules cubicular. In some the corner where four granules meet is occupied by squarish dark area. Dark slits mostly invisible or absent. These characters shared by several cultivated varieties of *O. sativa* with minor differences between them.

Sharma (1983:52–3), working several years later, was able to take advantage of technical advances and new equipment, used the scanning electron microscope together with the SUMP (Suzuki Universal Microprinting) method, and assessed her material as follows:

> *Oryza rufipogon* (based upon 12 specimens). Shape varies from Slender, Broad-Slender and Short-Round; few to many horizontal wavy rows on the husk; few on husk of slender grains, but more on broad slender grains. Granules [tubercules] closely arranged rounded, and protruded from the surface. In some specimens a squarish to rectangular dark area, where the four granules meet, is present. Less spacing between the granules. Granules broader, each with 2-3 horn-like structures (SEM). Ring-like structures present between the granules (SUMP, SEM).
>
> *Oryza nivara* (based on 2 specimens). Shape Broad-Slender with rounded ends; few horizontal wavy rows present on the husks. Granules closely arranged, neither completely cubical nor rectangular. Vertical bars between two adjacent granules arranged in straight lines (SUMP). Less spacing between the granules each with two horn-like structures and with ring-like structures present between the granules (SEM).
>
> *Oryza sativa* (based on 29 specimens). Shape varies from Slender, Narrow-Slender, Broad-Slender with ends rounded, and Round (Short-Large) grains; many horizontal wavy rows on the husk. Granules small cubicular not much raised, dark area observed in some cases where the four granules meet. More spacing between the granules (SEM), a squarish or circular dark area, each with two smooth horn-like structures.

The other major archaeobotanical contribution on rice husk topography is the analysis of the Ban Chiang pottery with rice-husk inclusions (Yen 1982). Working with the advice of IRRI geneticist Dr T.-T. Chang (Table 40), and after further metric studies of cell patterns and tubercule arrangement in modern cultivated rice and its postulated wild relatives, Yen went on to investigate fragments of husk from prehistoric ceramic temper. The cell size of tubercules in the central area of the spikelet, as measured for three lines of ten cells, was found to be more variable in modern *O. nivara* than in *O. sativa*, with a range extending beyond that for husk cells from the cultivar.

Some of the criteria originally passed on from Chang to Yen are now questioned, since it was suggested that *O. sativa* husks have no trichomes. As Yen points out (1982) and is confirmed by the current study, these hairs do indeed feature on the husks of traditional cultivars, so their simple presence or absence cannot be used to separate a wild husk from that of a crop plant. Poorly defined and quantitative differences are noted between species. The spikelets of cultivars tend to be more hirsute than those of their wild relatives, but the range is continuous and neither the presence/absence nor the density of trichomes is a reliable diagnostic character. Furthermore, while trichome morphology may, for some taxonomic groups, have systematic importance (Staudermann 1924, Carlquist 1961), this is not the case for rice.

The application of husk surface characters in the separation of wild from cultivated *Oryza* in archaeological material is problematic. For example, the Khok Phanom Di specimens were similar to the Banyan Valley Cave rice spikelets in lacking awns (Yen 1977), which is a feature exclusive to cultivars, yet the Banyan Valley specimens were asserted to be wild, in terms of the cell patterns on their lemmas (pers. comm. T.-T. Chang in Yen 1977).

COMPARATIVE RICE COLLECTIONS AND THE ARCHAEOLOGICAL MATERIAL

With the above work in mind, especially that of Yen, further SEM studies were undertaken to investigate surface morphology of traditional varieties of cultivated rice and examples of *O. rufipogon* from ephemeral swamps, all collected from south-eastern Thailand, and accessions of *O. nivara* and *O. rufipogon* provided by the International Rice Research Institute (Philippines) and the Rice Research Centre at Pathum Thani near Bangkok.

Problems in creating a reference collection of modern rices

Most of the modern wild-type specimens used as reference material were provided from the seed stocks of rice research institutes in Thailand and the Philippines. This was due to the difficulty in finding collection sites for truly wild rices along the south-eastern seaboard of Thailand today. The loss of natural habitats for wild rices has been due to accelerated urbanization and improvements in agriculture throughout the region. Even in the late 1950s, when Morishima and colleagues were first collecting wild rices in Thailand, there were few communities of wild rice, isolated from cultivars, to be found (Morishima *et al.* 1961). Many of today's so-called 'wild rices' are in fact weedy races, adapted to conditions which would not have existed in a pre-agricultural landscape (Harlan 1965), thus making them less than ideal for an archaeobotanical reference collection. This situation is not confined to the wild rices. The ancient landraces (traditional, established lines of cultivars) have been subject to genetic erosion by their replacement with modern 'improved' varieties. Furthermore, there has been 'accelerated evolution' of the species of cultivars (Morishima and Oka 1960) in the *c.* 4000 years since the archaeological rices were alive, so that the modern varieties may differ somewhat from the cultivars of past times. Thus, modern voucher specimens are unlikely to be exact analogues to the prehistoric plants.

Wild rices in Thailand today

Perennial wild rice species (*O. officinalis*, *O. perennis*, *O. obtusifolia* and *O. rufipogon*), as well as the annuals *O. nivara* and *O. sativa* f. *spontanea*, grow in Thailand today, with the last being the most common species, especially as it is a common weed of rice paddies (Tateoka 1964, Vongsaroj n.d.). *Oryza granulata* (=*O. meyeriana*) (*khao nok*) and *O. ridleyi* (*yaa khao thaam*) are reported from the northern parts of the country, around the Burmese border (Bor 1962, Akihama and Watabe 1970), while *O. punctata* (Lazarides 1980), *O. latifolia* (*yaa lamaan*) (Smitinand 1980) and the tetraploid *O. ridleyi* are additional members of the genus recorded for Thailand (Wang *et al.* 1992). SEM analysis was restricted to the cultivar, *O. sativa*, and its putative ancestors *O. rufipogon* and *O. nivara*.

Exploring novel diagnostic criteria and their archaeological applications

Dry spikelets of *O. rufipogon*, *O. nivara* and *O. sativa* were mounted on aluminium stubs, coated with 250 Åof gold and examined using a Cambridge scanning electron microscope, model S360, operating at 20 kV. The parts of the inflorescence studied were confined to those elements found in the archaeological record at Khok Phanom Di, namely the lemma and the palea, the rachilla and the abscission scar. Naked caryopses were excluded, since they are not recorded archaeologically at Khok Phanom Di.

Gold-coated specimens were used for acquiring secondary electron images. Additional specimens were mounted on carbon stubs and carbon-coated for X-ray analysis (energy-dispersive X-ray analysis or EDAX), which is especially good for comparison of silica deposition sites in different areas of the same tissue and for mapping silicon distribution across a tissue.

The degree of sclerification of wild and cultivated rice husks (by silica deposition) was also initially examined using backscattered imaging (following Brandenburg *et al.* 1985). Patterns of distribution of silicon in the epidermis were recorded but were difficult to assess. Pairs of secondary electron images and backscattered images of *O. rufipogon* and *O. sativa* husks were observed and photographed, in addition to silicon X-ray maps of husks. Minor differences were inadequate for differentiating between taxa, and the uneven surface topography of the husks confused the backscattered images.

Most SEM work with the reference material was therefore undertaken with secondary electron imaging, with the specimens viewed at magnifications of x50–x1,000 and photographs routinely taken at x100, x200 and x500.

The application of abscission characteristics to archaeological specimens

The archaeobotanical assemblage from Khok Phanom Di included some remarkably well-preserved spikelet fragments in the coprolite found in burial 67. These were mainly fragments of lemmas and paleas, but also rachillas with abscission scars. Rachis fragments and pedicels were absent from the assemblage, so were not screened for diagnostic characters in this study. These plant parts are so delicate that they are unlikely to be preserved unless the deposits are waterlogged. Under such conditions archaeobotanical assemblages of crop-processing debris might include pedicels and panicle branches, where examination of pedicel scars would be given high priority.

Among the archaeobotanical assemblages from India, rice remains with complete rachillas and abscission scars have sometimes been noted, for example, among the plant remains from Atranjikhera (Chowdhury *et al.* 1977) and Hastinapura (Chowdhury and Gosh 1954–5:122), but although the scars are illustrated, they are neither described anatomically nor discussed in terms of whether the original plants were domesticated or wild.

Abscission scars in modern reference material

Photomicrographs were taken of abscission scars of *O. sativa*, *O. nivara* and *O. rufipogon* from the reference collection assembled in Thailand. Ten spikelets from each of five accessions of *O. rufipogon* and *O. sativa*, along with four spikelets from a single accession of *O. nivara*, were mounted in abaxial view on aluminium stubs, using araldite. Double-sided cellulose tape was initially tried but provided inadequate contact between specimen and stub. Again, all specimens were gold-coated and observed by scanning electron microscope at 20 kV. Where the contact between the specimen and the stub was poor and charging was likely to result, additional colloidal silver or carbon was painted under the specimen to improve the contact (following Stemler and Falk 1981). Photographs were taken at magnifications of x200 and measurements were made of the maximum width and length of the scar, as illustrated in table 41 and figure 39. Length was measured parallel to the long axis of the spikelet and width measurements were perpendicular to that.

TABLE 41: *Length and width dimensions for abscission scars in wild and cultivated rices*

Taxon (Accession No.)	Mean length (microns)	Mean width (microns)	Mean l/w ratio
O. rufipogon (41)	349.1	370.0	0.945
S.D.	23.1	14.7	0.079
O. rufipogon (132)	333.4	339.4	0.981
S.D.	36.1	23.4	0.063
O. rufipogon (142)	338.1	356.5	0.953
S.D.	28.7	24.6	0.108
O. rufipogon (143)	345.7	384.9	0.900
S.D.	23.1	20.6	0.072
O. rufipogon (602)	311.0	376.3	0.824
S.D.	50.6	43.1	0.066
O. nivara (603)	358.8	427.8	0.838
S.D.	24.5	7.8	0.046
O. sativa (220)	343.7	416.7	0.826
S.D.	25.8	17.8	0.063
O. sativa (222)	339.8	421.3	0.811
S.D.	33.1	31.0	0.105
O. sativa (224)	347.1	401.7	0.865
S.D.	23.9	21.4	0.052
O. sativa (258)	350.4	414.4	0.847
S.D.	27.4	21.1	0.075
O. sativa (262)	336.8	414.2	0.813
S.D.	31.8	16.4	0.067

Criteria for distinction based on abscission scars

The morphology of abscission scars in *O. rufipogon* and *O. sativa* was observed to differ in three major respects: general shape, depth and cell morphology. The wild rice spikelets examined (Fig. 44:5) each had a circular scar after seed detachment, similar to those in wild oats (Yeung *et al.* 1987). The scar margins were smooth and well defined, with the vascular bundle clearly visible as a circular pit central to the scar. The wild-type scars were shallower than the domestic ones (also noted by Chalam 1942 and Srinivas *et al.* 1979), while the parenchymatous tissue, which had sheared naturally at abscission, had thin-walled parenchymatous cells. Domesticates typically had a reniform scar (Fig. 45:3), deeper and more ragged than the wild-types, and in the central area

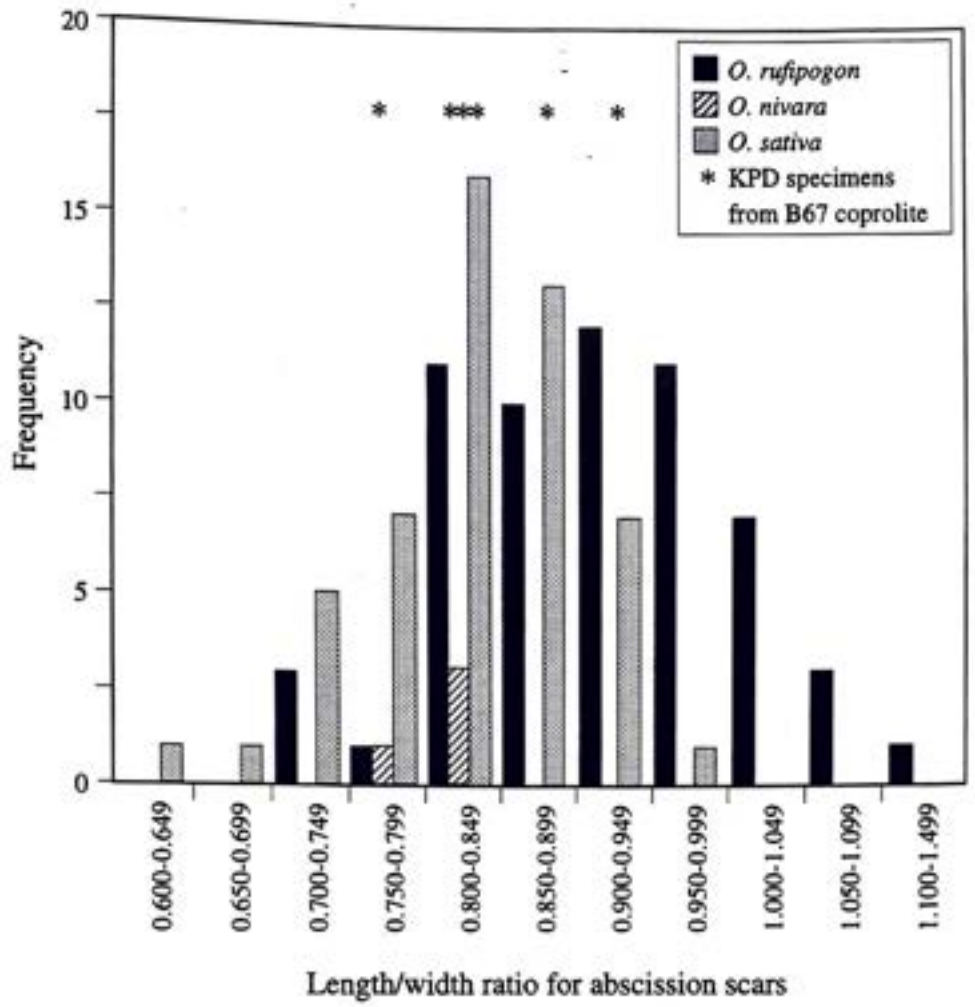


FIG. 39. Frequency distribution of length/width ratios for abscission scars in wild and domesticated rices

the vascular bundle was irregularly broken, leaving an upstanding stump of tissue or a sub-circular hole.

The rice remains from burial 67: abscission scars

The coprolite found in burial 67 was disaggregated. The husks extracted were soaked in alcohol for five minutes then agitated in an ultrasonic bath for a further two minutes to dislodge sand grains, indeterminate fibres and insect fragments. Once clean, they were set aside to air-dry slowly before being mounted on SEM stubs.

The husks were pale brown in colour and neither fragile nor brittle. Many of them were curled parallel to their length, but were not greatly distorted. All parts of the spikelet except caryopses and awns were represented in the collection (Table 42). Every item was damaged in some way and the fractures were not always clean.

TABLE 42: *Husk fragments from the coprolite in burial 67*

Plant part	Number of items
Complete spikelet	1
Rachilla	13
Rachilla with lemma	5
Rachilla with palea	8
Distal end of lemma or palea	22
Palea fragment	37
Lemma/palea fragment	109

Abscission scars were noted in twenty seven items. Some of these were simply the rachilla, while others still had part of the lemma and/or palea attached. They were mounted on aluminium stubs, coated with gold and viewed by SEM under the same conditions as the reference material.

On close inspection it was obvious that, while most husk fragments were well preserved and had clear surface topography, some surfaces were abraded and pitted. This was particularly true of the rachillas, perhaps more susceptible to chemical etching in the digestive tract because they have less silica coating than the husks. Although the specimens had been cleaned in alcohol, a little organic matter adhered to them and this sometimes obscured the abscission zone. This area was also pitted and 'weathered', where the external layer of epidermal cells had been partially removed (Fig. 45:1-3). This is presumably due to the chemical effect of having been passed through the gut, which has stripped away patches of the outer epidermal layers of the spikelet. Nevertheless, the overall shape of the abscission scar remained clear in some specimens. Where possible, length and width dimensions of the scar were measured (Table 43). These data have been superimposed on figure 39, which illustrates the frequency distribution for mean length/width ratios for abscission scars in modern wild and domesticated rice plants from the reference collection. This graph shows that length/width ratios for abscission scars of cultivars are often less than those of wild-types, because the former tend to be reniform and the latter circular. An obvious morphological difference between the two types is not supported by the metric data where the frequency distributions for the wild-types and the domesticates overlap considerably. As a result, measurements for the Khok Phanom Di specimens fall into the indeterminate zone on the graph. Morphologically, though, the abscission scars from the coprolite material appear to have features of domestication, such as reniform outline and broken dehiscence surface. The number of specimens is small and preservation, at a microscopic level, is not ideal. Nevertheless, the general abscission scar morphologies suggest that these specimens from burial 67 are from a domestic population.

Length and width measurements of spikelets

As mentioned earlier, length and width measurements were recorded from spikelet impressions and husks found in soil samples and in the ceramics (Tables 44 and 45). Only a handful of specimens were well preserved with both dimensions intact, so the number of length/width ratios calculated

TABLE 43: *Length and width dimensions of abscission scars for spikelets from the coprolite in burial 67*

Specimen (stub/specimen no.)	Length (microns)	Width (microns)	l/w ratio
T7/1	285	330	0.86
T7/2	270	obscured	-
T7/4	317	422	0.75
T7/5	288	335	0.86
T7/6	272	295	0.92
T7/8	350	360	0.97
T7/9	275	314	0.88

is limited to 15. These range from 2.19 to 3.67, which is probably more indicative of measurement error associated with incomplete preservation than an accurate reflection of variation in the prehistoric rice population.

The variability in length/width ratios for spikelets from modern vouchered rices is high and, as demonstrated earlier, the reliability of this index for separating wild from domestic spikelets is low, because spikelet shape varies along continuous gradients from short and broad to long and narrow. If one examines solely the length/width distributions from Morishima *et al.* (1961:330) (Fig. 38A), where all the samples were from Thailand, then some of the Khok Phanom Di specimens fall into the domestic side of the distribution and others into the overlap between wild and domestic types. The greater regional perspective provided by other data summarized in figure 38 A-C indicates that the wild/domestic dichotomy is less clear-cut, so that we cannot state definitively whether the rice husk specimens from the archaeological contexts at Khok Phanom Di are from wild or domestic plants simply on the grounds of the shape or size of their spikelets.

The precise extent of shrinkage during firing for rice remains found in the clay coating is unknown. Less than 2 per cent shrinkage was estimated for rice husk tempered bricks (Watabe *et al.* 1970), while experimental kiln-firing of rice husk tempered bricks and pottery at temperatures greater than those probably applied to the Khok Phanom Di ceramics, has indicated slight shrinkage at 375°C, increasing with temperature (Stargardt 1983).

Cell size

Measurements of cell size were taken for archaeological specimens (following Yen 1982:60), so that the Khok Phanom Di material could be compared with the archaeological remains from Ban Chiang, as well as Yen's characterization of modern reference material. Yen had measured cell widths from a minimum of three and a maximum of ten rows of ten cells, with measurements along the longitudinal axis of the spikelet. For the Khok Phanom Di specimens, equivalent measurements were taken from SEM photomicrographs with a magnification of x200, using the Jandel Sigma Scan (version 3.1) image analysis program. A minimum of thirty cells was measured per

TABLE 44: *Length and width measurements for spikelets from soil samples*

Context	Length (mm)	Complete	Width (mm)	Complete	Length/ width ratio
8:7	-	-	2.4	Y	-
10:8	8.0	Y	-	-	-
10:14	6.0	N	2.5	Y	2.60
10:16	6.0	N	2.6	Y	-
10:16	-	-	2.2	N	-
10:16	8.0	Y	3.5	N	-
10:16	8.0	Y	2.5	Y	3.12
10:19	8.0	Y	2.8	Y	2.68
10:19	8.0	Y	-	-	-
10:19	-	-	2.6	Y	-
10:19	8.0	Y	3.0	*	-
10:19	8.0	N	-	-	-
10:19	8.0	N	-	-	-
10:19	8.0	Y	2.4	N	-
10:19	6.0	Y	-	-	-
10:20	8.0	Y	2.0	*	-
10:20	8.0	Y	3.0	Y	2.67
10:21	8.0	Y	2.5	Y	3.00
10:22	8.0	Y	2.8	*	-

Y = complete dimension, N = incomplete dimension, * = possibly incomplete dimension

archaeological husk fragment, but these were not always from rows of ten cells, firstly because the husks had broken down into square rather than rectangular shapes, with blocks of less than ten cells, and secondly because the measurements were taken from x200 rather than x100 photographs. Yen had been able to take measurements from enlarged x100 images which illustrate in the order of 12-18 tubercules per row, but for the Khok Phanom Di material it was considered more economical and expedient to take the measurements from illuminated and magnified contact prints. The clarity and resolution were better in the x200 than the x100 exposures, so measurements were taken from these wherever possible, although they illustrated fewer cells per image. Measurements were taken parallel to the long axis of the spikelet, from the midpoint of one depression between two tubercules to the next depression. This corresponds to the cell dimension rather than the width of the upstanding tubercule. The relationship between tubercule width and cell width was not consistent. Sometimes the projection was narrow and did not fill the entire cell, giving the overall impression of widely spaced papillae (Fig. 48:4), while at other times the papillae appeared to be more closely

TABLE 45: *Length and width measurements for spikelets from the clay coating on cordmarked bodysherds*

Context	Length (mm)	Complete	Width (mm)	Complete	Length/ width ratio
9:6	6.0	Y	2.5	Y	2.40
9:6	6.5	Y	-	-	-
9:6	5.0	Y	-	-	-
9:6	5.5	Y	-	-	-
9:7	7.0	N	-	-	-
10:1	6.5	Y	-	-	-
10:1	5.0	Y	-	-	-
10:1	5.0	Y	1.7	Y	2.94
10:1	6.0	Y	-	-	-
10:1	6.0	Y	-	-	-
10:3	7.0	Y	2.5	Y	2.80
10:3	7.0	Y	3.0	Y	2.33
10:3	-	-	2.5	Y	-
10:3	-	-	2.5	Y	-
10:3	6.0	Y	-	-	-
10:3	6.5	Y	1.5	N	-
10:3	5.0	Y	-	-	-
10:3	-	-	2.5	Y	-
10:3	6.4	Y	1.8	N	-
10:3	6.6	Y	-	-	-
10:3	6.0	Y	-	-	-
10:3	-	Y	2.5	Y	-
10:4	6.0	Y	-	-	-
10:4	7.0	Y	-	-	-
10:4	5.0	P	-	-	-
10:4	4.8	Y	-	-	-
10:5	6.8	Y	1.8	Y	3.78
10:5	7.0	Y	3.2	Y	2.19
10:5	7.2	Y	-	-	-
10:5	6.8	Y	-	-	-
10:6	6.0	Y	1.8	Y	3.33
10:6	7.0	Y	-	-	-
10:7	5.0	Y	1.5	Y	3.33
10:7	-	-	2.5	Y	-
10:8	5.5	Y	1.5	Y	3.67
10:8	4.8	Y	1.5	Y	3.20
10:17	-	-	2.5	Y	-
10:17	6.8	Y	-	-	-
10:17	-	-	2.5	Y	-

Y = complete dimension, N = incomplete dimension, - = possibly incomplete dimension

spaced (Fig. 40f). The spacing of tubercules did not bear a close relationship to the taxonomic groups.

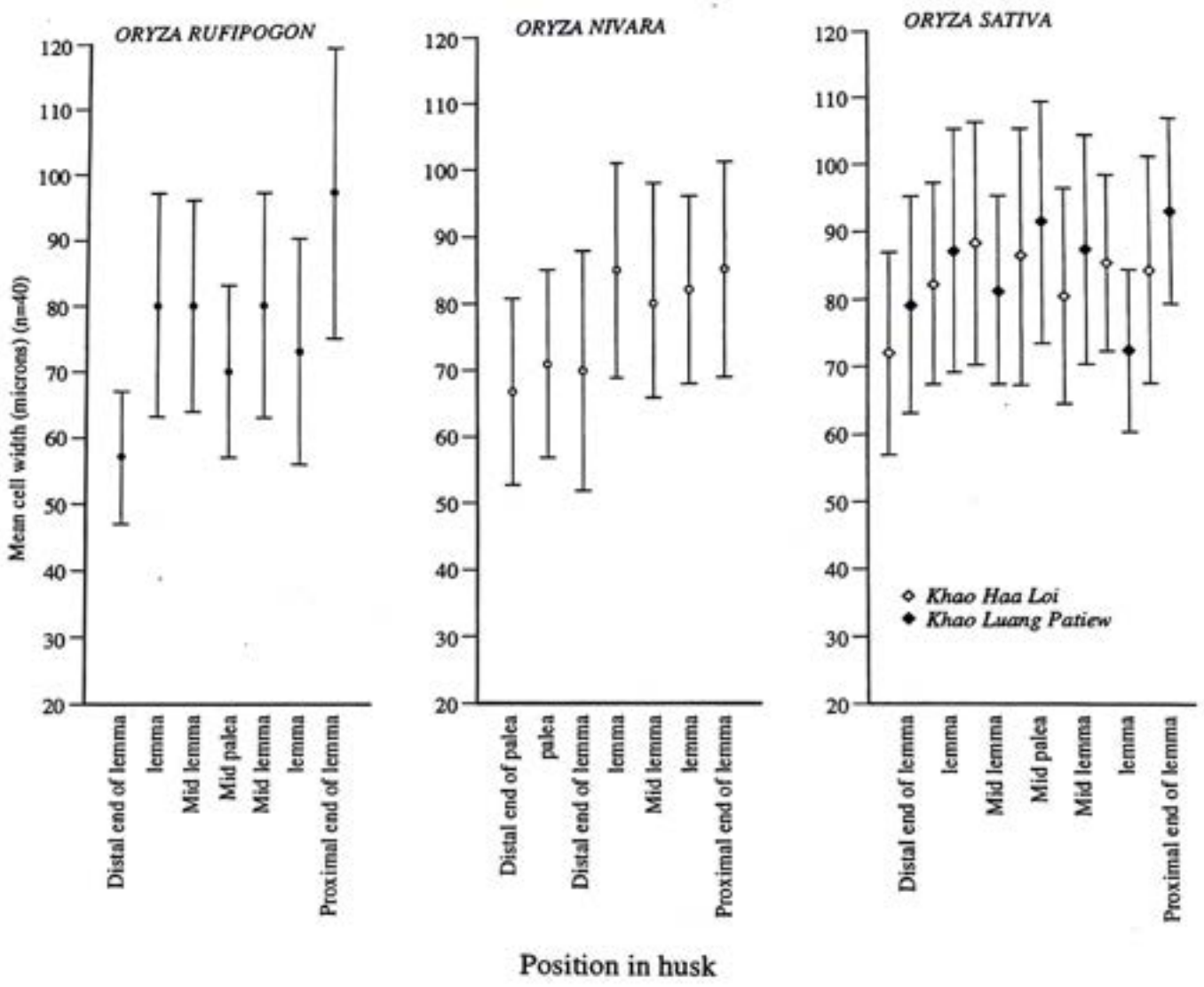


FIG. 40. Comparisons between mean cell widths for spikelets within a population and between wild and domestic rices. Bars indicate the standard deviation from the mean

Cell size measurements from the Khok Phanom Di material were converted to a mean cell width per husk fragment (Fig. 41). Mean cell widths span the range 57–97 microns. This is incompatible with the graph of the Ban Chiang data (Yen 1982:59), where equivalent figures range from *c.* 94 to *c.* 194 microns. However, the Khok Phanom Di data would fit well with the earlier work, if Yen's results were divided by a factor of two. Calibration factors were double-checked and found

TABLE 46: *Comparisons of mean cell width (microns) (with standard deviation) from the central area of a number of* O. rufipogon, O. nivara *and* O. sativa *spikelets*

Oryza rufipogon	*Oryza nivara*	*Oryza sativa* (i)	(ii)	(iii)
86 (16)	83 (15)	75 (17)	76 (14)	58 (15)
81 (16)	71 (12)	81 (19)	86 (19)	69 (20)
85 (16)	82 (14)	82 (17)	86 (17)	60 (12)
79 (17)		82 (18)	79 (18)	71 (15)
81 (13)		80 (16)	78 (19)	63 (13)
88 (17)				56 (10)
78 (13)				70 (11)
78 (19)				

Three traditional cultivars: (i) *khao haa loi* (ii) *khao luang patiew* (iii) *khao met lek*

to be correct for the current work. This inconsistency does not affect the validity of Yen's original conclusions, but it has made it difficult to integrate the new results with the previous analyses.

In the case of reference material measured in this study, the variation in mean cell width was estimated (a) within a single spikelet (n=40 cells for seven areas across each spikelet) (Table 47, Fig. 40) and (b) within each type, between cells in the central lemma area of several spikelets from a single population (Table 46, Fig. 40).

The graphs in figure 40 indicate the variation in cell width within an individual spikelet. Measurements were taken of 40 cells from seven areas of the lemma and palea surfaces, marked using the split screen function of the SEM. These data confirm that cells are largest in the central part of the lemma and at its proximal end, declining in size towards the distal end. Most rows gradually taper towards the narrow ends of the spikelet. Others taper a little then terminate. Cells of the lemma were also found to be somewhat larger than those at a comparable position on the palea. This wide range of variation within a single spikelet obscures any differences between wild and domestic specimens and reduces the reliability of cell width for making archaeobotanical identifications, as the original position of an archaeological husk fragment is usually difficult to discern.

Turning now to data comparing a number of spikelets from a single population (Table 46, Fig. 41), where measurements were repeatedly taken from the central lemma, we again observe a wide range in cell widths within the sample. In *O. nivara* and *O. sativa*, the range between spikelets is comparable to that within an individual spikelet. The specimens of the perennial wild *O. rufipogon* stand out, however, as having greater variation within an individual spikelet than within the sample of eight spikelets when only the central part of the husk was measured. Taking all this into account then, these data both confirm and augment Yen's general results. The wide range in variation between different areas on an individual spikelet, between different spikelets from a single population and between the three taxonomic groups means that cell size cannot be relied upon for discriminating between archaeological husk fragments from wild and domestic rices.

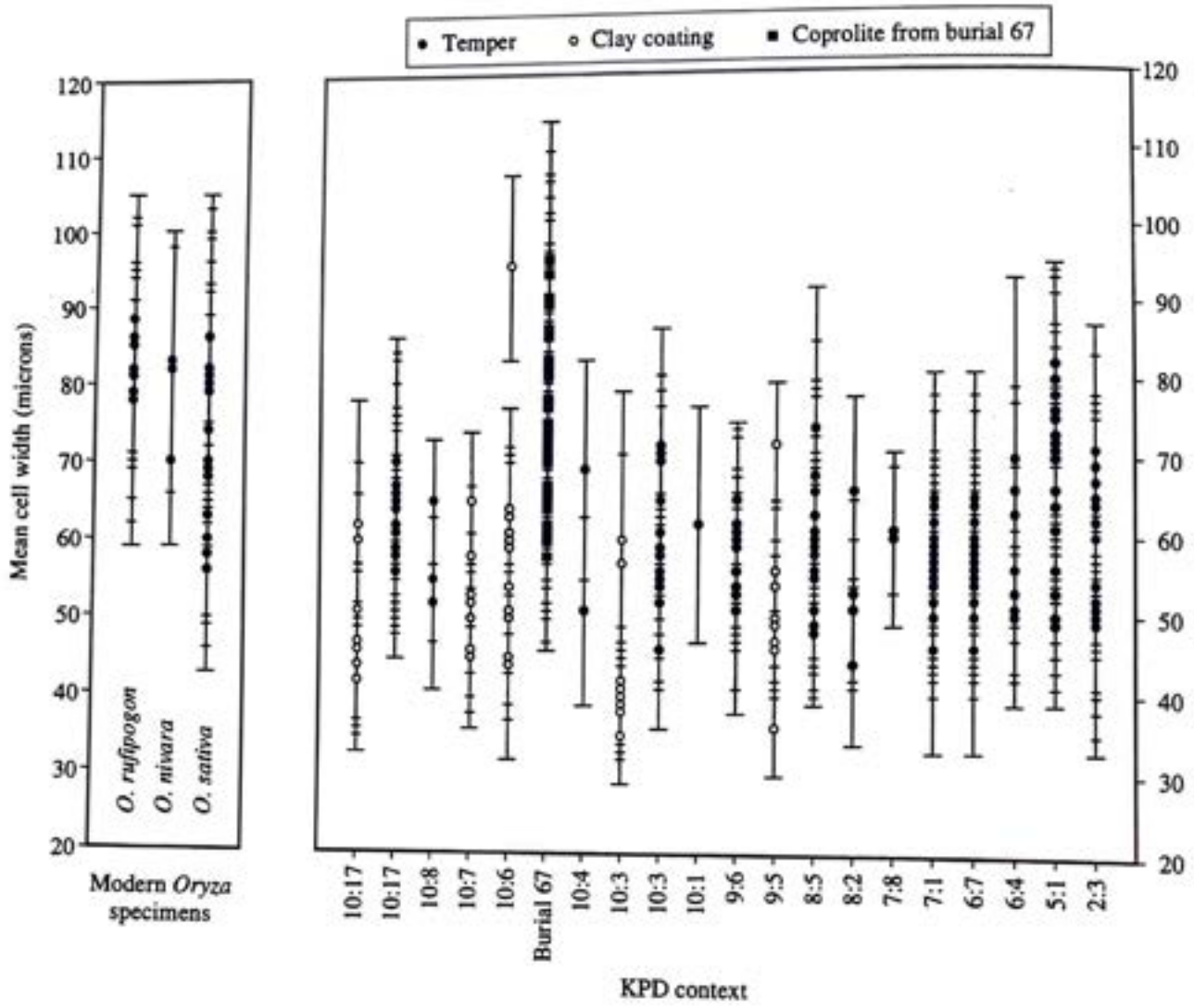


FIG. 41. Comparing mean cell widths for husks from modern *Oryza* and archaeological specimens from Khok Phanom Di. Each point represents the mean cell size (a) for a patch from the central area of the spikelet, in the case of reference material (n=70), and (b) for a single husk fragment, in the case of archaeological specimens (n exceeds 30). Bars indicate the standard deviation from the mean

The data on cell widths taken from rice husk fragments from eighteen archaeological contexts at Khok Phanom Di are presented as figure 41. This shows that the husks used as ceramic temper from the early phase do not differ significantly in terms of cell size from those in the later phases. In the two instances where husks were extracted from both sherds and the clay coating from a single context (10:17 and 10:3), those from the clay had consistently smaller cells than specimens from

the body of the sherd. This is counter-intuitive as husks from the body of the sherd, presumably exposed to higher firing temperatures and therefore more disposed to shrinkage, had larger cells than the chaff from the low-fired clay coating. This difference adds weight to the idea that the husks in the surface clay layer and in the body of the sherds were from different sources and that the clay was applied after the main firing of the pot.

Cell shape and arrangement

The chequerboard pattern of tubercules on the husks of *Oryza* spikelets makes the remains of rice and its wild relatives, all members of the *O. sativa* complex, clearly distinctive from other plant debris in the Asian archaeobotanical record, but the patterning is less reliable at the species level. Hoagland and Paul (1978) reported on lemma and palea surfaces of cultivars and conspecific weedy red rice and saw no significant differences in the tubercule topography, but Savithri and Sharma, whose characterizations of husk morphology have been quoted earlier, state that despite considerable variability within the cultivars and between populations of the wild-type grown in different regions, it is possible to separate unambiguously between *O. sativa* and the wild *O. nivara* and *O. rufipogon* using husk characters alone. They have applied their criteria in the identification of a number of archaeobotanical assemblages, even to the level of rice varieties (Savithri 1976:69–73, Sharma 1983:74–81), although they acknowledge the significant variability within taxa and the small samples analysed, both highly important points.

With verbal descriptions, even accompanied by photomicrographs or illustrations, it is often difficult to convey accurately a personal and impressionistic view about a surface texture. Photographs and descriptions are perceived subjectively and are open to reinterpretation. Savithri's and Sharma's identifications rely upon personal familiarity with the material, as Chang's and Yen's evidently rests on their personal expertise, but the diagnostic criteria have often been reported in ambiguous terms. Replicating the results of these studies and applying them to the Khok Phanom Di rice remains has been problematic, partly due to difficulties in comprehending and reinterpreting the accounts, but also due to the inherent variability of the topographic features in rice husks.

If we are to adopt tubercule arrangement as an aid to archaeobotanical identification, there is a strong need for a more objective approach, with formal standardized descriptions and the explicit definition of diagnostic criteria. One potentially profitable direction for future research would be the development and application of automated image processing, particularly texture analysis. This could first classify the complex surface textures of modern lemmas and paleas, then match those of archaeological remains with patterns from authenticated specimens of modern rice. Variation in spikelet anatomy may be linked to a range of external, environmental factors such as the degree of maturity and the availability of water to the plant, rather than genetic factors, and these should be controlled for in future investigations.

It is possible to discriminate between images of textures using second order statistical measures. Suitable approaches to this particular rice husk problem would be the use of grey-tone spatial dependence analysis or Fourier Power Spectrum analysis (pers. comm. P. Sobey, Russ 1990). These could be applied to digitized photomicrographs or digital images taken directly from an SEM screen to provide statistical information on periodicity and directionality of the cell patterns.

Such techniques have been applied to the classification of textures in images from aerial photographs and geological and biomedical photomicrographs, while their potential has been acknowl-

edged in the field of palynology. Research into novel techniques for automated pollen grain identification, based on exine texture and features, is well underway (Langford *et al.* 1986, Langford 1988, Witte 1988, Treloar 1992). In archaeobotany, computer-assisted image analysis has been used in the categorization of phytoliths, using gross morphology of the discrete silica bodies rather than surface texture (Russ and Rovner 1989). The application of image analysis to the distribution of silica bodies in leaf blades of rice has been described by Takeoka *et al.* (1983) and could well be extended to the examination of other plant parts, such as the spikelet.

The chequerboard pattern of tubercules on rice husks can be analysed in terms of (a) the shapes of the projecting papillae and (b) their spatial arrangement. The tubercules of the archaeological specimens from Khok Phanom Di range widely in shape between laterally elongate and rectangular to square. Within-context diversity was least in the fragments from the burial 67 coprolite. Here, tubercules were generally rounded, but some had additional warty projections while others tended to be laterally elongate. Many of the fragments from the coprolite exhibited widely spaced tubercules, separated by relatively broad, flat depressions. Enlarged, protruding papillae were observed flanking some macrohair-bases, notably in fragments from the distal end of the bract.

Variation in husk topography in specimens from ceramic temper within any single context was considerable, ranging from smooth to rough to pointed, with single, double and multiple points to the tubercules. The texture's regularity or irregularity has been indicated, in rather a simplified way, by the standard deviations for the mean cell widths in table 47, with the greatest standard deviations corresponding to the least regular patterns. Among the modern specimens, *O. rufipogon* had a greater range in cell size within a single spikelet than did the cultivars, indicating a more irregular arrangement of tubercules, but attempts to compare this with the archaeological fragments were inconclusive. In general, the cell arrangements of rice husks studied here varied from regular to irregular, with spacing between tubercules ranging from wide to narrow.

Split trichomes

Finally, one notable feature of the rice husk remains from Khok Phanom Di which was not observed in the modern voucher specimens was split and twisted trichomes (Fig. 49:2-4). Individual macrohairs were divided into two strands from the tip to approximately the midpoint and were often twisted in their central portion. These features do not appear to be a consequence of distortion by firing during ceramic production as they were also noted in the coprolite, which had probably not undergone heating. This type is not described in the typologies of Staudermann (1924) or Metcalfe and Chalk (1983).

CONCLUSIONS

The general themes pervading this assessment of the various diagnostic characters for identifying archaeological rice remains have been the wide variability inherent within each species of *Oryza*, especially the cultivar, together with the inter-specific overlap in quantitative features such as spikelet shape or size and husk topography, which make them weak in diagnostic terms. The strongest diagnostic features are those with qualitative rather than quantitative differences at the species level. These are restricted to the presence or absence of awns and the smooth or rough,

circular or reniform nature of the abscission scar. As pointed out earlier, however, these are the parts of the spikelet least likely to appear in an archaeobotanical assemblage.

Other avenues of inquiry have focused on the regularity of tubercule shape and the distribution of tubercules across the surface of the husk, as fragmentary lemmas and paleas are the most commonly encountered component of the archaeobotanical record, at least in mainland South-East Asia under current excavation methods. The need has been highlighted, and is worth reiterating, for standardized means of assessing and comparing the regularity of husk topography. Computerized texture analysis offers potential, but is technically complex. Until advances have been made in this direction, one goal should be systematically to retrieve larger samples of plant remains from archaeological sites, so that greater numbers of rachillae and the distal ends of spikelets are recovered. These have been the most informative examples of rice remains in the Khok Phanom Di assemblage, but the numbers of items with reliable diagnostic features is very small, and almost entirely due to excellent preservation of rice husks in the coprolite from burial 67. Here, and in a few specimens from the flot, there were rachillae preserved with the abscission scar visible. Their reniform shape and rough surface bore closer resemblance to modern cultivars than to wild rices. Secondly, those husk fragments with intact distal ends, had rounded apiculi, lacking an awn, which is a clear sign that they came from a domesticated crop and one which had undergone extended selection and evolution under cultivation. The implications of this for the occupants of the site will be explored in chapter VIII.

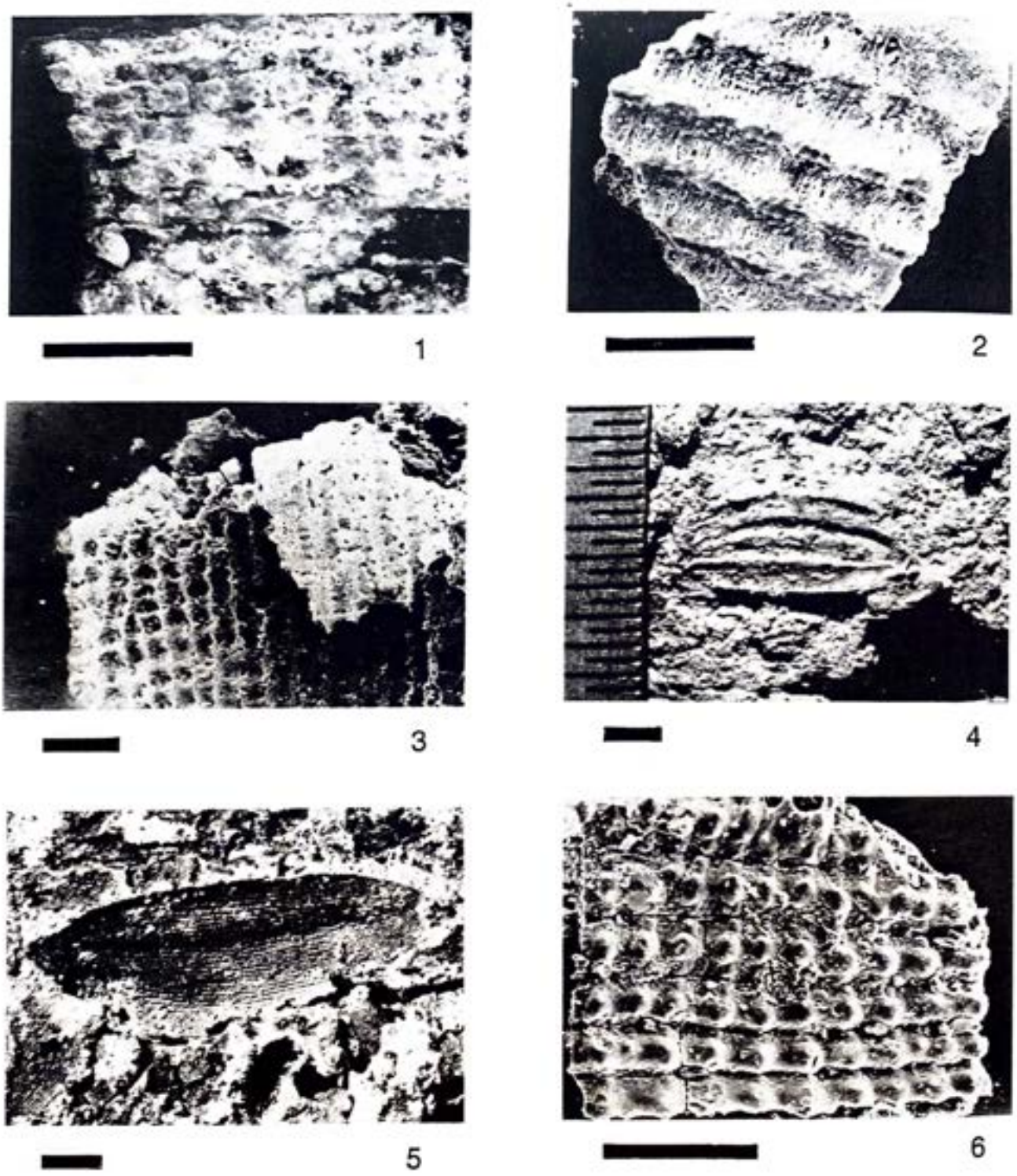


FIG. 42. Archaeological rice remains from flot, soil, clay coating and temper
1. A fragment of rice husk from layer 6:1 flot. Tubercules can be seen, although their morphology and arrangement are obscured, scale 200 microns **2.** Degraded rice husk, with surface stripped away, from layer 10:25 flot, scale 200 microns **3.** Rice husk from layer 11:2 flot. A husk fragment adheres to a soil particle, scale 200 microns **4.** The remains of an entire spikelet, scale 2 mm **5.** The impression of a spikelet found in clay coating, scale 1 mm **6.** Rice husk from clay coating on pottery from layer 10:6, typical of the preservation of husk from ceramics, scale 200 microns

TABLE 47: *Comparisons between seven different areas of cells across four individual spikelets*

Taxon Accession Part of the spikelet	Mean cell width (microns) n=70	Standard deviation
Oryza rufipogon (R4/1)		
Distal end of lemma	57	10
Lemma	80	17
Mid lemma	80	16
Mid palea	70	13
Mid lemma	80	17
Lemma	73	17
Proximal end of lemma	97	22
Oryza nivara (R2/1)		
Distal end of palea	67	14
Palea	71	14
Distal end of lemma	70	18
Lemma	85	16
Mid lemma	82	16
Lemma	82	14
Proximal end of lemma	85	16
Oryza sativa (*khao haa loi*)		
Distal end of lemma	72	15
Lemma	82	15
Palea	88	18
Mid palea	86	19
Mid lemma	80	16
Palea	85	13
Proximal end of lemma	84	17
Oryza sativa (*khao luang patiew*)		
Distal end of lemma	79	16
Lemma	87	18
Palea	81	14
Mid palea	91	18
Mid lemma	87	17
Palea	72	12
Proximal end of lemma	93	14

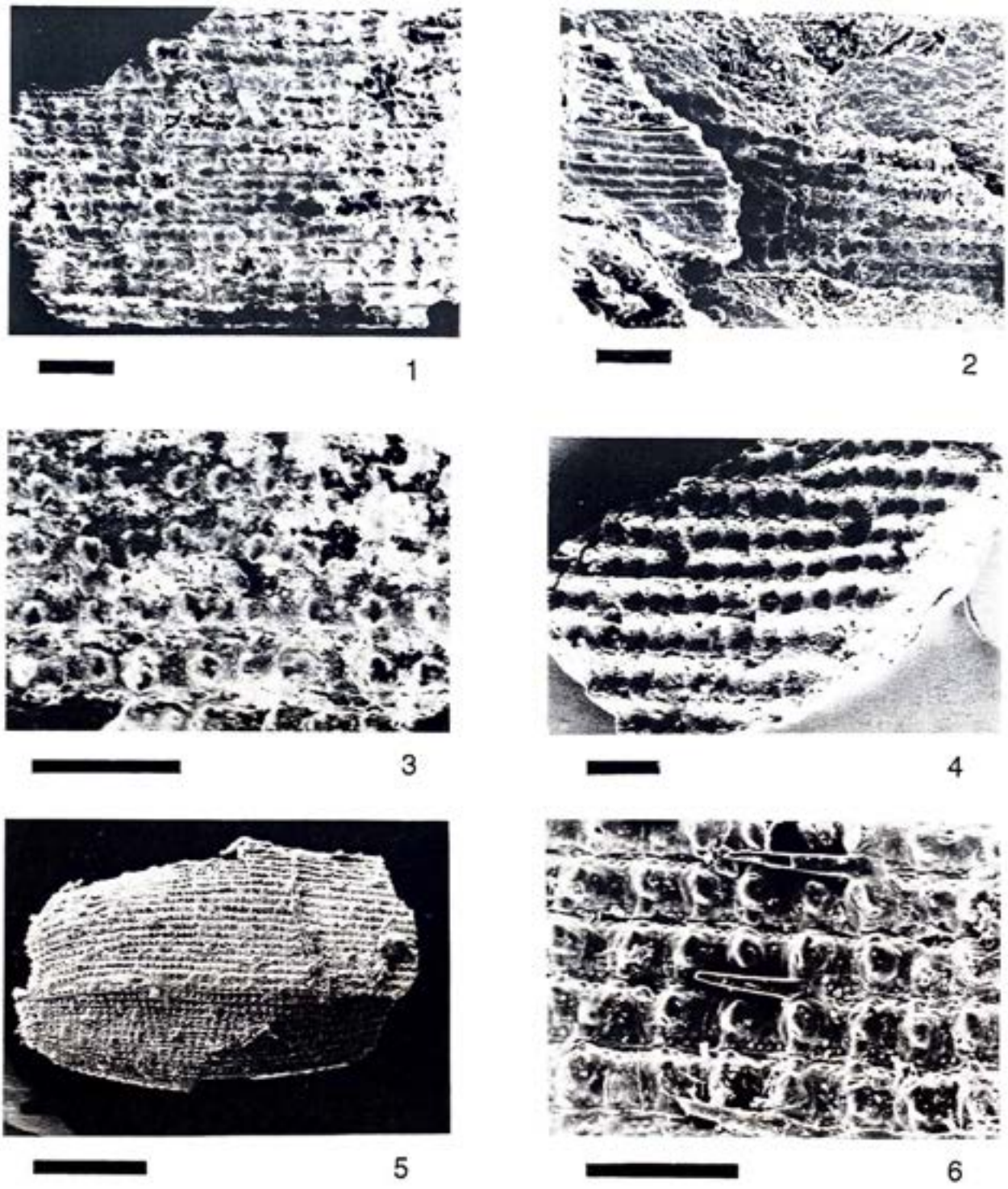


FIG. 43. Archaeological rice remains
1. Husk as temper in pottery from layer 2:3, scale 200 microns **2.** Husk temper attached to a potsherd. The smooth inner surface of the lemma or palea is visible on the left and to the right, where the husk fragment has broken away, an impression remains in the sherd, scale 200 microns **3.** Rice husk from flot, scale 200 microns **4.** Impression of a rice husk with a ?dog coprolite from layer 4, scale 200 microns **5.** The burial 67 coprolite provided some unusually large fragments of husk indicating gross morphology which could not be seen in specimens from ceramics, scale 1 mm **6.** A closer view of the same material from the burial 67 coprolite, scale 200 microns

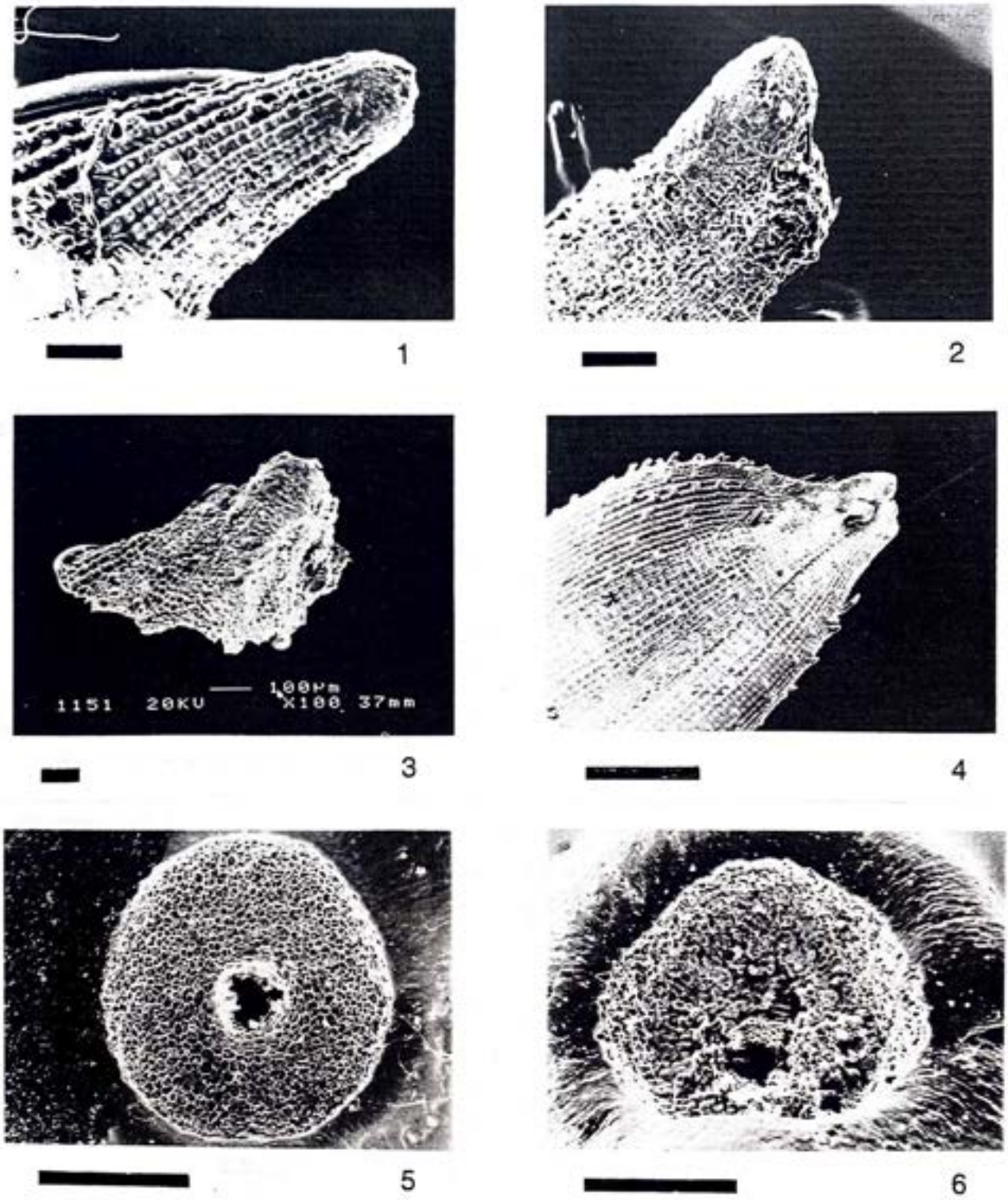


FIG. 44. Further archaeological rice remains and modern comparative material
1. The rounded distal end of a lemma from the burial 67 coprolite, scale 200 microns **2.** Another example of a rounded distal end of a lemma from the burial 67 coprolite, scale 200 microns **3.** A distal end of a lemma or palea from the clay coating on pottery from layer 10:7, scale 100 microns **4.** The distal end of a modern spikelet of *Oryza sativa*, scale 1 mm **5.** The circular smooth abscission scars on a spikelet of modern wild *Oryza rufipogon*, scale 200 microns **6.** The reniform rough abscission scar on a spikelet of modern cultivar *Oryza sativa*, scale 200 microns

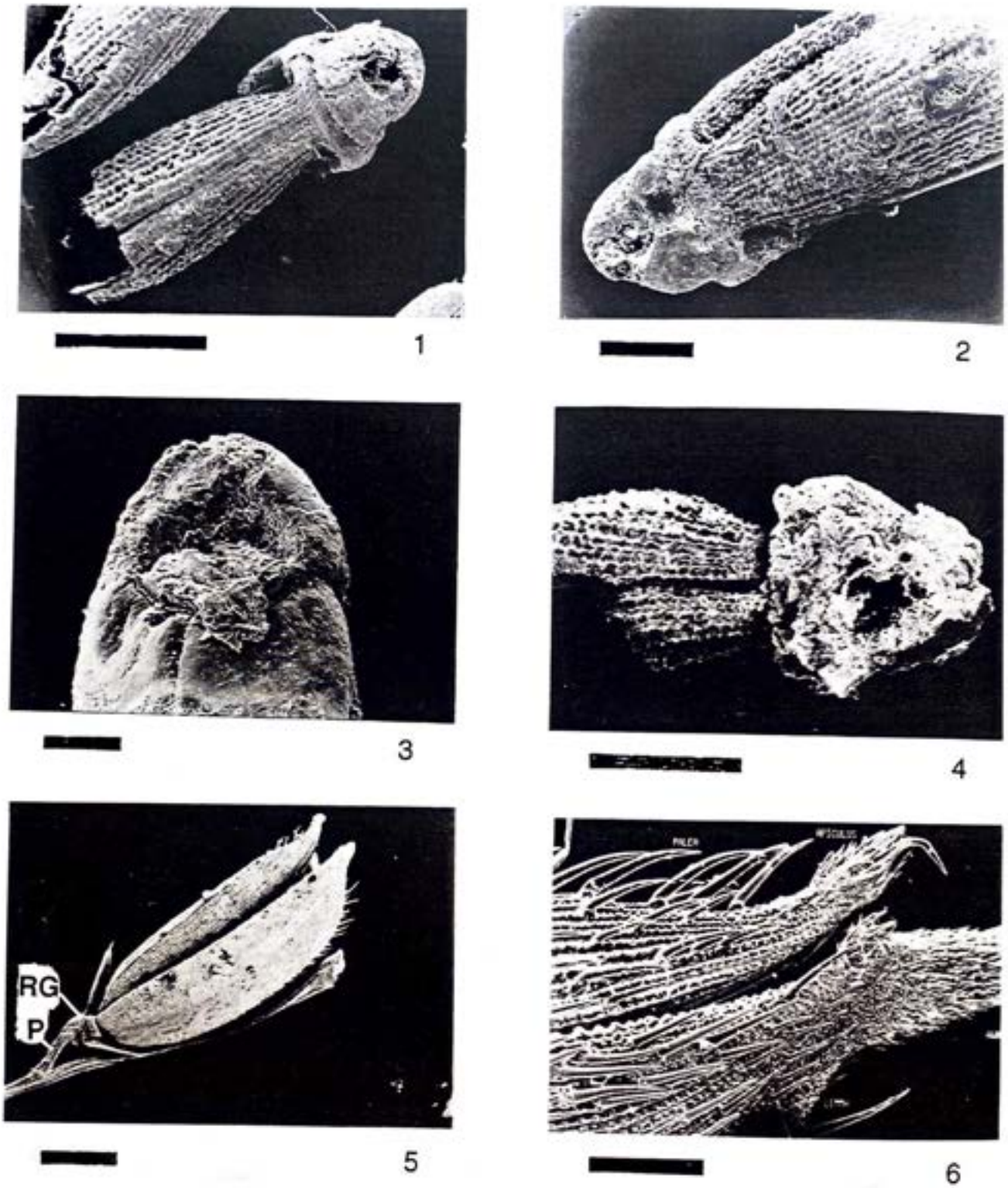
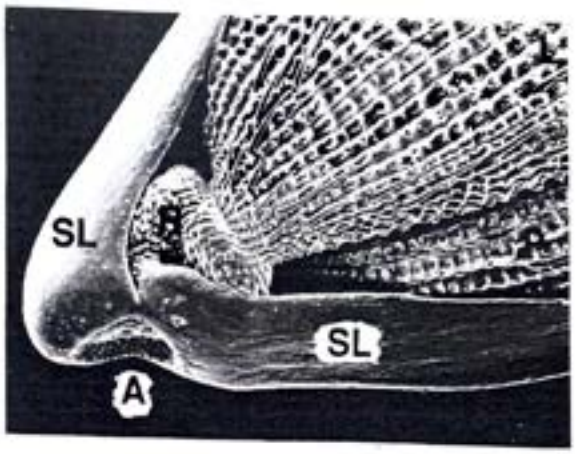


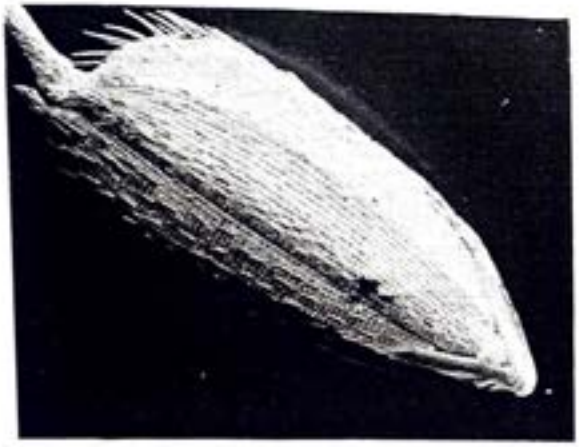
FIG. 45. Abscission scars and features of modern rice spikelets
1. A large and almost complete spikelet from the coprolite found in burial 67, indicating the general state of preservation of these remains, especially that of the abscission scar, scale 1 mm **2.** The proximal portion of a spikelet from the burial 67 coprolite illustrating the position of the abscission scar, scale 500 microns **3.** Another example of an abscission scar preserved as part of the burial 67 coprolite. Part of the scar is obscured, but the general morphology is closer to the reniform than the circular, scale 200 microns **4.** The sole specimen of a rachilla (with poorly preserved abscission scar) found as temper in pottery, scale 500 microns **5.** An *Oryza sativa* spikelet attached to the pedicel (P) indicating the rudimentary glumes (RG) at the distal end of the pedicel, scale 2 mm **6.** The distal part of a spikelet of *Oryza rufipogon* indicating the denser growth of trichomes around the base of the awn, scale 100 microns



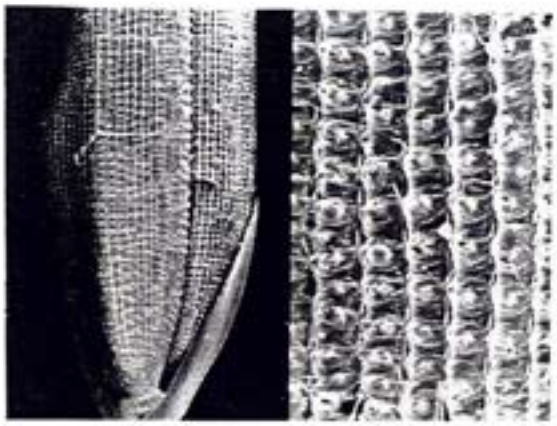
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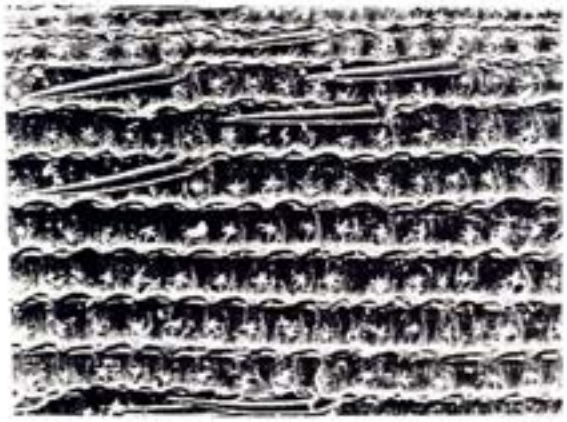
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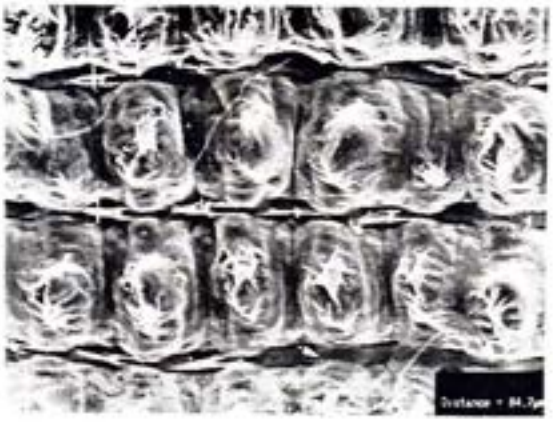
3



4



5



6

FIG. 46. General features of the spikelet and anatomical details of *Oryza rufipogon*
1. A single large trichome and smaller microhairs between the rows of tubercules, scale 100 microns **2.** The distal end of the spikelet, with the sterile lemmas (SL) wrapping around the rachilla (R) and the lemma (L) and palea (P). At the base is the oblique abscission scar (A) which articulates with the pedicel, scale 500 microns **3.** An entire spikelet of the wild *Oryza rufipogon*, scale 2 mm **4.** Central lemma surface, scale 2 mm (left) and 500 microns (right) **5.** Lemma surface with distally pointing tubercules, scale 200 microns **6.** Detailed view of lemma surface with pointed tubercules and microhairs between the rows, scale 100 microns

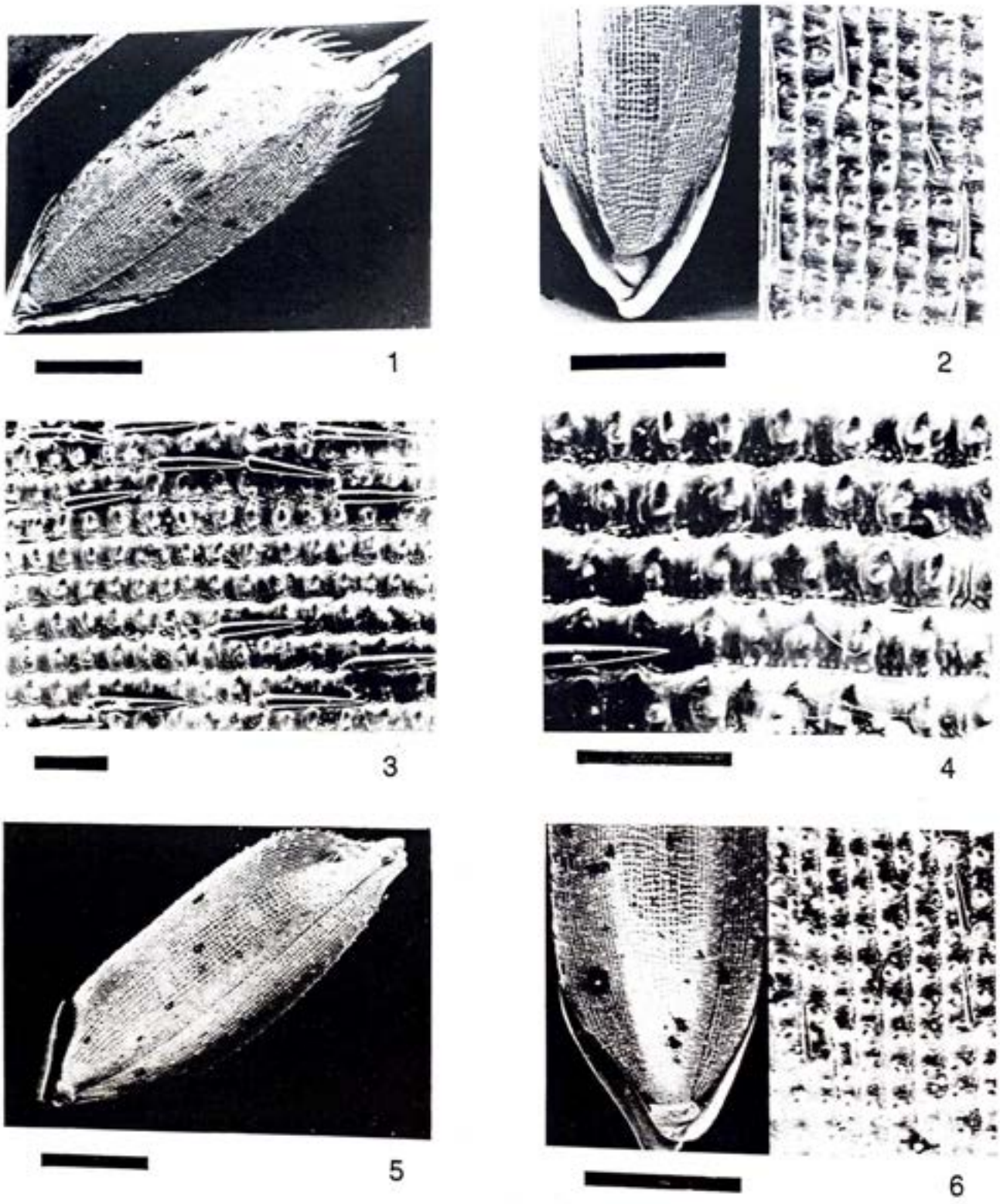


FIG. 47. Anatomical details of *Oryza rufipogon* and *O. nivara*
1. A spikelet of the wild annual *O. nivara*, scale 2 mm **2.** Details of tubercule arrangement in the central area of the lemma, scale 2 mm (left) and 100 microns (right) **3.** Rectangular shaped tubercules in the central part of the husk, scale 200 microns **4.** modern *Oryyza nivara*, scale 200 microns **5.** A spikelet of the traditional rice cultivar, *khao luang patiew*, scale 2 mm **6.** Modern *Oryza sativa*, scale 2 mm (left) and 500 microns (right)

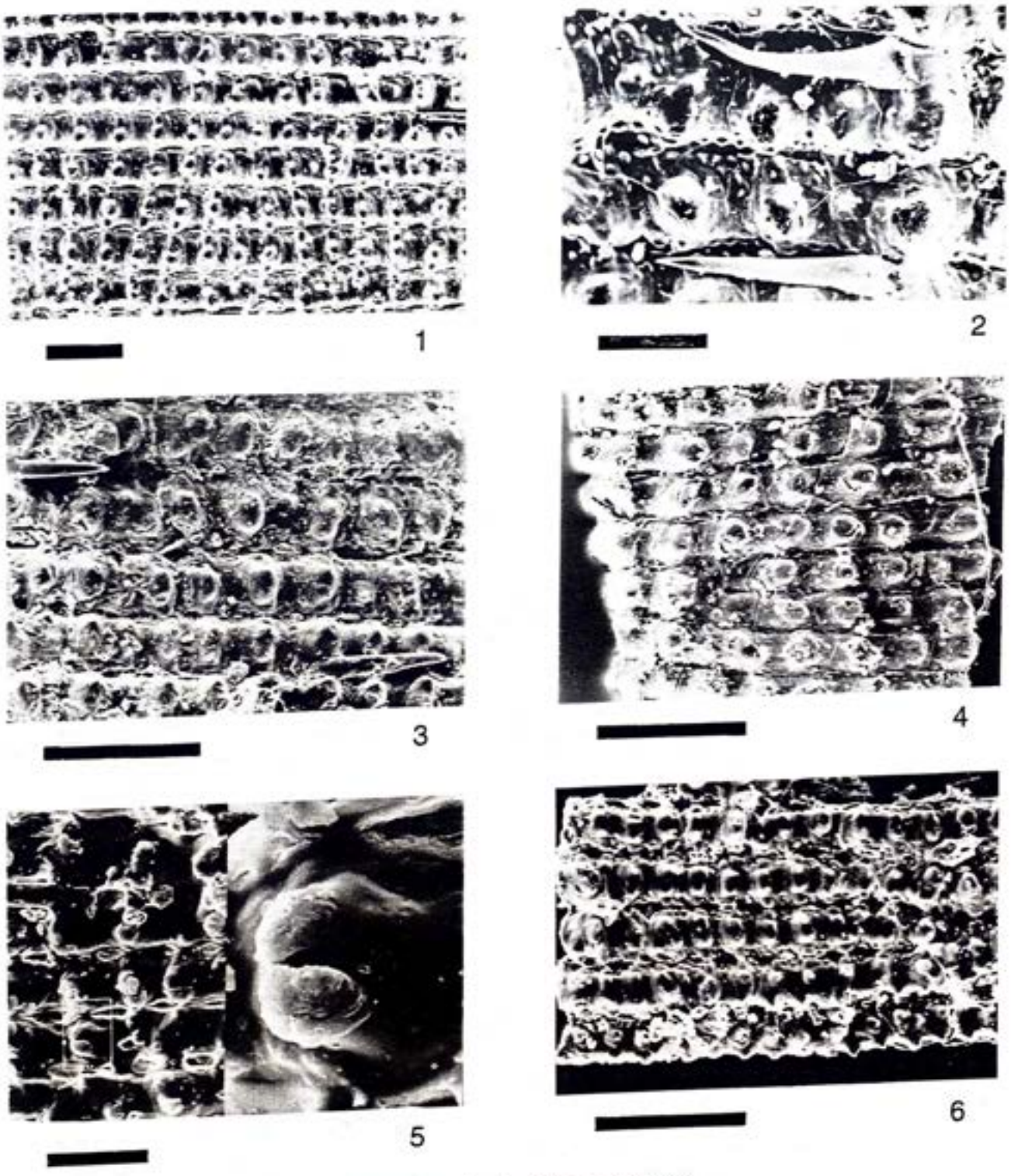


FIG. 48. Modern *Oryza sativa* and further archaeological rice specimens
1. Central area of lemma, scale 200 microns **2.** Siliceous granules visible along the flanks of the tubercules of this example of the traditional Thai cultivar *khao haa loi*, scale 100 microns **3.** Smoothly rounded tubercules from a specimen from the burial 67 coprolite, scale 200 microns **4.** Widely spaced tubercules in husk from ceramic temper, layer 5:1, scale 200 microns **5.** The siliceous tip of a tubercule from the husk found in clay coating from layer 10:7, scale 100 microns (left) and 25 microns (right) **6.** Rectangular or laterally elongate tubercules in the husk in clay coating from 10:7, scale 200 microns

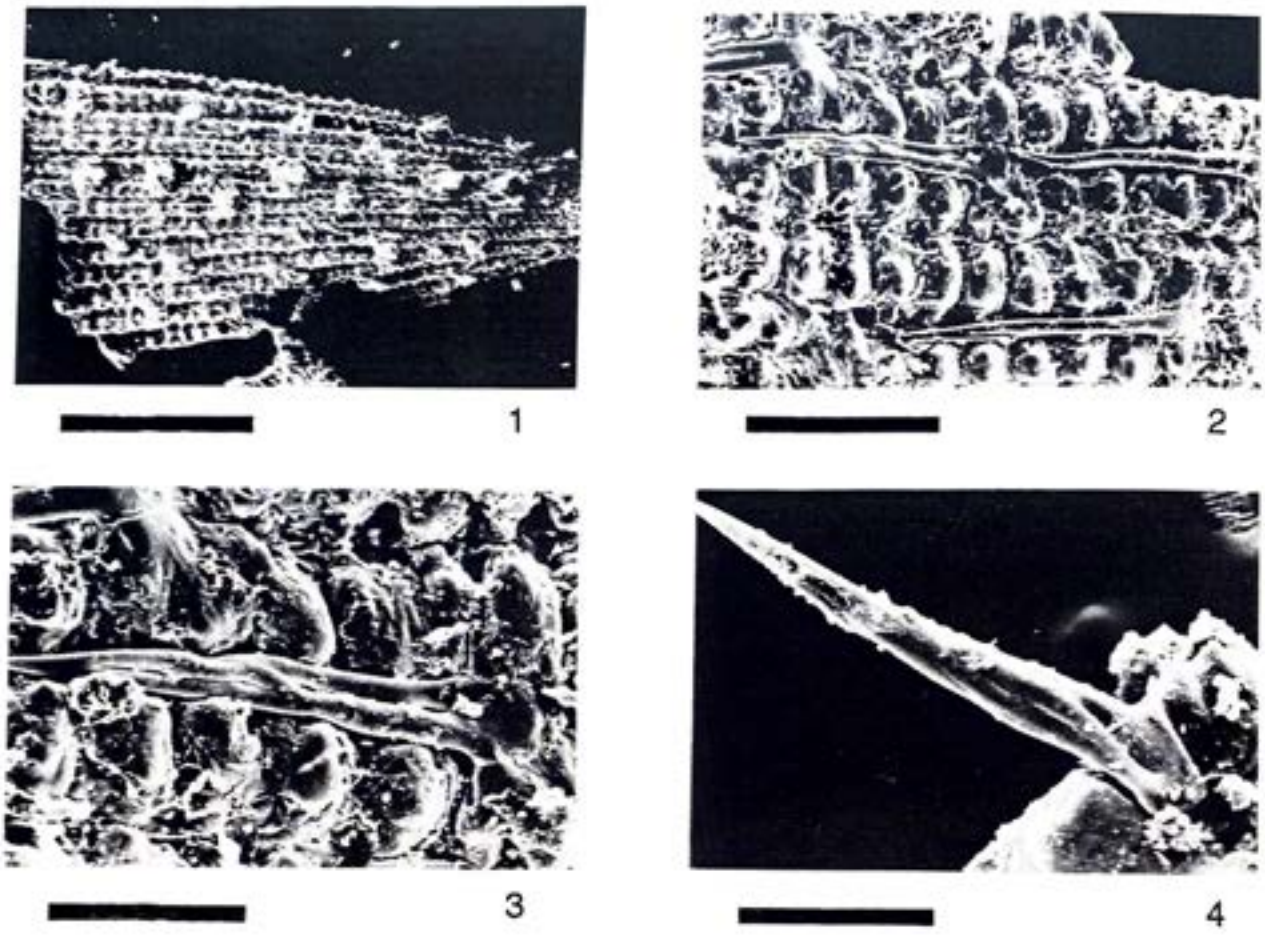


FIG. 49. Further archaeological rice husks
1. Numerous enlarged trichome bases, with the trichomes broken away, at the distal end of the lemma or palea. From the burial 67 coprolite, scale 500 microns **2.** Husk found as temper in ceramics from layer 2:3. Split trichomes, scale 200 microns **3.** A closer view of the previous specimen showing an example of a split and twisted trichome, scale 100 microns **4.** Twisted and split trichome attached to a husk found in clay coating in layer 9:5, scale 300 microns

VIII. INTERPRETATIONS AND CONCLUSIONS

THIS final chapter will summarize and integrate the archaeobotanical evidence for ecology and subsistence presented in previous chapters, and examine the generally accepted premise that plant foods are invisible in the prehistoric tropical diet. We shall return to the problems set out in the introductory remarks, those of the changing environment around Khok Phanom Di, evidence for rice cultivation in the region and the integration of rice into the economic and social life of the community, all with reference to the plant remains identified. In addition, the resource potential and environmental constraints of the major habitats indicated by the plant macroremains will be explored, as these provide clues to plant use beyond the important role of a dietary staple.

The research presented here was conceived as a pioneering study in Asian archaeology as it deals with the archaeobotany of an open site in the seasonally wet tropics. One of the main achievements has been to demonstrate that useful plant remains can be recovered from such sites by conventional means. The utility of analysing botanical remains from South-East Asian archaeological sites is increasingly recognized, with many projects setting out to retrieve botanical samples during excavation. The results have not always been as rewarding as at Khok Phanom Di. Flotation at Pha Chang rockshelter in Chiang Mai Province failed to find charcoal or seeds despite considerable effort (Santoni *et al.* 1990), whereas the alkalinity of midden layers was thought to have destroyed plant material at Non Ban Kham and Ban Tamyae, near Phimai on the Khorat plateau (Welch and McNeill 1988-89). The recovery of charred remains at Khok Phanom Di did not entirely meet our expectations which were based on the results from flotation at prehistoric sites in temperate and arid regions. Base-rich conditions like those in the Phimai district sites and at Khok Phanom Di are conducive to preservation of faunal remains but detrimental to plants. Such conditions may, however, promote mineralization of organics, for example the remnants of wooden coffins or biers at Khok Phanom Di. As this is one of the few archaeological sites in mainland South-East Asia where plant remains have been thoroughly and systematically analysed, it is impossible to say definitively whether preservation conditions encountered are typical of the region, but the positive results should encourage others to include archaeobotany in future research designs.

Although the site was not barren of plant remains, there were deficiencies in the material present, in its state of preservation and the completeness of specimens. There were surprises in what was found and what was not, and both aspects are worthy of consideration. The remains were more diverse than expected in some respects and less so in others. For example, the large number of mineralized specimens was not predicted. There were coprolites, leaf impressions, rare large seeds and wood from burial and structural contexts. Conversely, other classes of preservation were less common than anticipated. Carbonized rice grains were absent, but charred rice husks and the seeds from wild plants were successfully retrieved by flotation. The seed frequencies (0.03–6.5 seeds per litre of soil) were comparable to, and sometimes greater than, those for other lowland tropical sites (0.11–0.94 seeds per litre) (Miksicek 1987).

Standard identification methods were generally applied to the wood and seeds, but the use of SEM permitted better documentation of the material than conventional light microscopy, and its superior resolution and magnification revealed supplementary identification features such as seed

testa topography. In the case of rice it also proved necessary to explore and refine techniques for identifying parts of the plant normally excluded from taxonomic work. Taphonomic factors discussed in chapter VI help explain why the lemmas and paleas of rice were more commonly encountered in the archaeological record than whole caryopses. A critical assessment of quantitative identification criteria based on rice husk topography has illustrated that the variability within taxa, populations and even individual spikelets makes these measures difficult to quantify, apply and communicate. Minute husk fragments, therefore, offer less reliable features for distinguishing between wild and domestic types than do abscission scars or the presence/absence of awns. As the rachillas and the lemma tips are only rarely encountered, due to their fragility and taphonomy, large samples of plant macroremains need to be collected and examined to provide even a small number of diagnostic items.

ECOLOGICAL INTERPRETATION FROM THE ARCHAEOBOTANICAL ASSEMBLAGES

From an interpretative point of view, the plant remains have contributed to our understanding of both ecological and economic aspects of the site, with charcoal and seeds providing indications of nearby forest and herbaceous plant communities respectively. Together they confirm the site's location close to an estuary, within or with access to mangrove forest and backed by open, saline plains and herbaceous swamps.

Pollen and macroremains offer complementary perspectives on the vegetation growing at and around the site during its prehistoric occupation. The pollen spectrum reflects a regional pollen rain, even extending to upland taxa like *Pinus* sp. (Maloney 1991). By contrast, the charred seeds and wood from the archaeological deposits are more likely to be the product of plants growing in the immediate vicinity of the site and possibly brought into the settlement by human agency. The plant macroremains also provide evidence of the local vegetation during the occupation period of the site, which is not entirely covered by the pollen and phytolith record.

The site contained good quantities of charcoal from stratified deposits. This has provided a chronological framework and abundant material for identification. The vast majority of the charcoal from layers 9–11 has been identified as from Rhizophoraceae trees, *Rhizophora*, *Bruguiera* or *Ceriops*. In the current context the latter two taxa, usually found growing to landward of water's-edge *Rhizophora*, seem the most likely. Their abundance may be attributed to local availability (echoing pollen evidence from cores JB2 and BMR2), the convenience of gathering nearby fuel sources, and the fact that these fuelwoods are highly regarded for their excellent hot-burning fires. Interpretation of the pollen spectra has moved from a proposed intertidal position for the site to one within mangrove, but behind rather than within the *Rhizophora* zone (Maloney *et al.* 1989, Maloney 1991) and although the charcoal data cannot adjudicate on this, the general picture is confirmed.

Charcoal spreads were common features of the zone A deposits and have been interpreted as the debris from pot firing and from cooking shellfish for mortuary feasting at the time of an interment (Bannanurag 1989, Higham and Bannanurag 1990b). The high proportion of Rhizophoraceae-type charcoal throughout samples from layers 11–8 shows that fuelwood choices were consistent for the first 2–300 years of the site's occupation, that is up to layer 8 where the most reasonable of the three dates is from 8:2, at 3430 +/- 80 bp (1930–1525 BC, ANU-5483). Charcoal density

and fragment size diminished after layer 9. If this accurately reflects the availability of timber in the locality (rather than the need for it), the charcoal record is witness to a shift from a timber-rich to a timber-poor setting, from forest to open plain. A change from mangrove-dominated charcoals to those of the Non-Rhizophoraceae was observed to post-date this point in the stratigraphic sequence, around the layer 7/8 interface. A gradual transition from one type to another might be expected if fuelwoods continued to be exploited entirely on the basis of proximity and availability, and the environmental situation was being gradually modified by progradation of the river and vegetation succession. However, the perceived break in charcoal sample composition at layer 8 is consistent with the results from independent lines of analysis, such as the molluscan data. These also point to a remarkable change in the local environment, from layer 7 and the upper part of 8, indicated by diminishing mangal taxa and the sudden intrusion of pulmonate landsnails into the previously marine-estuarine molluscan assemblage (Mason 1991). Indicators of freshwater habitats became more prominent as estuarine and even riverine environmental signals diminished. The same situation is seen in the fish bones and crab remains (Kijngam 1991). There is a gradual decrease in marine fish like *Plotosus canius* and a simultaneous increase in freshwater *Clarius* sp. (Higham *et al.* 1992), at the same time as greater exploitation of terrestrial resources. This is seen in the increased numbers of deer bones from layer 8 onward, and greater representation of wild water-buffalo from layer 6 (Grant and Higham 1991).

Seeds and charcoal offer complementary information on local ecology, especially where one of the major vegetation units, mangrove, comprises almost exclusively arboreal taxa while the abutting swamplands and saltflats are typically restricted to herbaceous vegetation. The reconstruction of the site's surroundings is drawn from a number of sources of biological data including plant remains. The molluscs are sensitive indicators for this, offering fine resolution of a range of precisely defined microenvironments, especially in the intertidal zone. Their habitats include muddy marine sand, clean intertidal sand associated with coralline growth, mudflats and the seaward and landward aspects of the mangal. These habitats cannot be differentiated by plant remains, but the presence of *Trianthema portulacastrum* and *Suaeda maritima* seeds at the site indicate a further habitat within the site catchment not recognized by either faunal or pollen analyses. This is the barren, dry, open, saline or hypersaline plain landward of mangrove forest in regions with a seasonally arid climate. The remains of these plants are most common in the zone A samples, especially in layer 10, and they persist at much lower frequencies through to layer 5. They are completely absent from zone C.

Evidence for temporary and permanent, brackish to freshwater, herbaceous swamp takes the form of charred grass caryopses and achenes from the Cyperaceae, including the genera *Eleocharis*, *Fimbristylis* and *Schoenoplectus*. These, together with *Cyperus*, are some of the most common components of vegetation in swampy depressions, along the banks of slow-moving streams and in pools across the Central Plains of Thailand today. They occur most commonly in zones A and B and at low levels in zone C, just as frequencies of freshwater molluscs are at low levels in zone A, expand in zone B and fall off dramatically in zone C (Mason 1991, Higham *et al.* 1992). Seed samples from the uppermost phase of occupation at Khok Phanom Di are less diverse, less well preserved and less abundant than those from the older deposits. They nevertheless include the remains of *Amaranthus* sp., *Sida* sp. and *Portulaca* cf. *oleracea*. These small herbs often colonize disturbed, dry habitats. These may well be from plants growing on the mound, but their ecology

also fits with the possibly non-riverine, open dry plains suggested by the molluscs, ostracodes and foraminifera (Mason 1991, McKenzie 1991).

As indicated by the charcoal evidence and further emphasized by the seeds, phasing the site in terms of material culture (zones A, B and C, according to Higham *et al.* 1987) or the stratigraphic relationships between burials and the style of the burial practices (Mortuary Periods 1–7, Bannanurag 1989, Higham and Bannanurag 1990a) is not appropriate for the botanical material. Cultural change is not directly correlated with environmental change. The plant remains suggest that the site was first occupied close to the bank of a mangrove estuary, with some access to freshwater herbaceous swamps and wide, dry, saline plains, possibly at some distance from the mound. Layers 11–7 (zone A and the lowest part of zone B) were dominated by the remains of plants from mangrove swamps and the dry, open, inhospitable plains lying immediately landward. During the deposition of layer 8, a major shift in vegetation zones was experienced, to provide a more riverine situation, and removing access to the sea. It has been postulated that the site's surroundings changed because the river shifted its course laterally, possibly in response to a major flood (Mason 1991). An alternative explanation could be that the mangrove migrated downstream as the river prograded, or that vegetation change was prompted by a marine regression affecting the entire Gulf of Thailand. A combination of the three is possible, but it would be difficult to differentiate these using bioarchaeological data. The need to distinguish between an ecologically decisive catastrophe like an extreme flood and general channel instability, and the relationship between fluvial geomorphology and eustatic sea level change could be addressed by fine-scale mapping of geomorphic units and more intensive investigation of floodplain stratigraphy. Thus, the bioarchaeological results, including those from archaeobotany, set up further hypotheses for later investigation.

Ecological reconstruction on the basis of micromolluscs, ostracodes and foraminifera provides habitat data with finer resolution than do botanical remains. However, the patchwork of plant communities and the resources they represented were probably more prominent in the awareness of the residents of Khok Phanom Di because they provided resources for sustenance and multiple non-food uses. Their remains in the archaeological samples therefore convey cultural and behavioural information, and it is to this aspect of the data that we now move.

CONVERGING EVIDENCE FOR RICE CULTIVATION

Rice was the main economic plant found at Khok Phanom Di. Indeed, rice was virtually the only foodplant found. One of the prime objectives of the 1985 excavation was to gather data to address questions regarding methods of rice exploitation. The rice remains were examined in terms of their contribution to the subsistence base as well as to our understanding of the domestication process and the evolution of a major world crop.

Prior to the analysis of the macroremains, pollen had been thought to offer three strands of evidence relating to rice cultivation. The first of these was the presence of pollen and spores from plants such as *Scirpus* comp., Commelinaceae, *Ludwigia*, *Monochoria*, *Nymphoides* and *Ceratopteris thalictroides*, all known as weeds in paddy fields, though also figuring in natural wetland communities (Maloney 1991). The same can be said of the achenes of *Eleocharis* and other sedges, and the charred grass caryopses among the plant macrofossils discussed in chapter V. Both types of data are, however, limited in their ability to identify agriculture unequivocally, as the distribution

of paddy field weeds closely overlaps with the natural herbaceous flora of swamplands. All lines of evidence point to the existence of ephemeral ponds and seasonally flooded depressions in the area. Wild rice could have been one of a number of freshwater swamp grasses and some form of rice cultivation could have been practised there.

Secondly, there are the grass pollens, where the diameters and surface texturing of some grains fall within the range of modern cultivated rices (cf. Maloney 1990, 1991). Thirdly, high levels of microfossil charcoal coincide with markedly increased levels of Gramineae pollen. The stratigraphic core KL2 contained fragmentary charcoal in deposits laid down from about 5000 BC (5870–4685 BC, OxA-1359) and there is also a massive and sustained increase in Gramineae pollen at about 4300 BC (4770–4040 BC, OxA-1356) concomitant with *Bruguiera*'s decline (Maloney *et al.* 1989). This could be evidence of the deliberate burning of vegetation in the catchment or could be the product of natural forest fires started by lightning. The pollen assemblage, the microfossil charcoal and the grass pollen curve are all circumstantial, but they have been taken to indicate human intervention in the wetlands around the site, through burning stands of vegetation and expanding the range of freshwater swamp within which rice was thought to be cultivated (Maloney *et al.* 1989, Maloney 1991). This is at a point more than 2000 years before archaeological evidence of occupation at the mound. As the palynological data could not provide definitive conclusions on whether the Khok Phanom Di people were rice cultivators, research was redirected to the excavated remains of rice for further evidence on domestication and cultivation (Higham *et al.* 1987, Maloney *et al.* 1989).

From the excavation, further supporting evidence was found in the artefacts thought to be associated with rice exploitation (Maloney *et al.* 1989). These include polished stone axes and leucogranite hoes (Pisnupong 1988, 1993) possibly used for clearing plots and breaking ground, together with shell knives for reaping grasses (Higham 1993). Today in Thailand most other tools for post-harvest rice processing are made of wood or bamboo, so are far less likely to be visible in the archaeological record than stone or shell implements. At Khok Phanom Di the choice of wood for mortars and pestles would have been reinforced by the ready availability of hard, durable timber compared with the considerable cost of acquiring stone. Among the lithics, some of the sandstone grinders may conceivably have been employed in food preparation, including the dehulling of rice, but their specific uses have not been confirmed by residue analysis.

We turn now to the plant remains themselves. The use of rice at the site is well documented. Husks were found from the earliest deposits onward, at all stratigraphic levels except layer 1. Rice husks, mostly as small fragments, were retrieved in a number of forms: in coprolites, as temper in the body of pottery, in clay on the external surface of pottery, as ash fragments and partial silica skeletons within the deposit. Having explored the reliability of a number of identification criteria, it is considered that at least some of the specimens are from a cultigen. Nothing conclusively suggests the exploitation of wild grasses, but the vast majority of husks examined lacked those critical parts of the spikelet with features capable of supporting a confident identification. Evidence for domestication takes the form of rough, reniform abscission scars, as opposed to the smooth circular scars in wild rices, and the awnless apiculi of lemmas, found exclusively but not consistently in the cultigen.

Primarily a stable carbohydrate foodstuff, rice and its by-products are put to numerous additional uses. Rice husks were used in a minority of burial ceramics in zones A and B, but came to be employed as a common tempering agent in the local utilitarian ceramic wares, late in the site's

occupation (Vincent 1987). If potting practices and village life in present-day Thailand are a guide to interpreting evidence of the past, it is quite possible that rice husks and straw were used as kindling in kitchen fires and for firing the pottery around the edge of the mound, and that winnowing products were fed to dogs and fowl. Husks were evidently strewn around the open areas and have become incorporated in the soil as silica skeletons.

The rice remains indicate consumption at the site, and that the rices in question were domesticated, but further questions remain unresolved: was Khok Phanom Di a rice producing site, or did the people living there depend on crops cultivated elsewhere? Perhaps rice was exchanged with inland communities for fish and fish products, just as is done by mangrove villagers today (Aksornkoae *et al.* 1984, Mathur 1986). We know that Khok Phanom Di was a highly specialized and skilled potting community, occupying an important node in the prehistoric trade network. Burnishing pebbles were imported, possibly from streams issuing from Khao Kirirom, and along the margin of the Bang Pakong floodplain (Moore 1993). Good quality lithics for axes and adzes, and the sandstone grinders for sharpening them came from even further afield (Pisnupong 1993), while exotic ceramic artefacts were brought from widely separated sources (Vincent 1987). In return, the Khok Phanom Di people probably supplied pottery and trochus shell jewellery. Additional possibilities for export are salt, plant resins, nipa products, dyes and even preserved or smoked fish if there was excess to local needs. The archaeological record is silent on all these perishable products but historic accounts attest to bartering in these goods between coastal communities and rice-growing villages around Ayutthaya up to the nineteenth century (cf. Johnston 1976) and remind us of other potential trade goods. The possibility of rice being acquired as an exchange commodity should not be forgotten.

A particular issue in view of Higham's rice domestication hypothesis is whether rice grows in saline areas. Given the fact that rice does not thrive along the coast, where was the crop most likely to have been growing? The mangroves and their immediate hinterland seem highly unlikely. Today rice is totally lacking from the coastal part of the Bang Pakong and Chao Phraya delta (Takaya and Thiramongkol 1982). Here brackish tidal land is used for forestry, shrimp breeding, salt evaporation and has also been ridged for coconut groves. Further inland, where rice is grown, this is transplanted rather than broadcast. Fresh water is used to flush out salt from the soil prior to planting the young seedlings which have been raised for 60 days in a salt-free seed bed (Arunin and HilleRisLambers 1984). During the zone A occupation, ecological conditions in the immediate vicinity of the mound would probably have been extreme for rice agriculture due to saline groundwater intrusion and tidal flooding if the site was indeed close to, or on the banks of a mangrove-fringed estuary.

Historic records indicate that widespread rice production was not started in the region until the mid-nineteenth century when major drainage and canal-building initiatives were underway (Johnson 1976a and 1976b). Mangrove soils in general and those in the Central Plain of Thailand in particular, are anaerobic, become acid on oxidation, and are generally not suited to agriculture without a buffering additive such as slaked lime (Fukui and Takahashi 1969, Watson 1975, van Breemen 1976, Hattori and Kyuma 1978) although soils developed under *Avicennia* are said to be more productive than those from the *Rhizophora* belt (Hesse 1961, Jordan 1964). Rice is more salt-tolerant than many other crops and can grow in soils with electric conductivity up to 4 mmho/cm (Barnes 1990) but this still represents a limit to cultivation in the highly saline soils found in and behind mangrove. Rice growth is inhibited by salinity (Yan and Tan 1991) with salt-tolerant varieties consequently producing inferior grain (Kyaw and Escuro 1979). Rice yields under acid-sulphate

soil conditions are 500–700 kg/ha (Sin 1990), only about a third of the average productivity of inland freshwater paddies (1.8 tonnes/ha) (Fukui and Takahashi 1969).

Annual wild rices are aquatic plants, but live in fresh water, not saline or brackish. Their preferred habitats are along watercourses, in ephemeral freshwater ponds, lakes and swamps. Some strains of *O. sativa* are able to live in brackish water (Duistermaat 1987), but present-day salt-tolerant cultivars are the result of generations of concerted human selection for strains which can survive in marginal areas and early cultivars were probably less adaptable. Markedly salt-tolerant rice varieties continue to be sought by plant breeders so that additional genes can be bred into improved modern strains, allowing the range of crops to spread through ecologically marginal areas. Agricultural expansion in coastal areas, into tidal flats and saltwater swamps and in the upland zone where excessive salinity results from rising saline groundwater, has been the result of crop breeding and labour-intensive water control (Tanaka 1991). Novel varieties of salt-resistant rice for planting in saline soils were not produced in south-eastern China until early in the 'late traditional' period (1350 AD–1900 AD) (Rawski 1972, Elvin 1975, 1982). Even then the establishment and maintenance of dykes, dams and polders preventing infiltration or inundation by saline water required significant investment of labour. Special procedures were followed to ensure a crop in saline areas. Planting was postponed until the fields had been flushed by early monsoon rains, seeds were sown in freshwater seedbeds before being transplanted into brackish paddies, and the crop was harvested prior to the intrusion of tidal seawater in the dry season.

In India, for example, special precautions against saltwater intrusion were taken to ensure a reasonable harvest:

> In salt rice land, neither ploughing nor manure is required. When the ground is well soaked with rain, the seed is either thrown in to the mud, or, when the land is low, it is wetted and placed in a heap, until it sprouts, when it is thrown into the mud or on the surface of the water. After the plants have grown a little, crowded patches are thinned and bare spaces planted. The chief labour and expense in growing salt rice is the making and mending of the banks. Every field is surrounded by a bank from two to four feet high according to the distance from a creek. This bank has to be renewed every year and kept in repair during the time the crop is on the ground. If by any over-sight, the field is flooded with salt water, years pass before it again yields a good crop. (Kumar 1988:180-181, summarising the writings of Campbell 1883 about Maharashtra).

While it is clear that direct inundation with saltwater is detrimental to rice production, there are other instances where salt-tolerant varieties may be grown upstream of mangroves, and within slightly brackish waters:

> The seed is simply sown broadcast on soft mud flats near the big rivers and then the mud is smoothed over it to protect it from the action of the tides. There is no ploughing, harrowing, transplanting or weeding, simply the sowing of the seed and the reaping of the harvest. It must, however, be admitted that the sowing is a little troublesome as the mud is so soft that the cultivator has to seek a precarious foothold on the trunk of a plantain tree or a couple of bamboos to prevent himself from sinking in. (Kumar 1988:164, extracting from an account by Allen 1912).

The geoarchaeological data from the excavation demonstrate that the culturally-sterile basal deposits at Khok Phanom Di are part of a river bank in a floodplain (Aitken 1992). Natural levée formation along major river channels may induce changes in local hydrology equivalent to those of building bunds. Both prevent sea-water incursion to the floodplains, permitting the establishment of wide herbaceous freshwater swamps. Such changes were found in Arnhem Land in northern Australia during the mid-Holocene (Hope *et al.* 1985), and a similar situation might have developed in the Bang Pakong lowlands. The tidal range is significantly less in the Gulf of Thailand than in Australia, though, and this has an important influence on the geomorphology of fluvial systems near their estuary so the situations are not directly analogous (pers. comm. G. Brierly). The geomorphology of the lower Bangkok Plain is less well documented but levées are conspicuously absent from the area of marine and brackish clays so it is uncertain whether they played a role in the formation of swamp grassland there during the mid Holocene (van Breemen 1976).

We cannot suppose that the coastal hinterland was particularly suited to rice cultivation without the co-ordination of a labour-force to dig drainage ditches and build dams. Infrastructural improvements like land levelling and bund digging are usually associated with centrally-organized societies. Burial rites indicate that Khok Phanom Di was a hierarchical community, with status apparently based on personal craft skills rather than central or hereditary authority. Despite all these problems with establishing rice agriculture close to the coast, there is abundant evidence for rice consumption at the site, presumably derived from a freshwater area further inland and beyond the saline influence of the estuary. More than four hundred worked shells were found, most made from the freshwater bivalve *Pseudodon inoscularis*. The gloss and striations along the sharpened edges and running over the back of the shells were similar to those produced by experimental cutting of rice (Higham 1993) providing further confirmation that the Khok Phanom Di people were involved in harvesting their own cereals. By using shell reaping knives, the harvesters were unconsciously selecting for tough rachised panicles, as observed in a few of the rice remains, rather than the naturally dehiscing scars perpetuated by beating.

The proximity of each of these habitats is difficult to estimate, but vegetation transects through modern Thai estuaries and inspection of aerial photographs indicate that herbaceous freshwater swamp communities may lie within 2 km of a riverbank village. Access may be difficult though, as the main communication routes are by water, making it easier to move up- and downstream, parallel, rather than perpendicular, to the vegetation zones.

One possible present-day analogue to the ecological and agrarian situation at Khok Phanom Di is the cultivation of rice in small, swampy areas by the downstream communities of Iban of Sarawak, and the Kantu' of Kalimantan, although these are inland rather than coastal situations (cf. Padoch 1982, 1988, Dove 1985). Here, rice cultivation is extensive, with minimal attempts at land levelling, soil preparation or water control (Padoch 1988). The agricultural cycle begins with cutting, drying and burning of vegetation, with unburnt tufts trampled underfoot, but without ploughing, puddling or harrowing. The rice may be broadcast or transplanted as seedlings. Additional crops like taro and *Ipomoea aquatica* are planted along the shallower edges of the swamp-fields. In Kalimantan, the Kantu' plant the driest swampland using conventional dryland technology but also broadcast rice in permanent swamps (Dove 1985). Such examples of minimal cultivation in permanent and ephemeral swamps closely follow the natural ecology, water regime and seasonal growth patterns of the wild rice plant and are the probable setting for early experimentation with rice harvesting.

ISSUES OF INCIPIENT DOMESTICATION

Returning to the initial rice domestication hypothesis (Higham 1984) outlined in the introduction, we see that there are problems inherent in the hypothesis, and that the evidence excavated at Khok Phanom Di was in some ways inadequate to test it.

The ecological basis of the hypothesis is brought into question by the fact that wild rices, though hydrophytes, are neither coastal nor even salt-tolerant grasses and are unlikely components in the mangrove backswamps, if we consider the site's territory in its narrowest definition. Harlan comments (1977) on the likelihood of the deltas of South-East Asia being the home of floating rice which could have been gathered by beating into boats, but goes on to add that these perennial floating rices are poor seed producers and that the deltas are 'not the place to begin domestication of rice' (Harlan 1977). The marshes and riverine plains further inland are nominated as more likely for early experiments in rice production.

Analysis of the faunal assemblage following the excavation soon brought into question another aspect of the rice domestication hypothesis as it had first been framed. The original contention had been that the occupants of Khok Phanom Di might have taken to rice cultivation when a higher sea level fell a few metres to its current position, which, in the flat landscape of the Bangkok Plain, meant leaving them stranded many kilometres inland and without access to their established food sources, including, perhaps, stands of wild rice (Higham 1984). Setting aside the doubtful autecological basis for this hypothesis, the faunal analysis and now the plant remains indicate that the major change in environmental conditions occurred about midway through the sequence and in an abrupt manner, although this may have been a single catastrophic event superimposed on the long-term trend of progradation. The remains of cultivated rice were found in some form in all levels of the site, both before and after the major change from a marine-estuarine situation to a more inland one, and they showed neither an increase in abundance nor a marked change in morphology through the sequence. The general concept of an environmental stimulus prompting cultivation therefore seems inappropriate. Indeed, with the shift from mangrove to inland conditions, access to freshwater wetlands with rice would only have improved.

The rice remains excavated from Khok Phanom Di were not preserved in a way which made it easy to detect whether there had been a transition from wild to domesticated rice during the 5–600 year occupation of the site. Most of the well preserved husk fragments from the distal end of spikelets and from the rachilla were encountered in a single context, burial 67 in layer 10, where superior preservation was due to their incorporation in a singular coprolite. Additional rare finds of awnless lemma apiculi from temper were from the pottery. Comparisons of plant anatomy from a series of large samples through the site were therefore not possible.

The prehistoric cultivation of wet rice in the low-lying hinterland behind the coast of the Gulf of Thailand adds additional weight to the evidence from previous rice finds in the piedmont of north-eastern Thailand, at Non Nok Tha and at Ban Chiang, also sites with seasonally flooded basins at hand. Evidence for rice production is thus better represented in naturally swampy locales than in mountainous parts of the country where dryland swiddening techniques would be applied. Dryland varieties were most probably selected later, during the course of pond-field cultivation, when the need arose to extend rice into more marginal habitats.

The dating for rice cultivation in South-East Asia remains sketchy, with the Non Nok Tha chronology still uncertain and the secondary evidence from Spirit Cave inadequate. Here the pu-

tative rice-cutting knives at about 6000 BC could equally have been used for obtaining wild plant material. Excavations at Pengtoushan (on the middle Yangzi Valley in Hunan Province) have reportedly pushed back the Chinese dates for early riziculture to 5500–7000 BC (Yan 1991) as yet unparalleled in neighbouring South-East Asia. Although rice remains (*Oryza* sp.) were found there, the agrarian status of the Pengtoushan community has yet to be confirmed botanically. The plant remains from Khok Phanom Di, dated at 2000 BC are not remarkably early but the adjunct pollen evidence, albeit circumstantial, and the phytolith data (Kealhofer and Piperno, below) suggest the possibility of rice cultivation by people living on the Bang Pakong lowlands around 4300 bc. The environmental data therefore set up a hypothesis for agriculture in the fifth millennium BC which may be confirmed by further archaeological survey and excavation.

One of the questions considered fundamental from the outset was whether the community at Khok Phanom Di employed an agrarian or non-agrarian economy. It has been shown that domestic rice was in use, probably throughout the site's occupation, and this has a number of implications for the use of the mound as a permanent base, with storage facilities for grain and other commodities. A beetle of the rice pest *Oryzaphilus surinamensis* found in the coprolite from burial 67 suggests the storage of grain at the site. This would have provided food at least into the dry season if not year-round.

The Khok Phanom Di excavations may not extend the chronology of rice cultivation in South-East Asia, but they offer well-dated and documented remains of the cultigen with clear signs of domestication which will contribute to an expanding botanical database and enhance our understanding of changing subsistence strategies in South-East Asia. Unfortunately the plant remains examined here cannot contribute to the debate over whether tubers such as taro (*Colocasia* sp.) or yams (*Dioscorea* spp.) preceded rice as a staple, or whether they were sister domesticates (Gorman 1974). Given the good preservation of charcoals, and the large number of fragments examined in the analysis, charred tuberous remains would most probably have been detected if they were preserved at the site, but none came to light.

The pollen sequence includes a number of plants with possible culinary uses beyond rice. Pre-eminent among these is *Cocos nucifera*, the coconut palm, which, with rice and fish, is the mainstay of contemporary South-East Asian diet. The liquid expelled after soaking grated coconut endosperm in water plays a central role in Thai cuisine and the juice from the inflorescence is tapped for making alcoholic drinks. This multi-purpose tree is also a source of oil, copra and coir fibre while the shells are used as vessels and scoops, and for making tools (Burkill 1966). The fruit-bearing climber *Passiflora* is also represented in the palynological evidence, along with a number of possibly cultivated fruit trees: *Citrus*, *Zizyphus*, *Eugenia*, *Decaspermum* and *Garcinia*. The fruits of wild *Elaeocarpus* trees are also regarded as edible, although their flesh has a sourish flavour (Burkill 1966).

ASSESSING THE WILD-PLANT CONTRIBUTION TO THE DIET

Having dealt with the plant remains, we can turn now to broader issues of subsistence, with particular emphasis on the plant component of the diet and the foods which might be missing from the archaeobotanical samples. As we have already seen, rice was prominent in the archaeological materials, but consideration of contemporary tropical coastal economies suggests that a broad-

spectrum diet would have been likely. The mineralized coprolites proved intractable to analysis for plant macroremains, and none of the other macroremains are unquestionably food debris. There is the single very large seed of the wild santal fruit (*Sandoricum* sp.) but this is a tentative identification. It must be asked whether these assemblages accurately reflect the dominance of rice in the diet or whether this might be a product of the durability of silica-rich rice husks and the taphonomy of alternative and supplementary plant foods. The faunal evidence indicates the ample supply of marine and estuarine fish from on-shore and off-shore waters, shellfish and crustaceans and that terrestrial animals were hunted, trapped and collected.

Khok Phanom Di's current inland delta flat environment barely resembles that of the estuarine setting 3–4000 years ago. Conventional catchment analysis to estimate resource availability is problematic and the reconstruction of ecological zones around the site is at best qualitative. The archaeobotanical data provide little unequivocal information on past diet other than the important use of rice, but they do provide indications of local habitats and the availability of certain foodstuffs. By combining ecological information with known food uses it is possible to speculate on additional plant foods in the non-agrarian part of the diet. Although we should not transpose ideas from the present or the recent past back to a prehistoric situation, these sources of information allow us to structure our thoughts on plant-procurement strategies, and to set up ethnographic models against which the archaeological data may be compared.

There is archaeological evidence for five major plant communities within the vicinity of the prehistoric settlement at Khok Phanom Di, but quantitative assessments of their extent and proximity to the site are difficult to establish as there are few indications of the scale of the vegetation mosaic. The major habitats extend from coastal mangrove, to landward mangrove, dry open salt-flats and, even further inland, permanent and ephemeral freshwater herbaceous swamps. The fifth area of upland/inland forest, hinted at by the pollen record, is not considered here as this is unlikely to have made a significant contribution to plant food resources consumed at the site. To this list we may add the intertidal zone, exploited for shellfish and possibly for edible algae like *Fucus kali* (Koenig 1894b) and *Catenella nipae*, gathered from mangroves for sale in Burmese markets (Post 1939, cited by Chapman 1980, Rollet 1975a), and *Caulerpa racemosa* and *Gracilaria crassa* gathered along the coast around Phuket in southern Thailand (Chapman 1980, Jacquat and Bertossa 1990). Although seaweed seems an unlikely botanical find from an archaeological site, charred remains have been found in Scotland, at Dunadd in Argyll (Milles 1985) so the possibility should not be dismissed.

Edible plants are found even in the sub-littoral zone, for example fruits of the sea grass *Enhalus acoroides* are eaten in peninsular Malaysia (Burkill 1966), but the mangrove forest warrants greater attention as this appears to have surrounded the site or at least been accessible to the Khok Phanom Di people during the first half of their occupation of the mound. Mangroves are primarily regarded as providing *non*-food plant resources: timber for houses and boats, poles for house-posts, leaves for thatching, bark and leaves for tanning, dyes and fishpoison, to list just a few. These areas are especially important as a breeding ground for fish, crustacea and molluscs. Intertidal zones, above all in the tropics, are among the most productive biomes in the world (Simmons 1979), but in the mangal, the food chain is based on decomposing leaf litter and other detritus in the water. Most of the biological productivity available to humans for food is consumed from animals, not plants. An estuarine location confers many nutritional advantages on a population, largely through access to low-key, reliable shellfish and crustaceans, and seasonal migratory fish. The

plant life offers less. The reasons for this are complex. Low floristic diversity and the absence of a specialized understorey, in conjunction with high levels of toxins in many plants mean that mangrove forests offer only limited plant foods compared with a wide range of edible animals. The mangrove belt alone cannot provide all the plant resources required for a balanced diet. A wide-ranging review of ethnographic sources from the Andaman Islands though South-East Asia to northern Australia suggest that the mangroves cannot now, and could not 4,000 years ago, sustain a sedentary population with a small catchment area relying solely on mangrove plant resources. Access to complementary habitats is vital (Man 1885).

To outline the mangrove edible plant resources briefly, hearts and shoots of the swamp palms *Oncosperma tigillaria* and *Phoenix paludosa* are widely regarded foodsources, but mangroves in general are not abundant sources of carbohydrates in the form of edible seeds, fruit or tubers. In the mangal, one plant product with potential for use as a carbohydrate staple is the hypocotyl, or germinating embryo, seen hanging from Rhizophoraceae trees. *Bruguiera* seems to have been used more extensively than the related genera, *Ceriops* and *Rhizophora*, but there are records of all three being exploited. These have previously been used, sometimes as a staple and sometimes as a sweetmeat or supplementary food, in widespread mangrove-based communities, from the Andaman Islands (Burkill 1966), through mainland South-East Asia (Burkill 1966, Phengklai 1985) and northern Australia (Specht 1958, Harris 1977b, 1979), across the Pacific (Barrau 1959, Rollet 1975a, David 1985) to Fiji (Seeman 1918). They are now generally regarded as famine food and have long been surpassed by alternatives requiring less elaborate processing. The 'fruits' of *Bruguiera* nevertheless have remarkably high caloric and protein values, with more than twice the protein and being three times more carbohydrate-rich than domestic or wild yams (Harris 1977b).

In Torres Strait and the Cape York Peninsula of northern Australia, the mangrove 'fruits' were the carbohydrate staple during the wet season when otherwise mobile groups were semi-sedentary (Harris 1979). In the Welu Estuary of south-eastern Thailand, *Bruguiera* hypocotyls were available and reported as used at all times of the year, if only as an occasional dessert. Their abundance and good nutritional value mean they have the potential to be a major carbohydrate source. The fruits of *Avicennia*, *Intsia retusa* and *Sonneratia* are also considered edible, as are the pods of *Barringtonia asiatica*. These, like *Bruguiera* hypocotyls and *Cycas* seeds, require laborious and time-consuming processing, through pounding and leaching, to remove the toxins, before being baked or boiled (see page 30). *Avicennia* fruits, for example, are leached of toxins by being soaked in water for a full two weeks before they can be cooked and eaten, according to some records (cf. Rollet 1975) and are steamed and baked in an earth oven, without mention of leaching, according to others (cf. Maiden 1889, Baker 1915). A starch-rich food like mangrove shoots, yams or rice is very necessary to complement a protein-rich fish and shellfish-based diet (cf. Noli and Avery 1988). As indicated earlier, we were prepared to find the remains of such plant foods in the archaeobotanical assemblages, and the charcoal reference collection included examples of both *Bruguiera* and *Rhizophora* hypocotyls (Fig. 5:6) but no such remains were identified.

Rhizophoraceae hypocotyls produce dense, firm charcoal, without the major lines of weakness (wide rays) seen in woods of this family. Their absence from the archaeobotanical assemblages cannot therefore be attributed to fragility of the specimens. *Bruguiera gymnorrhiza* remains, possibly calyxes, have been reported from an Australian cave with cultural deposits, Nara Inlet 1 in central Queensland, where preservation was by dessication (Barker 1991). The food debris was not accompanied by artefacts such as worked shell or stone grinders (pers. comm. B. Barker) to

provide an indication of associated technology. There are mid-nineteenth century accounts of processing *Bruguiera* hypocotyls from the Torres Strait Islands and Cape York Peninsula. The mangrove 'fruits' were first baked in ashes or an earth oven then their contents scraped out with a shell (Moore 1978) but similar tools are not reported from coastal archaeological sites. Residue analysis of worked shell and lithics from archaeological contexts might provide evidence of *Bruguiera* in the diet, but the fact that the hypocotyls are roasted in large quantities suggests that this food could be detected archaeobotanically through charred plant remains and burning pits.

The traditional Thai diet incorporates many succulent young leaves from trees, wild herbs and aquatic plants, as mentioned in chapter III (cf. Phengklai and Khamsai 1985, Jacquat and Bertossa 1990). In and around the mangroves these include immature shoots from the ferns *Acrostichum aureum*, *Ceratopteris thalictroides* and *Lygodium* sp., the climber *Flagellaria indica*, and the herbs *Pluchea indica*, *Suaeda maritima*, *Trianthema portulacastrum* and *Tupistra grandis*. The young leaves of several trees and shrubs are also eaten raw or cooked. These include *Aegiceras* sp., *Ardisia littoralis* and sometimes *Avicennia marina*, *Barringtonia asiatica* and *racemosa*, *Cycas rumphii*, *Hibiscus tiliaceus*, *Lumnitzera* spp., *Melaleuca leucadendra*, *Pemphis acidula*, *Scaevola taccada*, *Sonneratia caseolaris* and *Thespesia populnea*. In the Rhizophoraceae, tannin content of the leaves is prohibitively high for human consumption. Nevertheless, leaf monkeys (*Presbytis* sp. or langur) have a digestive tract where the relative acidity (pH 5–6.7) enables them to digest tannin-rich leaves and mangrove bark (Whitten *et al.* 1987) which is inaccessible to other mammals. They thus convert plant biomass to an accessible form (monkey meat), which the Khok Phanom Di people evidently exploited at low levels through all phases of the occupation (Grant and Higham 1991). The prehistoric human population therefore tapped the mangrove food web at a higher trophic level than in adjacent habitats where a wider range of edible plants was available.

Freshwater and brackish swamps lying inland of sand ridges, in blocked river channels, seasonally inundated depressions and along slow-flowing stream beds have the potential to make a significant contribution to food supplies. Streams and drainage channels, as well as freshwater swamps and their agricultural equivalents, rice paddies, continue to supply Thai villagers with many wild vegetable products. Some of the most conspicuous aquatic plants in Thai markets, used mainly for their leaves and stems, are: *Blyxa* spp., *Centella asiatica*, *Ipomoea aquatica*, *Limnocharis flava*, *Neptunia oleracea*, *Nymphaea nucifera*, *N. nouchali* and *Spilanthes paniculata*.

In assessing the possible range of starch-rich plant-foods from wetlands, an example is provided by the traditional plant use pattern in the swamplands of northern Australia. In lowland Thailand, paddy fields have almost completely replaced the natural swamps and rice has long been the staple food, whereas in northern Australia freshwater swamps still exist and are regularly exploited. Some contemporary patterns of wild plant exploitation by Aboriginal people in monsoonal Australia may therefore shed light on the non-agrarian use of allied taxa in South-East Asia. In this region, the ethnobotany of foraging communities in wetland ecosystems has been carefully and extensively documented through historical records and specific ethnographic and ethnobotanical research (cf. Specht 1958, Golson 1971, Harris 1977b, Meehan 1977, 1982, 1988, 1991, Jones 1980, Russell-Smith 1985, Waddy 1986, Jones and Meehan 1989, Smith 1991). Parallels in plant use between South-East Asian and Australian Aboriginal communities, particularly in the strand, mangrove and wetland areas of interest here, have been illustrated by Golson (1971) and similarities in the coastal archaeological record of the two regions discussed by Allen (1987).

Freshwater swamp resources include edible water lilies, *Nelumbo nucifera*, taro *Colocasia* spp. (Petterson 1977) and wild rice *Oryza rufipogon*. The wetlands also support sedges like *Cyperus esculentus* and water chestnut *Eleocharis dulcis*, which often grow in monospecific stands. Their roasted corms are eaten (Singh and Arora 1978, Meehan 1982, Phengklai and Khamsai 1985) during the dry season. By the end of that season they are very sweet but difficult to dig from the dry swamp-bed (Meehan 1982, 1988, Waddy 1986, Jones and Meehan 1989). As these are roasted on hot coals before being eaten whole, an occasional cooking accident might leave a charred tuber for the archaeobotanist to find. They are inherently more likely to leave an identifiable trace then, than the green leaves and stems listed earlier, most of which are boiled or consumed raw.

The remains of Cyperaceae achenes were prominent and persistent in the Khok Phanom Di seed assemblage, but the dietary significance of these plants is difficult to assess. Sedges, for example *Scirpus grossus*, are a common source of raw materials for making mats and baskets (Ridley 1891) and continue to be the basis of a home industry in rural Thailand. The inflorescences are more likely to have been brought to the site attached to stems and leaves for making baskets and mats, than if the plant was to be used as food. In this case the corm is consumed and the above-ground parts are left in the swamp.

The final ecological unit for discussion is that of the saline coastal flats which often intervene between the mangrove forest and the inland freshwater wetlands. These are very sparsely vegetated, and patches may be completely bare of vegetation. The only plant cover is from the halophytes *Suaeda maritima* and *Trianthema portulacastrum*, both of which were identified from the Khok Phanom Di flotation samples. The fleshy leaves of these low herbs are edible, but their nutritional qualities and palatability are unknown.

To summarize, we see that the mangroves are not abundant in food plants, nor are the saline saltflats immediately inland, yet the community living at Khok Phanom Di was probably situated in an ecotone with access to a wide range of plant food resources. High species diversity among aquatic animal resources contrasts with the low diversity and nutritional value of terrestrial plant foods in the mangrove and its immediate hinterland. These two plant communities are unlikely to have offered a secure and balanced diet, although starch from *Bruguiera* hypocotyls offers a nutritionally valuable staple, despite high processing costs. The paucity of palatable and easily-procured plant resources would have encouraged the occupants of the mound to acquire alternatives from the freshwater swamps. The resource-rich wetlands offer a range of starchy corms and roots, leafy green vegetables and fruits, together with fish, shellfish and rice, apparently the nutritional mainstays for Khok Phanom Di society. The extent of the community's territory was undoubtedly related to both the number of ecological niches in the area, to the seasonal availability of resources, to population levels and extractive technologies. Ethnographic evidence points to significant, sometimes seasonal, input from plant sources, especially from freshwater swamps. In Anbarra country, in northern Australia, for example, swamp foods are important twice in the annual round: during the late wet and early dry season for water plants and then at the end of the dry season when *Eleocharis dulcis* corms are gathered in bulk (Meehan 1988). In Thailand, the transition between the wet and dry seasons is also the time for gathering or harvesting rice, and at this time of year, camps may have been set up close to the pond-fields, to protect and then to harvest the grain.

The Khok Phanom Di people probably used their mound in the mangroves as a permanent base, gathered locally available foods on a daily basis, and established temporary camps beside freshwater swamps when foods were seasonally available. Year-round occupation of the site has

been inferred from the repeated superimposition of graves, the volume of intervening occupation buildup and architectural features suggestive of houses (Higham and Maloney 1989). This sedentism is thought to have been facilitated by the ample estuarine resources, particularly molluscs and fish (cf. Yesner 1989), but the input of domestic rice surely helped underpin the stability too. Bellwood (1990) points out that foraging communities in Arnhem Land were not fully sedentary despite resources similar to those exploited at Khok Phanom Di, although they do characterize themselves as sedentary saltwater people who live chiefly on fish and shellfish (Meehan 1991) for whom freshwater swamp foods are seasonally important. A similar seasonal mobility may be envisaged here. One critical point that we return to is the unknown resolution of the resource mosaic. This would help determine the community's ease of access to a wide range of resources, and the extent of movement across the landscape. Despite a recent graphic, hypothetical reconstruction of the site and its surroundings, based largely on molluscan data (Mason 1991, Higham *et al.* 1992), it remains difficult for us to know quite how far people needed or were willing to travel to harvest rice, and to haul it back to their home-base. The widespread finds of rice husks in the deposits throughout zones A and B suggest bulk processing and storage within the settlement. This was probably as reliant on good boat transport as was the procurement of open ocean fish.

OTHER LINES OF EVIDENCE FOR DIET AT KHOK PHANOM DI

The diet for Khok Phanom Di residents was evidently more than adequate. Fish were caught in offshore and in-shore waters, from an estuary, a river and its tributaries, caught by line, net, spear and trap. Shellfish and crabs were gathered, mainly from estuarine mudflats. Mammals were trapped and hunted from the mangrove forest and further inland. From the human skeletal remains we learn that the Khok Phanom Di people had robust bone structure despite probable ill health associated with exposure to malarial parasites and this is construed as resulting from a well-balanced diet (Tayles 1992). They also indicate a genetic anaemia and the probable prevalence of malaria, together considered responsible for the high infant and childhood morbidity and mortality, especially in zone A (Tayles 1992).

The preparation of large quantities of food in excess of nutritional requirements and its probable arrangement on magnificent ceramic platters, are thought to be associated with the display of prestige at mortuary feasting (Higham 1989). We have ample evidence for the inclusion of baked molluscs in these ritual meals, but can only speculate on the plant foods consumed. A surplus of shellfish may possibly be indicated by unopened *Anadara* shells in the midden deposits (Suchitta 1984, Higham and Bannanurag 1990a) although observation of modern middens has indicated that *Anadara* shells can be closed by the contraction of the hinge ligament after the meat has been scooped out, giving the appearance of a complete, unopened shell (pers. comm. G. Mason).

Anadromous fish, such as *Lates calcarifer*, provided a seasonally abundant, predictable and easily harvested food supply, and shellfish could have been a reliable, year-round staple resource (Yesner 1980), at least during the estuarine phase of occupation (zone A and early zone B, ie. layers 11–8/7). The dental data show sex differentiation, with males having extreme tooth wear and women having greater caries and tooth loss, interpreted as men consuming a more abrasive diet and women having a softer, perhaps more vegetable-based diet (Tayles 1992). The general trend in these data also indicates that an abrasive diet due to shellfish and dried fish consumption, gave way

to softer, more cariogenic foods after the change in local ecology which may have impeded access to estuarine resources (Tayles 1992). As described earlier, evidence for rice continues through the sequence, but ecological reasoning suggests that it became easier to procure this and other swamp plants after the major environmental change. The choice in animal foods may have become more restricted at this point, with a limited range of small terrestrial mammals (pigs, deer and macaques) and birds substituting for marine and estuarine fish, and mudflat molluscs and crustacea. It is conceivable that the plant component increased in variety and caloric input to the diet, after improved access to the seasonally abundant wetland plant resources. Some aspects of the skeletal features, such as the reduction in the size of males in the later phases, and the evidence of demographic structure from the burials indicate that the general health of the population declined after the layer 8 environmental change. The fall in infant mortality is attributed not to dietary change, but rather to declining exposure to mosquitoes, the vector for malaria or a change in burial practices (Tayles 1992, Higham *et al.* 1992).

The archaeological visibility of the plant and animal components of the diet is disproportionate to their nutritional contribution and the human effort expended in their procurement and processing. This is supported from divergent directions by documentation of forager communities living beside tropical coasts, and from the physiological limits to protein consumption in humans (Yesner 1980, Erlandson 1988, Noli and Avery 1988). The limitations of a protein-rich and carbohydrate-poor diet have been touched on earlier. It has been demonstrated that people may safely acquire only 20–50 per cent of their daily energy needs from protein. This means that although shellfish resources may be nutritious and reliable foodsources, their contribution to the diet is significantly less than their outstanding archaeological visibility suggests (Noli and Avery 1988). A balanced diet, preventing protein poisoning, limits the protein intake and incorporates carbohydrate- and fat-rich foods, many of which are plants, especially grains, tubers and nuts. Supplying bulk carbohydrates, vitamins and minerals, these and other plant resources complement the protein component of a coastal diet. In the seasonal tropics of northern Australia, an estimated 50 per cent of the total calorific intake for the Anbarra people of Arnhem Land was from plant foods (cf. Meehan 1979, 1982, Meehan and Jones 1986, Jones and Meehan 1989). These assessments further emphasize the importance of plant resources among coastal communities, and at Khok Phanom Di the plant macroremains show that this role was at least partially fulfilled by rice.

INTERCONNECTIONS BETWEEN FISHING TECHNOLOGY AND PLANT USE

An important point arises from the extensive use of aquatic resources at Khok Phanom Di, that is, the role of plant products in fishing. Tangible signs are harpoons, fish-hooks and netweights, but much of the allied extractive equipment was probably made from plant products which have not been preserved. Fish traps, lines and nets, floats and harpoon shafts are all fashioned from plant products. Indeed, strong, durable fibres from plants like *Hibiscus tiliaceus* (Burkill 1966), are major assets enabling or limiting the exploitation of anadromous or deep sea fish (Sallis 1989). Sather (1985) describes the *Bajau Laut* (sea nomads) of south-eastern Sabah making twine for fishing nets, and comments that its production is very time-consuming. This is a reminder that gathering and processing plant fibres to produce and maintain fishing equipment would have been a major occupation in a prehistoric fishing community like Khok Phanom Di.

The high level of tannins which makes certain mangrove plants unpalatable and indigestible to humans, also renders their timbers durable. Extracts from their bark and timber are used to produce tanning agents for strengthening nets, sails and lines (see Chapman 1976 for a long list of historic records). Poisons extracted from the comminuted wood of plants like *Aegiceras* sp., *Barringtonia asiatica*, *Cerbera manghas*, *Derris* sp., *Diospyros* sp. and *Excoecaria agallocha* are used to stupify fish in rivers and pools.

Plant products from the strand and mangroves have multiple uses in fishing. Fibres are strung into nets and lines, tannin from macerated, infused bark is used to strengthen them, wood and roots are made into floats, plant extracts are employed as fish stupefacients, boats, rafts and fishtraps are made from timber, and finally fuelwood is used to cook the catch, perhaps flavoured with aromatic leaves, fruits or roots. Excess fish and shellfish may also be preserved by smoking. These are just some of the many ways in which plant products are integrated in a fishing economy. Examples of the Asian mangrove plant taxa and their specific applications are set out in chapter III.

Possible links between early fishing technology and the cultivation of plants useful for fibre manufacture, have been raised by Sauer (1969), who argued that multipurpose plants, like *Cordyline fruticosa*, producing fibres, dyes and fish poisons, were cultivated earlier than foodplants. *Cocos nucifera* and *Hibiscus tiliaceus* have attracted similar comments from Barrau (1970). The antiquity of fibre plant cultivation or the use of fish poisons in South-East Asia are yet to be demonstrated archaeologically although fibres used to impress cord-marked pottery have been investigated (Marsh 1976). Well-preserved fibres are rarely encountered in prehistoric sites and although identification should be straightforward, this was not the case with the Khok Phanom Di '*tapa*'. Investigating Sauer's assertion may prove a difficult task.

FINAL THOUGHTS ON LIFE IN THE MANGROVES

Thai mangrove villages are, in today's terms, remote. Often located close to the estuary mouth, and approachable only by river, they comprise pile-built dwellings rising above the mud at low tide, and surrounded by shallow water as the tide rises. Each house has a wide bamboo platform facing the river. This space is used alternately as a jetty, a fish-drying rack and a general meeting place in the evening. Within the village, communication is by a network of narrow bamboo and wooden walkways high above the mud. The spatial arrangement of the village, extending one house deep along the river, and its elevated architecture, have evolved in response to the remarkable and demanding setting which places certain stringent limitations on the way people can live in this watery, muddy environment.

One of the prime contraints to population density in these areas is the lack of fresh, potable drinking water (Kundstadter 1986). Freshwater stress limits the location of settlements, prehistoric and modern, to areas where people can still find fresh water at the end of the dry season: at the mouths of estuaries and along the slightly higher areas of the main watercourses in the delta (Chappell and Thom 1977, Takaya 1978, Kundstadter 1986). Khok Phanom Di's initial location on a levée or estuary bank fits well with the modern settlement distribution and that described for prehistoric landscapes (e.g. Cooper 1985 on the Andaman Islands). The availability of freshwater may have become a more powerful constraint on occupation during the final, non-riverine phase,

zone C. The abandonment of the mound for large-scale occupation after 1500 BC may have been prompted more by 'freshwater stress' than a lack of food supplies.

The lack of drinking water today is managed through adaptive behaviours. Modern means of collecting and conserving water in the delta include storage of rainwater in ponds, tanks and large pots during the wet season for use during the dry. This is practiced at Khok Phanom Di, where well-water cannot be used for drinking on account of its salinity. In the absence of pumps and wells providing access to groundwater resources, which could be brackish if subjected to seawater intrusion, the residents of the Chachoengsao area today rely on rainwater from the roof for their drinking water supplies. This is stored in large water pots inside or under the house. Water is rationed, and recyled whenever possible. In certain mangrove villages such as those in the Thai peninsula, fresh water is carried precariously by boat from an island with freshwater wells (Sangdee 1986). Alternative water sources are fish and coconuts (Engelhardt 1989) both of which were used by the sea gypsies, or Bajau Laut, who live on boats at sea for extended periods, without access to potable water. The faunal and palynological evidence confirms the availability of both these alternative water sources at Khok Phanom Di.

The water shortage also has implications for human health. Fungal infections are associated with poor hygiene (Sangdee 1986). During the dry season, water is reserved for solely drinking, and in the modern situation, public bathing in the river is unacceptable for some sectors of the community, resulting in health problems. Further health problems arise from the prevalence of mosquitoes and other insects in the swamps. Smoky fires can be lit and the body smothered in mud to provide protection from biting insects (cf. Mouat 1863) but the skeletal analyses mentioned earlier indicate that the Khok Phanom Di population probably suffered significantly from malaria carried by mosquitoes.

After water shortage, a second striking limitation to life in the mangroves is mobility. This may have affected the lives of the first settlers at Khok Phanom Di when the site may have been located within or close to mangrove forest. Mangrove villages are, in effect, islands, approachable only by water. Movement through these sheltered creeks and watercourses is by boat or raft. Twice-daily flooding in the intertidal zone, and seasonal inundation over far wider areas restrict ease of access by foot across wide stretches of wet, unconsolidated mud, as do the stilt and buttress roots of many of the trees. In peninsular Malaysia special, flat-bottomed sledges are used by mollusc collectors to skim over the wet mudflats (Sandbucht 1983, Chan 1986, pers. comm. C. Sather). This simple but highly effective means of transport provides access to distant shellfish beds. Resting one knee on the sledge, and using the other to propel the board across the mud, offshore shell beds can be reached.

Moving around on foot in the seaward side of mangal areas can be even more difficult, if not impossible. The substrate underfoot is usually mud, sometimes very soft and the long, aerial roots of Rhizophoraceae trees are hazardous, slippery and difficult to clamber over or around. Small boats provide access along narrow drainage channels. The relative ease of movement along watercourses has implications for both prehistoric site catchment and trade. Access to terrestrial resources was easiest along the estuary, both up- and downstream of the site and trade links were probably most firmly established with other coastal communities and people within the same river system.

To conclude, despite these profound contraints to life in the mangal, and because of the good aquatic (largely animal) and freshwater (largely plant) resources available to the Khok Phanom Di

people, the community effectively exploited the highly productive ecotone between land and sea during the early phase of occupation at the mound and continued to live there for perhaps 20 generations and over 500 years. The broad resource diversity, with rice, shellfish and fish as dietary staples, allowed a more or less year-round occupation of the site, and the establishment of a diverse and technically accomplished potting industry which underwrote the development of an increasingly hierarchical society, based on those craft skills. The cultivation of rice, demonstrated by the crop remains analysed here, both permitted and necessitated a settled existence. The archaeobotanical analyses have helped modify the preliminary cultural zonation of the site by setting the material culture against the environmental setting. The biogeography, the resource base and the lives of the Khok Phanom Di population were all strongly affected by a major change in the local environment, perhaps a shift in the river's course brought about by a major flood. This has been detected by detailed analysis and integrated interpretation of several classes of biological materials, including the plant remains, all of which were excavated from the archaeological site. These are complementary to the regional reflections in pollen, phytolith and sedimentary data. The charcoals, seeds, rice and other plant remains have provided a sound basis for interpreting the vegetational history of the area. Moreover, with additional ethnobotanical understanding of coastal, estuarine and freshwater swamp ecology and plant resource use, they have pointed to the critical importance of terrestrial plant resources, above all domestic rice, to the prehistoric people of Khok Phanom Di, despite a bioarchaeological record dominated by aquatic faunal remains.

IX. TWO PHYTOLITH SEQUENCES FROM THE BANG PAKONG VALLEY

By Lisa Kealhofer and Dolores R. Piperno

INTRODUCTION

IN 1985, Maloney undertook a coring programme in the vicinity of Khok Phanom Di. His goal was to study the environmental history of the area in which the site developed. The materials analyzed from these cores, including pollen, macro-botanical remains, sediment and charcoal revealed evidence of cultural burning and possibly early agriculture in the 5th millennium BC (Maloney 1991). The phytoliths from two of these cores have now been analyzed to provide a more detailed record of agricultural and grass weeds. Phytolith research complements pollen studies by distinguishing many taxa, such as grasses and cultivated cereals, which do not have distinctive pollen.

The site of Khok Phanom Di (KPD) was investigated to clarify the role coastal habitats played in the development of rice agriculture in South-East Asia. Khok Phanom Di proved to have been first occupied at the beginning of the second millennium BC, late relative to the beginnings of agricultural development (Higham and Bannanurag 1990). Pollen cores taken from its environs, however, document a sequence of natural and human modified environments back to the sixth millennium BC (Maloney 1991). One of these cores, KL2, shows several intense charcoal peaks predating the site's occupation (5870–4685 BC at 4.95 m, 5370–4515 BC at 3.50–3.54 m; *ibid.*). Slightly later in the sequence, charcoal peaks co-occur with weeds associated with rice field cultivation (2.30 m, *c.* 4300 BC). While direct evidence of rice is not possible from pollen, the decline in mangrove taxa, increase in burning, and increase in rice field weeds strongly suggest that agriculture was practiced in this region in the fifth millennium BC (Maloney *et al.* 1989:367).

The phytolith analysis of KL2 and BMR2 was undertaken to illuminate, if possible, the role of agriculture in the culturally modified environments around Khok Phanom Di. The combined information, including pollen, phytoliths, macro-plant remains, charcoal and recent geomorphological work provides a much more coherent and detailed view of the environmental history of the area around Khok Phanom Di (Maloney 1991, Aitken 1992, Thompson, this volume).

Khok Phanom Di was initially settled, according to the radiocarbon chronology for the 1985 excavation, about 2000 BC. Geomorphological evidence suggests that the site was founded on a stream levée inland from the estuary of the Bang Pakong River (Aitken 1992). Mason's analysis of the shellfish, on the other hand, support a closer proximity to the estuary (Mason 1991 and this

We would like to thank the Smithsonian Tropical Research Institute (STRI) and the Mellon Foundation for their generous support of this research. Several people were particularly helpful, and we would especially like to thank them for their efforts: Guiselle Mora's technical asssistance in the STRI laboratory was invaluable; Bernard Maloney and Charles Higham both contributed to making this study possible and we appreciate their assistance and patience; and Jill Thompson and Graeme Mason both contributed thoughtful and useful comments on the research and the manuscript

volume). Over time, the site's distance from the coast increased, as sedimentation extended the coast seaward (Mason 1991, Aitken 1992, Thompson this volume). This ecotone locale allowed access to marine, mangrove, riverine, freshwater swamp, and alluvial plain/grassland resources. The diversity and abundance of subsistence resources available made this an advantageous niche (Takaya 1987, Higham *et al.* 1992). The site, however, was abandoned after 1500 BC, perhaps due to changes in the alluvial environment and a relocation of the river channel (Aitken 1992, Higham *et al.* 1992).

METHODS

Two of the six sediment cores taken by Maloney, KL2 (6.5 m) and BMR2 (7 m), from the Bang Pakong Valley (Fig. 50) were analyzed for phytoliths. These two cores were taken 170–200 m north west of the site of Khok Phanom Di, and were located within 30 m of each other. The pollen, spore, charcoal and sediment records have been discussed in detail elsewhere (Maloney 1991).

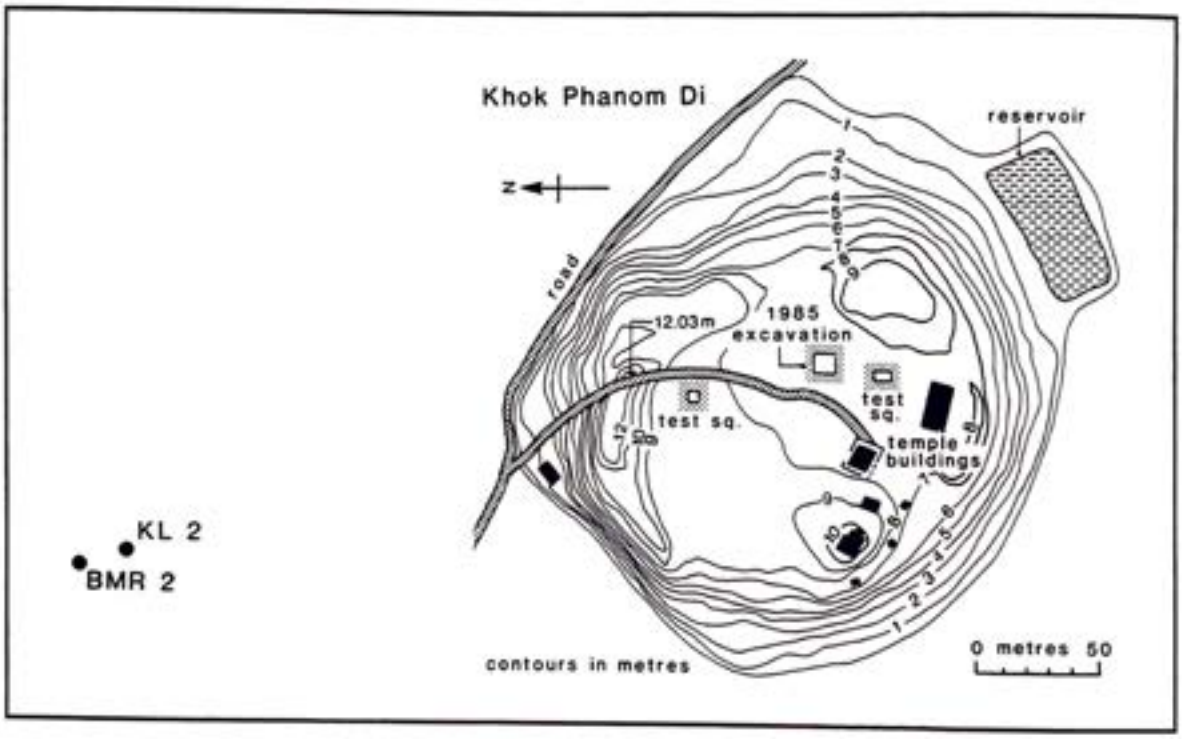


FIG. 50. Map of coring locations for KL2 and BMR2

Phytolith extraction from sediment samples followed standard methods of analysis (Piperno 1988). Soils were deflocculated in Na_2CO_3 and sieved to remove large particles. A USGS Standard 270 mesh sieve separated the sand fraction from the silts and clays. Clays were removed by the process of gravity sedimentation. The resultant silt sample was further fractionated into fine and coarse silts, also by gravity sedimentation. Soil samples are fractionated to keep the larger phytoliths from impeding the identification and quantification of the often more diagnostic small

phytoliths and grass short cells. The organics in each fraction were wet ashed in Schulze solution ($KClO_3$ and HNO_3). After rinsing in water and drying in acetone, the phytoliths were separated from the soil and minerals by floating in a heavy liquid of potassium and cadmium iodide (specific gravity 2.35). After rinsing in water and drying, the phytolith samples were then mounted in permount. The phytoliths were counted at 400x under an Olympus photomicroscope while the mounting medium was still fluid, to enable rotation and viewing of their forms in three dimensions.

Phytolith identification was based on a modern reference collection of over 340 species of plants, comprising most of the South-East Asian families known to be phytolith producers (after Piperno 1988). This type collection also included many previously untested Old World tropical taxa (Kealhofer and Piperno, in press).

One goal of the analysis was to evaluate the potential for retrieving and identifying rice (*Oryza*) phytoliths from sediment cores. The possibility of identifying phytoliths from *Oryza* was revealed by German botanists, late in the nineteenth century (Grob 1896, Formanek 1899, Edman and Soderberg 1929). They extensively studied grass phytolith morphology and identified distinctive *Oryza* glume phytoliths.

The distinctive *Oryza* forms identified by these early plant morphologists have proven to be genus specific, and hence very useful diagnostically. Many researchers have conducted comparative grass phytolith studies of both wild and domesticated grasses, and tropical and temperate grasses, and no other forms mistakable for rice glume hair cells were found (Parry and Smithson 1964, 1966, Twiss *et al.* 1969, Blackman 1971, Palmer and Tucker 1981, 1983, Brown 1984, Twiss 1992, Pearsall *et al.* in press). Morphological studies also reveal no forms identical to the distinctive rice bilobates (Metcalfe 1960, Clifford and Watson 1977, Terrell and Wergin 1981).

Rice phytolith identification was based on the German studies noted above and the work of Pearsall and co-workers (in press), which describes the glume and leaf phytoliths of the genus *Oryza*. We also analyzed 50 species of Thai grasses, as well as multiple species of *Oryza* and replicates of *Oryza sativa*. In addition to the forms noted in the literature, other *Oryza* specific (i.e., genus specific) phytoliths identified include distinctive bilobates and flat lobed bodies from leaves, and 'bottle'-shapes and 2-celled hairs from glumes. Recently, Pearsall and co-workers (in press) have suggested that phytoliths from domesticated rice can be metrically differentiated from wild rices in large assemblages. However, the small sample sizes of rice phytoliths recovered from these soil samples make these criteria difficult to apply. Further morphological and assemblage studies of *Oryza sativa* and its putative wild ancestor *Oryza rufipogon/nivara* are being conducted (Kealhofer ms).

Comparisons of phytoliths from species of the two series of *Oryza*, Latifoliae and Sativae (Shastry and Sharma 1974), show that they can be easily differentiated on the basis of the same generic indicators noted above. The distinctive bilobate types vary in size, shape, and proportion between species, as do additional morphologically distinctive bilobates. The Sativae series (A genome) of Oryzeae includes the African and Asian domesticated rices and their progenitors. Within this series, it also appears that the African and South-East Asian rices can be distinguished, based on glume short hair morphology, leaf bulliform shape and bilobate size and diversity. The rice phytoliths identified here all fall within the Sativae series of *Oryza*.

The KL2 core consisted of 6 m of sediments, deposited over 7300 years, based on the radiocarbon dates (Maloney 1991:61). Twenty-two samples from the KL2 core were analyzed for phytoliths. All but one of these samples (2.28 m) contained quantifiable phytolith concentrations.

Fourteen samples were analyzed from the BMR2 core, and thirteen of these contained phytoliths in sufficient concentrations to count. While most pollen and phytolith quantification procedures rely on influx, or pollen or phytolith concentrations per cubic centimeter of sediment, this procedure was not followed here. Terrestrial and alluvial environments are not continuously deposited, but include periods of erosion and episodes of variable deposition. These factors preclude a determination of influx. Instead, phytolith counts are presented as percentages per sample, based on counts of 200 phytoliths per slide.

THE PHYTOLITH RECORD

KL2

Three distinct phases occur in the KL2 sequence, and all are believed to be related, at least in part, to human activities: near the beginning of the sequence (5.45 m, before 5300 BC), slightly later (4.95 m, *c.* 5300 BC), and much later (1.65 m, after 4300 BC). After the first two rapid and distinctive shifts in vegetation the environment returned to its previous pattern. The final change, however, reflected a long term alteration of the habitat surrounding the site of KPD.

The baseline vegetation pattern revealed by the phytoliths, in between these three phases, was comprised of a strong arboreal component which included various arboreal indicators: palms, forest bamboo grasses, very few other grasses, and a small percentage of Compositae and sedge species (Fig. 52). The pollen from these levels consists of about 90 per cent mangrove species, mostly *Rhizophora* (Fig. 51, Maloney 1991:67–68, 73). The tendency to over-representation of *Rhizophora*, and the convincing presence of back mangrove species (such as *Pandanus*, *Bruguiera* etc.), suggests that the pollen rain came from the inland, freshwater side of the mangrove belt (Maloney 1991:65).

While there are fluctuations in this baseline vegetation pattern, including shifts in the relative frequency of *Rhizophora* and *Bruguiera* species, the overall composition and relative abundance of the taxa do not change. This stability is particularly marked between 4.0–2.0 m in both pollen and phytolith assemblages (*c.* 5000–4000 BC). The minor fluctuations may document sea level oscillations. Charcoal increases briefly in the *c.* 3.2 m sample, associated with an increase in pteridophyte spores, suggesting that some localised clearing did occur during this stable phase.

The three interruptive phases in the KL2 core present similar patterns of disturbance, but each has unique characteristics. The earliest change is characterized by an increase in carbon and particular bamboos, and a shift in arboreal species. The various phytolith sphere types clearly indicate a variety of arboreal taxa, but are not taxonomically distinct enough to differentiate species. Hence, it would seem that mangrove species sharply oscillate at this time, but the exact pattern is not clear. The earliest rice phytoliths, fragments of burned *Oryza* glumes, are found in this level (5.0–5.1 m), as well, suggesting an increase in freshwater availability. The assemblage found in this early perturbation does not unambiguously support the presence of agriculture, but this can not be ruled out. More likely, local groups cleared and used the mangrove forest for fuel, which fostered the expansion of some bamboo grasses. Bamboos are often found along river banks, as well, supporting the expansion of freshwater environments (Takaya 1987). The increase in some tree species relative to others might indicate their protection, an ecological succession, or their lack of economic usefulness. The pollen and charcoal evidence presented by Maloney (e.g., 1991:66) does

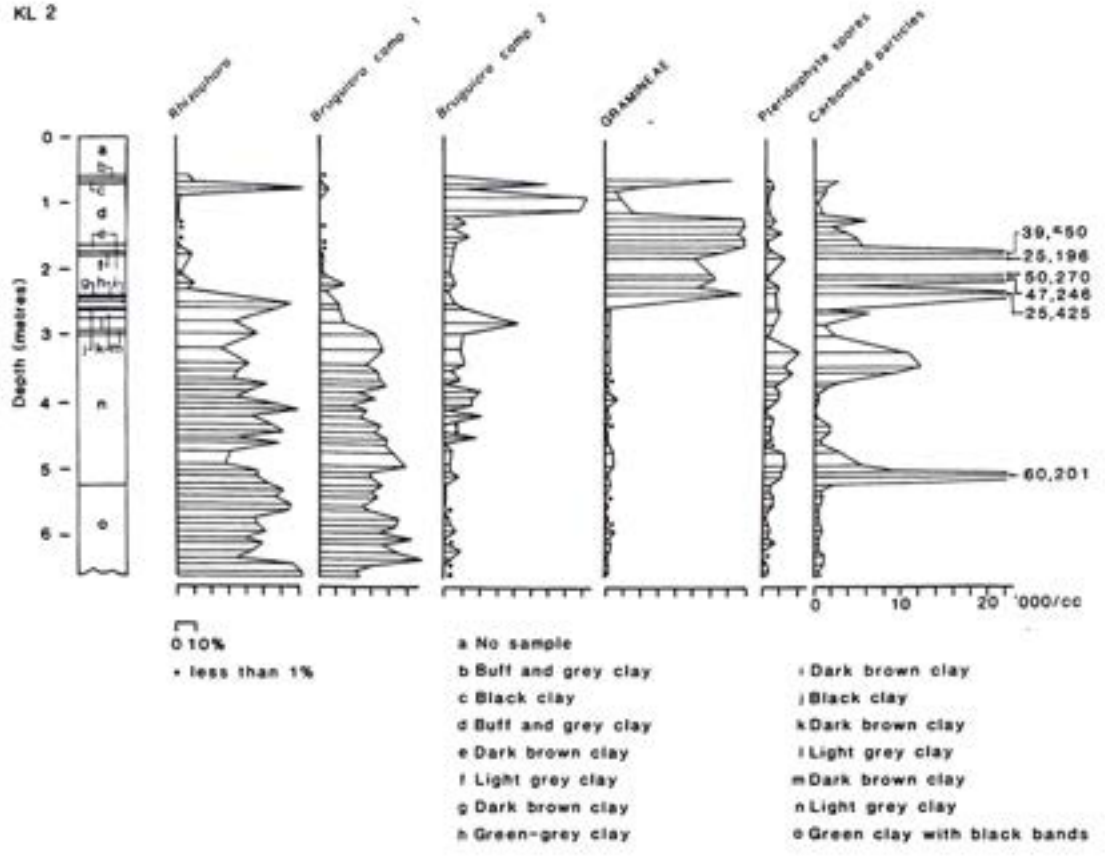


FIG. 51. Summary pollen diagram for coring site KL2

not show the shift revealed in the phytolith samples. This is probably due to the short duration of the perturbation (in between sampling intervals) and the finer grass species resolution available from phytoliths.

The second phase, at *c.* 4.5 m, presents a more uniform disruption in the vegetational assemblage (Fig. 52). Between 4.5–4.0 m (*c.* 5300–5000 BC) field grasses, rice and freshwater indicators increase substantially, while arboreal species decline. Interestingly, a very sharp decline in trees and increase in secondary bamboo species occurs immediately prior to the onset of this apparently agricultural phase. This suggests the presence of cleared land before agriculture began. Since Maloney's (1991:66) charcoal evidence reveals huge peaks in charcoal prior to this phase (*c.* 4.9 m), perhaps slash and burn or fuel producing activities preceded more intensive agricultural strategies in this locale.

The final transition documented in this sequence began just above 2.0 m (*c.* 4000 BC). Except for palm, arboreal indicators declined dramatically, while rice and other non-forest grasses dominate the assemblage. The small number of rice phytoliths in the lower samples precludes the possibility of differentiating their status as wild or domesticated Sativae. However, the association of *Oryza* (Sativae series) with plants known today to colonize agricultural fields constitutes strong

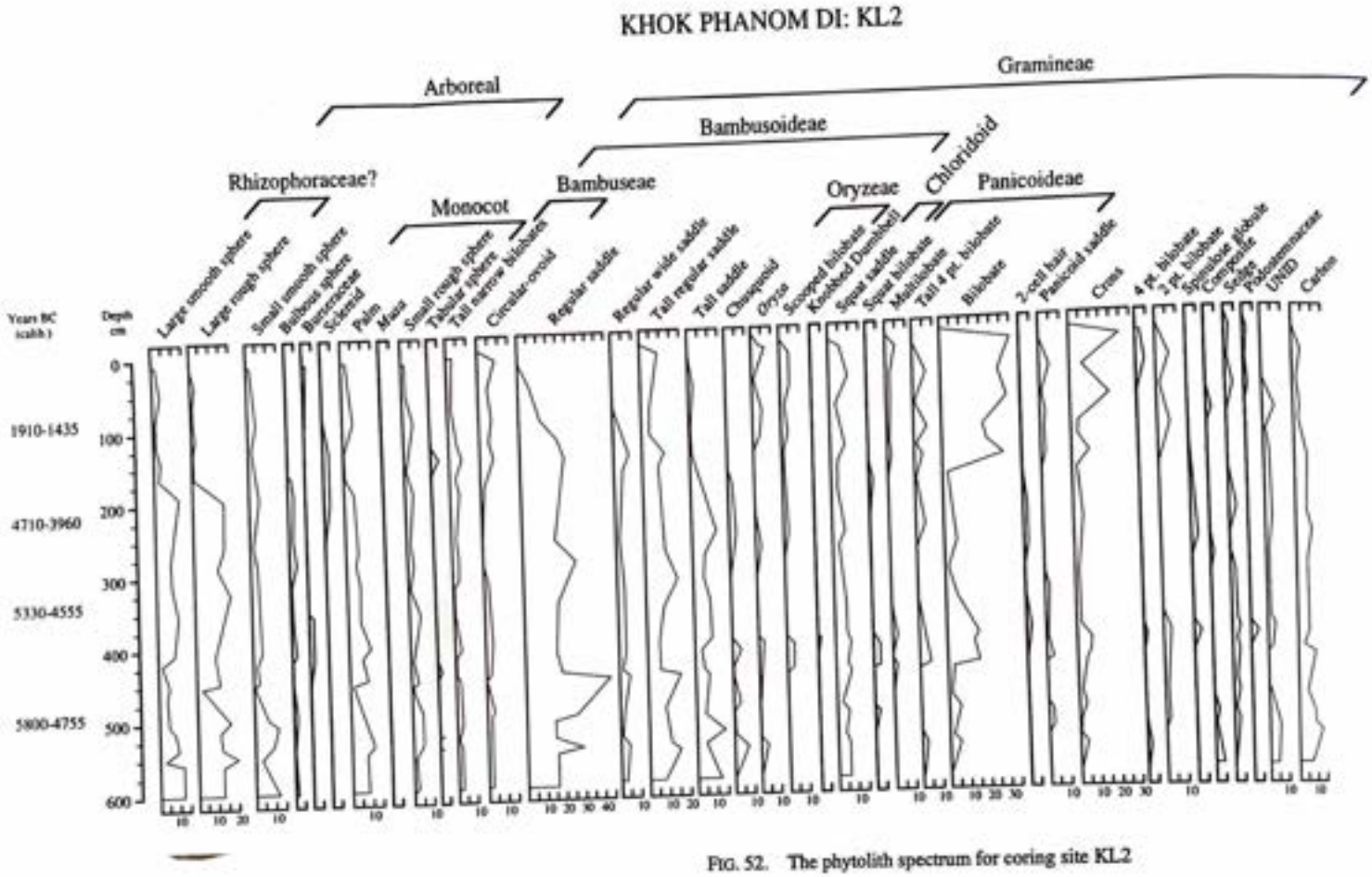


FIG. 52. The phytolith spectrum for coring site KL2

circumstantial evidence that rice was being cultivated. *Oryza* phytoliths are common in the 1.25 m sample (before 1650 BC, *c.* 2000 BC?), and reach their highest percentage above 90 cm (after 1650 BC). Based on the greater quantity of remains, and the size range of the glume hair cells present, these phytoliths are consistent with those found in domesticated *Oryza sativa* glume samples. The presence of freshwater is confirmed by Podostemaceae, a moss found in submerged riverine habitats. The contemporary increase in Panicoideae phytoliths may represent either other cultigens (e.g. millet or Job's Tears) or field weeds, but it strongly suggests agricultural activities. No Pan-

icoideae grasses are present in mangrove habitats, but they are found in back mangrove swamps (e.g. *Eragrostis* sp.). Bamboos, including both forest and secondary growth taxa, lose ground, suggesting that the local environment was carefully managed. Levels of burning dropped off significantly in these upper levels, possibly as burning due to clearing and fuel making decreased, as the mangroves were depleted in the region around the site.

Several shifts among the weedy grass sub-families occurred over the last 6000 years. These changes may be due either to changes in agricultural strategies or in the distribution of surface and sub-surface water.

Oryza phytoliths increase at the time of site occupation (*c.* 2000 BC), suggesting local intensification of rice cultivation. In the sediment cores, agricultural activity seems to begin at least 2000 years before the occupation of Khok Phanom Di. Where settlements were located in this interval, prior to KPD's occupation, may have been dictated by the changes in sea levels and river channels, or simply related to demographic infilling in a geographically constrained but productive zone.

Two types of discrepancy occur between the pollen and the phytolith record that should be mentioned. The timing of vegetation shifts differs between the two types of sequences. The cause of this varies: in some cases it seems to be an issue of sampling resolution and interval (e.g. between 2.25 m and 1.75 m), while elsewhere (e.g. 5.5 m) the difference in the nature of the data is critical. The pollen rain is likely to represent a larger region than the phytoliths, and it suggests a pattern of disturbance which intensifies in the area around 5000 BP. The charcoal/carbon evidence is also variable between the two data sets. The sharp peaks recorded in the pollen record are absent in the phytolith samples. It is possible, in this case, that the carbonized particles represent different parts of the record of vegetational burning. While the pollen carbon signature has more general applicability, the phytolith carbon signature presents a complementary pattern of interrelated vegetational shifts and burning. The overall trend toward decreased burning, particularly associated with more intensive agriculture, is of specific interest. The charcoal record from the pollen sequence seems to provide a better record of cutting and burning events (compare, for example, 5.0–4.9 m samples). Pollen charcoal peaks correlate with higher percentages of bamboos and lower percentages of agricultural weeds and rice. This seems to suggest that the burning was not related to agricultural techniques, but was tied into other cultural activities (such as mangrove charcoal production?).

BMR2

The phytolith record from the BMR2 core presents quite a different picture of human activity in the region (Fig. 53). Until the uppermost sample, there is limited evidence of disturbance. The pollen sequence shows virtually the same pattern (Fig. 54). Few major changes, even natural ones, occur until the end of the sequence. Neither the pollen nor the phytolith samples contained high carbon concentrations.

Palm phytoliths are more common in BMR2 than in KL2 samples. The most common palm phytolith sizes are consistent with *Borassus* and *Calamus*. *Nypa* palm phytoliths were identified at 1.7 m (with *Caryota*?) and 4.25 m (correlates with *Pandanus* in pollen diagram?). *Nypa* is found in brackish waterlogged soils, and it co-occurs here with peaks in the other arboreal indicators and declines in grasses. A small palm phytolith, comparable in size to the tiny *Phoenix* phytoliths, was identified at 5.75 m. Palms seem to be more abundant in modern back mangrove than in *Rhizophora* mangrove, and include those types tentatively identified here, particularly *Borassus* (Maloney 1991).

Only two distinctive transitions occur in the BMR2 core. The first change took place early on (5.8–6.2 m, *c.* 5500 BC), and is most clearly seen in the assemblage of bamboo taxa. Arboreal indicators, which are roughly parallel to each other for the rest of the sequence, show an inverse trend in this earliest sample. The greatest carbon peak also occurs at this time. This signature is mirrored in the pollen diagram, which has a *Rhizophora* decline, a *Bruguiera* peak, and a charcoal increase. This is basically the same pattern that is seen at roughly the same time at the bottom of the KL2 sequence, although there are insufficient dates to correlate the two cores more closely. The presence of this event in both BMR2 and KL2 lends some support to a broader use of the landscape at this time, with both clearing and burning activities. This period is associated with rising sea levels, precluding an interpretation of a natural succession for the expansion of bamboos, the decline in mangrove species, and the peaks in burning.

Both arboreal indicators and grass sub-families oscillate throughout the central portion of this sequence, documenting a subtly shifting back mangrove-swamp margin habitat. The grass component of this habitat was dominated by Bambusoideae species. Based on changes in sea level and hypothesized tectonic uplift of the delta (Pramojanee and Hastings 1983, Tjia *et al.* 1983), it is likely these variations in species' distributions are related to the shifting proximity of salt- and freshwater (e.g. *Nypa*). For example, in the 5.25 m sample, faceted spheres, likely to be Annonaceae, were identified. In this context, Annonaceae species are found in freshwater swamps and not in the mangrove belt. The appearance of *Oryza* above 2.4 m (*c.* 4000 BC), although in low frequencies, correlates with the beginning of the last transition noted in KL2, and the local onset of more intensive agricultural activities.

The final change in the vegetation began somewhere between 1.3–0.8 m (before or by *c.* 2400 BC). Arboreal species began a long decline, temporarily bolstered by palms, which subsequently also disappear in the most recent sample. Bamboos, from both forest and secondary growth, decline even more rapidly. Panicoid, or weedy grass species, on the other hand, spread rapidly. Interestingly, sedge abundance increases at the top as well, suggesting more damp, freshwater swamp edge habitats develop. This apparently agricultural signature roughly correlates with the KL2 sequence, although the lack of chronological resolution impedes this comparison.

A complementary picture is painted in the pollen record (Maloney 1991). Above 1.3 m, *Rhizophora* dominated mangrove shifts toward *Bruguiera* mangrove, and non-saline indicators also expand (e.g. *Pandanus*, *Scirpus*, etc.). This represents a shift toward the landward margin of the mangrove belt, with freshwater swamp nearby. Shortly thereafter *Bruguiera* disappears and grass pollen dominates. The minimal evidence of burning in this sequence virtually disappears at this time, suggesting it was related to the presence (and use?) of *Rhizophora* mangrove. Potential palm cultivars identified in the pollen record included *Cocos nucifera* (above 1.0 m) and *Areca* (2.21 m and upper two samples). Possible phytolith support for these is found above 1.0 m, where small rough sphere phytoliths (5–10 microns), possibly *Cocos* or *Areca*, increase.

The late evidence for agricultural weeds in this sequence, the slow decline in arboreal taxa, and the limited evidence for cultigens make an agricultural interpretation of this last transition more ambiguous. The pollen profile, in particular, portrays what would appear to be a natural progression of *Rhizophora* to *Bruguiera* to grasses, following a regressive sea. It is, in fact, likely that the pollen does provide a good proxy for the regional environmental change beginning 6000 years ago as the sea levels declined. However, when the charcoal and phytolith evidence is added to the picture, the contribution of humans to this natural sequence is clarified. The abundance of both Panicoideae

grasses and sedges, alongside rice, suggests the presence of rice agriculture (compare assemblages listed in Maloney 1991:40–44). While this transition (1.3–1.0 m) begins just before *c.* 2500 BC, it is most evident thereafter, corresponding with the abundant evidence for rice agricultural activities at KPD beginning *c.* 2000 BC.

DISCUSSION

These cores are from deposits which include shallow marine and river alluvium, and therefore they sample a different ecological zone than lake sediments would. During intervals when the coring sites were not subject to alluviation, phytolith deposition, in particular, would have been quite localized. Based on pollen grain studies, some tidal redeposition did sporadically occur during the period of higher sea levels (4.8–1.8 m, 5000–2000 BC; Maloney 1991:64). However, the differences between the two cores primarily reflect the diverse micro-environments in the Bang Pakong floodplain in this coastal zone. Finding strong evidence for an early field at about 5000 BC is unlikely given these sampling factors unless such activities were relatively common.

Human agricultural activities in the coastal region of Thailand, specifically at the interface of the back mangroves and the alluvial plain, are indicated by the presence of agricultural weeds in samples from the end of the sixth millennium BC, as was suggested by Maloney and co-workers (1989). Domesticated rice cannot, at present, be positively identified; however, the complement of weedy taxa in the assemblage is the same as in an assemblage from a modern agricultural regime. This period predates the maximum sea transgression (*c.* 4000 BC), and therefore the presence of rice cannot be interpreted as part of a natural transition from mangrove to alluvial plain following regressing seas. More likely, the warmer and wetter environment of that era made the ecotone swamp/back mangrove a viable location for rice manipulation.

The detailed and localized pattern of vegetation changes revealed in the phytolith sequences, complements the pollen data. The changing composition of grass species and their relationship to cultural and natural fluctuations in this geologically active area need to be studied in more detail, but the fingerprint of human activities, both from burning and agricultural weeds, is evident from near the beginning of this 8000 year old sequence. The burning activities may or may not be related to early agriculture here, but it is doubtful they related to early rice agriculture. More likely, they relate to fuel production and use of the mangroves. In other habitats, such as dry seasonal forest, burning events could be ambiguous, representing either cultural or natural events. In the mangrove area, however, natural burning rarely if ever occurs. Major burning events are cultural phenomena.

A sea level rise has been suggested for the period from 5000–4000 BP (Geyh *et al.* 1979, Maloney 1991). One would have expected this to correlate with an expansion of *Rhizophora* mangrove inland, nearer the site, during the period of higher sea levels. However, the changes in mangrove abundance are inversely correlated with the hypothesized sea level transgressions and regressions. Both cores begin with abundant mangrove species prior to the suggested sea transgression, and decline in mangrove indicators during the transgression, shifting toward intensive cultivation (most apparent in KL2). Possibly the tectonic uplift of this region suggested by Pramojanee and Hastings (1983) did raise the coastal region out of reach of this transgression. The relationship between sea level changes and the occupation of the region needs to be explored further, but correlations with the onset of a transgression *c.* 7000–6000 BP in the larger region are likely (cf. Thompson, this

volume). The decline in mangroves seen in the phytolith record just prior to and at the time of site occupation supports the geomorphological interpretation that the site was located inland from the Bang Pakong estuary (Aitken 1992).

Unfortunately, data providing the resolution for short term climatic change do not exist in this region. As presented above, the current sampling regime provides a resolution of 200–500 years. Climatic change was most dramatic during the early Holocene, with the very rapid warming subsequently leading to higher sea levels and elevated humidity. A slight reversal of this trend occurred 4000–5000 years ago with the onset of the Neoglacial period. This shift played an important role in the sea level regression, the progradation of the delta, and the displacement of the mangrove and backswamp zones. If, as would be expected, the mangroves moved coastward with sea level regression, a gradual transition to back mangrove species, and eventually deciduous forest would be expected. The evidence from the cores, however, reveals an abrupt change from mangroves to no mangroves in the immediate vicinity, and a dramatic onset of weeds and weedy grasses, including rice. The non-natural assemblage composition and the rate at which it changed strongly argue that cultural rather than natural activities created the signature seen.

The confluence of the alluvial plain with the freshwater swamp zone behind the coastal mangroves at Khok Phanom Di would have been a suitable habitat for early *Oryza* annuals (Takaya 1987). In this zone, rivers commonly overflow in the rainy season creating a shallow swamp. During the dry season these alluvial margins dry out. The evidence from Khok Phanom Di in central Thailand suggests that agricultural communities settled in ecotones not far from the coast early in the process of developing domesticated cereals and sedentism.

The presence of rice (Sativae) prior to 7000 years ago in the coastal backswamps of Thailand reveals that at least the wild precursors of domesticated rice were available for human manipulation in this region in the early Holocene. This suggests that Chang's (1976a and b) map of the rice homeland, with its southern boundary far to the north, needs to be re-evaluated to include a larger part of South-East Asia.

CONCLUSION

The exploratory analysis of these core sediment samples to identify *Oryza* phytoliths and evidence of agriculture in the Thai record, has proven even more successful than expected. Rice phytoliths were found to be well-preserved in 7000–8000 year old sediments. The pattern of grass assemblages documented in these two phytolith sequences confirms that phytolith analysis will be able to play a significant role in understanding the development of rice agriculture in Thailand.

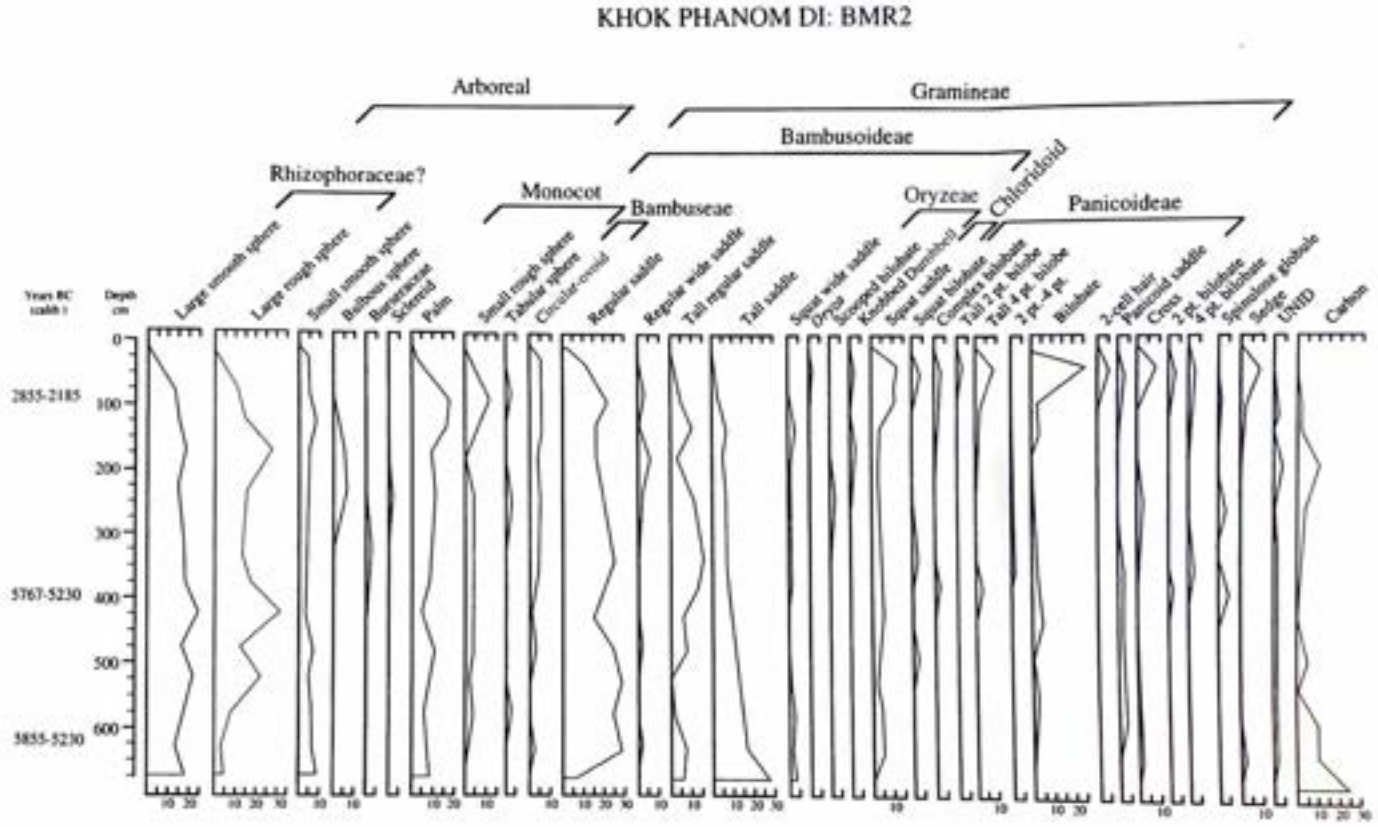


FIG. 53. The phytolith spectrum for coring site BMR2

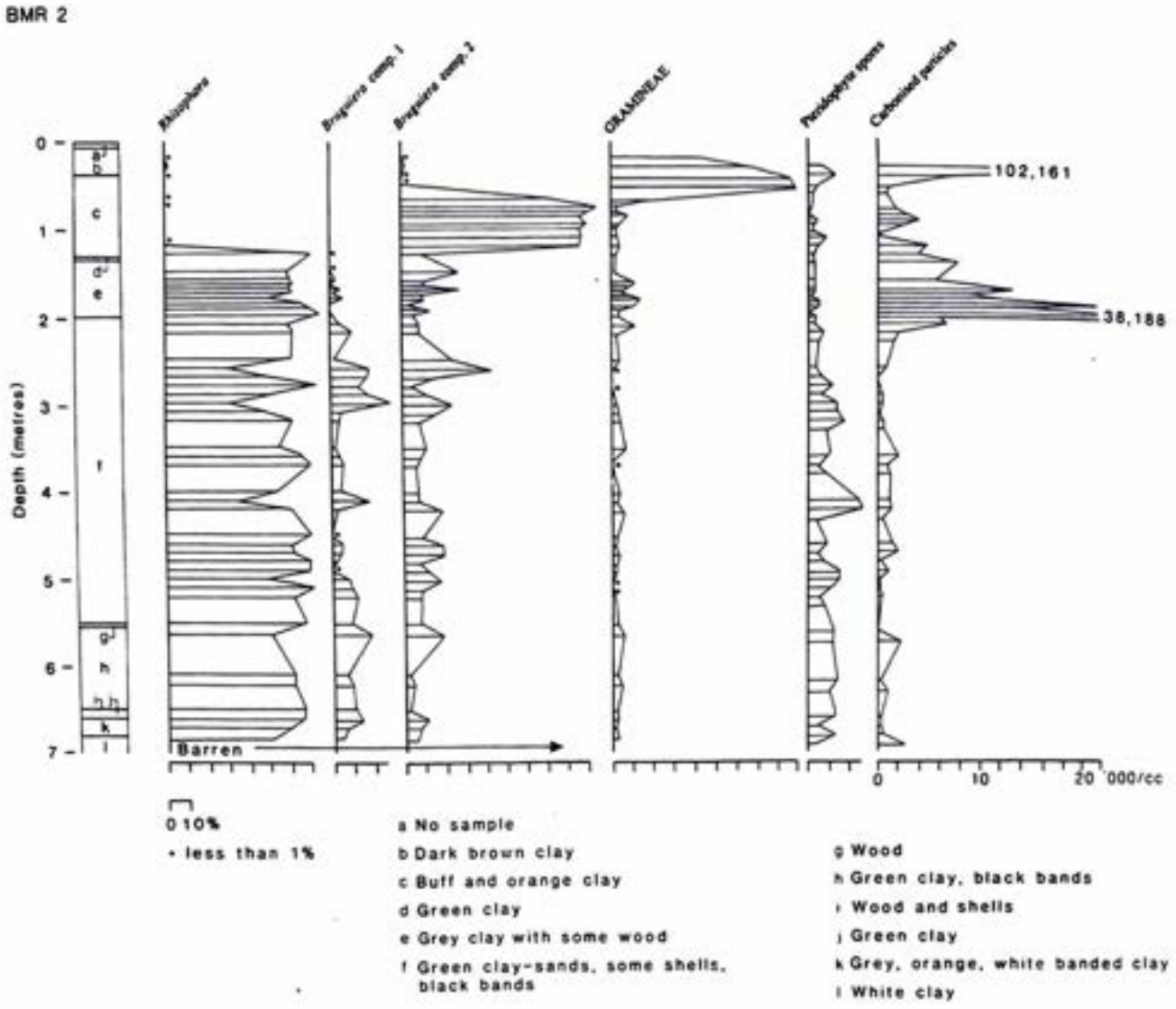


FIG. 54. BMR2 pollen diagram summary

X. THE MICROMOLLUSCS

By G.M. Mason

INTRODUCTION

THIS is the second and last report on the molluscan remains from Khok Phanom Di with respect to their palaeoenvironmental significance. The first report dealt with all those specimens generally larger than one centimetre in longest dimension, recovered in the course of excavation. This report describes the minute species recovered predominantly by means of flotation of samples collected systematically from top to bottom of the site. Forty-three species are considered and their contribution to our knowledge of the site's setting is discussed.

MATERIALS AND METHODS

The shells were recovered as part of the archaeobotanical studies of Thompson (this volume) utilizing a water flotation tank and sieves to recover small, low density objects (mainly charcoals and seeds) from the archaeological deposits. The technique is described above. Briefly restated, from each excavational unit and feature in each of the four quadrants was taken, in small scattered amounts, a total of ten buckets of sediment to make up a nominal 100 l sample. At the midpoint of layer 9, the onset of the monsoon necessitated a reduction to half of the sample size. This change had no discernable effect on the species composition of the samples, from which one may conclude that the smaller sample size was adequate to detect all species present. The light fraction was recovered from the flotation sieves, air-dried on the site and then packed for laboratory sorting. Each flot sample was sorted into shell/non-shell fractions and the former, where deemed robust enough, were ultrasonicated for a few seconds to dislodge adhering sediment. Specimens were then sorted to species by naked eye or low power stereomicroscope. Identifications were undertaken in conjunction with the available literature and a small amount of comparative material collected by the author and Mr Alan Grant. The marine and terrestrial collecting sites are shown in figure 55. These collections were in many cases the only clue to the habitat requirements of the landsnails.

HYDROBIIDAE

This large and diverse family of some 200 genus-group taxa is split into 22 subfamilies. Most of these small (less than 6 mm) snails live in a wide variety of freshwater habitats with a few adapted to estuarine conditions. A few have become amphibious but not fully terrestrialized. A cosmopolitan group, most speciose in the Northern Hemisphere, they eat mainly very finely divided organic detritus and graze microbial mats. Important references are Taylor (1966), Radoman (1973) and Ponder (1988).

TABLE 48: *The collecting sites for marine micro shellfish and their habitats. Figures denote an arbitrary score out of ten for the habitat*

Site	Habitat	1	2	3	4	5
Bang Saen	Sandy beach	8	2	-	-	-
Fisherman's Beach	Mud	-	-	10	-	-
Si Racha	Gravel beach	-	8	2	-	-
Si Racha	Sandy beach	3	7	-	-	-
Kho Si Chang	Sandy beach	8	2	-	-	-
Kho Si Chang	Rocky beach	2	7	1	-	-
Ban Ang Sila	Rocky mud	-	-	8	2	-
Ko Samet	Clean coral	3	1	-	-	6
Sattahip	Sandy beach	7	2	1	-	-
Chonburi	Clean sandy beach	8	2	-	-	-

The numbered columns denote: 1, low-gradient sandy beach extending subtidally; 2, sand with rocky outcrops; 3, rocky mud; 4, mangal/mangal mudflat; 5, clean coral environment

Clenchiella microscopica (Nevill, 1877)

Habitat/ecology: found in tidally influenced canals and on mudflats under slightly brackish water.

Range: from the head of the Gulf of Thailand near Bangkok eastwards as far as Trat Province.

Provenance in site: L10, 2[1] ; L9, 3; L8, 5.

STENOTHYRIDAE

This family of millimetre-sized snails inhabit generally tropical fresh and brackish waters ranging from Iran through India, South-east Asia north to China and Japan and south to New Guinea and northern Australia. They are to be found on sandy ground, decaying wood, stones and buried in mud. Micro-organisms encrusting decaying particulate organic debris appear to be their main food. Most species have narrow habitat ranges. Important references are: Brandt (1974) and Hoagland and Davis (1979).

Stenothyra acuta Brandt, 1974

Habitat/ecology: trenches in muddy, swampy ground.

Range: known only from the lower reaches of the Bang Pakong drainage system, Chachoengsao Province.

Provenance in site: L10, 2.

[1]The first figure refers to the layer, the second to the number of specimens found within it

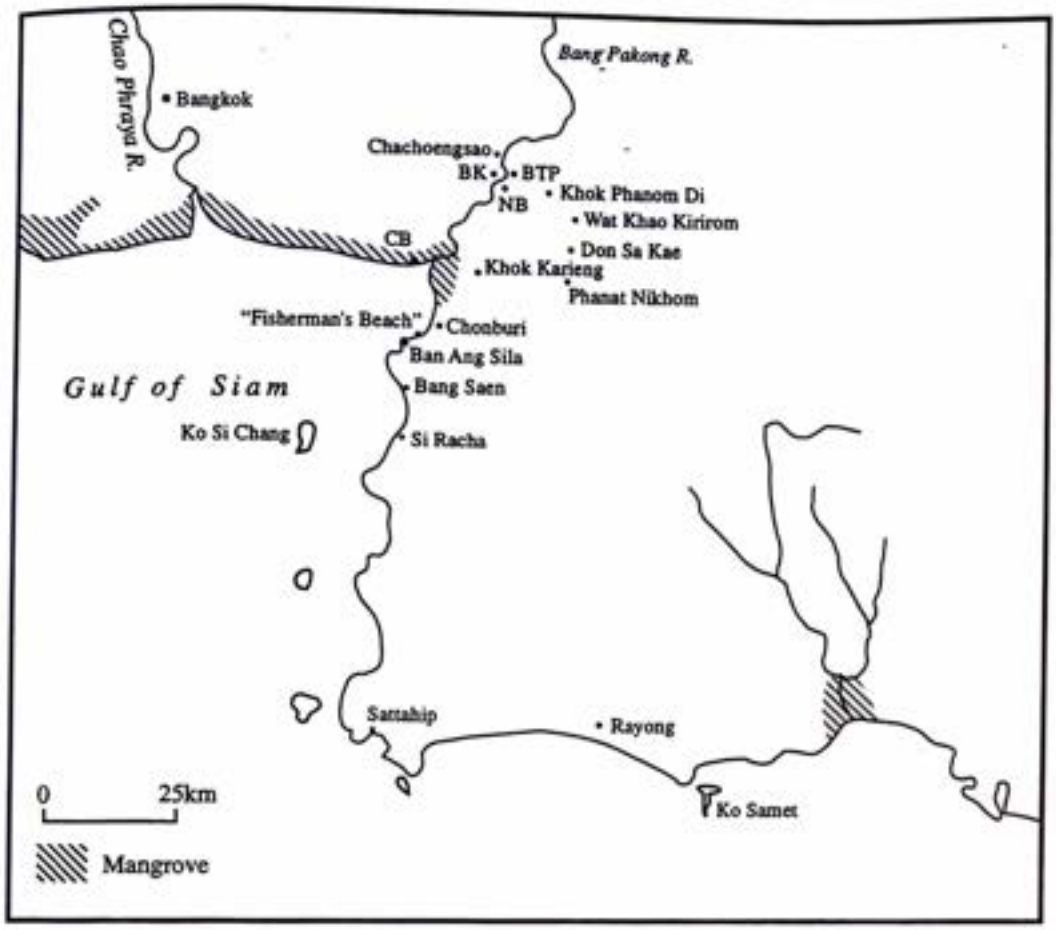


FIG. 55. Map showing modern collecting sites for comparative samples of shellfish. BK and NB are field names for otherwise unnamed localities close to the Bang Pakong River. BTP= Ban Ta Plaap, a hamlet close to the Bang Pakong; CB, a field name for an unnamed locality in coastal mangal, now somewhat modified by aquaculturalists. "Fisherman's Beach", is a field name for a locality about 2–3 km northeast of Point Ang Sila. At low tide there are mudflats backed to landward by regenerating mangal cleared for an industrial estate

Stenothyra annandalei Brandt, 1968

Habitat/ecology: modern examples of this species are thus far known only from the type locality, a trench draining into the Prasae River, Rayong Province. In the dry season the water is brackish, but virtually fresh during the monsoon rains.

Range: as above.

Provenance in site: L10, 8; L9, 13; L8, 13; L7, 1; L6, 2; L4, 1.

Stenothyra glabrata (A. Adams, 1851)

Habitat/ecology: intertidal brackish water creeks.

Range: coastal Thailand, Malaysia, Java and Sumatra.
Provenance in site: L10, 67; L9, 191; L8, 81; L7, 31; L6, 33; L5, 6; L4, 2.

Stenothyra hardouini Morgan, 1885

Habitat/ecology: tidal reaches of rivers.
Range: Penang Island and Ranong Province.
Provenance in site: L9, 2; L8, 1; L7, 0; L6, 1.

Stenothyra krungtepensis Brandt, 1968

Habitat/ecology: brackish, tidally-influenced canals.
Range: canals in and about Bangkok, also in Thonburi, Ayutthaya and Nakon Pathom provinces.
Provenance in site: L10, 261; L9, 152; L8, 62; L7, 30; L6, 14; L5, 4; L4, 1.

Stenothyra maculata Brandt, 1974

Habitat/ecology: brackish water canals.
Range: Tarua Khlung, Chantaburi Province and also Narathiwat Province (southern Thailand).
Provenance in site: L10, 3; L9, 0; L8, 1; L7, 0; L6, 1.

Stenothyra monilifera (Benson, 1856)

Habitat/ecology: this species lives in brackish water runnels on mudflats associated with mangal. They eat organic detritus found in and on the mud.
Range: all coastal areas of Thailand. Known also from Burma, Malaysia, Indonesia and southern Vietnam.
Provenance in site: L9, 2.

Stenothyra polita (A. Adams, 1851)

Synonyms: this species was originally placed in *Nematura*. *S. quadrasi* Moellendorf, 1895 is a synonym.
Habitat/ecology: common on mudflats and mangal on both the Gulf and Indian Ocean coasts of Thailand.
Range: Thailand, Malaysia, Indonesia and the Philippines.
Provenance in site: L10, 1; L9, 1; L8, 4; L7, 0; L6, 1.

Stenothyra spp.

Note: here is included all unidentifiable juvenile or damaged material.
Provenance in site: L10, 18; L9, 12; L8, 8; L7, 3; L6, 1; L5, 2.

IRAVADIIDAE

This family of marine and brackish water snails, found mainly in South and South-East Asia, Indonesia, northern Australia and Japan, contains about 13 genus-group taxa of which only two, *Iravadia* and its subgenus *Fairbankia* are recorded from Thailand. Members of this family have subulate (tall and slender) shells and less than 15 mm long. The Thai species inhabit mangal and nipa intertidal and subtidal mudflats of marine and estuarine aspect. They are microphagous detritus feeders. This interesting group is dealt with by Brandt (1974) and Ponder (1984, 1988).

Iravadia (Fairbankia) cochinchinensis (Bavay et Dautzenberg, 1910)

Habitat/ecology: commonly found in drainage channels on mangal and nipa mudflats.

Range: Surat Thani and Samut Prakan provinces of Thailand and extralimitally from southern Vietnam and peninsular Malaysia.

Provenance in site: L10, 4; L9, 20; L8, 41; L7, 4; L6, 15; L5, 1.

Iravadia reticulata Brandt, 1968

Habitat/ecology: this species is to be found in the drainage channels of brackish water mudflats associated with mangal and nipa palm swamps where they live, partly submerged in mud, eating organic detritus.

Range: presently known from Rayong, Chonburi, Chantaburi, Trat, Samut Prackan, Ranong and Krabi provinces. It may also be present in Burma and Malaysia.

Provenance in site: L7, 1; L6, 1.

ASSIMINEIDAE

This family of about 40 genus-group taxa falls into two subfamilies, the Assimineinae which are found in marine, brackish, and fresh waters and the Omphalotropinae, a terrestrial group tending to live in damp places. The shells are generally less than 10 mm tall, with convex whorls, well rounded and somewhat smooth.

Assiminea brevicula (Pfeiffer, 1854)

Synonyms: *Hydrocena marginata* Morelet, 1865; *Assiminea pinguis* von Martens, 1866; *Assiminea rubella* Blanford, 1867.

Habitat/ecology: widely distributed in mangrove and nipa palm swamps of varying degrees of salinity.

Range: throughout coastal Thailand, India, Burma, Malaysia, Indonesia, China and Taiwan.

Provenance in site: L10, 11; L9, 16; L8, 9; L6, 3.

Assiminea microsculpta Nevill, 1880

Habitat/ecology: unknown, but most likely riverine mudflats in nearly fresh water.

Range: in Thailand known from Rayong, Trat, Ranong, Trang and Satun provinces: otherwise from the Gulf of Bengal, Malaysia, Java and Sumatra.

Provenance within site: L 6, 1.

Assiminea nitida (Pease, 1865)

Synonyms: *Hydrocena nitida* Pease, 1865; *Syncera nitida* of Abbott 1949. Many subspecies and races have been named, but are not listed here.

Habitat/ecology: these animals are to be found adhering to the undersides of stones, logs and branches where they feed apon decaying vegetation and microbial slimes. Mangal and nipa palm mudflats in coastal areas are their preferred habitat.

Range: common on both the Indian Ocean and Gulf coasts of Thailand and elsewhere extend widely into the eastern Indian and western Pacific oceans. In the latter, they reach Hong Kong to the north and the Philippines to the south.

Provenance in site: L10, 84; L9, 16; L8, 9; L 6, 3.

Assiminea philippinica O. Boettger, 1887

Synonyms: *A. australis* Petterd, 1889 and *Assiminea philippinica lirocincta* O. Boettger, 1893. Habitat/ecology: lives on mudflats and in muddy brackish-water creeks where it feeds on decaying organic material.

Range: southern Thailand, Philippines, Java and possibly Tasmania. Provenance within site: L8, 1.

Assiminea woodmasoniana Nevill, 1880

Synonym: *Syncera woodmasoniana* of van Benthem-Jutting, 1956.

Habitat/ecology: lives on mudflats under nipa palms and mangal vegetation.

Range: in Thailand, all coastal areas of the Gulf and Indian Ocean shores and extralimitaly extends from the Gulf of Bengal to Sumatra and Malaysia.

Provenance in site: L10, 16; L9, 3; L8, 1.

Assiminea zilchi Brandt, 1974

Habitat/ecology: living in a coastal canal in brackish water.

Range: known only from the type locality near Ban Klong Sun, Trat Province.
Provenance in site: L10 B 143, 1.

Assiminea spp.

Included here are unidentifiable juveniles and mature specimens which are weathered or otherwise damaged to preclude specific identification.

Provenance in site: L10, 9; L9, 2; L6, 2.

Paludinella kuiperi Brandt, 1974

Habitat/ecology: brackish, riverine grass/reed swamp.

Range: modern examples are known only from the type locality, a swamp on the Bang Pakong at the Highway Three Bridge.

Provenance in site: L10, 3; L9, 1; L8, 1; L6, 1.

TORNIDAE

This family of cosmopolitan, predominantly marine snails have thin, trochoidal depressed shells that are usually of few whorls and a wide umbilicus. Of the twelve genera relegated to this family, only two, (*Chamlongia*, endemic to Thailand and *Phaneta*), are found in brackish water.

Chamlongia harinasutai Brandt, 1968

Habitat/ecology: found in brackish water trenches and creeks in estuarine areas.

Range: endemic to Thailand: known from Chantaburi and Rayong provinces and is thought by Brandt (1974:159) to probably occur at other localities in the Gulf of Thailand.

Provenance in site: L10, 6.

THIARIDAE

A family of essentially freshwater snails with a few representatives in brackish water. About 20 genera are found in southern Europe, Africa, South and South-East Asia, South America and some Pacific islands. Reproduction is almost completely parthenogenic, functional males being found in very few species. The widespread distribution of many species, their ability to occupy a great range of habitats and their reproductive mode has led to a large number of species names. Under *Melania* alone, between 1850-1870 some 650 epithets were introduced (Morrison 1954, Solem *et al.* 1982, Ruhoff 1980).

Melanoides tuberculata (O. F. Müller, 1774)

Synonyms: This highly polymorphic, widely distributed species has received a large number of names, about 35 of which are listed by Brandt (1974:165-6). The interested reader should consult this list. Many of the references to *Melania* sp. in the older archaeological literature of the South-East asian region would appear to relate to this species.

Habitat/ecology: it is to be found in lakes, streams, rivers and mountain torrents, but appears to prefer slightly brackish water and may be locally very abundant in tidal areas. This snail appears to be an unselective deposit feeder. Its parthenogenic habit allows it to colonize new areas of suitable habitat with quite remarkable speed.

Range: from southern Europe through Africa and Asia, to the West Pacific islands and Australia. It is common throughout Thailand.

Note: This, and closely related "melanian" species were widely and frequently eaten. The adult shell may reach about 40 mm. The animal is removed by breaking off the top of the spire and then sucking on the apperture.

Provenance in site: L10, 51; L9, 11; L8, 11; L7, 5; L6, 15; L5, 2.

Sermyla riqueti (Grateloup, 1840)

Synonyms: *Melania harpula* Dunker, 1844; *M. semicostata* Philippi, 1847; and *M. tornatella* Lea, 1850.

Habitat/ecology: this species prefers brackish water or estuarine areas under tidal influence over a muddy to sandy substrate.

Range: coasts throughout the Indian and Western Pacific oceans. Found in virtually all Thai river estuaries.

Provenance in site: L10, 6; L6, 2.

PYRAMIDELLIDAE

A large, cosmopolitan family of generally small, parasitic gastropods. They are hermaphrodite and are to be found in marine and, very rarely, brackish waters. The family is second in size only to the Turridae, containing thousands of species to which have been applied some 370 generic names.

Morrisonietta krungtepensis Brandt, 1968

Habitat/ecology: tidal canals and mudflats with brackish water.

Range: canals in and about Bangkok and the Rayong, Thonburi, and Surat Thani provinces.

Provenance in site: L10, 6; L9, 4; L8, 1; L4, 1.

Morrisonietta siamensis Brandt, 1968

Habitat/ecology: tidal canals and mudflats with brackish water.

Range: *klongs* in Rayong and Chantaburi provinces.

Provenance in site: L10, 5; L8, 1.

Morrisonietta sp.

Habitat/ecology: probably tidal canals and mudflats with brackish water.

Range: unknown.

Note: This may be either an undescribed member of this genus or a species wrongly placed in one of the other numerous related genera.

ACTEONIDAE

Acteocina sp.

Habitat/ecology: This marine opisthobranch gastropod genus has species found on coastal mangal mudflats in Malaysia, Vietnam and southern China.

Range: tropical Indo-West Pacific Ocean.

Provenance in site: L10, 1.

HAMINEIDAE

"Atys" sp.

Habitat/ecology: As with the previous species, this opisthobranch is also known from similar mudflats through the same geographic area.

Range: tropical Indo-West Pacific Ocean.

Provenance in site: L10, 1.

AURICULIDAE

This cosmopolitan group of primitive pulmonates contains about 30 genera whose members are typically to be found in a maritime setting near high tide or in reach of spring high tides. These animals appear to be mainly vegetarian, grazing micro-algae and eating organic detritus (Morton 1955a, 1955b).

Ellobium aurisjudae Linnaeus, 1758

These juvenile specimens somewhat resemble *Cylindrotis*, but a growth series clearly shows them to be *Ellobium aurisjudae*.

Habitat/ecology: Typical of the genus, they are found in coastal mangal and raised areas in nipa groves.

Range: Westward to Africa from the western Pacific. Provenance in site: L10, 66; L8, 1.

Laemodonta punctigera (H. & A. Adams, 1853)

Synonyms: *Plecotrema punctigera/um* auctt.; *Plecotrema imperforatum* H. & A. Adams, 1853.

Habitat/ecology: common on mudflats associated mangal and nipa palm swamps.

Range: ubiquitous throughout coastal Thailand with appropriate habitat, and extralimitaly known from all countries margining the Indian Ocean, the coasts of mainland and island South-East Asia and the South China Sea.

Provenance in site: L10, 1; L9, 1.

Laemodonta siamensis (Morelet, 1875)

Synonym: formerly placed in *Plecotrema* H. & A. Adams, 1853, a junior synonym of *Laemodonta* Philippi, 1846.

Habitat/ecology: estuarine mudflats under mangal.

Range: in Thailand from the coasts of Chantaburi, Rayong, Chonburi and Trat provinces; elsewhere known from Malaysia, Indonesia and the Philippines.

Provenance in site: L10, 1; L9, 1.

Melampus nucleolus von Martens, 1865.

Habitat/ecology: coastal, but precise setting unknown.

Range: in Thailand, Trang Province; elsewhere in New Guinea and the Philippines.

Provenance in site: L10, 4; L9, 1; L6, 1; L5, 1.

Melampus siamensis von Martens, 1865

Habitat/ecology: on mudflats under brackish water coastal mangal.

Range: in Thailand known only from Petchburi Province; elsewhere, from numerous Indo-West Pacific coastal localities.

Provenance in site: L10, 16; L9, 14; L8, 9; L7, 4; L6, 3; L5, 1.

PLANORBIDAE

This family of "rams horn snails" is virtually cosmopolitan in fresh water and its ranks include many important disease (especially schistosome) vectors. The generally small shells are usually planispiral or discoidal, with a few that are high spired, even scalariform.

Gyraulus hubendicki Brandt, 1974

Habitat/ecology: known from a coastal, brackish-water ditch.
Range: found only at the type locality in Satun Province, southern Thailand.
Provenance in site: L10, 3; L9, 9; L8, 1.

ACHATINELLIDAE

This family of generally 1–3 mm-sized land snails contains about 43 genus-group taxa largely confined to the western and central Pacific islands, South-East Asia and Japan. The group is primitive.

Tornatellinops sp.

Range: Japan, South-East Asia, Pacific Islands.
Habitat/ecology: modern examples of this species were collected in cut-over mangal on the coast northwest of the Bang Pakong River mouth.
Provenance in site: L10, 3.

PUPILLOIDEA

This superfamily is generally held to contain six families of hermaphroditic oviviparous and vipiparous land snails. All the families have Euro-Asian representatives. Some, such as the Pupillidae are large, with over 500 species.

Pupilloid sp.

Details beyond its broad classification are unkown. Not seen by the author in recent collecting.
Provenance in site: L10, 1.

VERTIGINIDAE

This member of the superfamily Pupilloidea comprises minute, oval to compact cylindrical shells generally less than 5 mm long. The shell aperture generally has dentate or lamellar barriers to deter micropredators. The family has numerous species, all terrestrial, most of which are ground-dwelling. Members of the subfamily Truncatellinae (treated by some as a full family, see Vaught 1989:80), were not recovered from the site, but are known from the Gulf of Siam area (see check-list). While this is negative evidence, there is no other indication of an *Ipomoea pes-caprae* coastal vegetation association, but *Truncatella* sp. is present in modern, non-mangal non-muddy coastal areas.

Gastrocopta sp.

Habitat and ecology: modern collections were made at Wat Khao Kirirom under deciduous scrub and small trees. It appeared to be ground dwelling.

Range: unknown

Provenance in site: L10, 1.

SUBULINIDAE

This family of pulmonate land snails are generally from millimetre to centimetre sized and tend to have tall, narrow shells. A number of species are markedly synanthropic, with *Subulina octona* (Bruguière, 1792) from tropical America having been distributed around the world through commerce. There are some 1300 nominal species within 70 genera.

Bacillum sp.

Range: throughout Indonesia.

Habitat and ecology: beyond being terrestrial, probably ground dwelling, unknown. No modern examples have been collected by the author.

Provenance in site: L8, 1; L7, 5; L6, 41; L5, 269; L4, 1093.

Paropeas achatinaceum (Pfeiffer, 1846)

Synonyms: The most important synonyms are: *Bulimus achatinaceus* Pfeiffer, 1846); *Achatina javanica* Reeve, 1849; *Opeas javanica* (Reeve, 1849); *Bulimus decoratus* Reeve, 1849 and *Stenogyra discernabilis* Martens, 1896. The genus *Prosopeas* has long been used, but Naggs (1994) shows that it should be placed in *Paropeas* independently of the former.

Range: this species is one of a group of subulinid synanthropic colonizers which includes *Subulina striatella* (Rang, 1847), *Subulina octona* (Bruguière, 1792), *Opeas pumilum* (Pfeiffer, 1840) and *Allopeas gracile* (Hutton, 1834), all of which have become widespread. *P. achatinaceum* is now widely distributed around the Indo-Pacific region. Most of these species are discussed by Solem (1988:520-30).

Habitat and ecology: this species appears to be confined to disturbed habitats with damp hollows in well-drained, tree-shaded areas near human habitation. Domestic gardens in Phanat Nikhom appear to be commonly infested with this species, which Naggs (1994) describes as a predatious micro-carnivore.

Provenance in site: L9, 4; L8, 6; L7, 35; L6, 173; L5, 416.

Pupisoma sp.

Habitat and ecology: an arboreal snail, ubiquitously present on domestic trees and shrubs, nipa palms (both coastal and inland), dry dipterocarp scrub and coastal mangal.

Range: Western Pacific and South-East Asia.

Provenance in site: L. 10, 13; L9, 4; L6, 1; L5, 13; L4, 40; L1, 1.

Vertiginid sp.

Habitat and ecology: this species was collected as dead shells on Ko Si Chang from a well drained, sunny hillside under closed canopy broad-leaved scrub.

Provenance in site: L4, 1.

BULIMINIDAE (ENIDAE)

This family of land snails, widely distributed in Asia, Europe and Africa, contains about 80 genera of dextral (sometimes sinistral) species generally less than 10 mm in size. The shell aperture usually bears columellar plates and apertural barriers. In outline, the shells are broadly conical to sub-cylindrical.

Buliminid sp.

Habitat and ecology: dry shells of this species have been collected by the author at the Khok Karieng and Khok Phanom Di mounds. An account of the vegetation of the latter is to be found in Maloney 1991:28-9 and Thompson, this volume. The vegetation of Khok Karieng is essentially similar. Both mounds are well drained and have areas of closed canopy deciduous trees and varying amounts of scrub understorey.

Range: unknown.

Provenance in site: L6, 2; L5, 5; L4, 21.

ACHATINOIDEA

Achatinoid sp.

This may be a subulinid, but differs from those listed above in many minor shell characteristics.

Habitat and ecology: this snail is probably still living on the Khok Phanom Di mound and is found under deciduous trees and thorny scrub on sunny, well-drained slopes.

Provenance in site: L10, 1; L9, 1; L8, 1, L7, 3; L6, 27; L5, 177; L4, 396.

HELIXARIONIDAE

This large family of over 150 genera has shells of variable shape but not infrequently discoidal. These land snails range in size from a few millimetres to over 130 mm.

? *Geotrochus* sp.

Range: this genus appears to be confined to Sulawesi, Java, Malaysia and New Guinea.

Habitat and ecology: shells of this animal were found in a modern collection from Khok Phanom Di, and may be living in or on bamboo thickets.

Provenance in site: L6, 1; L5, 6; L4, 4.

ARIOPHANTIDAE

This predominantly tropical family of land snails is found mainly in east and South-East Asia. Shell size and shape are variable.

Macrochlamys sp.

Habitat and ecology: present day populations are found on the low, well-drained scrub-covered mounds of Khok Karieng, Khok Phanom Di and Khao Kirirom on the East Bangkok Plain. They were also present on elevated, well-drained gardens in Phanat Nikhom and an abandoned garden on Kho Si Chang. It was terrestrial in all cases, living in hollows under damp vegetation. It is thought to be a carnivorous predator. There are extra limital records of burrowing in hot, dry weather.

Range: South, East and South-East Asia, including the Philippines and Indonesia.

Provenance in site: L9, 2; L8, 4; L7, 3; L6, 24; L5, 105; L4, 162.

ZONITIDAE

Members of this land snail family generally have a helicoid low-spired shell that is both shiny and transparent (vitreous). Most species are holarctic-nearctic in distribution. The family appears not to have been previously recorded from Thailand.

? Zonitid sp.

If the species is indeed a zonitid (and apparently close to *Oxychilus*), this would be a range extension for the family.

Habitat and ecology: This species has been collected from the modern Khok Phanom Di mound and Khao Sam Mook, both under deciduous trees and shrubs on dry, well-drained soil. It was also collected from Ko Si Chang in a similar setting.

Provenance in site: L11, 1; L10, 4; L9, 7; L8, 7; L7, 11; L6, 64; L5, 322; L4, 143; L3, 3; L2, 4; L1, 2.

STYLOMMATOPHORA

Pulmonid species A

Habitat and ecology: This species was found in a modern leaf litter collection from the Khok Karieng and Khok Phanom Di mounds, thus suggesting that it enjoys dry, well-drained conditions under deciduous trees and shrubs.

Provenance in site: L6, 2; L5, 5; L4, 27.

Pulmonid species B

Habitat and ecology: this species was found in a modern leaf litter collection on the sunny side of the Khok Phanom Di mound under thorny scrub and acacia trees.

Provenance in site: L6, 1; L5, 13; L4, 27.

LAND SNAIL EGGS

These eggs appear to be compatible in their characteristics with those described for *Paropeas achatinaceum* by Naggs, 1994. If not of this species, they are almost certainly from the family Subulinidae.

Provenance in site: L8, 1; L7, 1; L6, 26; L5, 76; L4, 652.

FIG. 56. The distribution of brackish/freshwater species and terrestrial snails against time. The number of species per excavation unit is shown on the vertical axis and the excavation units from the bottom (on left) to the top of the site on the horizonal axis. The points are a rolling mean over five cells, rounded to the nearest integer (except zero)

THE DISTRIBUTION OF SPECIES

Brackish/freshwater taxa

Figure 56 shows the presence of six to seven species for most of layer 10, but with a dip to three species at the top of the layer and the base of layer 9, followed by a rapid climb to a climax of ten species per excavation unit. It is unfortunate that the aquatic micromolluscs are dominated by two genera (*Stenothyra* and *Assiminea*) whose numerous species have very broad salinity tolerances, ranging in some cases from intertidal mudflats (*Stenothyra polita*) to nearly completely fresh, but tidally affected water (*Stenothyra acuta*) . Most of the species run, with greater or lesser intermittancy, through the thickness of the site to mid layer 3. Their decline from about mid layer 4 is due to increasing leaching of the upper layers not protected by massive middens controlling soil pH. Large shell species suffered the same fate (Mason 1991). The most conservative interpretation of this distribution curve is that tidal estuarine/riverine waters were accessible close to the site until layer 8 times. This is based on the assumption that the bulk of the aquatic microgastropods have

been imported onto the site via fish guts. Of the fish mentioned by Kijngam (1991:223-29) *Plotosus canius* Hamilton, 1822 almost certainly includes *P. lineatus*, (Thunberg, 1791) which is recorded by Cantor (1849:1247) as eating small estuarine molluscs. Both species are listed as inhabiting the sea, estuaries and to some extent, fresh water. *Anabas testudineus* (Bloch, 1792) is noted by Smith (1945:448) as consuming snails, shrimps and insects. Not mentioned by Kijngam (l.c.) are pomasids, noted by Suvatti (1981) as inhabiting the Bang Pakong estuary. At least one species of these fish (and probably most) eat small molluscs. Cantor (1849:1061) recorded a specimen of *Plectorhinus balteanus* (Kuhl & van Hasselt, 1820) as having a gut full of minute shells. The other constant source of small aquatic shells, particularly *Clenchiella microscopica* and *Gyraulus hubendicki* is comestible plants from streams, canals and ponds. This may explain why these two species so abundant in nature are so sparcely and sporadically present in the site. In the light of these remarks, perhaps the presence pattern of the aquatic micromolluscs reflects fishing effort rather than the nature of the circumjacent landscape. However, this view must be tempered by the general concordance of figure 56 with figures 73 and 74 in Mason (1991:318-9) showing the estuarine and fresh water environments respectively. As different species sets are used, the close coincidence of the graphs is not likely to be purely fortuitous.

Terrestrial species

A comparison between figure 56 with figure 75 of Mason (1991:319) shows the same general profile: a long flat line from layer 11 to upper layer 7 representing one to two or zero species respectively, then a steady climb to a maximum of ten species in mid layer 4 and a rapid decline to a single species from mid layer 3 onwards. The small (often sub-millimetre sized) snail, dubiously identified as a zonitid, is unlikely to be coeval with the sediments from which it is apparently associated. Wind-blown dust from the present-day surface of the site where it is known to be living is a more plausible source for some of these very fresh shells, including some from near the base of the site. The author feels no need to invoke Plugg's (1990) observations on burrowing land snails to explain these anomalies. In detail, the earliest part of the site until mid layer 9 has on average one snail species per excavation unit. This presence is usually one or other of either *Pupisoma* sp. or the putative zonitid both of which are in modern times ubiquitous from the coast to inland areas. *Tornatellinops* sp., a mangal species is present, with *Ellobium aurisjudae* juveniles, during this period of time, suggesting strongly that the site was then surrounded by mangal. The more or less sustained increase to two landsnail species per excavation unit from mid layer 9 to the base of layer 6 appears to be due to the presence of *Paropeas* sp., a frequenter of horticulturally disturbed ground. Its incursion may indicate no more than the arrival of a new herbaceous (non-rice) cultivar in gardens on the site, rather than any profound environmental change. The rapid rise in the number of landsnail species from upper layer 7 to mid layer 4, coupled with a concommitant overall drop in non-marine aquatic species does suggest significant environmental change. The changes seen here are in full accord with those reported earlier and only serve to reinforce the conclusions already drawn that there was a somewhat abrupt change in the landscape which permitted the site to be invaded by dry-footed land snails and simultaneously reduced the number of estuarine/freshwater gastropods being brought on to the site.

SUMMARY

The new information from the micromolluscs treated in this report, coupled with the habitat data afforded by collections of modern material (presented in table 49) is in complete agreement with, and reinforce, the conclusions reached in Mason (1991:314, Thompson this volume, Kealhofer and Piperno this volume) that at first occupation the site was set in mangal behind open coast mudflats and adjacent to a major estuary. With the passage of time, the seaward mangal species fall away probably due to coastal progradation by predominantly muddy sediments. Freshwater species are more in evidence at this stage, followed by the abrupt increase in terrestrial species. This latter influx is thought to denote a major environmental event such as a flood revision of the Bang Pakong River or a seismo-tectonic event that altered local land drainage patterns leading to the eventual abandonment of the Khok Phanom Di site.

MODERN MARINE COLLECTIONS

Ten coastal sites in the Chonburi and Rayong provinces were collected as opportunity arose during fieldwork at the Nong Nor site (1990-93). Most material was collected dead from beaches, the predominant habitat (scored out of 10) is shown in table 48.

TABLE 49: *List of species with collecting localities*

Family and species	1	2	3	4	5	6	7	8	9	10	11
Haliotidae											
Fissurellidae											
Diodora sp.	-	•	-	-	-	-	•	-	-	-	-
Acmeidae											
Patellidae											
patellid sp. 2	-	•	-	•	-	•	•	-	-	-	-
Trochidae											
Monilea callifera	-	•	-	-	•	-	-	-	-	•	-
Chrysostoma paradoxum	-	-	-	-	-	-	•	-	•	-	-
Minolia sp.	-	•	-	•	-	-	-	-	-	•	-
trochid sp. 8	-	-	-	-	-	•	•	-	-	-	-
Stomatellidae											
Turbinidae											
Angari delphinium	-	-	-	-	-	-	•	-	•	-	-
Neritidae											
N. articulata	•	-	-	-	-	-	-	-	-	-	-
N. undata	-	-	-	-	-	•	-	-	-	-	-
Theodoxus oualanensis	-	•	-	•	-	•	•	-	-	•	-
Littorinidae											
L. undulata	•	•	-	•	-	•	•	-	-	-	-
Peasiella sp.	-	-	-	•	-	•	•	-	-	-	-
Truncatellidae											
Stenothyridae											
Iravadiidae											
Rissoidae											
Manzonia sp.	-	-	-	•	-	-	-	-	-	-	-
Rissoina sp.	-	-	-	-	-	-	-	-	-	-	-
Caecidae											
Vitrinellidae											
Pseudoliotia sp. 2	-	-	-	-	-	-	-	-	-	-	-
Tornidae											
Thiaridae											
Melanoides tuberculata	•	•	-	-	-	-	-	-	-	-	-
Planaxidae											
Planaxis sulcata	-	•	-	•	•	•	•	-	•	•	-
Cerithidae											
Rhinoclavis sinensis	-	-	-	-	-	-	•	-	•	-	-
Clypeomorus bifasciata	-	-	-	-	•	•	•	-	•	-	-
Bittium craticulum	-	-	-	-	-	•	-	-	-	-	-
Scaliolidae											
Potamididae											
Cerithidea cingulata	•	-	-	-	-	-	-	•	-	-	-
Telescopium telescopium	•	-	-	-	-	-	-	-	-	-	-
potamidid sp. 4	-	-	-	-	-	-	-	-	-	•	-
potamidid sp. 6	-	-	-	•	-	•	•	-	-	-	-
Fossariidae											
'*Fossarus*' sp. 2	-	-	-	-	-	•	-	-	-	-	-
Turritellidae											
Siliquaridae											
Vermetidae											
Vanikoridae											
Strombidae											
S. variabilis	-	•	-	•	-	-	-	-	-	•	-
S. marginatus	-	-	-	-	-	-	-	-	-	•	-
S. ?digitatus	-	-	-	-	-	-	-	-	•	-	-

Species	1	2	3	4	5	6	7	8	9	10	11
Haliotis ovina	-	-	-	-	-	-	-	-	•	-	-
Diodora mus	-	•	-	•	-	•	•	-	-	•	-
'*Acmea*' sp.	-	•	-	•	-	-	•	-	-	-	-
patellid sp. 1	-	-	-	-	-	•	•	-	-	•	-
Monodonta labio	-	-	-	•	•	•	•	-	•	•	-
Trochus maculatus	-	-	-	-	-	•	•	-	•	•	-
Granata sp.	-	-	-	-	-	-	•	-	-	-	-
Umbonium vestiarum	-	•	-	-	-	-	•	-	-	•	-
trochid sp. 9	-	•	-	-	-	-	-	-	-	-	-
?Stomatolina sp.	-	-	-	•	-	-	-	-	-	-	-
Turbo argyrostoma	-	-	-	-	-	-	•	-	•	•	-
Gabrielona sp.	-	-	-	-	-	-	-	-	-	-	-
Nerita albicilla	•	•	•	•	•	•	•	-	•	•	-
N. polita	-	-	-	-	-	•	-	-	•	-	-
Neritina violacea	•	-	-	-	-	-	-	-	-	-	-
Littoraria melanostoma	•	-	-	-	-	-	-	-	-	-	-
Nodilittorina pyramidalis	-	•	-	•	-	•	•	-	-	•	-
Truncatella sp.	-	-	-	-	•	•	-	-	-	-	-
Stenothyra annandalei	•	•	-	-	-	-	-	-	-	-	-
Iravadia reticulata	•	-	•	-	-	-	-	-	-	-	-
Rissolina costulata	-	-	-	-	-	-	•	-	-	-	-
Phosinella fusca	-	-	-	-	-	•	•	-	-	•	-
Rissoid sp. 5	-	-	-	-	-	-	-	-	-	-	-
Caecum glabellum	-	•	-	-	-	-	-	-	-	-	-
Pseudoliotia pulchella	-	•	-	-	-	•	-	-	-	-	-
?Pygmaeorota sp.	-	•	-	•	-	-	-	-	-	-	-
Tarebia granifera	-	-	-	-	-	-	-	•	-	-	-
Sermyla riqueti	•	-	-	-	-	-	-	-	-	•	-
Angiola longispira	-	•	-	-	-	•	•	-	-	-	-
Cerithium columna	-	-	-	-	-	-	-	-	•	-	-
R. vertagus	-	-	-	-	-	-	•	-	-	-	•
C. batillaraeiformis	-	-	-	-	•	•	•	-	-	•	-
?Obtortio sp.	-	•	-	-	-	-	-	-	-	•	-
Terebralia palustris	•	-	-	-	-	-	-	-	-	-	-
C. obtusa	•	-	-	-	-	-	-	-	-	-	-
potamidid sp. 3	-	-	-	•	-	-	-	-	-	•	-
potamidid sp. 5	-	-	-	-	-	-	-	-	-	•	-
'*Fossarus*' sp. 1	-	-	-	-	-	•	-	-	-	-	-
Turritella terebra	-	-	-	•	•	-	-	-	-	•	-
Siliquaria anguina	-	-	-	-	-	•	-	-	-	-	-
Vermetus sp.	-	•	-	•	-	-	•	-	-	•	-
Vanikoro fenestrata	-	-	-	•	-	-	•	-	-	-	-
Strombus canarium	•	-	-	-	-	-	•	•	-	•	-
S. luhuanus	•	-	-	-	-	•	•	-	•	-	-
S. urceus	-	-	-	-	-	-	-	-	•	•	-

Collecting localities are: 1. Khok Phanom Di, 2. Bang Saen, 3. Fisherman's, 4. Si Racha gravel beach, 5. Si Racha sandy beach, 6. Kho Si Chang sandy beach, 7. Kho Si Chang rocky beach, 8. Ban Ang Sila, 9. Ko Samet, 10. Sattahip, 11. Chonburi clean sandy beach

Table 49 (cont.) *List of species with collecting localities*

Species	1	2	3	4	5	6	7	8	9	10	11
Calyptraeidae											
Calyptraea sp. 2	-	•	-	•	-	-	-	-	-	-	-
Cypraeidae											
C. errones	•	-	-	-	-	-	-	-	-	-	-
C. miliaris	•	-	-	-	-	-	-	-	-	-	-
C. arabica	-	-	-	-	-	-	-	-	•	-	-
C. cylindrica	-	-	-	-	-	-	•	-	•	-	-
Naticidae											
N. onca	-	-	-	-	-	-	•	-	-	•	-
Polinices cumingianus	•	-	-	-	-	-	-	-	-	-	-
P. tumidus	•	-	-	•	-	•	-	•	•	•	-
P. sp. 5	-	-	-	-	-	-	-	-	-	•	-
Eunaticina papilla	-	•	-	-	-	-	-	-	-	•	-
naticid sp. 11	-	-	-	-	-	•	-	-	-	-	-
Cassidae											
Bursidae											
Triphoridae											
Epitoniidae											
epitoniid sp. 2	-	-	•	-	•	-	-	•	-	-	-
Eulimidae											
Muricidae											
Naquetia capucina	•	-	-	-	-	-	•	-	-	-	-
Thaididae											
Th. hippocastanum	-	-	-	-	-	-	-	-	•	-	-
Th. tissoti	•	-	-	-	-	-	-	•	-	-	-
M. musiva	-	•	-	-	-	-	•	-	-	-	-
Buccinidae											
Cantharus af. *cecillei*	-	-	-	•	-	-	-	-	•	-	-
Columbellidae											
Zaphra sp. 1	-	-	-	•	-	•	-	-	-	-	-
columbellid sp. 4	-	-	-	-	-	-	•	-	-	-	-
Nassariidae											
N. livescens	•	•	•	•	-	•	-	-	-	•	-
N. pullus	•	•	-	-	-	-	-	•	-	-	-
Hebra corticata	-	-	-	•	-	-	-	-	-	-	-
Melongenidae											
Hemifusus ternatanus	•	-	•	-	-	-	-	-	•	-	-
Volutidae											
Olividae											
Mitridae											
M. columbelliformis	-	-	-	-	-	•	-	-	-	-	-
Costellariidae											
Vexillum amanda	-	-	-	-	-	-	-	-	-	•	-
Cancellariidae											
Conidae											
C. cattus	-	-	-	-	-	-	-	-	•	-	-
C. textile	-	-	-	-	-	-	-	-	•	-	-
Turridae											
Eucithara crassilabrum	-	-	-	-	-	-	-	-	-	•	-
Kermia sp.	-	•	-	•	-	-	-	-	-	-	-
turrid sp. 6	-	-	-	•	-	-	-	-	-	-	-
turrid sp. 8	-	-	-	-	-	-	-	-	-	•	-
Terebridae											
Terebra columellaris	-	-	-	-	-	-	-	-	-	•	-
Architectonicidae											

Species	1	2	3	4	5	6	7	8	9	10	11
Calyptraea extinctorum	-	•	-	•	-	-	-	•	-	•	-
Crepidula walshi	•	•	•	•	-	-	-	-	-	-	-
Cypraea asellus	-	-	-	-	-	-	-	-	•	-	-
C. helvola	•	-	-	-	-	-	-	-	-	-	-
C. onyx	•	-	-	-	-	-	-	-	-	-	-
C. gracilis	-	-	-	-	-	-	-	-	•	-	-
C. walkeri	-	-	-	-	-	-	-	-	-	•	-
Natica tigrina	•	•	-	•	-	-	•	•	-	-	-
N. sp. 3	-	•	-	-	-	-	-	-	-	•	-
P. didyma	•	-	-	•	-	-	-	•	-	-	-
P. sp. 4	-	•	-	-	-	-	-	-	-	-	-
Sinum sp.	-	-	-	•	-	-	-	-	-	-	-
cassid sp.	-	•	-	-	-	-	-	-	-	-	-
Bursa rana	-	-	-	-	-	-	•	-	-	•	-
triphorid spp.	-	•	-	•	-	•	•	-	-	-	-
epitoniid sp. 1	-	•	-	•	-	-	•	-	-	-	-
Pictobalcis sp.	-	-	-	-	-	-	•	-	-	-	-
Murex trapa	-	-	•	•	-	-	•	-	-	-	-
N. brunneus	-	-	-	-	-	-	•	-	-	•	-
Thais mancinella	-	-	-	-	-	-	-	•	-	-	-
Th. carinifera	•	-	•	-	-	-	-	•	-	-	-
Morula ?funiculus	-	-	-	•	-	•	•	-	•	-	-
M. sp. 3	-	-	-	-	-	-	-	-	•	-	-
Babylonia areolata	-	-	-	-	-	-	-	•	-	-	-
C. undosus	-	-	-	-	-	-	-	-	•	-	-
Pyrene versicolor	-	-	-	-	-	•	•	-	-	•	-
columbellid sp. 3	-	-	-	•	-	-	-	-	-	-	-
columbellid sp. 5	-	-	-	•	-	•	-	-	-	-	-
Nassarius foveolatus	•	-	-	•	-	-	-	-	-	-	-
N. olivaceus	•	-	-	-	-	-	-	-	-	-	-
N. pauperatus	-	•	-	•	-	-	-	-	-	•	-
Pugilina cochlidium	-	-	•	-	-	•	•	•	-	-	-
Cymbiola nobilis	•	-	-	-	-	-	-	•	-	-	-
Oliva oliva	•	-	-	-	-	-	-	-	-	-	-
Mitra aurantia	-	-	-	-	-	-	-	-	•	-	-
M. rubiginosa Rve	-	-	-	-	-	-	-	-	-	•	-
Zierliana sp.	-	-	-	-	-	-	•	-	-	-	-
Scalptia crossei	•	•	-	•	-	-	-	-	-	-	-
Conus betulinus	•	-	-	-	-	-	-	-	-	-	-
C. coronatus	-	-	-	-	-	-	-	•	-	-	-
Turricula javana	•	•	-	-	-	-	-	-	-	-	-
Daphnella deluta	-	-	-	-	•	-	-	-	-	-	-
turrid sp. 5	-	-	-	•	-	-	-	-	-	-	-
turrid sp. 7	-	-	-	-	-	-	-	-	•	-	-
turrid sp. 9	-	•	-	-	-	-	-	-	-	-	-
Duplicaria duplicata	•	-	-	-	-	-	-	-	-	-	-
Architectonica perspectiva	•	-	•	-	-	-	-	-	-	-	-

Table 49 (cont.) *List of species with collecting localities*

Species	1	2	3	4	5	6	7	8	9	10	11
Pyramidellidae											
Mormula sp.	-	-	-	-	-	•	-	-	-	-	-
Babella sp. 1	-	-	-	•	-	-	-	-	-	-	-
Oscilla lirata	-	-	-	-	-	•	-	-	-	-	-
pyramidellid sp. 8	-	-	-	•	-	-	-	-	-	-	-
pyramidellid sp. 10	-	-	-	•	-	-	-	-	-	-	-
pyramidellid sp. 12	-	-	-	-	-	-	-	-	•	-	-
pyramidellid sp. 14	-	-	-	-	-	-	-	-	•	-	-
pyramidellid sp. 16	-	-	-	-	-	•	-	-	-	-	-
Amathinidae											
Ringiculidae											
Acteonidae											
Pupa sp.	-	-	-	-	-	-	•	-	-	-	-
Philinidae											
Hamineidae											
Aliculastrum cylindricus	-	-	-	-	-	-	-	-	•	-	-
Retusidae											
Retusa sp.	-	-	-	•	-	-	-	-	-	•	-
Acteocina sp.	-	-	-	•	-	-	-	-	-	-	-
Ellobiidae											
A. elongata	•	-	-	-	-	-	-	-	-	-	-
C. mustellina	•	-	-	-	-	-	-	•	-	-	-
E. aurismidae	•	-	-	-	-	-	-	-	-	-	-
L. typica	-	-	-	•	-	•	•	-	•	-	-
M. nucleolus	•	-	-	-	-	-	•	-	-	-	-
Siphonariidae											
Siphonaria ?javanica	-	-	-	-	-	-	•	-	-	-	-
Scaphopoda											
Cephalopoda: Sepiidae											
S. pharaonis	-	-	-	-	-	-	•	-	-	•	-
Bivalvia: Nuculanidae											
Arcidae											
A. nodifera	•	-	•	-	•	•	-	-	-	-	-
A. ?scapha	-	•	-	-	-	•	-	-	-	•	-
A. pilula	-	-	-	-	-	-	-	-	-	-	•
A. ?secticostata	•	-	-	-	-	-	-	-	-	-	-
A. sp. 10	-	-	-	-	-	-	•	-	-	•	-
B. velata	-	-	-	-	-	•	-	-	•	•	-
B. sp. 4	-	-	-	-	-	•	•	-	-	-	-
arcid sp. 16	-	•	-	•	•	-	-	-	-	-	-
arcid sp. 18	-	-	-	•	-	-	-	-	-	-	-
Noetiidae											
Arcopsis sp.	-	•	-	•	-	•	•	-	-	•	-
Mytilidae											
Modiolus metcalfei	-	-	-	-	-	-	-	-	-	•	-
Musculus sp. 1	-	-	•	•	-	-	•	-	-	-	-
Septifer bilocularis	-	-	-	-	-	•	•	-	•	•	-
Pteriidae											
Malleidae											
Vulsella vulsella	-	-	-	-	-	-	-	-	-	•	-
Isognomonidae											
'Isognomon' sp. 2	-	-	-	-	-	•	•	-	-	•	-
'Isognomon' sp. 4	-	-	-	•	-	•	•	-	-	-	-
Limidae											
Ostreidae											
ostreid sp.	•	-	-	-	-	•	-	•	-	•	-

Species	1	2	3	4	5	6	7	8	9	10	11
Pyrgulina sp.	-	-	-	•	-	•	-	-	-	-	-
Hinemoa indica	-	-	-	-	-	-	-	-	-	•	-
Af. *Babella* sp. 2	-	-	-	•	-	-	-	-	-	-	-
'Chemnitzia' sp.	-	-	-	•	-	-	-	-	-	-	-
pyramidellid sp. 9	-	-	-	•	-	-	-	-	-	-	-
pyramidellid sp. 11	-	-	-	•	-	-	-	-	-	-	-
pyramidellid sp. 13	-	-	-	-	-	-	-	-	•	-	-
pyramidellid sp. 15	-	•	-	-	-	-	-	-	-	-	-
pyramidellid sp. 17	-	-	-	-	-	-	•	-	-	-	-
Amathina tricarinata	-	-	-	•	-	•	-	-	-	•	-
Ringicula sp.	-	•	-	-	-	-	-	-	-	-	-
Pupa sulcata	-	-	-	-	-	-	-	-	-	•	-
acteonid sp. 3	-	-	-	-	-	-	-	-	•	-	-
philinid sp.	-	•	-	-	-	-	-	-	-	-	-
Atys naucum	-	-	-	-	-	-	-	-	•	-	-
Retusa (Decorifer) sp.	-	•	-	-	-	•	•	-	-	•	-
Rhizorus sp.	-	-	-	-	-	-	-	-	•	-	-
Auriculastra subula	•	-	-	-	-	-	-	-	-	-	-
Cassidula aurisfelis	•	-	-	-	-	-	-	-	-	-	-
Ellobium aurisjudae	•	-	-	-	-	-	-	-	-	-	-
Laemodonta siamensis	•	-	-	-	-	-	-	-	-	-	-
Melampus flavus	•	-	-	-	-	•	-	-	-	-	-
M. siamensis	-	-	-	-	-	•	•	-	-	-	-
Siphonaria laciniosa	-	•	-	•	-	•	•	•	-	-	-
S. sp. 3	-	•	•	•	-	•	-	-	-	-	-
Scaphopod spp.	-	-	-	•	-	•	•	•	-	-	-
Sepia aculeata	•	-	-	-	-	•	-	-	-	-	-
S. recurvirostra	•	•	-	•	•	-	-	-	-	•	-
Jupiteria ?cuspidata	•	-	•	•	•	•	•	•	-	•	-
Anadara granosa	•	-	•	-	•	•	-	•	-	-	-
A. uropygmelana	-	•	-	-	-	•	-	-	-	-	-
A. setigericosta	•	-	•	-	-	-	-	•	-	-	-
A. gubernaculum	-	•	-	-	-	-	•	-	-	-	-
A. ?velicata	-	-	-	-	-	-	-	-	•	-	-
Barbatia bicolorata	-	-	-	-	•	•	•	•	-	•	-
B. sp. 3	-	•	-	•	-	•	-	-	•	•	-
Arca navicularis	-	•	-	•	-	-	-	-	-	-	-
arcid sp. 17											
Scelidionarca pectunculiformis	•	-	-	-	-	-	-	-	-	-	-
Perna viridis	-	•	•	•	•	-	•	-	-	-	-
Modiolus sp. 2	-	-	-	-	-	-	-	-	-	-	-
Musculus sp. 2	-	-	-	•	-	-	-	-	-	•	-
mytilid sp. 8	-	-	-	-	-	-	•	-	-	-	-
Pinctada furcata	•	-	-	-	-	-	-	•	-	•	-
Malleus albus	-	-	-	-	-	•	•	-	•	-	-
'Isognomon' sp. 1	-	-	-	-	-	-	-	•	-	-	-
'Isognomon' sp. 3	-	-	-	-	-	-	•	-	-	-	-
Limaria sp.	-	-	-	-	-	-	-	-	-	•	-
Saccostrea cucullata	•	•	-	•	•	•	•	•	•	•	-

Table 49 (cont.) *List of species with collecting localities*

Species	1	2	3	4	5	6	7	8	9	10	11
Plicatulidae											
Pectinidae											
Propeamussiidae											
Spondylidae											
Spondylus versicolor	-	-	-	-	-	•	•	-	•	-	-
Spondylus sp. 4	•	-	-	-	-	-	-	-	-	-	-
Anomiidae											
Placunidae											
Lucinidae											
E. divergens	-	-	-	•	-	•	•	-	•	-	-
Pillucina striata	-	•	-	-	-	-	-	-	-	•	-
'Lucina' philippinarum	•	-	-	-	-	-	-	-	-	-	-
lucinid sp. 8	-	-	-	-	-	•	-	-	-	-	-
Montacutidae											
Barrimysia sp.	-	-	-	•	-	-	-	-	-	-	-
Carditidae											
Chamidae											
Chama reflexa	•	•	-	•	-	-	•	-	•	•	-
Crassitellidae											
Cardiidae											
T. alternatum	-	-	-	-	-	•	•	-	-	•	•
Papyridea levisulcatum	-	-	-	-	-	-	-	-	-	•	-
Lunulicardium retusa	-	-	-	-	-	-	-	-	-	-	•
Fragum fornicatum	-	-	-	-	-	-	-	-	-	-	•
Fragum sp. 3	-	-	-	-	-	-	-	-	-	•	-
Tridacnidae											
Mactridae											
M. crossei	-	•	•	-	-	-	-	-	-	-	-
Meropesta nicobarica	-	-	-	-	-	-	-	-	-	•	-
mactrid sp. 6	-	•	-	-	-	-	-	-	-	-	-
mactrid sp. 8	-	•	-	-	-	-	-	•	-	-	-
Mesodesmatidae											
Donacilla nitida	•	•	•	-	-	•	•	•	-	•	-
Solenidae											
Cultellidae											
Tellinidae											
Moerella sp.	-	•	•	-	-	-	-	•	-	•	-
T. virgata	-	-	-	-	-	-	-	-	-	•	-
T. ovalis	-	-	-	-	-	•	-	-	-	•	-
T. (Laciolina) sp.	-	-	-	•	-	-	-	-	-	-	-
tellinid sp. 10	-	-	-	•	-	-	-	-	-	-	-
Semelidae											
Psamobiidae											
Gari elongata	-	-	-	-	-	-	-	•	-	-	-
Donacidae											
Trapezium cf. *linatum*	-	•	-	•	-	-	-	-	•	-	-
Corbiculidae											
Veneridae											
Gafrarium dispar	-	-	-	-	-	-	-	-	•	-	-
G. tumidum	-	-	•	-	-	•	•	•	-	•	-
Anomalocardia squamosa	•	•	•	•	-	•	-	•	-	•	-
Clausinella gilva	•	-	•	-	-	•	•	•	-	-	-
Dosinia trailli	•	-	-	-	-	-	-	-	-	-	-
Pelecyora trigona	•	-	-	-	-	-	-	-	-	-	-
P. crassiuscula	-	-	-	-	-	-	-	•	-	-	-

Species	1	2	3	4	5	6	7	8	9	10	11
Plicatula sp.	-	-	•	•	-	-	-	-	-	•	-
Chlamys cf. *larvata*	-	-	-	•	-	-	-	-	-	•	-
Amussium pleuronectes	-	-	-	-	-	-	-	•	-	•	-
Spondylus squamosus	-	-	-	-	-	-	-	-	•	-	-
Spondylus sp. 3	-	-	-	-	-	-	-	-	-	•	-
Anomia sp.	•	-	-	-	-	-	-	-	-	-	-
Placuna sella	•	-	-	-	-	-	•	-	-	-	-
Epicodakia delicatula	-	-	-	-	-	-	-	-	-	•	-
Bellucina sp.	-	-	-	•	-	-	-	•	-	•	-
P. pisidium	-	•	-	-	-	-	-	•	-	•	-
Anodontia edentula	-	-	-	-	-	-	-	-	-	•	-
lucinid sp. 9	-	•	-	-	-	-	•	-	-	-	-
Curvemysella paula	-	•	•	•	-	-	-	-	-	-	-
Cardita variegata	-	-	-	•	-	•	-	-	•	•	-
Chama iostoma	-	-	-	-	-	-	-	-	-	•	-
Chama sp. 3	-	-	-	•	-	-	-	-	-	•	-
Bathytormus sp.	-	-	-	•	-	-	-	-	-	•	-
Trachycardium flavum	•	-	-	-	-	-	-	-	-	-	-
T. ?enode	-	-	-	-	-	-	-	•	-	-	-
Vepricardium asiaticum	-	-	•	-	-	-	-	-	-	-	•
Fulvia cf. *aperta*	-	-	-	-	-	-	-	-	-	-	•
Fragum carinatum	-	•	-	-	-	-	-	-	-	•	-
Tridacna spp.	•	-	-	-	-	-	-	-	-	-	-
Mactra antiquata	-	•	-	-	-	-	-	-	-	•	-
M. cuneata	-	-	-	-	-	-	-	-	-	•	-
Raetellops pulchella	-	-	-	-	-	-	-	-	-	•	-
mactrid sp. 7	-	-	•	-	-	-	-	-	-	-	-
Atactodea striata	•	-	-	-	•	•	•	-	-	•	-
Coecella horsfieldi	•	-	-	-	-	•	-	-	-	-	-
Solen sp.	-	-	-	-	-	-	-	-	-	•	-
Phaxas sp.	•	-	-	-	-	-	-	-	-	-	-
Apolymetis spectabilis	•	-	-	-	-	-	-	-	-	-	-
Tellina capsoides	•	-	-	-	-	-	-	-	-	-	-
T. opalina	•	-	-	-	-	-	-	-	-	-	-
T. (Cadella) sp.	-	•	-	-	-	-	-	-	-	-	-
T. (Semelangulus) sp.	-	-	-	•	-	-	-	-	-	-	-
Semele jukesi	-	-	-	-	-	•	•	-	-	-	-
Asaphis violascens	•	-	-	-	•	•	•	-	•	•	-
Donax (Chion) sp.	-	•	-	-	-	-	-	•	-	•	-
Polymesoda erosa	•	-	-	-	-	-	-	-	-	-	-
Ruditapes philippinarum	•	•	-	•	•	•	•	•	•	•	-
G. divaricatum	-	•	•	•	-	•	•	•	-	•	-
Circe scripta	•	-	-	•	-	-	-	•	-	•	-
Marcia hiantina	•	-	•	-	-	-	-	•	-	•	-
Dosinia juvenilis	•	-	-	-	-	-	-	-	-	-	-
Dosinia sp. 3	-	-	-	-	-	-	-	-	-	•	-
Paphia undulata	•	-	-	-	•	-	•	-	-	•	-
P. schnelliana	-	-	•	-	-	-	-	-	-	•	-

Table 49 (cont.) *List of species with collecting localities*

Species	1	2	3	4	5	6	7	8	9	10	11	Species	1	2	3	4	5	6	7	8	9	10	11
Meretrix lusoria	•	•	-	-	-	-	•	-	-	•	•	*Periglypta clathrata*	-	-	-	-	-	•	•	-	•	-	-
Irus irus	-	•	-	•	-	•	-	-	-	•	-	*Veremolpa micra*	-	•	-	•	-	-	-	-	-	•	-
Timoclea siamensis	-	-	-	•	-	-	-	-	-	•	-	venerid sp. 21	-	•	-	•	-	•	-	-	-	-	-
venerid sp. 22	-	•	-	•	-	-	-	-	-	-	-												
Glauconomidae												*Glauconome* sp.	-	-	-	-	-	-	-	•	-	-	-
Corbulidae												*Corbula ?erythrodon*	•	-	-	•	-	-	-	-	-	-	-
Corbula ?scaphoides	-	-	-	-	-	•	-	-	-	•	-	*Corbula* sp. 3	-	-	-	•	-	-	-	-	-	-	-
Corbula sp. 4	-	•	-	•	-	•	•	-	-	-	-												
Gastrochaenidae												*Gastrochaena cymbium*	-	-	-	-	-	-	-	-	-	•	-
Hiatellidae												*?Panopea* sp.	-	-	-	•	-	-	-	-	-	-	-
Hiatella sp.	-	-	-	•	-	-	-	-	-	-	-												
Pholadidae												*Martesia striata*	-	•	-	•	-	-	-	-	-	-	-
pholadid sp.	-	-	-	-	-	•	-	-	-	-	-												
Teredinidae												teredinid sp.	•	-	-	-	-	-	-	-	-	-	-
Thraciidae												*Thraciopsis* sp.	-	-	-	•	-	-	-	-	-	-	-
Cuspidariidae												cuspidariid sp.	•	-	-	-	-	-	-	-	-	-	-

COMMENTS ON THE MODERN MATERIAL

Inspection of the list of modern species (which includes the marine species recovered from Khok Phanom Di for comparison) shows that many of the archaeologically common (comestible) species are not present. This probably reflects the large-scale destruction of the mangal habitat in the case of *Nerita articulata*, *Terebralia palustris*, *Telescopium telescopium*, *Cerithidea obtusa* and *Naquetia capucina* which are all large, edible gastropods, and over exploitation to the point of local extinction in the case of sandy/muddy shore bivalves such as *Meretrix lusoria*, *Pelecyora trigona*. In reverse, clean, sandy shore/coral association species are in eclipse at Khok Phanom Di, as are rocky shore species (such as *Planaxis sulcata*, *Nerita undata*, *Peasiella* sp., *Siphonaria* spp. etc). This list serves to reinforce the view, based on the archaeological molluscan evidence, that rocky shores and coral habitats were only minimally (if at all) available in prehistory and that clean sandy beaches bearing mactrid and donacid bivalves were equally absent or inaccessible.

TABLE 50: *The distribution of micromolluscs in successive layers and contexts*

Species	11:1	10:25	10:24	10:23	10:22	10:21	10:20	10:19	10:18	10:17	10:16	10:15	10:14	10:13
Clenchiella microscopica	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenothyra acuta	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. annandalei	-	1	1	-	-	-	-	1	1	-	-	-	-	-
S. glabra	-	3	4	1	1	2	4	3	-	2	2	1	1	-
S. hardouini	-	-	-	-	-	-	-	-	-	-	-	-	5	3
S. krungtepensis	-	13	3	3	-	16	29	32	28	10	13	12	-	-
S. maculata	-	-	-	-	-	-	-	-	-	-	-	-	12	7
S. monilifera	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. polita	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenothyra spp.	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Iravadia cochinchinensis	-	-	-	-	-	-	1	-	-	-	-	-	-	-
I. reticulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Assiminea brevicula	1	1	-	-	-	-	-	1	-	-	1	-	-	-
A. microsculpta	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. nitida	-	2	1	1	3	2	-	1	1	2	-	1	1	-
A. philippinica	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. woodmasoniana	10	10	4	11	2	5	3	7	2	4	8	5	4	3
A. zilchi	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Assiminea spp.	-	-	-	-	-	3	-	1	-	1	-	-	-	1
Paludinella kuiperi	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Chamlongia harinasutai	-	-	-	-	2	3	-	1	-	-	-	-	-	-
Melanoides tuberculata	-	2	-	2	-	-	4	-	-	2	1	3	7	2
Sermyla riqueti	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Morrisonietta krungtepensis	-	-	-	-	-	-	-	-	-	-	2	-	2	-
M. siamensis	-	5	-	-	-	-	-	-	-	-	-	-	-	-
Morrisonietta sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyramidellid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Acteocina sp.	-	-	-	-	1	-	-	-	-	-	-	-	-	-
"Atys" sp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Ellobium aurisjudae	6	24	20	7	5	1	1	-	-	-	2	-	-	-
Laemodonta punctigera	-	-	-	-	1	-	-	-	-	-	-	-	-	-
L. siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melampus nucleolus	-	-	-	-	-	-	-	-	-	-	-	-	1	-
M. siamensis	-	-	-	3	-	-	-	-	-	1	1	2	1	2
Gyraulus hubendicki	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gyraulus siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tornatellinops sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pupilloid sp.	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Gastrocopta sp.	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Pupisoma sp.	-	-	1	-	1	1	-	3	1	-	-	-	1	1
Vertiginid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Enid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacillum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paropeas achatinaceum	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Achatinoid sp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-
?Geotrochus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Macrochlamys sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
? Zonitid sp.	1	-	-	-	-	1	-	-	-	-	-	-	-	2
Pulmonid species A	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pulmonid species B	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Landsnail eggs	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 50 (cont.) *The distribution of micromolluscs in successive layers*

Species	10:12	10:11	10:10	10:9	10:8	10:7	10:6	10:5	10:4	10:3	10:2	10:1	9:7	9:6	9:5	9:4
Clenchiella microscopica	-	-	-	-	-	2	-	-	-	-	-	-	-	2	-	-
Stenothyra acuta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. annandalei	-	-	-	1	-	-	1	-	-	-	1	-	1	-	-	1
S. glabra	2	1	5	1	1	5	6	2	4	4	4	2	21	23	15	33
S. hardouini	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. krungtepensis	12	19	13	3	6	10	6	3	1	3	7	-	27	27	11	22
S. maculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. monilifera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenothyra polita	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenothyra spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iravadia cochinchinensis	-	-	2	1	-	-	-	-	-	-	-	-	2	-	2	-
I. reticulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Assiminea brevicula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
A. microsculpta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. nitida	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
A. philippinica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. woodmasoniana	1	1	1	2	-	-	-	-	-	-	1	-	-	1	2	1
A. zilchi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Assiminea spp.	-	-	2	1	-	-	-	-	-	-	-	-	-	-	1	-
Paludinella kuiperi	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
Chamlongia harinasutai	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melanoides tuberculata	5	5	1	1	1	5	2	5	-	-	-	-	-	-	-	2
Sermyla riqueti	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Morrisonietta krungtepensis	1	1	-	-	-	-	-	-	-	-	-	-	-	1	-	1
M. siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M. sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyramidellid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acteocina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
"*Atys*" sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ellobium aurisjudae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laemodonta punctigera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L. siamensis	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melampus nucleolus	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-
M. siamensis	-	-	2	1	1	-	-	1	-	1	-	1	-	-	1	3
Gyraulus hubendicki	-	-	-	-	-	1	1	-	-	-	-	1	-	1	1	3
Gyraulus siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tornatellinops sp.	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Pupilloid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastrocopta sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pupisoma sp.	-	-	2	-	1	-	-	1	-	-	-	-	1	-	1	-
Vertiginid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Enid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacillum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paropeas achatinaceum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Achatinoid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
?*Geotrochus* sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Macrochlamys sp.	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
? Zonitid sp.	-	-	-	-	-	1	-	-	-	-	-	-	-	-	3	-
Pulmonid species A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pulmonid species B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Landsnail eggs	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 50 (cont.) *The distribution of micromolluscs in successive layers*

Species	9:3	9:2	9:1	8:7	8:6	8:5	8:4	8:3	8:2	8:1	7:7	7:6	7:5	7:4	7:3
Clenchiella microscopica	1	-	2	-	-	-	1	1	1	1	-	-	-	-	-
Stenothyra acuta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. annandalei	7	2	3	5	2	-	-	5	-	1	-	-	-	-	-
S. glabra	62	24	13	30	5	4	-	11	8	23	15	5	-	1	-
S. hardouini	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. krungtepensis	40	18	9	37	5	2	-	7	-	11	11	5	3	3	1
S. maculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. monilifera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. polita	1	-	-	-	-	2	1	1	-	-	-	-	-	-	-
Stenothyra spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iravadia cochinchinensis	4	6	6	4	5	13	11	6	2	1	-	1	-	-	-
I. reticulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Assiminea brevicula	2	-	-	1	1	3	-	-	-	-	-	-	-	-	-
A. microsculpta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. nitida	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-
A. philippinica	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
A. woodmasoniana	10	1	1	6	1	1	-	-	-	1	-	-	-	-	-
A. zilchi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Assiminea spp.	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Paludinella kuiperi	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Chamlongia harinasutai	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melanoides tuberculata	2	6	1	5	1	1	1	3	1	-	-	-	1	-	-
Sermyla riqueti	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Morrisonietta krungtepensis	2	-	-	1	-	-	-	-	-	-	-	-	-	-	-
M. siamensis	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-
M. sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyramidellid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acteocina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
"Atys" sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ellobium aurisjudae	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Laemodonta punctigera	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L. siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melampus nucleolus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M. siamensis	6	3	1	3	5	1	-	-	-	-	3	-	-	-	1
Gyraulus hubendicki	4	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Gyraulus siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tornatellinops sp.	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-
Pupilloid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastrocopta sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pupisoma sp.	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vertiginid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Enid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacillum sp.	-	-	-	-	1	-	-	-	-	-	1	-	1	-	-
Paropeas achatinaceum	1	-	1	5	-	-	-	-	-	1	7	2	2	-	-
Achatinoid sp.	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-
?Geotrochus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Macrochlamys sp.	-	-	1	-	1	-	-	1	-	2	-	-	-	-	1
? Zonitid sp.	2	-	2	3	2	-	-	1	-	1	3	1	1	2	-
Pulmonid species A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pulmonid species B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Landsnail eggs	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-

Table 50 (cont.) *The distribution of micromolluscs in successive layers*

Species	7:2	7:1	6:7	6:6	6:5	6:4	6:3	6:2	6:1	5:5	5:4	5:3	5:2	5:1	4:5
Clenchiella microscopica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenothyra acuta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. annandalei	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
S. glabra	2	8	1	3	10	1	15	1	1	-	-	5	1	-	1
S. hardouini	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. krungtepensis	-	7	2	-	2	4	3	2	1	3	1	-	-	-	-
S. maculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. monilifera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. polita	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Stenothyra spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iravadia cochinchinensis	2	1	2	3	-	3	2	3	2	-	-	1	-	-	-
I. reticulata	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-
A. brevicula	1	1	-	2	-	3	-	2	-	1	-	-	-	-	-
A. microsculpta	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
A. nitida	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. philippinica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. woodmasoniana	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-
A. zilchi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Assiminea spp.	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
Paludinella kuiperi	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Chamlongia harinasutai	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melanoides tuberculata	1	3	1	1	1	2	6	-	3	-	-	-	-	2	-
Sermyla riqueti	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Morrisonietta krungtepensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
M. siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M. sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyramidellid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acteocina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
"*Atys*" sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ellobium aurisjudae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laemodonta punctigera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L. siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melampus nucleolus	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
M. siamensis	-	-	-	1	-	2	-	-	-	-	-	-	1	-	-
Gyraulus hubendicki	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gyraulus siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tornatellinops sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pupilloid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastrocopta sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pupisoma sp.	-	-	1	-	-	-	-	-	-	1	3	1	1	8	-
Vertiginid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Enid sp.	-	-	-	-	-	-	2	-	-	1	1	2	1	-	2
Bacillum sp.	-	3	2	1	-	4	5	19	12	54	56	41	55	63	76
Paropeas achatinaceum	-	24	8	3	78	8	22	16	38	58	66	71	97	128	41
Achatinoid sp.	-	3	-	-	3	-	3	8	13	21	34	18	68	36	61
?*Geotrochus* sp.	-	-	-	-	-	-	-	1	-	-	1	-	3	2	3
Macrochlamys sp.	-	2	-	-	1	-	11	6	6	11	10	8	38	38	22
? Zonitid sp.	-	4	9	1	4	2	6	2	40	51	42	50	79	100	26
Pulmonid species A	-	-	-	-	-	-	2	-	-	-	2	-	-	3	2
Pulmonid species B	-	-	1	-	-	-	-	-	-	1	-	-	5	7	3
snail eggs	-	1	1	-	3	1	2	-	20	2	7	2	27	38	28

Table 50 (cont.) *The distribution of micromolluscs in successive layers*

Species	4:4	4:3	4:2	4:1	3:5	3:4	3:3	3:2	3:1	2:3	2:2	2:1	1:3	1:2	1:1
Clenchiella microscopica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenothyra acuta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. annandalei	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
S. glabra	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
S. hardouini	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. krungtepensis	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. maculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. monilifera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S. polita	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenothyra spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iravadia cochinchinensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
I. reticulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Assiminea brevicula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. microsculpta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. nitida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. philippinica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. woodmasoniana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A. zilchi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Assiminea spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paludinella kuiperi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chamlongia harinasutai	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melanoides tuberculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sermyla riqueti	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Morrisonietta krungtepensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M. siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M. sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyramidellid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acteocina sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
"*Atys*" sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ellobium aurisjudae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laemodonta punctigera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L. siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melampus nucleolus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M. siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gyraulus hubendicki	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gyraulus siamensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tornatellinops sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pupilloid sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastrocopta sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pupisoma sp.	1	39	-	-	-	-	-	-	-	-	-	-	-	-	1
Vertiginid sp.	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Enid sp.	-	8	-	1	-	-	-	-	-	-	-	-	-	-	-
Bacillum sp.	107	903	-	7	-	-	-	-	-	-	-	-	-	-	-
Paropeas achatinaceum	46	380	-	-	-	-	-	-	-	-	-	-	-	-	-
Achatinoid sp.	57	278	-	-	-	-	-	-	-	-	-	-	-	-	-
?*Geotrochus* sp.	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Macrochlamys sp.	19	107	-	14	-	-	-	-	-	-	-	-	-	-	-
? Zonitid sp.	39	76	-	2	-	-	-	1	2	2	1	1	2	-	-
Pulmonid species A	-	27	-	-	-	-	-	-	-	-	-	-	-	-	-
Pulmonid species B	2	25	-	-	-	-	-	-	-	-	-	-	-	-	-
Landsnail eggs	102	520	2	-	-	-	-	-	-	-	-	2	-	-	-

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